WASTEWATER TREATMENT
WATER QUALITY

PROFESSIONAL DEVELOPMENT HOUR
CONTINUING EDUCATION COURSE

Technical Learning College

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You can obtain a printed version from TLC for an additional $69.95 plus shipping charges.

All downloads are electronically tracked and monitored for security purposes.

Some States and many employers require the final exam to be proctored.

Do not solely depend on TLC's Approval list for it may be outdated.

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Most of our students prefer to do the assignment in Word and e-mail or fax the assignment back to us. We also teach this course in a conventional hands-on class. Call us and schedule a class today.

This course contains EPA's federal rule requirements. Please be aware that each state implements wastewater/safety regulations that may be more stringent than EPA's or OSHA's regulations.

Check with your state environmental agency for more information. You must abide with your discharge or NPDES permit and do not follow the instructions in this course. You are solely responsible in ensuring that you abide with your jurisdiction or agency's rules and regulations.

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Contributing Editors
James L. Six Received a Bachelor of Science Degree in Civil Engineering from the University of Akron in June of 1976, Registered Professional Engineer in the State of Ohio, Number 45031 (Retired), Class IV Water Supply Operator issued by Ohio EPA, Number WS4-1012914-08, Class II Wastewater Collection System Operator issued by Ohio EPA, Number WC2-1012914-94

Joseph Camerata has a BS in Management with honors (magna cum laude). He retired as a Chemist in 2006 having worked in the field of chemical, environmental, and industrial hygiene sampling and analysis for 40 years.

James Bevan, Water Quality Inspector S.M.E. Twenty years of experience in the environmental field dealing with all aspects of water regulations on the federal, state, and local levels. Teacher and Proctor in Charge for Backflow Certification Testing at the ASETT Center in Tucson for the past 15 years and possess an Arizona Community College, Special Teaching Certificate in Environmental Studies.

Dr. Pete Greer S.M.E., Retired biology instructor, chemistry and biological review.

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  Professor of Environmental Engineering at Manhattan College
- Dr. H. David Stensel, Professor of Civil and Environmental Engineering at the University of Washington

Operators analyze sludge samples to improve wasting.

Technical Learning College's Scope and Function

Welcome to the Program,

Technical Learning College (TLC) offers affordable continuing education for today's working professionals who need to maintain licenses or certifications. TLC holds several different governmental agency approvals for granting of continuing education credit.

TLC's delivery method of continuing education can include traditional types of classroom lectures and distance-based courses or independent study. TLC's distance based or independent study courses are offered in a print - based distance educational format. We will beat any other training competitor's price for the same CEU material or classroom training.

Our courses are designed to be flexible and for you do finish the material on your leisure. Students can also receive course materials through the mail. The CEU course or e-manual will contain all your lessons, activities and instruction to obtain the assignments. All of TLC's CEU courses allow students to submit assignments using e-mail or fax, or by postal mail. (See the course description for more information.)

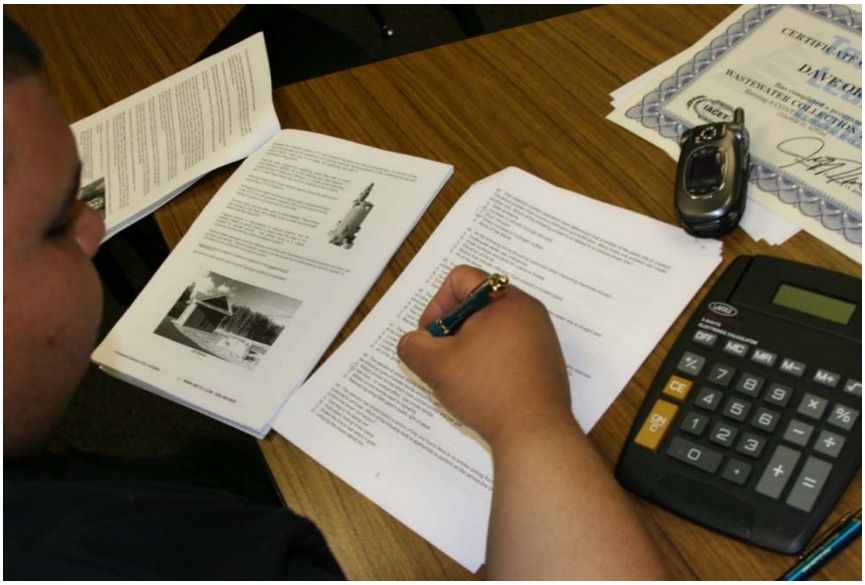
Students have direct contact with their instructor—primarily by e-mail or telephone. TLC's CEU courses may use such technologies as the World Wide Web, e-mail, CD-ROMs, videotapes and hard copies. (See the course description.) Make sure you have access to the necessary equipment before enrolling, i.e., printer, Microsoft Word and/or Adobe Acrobat Reader. Some courses may require proctored closed-book exams depending upon your state or employer requirements.

Flexible Learning
At TLC, there are no scheduled online sessions or passwords you need contend with, nor are you required to participate in learning teams or groups designed for the "typical" younger campus based student. You can work at your own pace, completing assignments in time-frames that work best for you. TLC's method of flexible individualized instruction is designed to provide each student the guidance and support needed for successful course completion.

Course Structure
TLC's online courses combine the best of online delivery and traditional university textbooks. You can easily find the course syllabus, course content, assignments, and the post-exam (Assignment). This student friendly course design allows you the most flexibility in choosing when and where you will study.

Classroom of One
TLC offers you the best of both worlds. You learn on your own terms, on your own time, but you are never on your own. Once enrolled, you will be assigned a personal Student Service Representative who works with you on an individualized basis throughout your program of study. Course specific faculty members (S.M.E.) are assigned at the beginning of each course providing the academic support you need to successfully complete each course. Please call or email us for assistance.

Satisfaction Guaranteed
We have many years of experience, dealing with thousands of students. We assure you, our customer satisfaction is second to none. This is one reason we have taught more than 20,000 students.



We welcome you to do the electronic version of the assignment and submit the answer key and registration to us either by fax or e-mail.

If you need this assignment graded and a certificate of completion within a 48-hour turn around, prepare to pay an additional rush charge of $50.

Precept-Based Training Course

This training course is based upon a form of induction training, made of topical and technical precepts. The training topics are made up of "micro-content" or "precepts"– or small chunks of information that can be easily digested. These bite-size pieces of technical information are considered to be one of the most effective ways of teaching people new information because it helps the mind retain knowledge easier.

Micro-learning or precept-based training doesn't rely on the student to process a large amount of information before breaking it down. Our method includes short modules with clearly defined learning goals for each section. This method allows a student to hone in on a particular skill, then given the opportunity to exhibit their knowledge in the final assessment.

Contact Numbers
Fax (928) 468-0675
Email Info@tlch2o.com
Telephone (866) 557-1746

Course Description

Wastewater Treatment Water Quality CEU Training Course

This is a review of various and complex wastewater treatment methods, water quality, sampling techniques, bug identification, disinfection, sludge disposal and related WWT subjects. This course is general in nature and not state specific but will contain different wastewater treatment, activated sludge methods and wastewater quality, permit writing methods, sampling policies and ideas. You will not need any other materials for this course.

This course will cover various wastewater treatment methods including:

- Best conventional pollutant control technology (BCT) for conventional pollutants and applicable to existing dischargers.
- Best practicable control technology currently available (BPT) for conventional, toxic and non-conventional pollutants and applicable to existing dischargers.
- Best available technology economically achievable (BAT) for toxic and non-conventional pollutants and applicable to existing dischargers.
- New source performance standards (NSPS) for conventional pollutants and applicable to new sources.

Intended Audience

Wastewater Treatment Operators; Pretreatment and Industrial Waste Inspectors. The target audience for this course is the person interested in working in a wastewater treatment or pretreatment/industrial wastewater facility and/or wishing to maintain CEUs for certification license or to learn how to do the job safely and effectively, and/or to meet education needs for promotion.

Prerequisites: None

Course Procedures for Registration and Support

All of TLC's correspondence courses have complete registration and support services offered. Delivery of services will include e-mail, web site, telephone, fax and mail support. TLC provides immediate and prompt service.

When a student registers for a correspondence course, he or she is assigned a start date and an end date. It is the student's responsibility to note dates for assignments and keep up with the course work.

If a student falls behind, he or she must contact TLC and request an end date extension in order to complete the course. It is the prerogative of TLC to decide whether to grant the request.

All students will be tracked by a unique number assigned to the student.

Instructions for Written Assignments

The Wastewater Treatment Water Quality CEU training distance learning course uses a fill-in-the-blank style answer key. You can write your answers in the assignment or type out your own answer key. TLC would prefer that you type out and e-mail final assignment to TLC, but it is not required.

Feedback Mechanism (examination procedures)
Each student will receive a feedback form as part of the study packet. You will be able to find this form in the front of the course assignment or lesson.

Security and Integrity
All students are required to do their own work. All lesson sheets and final exams are not returned to the student to discourage and sharing of answers. Any fraud or deceit and the student will result in forfeiture of all fees, and the appropriate agency will be notified.

Grading Criteria
TLC will offer the student either pass/fail or a standard letter grading assignment. If TLC is not notified, you will only receive a pass/fail notice.

Required Texts
The Wastewater Treatment Water Quality CEU training course will not require any other materials. This course comes complete. No other materials are needed.

Environmental Terms, Abbreviations, and Acronyms
TLC provides a glossary that defines, in non-technical language, commonly used environmental terms appearing in publications and materials. It also explains abbreviations and acronyms used throughout EPA and other agencies. You can find the glossary in the rear of the manual.

Recordkeeping and Reporting Practices
TLC will keep all student records for a minimum of five years. It is your responsibility to give the completion certificate to the appropriate agencies. TLC will mail a copy to Indiana, Pennsylvania, Texas, or any other state that requires a copy from the Training Provider.

ADA Compliance
TLC will make reasonable accommodations for persons with documented disabilities. Students should notify TLC and their instructors of any special needs. Course content may vary from this outline to meet the needs of this particular group. There is an alternative assignment available.

The final grade options are as follows:
Letter grade (**A**, **B**, **C**, **D**, **F**) - These grades are awarded based on the course grading scale. Withdrawn (**W** or **Y**) - Students who enroll but do not participate in the class may withdraw themselves by calling Admissions and Records, or their instructor may withdraw them. Either case will result in a grade of "**W**." Note that participation means the completion of a single homework assignment or an exam. Completion of the pretest and/or syllabus receipt does not imply course participation. Credit/no credit option (**P**/**Z**) - None Available

Note to students: Keep a copy of everything you submit. That way if your work is lost you can submit your copy for grading. If you do not receive your graded assignment or quiz results within two or three weeks after submitting it, please contact your instructor.

We expect every student to produce his/her original, independent work. Any student whose work indicates a violation of the Academic Misconduct Policy (cheating, plagiarism) can expect penalties as specified in the Student Handbook, which is available through Student Services; contact them at (928) 468-0665.

A student who registers for a Distance Learning course is assigned a **"start date"** and an **"end date."** It is the student's responsibility to note due dates for assignments and to keep up with the course work.

If a student falls behind, she or he must contact the instructor and request an extension of her/his ***end date*** in order to complete the course. It is the prerogative of the instructor to decide whether or not to grant the request.

You will have 90 days from receipt of this manual to complete it in order to receive your Continuing Education Units (**CEUs**) or Professional Development Hours (**PDHs**). A score of 70% or better is necessary to pass this course.

If you need any assistance, please email all concerns to info@tlch2o.com.

Educational Mission
The educational mission of TLC is:
To provide TLC students with comprehensive and ongoing training in the theory and skills needed for the environmental education field,

To provide TLC students opportunities to apply and understand the theory and skills needed for operator certification,

To provide opportunities for TLC students to learn and practice environmental educational skills with members of the community for the purpose of sharing diverse perspectives and experience,

To provide a forum in which students can exchange experiences and ideas related to environmental education,

To provide a forum for the collection and dissemination of current information related to environmental education, and to maintain an environment that nurtures academic and personal growth.

Course Objective
To provide a detailed understanding in effective and efficient wastewater treatment and disinfection methods including activated sludge methods and generally accepted wastewater treatment sampling techniques and biological monitoring, bug identification and microorganism control methods.

Important Information about this Manual

This manual has been prepared to educate employees in the general awareness of dealing with complex wastewater treatment procedures and regulatory requirements for safely handling hazardous and toxic materials.

The scope of the problem is quite large, requiring a major effort to bring it under control. Employee health and safety, as well as that of the public, depend upon careful application of safe treatment procedures. The manner in which we deal with such hazards will affect the earth and its inhabitants for many generations to come.

This manual will cover general laws, regulations, required procedures and generally accepted policies relating to wastewater treatment and wastewater sampling. It should be noted, however, that the regulation of wastewater treatment, sampling and other hazardous materials is an ongoing process and subject to change over time. For this reason, a list of resources is provided to assist in obtaining the most up-to-date information on various subjects. However, you are solely responsible in following your specific NPDES permit instruction and do not follow the instructions in this course.

This manual is not a guidance document for employees who are involved with pollution control or wastewater treatment. It is not designed to meet the requirements of the United States Environmental Protection Agency (EPA) or Department of Labor-Occupational Safety and Health Administration (OSHA) or state environmental or health departments.

This course manual will provide general educational awareness guidance of wastewater treatment and sampling methods. This document is not a detailed wastewater treatment textbook or a comprehensive source book on occupational safety and health.

Technical Learning College or Technical Learning Consultants, Inc. makes no warranty, guarantee or representation as to the absolute correctness or appropriateness of the information in this manual and assumes no responsibility in connection with the implementation of this information. It cannot be assumed that this manual contains all measures and concepts required for specific conditions or circumstances. This document should be used for educational guidance and is not considered a legal document.

Individuals who are responsible for the treatment of wastewater, wastewater sampling or the health and safety of workers at wastewater sites shall abide with all discharge or NPDES permit instruction and obtain and comply with the most recent federal, state, and local regulations relevant to these sites and are urged to consult with OSHA, EPA and other appropriate federal, state, health and local agencies.

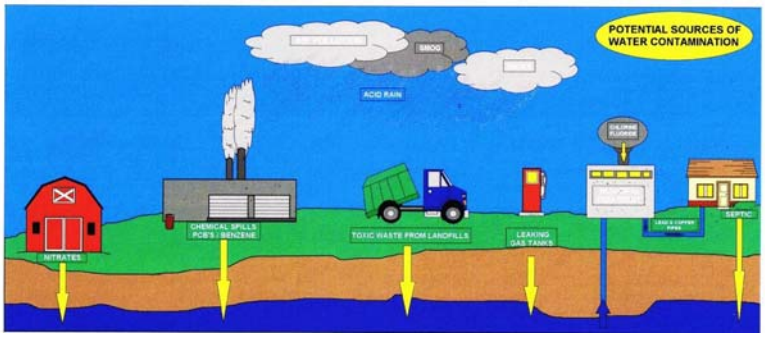


Table of Contents (See Topic Legend on page 20)

Topic Legend

This CEU course covers several educational topics/functions/purposes of conventional wastewater treatment or activated sludge process. The topics listed below are to assist in determining which educational area is covered in a specific topic area:

CRAO: The regulatory and compliance component. May be a requirement of your NPDES permit. Compliance, non-compliance, process control and local limits. All of the compliance and regulatory related tasks require A/S to be sampled/monitored throughout the process including dried sludge. This along with the EPA information is to satisfy the regulatory portion of your operator training. Part of O&M or laboratory training requirement for many operators.

DISINFECTION: This area covers plant or effluent disinfection procedures. Part of O&M training for many operators.

M/O: The biological component. The microorganisms that are WWT/A/S specific. This is a broad definition, but applies to any wastewater operation or specific process that grows and utilizes microorganisms (recirculated RAS) to digest or eat food. This can apply to lagoons, oxidation or devices that utilize some form of A/S. Also covers microorganism identification, sampling and process control. Part of O&M or laboratory training requirement for many operators.

O&M: This area is for normal operation and/or maintenance of the plant. Part of O&M training requirement for many operators.

SAFETY: This area is describing process safety procedures. Part of O&M training requirement for many operators.

TECHNICAL: The mechanical or physical treatment process/component. The WWT or A/S process including pretreatment processes/applications/engineering/theories. Bar screens to Outfall, Fixed-film to Clarifiers. Blowers to Chemical feeders. Part of O&M training for many operators.

WQ: Having to do with water quality or pollutants. May be a requirement of your NPDES permit. This along with the EPA information is to satisfy the regulatory portion of your operator training.

ETC: Related A/S or wastewater Information.

Acronyms and Terms

LIST OF ACRONYMS

AMS	Asset Management System
APP	Aquifer Protection Permit
ASTM	American Society for Testing and Materials
CADD	Computer-Aided Drafting and Design
CCTV	Closed-Circuit Television
CIP	Capital Improvement Plan or capital improvement project
CIPP	Cured-In-Place Pipe
CMMS	Computerized Maintenance Management System
CMOM	Capacity, Management, Operation and Maintenance
COOL	Computerized On-line Operations Log
CPM	Capital Project Management
CWA	Clean Water Act
d/D	depth divided by diameter
DIP	Ductile Iron Pipe
DVD	Digital Video Disk
EPA	Environmental Protection Agency
ERP	Enterprise Resource Planning Software; Emergency Response Plan
FOG	Fats, Oil, and Grease
fps	Feet per second
GIS	Geographic Information System
gpm	Gallons per minute
GPS	Global positioning system
HVAC	Heating, ventilation, and air conditioning
I/I	Infiltration and Inflow
IAS	Information Access System
IGA	Intergovernmental Agreement
IT	Information Technology
JEPA	Joint Exercise of Powers Agreement (SROG)
lf	Linear Feet
mgd	Million gallons per day
NOI	Notice of Intent
NOV	Notice of Violation
NPDES	National Pollutant Discharge Elimination System
O&M	Operation and Maintenance
PLC	Programmable Logic Controller
POTW	Publicly-Owned Treatment Works
Psi	Pounds per square inch

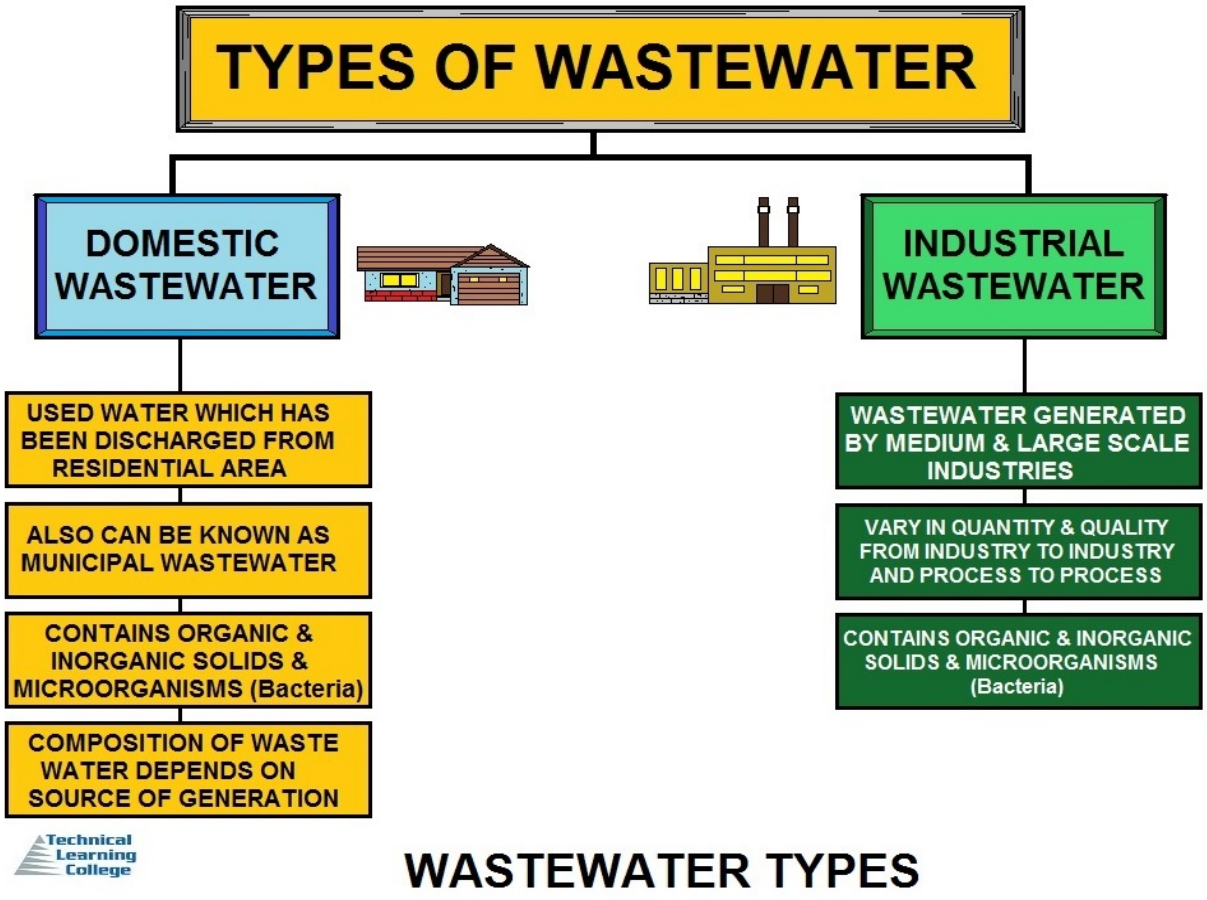
LIST OF ACRONYMS (continued)

PVC	Polyvinyl Chloride
RDBMS	Relational Database Management System
RFQ	Request for Qualifications
SAI	Southern Avenue Interceptor
SDR35	Standard Dimension Ratio 35
SCADA	Supervisory Control and Data Acquisition
SECAP	System Evaluation and Capacity Assurance Plan
SIU	Significant Industrial User
SROG	Sub-Regional Operating Group
SSO	Sanitary Sewer Overflow
SSORP	Sanitary Sewer Overflow Response Plan
VCC	Virtual Call Center
VCP	Vitrified Clay Pipe
WO	Work order
WRF	Water Reclamation Facility
WRP	Water Reclamation Plant
WTP	Water Treatment Plant
WWTF	Wastewater Treatment Facilities (may include WWTP and WRP)
WWTP	Wastewater Treatment Plant

Topic 1 – Wastewater Introduction

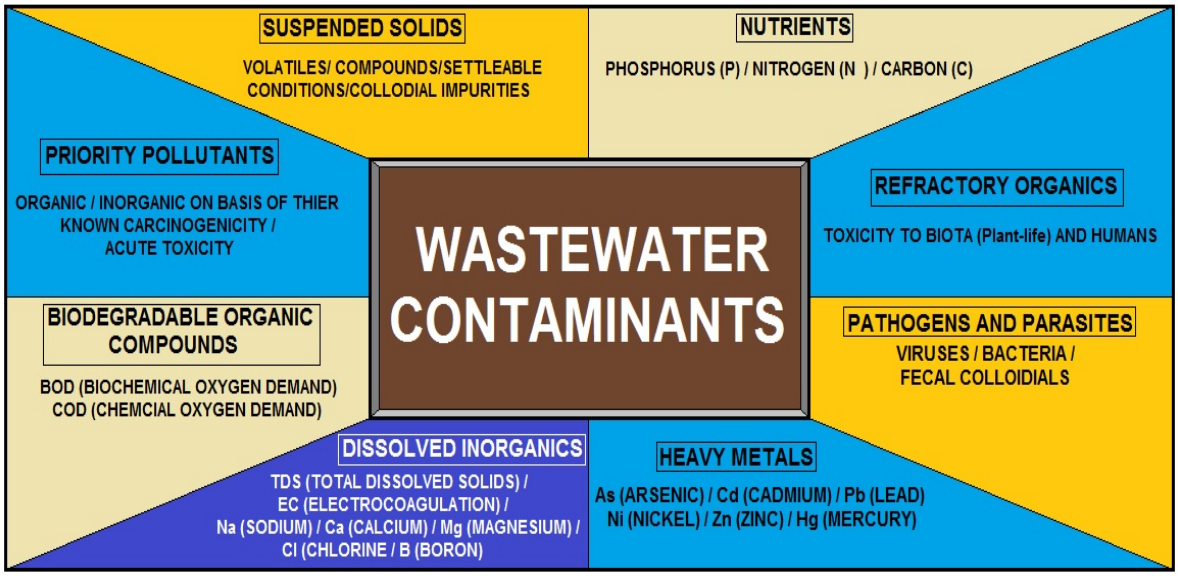
Topic 1 - Section Focus: You will learn the basics of the Clean Water Act, the need for wastewater treatment and common wastewater constituents. At the end of this section, you the student will be able to understand and describe the need for wastewater treatment and the composition/components of wastewater. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Topic 1 – Scope/Background: Under the CWA, EPA has implemented pollution control programs such as setting wastewater standards for industry. EPA has also developed national water quality criteria recommendations for pollutants in surface waters.



The diagram above shows the difference between domestic wastewater and industrial wastewater. Not all communities have industrial waste and if they do, the plant generally treats a high volume of flow.

The EPA information is to satisfy the regulatory portion of your training. Credit to the USEPA for this information.



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TYPES OF WASTEWATER CONTAMINANTS

Above are the common wastewater contaminants that we must deal with correctly to achieve our permit requirements. Below a pump from a lift station was damaged by rocks and clogged with flushable wipes. *Flushable wipes are <u>not</u>*.

Wastewater Treatment Overview

Wastewater treatment is the process of cleaning used water and sewage so it can be returned safely to our environment. Wastewater treatment is the last line of defense against water pollution. If you envision the water cycle as a whole, you can clean water produced by wastewater treatment is the same water that eventually ends up back in our lakes and rivers, where we get our drinking water.

Why Are Wastewater Treatment Plants Important?
Wastewater treatment plants are vital to our communities. They protect public health by eliminating disease-causing bacteria from water. By protecting water quality, wastewater treatment plants make it possible for us to safely enjoy the recreational use of clean oceans, lakes, streams and rivers.

33 U.S.C. s/s 1251 et seq. (1977)
The Clean Water Act is a 1977 amendment to the Federal Water Pollution Control Act of 1972, which set the basic structure for regulating discharges of pollutants to waters of the United States.

The law gave the EPA the authority to set effluent standards on an industry basis (technology-based) and continued the requirements to set water quality standards for all contaminants in surface waters. The CWA makes it unlawful for any person to discharge any pollutant from a point source into navigable waters unless a permit (NPDES) is obtained under the act.

The 1977 amendments focused on toxic pollutants. In 1987, the PCA was reauthorized and again focused on toxic substances, authorized citizen suit provisions, and funded sewage treatment plants (POTW's) under the Construction Grants Program.

The CWA provides for the delegation by the EPA of many permitting, administrative, and enforcement aspects of the law to state governments. In states with the authority to implement CWA programs, the EPA still retains oversight responsibilities.

In 1972, Congress enacted the first comprehensive national clean water legislation in response to growing public concern for serious and widespread water pollution. The Clean Water Act is the primary federal law that protects our nation’s waters, including lakes, rivers, aquifers, and coastal areas.

Lake Erie was dying. The Potomac River was clogged with blue-green algae blooms that were a nuisance and a threat to public health. Many of the nation's rivers were little more than open sewers and sewage frequently washed up on shore. Fish kills were a common sight. Wetlands were disappearing at a rapid rate.

Today, the quality of our waters has improved dramatically as a result of a cooperative effort by federal, state, tribal and local governments to implement the pollution control programs established in 1972 by the Clean Water Act.

The Clean Water Act's primary objective is to restore and maintain the integrity of the nation's waters. This objective translates into two fundamental national goals:

- eliminate the discharge of pollutants into the nation's waters, and
- achieve water quality levels that are fishable and swimmable.

The Clean Water Act focuses on improving the quality of the nation’s waters. It provides a comprehensive framework of standards, technical tools and financial assistance to address the many causes of pollution and poor water quality. This includes municipal and industrial wastewater discharges, polluted runoff from urban and rural areas, and habitat destruction.

For example, the Clean Water Act requires major industries to meet performance standards to ensure pollution control; charges states, and tribes with setting specific water quality criteria appropriate for their waters and developing pollution control programs to meet them; provides funding to states and communities to help them meet their clean water infrastructure needs; protects valuable wetlands and other aquatic habitats through a permitting process that ensures development, and other activities are conducted in an environmentally sound manner. After 25 years, the act continues to provide a clear path for clean water and a solid foundation for an effective national water program.

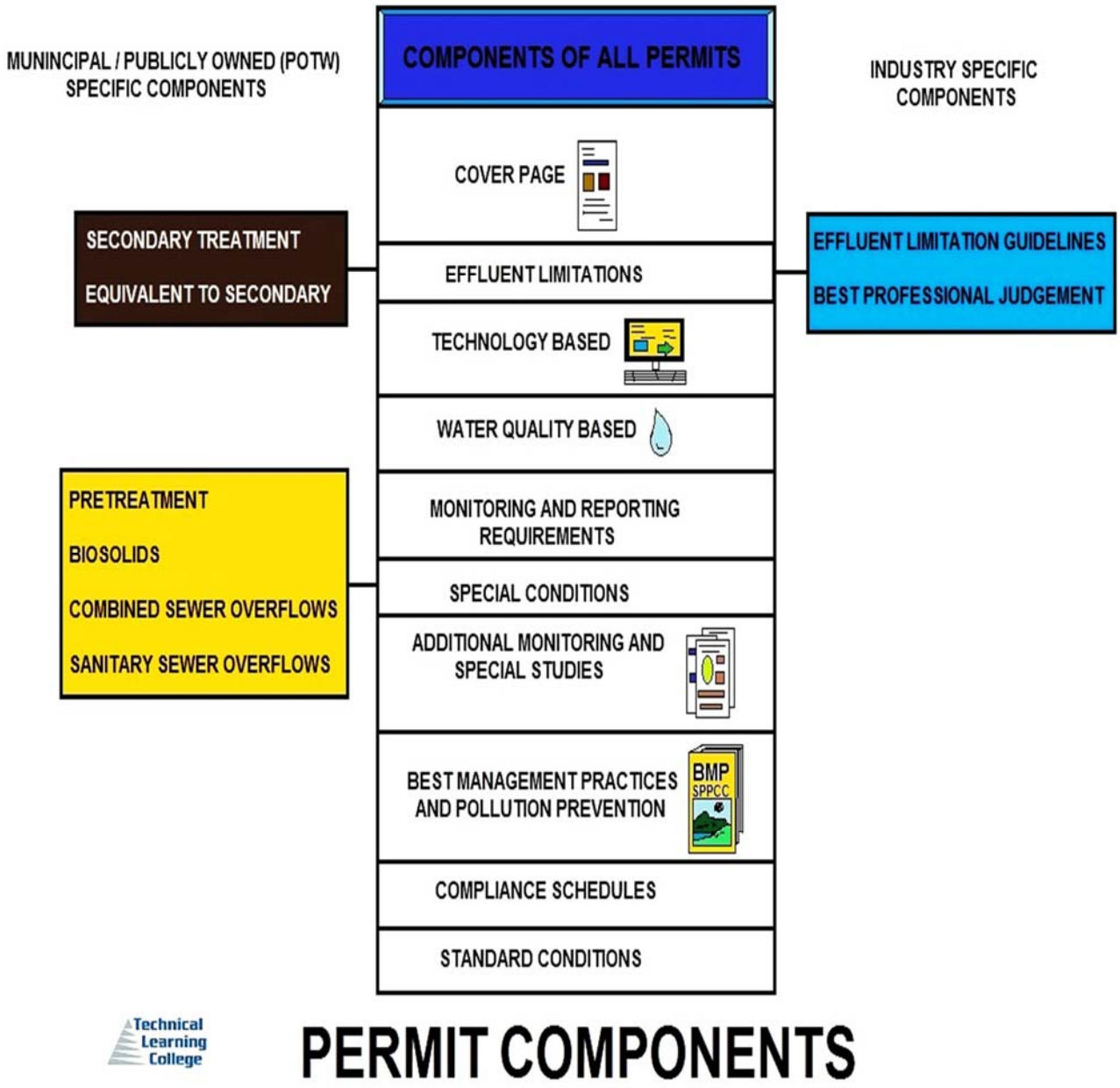
In 1972
Only a third of the nation's waters were safe for fishing and swimming. Wetlands losses were estimated at about 460,000 acres annually.

Agricultural runoff resulted in the erosion of 2.25 billion tons of soil and the deposit of large amounts of phosphorus and nitrogen into many waters. Sewage treatment plants served only 85 million people.

Today
Two-thirds of the nation's waters are safe for fishing and swimming. The rate of annual wetlands losses is estimated at about 70,000-90,000 acres according to recent studies.

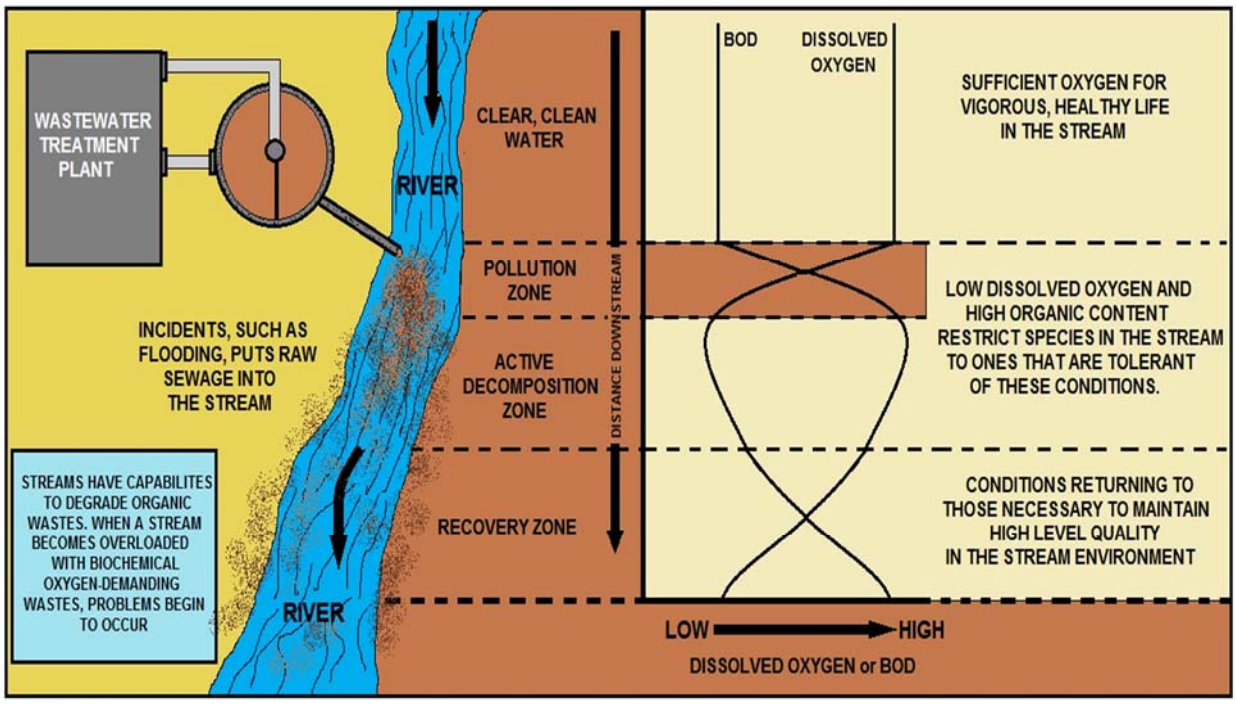
The amount of soil lost due to agricultural runoff has been cut by one billion tons annually, and phosphorus and nitrogen levels in water sources are down. Modern wastewater treatment facilities serve 173 million people.

The Future
All Americans will enjoy clean water that is safe for fishing and swimming. We will achieve a net gain of wetlands by preventing additional losses and restoring hundreds of thousands of acres of wetlands. Soil erosion and runoff of phosphorus and nitrogen into watersheds will be minimized, helping to sustain the nation's farming economy and aquatic systems. The nation's waters will be free of effects of sewage discharges.



NPDES Permit Foreword

Once a wastewater plant is designed and built, state or federal agencies will determine the type of permit required using the information illustrated above. You will need to understand that this discharge permit is your legal standard for proper sampling, treatment and discharging. You need to abide by your permit and not by the course information.



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EFFECTS OF BOD ON WATER QUALITY

Biochemical Oxygen Demand or BOD Introduction

Wastewater is composed of a variety of inorganic and organic substances.

Organic substances refer to molecules that are based on carbon and include fecal matter as well as detergents, soaps, fats, greases and food particles (especially where garbage grinders are used). These large organic molecules are easily decomposed by bacteria in the septic system.

However, oxygen is required for this process of breaking large molecules into smaller molecules and eventually into carbon dioxide and water.

The amount of oxygen required for this process is known as the biochemical oxygen demand or BOD.

The Five-day BOD, or BOD_5, is measured by the quantity of oxygen consumed by microorganisms during a five-day period, and is the most common measure of the amount of biodegradable organic material in, or strength of, sewage.

We will cover this area in detail in several different areas of this course. We will cover this area in about ten more pages and again in the Microorganism and Laboratory Sections at the end of the course. Please make notes on this difficult subject.

Wastewater Treatment Process Preface

During the early days of our nation's history, people living in both the cities and the countryside used cesspools and privies to dispose of domestic wastewater. Cities began to install wastewater collection systems in the late nineteenth century because of an increasing awareness of waterborne disease and the popularity of indoor plumbing and flush toilets.

The use of sewage collection systems brought dramatic improvements to public health, further encouraging the growth of metropolitan areas. In the year 2000, approximately 208 million people in the U.S. were served by centralized collection systems.

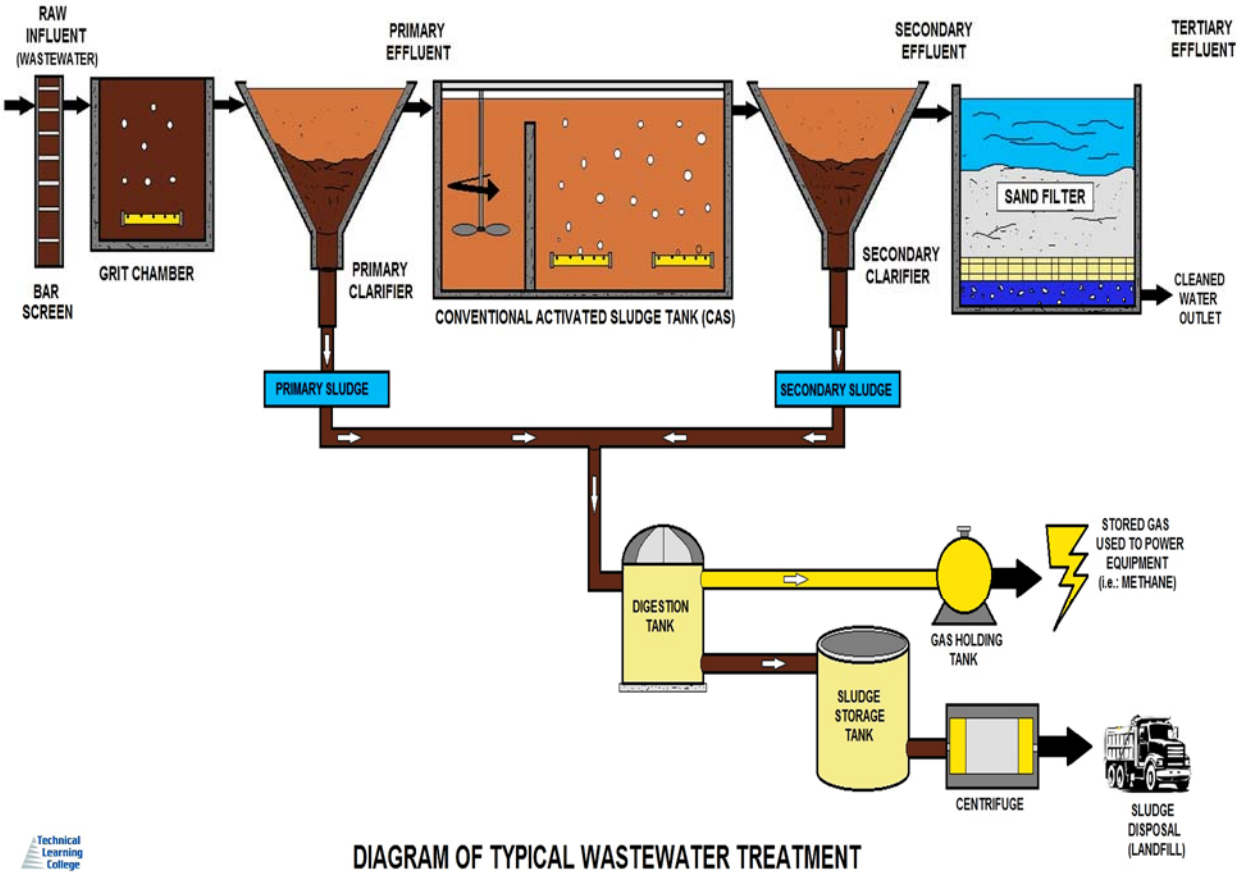


DIAGRAM OF TYPICAL WASTEWATER TREATMENT

Physical, Biological or Chemical Wastewater Treatments

There are two wastewater treatment processes namely chemical or physical treatment plant, and biological wastewater treatment plant. Biological waste treatment plants use biological matter and bacteria to break down waste matter.

Physical waste treatment plants use chemical reactions as well as physical processes to treat wastewater. Biological treatment systems are ideal for treating wastewater from households and business premises

What Exactly is in Wastewater?

Wastewater is mostly water by weight. Other materials make up only a small portion of wastewater, but can be present in large enough quantities to endanger public health and the environment. Because practically anything that can be flushed down a toilet, drain, or sewer can be found in wastewater, even household sewage contains many potential pollutants. The wastewater components that should be of most concern to homeowners and communities are those that have the potential to cause disease or detrimental environmental effects.

Domestic Wastewater Quality Characteristics

Typical major pollutant characteristics of domestic wastewater

Type	Pollutant	Conc. (mg/L)
Physical	Total Suspended Solids	300
	Volatile Suspended Solids	240
	Fixed Suspended Solids	60
	Total Dissolved Solids	440
	Volatile Suspended Solids	175
	Fixed Suspended Solids	265
	Temperature	10 - 25 ^{o}C
	Color	Grey - Black
Chemical	BOD_5	250
	COD	500
	TOC	160
	Total N	40
	Organic N	15
	Free ammonia N	25
	Nitrite N	0
	Nitrates N	0
	Total P	9
	Organic P	4
	Inorganic P	5
	Alkalinity	100
	Fats, oil and grease (FOG)	100
Microbiological	Total coliform	10^8 - 10^9 MPN/L
	Fecal coliform	10^7 - 10^8 MPN/L
	Non-fecal coliform	$9x10^7$ - $9x10^8$ MPN/L
	Total viruses	1,000-10,0000 infectious units/L

This course contains general EPA's federal rule requirements. Please be aware that each state implements wastewater/safety/environment regulations that may be more stringent than EPA's regulations. Check with your permit or state environmental agency for more information.

Conventional Wastewater Treatment Processes

Physical

Physical processes were some of the earliest methods to remove solids from wastewater, usually by passing wastewater through screens to remove debris and solids. In addition, solids that are heavier than water will settle out from wastewater by gravity. Particles with entrapped air float to the top of water and can also be removed. These physical processes are employed in many modern wastewater treatment facilities today.

Biological

In nature, bacteria and other small organisms in water consume organic matter in sewage, turning it into new bacterial cells, carbon dioxide, and other by-products. The bacteria normally present in water must have oxygen to do their part in breaking down the sewage.

In the 1920s, scientists observed that these natural processes could be contained and accelerated in systems to remove organic material from wastewater.

With the addition of oxygen to wastewater, masses of microorganisms grew and rapidly metabolized organic pollutants.

Any excess microbiological growth could be removed from the wastewater by physical processes. Activated Sludge is a suspended growth process for removing organic matter from sewage by saturating it with air and microorganisms that can break down the organic matter. Advanced Treatment involves treatment levels beyond secondary treatment.

Chemical

Chemicals can be used to create changes in pollutants that increase the removal of these new forms by physical processes. Simple chemicals such as alum, lime or iron salts can be added to wastewater to cause certain pollutants, such as phosphorus, to floc or bunch together into large, heavier masses which can be removed faster through physical processes.

Over the past 30 years, the chemical industry has developed synthetic inert chemicals known as polymers to further improve the physical separation step in wastewater treatment. Polymers are often used at the later stages of treatment to improve the settling of excess microbiological growth or biosolids.

Organisms

Many different types of organisms live in wastewater and some are essential contributors to treatment. A variety of bacteria, protozoa, and worms work to break down certain carbon-based (organic) pollutants in wastewater by consuming them. Through this process, organisms turn wastes into carbon dioxide, water, or new cell growth.

Bacteria and other microorganisms are particularly plentiful in wastewater and accomplish most of the treatment. Most wastewater treatment systems are designed to rely in large part on biological processes. We will cover this area in greater detail later in the course.

Pathogens

Many disease-causing viruses, parasites, and bacteria also are present in wastewater and enter from almost anywhere in the community. These pathogens often originate from people and animals that are infected with or are carriers of a disease.

Graywater and blackwater from typical homes contain enough pathogens to pose a risk to public health. Other likely sources in communities include hospitals, schools, farms, and food processing plants.

Some illnesses from wastewater-related sources are relatively common.

Gastroenteritis can result from a variety of pathogens in wastewater, and cases of illnesses caused by the parasitic protozoa Giardia lambia and Cryptosporidium are not unusual in the U.S.

Other important wastewater-related diseases include hepatitis A, typhoid, polio, cholera, and dysentery.

Outbreaks of these diseases can occur as a result of drinking water from wells polluted by wastewater, eating contaminated fish, or recreational activities in polluted waters. Some illnesses can be spread by animals and insects that come in contact with wastewater.

Even municipal drinking water sources are not completely immune to health risks from wastewater pathogens.

Drinking water treatment efforts can become overwhelmed when water resources are heavily polluted by wastewater. For this reason, wastewater treatment is as important to public health as drinking water treatment. We will cover this area in greater detail later in the course.

Primary Wastewater Pollutant Effects

We will cover all these effects in detail later.

Effect of BOD

- Depletes dissolved oxygen from streams, lakes and oceans.
- May cause death of aerobic organisms (fish kills, etc.).
- Increases anaerobic properties of water.

Effect of TSS

- **Increases turbidity**
  - Less light - reduced photosynthesis.
  - Causes fish's gills to get plugged up.
- **Increases silting**
  - Reduces lifetime of lakes.
  - Changes benthic (i.e., bottom) ecology.

Effects of Phosphorous and Nitrogen

- **Increases algal photosynthesis (eutrophication)**
  - Increased plant life on surface.
  - Reduces light in lower levels.

Additional Effects of Nitrogen

- Organic nitrogen and ammonia are converted to nitrates in water.
- Nitrates are converted to nitrites in digestive system.
- Nitrites are assimilated into blood stream where they are converted by respired oxygen to nitrates.
- May cause suffocation (blue baby syndrome).

Effect of pH

- Organisms are very susceptible to acids and bases.
- Recommended to have near neutral conditions (6.5 - 8.5).

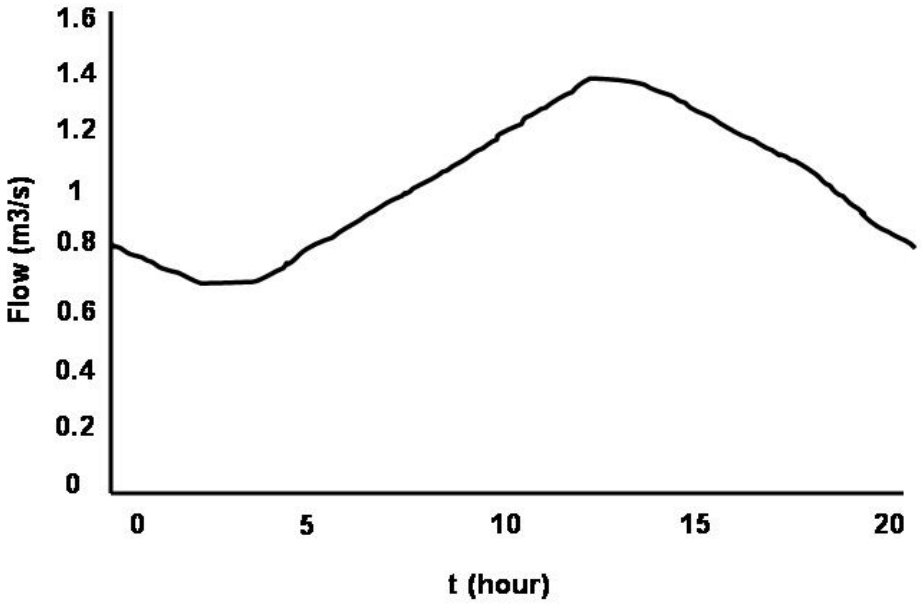
Effect of Pathogens

May infect:

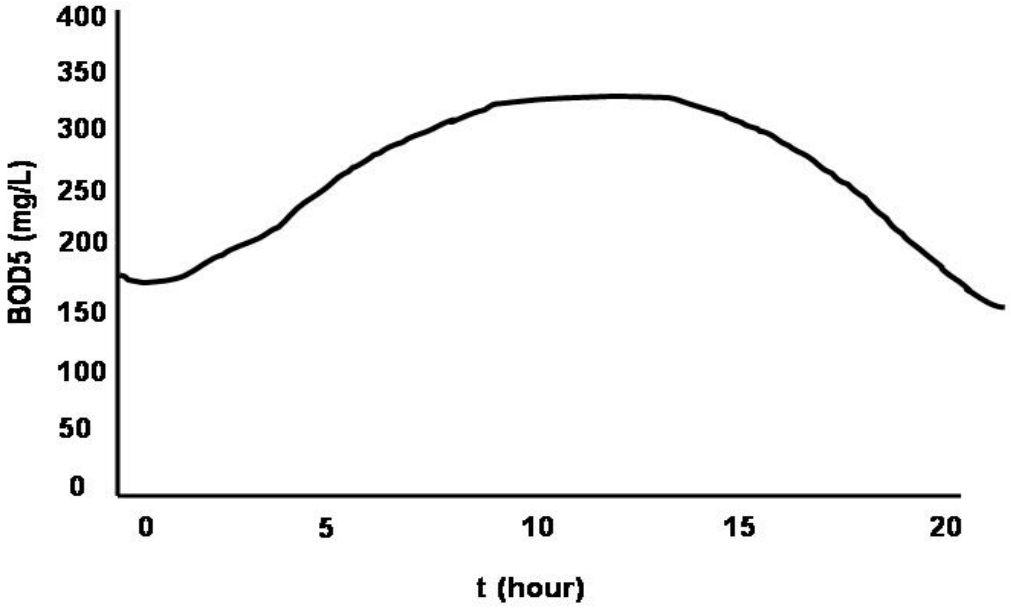
- Humans
- Animals

Domestic waste overflow at the headworks. Yes, incredibly headworks do overflow, usually due to rags, grease and debris or operator error. We do not like to see this happening and are very careful about letting the public and state regulatory agencies see this activity. One activity the State does not want to see but will happen is bypassing untreated waste to the outfall during a rainstorm.

Typical Flow Rate of Domestic Wastewater



Typical BOD5 Variation of Domestic Wastewater



Primary Wastewater Components and Constituents

Before we start, we will cover all the important components of wastewater (the basics) that specifically relate to A/S.

Important Wastewater Characteristics

In addition to the many substances, (liquids, inorganics-solids, trash, contaminants) found in wastewater, there are other characteristics system engineers and operators use to evaluate wastewater. For example, the color, temperature, pH, odor, DO, Total Solids and turbidity of wastewater give clues about the amount and type of pollutants present and treatment necessary. We will examine these characteristics, which can affect public health and the environment, as well as the design, cost, and effectiveness of treatment.

Organic Matter

Organic materials are found everywhere in our environment. These materials are composed of the carbon-based chemicals that are the building blocks of most living things. Organic materials in wastewater originate from plants, animals, or synthetic organic compounds, and enter wastewater in human wastes, paper products, detergents, cosmetics, foods, and from agricultural, commercial, and industrial sources.

Organic compounds normally are some combination of carbon, hydrogen, oxygen, nitrogen, and other elements. Many organics are proteins, carbohydrates, or fats and are biodegradable, which means they can be consumed and broken down by organisms. However, even biodegradable materials can cause pollution. In fact, too much organic matter in wastewater can be devastating to receiving waters.

ORGANIC LOADING RATE

Organic loading rate is defined as the application of soluble and particulate organic matter. It is typically expressed on an area basis as pounds of BOD5 per unit area per unit time, such as pounds of BOD5 per square foot per day ($lb/ft^2/day$). The concept of using **organic loading rates** to size an infiltration surface is based on the currently allowable hydraulic loading rates and typical organic concentrations of residential septic tank effluent (STE).

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Large amounts of biodegradable materials are dangerous to lakes, streams, and oceans, because organisms use dissolved oxygen in the water to break down the wastes. This can reduce or deplete the supply of oxygen in the water needed by aquatic life, resulting in fish kills, odors, and overall degradation of water quality.

The amount of oxygen organisms need to break down wastes in wastewater is referred to as the biochemical oxygen demand (BOD) and is one of the measurements used to assess overall wastewater strength. Some organic compounds are more stable than others and cannot be quickly broken down by organisms, posing an additional challenge for treatment. This is true of many synthetic organic compounds developed for agriculture and industry.

In addition, certain synthetic organics are highly toxic. Pesticides and herbicides are toxic to humans, fish, and aquatic plants and often are disposed of improperly in drains or carried in stormwater. In receiving waters, they kill or contaminate fish, making them unfit to eat. They also can damage processes in treatment plants. Benzene and toluene are two toxic organic compounds found in some solvents, pesticides, and other products. New synthetic organic compounds are being developed all the time, which can complicate treatment efforts.

Oil and Grease (Scum)

Fatty organic materials from animals, vegetables, and petroleum also are not quickly broken down by bacteria and can cause pollution in receiving environments. When large amounts of oils and greases are discharged to receiving waters from community systems, they increase BOD and they may float to the surface and harden, causing aesthetically unpleasing conditions. They also can trap trash, plants, and other materials, causing foul odors, attracting flies and mosquitoes and other disease vectors. In some cases, too much oil and grease causes septic conditions in ponds and lakes by preventing oxygen from the atmosphere from reaching the water.

Volatile Fatty Acid

Volatile fatty acid **(VFA) analysis forms an important means of assessing the effectiveness of the digestion process within a wastewater treatment plant**. This new analytical technique provides wastewater treatment plant operators with a much improved means of being able to optimize the operation of the digesters in the wastewater treatment plants.

Onsite septic systems also can be harmed by too much oil and grease, which can clog onsite system drainfield pipes and soils, adding to the risk of system failure. Excessive grease also adds to the septic tank scum layer, causing more frequent tank pumping to be required. Both possibilities can result in significant costs to homeowners.

Petroleum-based waste oils used for motors and industry are considered hazardous waste and should be collected and disposed of separately from wastewater.

FAT AND GREASE REMOVAL

In some larger plants, **fat and grease** are removed by passing the sewage through a small tank where skimmers collect the fat floating on the surface. Air blowers in the base of the tank may also be used to help recover the fat as a froth. Many plants, however, use primary clarifiers with mechanical surface skimmers for fat and grease removal.

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Inorganics
Inorganic minerals, metals, and compounds, such as sodium, potassium, calcium, magnesium, cadmium, copper, lead, nickel, and zinc are common in wastewater from both residential and nonresidential sources. They can originate from a variety of sources in the community including industrial and commercial sources, stormwater, and inflow and infiltration from cracked pipes and leaky manhole covers. Most inorganic substances are relatively stable, and cannot be broken down easily by organisms in wastewater.

Large amounts of many inorganic substances can contaminate soil and water. Some are toxic to animals and humans and may accumulate in the environment. For this reason, extra treatment steps are often required to remove inorganic materials from industrial wastewater sources. For example, heavy metals which are discharged with many types of industrial wastewaters are difficult to remove by conventional treatment methods. Although acute poisonings from heavy metals in drinking water are rare in the U.S., potential long-term health effects of ingesting small amounts of some inorganic substances over an extended period of time are possible.

Nutrient Introduction ***(we will return to this subject in detail later.)***
Wastewater often contains large amounts of the nutrients nitrogen and phosphorus in the form of nitrate and phosphate, which promote plant growth. Organisms only require small amounts of nutrients in biological treatment, so there normally is an excess available in treated wastewater. In severe cases, excessive nutrients in receiving waters cause algae and other plants to grow quickly depleting oxygen in the water, deprived of oxygen, fish and other aquatic life die, emitting foul odors.

Nutrients from wastewater have also been linked to ocean "red tides" that poison fish and cause illness in humans. Nitrogen in drinking water may contribute to miscarriages and is the cause of a serious illness in infants called methemoglobinemia or "blue baby syndrome."

NUTRIENTS

Nutrients are components in foods that an organism uses to survive and grow. Macronutrients provide the bulk energy an organism's metabolic system needs to function while micronutrients provide the necessary cofactors for metabolism to be carried out. Both types of nutrients can be acquired from the environment.

Carbon, nitrogen, and phosphorus are essential to living organisms and are the chief nutrients present in natural water. Large amounts of these nutrients are also present in sewage, certain industrial wastes, and drainage from fertilized land.

Conventional secondary biological treatment processes do not remove the phosphorus and nitrogen to any substantial extent. They may convert the organic forms of these substances into mineral form, making them more usable by plant life.

When an excess of these nutrients over-stimulates the growth of water plants, the result causes unsightly conditions, interferes with drinking water treatment processes, and causes unpleasant and disagreeable tastes and odors in drinking water.

The release of large amounts of nutrients, primarily phosphorus but occasionally nitrogen, causes nutrient enrichment which results in excessive growth of algae.

Uncontrolled algae growth blocks out sunlight and chokes aquatic plants and animals by depleting dissolved oxygen in the water at night. The release of nutrients in quantities that exceed the affected waterbody's ability to assimilate them results in a condition called eutrophication or cultural enrichment.

Because nutrients are very essential to the process, we will cover this in several different sections.

Gases
Certain gases in wastewater can cause odors, affect treatment, or are potentially dangerous. Methane gas, for example, is a byproduct of anaerobic biological treatment and is highly combustible. Special precautions need to be taken near septic tanks, manholes, treatment plants, and other areas where wastewater gases can collect.

Solids Introduction *(we will return to this subject in detail later.)*
Solid materials in wastewater can consist of organic and/or inorganic materials and organisms.

The solids must be significantly reduced by treatment or they can increase BOD when discharged to receiving waters and provide places for microorganisms to escape disinfection. They also can clog soil absorption fields in onsite systems.

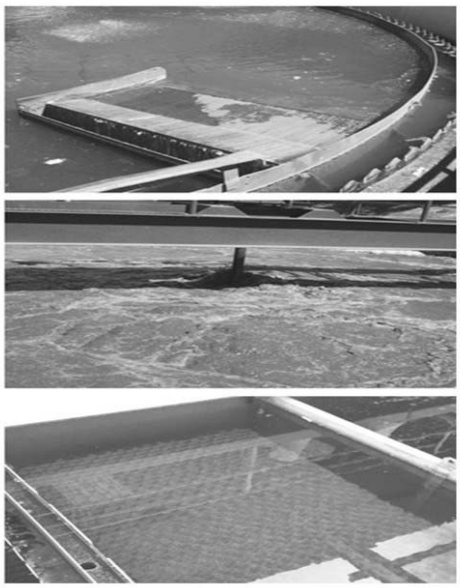
> **Settleable solids:** Certain substances, such as sand, grit, and heavier organic and inorganic materials settle out from the rest of the wastewater stream during the preliminary stages of treatment. On the bottom of settling tanks and ponds, organic material makes up a biologically active layer of sludge that aids in treatment.
>
> **Suspended solids:** Materials that resist settling may remain suspended in wastewater. Suspended solids in wastewater must be treated, or they will clog soil absorption systems or reduce the effectiveness of disinfection systems.
>
> **Dissolved solids:** Small particles of certain wastewater materials can dissolve, like salt in water. Some dissolved materials are consumed by microorganisms in wastewater, but others, such as heavy metals, are difficult to remove by conventional treatment. Excessive amounts of dissolved solids in wastewater can have adverse effects on the environment.

This area is covered in the detail in the Laboratory Procedure section towards the rear of the book.

PRIMARY TREATMENT
- PHYSICAL PROCESS
  - BAR SCREENS
  - GRIT CHAMBERS
  - SETTLING BASINS

SECONDARY TREATMENT
- BIOLOGICAL PROCESS
  - PONDS / LAGOONS
  - OXIDATION DITCHES
  - ACTIVATED SLUDGE

TERTIARY TREATMENT
- CHEMICAL / PHYSICAL PROCESS
  - FILTER AIDS
  - FILTRATION
  - WETLAND



CONVENTIONAL WASTEWATER TREATMENT

- PRIORITY POLLUTANTS
- PHARMACEUTICALS
- HEAVY METALS
- BIODEGRADABLE SOLIDS
- DISSOLVED INOGANICS
- NUTRIENTS
- SOLIDS
- PATHOGENS AND PARASITES

WASTEWATER TREATMENT OVERLOAD INDICATORS

Essential Wastewater Treatment Terms

Aerobic (AIR-O-bick) – a condition in which free or dissolved oxygen is present in the aquatic environment.

Aerobic Bacteria (Aerobes) – bacteria which will live and reproduce only in an environment containing oxygen. Oxygen combined chemically, such as in water molecules (H_2O), cannot be used for respiration by aerobes.

Anaerobic (AN-air O-bick) - a condition in which ***"free"*** or dissolved oxygen is not present in the aquatic environment.

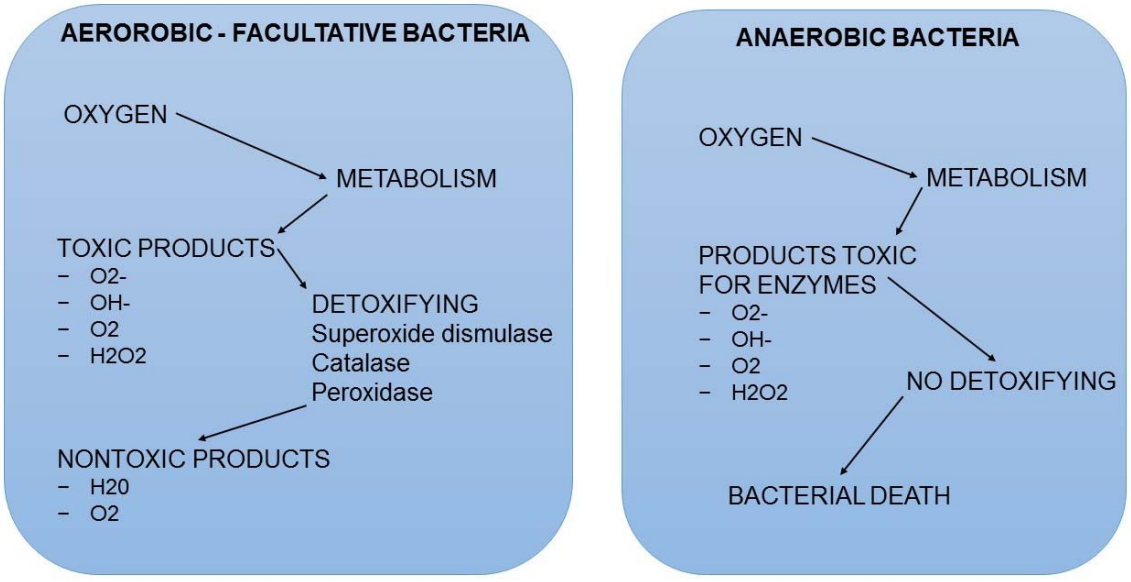
Anaerobic Bacteria (Anaerobes) – bacteria that thrive without the presence of oxygen.

Saprophytic Bacteria – bacteria that break down complex solids to volatile acids.

Methane Fermenters – bacteria that break down the volatile acids to methane (CH_4) carbon dioxide (CO_2) and water (H_2O).

Oxidation – the addition of oxygen to an element or compound, or removal of hydrogen or an electron from an element or compound in a chemical reaction. The opposite of reduction.

Reduction – the addition of hydrogen, removal of oxygen or addition of electrons to an element or compound. Under <u>anaerobic</u> conditions in wastewater, sulfur or compounds elemental sulfur are reduced to H_2S or sulfide ions.



ANAEROBIC OXYGEN REQUIREMENTS

Wastewater Components Continued

Hydrogen Sulfide and Ammonia Section

The gases hydrogen sulfide and ammonia can be toxic and pose asphyxiation hazards. Ammonia as a dissolved gas in wastewater also is dangerous to fish. Both gases emit odors, which can be a serious nuisance. Unless effectively contained or minimized by design and location, wastewater odors can affect the mental well-being and quality of life of residents. In some cases, odors can even lower property values and affect the local economy.

AMMONIA

Ammonia is a compound of nitrogen and hydrogen with the formula **NH_3**. The simplest pnictogen hydride, ammonia, is a colorless gas with a characteristic pungent smell. It is a common nitrogenous waste, particularly among aquatic organisms, and it contributes significantly to the nutritional needs of terrestrial organisms by serving as a precursor to food and fertilizers.

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Hydrogen sulfide or H_2S problems are very common in the collection and wastewater system. There are many chemicals used to help or treat this problem. Here are a few used in the treatment of hydrogen sulfide problems: Salts of zinc, lime, hydrogen peroxide, chlorine and magnesium hydroxide. Hydrogen sulfide production in collection systems can cause a number of problems such as corrosion of the pipes, manholes, and creation of hazardous atmospheres and foul odors.

The best method of controlling hydrogen sulfide is to eliminate its habitat or growth area by keeping sewers cleaner, this will harbor fewer slime bacteria. Here are some important statements regarding the reduction of hydrogen sulfide: Salts of zinc and iron may precipitate sulfides, lime treatments can also kill bacteria that produce hydrogen sulfide, but this creates a sludge disposal problem and chlorination is effective at reducing the bacteria which produce hydrogen sulfide. Hydrogen sulfide conditions occur in the sewer system because of the lack of oxygen.

HYDROGEN SULFIDE

Hydrogen sulfide is the chemical compound with the chemical formula **H_2S**. It is a colorless gas with the characteristic foul odor of rotten eggs. It is very poisonous, corrosive, and flammable. **Hydrogen sulfide** is often produced from the microbial breakdown of organic matter in the absence of oxygen gas, such as in swamps and sewers; this process is commonly known as anaerobic digestion that is done by sulfate-reducing microorganisms.

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ODORS

Odors emitted by sewage treatment are typically an indication of an anaerobic or "septic" condition. Early stages of processing will tend to produce foul-smelling gases, with hydrogen sulfide being most common in generating complaints.

Large process plants in urban areas will often treat the odors with carbon reactors, a contact media with bio-slimes, small doses of chlorine, or circulating fluids to biologically capture and metabolize the noxious gases. Other methods of odor control exist, including addition of iron salts, hydrogen peroxide, calcium nitrate, etc. to manage hydrogen sulfide levels.

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Pollutants - Oxygen-Demanding Substances

CONVENTIONAL POLLUTANTS

POTWs are designed to treat typical household wastes and biodegradable commercial and biodegradable industrial wastes. The Clean Water Act defines the contaminants from these sources as **conventional pollutants**. **Conventional pollutants** are biological oxygen demand (BOD), total suspended solids (TSS), fecal coliform, oil and grease, and pH**.**

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Dissolved oxygen is a key element in water quality that is necessary to support aquatic life. A demand is placed on the natural supply of dissolved oxygen by many pollutants in wastewater. This is called biochemical oxygen demand, or BOD, and is used to measure how well a sewage treatment plant is working. If the effluent, the treated wastewater produced by a treatment plant, has a high content of organic pollutants or ammonia, it will demand more oxygen from the water and leave the water with less oxygen to support fish and other aquatic life. Organic matter and ammonia are “oxygen-demanding” substances.

Oxygen-demanding substances are contributed by domestic sewage and agricultural and industrial wastes of both plant and animal origin, such as those from food processing, paper mills, tanning, and other manufacturing processes.

These substances are usually destroyed or converted to other compounds by bacteria if there is sufficient oxygen present in the water, but the dissolved oxygen needed to sustain fish life is used up in this break down process.

Pathogens ***(we will return to this subject in detail later.)***
Disinfection of wastewater and chlorination of drinking water supplies has reduced the occurrence of waterborne diseases such as typhoid fever, cholera, and dysentery, which remain problems in underdeveloped countries while they have been virtually eliminated in the infectious microorganisms, or pathogens, may be carried into surface and groundwater by sewage from cities and institutions, by certain kinds of industrial wastes, such as tanning and meat packing plants, and by the contamination of storm runoff with animal wastes from pets, livestock and wild animals, such as geese or deer.

Humans may come in contact with these pathogens either by drinking contaminated water or through swimming, fishing, or other contact activities. Modern disinfection techniques have greatly reduced the danger of waterborne disease.

Inorganic and Synthetic Organic Chemicals
A vast array of chemicals is included in this category. Examples include detergents, household cleaning aids, heavy metals, pharmaceuticals, synthetic organic pesticides and herbicides, industrial chemicals, and the wastes from their manufacture. Many of these substances are toxic to fish and aquatic life and many are harmful to humans. Some are known to be highly poisonous at very low concentrations.

Others can cause taste and odor problems, and many are not effectively removed by conventional wastewater treatment. Heavy metals are discharged with many types of industrial wastewaters, are difficult to remove by conventional wastewater treatment.

TEMPERATURE AND GROWTH RATES

All biological and chemical reactions are affected by temperature. Microorganisms growth and reaction rates are slow at cold temperatures and much faster at warmer temperatures. Most microorganisms do best under moderate temperatures (10-25ºC). Aeration basin temperatures should be routinely measured and recorded.

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Thermal

Heat reduces the capacity of water to retain oxygen. In some areas, water used for cooling is discharged to streams at elevated temperatures from power plants and industries.

Even discharges from wastewater treatment plants and storm water retention ponds affected by summer heat can be released at temperatures above that of the receiving water, and elevate the stream temperature. Unchecked discharges of waste heat can seriously alter the ecology of a lake, a stream, or estuary.

Biological Components Section Introduction

Biochemical Oxygen Demand
Biochemical Oxygen Demand (**BOD or BOD5**) is an indirect measure of biodegradable organic compounds in water, and is determined by measuring the dissolved oxygen decrease in a controlled water sample over a five-day period.

During the five-day period, **aerobic** bacteria (oxygen-consuming) decompose organic matter in the sample and consumes dissolved oxygen in proportion to the amount of organic material that is present. Then what happens is a high BOD concentration of substance can be biologically degraded, thus consuming oxygen and possibly resulting in low dissolved oxygen in the receiving water.

The BOD test was developed for samples dominated by oxygen-demanding pollutants like sewage. While its merit as a pollution parameter continues to be debated, BOD has the advantage of a long period of record.

Organic Carbon
Most organic carbon in water occurs as partly degraded plant and animal materials, some of which are resistant to microbial degradation. Organic carbon is important in the estuarine food web and is incorporated into the ecosystem by photosynthesis of green plants, then consumed as carbohydrates and other organic compounds by higher animals. In another process, formerly living tissue containing carbon is decomposed as detritus by bacteria and other microbes.

Total Organic Carbon
(**TOC**) bears a direct relationship with biological and chemical oxygen demand; high levels of TOC can result from human sources, the high oxygen demand being the main concern.

Clarification
A process to reduce the concentration of suspended matter in water. In the activated sludge treatment process, the removal of suspended solids from wastewater is usually through gravity separation in a clarifier.

Waste Activated Sludge
The activated sludge (excess biomass or cell mass) removed from the secondary treatment process. For most treatment plants, this will be a portion of the Return Activated Sludge (RAS) flow stream.

Return Activated Sludge
The settled activated sludge (biomass) that is collected in a secondary clarifier and returned to the secondary treatment process to mix with incoming wastewater. This returns a concentrated population of microorganisms back into the aeration basin.

Sludge Volume Index
A numerical expression of the settling characteristics of activated sludge in the final clarifier. SVI is expressed as the ratio of the volume in milliliters of activated sludge settled from a 1,000-mL sample in 30 minutes divided by the concentration of mixed liquor in milligrams per liter multiplied by 1,000. A good settling sludge (textbook value) is 100, but can commonly be between 80-150.

CHEMICAL OXYGEN DEMAND

Oxidizable chemicals (such as reducing chemicals) introduced into a natural water will similarly initiate chemical reactions (such as shown above). Those chemical reactions create what is measured in the laboratory as the **chemical oxygen demand (COD).**

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B.O.D.

Biochemical Oxygen Demand (**BOD**, also called **Biological Oxygen Demand**) is the amount of dissolved oxygen needed (i.e. demanded) by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. The **BOD** value is most commonly expressed in milligrams of oxygen consumed per liter of sample during 5 days of incubation at 20 °C and is often used as a surrogate of the degree of organic pollution of water.

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BOD TESTING CONCEPT

BOD test must create ideal growing conditions which will encourage microorganisms to effectively and efficiently utilize the digestible organic materials (waste). Running a **BOD analysis** on a sample consists of placing a portion of a sample (along with prepared dilution water) into an air-tight bottle (300 ml volume) and incubating the bottle at 20 +/- 1 deg C for (usually) 5 days.

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These concerns are also covered in the Laboratory Procedure-Process Control section towards the back of the book.

Topic 1 – Wastewater Treatment Introduction Post Quiz

This is not your final assignment. You can find the final assignment online.

1. Ammonia is an important component of the nitrogen cycle and because it is oxidized in the environment by microorganisms (i.e., nitrification), it is a large source of available nitrogen in the environment.
True or False

2. Ammonia is a nutrient that contains nitrogen and sulphur.
True or False

3. Un-ionized ammonia refers to all forms of ammonia in water with the exception of the ammonium ion (NH4+). Ionized ammonia refers to the ammonium ion.
True or False

4. Indicators of low dissolved-oxygen conditions include substantial presence of high dissolved-oxygen filamentous bacteria in the activated sludge, non- turbid effluent, or dark gray or black-colored mixed liquor (often with a pleasant odor).
True or False

5. Carbon, ammonia, and copper are essential to living organisms and are the chief nutrients present in natural water.
True or False

6. The best temperatures for wastewater treatment probably range from 77 to 95 degrees Fahrenheit.
True or False

7. In general, biological treatment activity accelerates in cold temperatures and slows in warm temperatures, but extreme hot or cold can stop treatment processes altogether.
True or False

8. The acidity or alkalinity of wastewater affects both treatment and the environment.
True or False

9. Low pH indicates increasing acidity while a high pH indicates increasing alkalinity (a pH of 7 is low). The pH of wastewater needs to remain between 4 and 5 to protect organisms. True or False

10. Inorganic minerals, metals, and compounds, such as sodium, potassium, calcium, magnesium, cadmium, copper, lead, nickel, and zinc are not common in wastewater.
True or False

11. Heavy metals which are discharged with many types of industrial wastewaters are easy to remove by conventional treatment methods. True or False

12. Although acute poisonings from heavy metals in drinking water are rare - potential long-term health effects of ingesting small amounts of some inorganic substances over an extended period of time are possible. True or False

13. The solids must be significantly reduced by treatment or they can increase BOD when discharged to receiving waters and provide places for microorganisms to escape disinfection. They also can clog soil absorption fields in onsite systems. True or False

14. Certain substances, such as sand, grit, and heavier organic and inorganic materials settle out from the rest of the wastewater stream during the preliminary stages of treatment. True or False

15. Excessive amounts of dissolved solids in wastewater cannot have adverse effects on the environment. True or False

Answers are found in the rear before the References.

Topic 2 – Primary Wastewater Treatment Section

Topic 2 - Section Focus: You will learn the basics of the primary wastewater treatment process. At the end of this section, you the student will be able to understand and describe primary wastewater treatment process. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

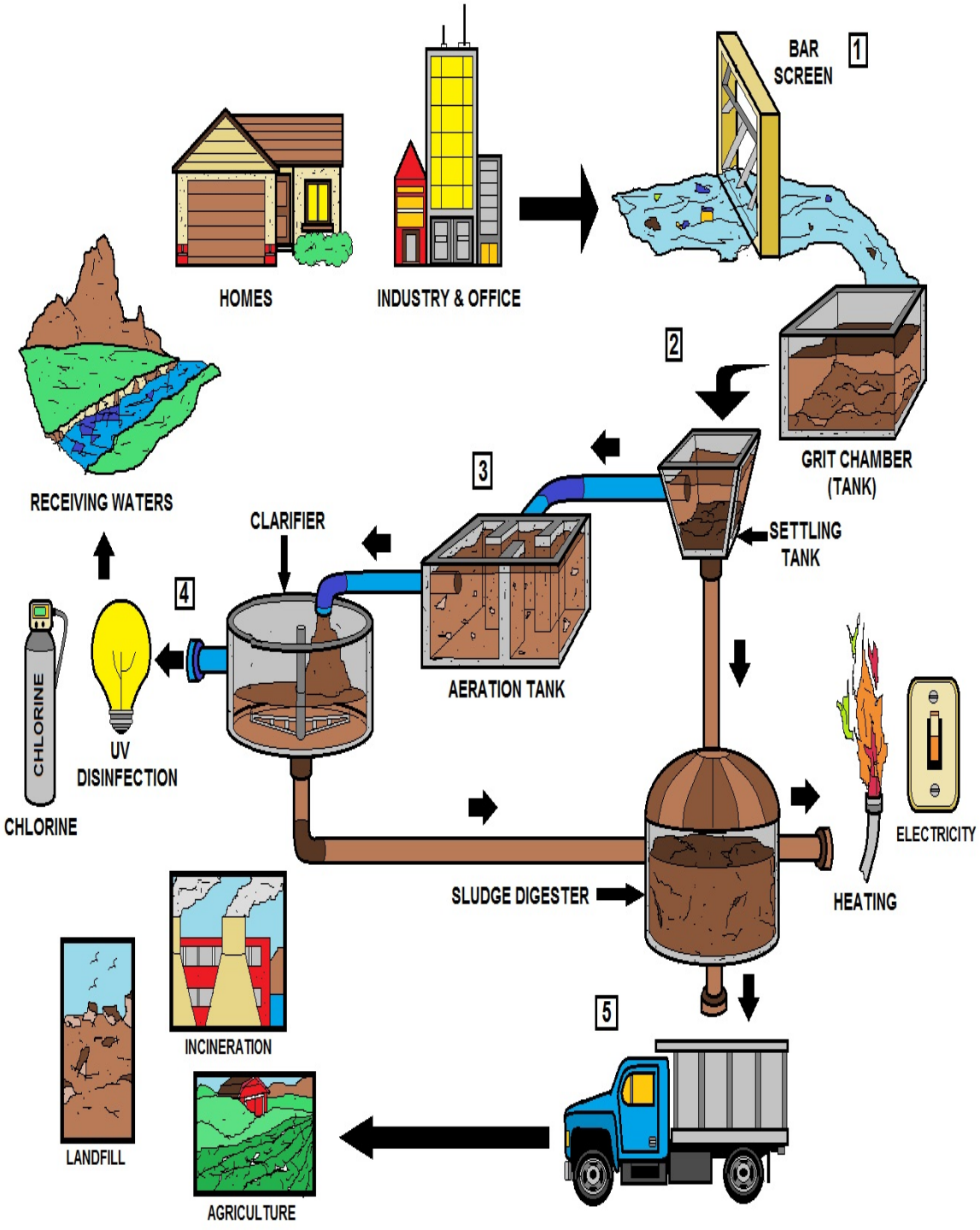
Topic 2 – Scope/Background: Primary treatment of wastewater involves sedimentation of solid waste within the water. This is done after filtering out larger contaminants within the water. Wastewater is passed through several tanks and filters that separate water from contaminants. The resulting "sludge" is then fed into a digester, in which further processing takes place. This primary batch of sludge contains nearly 50% of suspended solids within wastewater.

Primary Treatment Wastewater is a plain sedimentation process to remove suspended organic solids from the sewage. Chemical are sometimes used to remove finely divided and colloidal solids.

Objectives of Primary Treatment

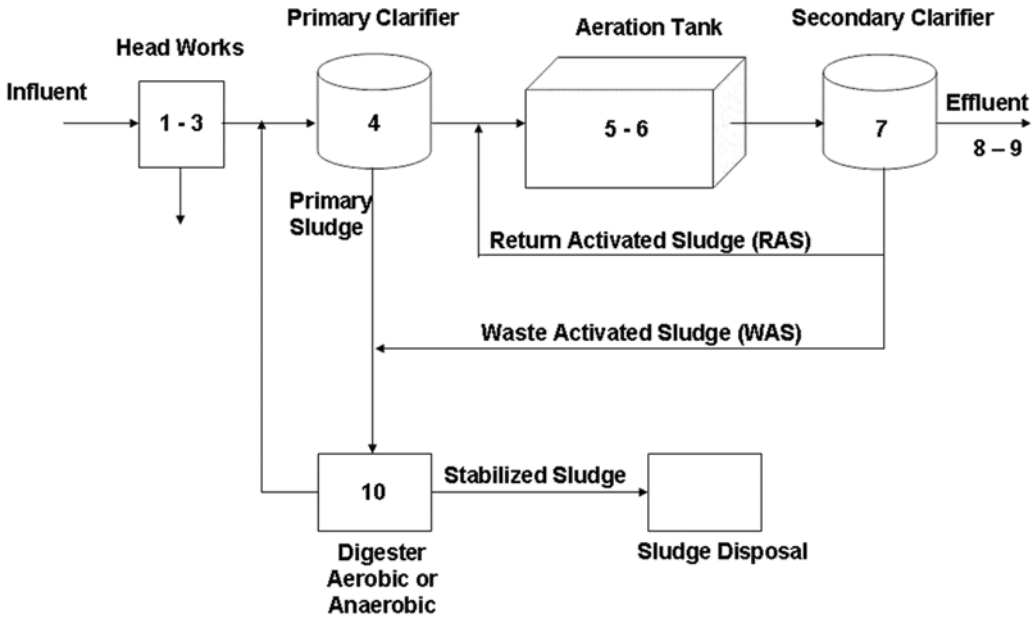
The main objectives of primary treatment of wastewater are:

1. To reduce the strength of sewage to the extent 30% to 50%.
2. To remove settleable solids by 80% to 90%.
3. To reduce BOD by 30% to 35%.
4. To make the sewage fit for further treatment process.



WASTEWATER TREATMENT PROCESS

Wastewater Treatment Plant Overview



The following is a description of each numbered section in the illustration above.

Wastewater treatment plants are constantly pushed to meet higher standards of water quality. Careful consideration needs to be made when designing pretreatment for an A/S facility.

Traditional activated sludge process headworks (pretreatment) includes bar screens, grit removal and possibly a pre-sedimentation basin. Newly designed systems may include chemicals to enhance precipitation of nutrients or to decrease issues with hydrogen sulfide. We will examine these processes in detail.

Plant Influent: Waste enters the treatment facility through the municipal sewer system. Raw *Wastewater* enters the treatment facility at the beginning of the treatment plant, referred to as the "headworks" of the plant. The *wastewater* is being pumped to the wastewater treatment facility using pumps.

Illustration box 1 – 3:

1. Preliminary treatment removes large objects from the *wastewater* to help prevent clogging of pipes and damaging the treatment equipment. The removed during preliminary treatment is typically hauled to a landfill for disposal.

2. **Coarse Bar Screen**: Metal bars collect large *debris* such as rags, wood, plastics, etc.

3. **Grit Removal**: The *wastewater* flows through a channel, allowing dense, inorganic material to settle on the bottom. Scrapers, hoppers and clam buckets remove the collected grits.

Illustration box 4:
Primary Settling: The wastewater flows into large settling tanks that allow *suspended solids* and organic material to sink to the bottom of this tank.

Phosphorous Removal: Partially treated *wastewater* is drawn from the top of the settling tanks and in some treatment facilities, chemicals are added to remove phosphorous.

Illustration box 5-6:
Aeration Basins: Large aeration basins or tanks mix the partially treated *wastewater* with oxygen to support bacteria that devour organic waste. The bacteria levels are managed to provide the most efficient removal process.

Return Activated Sludge (RAS) brings sludge back to the aeration process for further treatment while Waste Activated Sludge (WAS) removes the excess or older sludge.

Illustration box 7:
Final Settling: The *clearest wastewater* is drawn from the top of the aeration tanks through spillways. By this point, the water is already quite clear. Polymers may be added to concentrate any remaining material. Once again, *suspended particles* settle to the bottom and are removed by scrapers or hoppers.

Illustration box 8-9:
Disinfection: The *cleanest water* is drawn from the surface and disinfected with chlorine or ultra-violet light to kill bacteria.

De-chlorination: The treated water is de-chlorinated. The treated water is tested to ensure it meets the EPA standards and is returned to the original water source. Before the treated water is discharged to the receiving stream, it must be sampled and chlorine-free. The samples are then analyzed in a laboratory. An automatic sampler will automatically take samples at designated times. The samples are kept refrigerated in the sampler until they can be *analyzed in the lab*.

Illustration box 10:
Sludge Digestion: Sludge from the final settling tanks is drawn from the bottom of the tanks and pumped to the primary settling tank. Not only does this sludge have a *high water content*, but it also contains oxygen and bacteria that improves the efficiency of the treatment process. The gravity belt thickener is one way to reduce the amount of water in the biosolids before further treatment. The *Volume reduction* is occurring from the loss of water.

Thickening of the *biosolids* improves digester operation and reduces the cost of sludge digestion. Aerobic sludge digestion produces a sludge that has higher water content.

Sludge disposal: Even this box needs sampling of the sludge for local limits and process control and is considered part of the activated sludge process.

We will return to this diagram several times throughout the course.

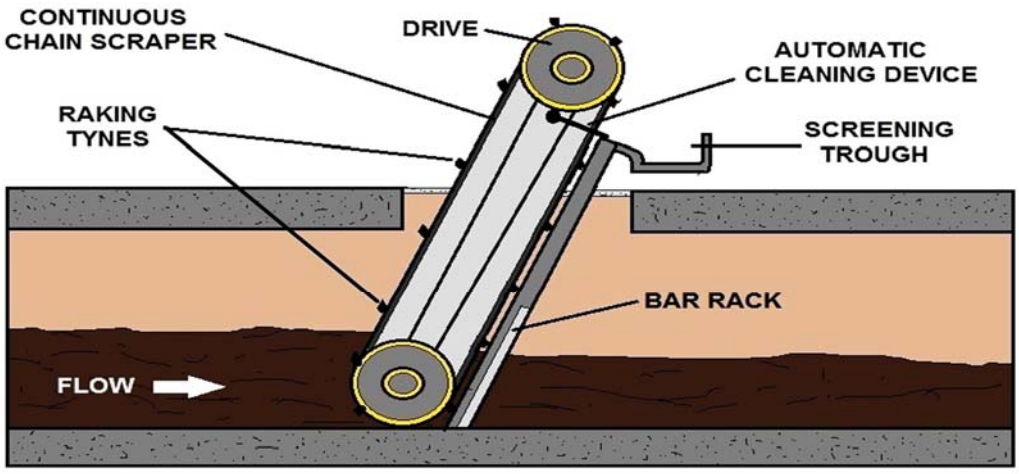
Primary Treatment Methods Photo Journal #1

Pretreatment and Activated Sludge

Wastewater treatment plants are constantly pushed to meet higher standards of water quality. Careful consideration needs to be made when designing pretreatment for a facility. Traditional activated sludge process headworks (pretreatment) includes bar screens, grit removal and possibly a pre-sedimentation basin. Newly designed systems may include chemicals to enhance precipitation of nutrients or to decrease issues with hydrogen sulfide. We will examine these processes in detail.

As sewage enters a plant for treatment it is sometimes referred to as the “Headworks”. The influent flows through a screen, which removes large *floating objects* such as rags and sticks that might clog pipes or damage equipment.

All of these devices or similar processes are found at most A/S facilities.



CONSISTS OF PARALLEL BARS, RODS OR WIRES (Course Screen) OR PERFORATED PIPE (Fine Screen)
FLOW PASSES THROUGH SCREENS AND LARGE SOLIDS ARE TRAPPED ON THE BARS FOR REMOVAL
SCREENS MAY BE COURSE (0.25 - 6 Inch In Size Openings) OR FINE (Less Than 0.25 Inch In Size Openings)
THE BARS SCREEN / BAR RACK MAY BE MANUALLY CLEANED OR MECHANICALLY CLEANED (Performed Frequently Enough To Prevent Buildup Of Solids And Reduce Flow Into Plant)

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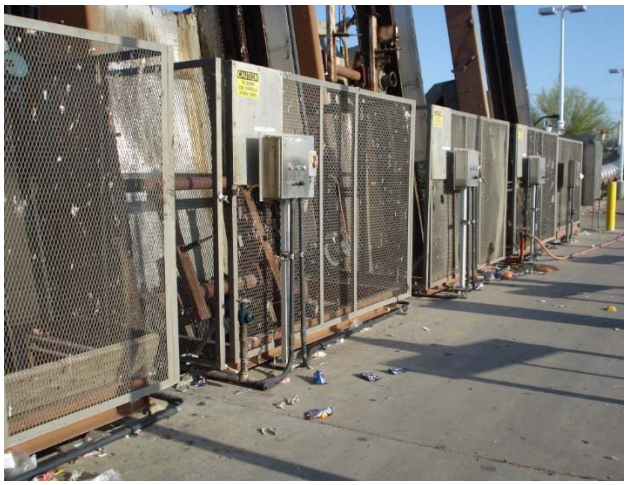
PRETREATMENT PROCESS
(BAR SCREEN / BAR RACK)

Most wastewater facilities are designed to screen out large solids and debris using several types of bar screen sizes as illustrated above.



Mechanical Bar Screens. Operators are necessary to pick up trash that is blown off the automatic rakes.

Here is a grinder pump that is installed after the bar screens. The debris is sent to the landfill. Below an operator pulled wipes that should not be flushed and clearly clogs equipment.

Flow Measurement

Flow measurement is crucial for the design and success of the treatment process. There are different device used such as weirs and magnetic flow meters. The most common used is the Parshall flume as pictured below.

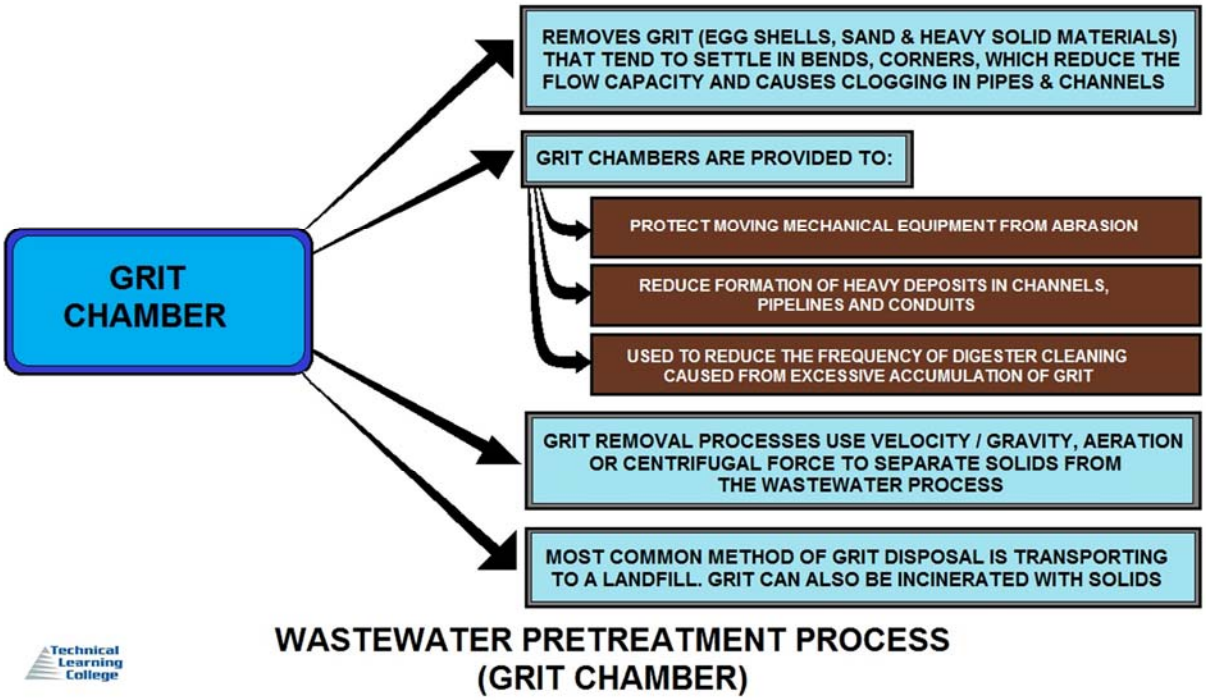
A sonic head is used for flow measurement and used for flow weighted composite samples. Another application using sonic heads are weir boxes or sometimes referred to as a splitter box as illustrated below.

Grit Chamber

A *grit chamber* is particularly important in communities with combined sewer systems where sand or gravel may wash into sewers along with stormwater. After screening is completed and grit has been removed, sewage still contains organic and *inorganic matter* along with other suspended solids.

These solids are *minute particles* that can be removed from sewage in a sedimentation tank. When the speed of the flow through one of these tanks is reduced, the suspended solids will gradually sink to the bottom, where they form a *mass of solids* called raw primary biosolids formerly called raw primary sludge.

There are many different mechanisms to remove grit. We will return to this subject later.



Caked grease (scum) stuck on weir. This process keeps the solids from entering the A/S process. Not all A/S systems have weirs. There are many different methods of pretreatment and treatment of A/S.

Floating scum in primary clarifier.

Maintenance on a circular clarifier should be performed annually.

Scum Box

The photo above and below is a Rotary Screen that works with centrifugal for to break up granule of sand and agglomerates. Like all mechanical devices, this unit failed and sheared apart.

The product “Zeeweed” is often used in the Activated sludge tank to filter the treated water. Above is a cartridge that operators removed to repair the Hollow Fibers.

BOD and COD Reduction

Wastewater treatment plants are designed to reduce the BOD and COD in the effluent discharged to natural waters, the goal is to meet state and federal discharge criteria and protect the environment. It has been said that wastewater treatment plants are designed to function as "microbiology farms," where bacteria and other microorganisms are fed oxygen and organic waste. Treatment of wastewater usually involves biological processes such as the activated sludge system in the secondary stage after preliminary screening to remove coarse particles and primary sedimentation that settles out suspended solids. These secondary treatment steps are generally considered environmental biotechnologies that harness natural self-purification processes contained in bioreactors for the biodegradation of organic matter and bioconversion of soluble nutrients in the wastewater.

Application Specific Microbiology

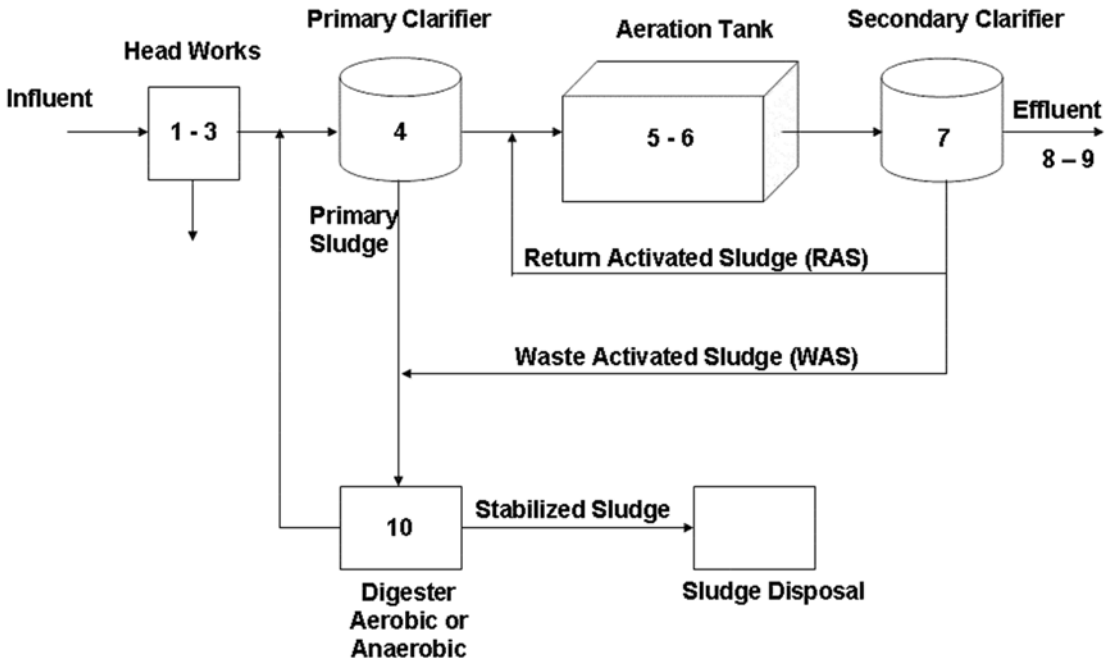
Each wastewater stream is unique, and so too are the community of microorganisms that process it. This "application-specific microbiology" is the preferred methodology in wastewater treatment affecting the efficiency of biological nutrient removal. The right laboratory prepared bugs are more efficient in organics removal if they have the right growth environment.

This efficiency is multiplied if microorganisms are allowed to grow as a layer of biofilm on specifically designed support media. In this way, optimized biological processing of a waste stream can occur. To reduce the start-up phase for growing a mature biofilm one can also purchase "application specific bacterial cultures" from appropriate microbiology vendors.

Draining Biofilm

Aeration is often used to refresh the wastewater flow at the influent channel.

Conventional A/S Wastewater Treatment Plant Overview



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We will examine these in closer detail.

Headworks Box 1-3

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Illustration Box 1 – 3:

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3. Grit Removal: The *wastewater* flows through a channel, allowing dense, inorganic material to settle on the bottom. Scrapers, hoppers and clam buckets remove the collected grits.

Conventional Wastewater Treatment - Primary Overview

The initial stage in the treatment of domestic wastewater is known as primary treatment. Coarse solids are removed from the wastewater in the primary stage of treatment. In some treatment plants, primary and secondary stages may be combined into one basic operation.

At many wastewater treatment facilities, influent passes through preliminary treatment units before primary and secondary treatment begins. One of the most common forms of pollution control in the United States is *wastewater treatment.*

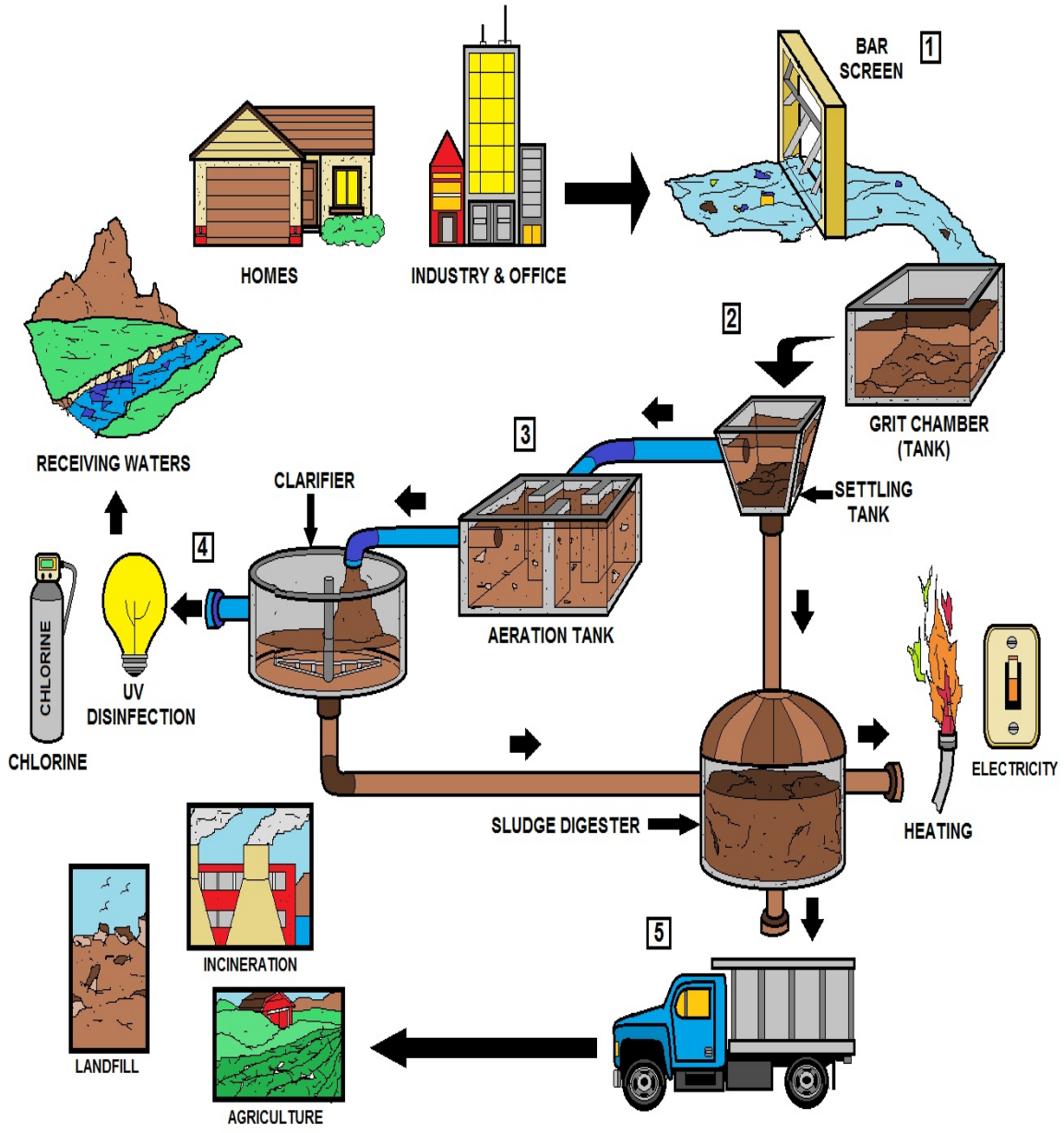
The country has a vast system of collection sewers, pumping stations, and treatment plants. Sewers collect the wastewater from homes, businesses, and many industries, and deliver it to plants for treatment. Most treatment plants were built to clean wastewater for discharge into streams or other receiving waters, or for reuse. For some time, sewage was dumped into waterways, a natural process of purification started.

First, the volume of clean water in the stream diluted wastes. Bacteria and other small organisms in the water consumed the sewage and other organic matter, turning it into new bacterial cells, carbon dioxide and other products.

Today's higher populations and greater volume of domestic and industrial wastewater require that communities give nature a helping hand. The basic function of wastewater treatment is to speed up the natural processes by which water is purified.

There are two basic stages in the treatment of wastes, *primary (physical)* and *secondary (biological)*. In the primary stage, solids are allowed to settle and removed from wastewater. The secondary stage uses biological processes to further purify wastewater. Sometimes, these stages are combined into one operation.

An example of extended aeration train or channel containing mixed liquor (MLSS) in secondary treatment.



WASTEWATER TREATMENT PROCESS

There are many different ways, systems, processes, methods to treat wastewater. In this diagram, numbers 1 and 2 are normally considered primary treatment.

Sometime numbers 1,2 are considered pretreatment.

Box 3 is generally referred to as the activated sludge process and is secondary treatment.

Numbers 4 and 5 are considered secondary treatment methods. It is possible to modify this process and add many different processes like various filters or BNR. We will try to cover many of these related A/S processes in this course.

Sampling Influent and Industrial Waste Introduction

Industrial Waste

Industrial waste is a killer of activated sludge bugs. In the photograph, the Inspector or Sampler is shaking the sample to make sure that the sample is mixed-up before pouring off a smaller sample into the smaller sample bottles on the ground. Normally, these Inspectors or Samplers will work in pairs. These professional need to get used to having wastewater and/or industrial waste/odors all over your clothes. But other than that, spiders, grease, confined spaces, irate customers, the interesting odors and dangerous Hydrogen Sulfide gas; this is a good job to have, a secure and well-paying job.

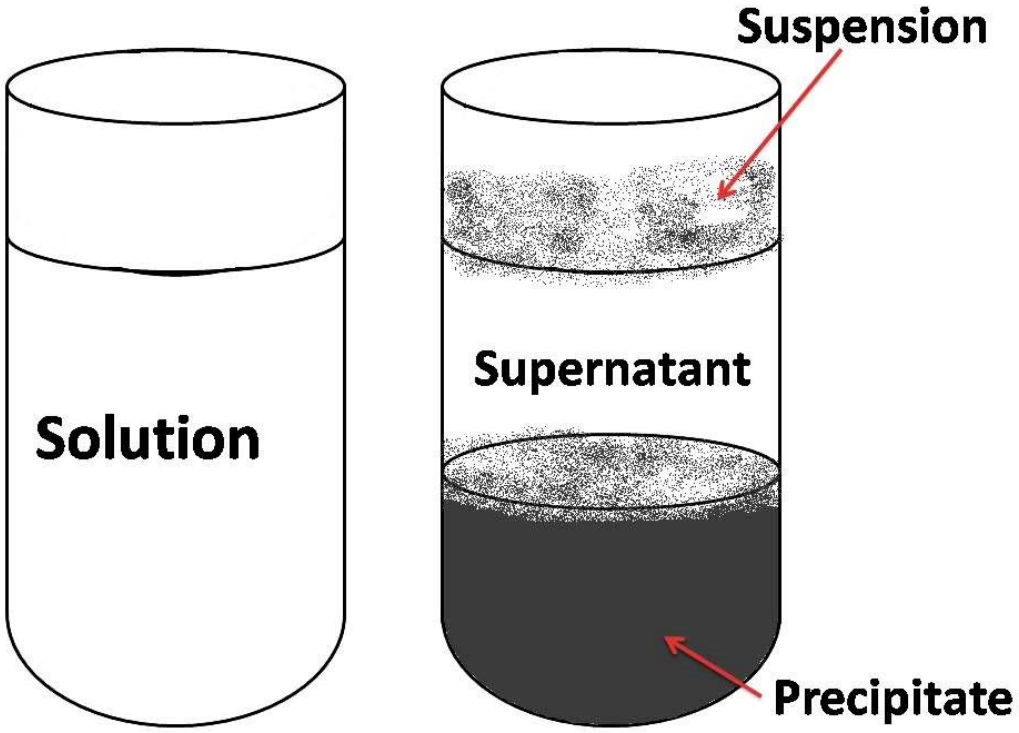
Temperature

The best temperatures for wastewater treatment probably range from 77 to 95 degrees Fahrenheit. In general, biological treatment activity accelerates in warm temperatures and slows in cool temperatures, but extreme hot or cold can stop treatment processes altogether. Therefore, some systems are less effective during cold weather and some may not be appropriate for very cold climates.

Wastewater temperature also affects receiving waters. Hot water, for example, which is a byproduct of many manufacturing processes, can be a pollutant. When discharged in large quantities, it can raise the temperature of receiving streams locally and disrupt the natural balance of aquatic life.

pH

The acidity or alkalinity of wastewater affects both treatment and the environment. Low pH indicates increasing acidity while a high pH indicates increasing alkalinity (a pH of 7 is neutral). The pH of wastewater needs to remain between 6 and 9 to protect organisms. Acids and other substances that alter pH can inactivate treatment processes when they enter wastewater from industrial or commercial sources.



Precipitation

Precipitation is the formation of a solid in a solution or inside another solid during a chemical reaction or by diffusion in a solid. When the reaction occurs in a liquid, the solid formed is called the precipitate. Without sufficient force of gravity (settling) to bring the solid particles together, the precipitate remains in suspension.

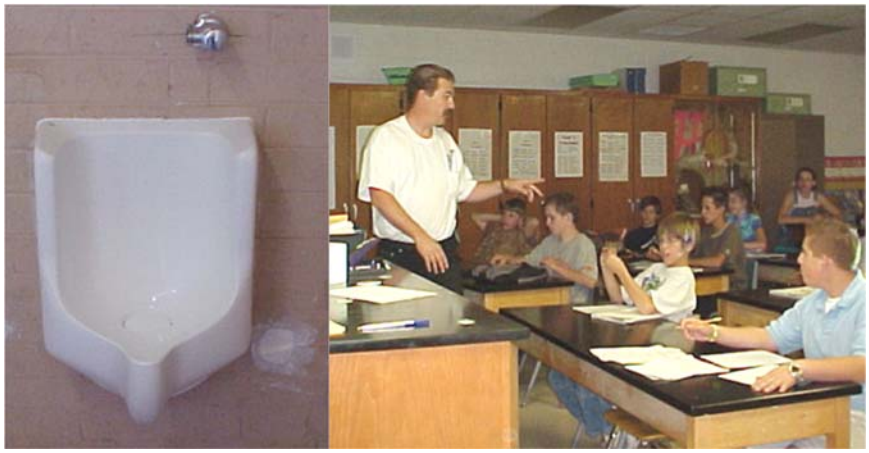
After sedimentation, especially when using a centrifuge to press it into a compact mass, the precipitate may be referred to as a pellet. The precipitate-free liquid remaining above the solid is called the supernate or supernatant.

Influent Flow Section

Whether a system serves a single home or an entire community, it must be able to handle fluctuations in the quantity and quality of wastewater it receives to ensure proper treatment is provided at all times. Systems that are inadequately designed or hydraulically overloaded may fail to provide treatment and allow the release of pollutants to the environment.

To design systems that are both as safe and as cost-effective as possible, engineers must estimate the average and maximum (peak) amount of flows generated by various sources. Because extreme fluctuations in flow can occur during different times of the day and on different days of the week, estimates are based on observations of the minimum and maximum amounts of water used on an hourly, daily, weekly, and seasonal basis. The possibility of instantaneous peak flow events that result from several or all water-using appliances or fixtures being used at once also is taken into account.

The number, type, and efficiency of all water-using fixtures and appliances at the source is factored into the estimate (for example, the number and amount of water normally used by faucets, toilets, and washing machines), as is the number of possible users or units that can affect the amount of water used (for example, the number of residents, bedrooms, customers, students, patients, seats, or meals served).



Waterless urinals are reducing water use but are concentrating the wastestream. Water conservation education is now taught at schools and this too is affecting our flow dynamics and microrganisms (MO's). Anything new always affects the bugs and no one cares but us.

According to studies, water use in many homes is lowest from about midnight to 5 a.m., averaging less than one gallon per person per hour, but then rises sharply in the morning around 6 am to a little over 3 gallons per person per hour. During the day, water use drops off moderately and rises again in the early evening hours.

Weekly peak flows may occur in some homes on weekends, especially when all adults work during the week. In U.S. homes, average water use is approximately 45 gallons per person per day, but may range from 35 to 60 gallons or more. In warmer states this number goes to 100 gallons.

Peak flows at stores and other businesses typically occur during business hours and during meal times at restaurants. Rental properties, resorts, and commercial establishments in tourist areas may have extreme flow variations seasonally.

Estimating flow volumes for centralized treatment systems is a complicated task, especially when designing a new treatment plant in a community where one has never existed previously.

Engineers must allow for additional flows during wet weather due to inflow and infiltration of extra water into sewers.

Excess water can enter sewers through leaky manhole covers and cracked pipes and pipe joints, diluting wastewater, which affects its overall characteristics. This can increase flows to treatment plants sometimes by as much as three or four times the original design load.

Infiltration or unwanted, unknown sewage flows are dangerous and critical to maintaining a health bug culture and decreases detention times. There are many times that some interference or industrial waste including high heat will disrupt or kill your bugs. Because of unwanted flows, many operators need to start from scratch to build a healthy bug population. Special treatments and/or processes may need to come online to assist during these times.

We have seen operators transport RAS from 50 miles away to re-start a healthy tank and that can take up to three to ten days using hundreds of gallons of RAS.

Grout is used to prevent infiltration into manholes or exfiltration out of the pipe.

Preliminary Wastewater Treatment Section

The Preliminary Treatment is purely physical stage consisting of Coarse Screening, Raw Influent Pumping, Static Fine Screening, Grit Removal, and Selector Tanks in the A/S BNR process or for filamentous bacteria control. The raw wastewater enters from the collection system into the Coarse Screening process. After the wastewater has been screened, it may flow into a grit chamber where sand, grit, cinders, and small stones settle to the bottom.

Fine Screening

Removing the grit and gravel that washes off streets or land during storms is very important, especially in cities with combined sewer systems.

Large amounts of grit and sand entering a treatment plant can cause serious operating problems, such as excessive wear of pumps and other equipment, clogging of aeration devices, or taking up capacity in tanks that is needed for treatment.

Collected Grit

In some plants, another finer screen is placed after the grit chamber to remove any additional material that might damage equipment or interfere with later processes. The grit and screenings removed by these processes must be periodically collected and trucked to a landfill for disposal or are incinerated.

The Coarse Screening consists of a basket shaped bar screen which collects larger debris (several inches in diameter) prior to the Raw Influent Pumping. This debris is removed and placed into a dumpster for disposal into the landfill.

Manual and Mechanical Bar Screens

The wastewater then passes into the Raw Influent Pumping process that consists of submersible centrifugal pumps. These influent pumps operate under a principal termed prerotation, which allows them to vary their pump rate hydraulically without the use of complex and expensive electronics.

The flow then passes into the Static Fine Screening process which consists of two stationary (or static) screens which remove finer debris not captured by the coarse screens. This screened debris is then dewatered and collected in hoppers for disposal into a landfill.

The wastewater then passes into the Grit Removal process which consists of two vortex grit separators which produce a whirlpool action to force the finest debris to the outside perimeter for subsequent collection. This debris is then collected in hoppers, dewatered, and disposed into a landfill. The screened and de-gritted wastewater then enters into Primary Sedimentation. *Credit to the USEPA*

GRIT

Grit consists of sand, gravel, cinders, and other heavy materials. It also includes organic matter such as eggshells, bone chips, seeds, and coffee grounds.

Pretreatment may include a sand or grit channel or chamber, where the velocity of the incoming sewage is adjusted to allow the settlement of sand and grit.

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GRIT REMOVAL

Grit removal is necessary to:

1. reduce formation of heavy deposits in aeration tanks, aerobic digesters, pipelines, channels, and conduits;

2. reduce the frequency of digester cleaning caused by excessive accumulations of grit; and

3. protect moving mechanical equipment from abrasion and accompanying abnormal wear. The removal of grit is essential for equipment with closely machined metal surfaces such as commutators, fine screens, centrifuges, heat exchangers, and high pressure diaphragm pumps.

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GRIT REMOVAL CHAMBERS

Grit chambers come in 3 types: **horizontal grit** chambers, **aerated grit** chambers and **vortex grit** chambers. Vortex type grit chambers include mechanically induced vortex, hydraulically induced vortex, and multi-tray vortex separators. Given that traditionally, grit removal systems have been designed to remove clean inorganic particles that are greater than 0.210 mm, most grit passes through the grit removal flows under normal conditions. During periods of high flow deposited grit is re-suspended and the quantity of grit reaching the treatment plant increases substantially.

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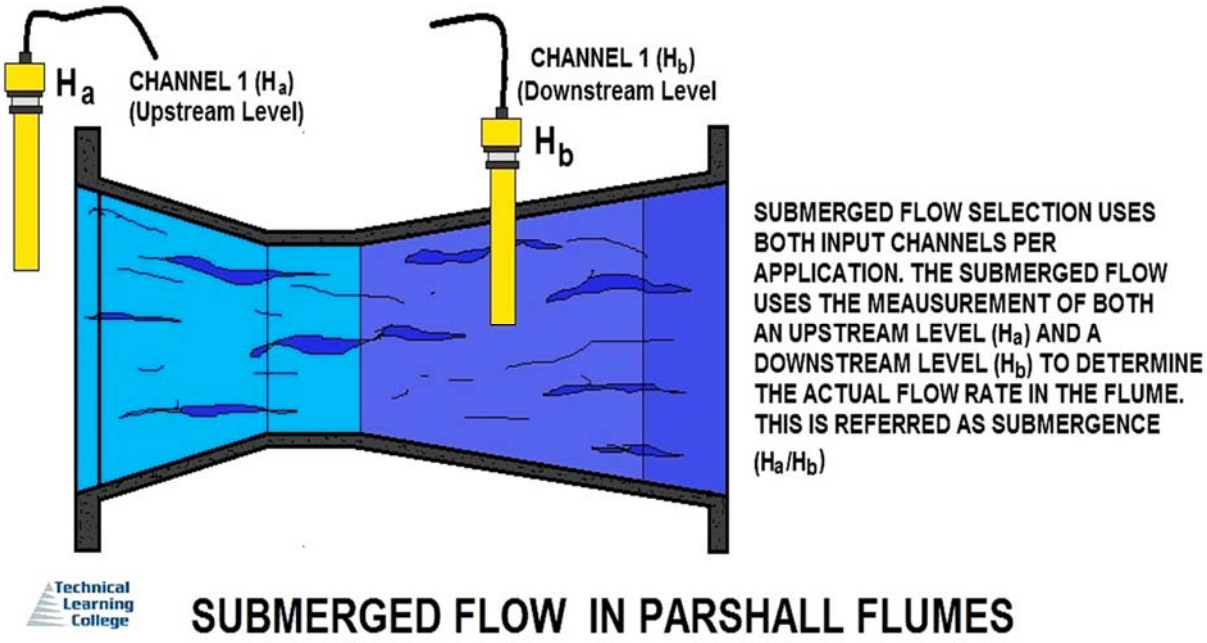
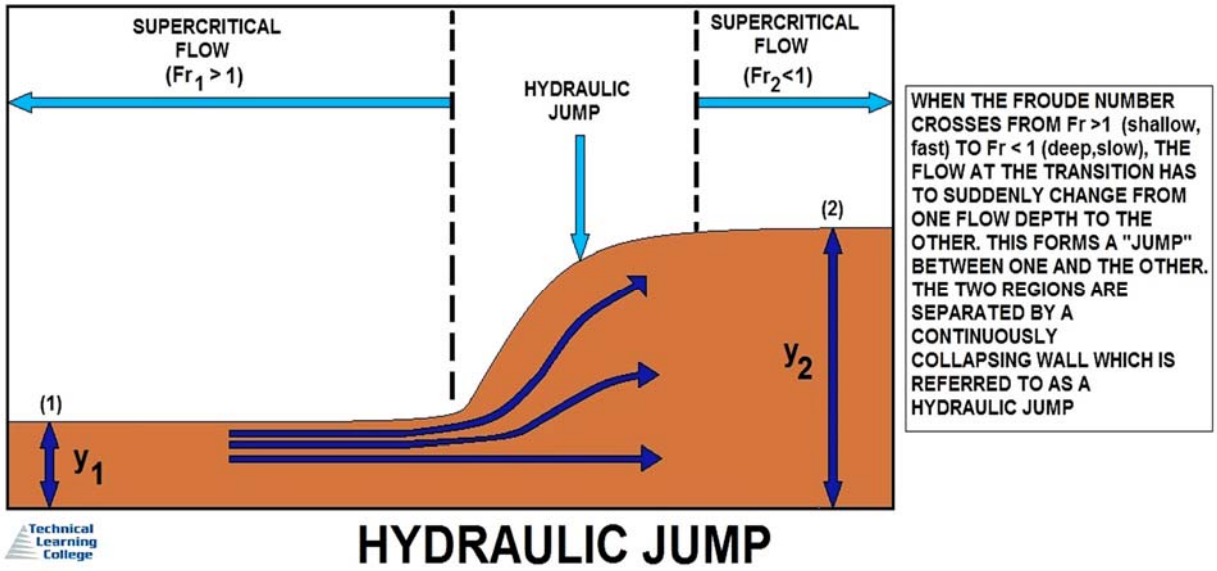
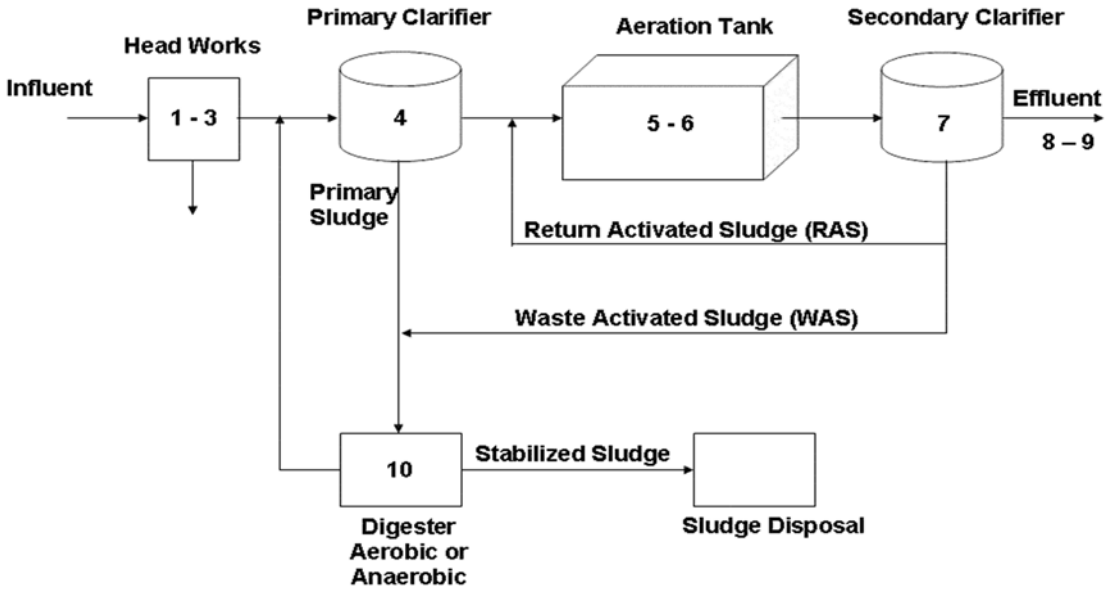
Most A/S processes have some type of grit and trash removal system. Even the most primitive wastewater system needs to remove all inorganics from the system. Otherwise, we would simply have a hole in the ground that we dump sewage into, but that did not work out because we threw all types of inorganics in this hole, disrupting the natural biological work. *We will cover grit later in the Aeration and Secondary Sections.*
Credit to the USEPA for this text.



Parshall Flumes measure the flow of the wastewater entering the plant. The diagram above and below shows how sonic heads measure the height of the flow in an open channel. In case of debris clogging the inlet of the flume, the operator needs easy to access.



Conventional A/S Wastewater Treatment Plant Overview



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Primary Clarifier Box 4

Primary Settling: The wastewater flows into large settling tanks that allow *suspended solids* and organic material to sink to the bottom of this tank.

Phosphorous Removal: Partially treated *wastewater* is drawn from the top of the settling tanks and in some treatment facilities, chemicals are added to remove phosphorous.

Primary Sedimentation
With the screening completed and the grit removed, wastewater still contains dissolved organic and inorganic constituents along with suspended solids. The suspended solids consist of minute particles of matter that can be removed from the wastewater with further treatment such as sedimentation or gravity settling, chemical coagulation, or filtration.

Primary Clairifer Box 4- See Illustration Chart

PRIMARY TREATMENT

Primary treatment consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface. The settled and floating materials are removed and the remaining liquid may be discharged or subjected to secondary treatment.

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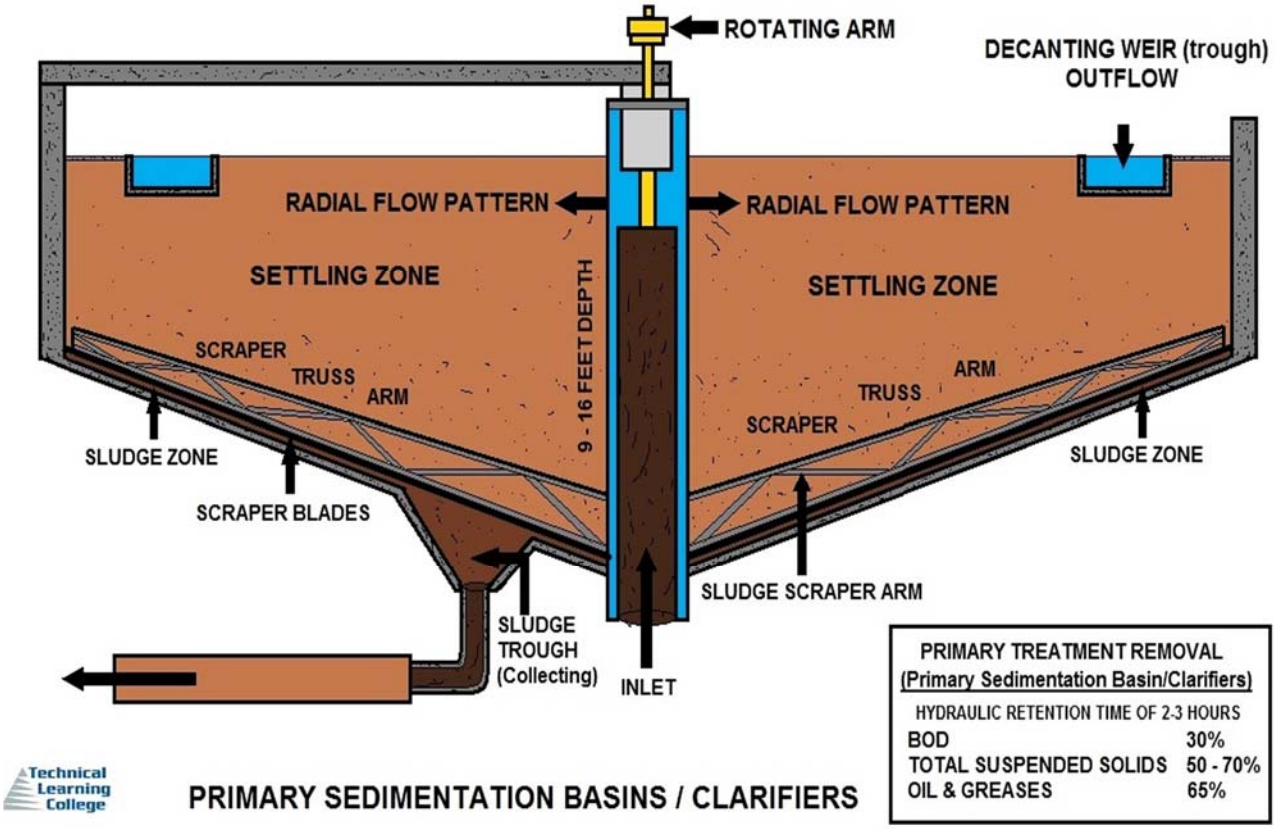
Most wastewater treatment facilities were designed with a primary and secondary clarifier. These two devices are excellent at handling the density of the sludge and the detention time. Primary clarifier sludge is usually denser than secondary sludge.

The effluent from a secondary clarifier is normally clearer than primary effluent and the primary will generally have grease and grit build up if not removed by pretreatment.

The method in which solids are removed will depend upon the shape of the clarifier. In a rectangular clarifier, the solids settle to the bottom of a clarifier and scraped to one end or to the middle. In circular clarifiers, the floor is sloped and the raking mechanism scrapes the solids to the center, a sump pump removes the solids.

Sludge handling or sludge disposal system vary from plant to plant and can include sludge digestion, vacuum filtration, incineration, land disposal, lagoons and burial.

The photograph the left is a rectangular basin and on the right is a circular clarifier. The rectangular basin has chains and flights to scrap sludge and a circular uses a raking mechanism.



Clarifier Operation

Primary treatment is done by pouring the wastewater into big tanks for the solid matter to settle at the bottom of the tanks.

The sludge, the solid waste that settles at the bottom of the tanks, is removed by large scrappers and is pushed to the center of the cylindrical tanks and later pumped out of the tanks for further treatment.

The remaining water is then pumped for secondary treatment.

The screening process along with grit removal enhances the operation of a primary clarifier, as seen above, by removing settable solids and non-settable such as oil and grease. This process involves the separation of macrobiotic solid matter from the wastewater.

Secondary Clarification Process Section

CLARIFICATION PROCESS

A process to reduce the concentration of suspended matter in water. In the activated sludge treatment process, the removal of suspended solids from wastewater is usually through gravity separation in a clarifier.

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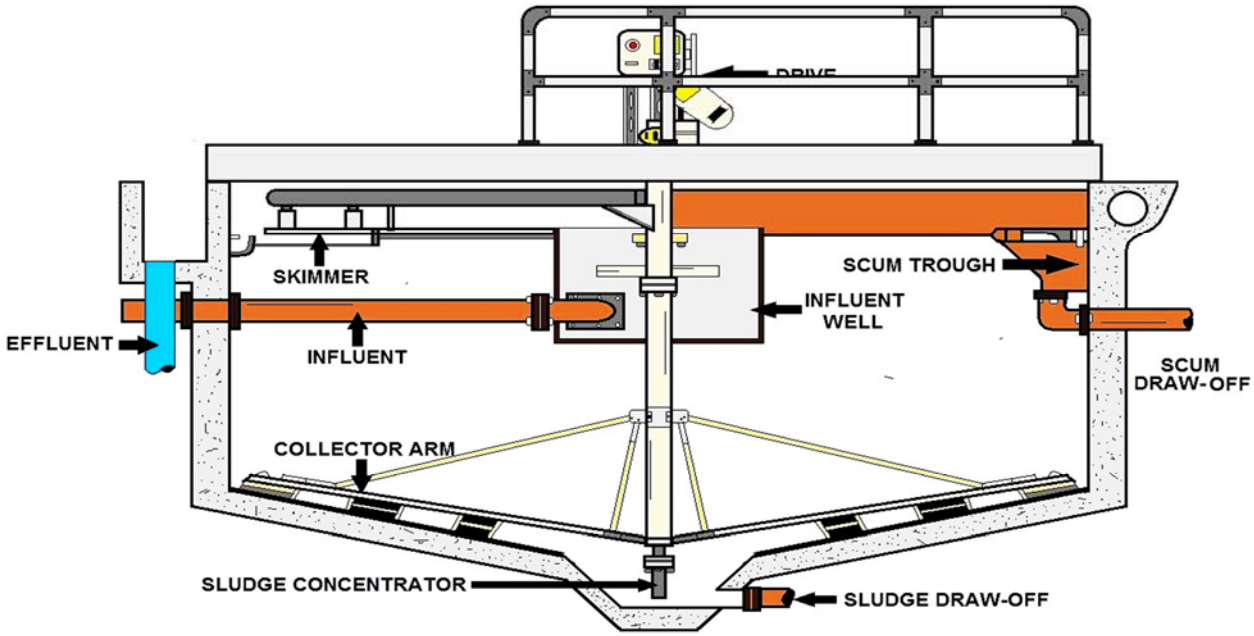
Many plants will have a second clarification process or filtration system for emergency, maintenance or demand issue. Many of these processes are not A/S processes per say, but again, anytime you cultivate a bug population for eating of wastewater food, this action is generally considered A/S.

The Secondary Clarification process generally consists of four rectangular tanks that provide quiescent (or calm) conditions that allow the larger aggregates of solids and microorganisms to settle out for collection. The clear overflow (or upper layer) is collected at the end of the tank and passed onto the Tertiary process for additional treatment if available.

The majority of microorganism-rich underflow (or lower layer) is re-circulated to Aeration Tanks as Return Sludge to help sustain the microorganism population in the Oxidation Ditches process.

However, if all the underflow was returned the plant would soon become overloaded with solids, therefore, a small portion of this mixture termed Waste Sludge is removed from the system for disposal. The Waste Sludge is transported into the Solids Handing process for disposal.

Secondary Clarifier



CIRCULAR CLARIFIER AND COLLECTOR MECHANISM

A settling tank used to remove suspended solids by gravity settling. Commonly referred to as sedimentation or settling basins, they are usually equipped with a motor driven chain and flight or rake mechanism to collect settled sludge and move it to a final removal point.

Because microorganisms are continually produced, a way must be provided for wasting some of the generated biological solids produced. This is generally done from the round or rectangular shaped clarifiers.

Let's first look at the components of a rectangular clarifier. Most are designed with scrapers on the bottom to move the settled activated sludge to one or more hoppers at the influent end of the tank. It could have a screw conveyor or a traveling bridge used to collect the sludge. The most common is a chain and flight collector.

Most designs will have baffles to prevent short-circuiting and scum from entering the effluent.

The activated sludge is removed from the hopper(s) and returned by a sludge pump to the aeration tank or wasted.

Clarifier - Constant Rate Versus Constant Percentage Return

There are two basic ways for returning sludge to the aeration tank:

- at a constant rate, independent of the secondary influent flow rate, and
- at a constant percentage of the varying secondary influent flow.

Clarifier size and hydraulics may limit the range of practical return adjustments. Regardless of calculated values, return rates should not be reduced to the level where slowly moving, thick clarifier sludge will plug the sludge withdrawal pipes.

Also, low return rates during the night should be increased to approach the anticipated higher return rates during the day before, rather than after, the increased wastewater flows actually reach the plant.

Increasing the return sludge flow after the flow increase may cause a hydraulic overload condition resulting in a carryover of solids into the clarifiers (washout).

Constant Rate Control
Returning activated sludge at a constant flow rate that is independent of the secondary influent wastewater flow rate results in a continuously varying MLSS concentration that will be at a minimum during peak secondary influent flows and a maximum during minimum secondary influent flows.

The aeration tank and the secondary clarifier must be looked at as a system where the MLSS are stored in the aeration tank during minimum wastewater flow and then transferred to the clarifier as the wastewater flow and then transferred to the clarifier as the wastewater flows initially increase.

The clarifier acts as a storage reservoir for the MLSS during periods of high flow. The clarifier has a constantly changing depth of sludge blanket as the MLSS moves from the aeration tank to the clarifier and vice versa.

Constant Percentage Control
The second approach is to pace the return flow at a fixed percentage of the influent wastewater flow rate (Q), at a constant rate (R) R/Q.

This may be done automatically with instruments, or manually with frequent adjustments.

This approach keeps the MLSS and sludge blanket depths more constant throughout high and low flow periods and also tends to maintain a more constant F/M and MCRT.

Settleability
The settleability test can be used to estimate the desirable sludge return rate. This method uses the sludge volume in a 2-L settleometer at the end of a 30-minute settling period to represent the underflow and the supernatant volume to represent the overflow.

COD:P Ratio

The PAOs need VFAs in the form of acetic and propionic acid. These acids may be in the feed or can be produced through fermentation of soluble rbCOD such as sugar, ethanol, etc., in the anaerobic zone. As a rough estimate of the propensity for phosphorus removal to an effluent concentration less than 1.0 mg/L, the COD:P ratio typically should be about 40 or more. VFA is produced through fermentation of municipal wastewater or it can be added as a commercial or waste product. Some wastewater collection systems that are relatively flat and have long collection times may have sufficient fermentation in the collection system to provide the necessary VFAs, but it will vary monthly depending upon the temperature and flow conditions in the collection system. Force mains are excellent fermenters for the production of VFA.

Systems that do not have a COD/P ratio of at least 40 will most likely need to supplement VFAs to achieve effluent phosphorus concentrations below 1.0 mg/L. However, they will still achieve substantial BPR with lower ratios if appropriately operated. See below for a more detailed discussion of VFAs.

Recent studies suggest that the instantaneous COD:P ratio is more important than the overall average (Neethling et al., 2005). Short term drops in the BOD:P ratio in the primary effluent to below that required for sustainable phosphorus removal correlated well with rises in effluent phosphorus. Intermittent recycles of phosphorus rich return streams may cause short term variability in the BOD:P ratio. Controlling or eliminating these recycles can improve plant performance. Weekend changes in the BOD:P ratio also can affect performance.

Another group of organisms, glycogen accumulating organisms (GAOs), also has the ability to take up acetate in the anaerobic zone, not by using energy in phosphate bonds but by using stored glycogen as the energy source. Under certain conditions, such as high temperatures or low phosphorus concentrations relative to the influent bioavailable COD, they may out-compete PAOs for the VFAs, which would result in less or no release of phosphorus in the anaerobic zone. This in turn will result in less or no overall phosphorus removal. GAOs use the stored energy in the form of glycogen to take up VFAs and store them as a complex carbohydrate containing poly-hydroxy valerate (PHV), instead of PHB formed with poly-phosphorus as the energy source. When this begins to happen, there is a slow decline of phosphorus removal by the biological system.

There is still a debate amongst researchers about the conditions likely to favor GAOs over PAOs. Summarizing a number of publications, it would appear that the following conditions favor the growth of GAOs over that of PAOs:

- High SRT
- High temperature over 28 °C
- Longer non-aerated zones
- Stronger wastes with low TKN content
- Periods of intermittent low BOD loads
- If the VFA consists mostly of either acetate or propionate
- Polysaccharides such as glucose are fed to the anaerobic zone.
- Low pH in the aerobic zone

Further confirmation is needed for some of these factors.

Volatile Fatty Acid Addition
Only VFAs such as acetic and propionic are taken up by PAOs. Reported doses of VFA for successful phosphorus removal range from 3 to 20 mg/L VFA per gram of phosphorus removed. These numbers, however, do not take into account the rbCOD that is fermented in the anaerobic zone. It is more accurate to look at the rbCOD/P ratio for good phosphorus removal, which ranges from 10 to 16. (Barnard, 2006). Surveys show that it is rare for a WWTP treating municipal sewage to achieve more than 95 percent removal of phosphorus by biological processes without adding VFAs (Neethling et al., 2005).

An Australian study shows that while both PAOs and GAOs could use acetate, PAOs will have a competitive advantage when the VFAs consist of roughly equal parts of acetic and propionic acid as a growth medium. PAOs that are fed on acetate are able to switch to propionate much more quickly and effectively than GAOs (Oehmen et al., 2005). This finding led to a strategy to feed equal amounts of acetic acid and propionic acid as the optimal for stimulating PAO growth (Oehmen et al., 2006, Bott et al., 2007). One study shows that isovaleric acid drives BPR even better than acetic acid (Bott et al.,2007).

Isovaleric acid, however, is much more expensive than acetic acid and is more odorous. It also is not significantly generated in the primary sludge fermentation process. Addition of rbCOD such as sugars and alcohols containing two carbons or more can increase phosphorus uptake by PAOs when added to the anaerobic zone but may cause sludge bulking if dosed in excess (Jenkins and Harper, 2003).

Sludge Fermentation
Anaerobic fermentation produces VFA consisting mainly of acetic and propionic acid. Some configurations, such as the Westbank and OWASA configurations, make use of anaerobic fermentation of the primary sludge to provide VFAs to the nutrient removal process. A fermentation process, however, can be added to any configuration to provide VFAs, especially in areas where little fermentation takes place in the collection system. Fermentation of the primary sludge or the RAS will produce VFA. Primary sludge fermentation is used more frequently.

There are several primary sludge fermenter designs that can accomplish this. The simplest configuration involves allowing the formation of a thicker sludge blanket in the primary clarifier itself and returning some of the thickened sludge to either the primary clarifier or to a mixing tank ahead of the primary clarifier to allow elutriation of the VFA to the primary effluent. This is referred to as an activated primary sedimentation tank (Barnard, 1984). Another variation is to pump some sludge to a complete-mix tank ahead of the primary clarifier, to accomplish fermentation.

The sludge is then passed to the primary clarifier for elutriation of the VFA. Both of these processes lead to an increased load on the primary clarifier and some VFA may be lost due to aeration between the primary clarifier and the anaerobic zone. Sludge age should also be controlled to prevent methanogenic bacteria from growing and converting the VFA to methane. Usually, a SRT less than 4 days is sufficient for this.

Alternative methods accomplish fermentation in a gravity sludge thickener by holding the sludge under anaerobic conditions for 4 to 8 days. The supernatant can then be fed directly to the anaerobic zone and a high load on the primary clarifier can be avoided. Thickening can either be accomplished with a single thickener or in two stages.
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Retention Time

The concentration of phosphorus in the sludge typically increases as the SRT increases, although the impact is very small over the SRT range of 4 to 30 days. Efficient phosphorus uptake typically requires a minimum SRT of 3 to 4 days depending on temperature. Higher SRTs will not increase phosphorus uptake, given there is sufficient VFAs available. If SRT becomes too great, however, effluent quality can degrade. This can be due to release of phosphorus as biomass degrades (WEF and ASCE, 2006). Both anaerobic and aerobic HRT can affect the amount of phosphorus stored by PAOs. Sufficient time should be allowed for the formation of VFAs and storage of the Polyhydroxyalkanoates (PHAs) in the anaerobic zone, although the reactions are relatively fast. If the time is too short, phosphorus uptake in the aerobic zone will be lower than achievable because insufficient PHAs were stored in the anaerobic zone. It has been reported that the ratio of HRT in the anaerobic zone to the HRT in the aerobic zone is important. One study found that a ratio of between 3 and 4 for aerobic HRT to anaerobic HRT led to optimal plant operation (Neethling et al., 2005).

Temperature

High temperatures can have an adverse effect on phosphorus removal. At temperatures greater than 28° C, phosphorus removal will generally be impaired, apparently by the predominance of the GAOs (Bott et al., 2007). At the low end of the temperature scale, Erdal et al. (2002) found that PAOs outcompeted GAOs at 5° C even though the PAO metabolism was slower at 5° C than at 20° C. The GAOs virtually disappeared in the 5° C reactor. Modeling studies have shown that GAOs can predominate at higher temperatures because of their increased ability to uptake acetate at those temperatures compared to PAOs (Whang et al., 2007). Low temperatures can also lower phosphorus uptake but have been shown to not be an issue in well operated and properly acclimatized plants (WEF and ASCE, 2006).

Presence of Oxygen or Nitrate in the Anaerobic Zone

If oxygen or nitrate is present in the anaerobic zone, organisms that use oxygen or nitrates as electron acceptors will preferentially grow by fully oxidizing the organics to CO2 and H2O, thereby reducing the VFAs available for polymerization and storage by the PAOs. Nitrate can also inhibit fermentation of rbCOD because most of the fermenters are facultative and can use the nitrate as an electron acceptor to fully oxidize the rbCOD instead of producing VFAs as an end product of fermentation, thus depriving the PAOs of organics they can polymerize and store. Therefore, recycle of streams containing high DO and nitrate concentrations to the anaerobic zone should be avoided. Introduction of oxygen through pumps and other devices should also be avoided.

Avoiding Backmixing of Oxygen

Another potential source of oxygen and nitrates to the anaerobic zone is backmixing from downstream zones. In configurations where the anaerobic zone is followed immediately by an anoxic or aerobic zone, backmixing can cause elevated concentrations of nitrates and/or DO in the anaerobic zone leading to favoring of organisms other than PAOs. The problem can be avoided by increased baffling or changing the mixing rates. This problem is more likely to occur when the downstream zone is aerated, because aeration of mixed liquor increases the liquid depth, making the liquid level in the aerobic zone higher than in the non-aerated zone.

pH

Low pH can reduce and even prevent BPR. Below pH 6.9 the process has been shown to decline in efficiency (WEF and ASCE, 2006). This is possibly due to competition with GAOs. Filipe, et al. (2001), found that GAOs grow faster than PAOs at a pH of less than 7.25.

Because many wastewater processes such as chemical addition and nitrification can lower pH, this should be monitored and adjusted if necessary. It also has been shown that it is not possible to establish enhanced biological phosphorus removal (EBPR) when the pH is less than 5.5, even though an abundant amount of acetic acid is present in the anaerobic zone (Tracy and Flammino, 1987; Randall and Chapin, 1997).

Anaerobic Release

Secondary release of phosphorus occurs when the PAOs are under anaerobic conditions in the absence of a source of VFA. The energy stored as polyphosphate is used for cell maintenance and phosphorus is released to the liquid phase (Barnard, 1984). There will then be no stored food to supply energy for the uptake of phosphorus upon subsequent aeration.

This may occur in the following process stages:

- In the anaerobic zone if the retention time is too high and the VFA is depleted well within the required retention time.
- In the main anoxic zone when that runs out of nitrates.
- In the second anoxic zone there are no nitrates to be removed.
- In the sludge blankets of final clarifiers when the RAS rate is too low and sludge is not removed fast enough.

Additionally, release may happen in aerobic zones that are too large, resulting in stored substrate depletion and destruction of PAO cells by endogenous metabolism. Since there was no food storage associated with the phosphorus release, additional carbon is then required to take up the phosphorus released, but the amount in the influent may be insufficient.

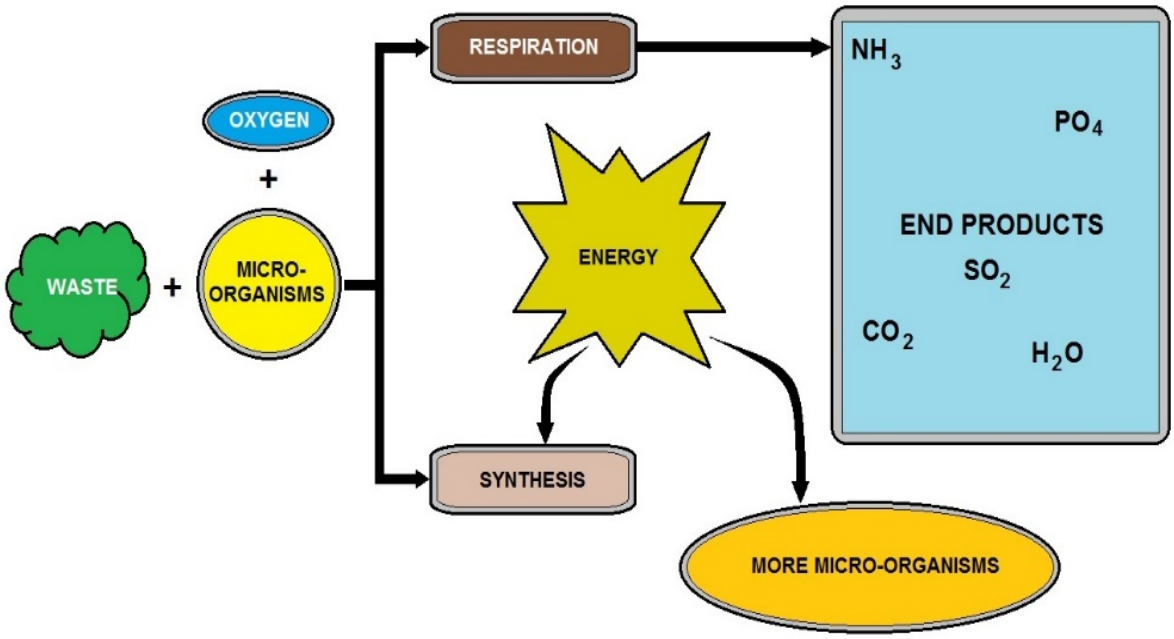
Therefore, chemicals must be added to remove the excess phosphorus. Over-design of biological nutrient removal systems could thus lead to a higher demand for an external source of VFA.

Phosphorus will be released in sludge treatment processes that are anaerobic. Gravity thickening of BPR sludge can lead to phosphorus release if long retention times are used. Using mechanical dewatering instead of gravity dewatering allows less retention time and less phosphorus release (Bott et al., 2007).

It is usually recommended that dissolved air flotation (DAF) be used to thicken BPR sludge to reduce the amount of phosphorus release. DAF thickening can be quite successful for the reduction of release, but if the thickened sludge is left on the DAF beach too long before removal, excessive release will occur, just as it will when the sludge is left too long in a gravity thickener.

Anaerobic digestion will also lead to phosphorus release although some phosphorus will be precipitated as either a metal salt (e.g. calcium phosphate) or as struvite (magnesium ammonium phosphate, MgNH4PO4).

BPR sludge takes up and releases magnesium along with phosphates, and these two ions combine with ammonium, also present in abundance in anaerobic digesters, to form struvite.



BASICS OF WASTEWATER MICROORGANISMS BREAKDOWN

Chemical Reaction Introduction

There are thousands of chemical reactions involved in the metabolism of a bacterium this diagram identifies three major processes that are relevant to the biological treatment of wastewater. These are Ingestion, Respiration, Growth and division.

These processes are very highly integrated and the relationship between them in a single bacterial cell and is illustrated in this picture that shows the pathway of the ingested organic carbon (waste). Some goes along the pathway of catabolism or Respiration and ends up as carbon dioxide. This carbon is lost to the system.

The remaining organic carbon follows the anabolism or Growth pathway and ends up in new biomass. This carbon is therefore retained in the system. The purpose of respiration is to provide the energy that is required for growth and for the maintenance of the bacterium.

Photo Journal #2

Top photograph, a clarifier's raking mechanism.
Bottom, scum armature equipment.

Here is an example of a rectangular clarifier used in the secondary settling process. Operation changes that should be employed if a dark brown foam is developing on the aeration basin is to increase the wasting rate.

Here is pen floc being carried over the weir do to a process upset. Algae growth in excess can also create several different problems.

Clairifer Problems and Solutions

We will cover filmentous bacteria later.

BULKING

An activated sludge that does not settle well and may overflow the weirs of the final clarifiers resulting in excess suspended solids in the effluent. It is usually caused by filamentous.

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BULKING SLUDGE

A phenomenon that occurs in activated sludge plants whereby the sludge occupies excessive volumes and will not concentrate readily. This condition refers to a decrease in the ability of the sludge to settle and consequent loss over the settling tank weir. Bulking in activated sludge aeration tanks is caused mainly by excess suspended solids (SS) content. **Sludge bulking** in the final settling tank of an activated sludge plant may be caused by improper balance of the BOD load, SS concentration in the mixed liquor, or the amount of air used in aeration.

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BULKING SLUDGE COMMON CAUSES

The following are a **few causes for bulking**:

1. Fats, Oils, and Grease
2. Low Dissolved Oxygen
3. Low F/M Ratio
4. Nutrient Deficiency
5. Septicity (Organic Acids and Sulfide)

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PIN FLOC

Very fine floc particles with poor settling characteristics, usually indicative of an old sludge (high MLSS levels).

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SLUDGE FERMENTATION

An **anaerobic medium containing sludge supernatant fluid and glucose** was used for enumeration of bacteria from the sludge fermentation.

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SLUDGE BLANKET

The sludge blanket is the layer of solids on the bottom of the clarifier.

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STRAGLER FLOC

Small, light, and fluffy floc particles with poor settling characteristics, usually indicative of a younger sludge and/or low MLSS levels.

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OLD SLUDGE

Old sludge consists of sludge in which the sludge age is too high to be most effective in a particular activated sludge process. Dark brown foam and a greasy or scummy appearance is an indicator of old sludge. Settling in the clarifier is rapid, but pin floc can be present in the effluent and the effluent is hazy. **Old sludge** is often associated with a low F/M ratio. To correct for old sludge, it is necessary to increase wasting rates and return less sludge to the aeration basin. This will reduce the amount of solids under aeration, increase the F/M ratio and decrease the sludge age.

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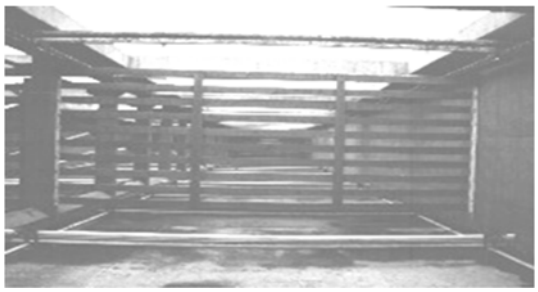
Scum Removal Section

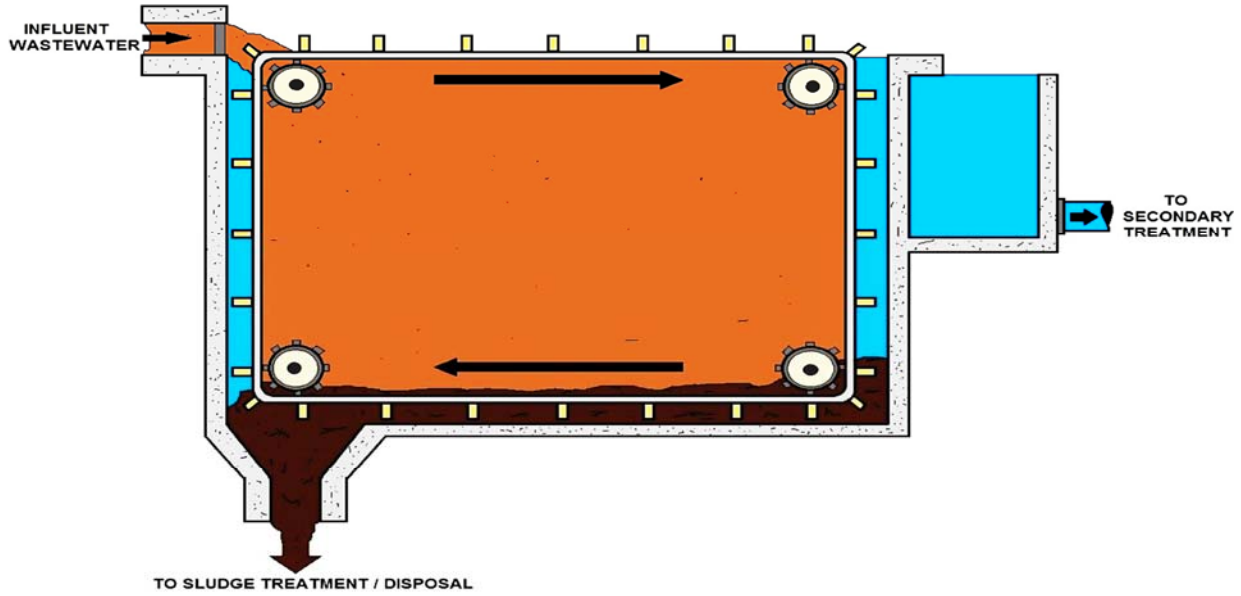
Scum removal equipment is desirable on secondary clarifiers. Skimmers are either of the type that rotates automatically or manually. The most important thing to consider is the sludge and scum collection mechanism. We will talk about "*flights and chains*". They move the settled sludge to the hopper in the clarifier for return and they also remove the scum from the surface of the clarifier. The flights are usually wood or nonmetallic flights mounted on parallel chains.

The motor shaft is connected through a gear reducer to a shaft which turns the drive chain. The drive chain turns the drive sprockets and the head shafts. The shafts can be located overhead or below.

Some clarifiers may not have scum removal equipment so the configuration of the shaft may vary. As the flights travel across the bottom of the clarifier, wearing shoes are used to protect the flights. The shoes are usually metal and travel across a metal track.

To prevent damage due to overloads, a shear pin is used. The shear pin holds the gear solidly on the shaft so that no slippage occurs. Remember, the gear moves the drive chain. If a heavy load is put on the sludge collector system, the shear pin should break. This means the gear would simply slide around the shaft and movement of the drive chain would stop.





WASTEWATER SLUDGE REMOVAL
(CHAIN AND FLIGHT SKIMMING BASIN)

Scum Removal Equipment

In some circular or square tanks rotating scrapers are used. The diagram below shows an typical scum removal equipment.

The most common type has a center pier or column. The major mechanical parts of the clarifier are the drive unit; the sludge collector mechanism; and the scum removal system. There is also some related equipment that we will consider briefly. Let's look at the drive unit first. There are three main parts to the drive unit; the motor (or gear motor); the gear reducer; and the turntable.

The motor is connected to a gear reduction unit which is commonly connected to additional gearing. The drive cage is rotated around a center column by the motor and gear reduction unit. Although the drive motor runs at about 1800 rpm, the gear reducer lowers the output speed so that the sludge collector mechanism goes through one revolution every 20 to 30 minutes. Usually, the motors used on clarifier mechanisms are totally enclosed, fan cooled motors, suitable for outside operation.

The horsepower of the motor is dependent on the size of the clarifier. The motor drives the chain and sprocket which drives the worm gear. The worm gear drives the gear that is mounted on a shaft that drives the turntable. The motor shaft speed is reduced by a series of gear reducers.

We looked at the main parts of the drive unit. Now let's take a look at the sludge collector and the scum removal system mechanism. The main parts of the unit are: the rake arm; the scraper blades; the adjustable squeegees; the surface skimmer; the scum baffles; and the scum box.

The surface skimmer rotates at the same speed as the collector mechanism and is usually supported by the collector rake arm. The scum baffle prevents scum from flowing over the effluent weir. The surface skimmer collects the scum and deposits it in the scum box. The stilling well or influent baffle projects above the liquid and directs the influent downwards to assist in settling suspected solids and reduce short circuiting.

Another important part of the secondary clarifier is the effluent weir, launder and pipe. An effluent weir goes around the circumference of the tank and allows clarified liquid to flow evenly from the tank. The effluent launder collects the tank overflow and takes it to a low point in the launder where a pipe is used to take the effluent to the chlorine contact basin or other means of treatment.

Some clarifiers may have a scum trough heater. The scum removal system rotates around the clarifier at a very slow rate. In subfreezing temperatures, the scum box and pipe could freeze. This problem can be overcome by using immersion heaters, or putting infrared lamps over the scum box. Some clarifiers are covered.

Wastewater Treatment Plant Problems

Retrofitting Older Treatment Technology

Most of our wastewater treatment plants in the United States were constructed more than two to four decades ago. Many of these treatment facilities need to be upgraded to improve capacity and treatment efficiency. This may be adding an A/S facility or an entire retrofitting.

The upgraded treatment processes that can best fit the existing technologies at Publicly Owned Treatment Works (POTWs) are selected based upon wastewater discharge (NPDES) permit requirements and their cost-effectiveness to achieve water quality objectives and protect public health. Such upgrades are often opportunities to employ emerging technologies or established technologies in newer and better ways.

Some of the areas of current and future interest are as follows:

- ✓ Innovative wastewater collection system designs that provide real-time condition assessment data for asset management decision-making.
- ✓ Determination of the long-term performance and life-cycle cost effectiveness of emerging system rehabilitation techniques, including new and existing materials.
- ✓ Advanced sewer system designs that minimize energy consumption and greenhouse gas emissions.

Credit to the USEPA

Maybe the biggest problem facing many WWTPs

Struvite (MAP Magnesium, Ammonia and Phosphate) Problem

Struvite also referred to as MAP. Struvite is a corrosion problem in wastewater treatment, particularly after anaerobic digesters release ammonium and phosphate from waste material. Struvite forms a scale on lines and belts, in centrifuges and pumps, clog system pipes and other equipment including the anaerobic digester itself.

MAP is found in channels, pipes and diffusers causing restrictions and friction, slowing the flow, even restricting sampling ports. Some operators refer to MAP as encrustation and its removal is a full-time maintenance issue. Struvite is magnesium ammonium phosphate. Magnesium is the ingredient in least supply in an anaerobic digester.

MAP forms when there is a mole to mole-to-mole ratio (1:1:1) of magnesium, ammonia and phosphate in the wastewater. The magnesium is found in soil, seawater and in some groundwater.

Ammonia is from the urea in wastewater, and phosphate, which is found through food, soaps and detergents. These elements in place, struvite is more likely to form in a high pH environment, where there is higher conductivity, lower temperatures, and higher concentrations of magnesium, ammonia and phosphate.

Recovery of phosphorus from wastestreams as struvite and recycling those nutrients into agriculture as fertilizer appears to be solution, particularly in agricultural manure and municipal wastewater treatment plants.

Photo Journal #3

The photo above shows the results of not having grit removal. As you can see as it builds up in the secondary process. Below, a buildup of grease balls.

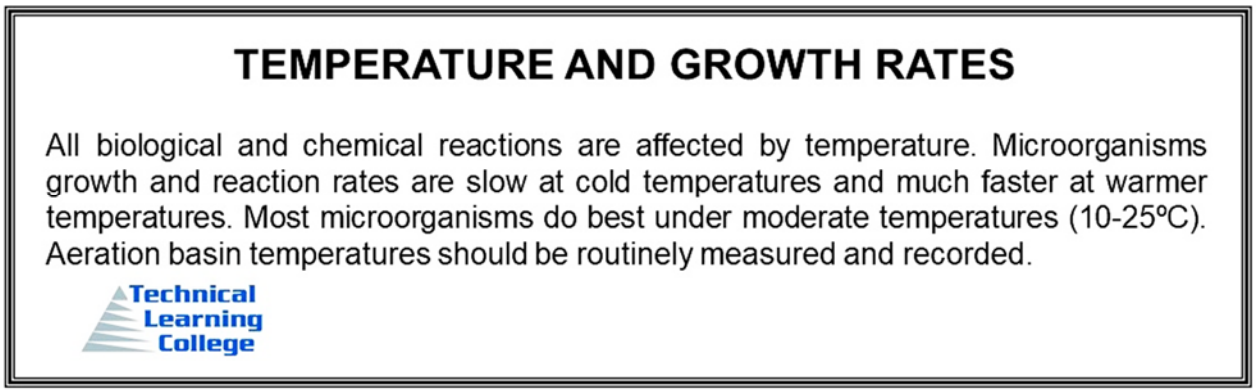
This clarifier is used to thicken sludge prior to the digester, this is not a digester but looks like one. Notice the light on the top for Operators to look inside.

Two massive anaerobic digesters.

Plant Key Design and Operational Issues

Temperature

In general, as temperature of the wastewater increases, the rate of nitrification and denitrification increases. For the typical range of liquid temperatures between 10 and 25° C, the nitrification rate will approximately double for every 8 to 10° C increase in temperature (WEF and ASCE, 2006). Rapid decreases in temperature without acclimation time will, however, cause even slower nitrification rates than predicted, strictly by the temperature change. Denitrification rates will also increase with increasing temperature, although not at the same magnitude as nitrification rates.

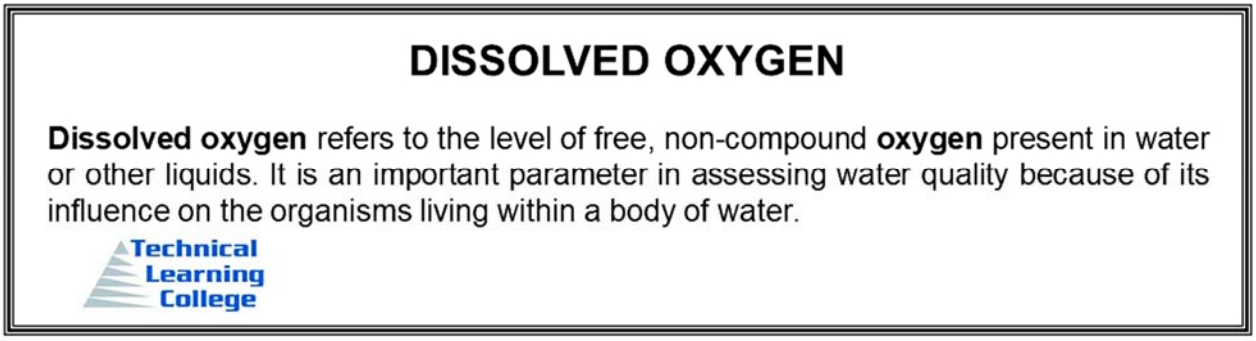


Dissolved Oxygen

Nitrifying bacteria are also more sensitive to DO levels as compared to aerobic heterotrophic bacteria, with growth rates starting to decline below 3 to 4 mg/L with significant reduction below 2 mg/L. The nitrification rate at a DO concentration of 0.50 mg/L is only about 60 percent of that at a 2.0 mg/L DO concentration.

Studies have shown that the amount of oxygen available to nitrifying bacteria can be limited by floc size, requiring higher bulk DO concentrations under higher organic loading conditions (Stenstrom and Song, 1991).

At DO concentrations less than 0.5 mg/L, the effect is greater for *Nitrobacter* than for *Nitrosomonas*. This can result in higher NO2-N in the effluent and have a negative impact on chlorine disinfection as 1 g of NO2-N consumes 5 g chlorine for oxidation. DO must normally be less than 0.2 to 0.5 mg/L, otherwise there will be inhibition of the denitrification process.



pH and Alkalinity
Nitrification generally operates well within a pH range of 6.8 to 8.0 (WEF and ASCE, 2006). At lower pH values the nitrification rate is much slower and at pH values near 6.0 the nitrification rate may only be about 20 percent of that with a pH of 7.0 (Tchobanoglous et al., 2003).

Alkalinity is consumed during the nitrification process but partially replenished (up to 62.5 percent) during the denitrification process. Depending on the influent wastewater alkalinity, there may be a sufficient alkalinity reduction due to nitrification to decrease to unacceptable levels. Addition of chemicals such as lime, sodium hydroxide, or soda ash can be used to replace the alkalinity consumed by nitrification to maintain acceptable pH levels.

Carbon Sources for Denitrification
Denitrifying bacteria need a readily available carbon food source, such as soluble BOD, to ultimately convert nitrate to nitrogen gas. WWTPs that meet very low total nitrogen limits typically use a secondary anoxic zone in which supplemental carbon is added. Supplemental sources can be “internal” such as fermented wastewater or sludge, or “external” sources such as purchased chemicals.

Methanol is currently the most common external carbon source used in denitrification because of it low cost. It has several drawbacks, however, namely:

- It is highly flammable and implicated in some storage tank explosions and fires (Dolan, 2007); however, with proper design and operation problems can be minimized.
- It is not the most efficient source for most treatment configurations.
- Costs have begun to fluctuate widely (deBarbadillo et al., 2008).
- Availability is a problem in some areas (Neethling et al. 2008).
- Reported low growth rates under cold temperatures (Dold et al. 2008).

Other sources of carbon include ethanol, acetic acid, corn syrup, molasses, glucose, glycerol, and industrial waste products. The WEF Nutrient Challenge Research Plan (2007) identified research on alternative carbon sources as priority for operators, owners, and engineers of wastewater systems. In December of 2007, the 2nd External Carbon Workshop was held in Washington, DC to discuss the state of the technology and research needs. WERF is also currently formulating a standard protocol for evaluation of external carbon alternatives.

Nitrification Inhibition from Toxic Chemicals
Nitrifying bacteria are very sensitive to heavy metals and other inorganic compounds in wastewater. The Local Limits Development Guidance Manual (USEPA 2004) has been the main source of information on inhibitory effects for a variety of wastewater treatment processes including nitrification. Appendix G of the 2004 version provides a summary table with the reported range of nitrification inhibition threshold levels for a number of metals, non-metal inorganics, and organic compounds. Actual inhibitory effects are site-specific and depend on many factors including the nature of biodegradable organic material, microorganism speciation, acclimation effects, temperature, and water quality conditions.

Wet Weather Events
Wet weather events can increase inflow and infiltration into the collection system and subsequently increase the hydraulic load to the wastewater treatment plant. This can in turn reduce the SRT leading to reduced performance of nitrification process units. In addition, wet weather flows have different characteristics than typical wastewater influent flow and can be less favorable for nitrification and denitrification.

Conditions that are less favorable for nitrification include decreased alkalinity and sudden temperature drops. Lower biodegradable COD concentrations and increased DO make wet weather flows less amenable to denitrification.

Flow equalization basins can be used to handle wet weather events; however, this requires available space and capital investment. USEPA (2008a) identifies a number of innovative storage and treatment technologies used to manage influent flows during wet weather events.

Guidance for Selecting Process Modifications

Nitrogen removal requires first that a biological nitrification process be present or that the facility be modified to accomplish nitrification. Considerably more volume is needed for activated sludge nitrification compared to designs for BOD removal only. If there is insufficient space to accommodate the increased volume, suspended growth or hybrid process options that require less space such as the MBR process or IFAS systems with suspended media in the activated sludge process should be considered. Another option is to use a fixed film nitrification process after the suspended growth process clarification step. This could be a BAF or a plastic media trickling filter. However, if nitrogen removal is required, an exogenous carbon source is needed, which has higher operating costs than using the influent BOD for denitrification.

Nitrification systems need sufficient oxygen transfer for ammonia oxidation in addition to BOD removal. Such systems should consider the impact to diurnal loadings and ammonia addition in recycle streams. The influent TN concentration may have daily peak values that are 1.5 to 2.0 times the daily average loading.

Higher peak loadings require longer SRTs to assure that sufficient nitrifying bacteria are present to remove ammonia at a greater rate, while maintaining a low effluent ammonia concentration. Often anaerobic digester sludge dewatering operations occur during the day and produce return recycle streams high in ammonia concentration (500-1000 mg/L) at times that coincide with the high influent diurnal ammonia loads. Recycle equalization or treatment helps to provide a more stable nitrification system and lower effluent NH3-N concentrations.

In many cases, it is advantageous to incorporate a denitrification pre-anoxic step with nitrification (MLE process) due to the many benefits and improved operational stability. The advantages include:

1) less aeration energy as the nitrate produced can be used for BOD removal,

2) the production of alkalinity to offset the alkalinity used by nitrification, which in some cases eliminates the need to purchase alkalinity, and

3) a more stable, better settling activated sludge process as the anoxic-aerobic processes favor good settling floc-forming bacteria over filamentous growth.

The effluent nitrogen goals greatly affect the process design choices and system operation. For an effluent goal of 10 mg/L TN, an MLE process is often sufficient for activated sludge treatment with secondary clarifiers or membrane separation. However, with water conservation leading to more concentrated wastewater, these processes alone may not be sufficient due to the fact that they are limited to 80-85% removal of the influent TN.

For TN effluent goals of 3 to 5 mg/L or lower, some form of post anoxic treatment is generally needed. One option is to convert an MLE process to a Bardenpho process by adding another anoxic aerobic set of tanks.

Although the endogenous respiration rate of the bacteria can be used to consume nitrate in the post anoxic tanks, it is often necessary to add an exogenous carbon source. Other alternatives to using exogenous carbon sources include denitrification filters instead of adding more activated sludge tank volume, step feed with carbon addition in the last pass, and IFAS processes.

Denitrification processes require sufficient carbon to drive the nitrate/nitrite reduction reactions. Characterization of the influent wastewater with regard to its organic strength and soluble fraction and the TN and ammonia concentrations is needed to fully understand a system's carbon needs. In addition, design and operating methods that eliminate or minimize DO feeding to anoxic zones can reduce the amount of exogenous carbon needed and provide a more stable operation. Low DO zones prior to downstream anoxic tanks or for withdrawal of recycle to preanoxic zones should be considered.

Impacts on Sludge Production and Handling

It has been documented by both research and full scale experiments that BOD removal by activated sludge using nitrate as the electron acceptor instead of DO will result in a 20% or more reduction in waste activated sludge (WAS) production for the same operating conditions. Full-scale investigations near Melbourne, Australia achieved as high as a 40% reduction in WAS, and implementation of nitrogen removal at the York River, VA, plant resulted in a reduction of more than 50% in WAS production. The impact this will have on total sludge production by a treatment plant will depend upon how much waste sludge is produced by other treatment units such as primary clarifiers and chemical treatment with precipitating chemicals.

Additionally, implementation of nitrogen removal at conventional activated sludge plants can improve the thickening characteristics due to decreasing the amounts of filamentous bacteria in the activated sludge. If an external carbon source is added to improve the rate of denitrification, there will be an increase in WAS production compared to when no external carbon source is added.

If an external carbon source is used to supplement denitrification, it is likely that the small increase in solids production will be offset by endogenous respiration due to longer SRTs. Solids produced from nitrogen removal processes generally thicken and dewater well and show no negative impact on any solids processing system.

Processed Wastewater Solids Section

Processed wastewater solids (“sewage sludge”) that meet rigorous standards allowing safe reuse for beneficial purposes. Currently, more than half of the activated sludge biosolids produced by municipal wastewater treatment systems are applied to land as a soil conditioner or fertilizer and the remaining solids are incinerated or landfilled. Even the solids need to be analyzed as part of your compliance, noncompliance or local limits requirements. We will return to this subject later in the course.

BIOSOLIDS

Biosolids are nutrient-rich organic materials resulting from the treatment of domestic sewage in a treatment facility. When treated and processed, these residuals can be recycled and applied as fertilizer. Compliance with pretreatment requirements is important to ensure that **biosolids** produced at the POTW have pollutant concentrations low enough to allow the beneficial use of this material. **Biosolids** recycling is the process of beneficially using treated residuals from wastewater treatment to promote the growth of agricultural crops, fertilize gardens and parks and reclaim mining sites.

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Large solids treatment facility

Ocean Dumping
Ocean dumping of these solids is no longer allowed. Even cruise ship will not dump in to the ocean and they are legally permitted to do so.

Biosolids Stabilization
Prior to utilization or disposal, biosolids are stabilized to control odors and reduce the number of disease-causing organisms. Sewage solids, or sludge, when separated from the wastewater, still contain around 98 percent water. They are usually thickened and may be dewatered to reduce the volume to be transported for final processing, disposal, or beneficial use.

Dewatering Processes
Dewatering processes include drying beds, belt filter presses, plate and frame presses, and centrifuges. To improve dewatering effectiveness, the solids can be pretreated with chemicals such as lime, ferric chloride, or polymers to produce larger particles which are easier to remove.


Centrifuge


Filter Press

Digestion
Digestion is a form of stabilization where the volatile material in the wastewater solids can decompose naturally and the potential for odor production is reduced. Digestion without air in an enclosed tank (anaerobic solids digestion) has the added benefit of producing methane gas which can be recovered and used as a source of energy. Stabilization of solids may also be accomplished by composting, heat treatments, drying or the addition of lime or other alkaline materials. After stabilization, the biosolids can be safely spread on land.

Land Application
In many areas, biosolids are marketed to farmers as fertilizer. Federal regulation (40 CFR Part 503) defines minimum requirements for such land application practices, including contaminant limits, field management practices, treatment requirements, monitoring, recordkeeping, and reporting requirements.

Properly treated and applied biosolids are a good source of organic matter for improving soil structure and help supply nitrogen, phosphorus, and micronutrients that are required by plants.

Biosolids have also been used successfully for many years as a soil conditioner and fertilizer, and for restoring and re-vegetating areas with poor soils due to construction activities, strip mining or other practices. Under this biosolids management approach, treated solids in semi liquid or dewatered form are transported to the soil treatment areas. The slurry or dewatered biosolids, containing nutrients and stabilized organic matter, is spread over the land to give nature a hand in returning grass, trees, and flowers to barren land.

Restoration of the countryside also helps control the flow of acid drainage from mines that endangers fish and other aquatic life and contaminates the water with acid, salts, and excessive quantities of metals.

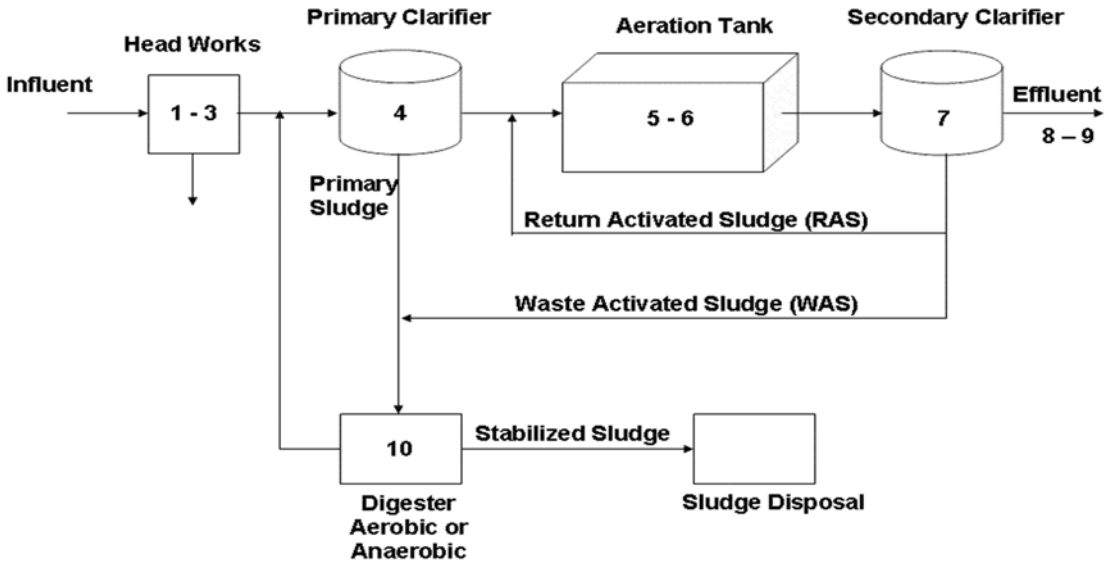
Incineration
Incineration consists of burning the dried solids to reduce the organic residuals to an ash that can be disposed of or reused. Incinerators often include heat recovery features. Undigested sludge solids have significant fuel value as a result of their high organic content. However, the water content must be greatly reduced by dewatering or drying to take advantage of the fuel potential of the biosolids.

For this reason, pressure filtration dewatering equipment is used to obtain biosolids which are sufficiently dry to burn without continual reliance on auxiliary fuels. In some cities, biosolids are mixed with refuse or refuse derived fuel prior to burning. Generally, waste heat is recovered to provide the greatest amount of energy efficiency.

Beneficial Use Products from Biosolids
Heat dried biosolids pellets have been produced and used extensively as a fertilizer product for lawn care, turf production, citrus groves, and vegetable production for many years. Composting of biosolids is also a well-established approach to solids management that has been adopted by a number of communities. The composted peat-like product has shown particular promise for use in the production of soil additives for re-vegetation of topsoil depleted areas, and as a potting soil amendment.

Effective pretreatment of industrial wastes prevents excessive levels of unwanted constituents, such as heavy metals (i.e. cadmium, mercury, and lead) and persistent organic compounds from contaminating the residuals of wastewater treatment and limiting the potential for beneficial use.

Effective stabilization of wastewater residuals and their conversion to biosolid products can be costly. Some cities have produced fertilizers from biosolids which are sold to help pay part of the cost of treating wastewater. Some municipalities use composted, heat dried, or lime stabilized biosolid products on parks and other public areas.



Credit to the USEPA for this text.

Solids Handling Box 10 *See Illustration chart below*

Aerobic Digestion

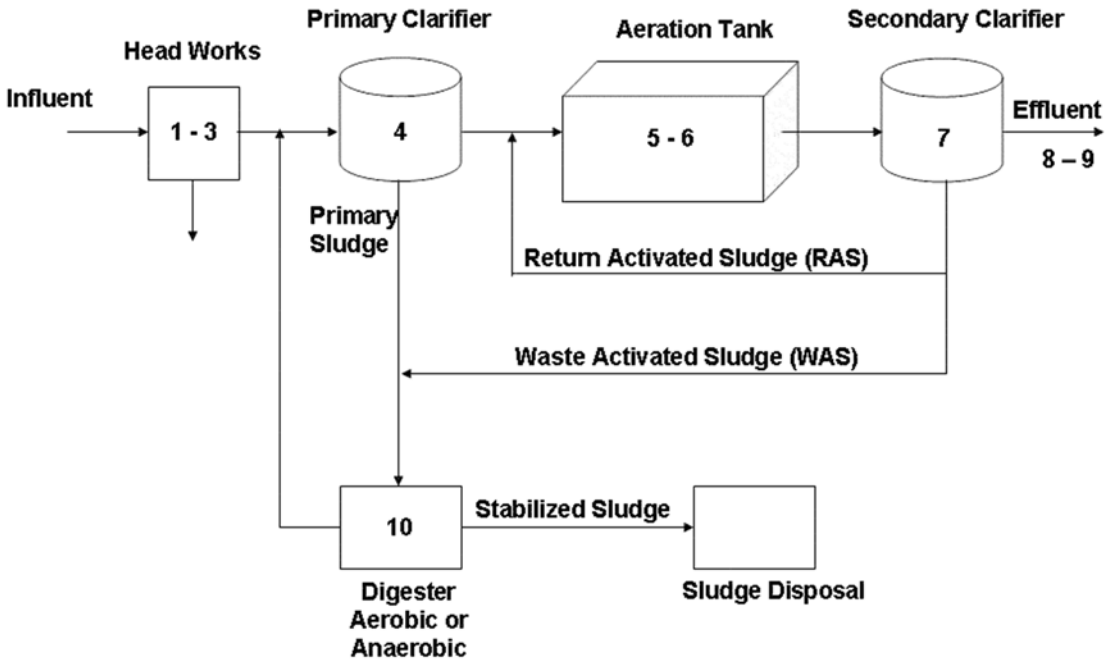
Primary sludge is the sludge that is taken from the bottom of the settling tank. The amount and rate of the raw sludge being pumped is determined by the depth of the sludge. Operators have to be mindful not to remove water from the tank.

Of all biological waste treatment methods, aerobic digestion is the most widespread process used throughout the world (more than 95%). Nature gives, takes and does everything in-between. Nowhere is this better exemplified than the biological solution it offers to mankind's waste problems. An illustration of nature's work is its influence on the constant cycle of biological waste treatment. Microorganisms, like all living things, require food for growth.

Biological sewage treatment consists of many different microorganisms, mostly bacteria, carrying out a stepwise, continuous, sequential attack on the organic compounds found in wastewater and upon which the microbes feed.

Aerobic digestion of waste is the natural biological degradation and purification process in which bacteria that thrive in oxygen-rich environments break down and digest the waste.

During this oxidation process, pollutants are broken down into carbon dioxide (CO_2), water (H_2O), nitrates, sulfates and biomass (microorganisms). By optimizing the oxygen supply with so called aerators the process can be significantly accelerated.



Topic 2 – Primary Wastewater Treatment Section
Post Quiz – Answers in rear after the Glossary

1. Wastewater treatment plants are designed to reduce the _____in the effluent discharged to natural waters, the goal is to meet state and federal discharge criteria and protect the environment.

2. Treatment of wastewater usually involves biological processes such as the activated sludge system in the secondary stage after preliminary screening to remove coarse particles and primary sedimentation that settles out _____.

3. The secondary treatment steps are generally considered environmental biotechnologies that harness _____ processes contained in bioreactors for the biodegradation of organic matter and bioconversion of soluble nutrients in the wastewater.

4. The initial stage in the treatment of domestic wastewater is known as_____.

5. _____ are removed from the wastewater in the primary stage of treatment. In some treatment plants, primary and secondary stages may be combined into one basic operation.

6. There are _____in the treatment of wastes, *primary (physical)* and *secondary (biological)*.

7. In the primary stage, solids are allowed to settle and removed from wastewater. The secondary stage uses _____to further purify wastewater. Sometimes, these stages are combined into one operation.

8. Primary treatment is done by pouring the wastewater into big tanks for the _____to settle on the bottom of the tanks.

9. Many plants will have a _____or filtration system for emergency, maintenance or demand issue.

10. The Secondary Clarification process generally consists of four rectangular tanks that provide _____that allow the larger aggregates of solids and microorganisms to settle out for collection.

11. The best temperatures for wastewater treatment probably range from _____degrees Fahrenheit.

12. In general, _____accelerates in warm temperatures and slows in cool temperatures, but extreme hot or cold can stop treatment processes altogether. Therefore, some systems are less effective during cold weather and some may not be appropriate for very cold climates.

13. _____ also affects receiving waters.

14. Hot water, a byproduct of many manufacturing processes, can be a pollutant. When discharged in large quantities, it can raise the temperature of receiving streams locally and disrupt the natural balance of _____.

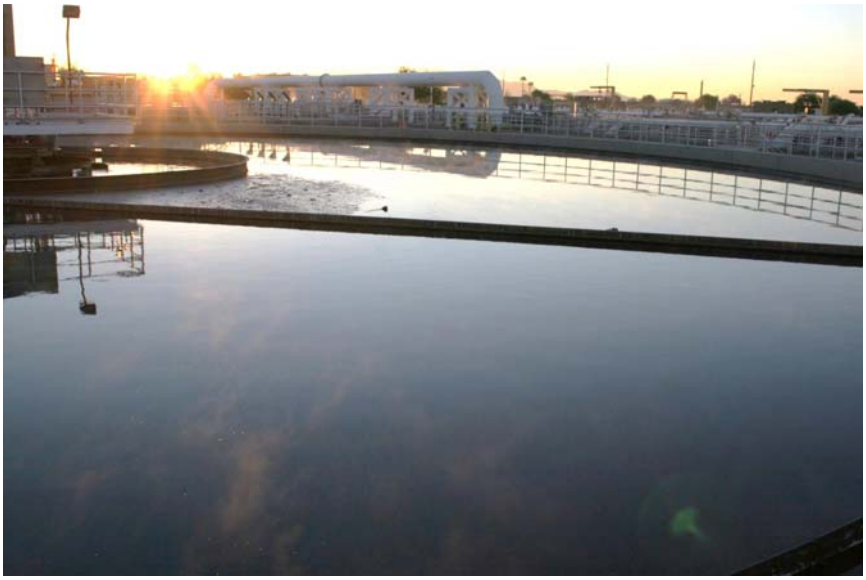
15. _____ of wastewater affects both treatment and the environment.

16. _____ indicates increasing acidity while a high pH indicates increasing alkalinity (a pH of 7 is neutral).

The pH of wastewater needs to remain between 6 and 9 to protect organisms. Acids and other substances that alter pH can inactivate treatment processes when they enter wastewater from industrial or commercial sources.

Topic 3 - Secondary Treatment Section

Topic 3 - Section Focus: You will learn the basics of the secondary wastewater treatment process and related subjects. At the end of this section, you the student will be able to understand and describe the process for wastewater to achieve a certain degree of effluent quality by using a sewage treatment plant with physical phase separation to remove settleable solids and a biological process to remove dissolved and suspended organic compounds. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.
Topic 3 – Scope/Background: The United States Environmental Protection Agency (EPA) defined secondary treatment based on the performance observed at late 20th-century bioreactors treating typical United States municipal sewage. Secondary treated sewage is expected to produce effluent with a monthly average of less than 30 mg/l BOD and less than 30 mg/l suspended solids. Weekly averages may be up to 50 percent higher. A sewage treatment plant providing both primary and secondary treatment is expected to remove at least 85 percent of the BOD and suspended solids from domestic sewage. The EPA regulations describe stabilization ponds as providing treatment equivalent to secondary treatment removing 65 percent of the BOD and suspended solids from incoming sewage and discharging approximately 50 percent higher effluent concentrations than modern bioreactors.



Secondary wastewater treatment processes remove waste organic (once living, biological) material from wastewater, typically using a biological treatment process.

The water quality parameter, biochemical oxygen demand (BOD), is a measure of the amount of oxygen needed to oxidize organic matter in a water sample. It is thus an indirect measure of the pollution of water by waste organic matter.

Secondary treatment of wastewater makes use of oxidation to further purify wastewater. This can be done in one of three ways:

Secondary Treatment Results

Secondary treatment removes 85 to 95 percent of BOD and TSS and minor portions of nitrogen, phosphorus, and heavy metals.

Tertiary treatment is the next wastewater treatment process after secondary treatment. This treatment is sometimes called as the final or advanced treatment and consists of removing the organic load left after secondary treatment for removal of nutrients from sewage and particularly to kill the pathogenic bacteria.

The effluents from secondary sewage treatment plants contain both nitrogen (N) and phosphorus (P). N and P are ingredients in all fertilizers.

When excess amounts of N and P are discharged, plant growth in the receiving waters may be accelerated which results in eutrophication in the water body receiving such waste. Algae growth may be stimulated causing blooms which are toxic to fish life as well as aesthetically unpleasing.

Secondary treated effluent also contains suspended, dissolved, and colloidal constituents which may be required to be removed for stipulated reuse or disposal of the treated effluent.

The purpose of tertiary treatment is to provide a final treatment stage to raise the effluent quality before it is discharged to the receiving environment such as sea, river, lake, ground, etc., or to raise the treated water quality to such a level to make it suitable for intended reuse.

This step removes different types of pollutants such as organic matter, SS, nutrients, pathogens, and heavy metals that secondary treatment is not able to remove.

Wastewater effluent becomes even cleaner in this treatment process through the use of stronger and more advanced treatment systems. It includes sedimentation, coagulations, membrane processes, filtration, ion exchange, activated carbon adsorption, electrodialysis, nitrification and denitrification, etc.

Tertiary treatment is costly as compared to primary and secondary treatment methods.

Secondary Treatment Boxes 5 – 6 *See Illustration chart*

Pollutants that are dissolved or are very fine and remain suspended in the wastewater are not removed effectively by gravity settling. When the wastewater enters a sedimentation tank, it slows down and the suspended solids gradually sink to the bottom. This mass of solids is called primary sludge.

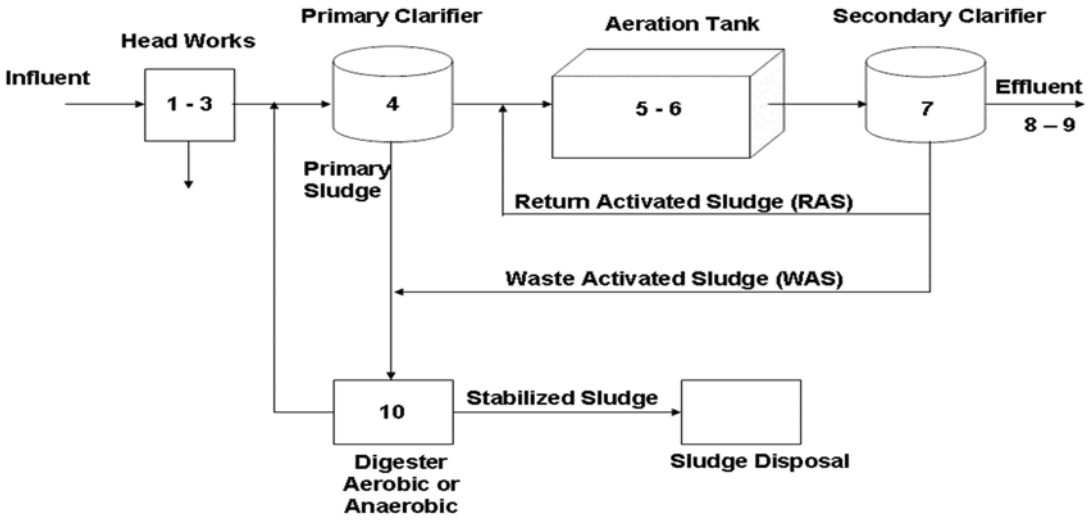
Various methods have been devised to remove solids, newer plants have some type of mechanical equipment to remove the settled solids and some plants remove solids continuously while others do so at intervals.

Secondary Treatment

After the wastewater has been through Primary Treatment processes, it flows into the next stage of treatment called secondary. Secondary treatment processes can remove up to 90 percent of the organic matter in wastewater by using biological treatment processes.

The two most common conventional methods used to achieve secondary treatment are attached growth processes and suspended growth processes.

The Secondary Treatment stage consists of a biological process such as **Oxidation Ditches** and a physical process, **Secondary Clarification**.



The Preliminary Treatment stage removed as much solids as possible using physical processes, however, very fine solids are still present that cannot be removed physically.

The wastewater enters from Preliminary Treatment into the Oxidation Ditches process which is a biological process consisting of two large oval shaped basins which are capable of removing these finer solids.

This is accomplished by maintaining a population of microorganisms within the oxidation basins which consume the very fine solids (which are primarily organic) and also adhere to the solids themselves.

By consuming and adhering to these finer solids they form larger and heavier aggregates that can by physically separated.

Consequently, after this process has taken place inside the Oxidation Ditches the wastewater then enters Secondary Clarification process which can provide this physical separation.

Most of the time, the Oxidation ditch is not considered part of the A/S system, however, sometimes it is. It all depends if you add bugs to the process. If you add bugs to eat food or kill bugs, this activity is also considered part of the A/S process.

DISSOLVED OXYGEN

Dissolved oxygen refers to the level of free, non-compound **oxygen** present in water or other liquids. It is an important parameter in assessing water quality because of its influence on the organisms living within a body of water.

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More on DO in the Laboratory Procedures (Process Control) near the rear of the book.

Ponds and Lagoons Introduction

The primary difference between ponds and lagoons is the depth. Pond are generally shallow, typically 3 to 5 feet, they are often used in small communities to treat domestic waste. The method ponds work to stabilize the waste is that the heavy solids settle to the bottom where it is decomposed by bacteria. The pond's clarity is dependent by the number of ponds in place. We refer to the configuration as singular (in a row) or parallel (side-by-side).

Dissolved nutrient materials, such as nitrogen and phosphorus are used by green algae which are microscopic plants floating and living in the water. The algae use carbon dioxide (CO_2) and bicarbonate to build body protoplasm. These algae need nitrogen and phosphorus in their metabolism much as land plants do. Like land plants, they release oxygen and some carbon dioxide as waste products.

LAGOONS

Lagoons are pond-like bodies of water or basins designed to receive, hold, and treat wastewater for a predetermined periods of time. In the lagoon, wastewater is treated through a combination of physical, biological, and chemical processes.

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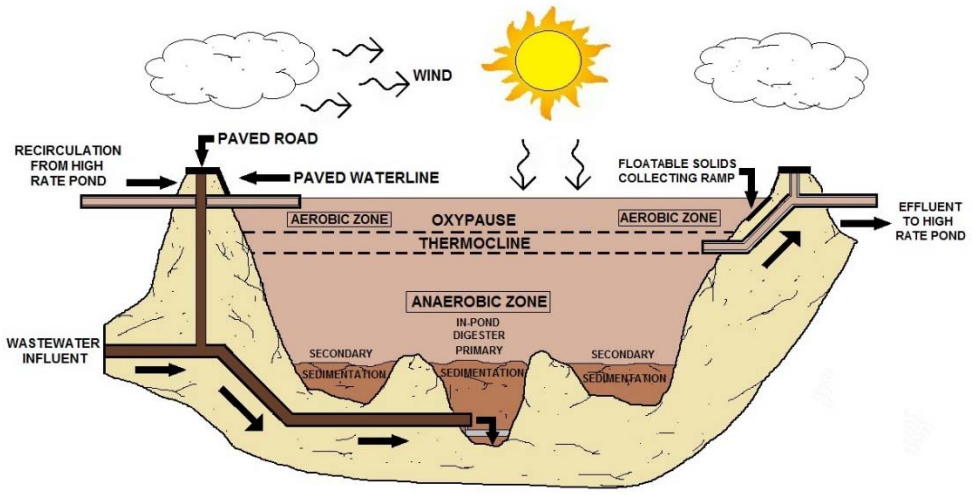


AEROBIC / ANAEROBIC POND

The most often used ponds in domestic wastewater treatment are the stabilization pond and facultative lagoon.

The stabilization pond is designed to be aerobic throughout its depth and the facultative lagoon will be anaerobic at the bottom and aerobic at the top. Stabilization ponds provide secondary biological treatment and are the most commonly used wastewater pond. Stabilization ponds must be preceded by some form of primary treatment to reduce the solids entering the pond.

DISSOLVED OXYGEN

Dissolved oxygen refers to the level of free, non-compound **oxygen** present in water or other liquids. It is an important parameter in assessing water quality because of its influence on the organisms living within a body of water.

Technical Learning College

More on DO in the Laboratory Procedures (Process Control) near the rear of the book.

Aerobic Process

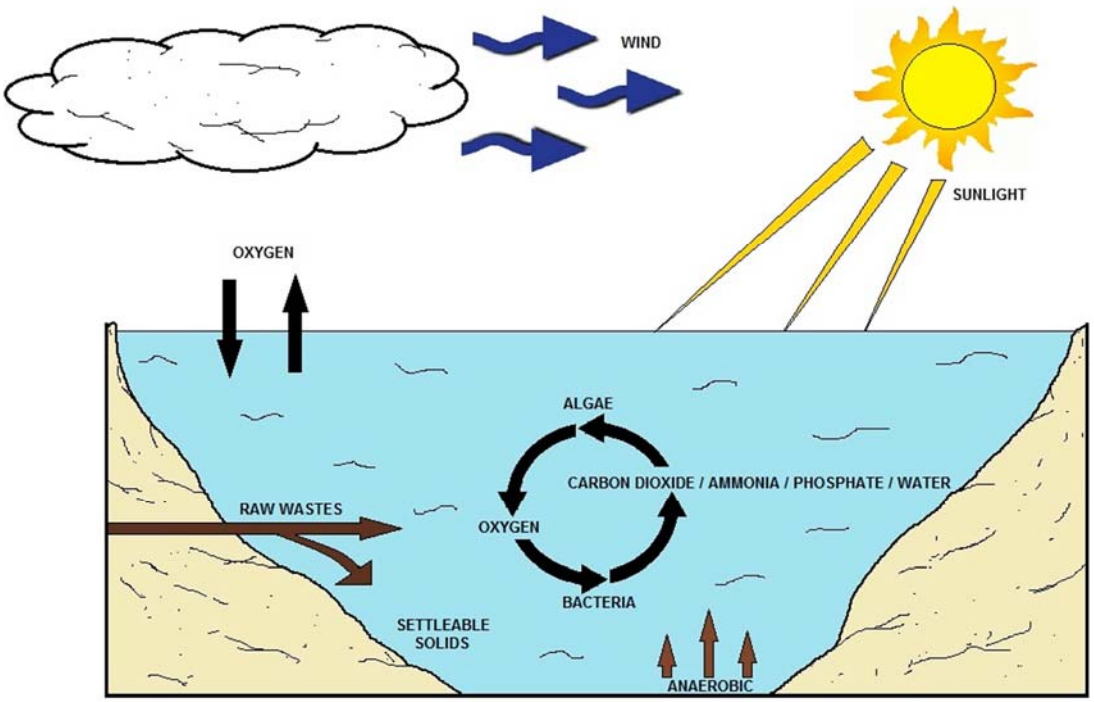
In the aerobic process, the reactions occurring can be summarized as:

organic load + oxygen + more cells -> CO_2 + H_2O

In fisheries wastewaters, the need for addition of nutrients (the most common being nitrogen and phosphorus) seldom appears, but an adequate provision of oxygen is essential for successful operation of the systems.

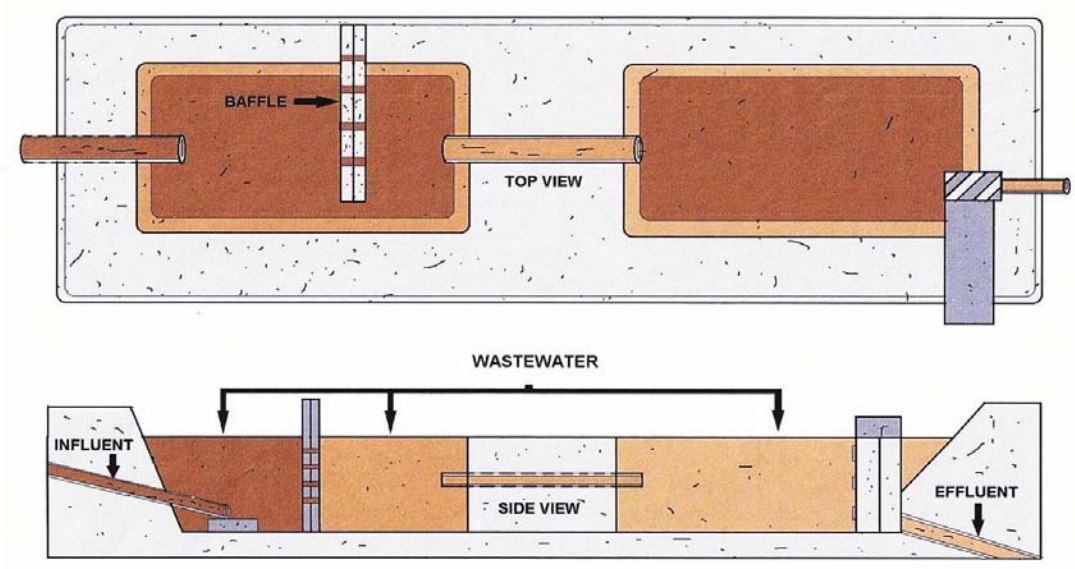
The most common aerobic processes are: activated sludge systems, lagoons, trickling filters and rotating disk contactors. These aerobic processes are described, together with the devices used for aeration.

The rotor used above is for increase oxygen and mixing.



SECONDARY FACULATIVE POND

Respiration in lakes recycles organic carbon arising from photosynthesis back to inorganic carbon. Prior to this transformation, the organic carbon is potentially available to support secondary production. Generally speaking, ponds rarely are part of the A/S system, but can be a great back-up for overflow conditions.

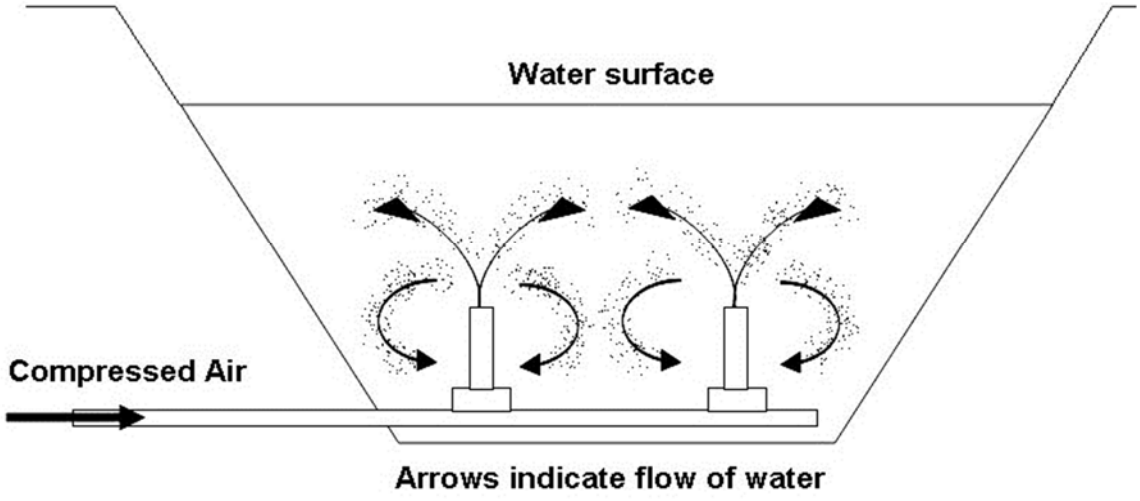


THREE CELL LAGOON
WASTEWATER TREATMENT SYSTEM

The original lagoon system consists of one aerated cell (Basin 1), followed by a non-aerated polishing cell (Basin 2) and a final chlorine contact chamber. This system has a third non-aerated cell (Basin 3) for sludge settling.

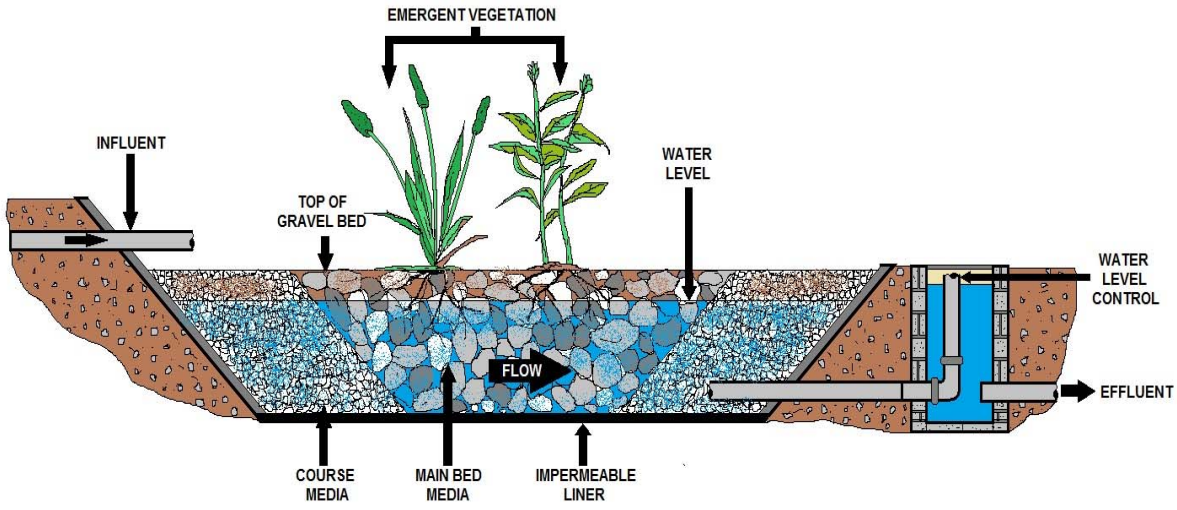
Aeration

Aeration is a long, but effective process that entails mixing wastewater with a solution of microorganisms. The resulting mixture is then aerated for up to 30 hours at a time to ensure results.



Oxidation Ponds

Oxidation ponds are typically used in warmer places. In addition, this method utilizes natural bodies of water like lagoons. Wastewater is allowed to pass through this body for a period of time and is then retained for two to three weeks.



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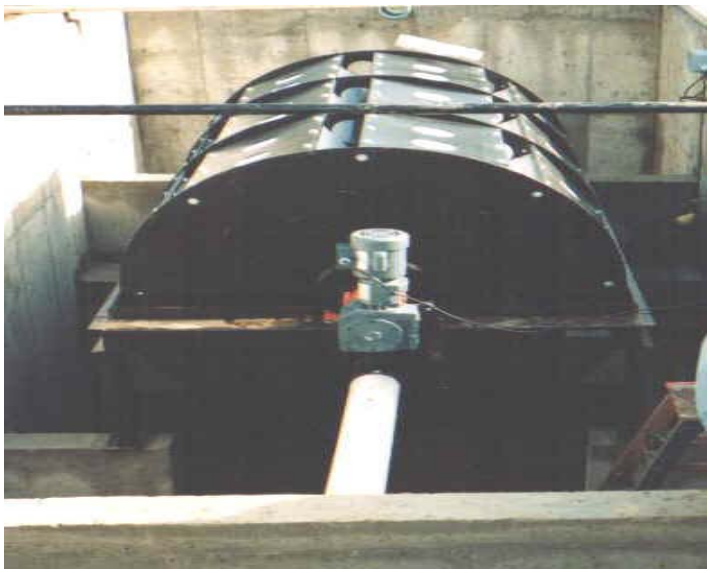
VEGETATIVE SUBMERGED BED (VSB)

Fixed Film Systems

Fixed film systems grow microorganisms on substrates such as rocks, sand or plastic. The wastewater is spread over the substrate, allowing the wastewater to flow past the film of microorganisms fixed to the substrate.

As organic matter and nutrients are absorbed from the wastewater, the film of microorganisms grows and thickens. Trickling filters, rotating biological contactors, and sand filters are examples of fixed film systems.



Empty RBC

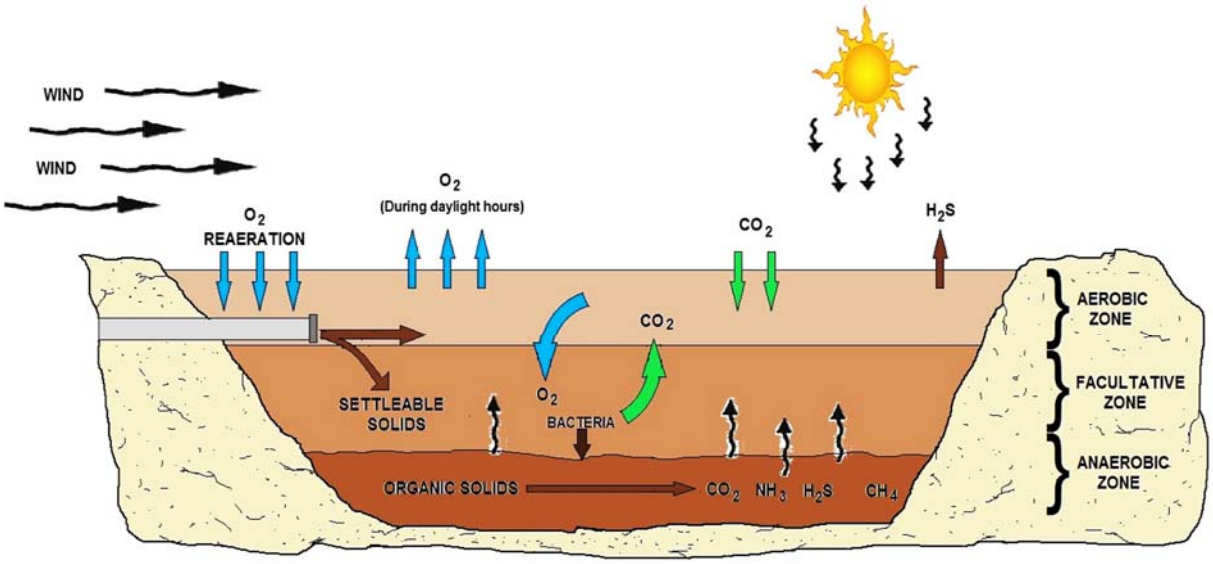
Suspended Film Systems

Suspended film systems stir and suspend microorganisms in wastewater. As the microorganisms absorb organic matter and nutrients from the wastewater, they grow in size and number.

After the microorganisms have been suspended in the wastewater for several hours, they are settled out as sludge.

Some of the sludge is pumped back into the incoming wastewater to provide "seed" microorganisms. The remainder is wasted and sent on to a sludge treatment process.

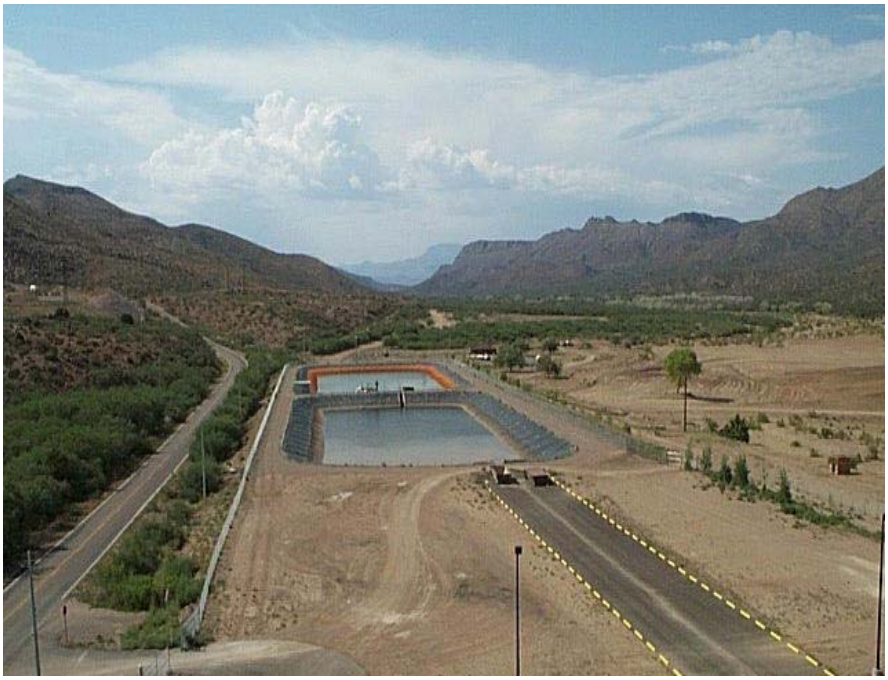
Activated sludge, extended aeration, oxidation ditch, and sequential batch reactor systems are all examples of suspended film systems.



FACULTATIVE LAGOON

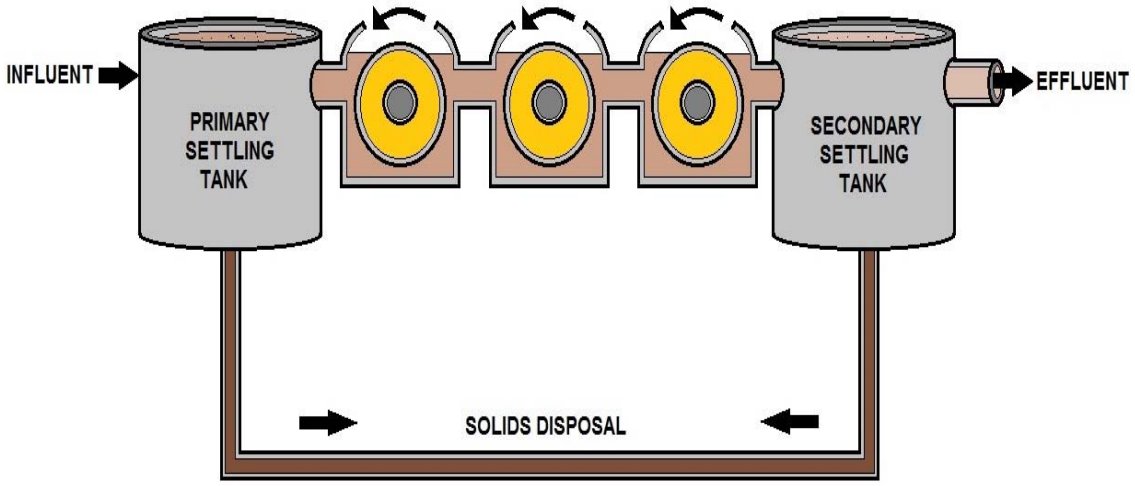
Lagoon Systems

Lagoon systems are shallow basins which hold the wastewater for several months to allow for the natural degradation of sewage. These systems take advantage of natural aeration and microorganisms in the wastewater to renovate sewage.



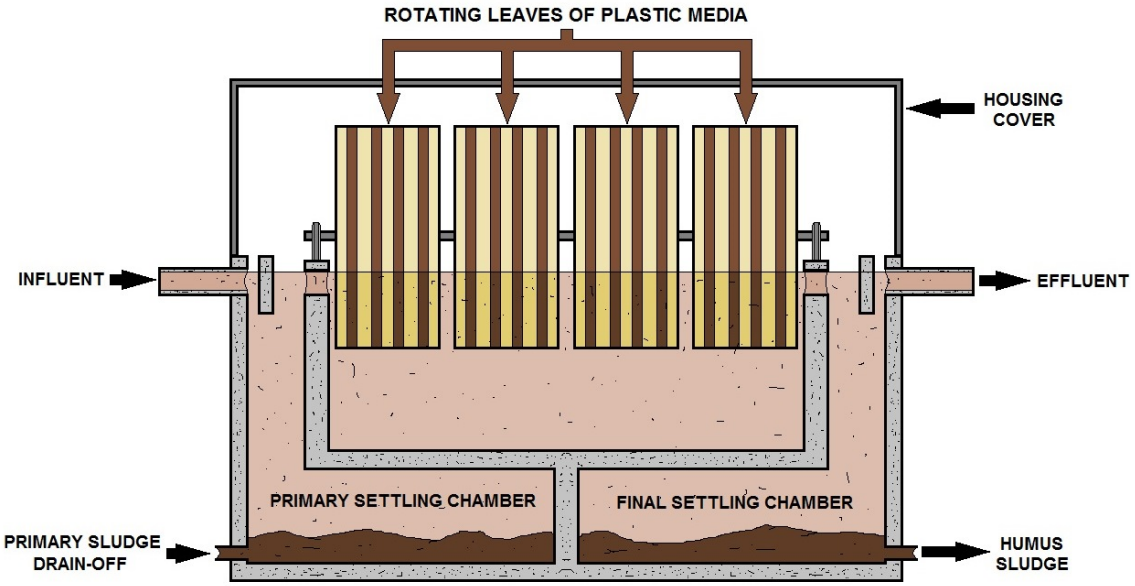
Lagoons in series. Some will argue that lagoons are not part of the A/S process, but according the EPA, if you maintain bugs for a process, it is part of the A/S process.

Rotating Biological Contactor (RBC) Section



ROTATING BIOLOGICAL CONTACTOR

The **rotating biological contactor** (RBC) is a fixed film biological secondary treatment device. The basic process is similar to that occurring in the trickling filter. In operation, a media, consisting of a series of circular disks mounted side by side on a common shaft is rotated through the wastewater flow.



ROTATING BIOLOGICAL CONTACTOR
(INTEGRAL TYPE)

RBC's with integral units treat unsettled sewage and has the capability of providing primary and secondary settling in the unit.

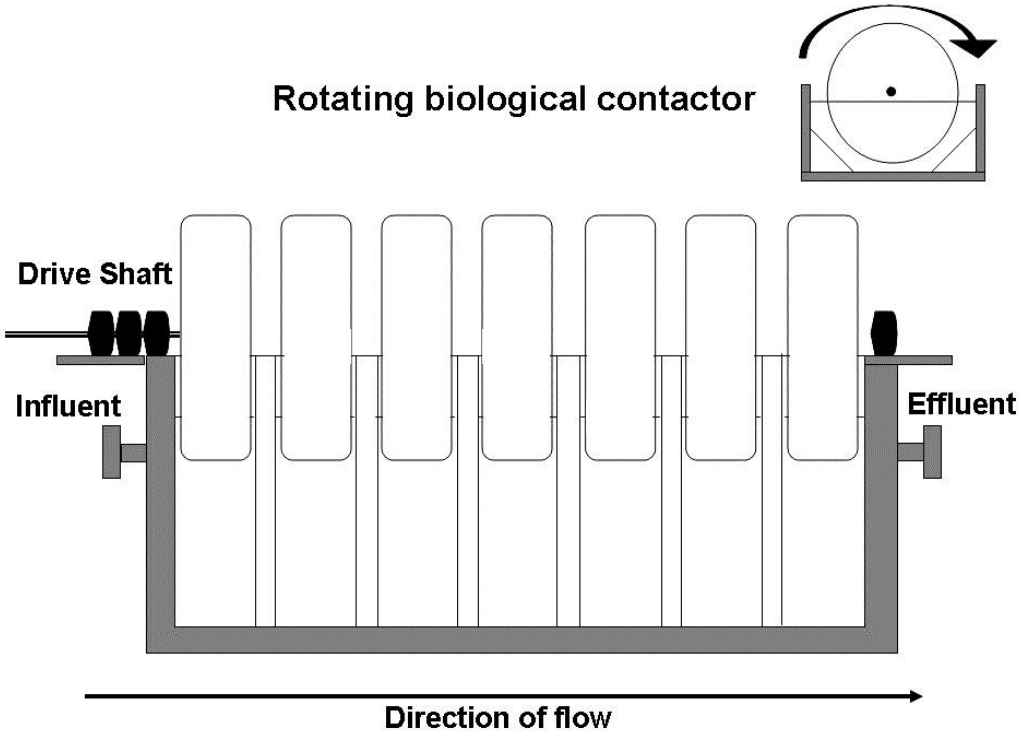
Rotating Biological Contactors is a remediation technology used in the secondary treatment of wastewater. This technology involves allowing wastewater to come in contact with a biological medium in order to facilitate the removal of contaminants.

In its simplest form, a rotating biological contactor consists of a series of discs or media blocks mounted on a shaft which is driven, so the media rotates at right angles to the flow of sewage. The discs or media blocks are normally made of plastic (polythene, PVC, expanded polystyrene) and are contained in a trough or tank so that about 40% of their area is immersed.

The biological growth that becomes attached to the media assimilates the organic materials in the wastewater. Aeration is provided by the rotating action, which exposes the media to the air after contacting them with the wastewater. The degree of wastewater treatment is related to the amount of media surface area and the quality and volume of the inflowing wastewater.

Rotating Biological Contactors can be supplied as part of an integral package plant to treat sewage from various communities. Integral units are provided in sizes of up to a 500-population equivalent. A smaller version is also available for small private installations.

Each plant is designed to meet the specific requirements of the site and the effluent quality required.



Advantages

- ✓ Short contact periods are required because of the large active surface.
- ✓ Capable of handling a wide range of flows.
- ✓ Sloughed biomass generally has good settling characteristics and can easily be separated from the waste stream.
- ✓ Operating costs are low, as little skill is required in plant operation.
- ✓ Retention times are short.
- ✓ Low power requirements.
- ✓ Low sludge production and excellent process control.

Problems

White biomass over most of a RBC disc can be resolved by increasing the age of the sludge.

RBC Principles

The principles of the rotating biological contactor originated in the early 1900's but its application to sewage treatment did not occur until the 1960's when the present system was developed. The process employed relies on the well-established principle of biological oxidation using naturally occurring organisms to ensure even the most stringent effluent standards can be achieved.

Primary Settlement Zone

Incoming flows of crude sewage enter the RBC primary settlement zone, which is designed to have a buffering capacity of balancing flows up to 6 mgd (million gallons a day). Settlement solids are retained in the tank's lower region while the partially clarified liquor passes forward to the biozone where it makes contact with the slowly rotating disks.

Contactors

Installation of Rotating Biological Contactors

Rotating Biological Contactors are available in sizes from 1100mm diameter up to 3800mm in diameter. The media packs that form the rotors are manufactured from vacuum formed black polyethylene sheets supported on the central shaft with a galvanized steel framework. The central shaft is manufactured from mild steel tube, protected internally against corrosion and fitted with end stub shafts, which are supported on split bearings.

Gearbox and Drive mechanism

Rotation is provided by a shaft mounted gearbox and motor fitted at one end.

Biozone

The rotor assembly is suspended within the biozone with 40% of the diameter submerged in the liquor at any one time. The disks slowly rotate and the continuous alternate exposure to air and sewage results in a growth of organisms known as biomass which adheres to the disks.

These organisms occur naturally in the sewage and carry out the purification process by feeding off the impurities present in the sewage. As they have a short life cycle, these organisms are continually shearing off the rotating disks and pass from the biozone to the final zone.

The biozone is fitted with a series of baffles between each bank of media to prevent short circuiting and to ensure maximum performance.

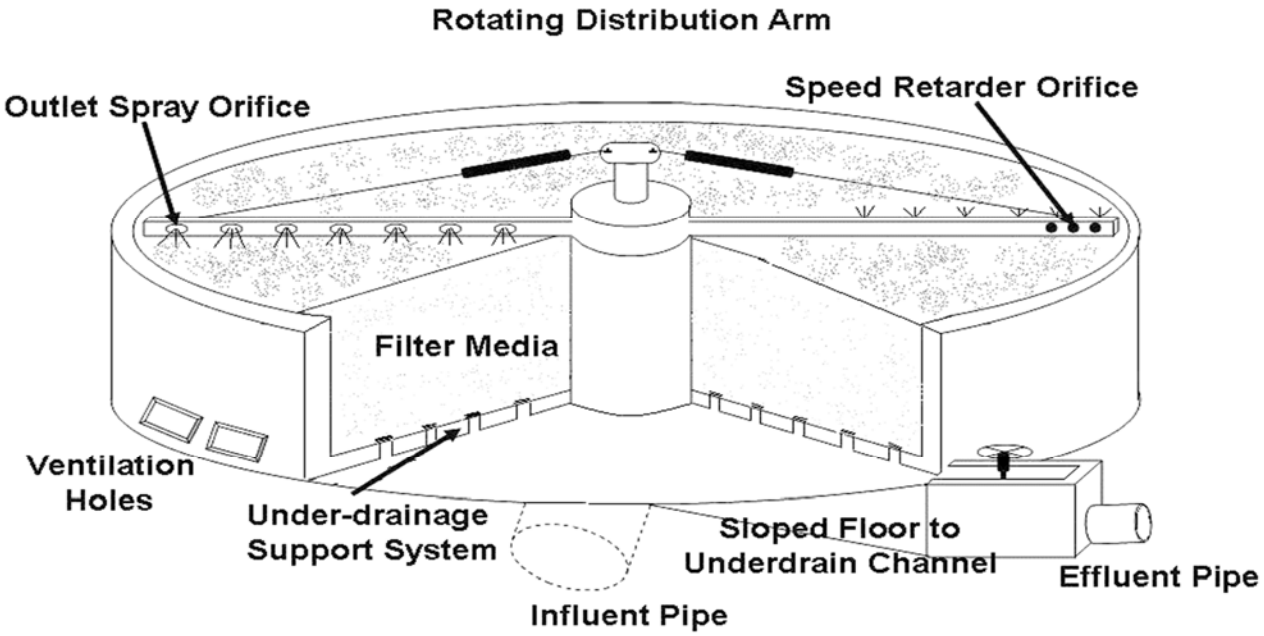
Final Settlement Zone

Culbokie, Scotland Water.

The biomass passes from the biozone into the final settlement zone where it settles to form humus sludge. This is then regularly pumped out using either an airlift system or submersible pumps and returned to the primary zone.

The clarified liquid decants from the top of the tank as effluent that can be discharged to a reed bed for further clarification or direct to a watercourse.

Biofiltration
This method of secondary treatment of wastewater employs sand filters, contact filters, or trickling filters to ensure that additional sediment is removed from wastewater. Of the three filters, trickling filters are typically the most effective for small-batch wastewater treatment.



Trickling Filter

The following four basic categories of filter design are based on the organic loading of the trickling filter.

Low-Rate Filters

Low-rate filters are commonly used for loadings of less than 40 kilograms five-day biochemical oxygen demand (BOD5)/100 meters cubed per day (25 lb. BOD5/1000cu ft/day). These systems have fewer problems than other filters with regards to filter flies, odors, and medium plugging because of the lower loading rate. Low-rate filters with a rock medium range in depth from 3 to 8 feet (0.9 to 2.4 meters).

Most low-rate filters are circular with rotary distributors, but some filters currently in use are rectangular. Both of these configurations are equipped with dosing syphons or periodic pumps to provide a high wetting rate for short intervals between rest periods. A minimum wetting rate of 0.4 liters per square meter-second (0.7 gal/sq. ft./min) is maintained to prevent the high rate plastic filter medium from drying out. With a rock medium, the filters tend not to be hydraulically limited and have application limits ranging from 0.01 to 0.04 liters per square meter-second (0.02 to 0.06 gal/sq. ft./min).

The sloughed solids from a low-rate filter are generally well-digested and as a result these filters yield less solids than higher rate filters. Secondary quality effluent is readily achievable if the low-rate trickling filter design incorporates filter media with bioflocculation capabilities or good secondary clarification.

Intermediate-Rate Filters
Intermediate rate filters can be loaded up to 64 kg BOD5/100 m 3-d (40 lb. BOD5/1000cu ft/day). In order to ensure good distribution and thorough blending of the filter and secondary effluent, the system should recirculate the trickling filter effluent.

The biological solids that slough from an intermediate trickling filter are not as well digested as those using a low-rate filter.

High-Rate Filters
High-rate filters are generally loaded at the maximum organic loading capabilities of the filter and receive total BOD5 loading ranging from 64 to 160 kg BOD5/100 m3-d (40 to 100 lb. BOD5/1000cu ft/day). Achieving a secondary quality effluent is less likely for a high-rate filter without a second-stage process. As a result, high-rate filters are often used with combined processes.

Roughing Filters
Roughing filters are designed to allow a significant amount of soluble BOD to bleed through the trickling filter. Filters of this type generally have a design load ranging from 160-480 kg BOD5/100 m 3-d (100 to 300 lb. BOD5/1000cu ft/day).

A trickling filter (TF) consists of permeable medium made of a bed of rock (As seen above), slag, or plastic over which wastewater is distributed to trickle through the armature.

Aeration Section

There are several designs and applications for aerators:

- Diffused Aerators
- Mechanical Surface Aerators
- Submerged Turbine Aerators

The two most common types of aeration systems are subsurface diffusion and mechanical aeration. Diffused air systems have been around longer than you.

Opened tubes were used or perforated pipes located at the bottom of aeration tanks. But a more efficient process was desired, born to the process, porous plate diffusers. In the diffused air system, compressed air is introduced near the bottom of the tank. Let's look at the definition for diffused aeration:

"The injection of a gas, air or oxygen, below a liquid surface."

There are a variety of hybrid air diffusion systems used in the process; we will focus on the basic components.

The following photo highlights the main parts of the diffused aeration system.

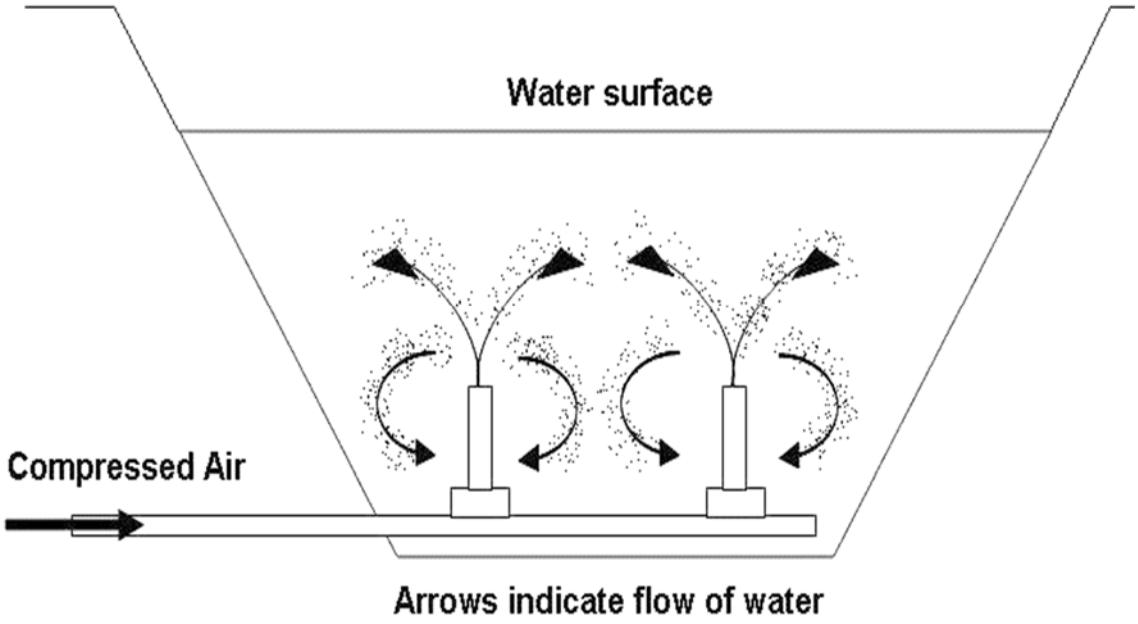
Here is a rare and up-close view of non-porous diffuser heads. Notice the heads that are missing in the bottom photograph.

Aeration Explained

The aerated systems as described need an oxygen supply. Depending on the characteristics of the process, different designs may be used. The oxygen can be supplied to the activated sludge by either diffused aeration, by turbine agitation, by static aerators, or by surface coarse or large bubble diffusers. The last two are also used in lagoon systems.

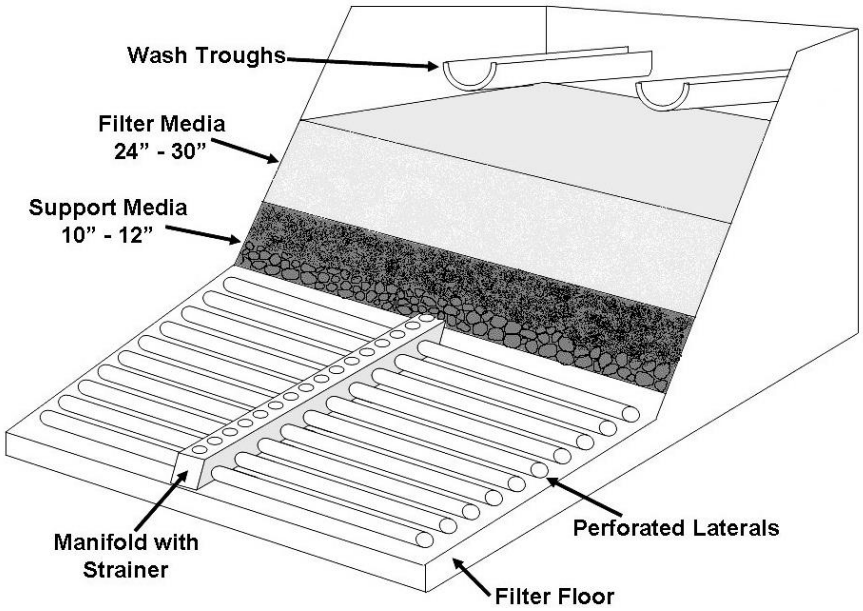
The diffused aeration systems are also divided into fine bubble, medium and coarse or large bubble diffusers. The fine bubble diffusers are built of porous materials (grains of pure silica or aluminum oxide are bonded ceramically or by resins) which provide very small bubbles of high surface area that favor the oxygen transfer from the air to the wastewater.

The medium bubble diffusers are perforated pipes or tubes wrapped with plastic or woven fabric. The coarse or large bubble diffusers can be orifice devices of various types, some of which are designed to be non-clogging.

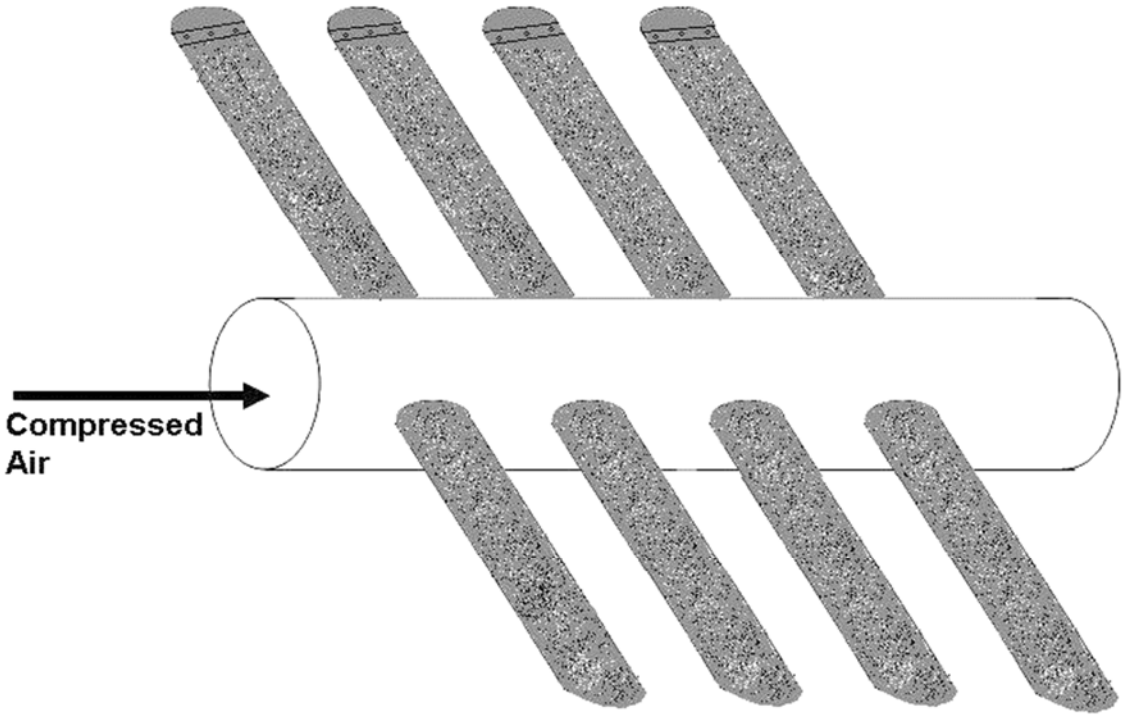


Coarse or Large Bubble Diffusers
With the small or fine bubble diffusers, it is important to use air free of particles that would otherwise clog them. Although somewhat less efficient for oxygen transfer, the coarse bubble diffusers are sometimes preferred because the presence of particles in the air is not a critical problem, and also for their lower cost and maintenance requirements. The diffusers are placed along air manifolds, close to the bottom of the aeration tanks.

The static aerators are vertical tubes placed at the bottom of the aeration tank, with packing material along its length. The compressed air is supplied from the bottom of the tubes, forcing a mixture of air and water through the packing, where most of the oxygen transfer to the wastewater takes place. They have been used mainly in aerated lagoons.



Effluent gravity filter showing diffused air piping manifold arrangement.



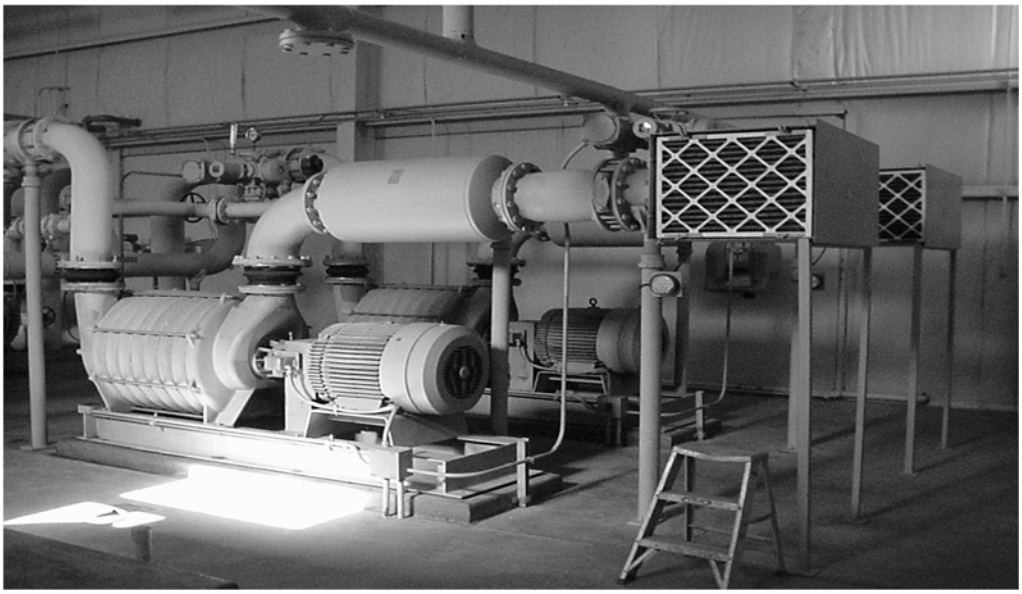
a. Fine bubble diffuser

Blowers

In the diffused aeration system, blowers are used to circulate the tank's contents by the air-lift effect. The air filter on the blower removes dirt from the air. Therefore, helps prevent diffuser clogging. Before all this begins, we need a power source to drive the blower. Usually, electric motors are used but in remote locations, gas or diesel engines can be used as well. In some states, solar energy is available to provide the power.

As illustrated in the photograph below, the rotation of the motor shaft is transferred to the blower shaft by means of a flexible coupling or through drive belts. The blowers that we will refer to are centrifugal blowers.

The centrifugal blower works like a centrifugal pump or a fan. Rotating impellers or fans cause movement of the air through the blowers. You have an intake side that takes in the air and the discharge side the forces the air out. The number of impellers you have will determine if it is a multi-stage or single-stage blower. The photographs below illustrate the major components of a centrifugal blower.



A lobe blower utilizes positive displacement; it also has an intake and a discharge side. The lobes turn in opposite directions in the casing. As they turn, the air is drawn in through the blower inlet and is trapped.

The lobes keep turning, opening the blower discharge, and forcing the trapped air through the outlet. Usually, an electric motor drives the blower with belt pulleys or flexible couplings.

Before we continue let's review what you just read about the blowers and motors.

1. What are two ways that the motor and the blowers can be attached?

2. When using flexible couplings, what are some maintenance concerns to consider?

Blowers may be provided with additional equipment. For example, safeguards can be installed to protect equipment and operators. Temperature sensors can be used for bearing housing, vibration sensors protect the unit by shutting it down if limits are exceeded. Condensation drains should be provided on the bottom of blowers to drain off any accumulated moisture.

The compressed air from the blowers moves into a system of pipes and valves. The amount of air supplied from the blower is controlled by regulating valves mounted on the intake and/or discharge side of the blower. Usually butterfly valves are used and depending on your budget, you could have manually operated or use automation.

Blowers usually discharge to a common manifold, so check valves are installed at the discharge of each blower. The intake and discharge pipes are called the air mains. They are connected by a flexible connection to allow for vibration and heat expansion in the piping. In the winter months, the best place to be is in the blower room. There is a pressure relief valve on the discharge manifold to protect the blower from excessive back pressure overload. When this occurs the operator will be awakened on the midnight shift. Pressure gauges are used in several areas on the discharge side of the blowers.

On the intake side, where air is supplied, you would have some type of filtering to remove dirt particles that could clog the diffusers. It also protects the blowers from excessive wear. Replaceable filter units are the simplest for operations. Bag house dust collectors are bulky and expensive, though maintenance may be less. In some cases, electrostatic precipitators may be an advantage, shocking if operators are not careful, in areas of poor air quality. Most systems have utilized pressure drop measuring to indicate when it is time to replace or clean the units.

The above photograph shows air being unevenly distributed.

Diffuser Layouts

There are many different design layouts and patterns of diffuser placement. Systems that allow longer and more complete contact between the air and the liquid are preferred. We will focus on fine bubble (porous) diffusers and coarse bubble (nonporous).

Coarse bubble diffusion devices, or large-hole diffusers, produce larger bubbles than porous plates, porous tubes, or synthetic socks. The larger bubbles provide less surface area for air-liquid contact and will result in less oxygen transfer efficiency than that obtained with fine bubble diffusers.

Answer this question:

An air stone like those used in aquariums is a good example of a?

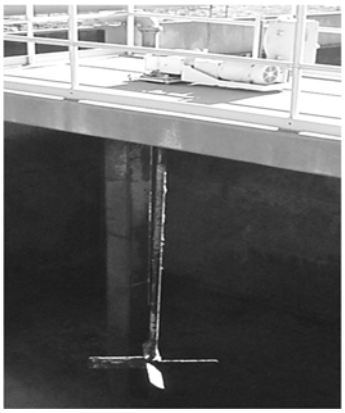
A. Porous material
B. Nonporous material

Mechanical Aeration

There are several main types of mechanical aeration devices. The floating and fixed bridge aerators are quite common. Some use a blade to agitate the tank's surface and disperse air bubbles into the aeration liquor. Others circulate the mixed liquor by an updraft or downdraft pump or turbine. This action produces surface and subsurface turbulence, while diffusing air through the mixed liquor.

The motor speeds are usually in the 1800 rpm range. This speed is reduced to the 30 to 70 rpm range with gear reducers.

Most vertical motors are mounted on a gear reduction unit as seen in the photograph on the right. The impeller drive shaft can be enclosed in a housing connected directly to the gear box. There is a bearing at the bottom of the shaft that steadies and aligns this shaft. This bearing needs lubrication, always check your manufactures recommendations.



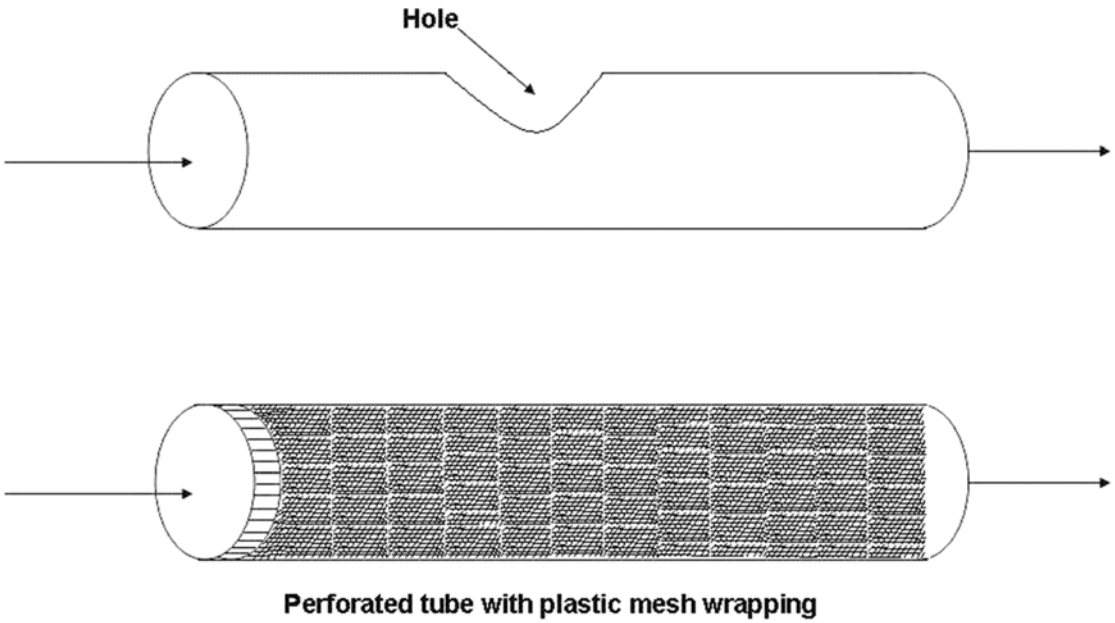
Some plants use an oxidation ditch in which rotating brushes, blades, or disks are rotated partially submerged in the mixed liquor. The turbulence produced traps the air bubbles and keeps the mixed liquor in motion.

Other systems use both compressed air and a mechanical device to trap the bubbles. In one such system, submerged turbine aeration, air is injected below a rotating turbine blade that shears and disperses the air.

Submerged turbine applications have also used a draft tube operating in a downdraft-pumping mode.

Jet and Aspirator

Aerators provide oxygen transfer by mixing pressurized air and water within a nozzle and then discharging the mixture into the aeration tank. The velocity of the discharged liquid and the rising air plume provide the necessary mixing action.



Fine Bubble Aeration Example

COARSE BUBBLE AERATION DIFFUSER

A device through which air is pumped and divided into large bubbles that are transferred and dissolved into the liquid. Coarse bubble diffusers normally discharge air at a high rate and are installed to induce a spiral or cross roll mixing pattern. Coarse bubble diffusers are typically installed in a non-clogging application.

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FINE BUBLE AERATION DIFFUSER

A device through which air is pumped and divided into very small bubbles that are used to introduce and dissolve oxygen into the liquid. Fine bubble diffusers are normally disks or tubes that use membranes or ceramic materials to create the bubbles and gentle mixing action. Fine bubble diffused aeration utilizes full floor coverage in order to be effective and energy efficient.

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CLARIFICATION PROCESS

A process to reduce the concentration of suspended matter in water. In the activated sludge treatment process, the removal of suspended solids from wastewater is usually through gravity separation in a clarifier.

Technical Learning College

RAS CONCENTRATION

Varying the **return activated sludge (RAS)** flow rate will affect the concentration and detention time of clarified solids. Adjusting the **RAS** pumping rate allows the return of more or less concentrated solids while also increasing or decreasing the depth of the sludge blanket. **RAS** flow rates can be paced off influent flow rates.

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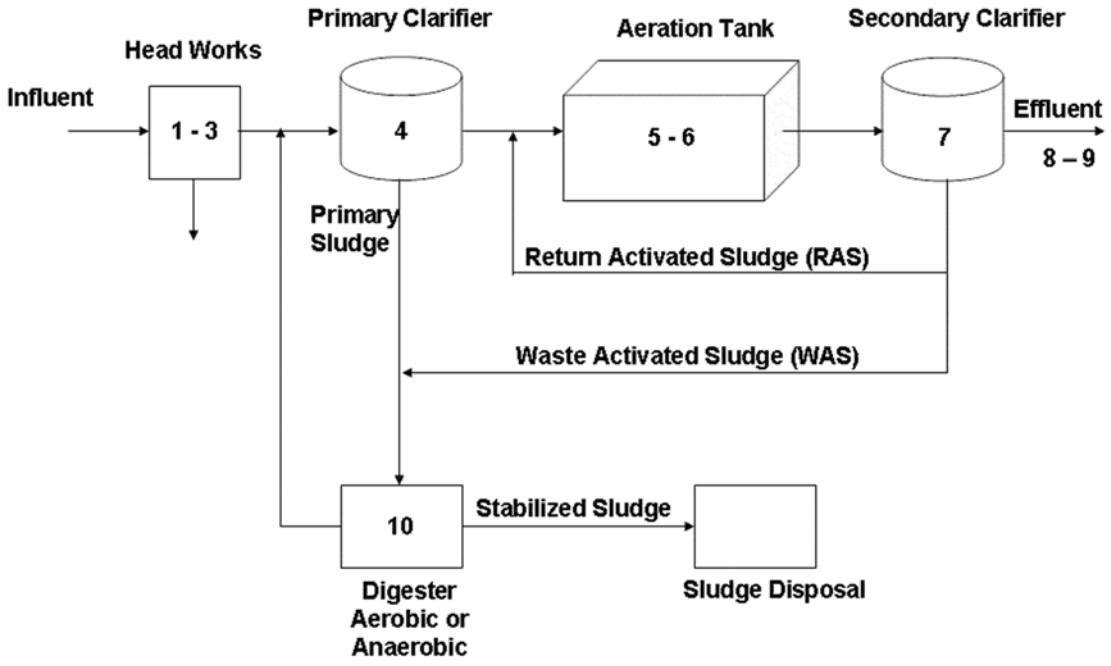

Air is necessary at process number 5-6.

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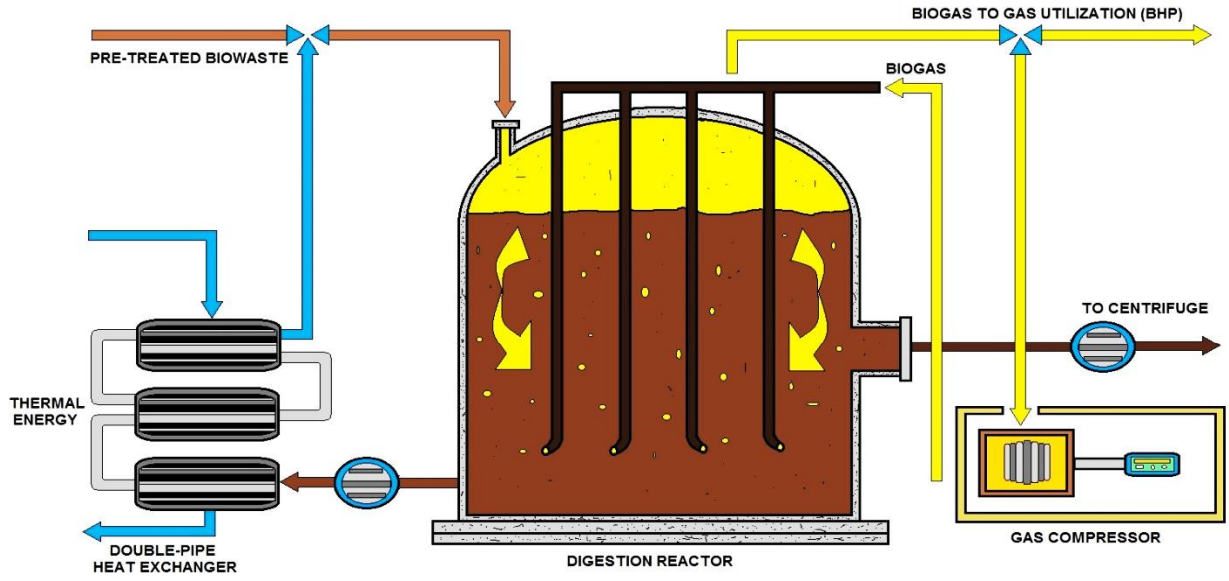
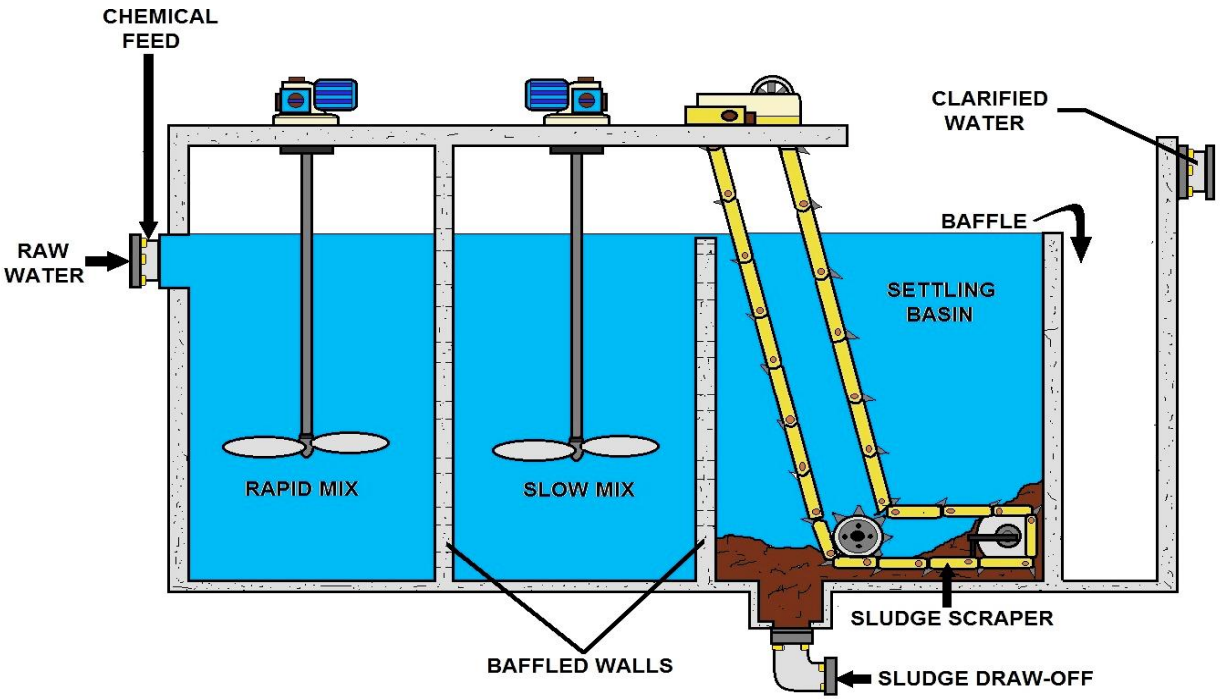
Photo Journal #4

Anoxic zone, denitrification area.

The same area from above photo, but clean and dry, these are porous air diffusers.



SINGLE-STAGE DIGESTION REACTOR



HORIZONTAL BASIN CLARIFIER

Review of Quality Process Goals

As previously noted, the activated sludge process can be used to remove carbonaceous BOD and also ammonia (nitrification). We can take the wastewater oxygen demand separated into two categories: carbonaceous and nitrogenous.

Carbonaceous BOD Removal
The carbonaceous demand should be expressed as a function of the number of days that the demand will be measured; 3-day, 5-day (most common), 7-day, and 20-day time periods are commonly used. To obtain only carbonaceous oxygen demand, it may be necessary to inhibit nitrification by adding chemicals.

The rate and extent of BOD5 (5-day BOD) removal in primary treated (settled) or untreated wastewater depends on the relative quantities of soluble, colloidal, and suspended BOD5, and a soluble BOD5 content of approximately 20 to 40% of the total. These proportions may vary, particularly in warmer climates where long collection system residence times and the higher wastewater temperatures may result in a higher proportion of soluble BOD5. This is caused by the bacterial degradation of a portion of the colloidal and settleable fractions.

With typical municipal wastewater, a well-designed activated sludge process should achieve a carbonaceous, soluble BOD5 effluent quality of 5mg/L or less. Similarly, with clarifiers designed to maximize solids removal at peak flows and adequate process control, the average SS in the effluent should not exceed 15 mg/L.

On a practical basis, an effluent with 20/20 mg/L BOD5 and SS should be attained, assuming proper operation. Potential capabilities of the process are 10/15 mg/L Bod5 and SS. To consistently achieve values lower than 10/15 mg/L, some type of tertiary treatment is required.

Nitrification
Of the total oxygen demand exerted by the wastewater, there is often a sizeable fraction associated with the oxidation of ammonia to nitrate. The autotrophic bacteria Nitrosomonas and Nitrobacter are responsible for this two-state conversion. Being autotrophic, these nitrifying organisms must reduce oxidized carbon compounds in the wastewater, such as CO_2 and its related ionic species, for cell growth. As a result, this characteristic markedly affects the ability of the nitrifying organisms to compete in a mixed culture.

The nitrifying bacteria obtain their energy by oxidizing ammonia nitrogen to nitrite nitrogen and then to nitrate nitrogen. Because very little energy is obtained from these oxidation reactions, and because energy is needed to change CO_2 to cellular carbon, the population of nitrifiers in activated sludge is relatively small. When compared to the normal bacteria in activated sludge, the nitrifying bacteria have a slower reproduction rate.

Nitrifying organisms are present to some extent in all domestic wastewaters. However, some wastewaters are not nitrified in existing plants because they are designed for the higher growth rate of bacteria responsible for carbonaceous removal. As the MCRT is increased, nitrification generally takes place. The longer MCRT prevents nitrifying organisms from being lost from the system when carbonaceous wasting occurs or, more accurately, the longer MCRT permits the build-up of an adequate population of nitrifiers.

Because of the longer MCRT required for nitrification, some systems are designed to achieve nitrification in the second stage of a two-stage activated sludge system. The oxygen demand for complete nitrification is high. For most domestic wastewaters, it will increase the oxygen supply and power requirements by 30 to 40% because complete nitrification requires from 4.3 to 4.6 lb. of oxygen for each lb. of ammonia nitrogen (4.3 to 4.6 mg/mg) converted into nitrate, and wastewaters generally contain 10 to 30 mg/L of reduced nitrogen. Nitrification systems generally are not operated at intermediate (40 to 80%) removals; stable operation is achieved when essentially complete nitrification (greater than 90%) occurs.

Minimum acceptable dissolved oxygen (**DO**) concentrations of 2 to 3 mg/L have been reported, but nitrification appears to be inhibited when the oxygen concentration is lower than 1 mg/L.

Optimum growth of nitrifying bacteria has been observed in the pH range of 8 to 9 although other ranges have been reported. A substantial reduction in nitrification activity usually occurs at pH levels below 7, although nitrification can occur at low pH.

While nitrification occurs over a wide temperature range, temperature reduction results in a slower reaction rate.

The temperature effect is made less severe by increasing the MCRT. During the conversion of ammonia to nitrate, mineral acidity is produced. If insufficient alkalinity is present, the system's pH will drop and nitrification may be inhibited.

Bacteria Highlights

A change in the numbers or predominance of microorganisms in activated sludge is usually gradual. The time required for a complete shift from one species to another will normally be seen in: 2 to 3 MCRT's. A large amount of long filamentous bacteria will prevent good settling. The liquid above this mass is called the supernatant. Endogenous respiration of microorganisms in an extended aeration plant will complete the oxidation process of an organic material.

The bug Nocardia causes frothing. Saprophytic type bacteria produces the most acid in an anaerobic digester.

The best location for microscopic examination of activated sludge in a conventional system is at the effluent end of the aeration system. The examination can reveal a predominant number of rotifers and nematodes, this condition may indicate that the F/M ratio is too low and this would be normal in an extended aeration process.

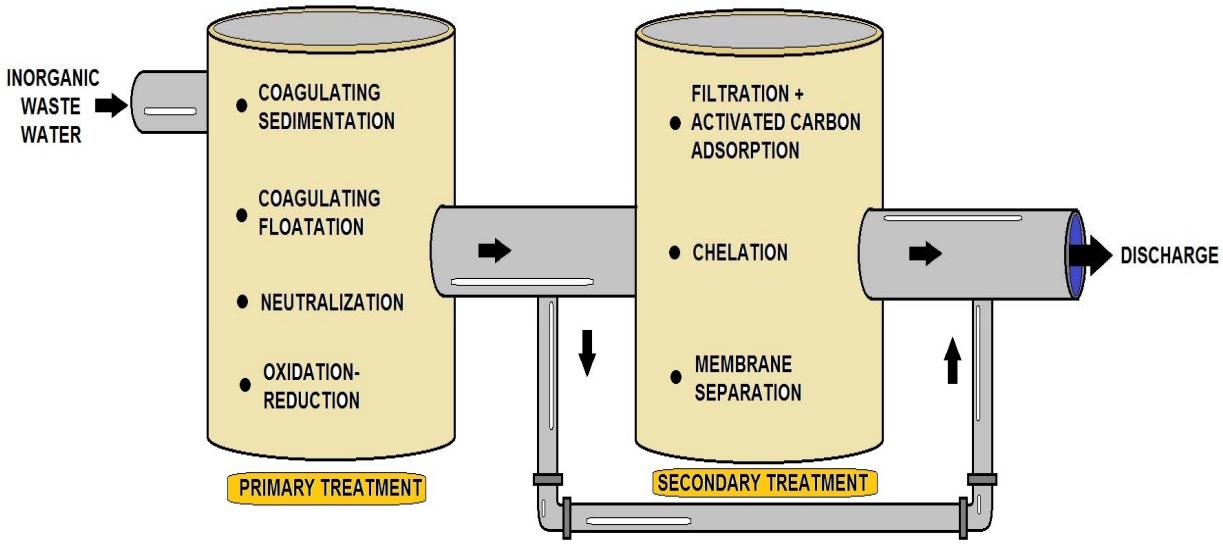
Food to microorganism ratio. A measure of food provided to bacteria in an aeration tank.

$$\frac{\text{Food}}{\text{Microorganism}} = \frac{\text{BOD, lbs/Day}}{\text{MLVSS, lbs}}$$

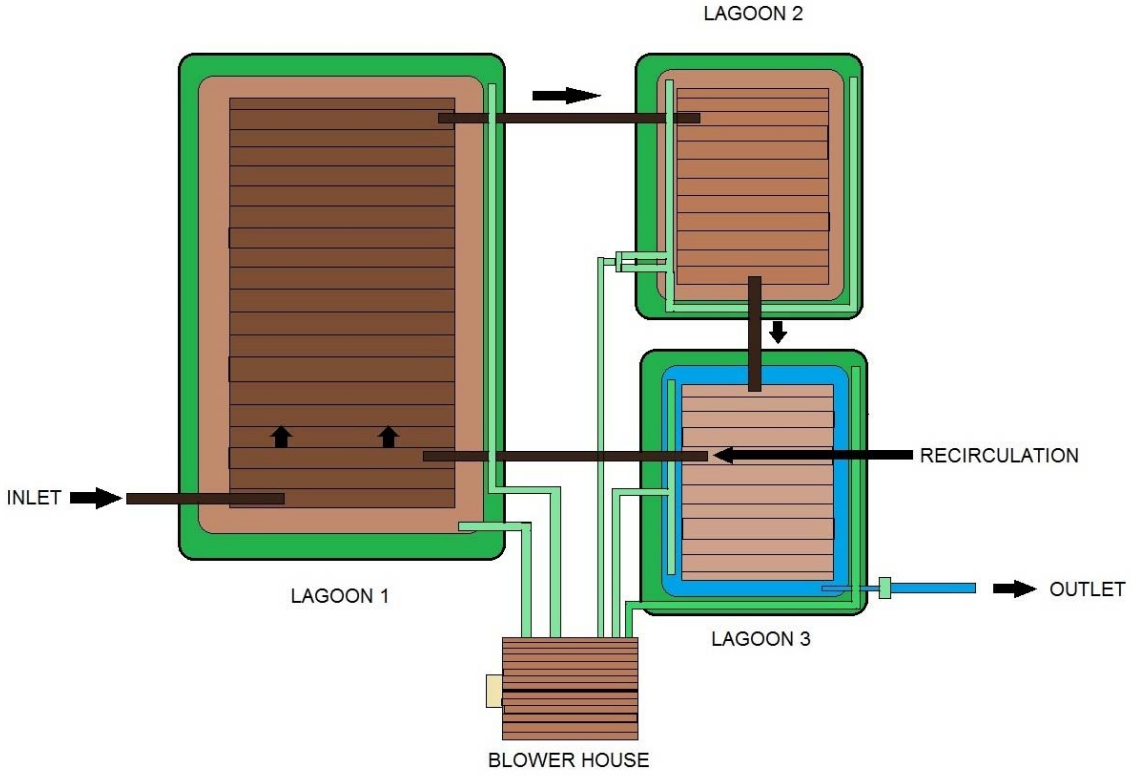
$$= \frac{\text{Flow, MGD} \times \text{BOD, mg/}L \times 8.34 \text{ lbs/gal}}{\text{Volume, MG} \times \text{MLVSS, mg/}L \times 8.34 \text{ lbs/gal}}$$

$$\text{or} = \frac{\text{BOD, kg/day}}{\text{MLVSS, kg}}$$

Secondary Treatment Methods Photo Journal #5



PROCESS OF REMOVING INORGANIC WASTE (Flow Diagram)

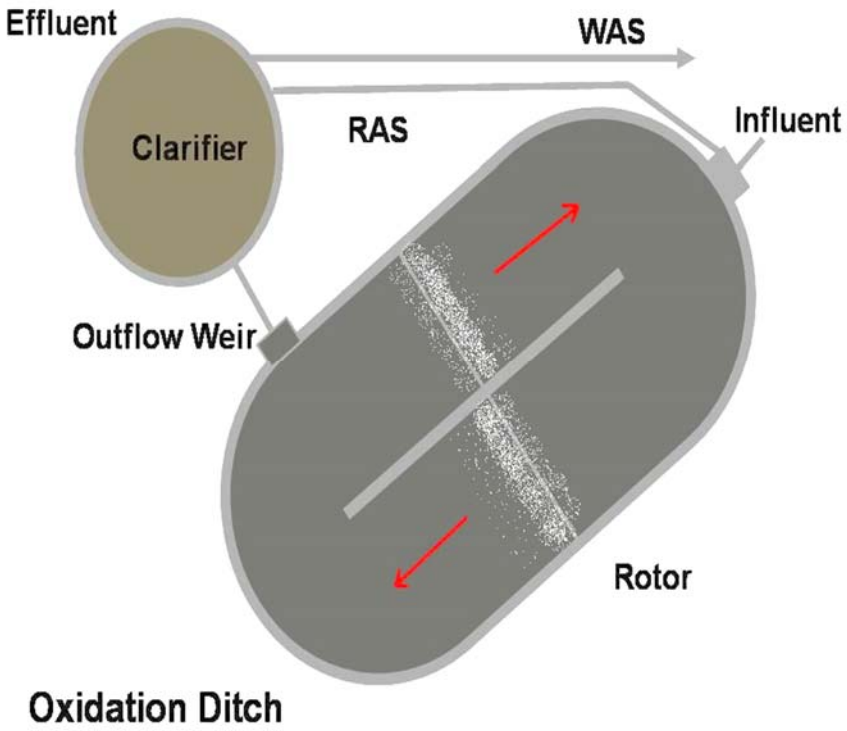


ADS LAGOON SYSTEM

These operators are making sure that the backwash pumps are working for the sand filter.

During a slight plant upset, sludge from the filters can be carried over to the chlorine contact channel.

Oxidation Ditch Section



Many times in plants that have advanced treatment methods, we as operators will send RAS to the oxidation ditch or lagoon to eat the raw food in the system.

An oxidation ditch is a modified activated sludge biological treatment process that utilizes long solids retention times (SRTs) to remove biodegradable organics. Oxidation ditches are typically complete mix systems, but they can be modified to approach plug flow conditions.

An oxidation ditch is a modified activated sludge biological treatment process that utilizes long solids retention times (SRTs) to remove biodegradable organics. Oxidation ditches are typically complete mix systems, but they can be modified to approach plug flow conditions. (Note: as conditions approach plug flow, diffused air must be used to provide enough mixing. The system will also no longer operate as an oxidation ditch).

Typical oxidation ditch treatment systems consist of a single or multichannel configuration within a ring, oval, or horseshoe-shaped basin. As a result, oxidation ditches are called “racetrack type” reactors. Horizontally or vertically mounted aerators provide circulation, oxygen transfer, and aeration in the ditch.

Preliminary treatment, such as bar screens and grit removal, normally precedes the oxidation ditch. Primary settling prior to an oxidation ditch is sometimes practiced, but is not typical in this design. Tertiary filters may be required after clarification, depending on the effluent requirements.
Disinfection is required and re-aeration may be necessary prior to final discharge. Flow to the oxidation ditch is aerated and mixed with return sludge from a secondary clarifier.

Advantages
The main advantage of the oxidation ditch is the ability to achieve removal performance objectives with low operational requirements and operation and maintenance costs.

Some specific advantages of oxidation ditches include:
- ✓ An added measure of reliability and performance over other biological processes owing to a constant water level and continuous discharge that lowers the weir overflow rate and eliminates the periodic effluent surge common to other biological processes, such as SBRs.
- ✓ Long hydraulic retention time and complete mixing minimize the impact of a shock load or hydraulic surge.
- ✓ Produces less sludge than other biological treatment processes owing to extended biological activity during the activated sludge process.
- ✓ Energy efficient operations result in reduced energy costs compared with other biological treatment processes.

Disadvantages
- ✓ Effluent suspended solids concentrations are relatively high compared to other modifications of the activated sludge process.
- ✓ Requires a larger land area than other activated sludge treatment options. This can prove costly, limiting the feasibility of oxidation ditches in urban, suburban, or other areas where land acquisition costs are relatively high.

Surface aerators, such as brush rotors, disc aerators, draft tube aerators, or fine bubble diffusers are used to circulate the mixed liquor.

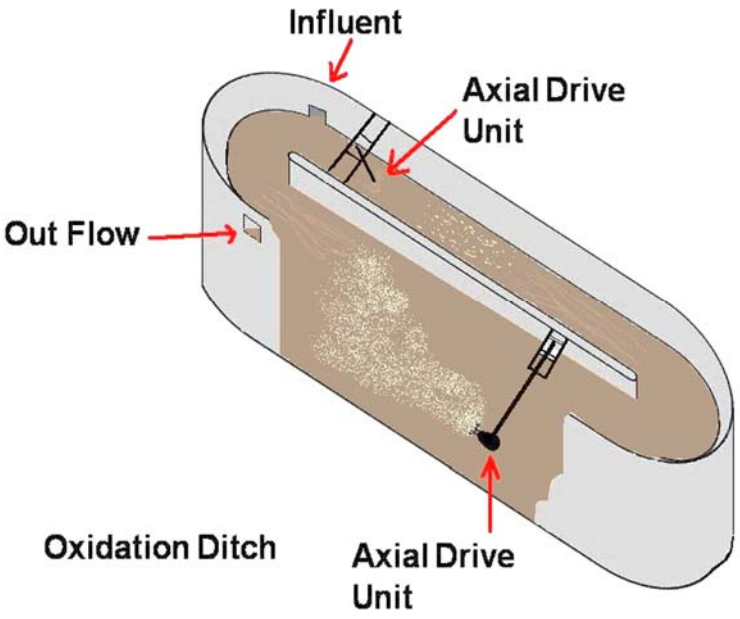
The mixing process entrains oxygen into the mixed liquor to foster microbial growth and the motive velocity ensures contact of microorganisms with the incoming wastewater.

The aeration sharply increases the dissolved oxygen (DO) concentration but decreases as biomass uptake oxygen as the mixed liquor travels through the ditch. Solids are maintained in suspension as the mixed liquor circulates around the ditch.

If design SRTs are selected for nitrification, a high degree of nitrification will occur.

Oxidation ditch effluent is usually settled in a separate secondary clarifier. An anaerobic tank may be added prior to the ditch to enhance biological phosphorus removal. An oxidation ditch may also be operated to achieve partial denitrification.

One of the most common design modifications for enhanced nitrogen removal is known as the Modified Ludzack-Ettinger (MLE) process.



Understanding the Reactor

Some oxidation ditches add an anoxic tank upstream of the ditch along with mixed liquor recirculation from the aerobic zone to the tank to achieve higher levels of denitrification. In the aerobic basin, autotrophic bacteria (nitrifiers) convert ammonia-nitrogen to nitrite-nitrogen and then to nitrate-nitrogen. In the anoxic zone, heterotrophic bacteria convert nitrate-nitrogen to nitrogen gas that is released to the atmosphere. Some mixed liquor from the aerobic basin is recirculated to the anoxic zone to provide a mixed liquor with a high- concentration of nitrate-nitrogen to the anoxic zone.

Manufacturers have developed modifications to the oxidation ditch design to remove nutrients in conditions cycled or phased between the anoxic and aerobic zones. While the mechanics of operation differ by manufacturer, the process typically consists of two separate aeration basins, the first anoxic and the second aerobic.

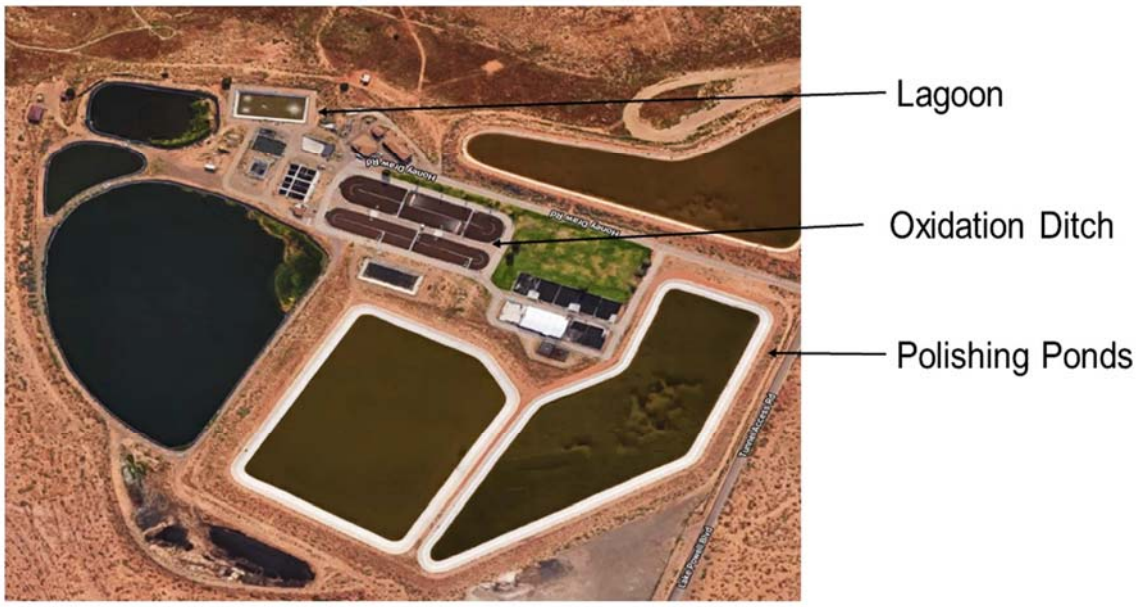
Raw wastewater and return activated sludge (RAS), low dissolved oxygen (DO), are introduced into the first reactor that operates under anoxic conditions.

Mixed liquor (MLSS) then flows into the second reactor operating under aerobic conditions. The process is then reversed and the second reactor begins to operate under anoxic conditions.

The oxidation ditch process is a fully demonstrated secondary wastewater treatment technology, applicable in any situation where activated sludge treatment (conventional or extended aeration) is appropriate.

Oxidation ditches are applicable in plants that require nitrification because the basins can be sized using an appropriate SRT to achieve nitrification at the mixed liquor minimum temperature. This technology is very effective in small installations, small communities, and isolated institutions, because it requires less land than conventional treatment plants.

OXIDATION DITCH AND LAGOON



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Microorganisms - Lagoons and Activated Sludge

If you feed bugs or maintain bugs to degrade waste, this can be considered part of the A/S. Before we look at the bugs themselves, let us look at eating habits. Have you ever met a person who was a picky eater?

You have people who will put their noses up at some things and others who would eat anything. Predators typically eat from a narrow set of prey, while omnivores and scavengers eat from a broader food selection.

- Swimming and gliding ciliates engulf bacteria or other prey.
- Stalked ciliates attach to the biomass and vortex suspended bacteria into their gullets, while crawlers break bacteria loose from the floc surface.
- Predators feed mostly on stalked and swimming ciliates. The omnivores, such as most rotifers, eat whatever is readily available, while the worms feed on the floc or prey on larger organisms. Microorganisms are directly affected by their treatment environment.
- Changes in food, dissolved oxygen, temperature, pH, total dissolved solids, sludge age, presence of toxins, and other factors create a dynamic environment for the treatment organisms.

Food (organic loading) regulates microorganism numbers, diversity, and species when other factors are not limiting. The relative abundance and occurrence of organisms at different loadings can reveal why some organisms are present in large numbers while others are absent.

The aerobic bacteria that occur are similar to those found in other treatment processes such as in the activated sludge process. Three functional groups occur: freely dispersed, single bacteria; floc-forming bacteria; and filamentous bacteria. All function similarly to oxidize organic carbon (BOD) to produce CO_2 and new bacteria (new sludge).

Many bacterial species that degrade wastes grow as single bacteria dispersed in the wastewater. Although these readily oxidize BOD, they do not settle and hence often leave the system in the effluent as solids (TSS). These tend to grow in lagoons at high organic loading and low oxygen conditions. More important are the floc-forming bacteria, those that grow in a large aggregate (floc) due to exocellular polymer production (the glycocalyx).

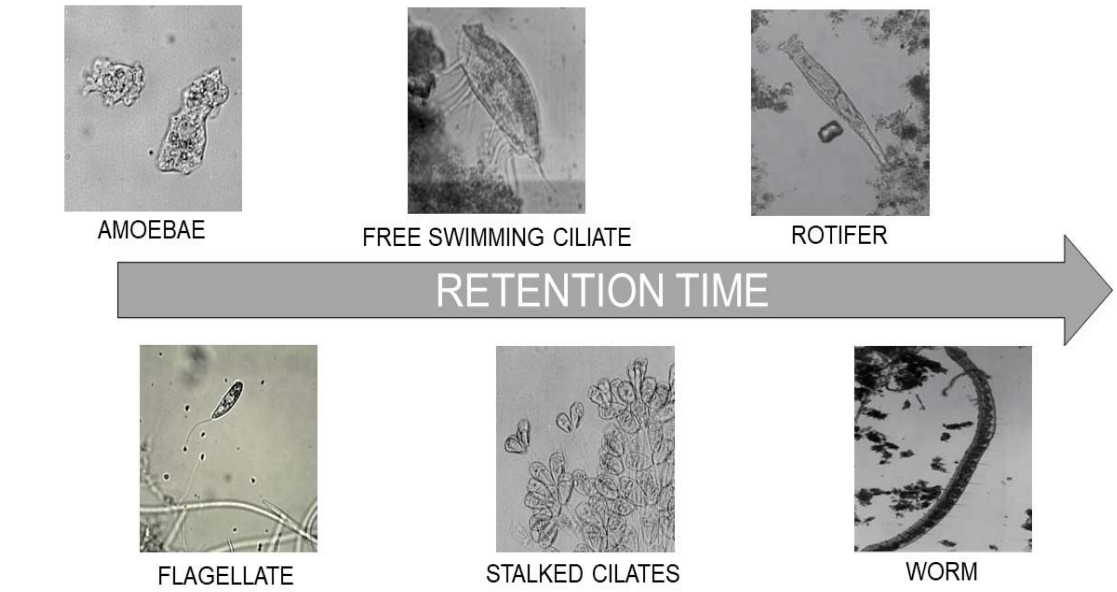
This growth form is important as these flocs degrade BOD and settle at the end of the process, producing a low TSS effluent.

A number of filamentous bacteria occur in lagoons, usually at specific growth environments. These generally do not cause any operational problems in lagoons, in contrast to activated sludge where filamentous bulking and poor sludge settling is a common problem. Most heterotrophic bacteria have a wide range in environmental tolerance and can function effectively in BOD removal over a wide range in pH and temperature.

Aerobic BOD removal generally proceeds well from pH 6.5 to 9.0 and at temperatures from 3-4°C to 60-70°C (37.4 -39.2° F to 140-158°F in the ATAD process (mesophilic bacteria are replaced by thermophilic bacteria at temperatures above 35°C).

BOD removal generally declines rapidly below 3-4°C and ceases at 1-2°C.

A very specialized group of bacteria occurs to some extent in lagoons (and other wastewater treatment systems) that can oxidize ammonia via nitrite to nitrate, termed nitrifying bacteria. These bacteria are strict aerobes and require a redox potential of at least +200 m V (Holt et al., 1994).



Mixed or Suspended Lagoons

The aerated lagoons are basins, normally excavated in earth and operated without solids recycling into the system. This is the major difference with respect to activated sludge systems. Two types are the most common: the completely mixed lagoon (also called completely suspended) in which the concentration of solids and dissolved oxygen are maintained fairly uniform and neither the incoming solids nor the biomass of microorganisms settle, and the facultative (aerobic-anaerobic or partially suspended) lagoons. In the facultative lagoons, the power input is reduced causing accumulation of solids in the bottom which undergo anaerobic decomposition, while the upper portions are maintained aerobic. The main operational difference between these lagoons is the power input, which is in the order of 2.5-6 Watts per cubic meter (W/m^3) for aerobic lagoons while the requirements for facultative lagoons are of 0.8-1 W/m^3.

Being open to the atmosphere, the lagoons are exposed to low temperatures which can cause reduced biological activity and eventually the formation of ice. This can be partially alleviated by increasing the depth of the basin. These units require a secondary sedimentation unit, which in some cases can be a shallow basin excavated in earth, or conventional settling tanks can be used.

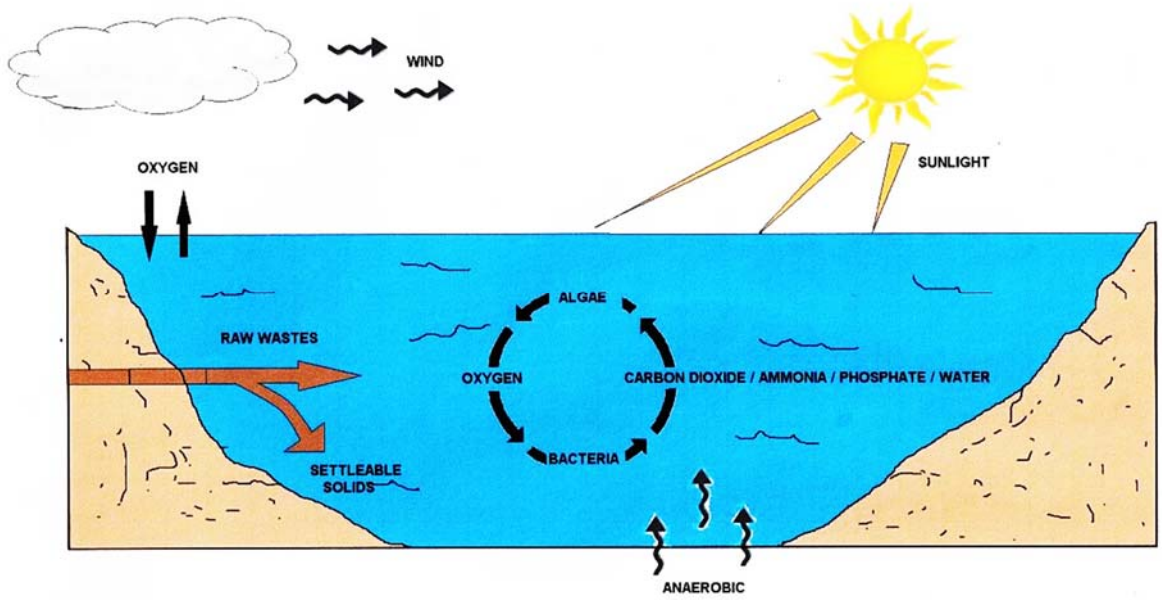


Diagram of facultative aerated lagoon.

If excavated basins are used for settling, care should be taken to provide a residence time long enough for the solids to settle, and there should also be provision for the accumulation of sludge. There is a very high possibility of offensive odor development due to the decomposition of the settled sludge, and algae might develop in the upper layers contributing to an increased content of suspended solids in the effluent.

Odors can be minimized by using minimum depths of up to 2 m, while algae production is reduced with liquid retention time of less than two days. The solids will also accumulate, all along the aeration basins in the facultative lagoons and even in comers, or between aeration units in the completely mixed lagoon.

These accumulated solids will, on the whole, decompose in the bottom, but since there is always a non-biodegradable fraction, a permanent deposit will build up. Therefore, periodic removal of these accumulated solids becomes necessary. We will cover this in much more detail in a few more pages.

SUBMERGED DIFFUSED AERATION LAGOON

Submerged diffused air is essentially a form of a diffuser grid inside a lagoon. There are two main types of submerged diffused aeration systems for lagoon applications: floating lateral and submerged lateral. Both these systems utilize fine or medium bubble diffusers to provide aeration and mixing to the process water. The diffusers can be suspended slightly above the lagoon floor or may rest on the bottom. Flexible airline or weighted air hose supplies air to the diffuser unit from the air lateral (either floating or submerged).

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SUSPENSION MIXED LAGOON

Suspension mixed lagoons flow through activated sludge systems where the effluent has the same composition as the mixed liquor in the lagoon. Typically, the sludge will have a residence time or sludge age of 1 to 5 days. This means that the chemical oxygen demand (COD) removed is relatively little and the effluent is therefore unacceptable for discharge into receiving waters. The primary objective of the lagoon is therefore to act as a biologically assisted flocculator which converts the soluble biodegradable organics in the influent to a biomass which is able to settle as a sludge.

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Algae Introduction

Algae are aerobic organisms that are photosynthetic and grow with simple inorganic compounds CO_2, NH_3, NO_3, and PO_4 using light as an energy source. (**Note that algae produce oxygen during the daylight hours and consume oxygen at night.)

Algae are desirable in lagoons as they generate oxygen needed by bacteria for waste stabilization. Three major groups occur in lagoons, based on their chlorophyll type: brown algae (diatoms), green algae, and red algae.

The predominant algal species at any given time is dependent on growth conditions, particularly temperature, organic loading, oxygen status, nutrient availability, and predation pressures. A fourth type of "algae" common in lagoons is the cyano-bacteria or blue-green bacteria.

These organisms grow much as the true algae, with the exception that most species can fix atmospheric nitrogen. Blue-green bacteria often bloom in lagoons and some species produce odorous and toxic by-products.

Blue-Green Bacteria
Blue-green bacteria appear to be favored by poor growth conditions including high temperature, low light, low nutrient availability (many fix nitrogen) and high predation pressure. Common blue-green bacteria in waste treatment systems include Aphanothece, Microcystis, Oscillatoria and Anabaena.

Algae can bloom in lagoons at any time of the year (even under the ice); however, a succession of algae types occurs over the season. There is also a shift in the algal species present in a lagoon through the season, caused by temperature and rotifer and Daphnia predation.

Diatoms usually predominate in the wintertime at temperatures <60°F. In the early spring, when predation is low and lagoon temperatures increase above 60°F, green algae such as Chlorella, Chlamydomonas, and Euglena often predominate in waste treatment lagoons.

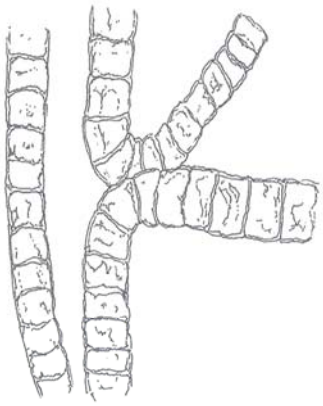
The predominant green algae change to species with spikes or horns such as Scenesdesmus, Micractinium, and Ankistrodesmus later in the season when Rotifers and Daphnia are active (these species survive predation better).

Algae grow at warmer temperatures, longer detention time, and when inorganic minerals needed for growth are in excess.

Alkalinity (inorganic carbon) is the only nutrient likely to be limiting for algal growth in lagoons.

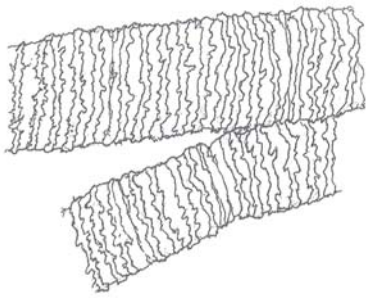
Substantial sludge accumulation in a lagoon may become soluble upon warming in the spring, releasing algal growth nutrients and causing an algal bloom. Sludge resolution of nutrients is a major cause of high algal growth in a lagoon, requiring sludge removal from the lagoon for correction.

Algae on the Secondary clarifier, not a healthy sign.



BLUE-GREEN ALGAE

ITS CELLS LACK NUCLEI AND ITS PIGMENT IS SCATTERED.
BLUE-GREEN ALGAE ARE ACTUALLY NOT ALGAE, BUT BACTERIA

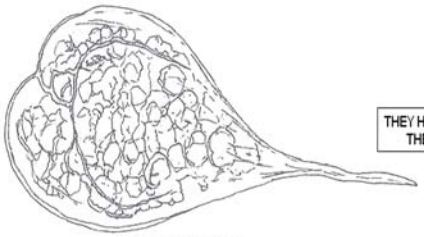


GREEN ALGAE

THEIR CELLS HAVE NUCLEI AND PIGMENT IS DISTINCT.
THEY ARE MOST COMMON ALGAE IN PONDS AND CAN BE MULTICELLULAR

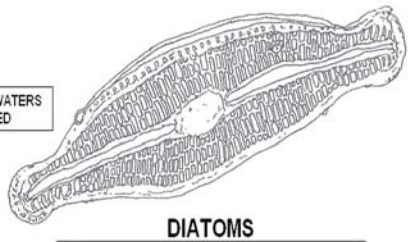
DINOFLAGELLATES

THEY HAVE FLAGELLA AND CAN SWIM IN OPEN WATERS
THEY ARE MICROSCOPIC AND SINGLE-CELLED



EUGLENOIDS

THEY ARE GREEN OR BROWN AND SWIM WITH THEIR FLAGELLUM.
EASY TO SPOT BECAUSE OF THEIR RED EYE. THEY ARE MICROSCOPIC AND SINGLE CELLED



DIATOMS

THEY LOOK LIKE TWO SHELLS THAT FIT TOGETHER.
THEY ARE MICROSCOPIC AND SINGLE CELLED

Treatment Lagoon pH and Alkalinity

The pH at a treatment lagoon is determined by the various chemical species of alkalinity that are present. The main species present are carbon dioxide (CO_2, bicarbonate ion (HCO_3), and carbonate ion (CO_2^3). Alkalinity and pH can affect which species will be present. High amounts of CO_2 yield a low lagoon pH, while high amounts of CO_2^3 yield a high lagoon pH.

Bacterial growth on BOD releases CO_2 which subsequently dissolves in water to yield carbonic acid (H_2CO_3). This rapidly dissociates to bicarbonate ion, increasing the lagoon alkalinity. Bacterial oxidation of BOD causes a decrease in lagoon pH due to CO_2 release.

Algal growth in lagoons has the opposite effect on lagoon pH, raising the pH due to algal use for growth of inorganic carbon (CO_2 and HCO_3). Algal growth reduces the lagoon alkalinity which may cause the pH to increase if the lagoon alkalinity (pH buffer capacity) is low.

Algae can grow to such an extent in lagoons (a bloom) that they consume all of the CO_2 and HCO_3 present for photosynthesis, leaving only carbonate (CO_2^3) as the pH buffering species. This causes the pH of the lagoon to become alkaline. pH values of 9.5 or greater are common in lagoons during algal blooms, which can lead to lagoon effluent pH violations (in most states this is pH = 9). It should be noted that an increase in the lagoon pH caused by algal growth can be beneficial. Natural disinfection of pathogens is enhanced at higher pH.

Phosphorus removal by natural chemical precipitation is greatly enhanced at pH values greater than pH = 8.5. In addition, ammonia stripping to the atmosphere is enhanced at higher pH values (NH_3 is strippable, not NH_4+).

Protozoans and Microinvertebrates Life

Many higher life forms (animals) develop in lagoons. These include protozoans and microinvertebrates such as rotifers, daphnia, annelids, chironomids (midge larvae), and mosquito larvae (often termed the zooplankton). These organisms play a role in waste purification by feeding on bacteria and algae and promoting flocculation and settling of particulate material.

Protozoans are the most common higher life forms in lagoons with about 250 species identified in lagoons to date (Curds, 1992). Rotifers and daphnia are particularly important in controlling algal overgrowth and these often "bloom" when algal concentrations are high. These microinvertebrates are relatively slow growing and generally only occur in systems with a detention time of >10 days. Mosquitoes grow in lagoons where shoreline vegetation is not removed, possibly causing a nuisance and public health problem.

Culex tarsalis, mosquito, the vector of Western Equine Encephalitis in the western U.S., grows well in wastewater lagoons (USEPA, 1983). The requirement for a minimum lagoon bank slope and removal of shoreline vegetation by most regulatory agencies is based on the public health need to reduce mosquito vectors.

Splitting the Sample We will cover this area in detail in the Laboratory Procedures (Process Control Section).

This operator is splitting the sample for bacteriological analysis. Every operator who works with A/S will need to take process samples and run analysis or process control. In an 8 hour day, you may run as many as 6-8 tests. Always wear gloves and eyewear for yours and others' safety.

Safety Commentary

We have all seen the operator who holds a sandwich in one hand while working in the lab, or the operator does not wear gloves at all. How about the operator who smokes a cigarette or eat while sampling. Somehow, we become ignorant of the dangers of raw sewage. I have had some terrible wastewater experiences, and so might you.

Somehow, we adjust to not wearing proper PPE and forget that this career is all about disease and disease prevention. I hope that you recognize these dangers and implement full PPE measures. The full contact with raw sewage will kill you either now or in the future and you will not see it coming. Most operators end up with some chronic condition related to sewage and cannot seem to connect the exposure to the disease.

Know how to protect yourself and be careful. Obtain your hepatitis inoculations, wear PPE, and do not freak out with a spill or mishap. Always be prepared for the worst. Bring extra clothes to work and soap too. Document all exposures.

Topic 3 Secondary Treatment Section Post Quiz

1. Many bacterial species that degrade wastes grow as single bacteria dispersed in the wastewater. Although these readily oxidize _____, they do not settle and hence often leave the system in the effluent as solids (TSS).

2. Most _____bacteria have a wide range in environmental tolerance and can function effectively in BOD removal over a wide range in pH and temperature.

3. _____removal generally proceeds well from pH 6.5 to 9.0 and at temperatures from 3-4^{o}C to 60-70°C (mesophilic bacteria are replaced by thermophilic bacteria at temperatures above 35°C). BOD removal generally declines rapidly below 3-4°C and ceases at 1-2°C.

4. There are several oxidation ditch designs that can remove_____.

5. An oxidation ditch is a modified activated sludge biological treatment process that utilizes long solids retention times (SRTs) to remove_____.

6. Oxidation ditches are typically_____, but they can be modified to approach plug flow conditions.

7. The rotating biological contactor (RBC) is a fixed film biological secondary treatment device. The basic process is similar to that occurring in the_____.

8. _____formation involves three different groups of anaerobic bacteria that function together to convert organic materials to methane via a three-step process.

9. Nitrifying bacteria are also more sensitive to DO levels as compared to aerobic_____, with growth rates starting to decline below 3 to 4 mg/L with significant reduction below 2 mg/L.

10. Wet weather events can increase inflow and infiltration into the collection system and subsequently increase the hydraulic load to the wastewater treatment plant. This can in turn reduce the _____to reduced performance of nitrification process units.

11. Land application of _____can supplement and may reduce fertilizer use. Land application results in the storage of carbon in the soil, thereby minimizing greenhouse gas (GHG) emissions to the atmosphere.

12. The concentration of phosphorus in the sludge typically increases as the SRT increases, although the impact is very small over the SRT range of _____.

13. High temperatures can have an adverse effect on _____removal.

14. Secondary release of phosphorus occurs when the PAOs are under _____in the absence of a source of VFA.

15. _____will also lead to phosphorus release although some phosphorus will be precipitated as either a metal salt (e.g. calcium phosphate) or as struvite (magnesium ammonium phosphate, $MgNH_4PO_4$).

Topic 4 - Activated Sludge Process Section

Topic 4 - Section Focus: You will learn the basics of the activated sludge process. At the end of this section, you the student will be able to understand and describe the activated sludge process and various treatment methods. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Topic 4 – Scope/Background: Activated sludge (A/S) is a term used both to refer to a widely utilized wastewater treatment process, and to the solid compounds which result from that process. The activated sludge technique is one of the most commonly used methods for handling human waste in municipal settings around the world, and it can also be employed in the treatment of industrial wastewater. The goal is to remove as much solid organic material from the wastewater as possible, to facilitate further stages in the water treatment.

ACTIVATED SLUDGE

The **activated sludge** process is a process for treating sewage and industrial wastewaters using air and a biological floc composed of bacteria and protozoa.

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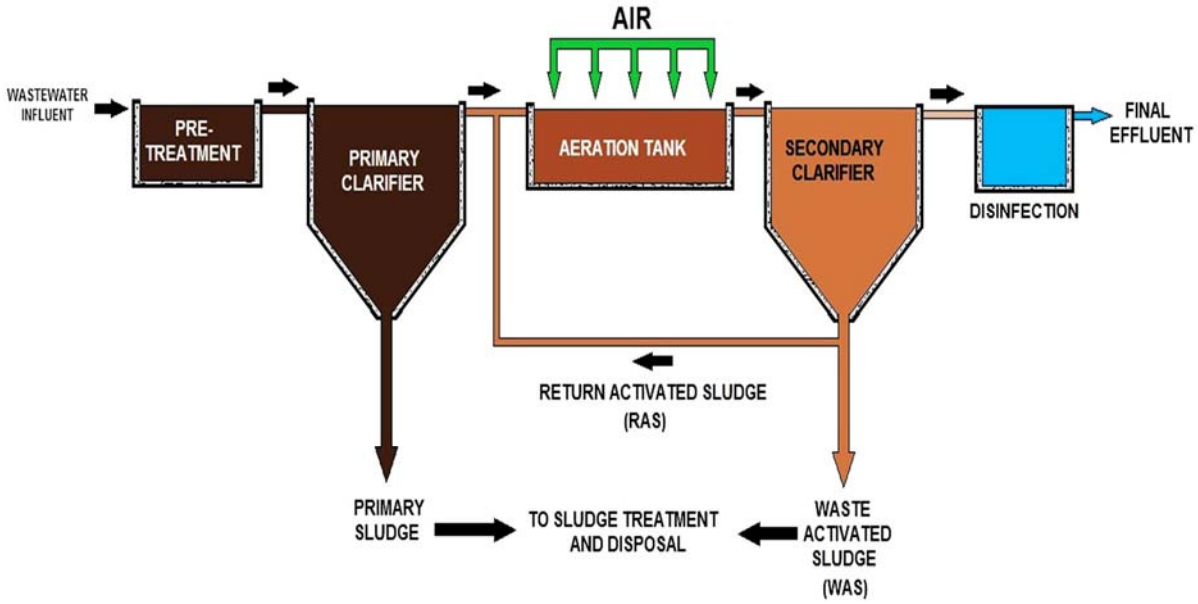

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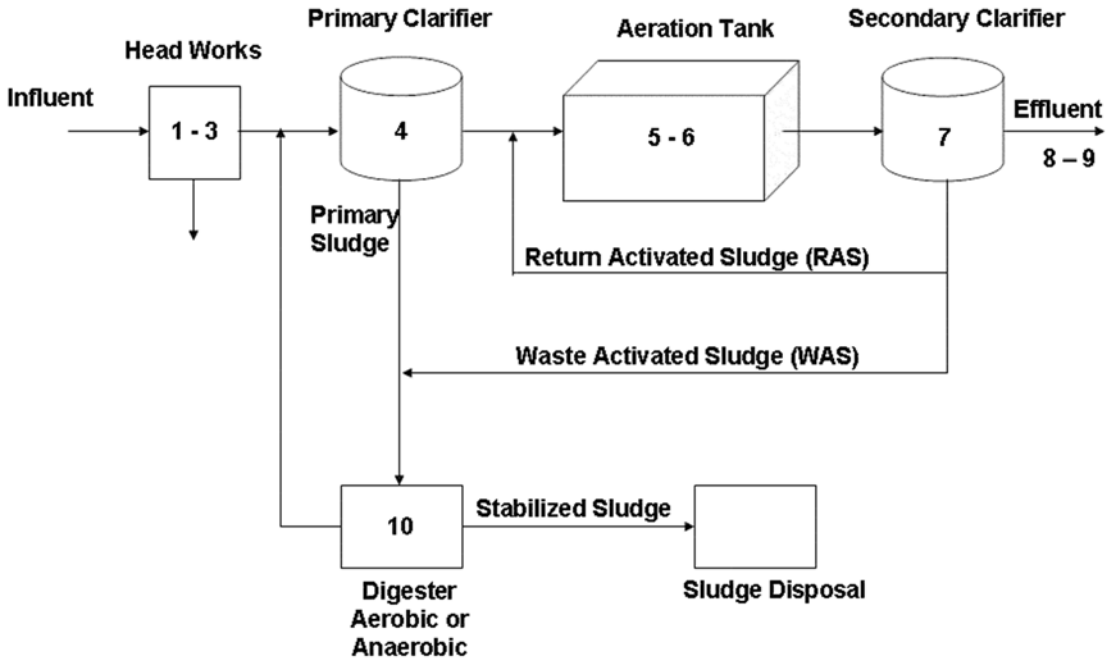
ACTIVATED SLUDGE WASTEWATER TREATMENT FLOW DIAGRAM

Sludge Section Illustrative Boxes 5-7



Aeration Basins: Large aeration basins or tanks mix the partially treated *wastewater* with oxygen to support bacteria that devour organic waste. The bacteria levels are managed to provide the most efficient removal process.

Return Activated Sludge (RAS) brings sludge back to the aeration process for further treatment while Waste Activated Sludge (WAS) removes the excess or older sludge.

ACTIVATED SLUDGE

The **activated sludge** process is a process for treating sewage and industrial wastewaters using air and a biological floc composed of bacteria and protozoa.

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Introduction to Activated Sludge (A/S)

The Activated Sludge Process is an aerobic biological waste *water treatment* process that uses microorganisms, including bacteria, fungi, and protozoa, to speed up decomposition of organic matter requiring oxygen for treatment. In this activated sludge process, microorganisms are thoroughly mixed with organics under conditions that stimulate their growth and waste materials are removed.

As the microorganisms grow and are mixed by the agitation of the air, the individual microorganisms clump (or *flocculate)* together to form a mass of microbes called ***activated sludge.***

In short, the activated sludge (A/S) process takes advantage of aerobic microorganisms or populations that can digest organic matter in wastewater, and clump together by flocculation as they do so. This action produces a liquid that is relatively free from suspended solids and organic material, and flocculated particles that will readily settle out and can be removed. We will cover all these details later in the course manual.

Generally speaking, the arrangement of a conventional activated sludge process for removing carbonaceous pollution includes the following items:

- Aeration tank where air (or oxygen) is injected in the mixed liquor.
- Settling tank (usually referred to as "final clarifier" or "secondary settling tank") to allow the biological flocs (the sludge blanket) to settle, thus separating the biological sludge from the clear treated water.
- Sometimes activated sludge is used to feed Return Activated Waste bugs to various tanks, BNR processes, fixed-film filters, lagoons and Oxidation ditches. There are times that A/S bugs will be transported to another plant for maintenance or start-ups.

Nitrogenous matter or phosphate treatment involves additional steps where the mixed liquor is left with no residual dissolved oxygen.

YOUNG SLUDGE

Young sludge consists of wastewater sludge which has not yet reached a high enough sludge age to be most effective in a particular activated sludge process. Billowing whitish foam is an indicator that the sludge age is too low. Young sludge will often have poor settling characteristics in the clarifier, and can leave straggler floc in the clarifier effluent. Young sludge is often associated with a high F/M. To correct for young sludge, it is necessary to decrease wasting rates. This will increase the amount of solids under aeration, reduce the F/M ratio, and increase the sludge age.

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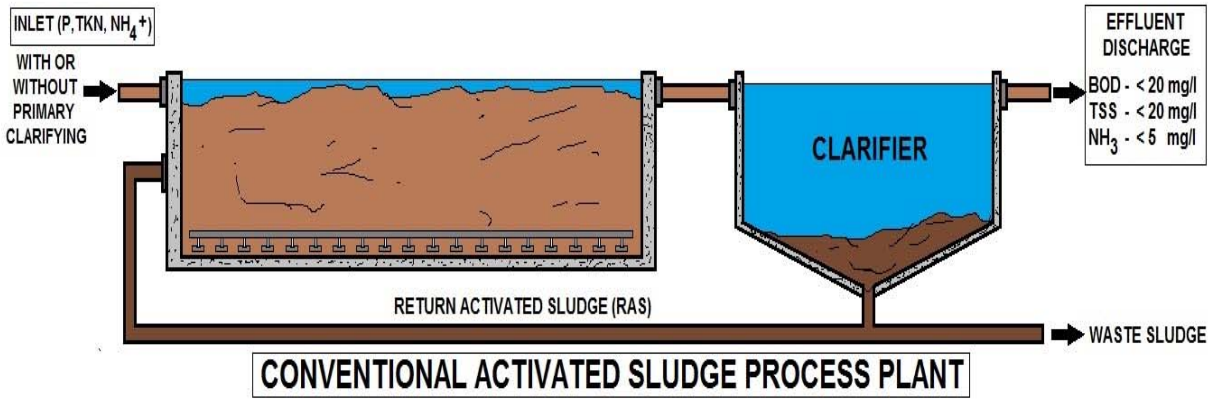
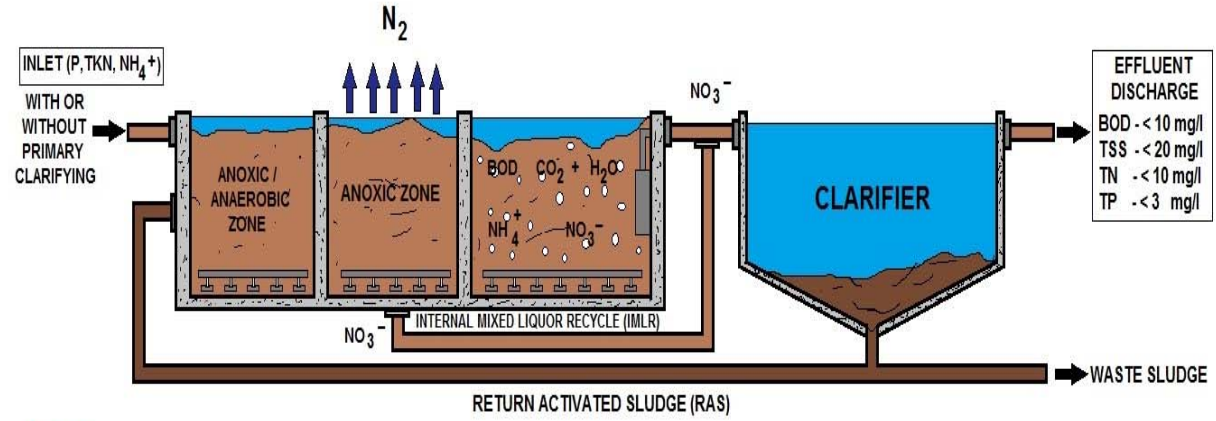


CONVENTIONAL ACTIVATED SLUDGE PROCESS PLANT



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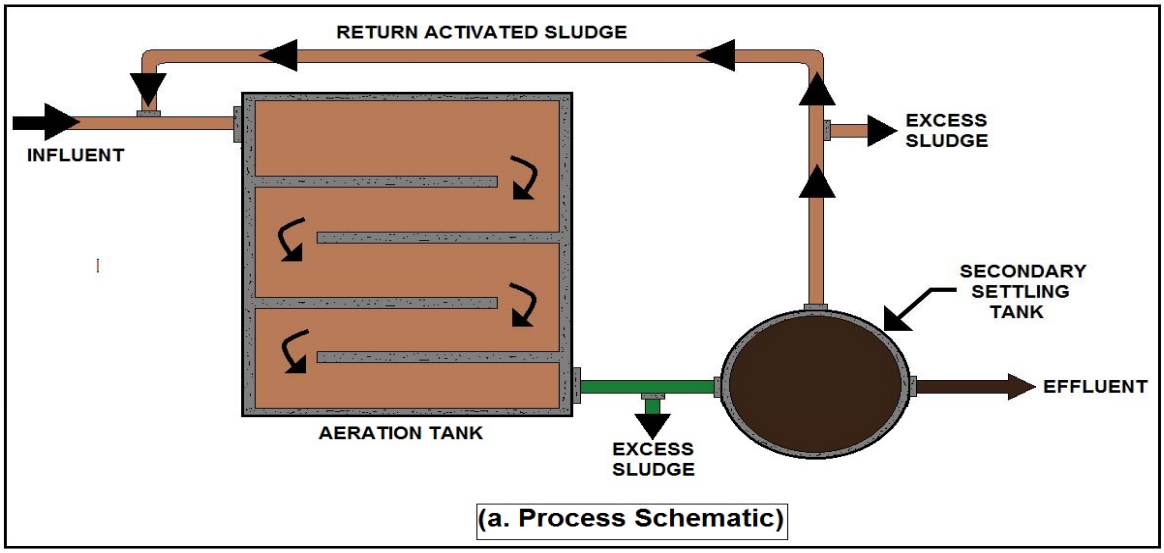
INTEGRATED FIXED-FILM ACTIVATED SLUDGE PROCESS (IFAS) PLANT

Basic A/S Process Overview



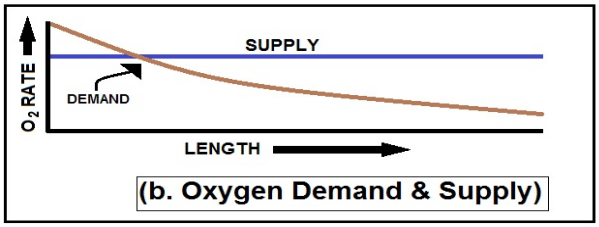


DIAGRAM OF CONVENTIONAL ACTIVATED SLUDGE PROCESS

Activated sludge (A/S) is a biological process that utilizes microorganisms to convert organic and certain inorganic matter from wastewater into cell mass. The activated sludge is separated from the liquid by clarification.

The settled sludge is either returned, returned activated sludge (RAS) or wasted, waste activated sludge (WAS). Sometimes, the RAS is sent to a lagoon or oxidation ditch or relate process to digest food within that process.

A basic activated sludge process consists of several interrelated components:

- An aeration tank where the biological reactions occur
- An aeration source that provides oxygen and mixing
- A tank, known as the clarifier, where the solids settle and are separated from treated wastewater
- A means of collecting the solids either to return them to the aeration tank, (return activated sludge [RAS]), or to remove them from the process (waste activated sludge [WAS]).

Aerobic bacteria thrive as they travel through the aeration tank. They multiply rapidly with sufficient food and oxygen. By the time the waste reaches the end of the tank (between four to eight hours), the bacteria has used most of the organic matter to produce new cells.

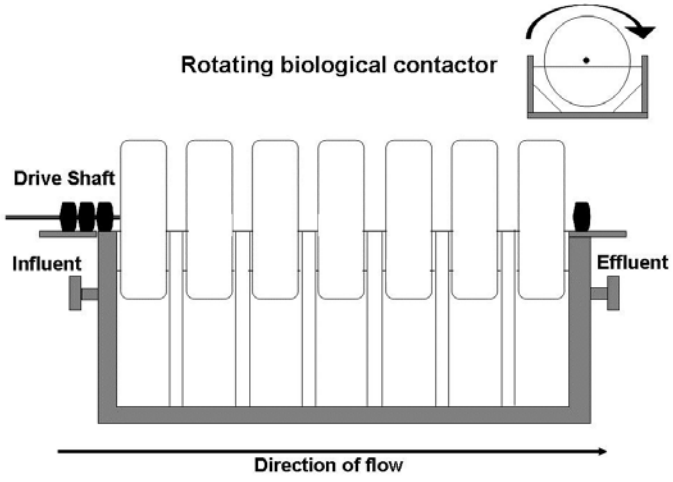
Final Clarifier Operation
The process involves oxygen or air being introduced into a mixture of screened, and primary treated wastewater combined with organisms to develop a biological floc that reduces the organic content of the sewage. Return activated sludge (RAS) comes from this or similar clarifiers. The purpose of the final clarifier is to separate the activated sludge, the biological floc, from the treated water. The floc will settle to form sludge that will be returned to the process or wasted for sludge conditioning.

Mixed Liquor and Microorganisms
This substance (MLSS) in healthy sludge is a brown floc, is largely composed of saprotrophic bacteria but also has an important protozoan flora component mainly composed of amoebae, Spirotrichs, Peritrichs including Vorticellids and a range of other filter-feeding species. Other important organisms include motile and sedentary Rotifers.

In poorly managed activated sludge, a range of mucilaginous filamentous bacteria can develop including *Sphaerotilus natans* which produces a sludge that is difficult to settle and can result in the sludge blanket decanting over the weirs in the settlement tank to severely contaminate the final effluent quality.

In all activated sludge plants, once the wastewater has received sufficient treatment, excess mixed liquor is collected into settling tanks and the treated supernatant is run off to undergo further treatment before discharge. Part of the settled sludge material, is returned to the head of the aeration system to re-seed the new wastewater entering the tank. This fraction of the floc is called *return activated sludge* (R.A.S.).

Bioreactor RBC
The operational treatment space required for a wastewater treatment plant can be reduced by using a membrane bioreactor to remove some wastewater from the mixed liquor prior to treatment. This results in a more concentrated waste product that can then be treated using the activated sludge process.



Sludge Cultivation – RAS and WAS
Active biological material produced by activated sludge plants is called activated sludge.

Excess sludge is either called "return activated sludge" or "waste activated sludge" and is removed from the treatment process to keep the ratio of biomass to food supplied in the wastewater in balance.

This sludge is usually mixed with primary sludge from the primary clarifiers and undergoes further sludge treatment for example by anaerobic digestion, followed by thickening, dewatering, composting and land application.

We will cover all of these processes in detail later in the course.

PROCESS TYPE	FLOW REGIME	MLSS (mg/l)	MLVSS / MLSS	F/M (kg BOD 5 days kg MLVSS)	HRT 0 (hrs.)	VOLUMETRIC ORGANIC LOADING (kg BOD 5days m3)	MCRT 0 (days)	Qr / Q r=	BOD REMOVAL (%)	kgO_2 per kg BOD_5 REMOVAL	AIR REQUIRED PER kg BOD_5 (m^3)
1. CONVENTIONAL	PLUG	1500 - 3000	0.8	0.2 - 0.4	4 -8	0.3 - 0.6	5 - 15	0.25 - 0.5	85 -95	0.8 - 1.1	40 - 100
2. TAPERED AERATION	PLUG	1500 - 3000	0.8	0.2 - 0.4	4 -8	0.3 - 0.6	5 - 15	0.25 - 0.5	85 -95	0.7 - 1.0	50 -75
3. STEP AERATION	PLUG	2000 - 3500	0.8	0.2 - 0.4	3.5	0.6 - 1.0	5 - 15	0.25 - 0.75	85 -95	0.7 - 1.0	50 -75
4. CONTACT STABILIZATION	PLUG	1000 - 3000 * 4000 - 10000 **	0.8	0.2 - 0.6	0.5 - 1.0* 3 - 6**	1.0 - 1.2	5 - 15	0.25 - 1.0	80 - 90	0.7 - 1.0	50 -75
5. COMPLETE MIX	COMPLETE MIX	3000 - 6000	0.8	0.2 - 0.6	3 - 5	0.8 - 2.0	5 - 15	0.25 - 1.0	85 -95	0.7 - 1.0	50 -75
6. MODIFIED AERATION	PLUG	200 - 500	0.8	1.5 - 5.0	1.5 - 3	1.2 - 2.4	0.2 - 0.5	0.05 - 0.15	60 -75	0.4 - 0.6	25 - 50
7. EXTENDED AERATION	COMPLETE MIX	3000 - 6000	0.6	0.05 - 0.15	18 - 36	0.1 - 0.4	20 - 30	0.75 - 1.5	95 - 98	1.0 - 1.2	100 - 125

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DESIGN AND CHARACTERISTIC PARAMETERS OF AN ACTIVATED SLUDGE PROCESS

RAW INFLUENT (WASTEWATER)
BAR SCREEN
GRIT CHAMBER
PRIMARY CLARIFIER
PRIMARY EFFLUENT
CONVENTIONAL ACTIVATED SLUDGE TANK (CAS)
SECONDARY CLARIFIER
SECONDARY EFFLUENT
SAND FILTER
TERTIARY EFFLUENT
CLEANED WATER OUTLET
PRIMARY SLUDGE
SECONDARY SLUDGE
DIGESTION TANK
GAS HOLDING TANK
STORED GAS USED TO POWER EQUIPMENT (i.e.: METHANE)
SLUDGE STORAGE TANK
CENTRIFUGE
SLUDGE DISPOSAL (LANDFILL)
DIAGRAM OF TYPICAL WASTEWATER TREATMENT
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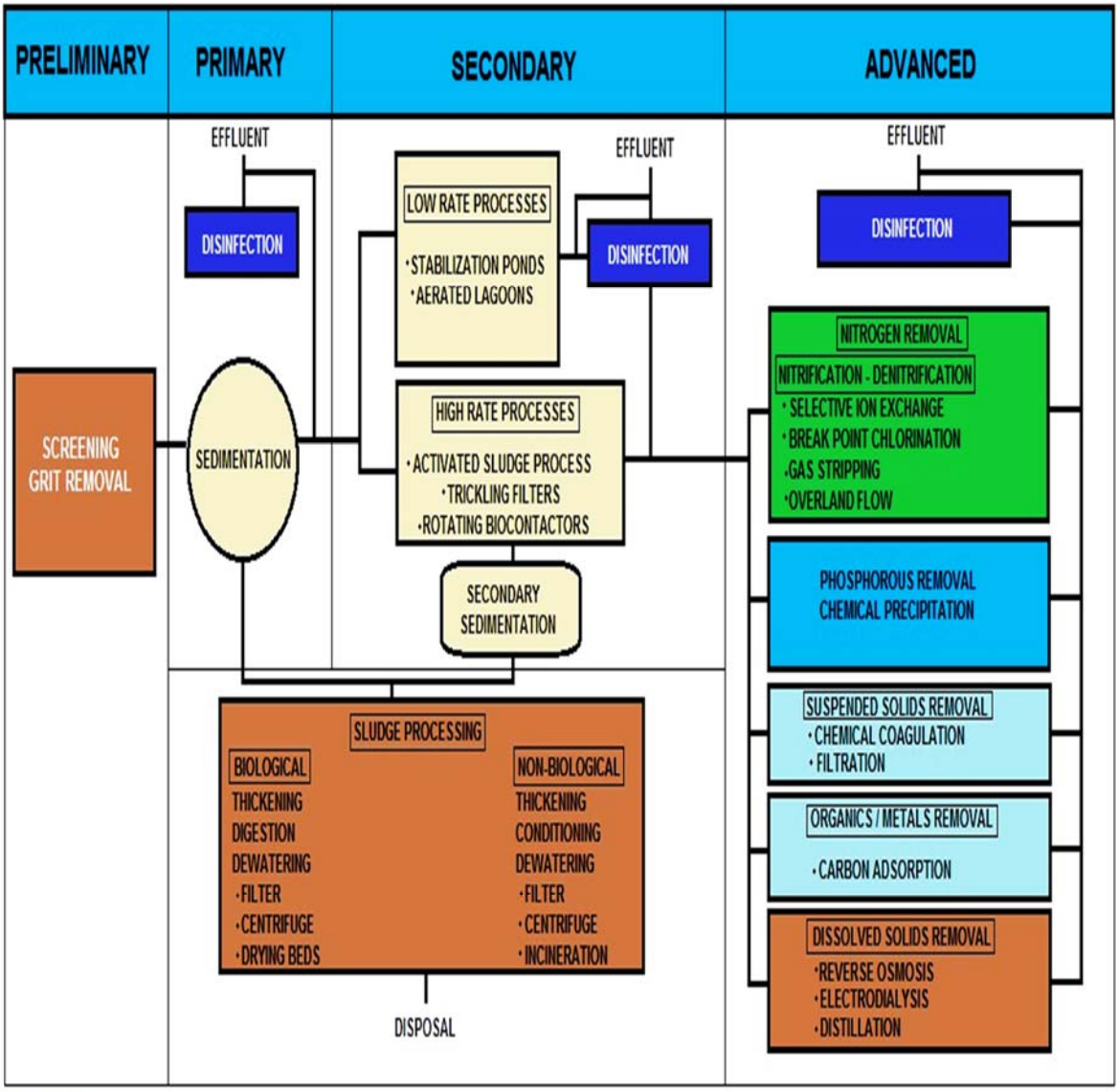

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SLUDGE PROCESSING FLOW DIAGRAM

This diagram is not conclusive. There are so many various methods and processes that are interchangable. Another problems is the lingo. Some operators call processes by different names in different areas. We will try to call methods and processes by the EPA's terminology. Generally speaking, many of the secondary processes utilize some form of A/S bugs.

Desired Finished Effluent

Activated Sludge facilities are designed based upon the characteristics of the wastewater being treated and the desired finished effluent quality.

The chart on the following page lists the quality of the influent for seven types of biological treatment and what to expect for removal of BOD based on retention time. the secondary treatment stage involves adding seed sludge to the wastewater to ensure that is broken down further.

Air is first pumped into huge aeration tanks which mix the wastewater with the seed sludge which is basically small amount of sludge, which fuels the growth of bacteria that uses oxygen and the growth of other small microorganisms that consume the remaining organic matter. This process leads to the production of large particles that settle down at the bottom of the huge tanks. The wastewater passes through the large tanks for a period of 3-6 hours.

DESCRIPTION OF FOAM	CAUSE(S)
WHITE TO GRAY, A THIN FOAM	LOW CELL RESIDENCE TIME (VERY YOUNG SLUDGE)
WHITE, FROTHY BILLOWING KIND OF FOAM	NON-BIODEGRADABLE DETERGENTS START-UP FOAM USUALLY SEEN WITH LOW ACTIVE BIOMASS AND HIGH F/M
PUMIC-LIKE, GREY ASHY TYPE OF FOAM	EXCESSSIVE RECYLING FROM DIGESTERS AND PRESSES, THEREFORE LEADING TO BUILDUP OF "FINES"
THICK SLUDGE BLANKET FLOATING IN FINAL CLARIFIER. SLUDGE RELEASES SMALL BUBBLES.	DENITRIFICATION; SLUDGE BLANKET BEEN KEPT TO LONG IN CLARIFIER, WHERE SLUDGE HAS NITRATE PRESENT
THICK, SLIMY TYPE OF FOAM (GREY to BROWN)	NUTRIENT DEFICIENCY CAUSE EXCESS POLYSACCHARIDE PRODUCTION IN FOAM. CAN BE EASILY DIAGNOSED WITH INDIA INK STAIN
THICK, BROWN COLOR, STABLE FOAM (With Filaments)	FILAMENT INDUCED FOAMING CAUSED BY NOCARDIA, MICROTHRIS PARVACELLA, OR TYPE 1863
FLOATING BROWN SCUM BUILDUP IN CLARIFIERS. FOAM HAS BROWN TO BLACK COLOR STREAKS	CAUSE BY OIL AND GREASES

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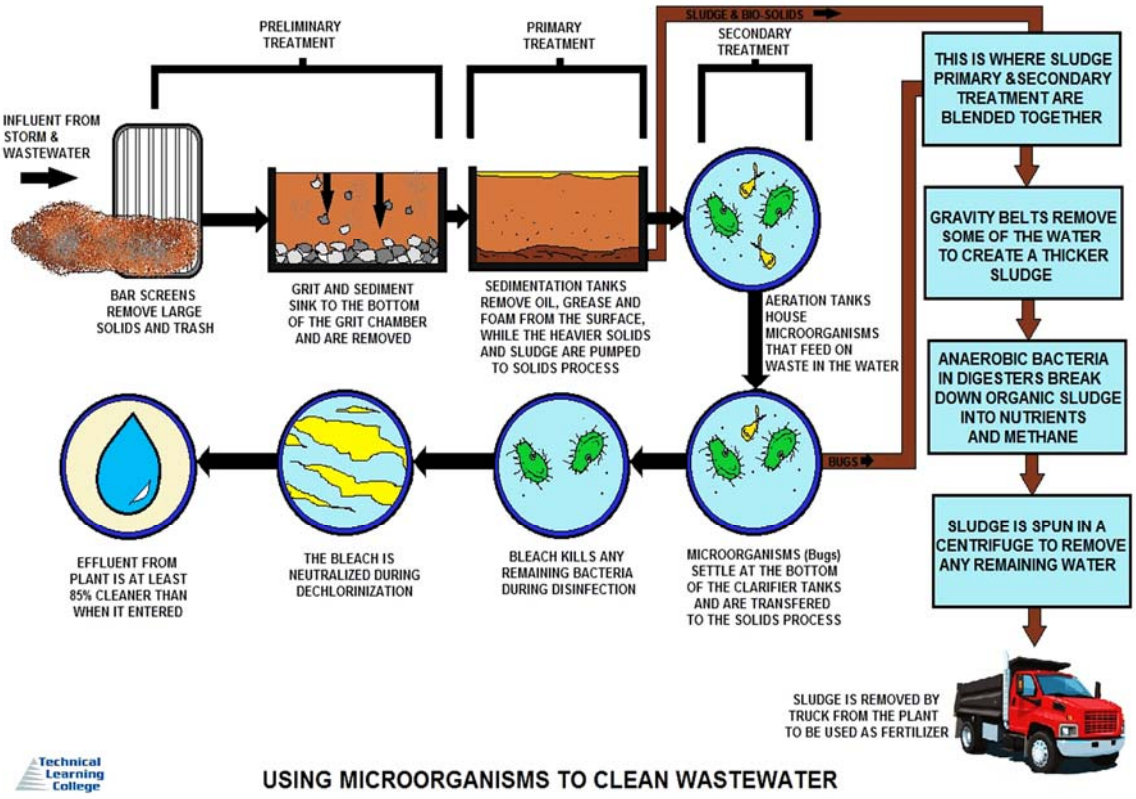
JUDGING FOAM AND CAUSES IN WASTEWATER PROCESS

Bug Introduction



Anaerobic Bacteria

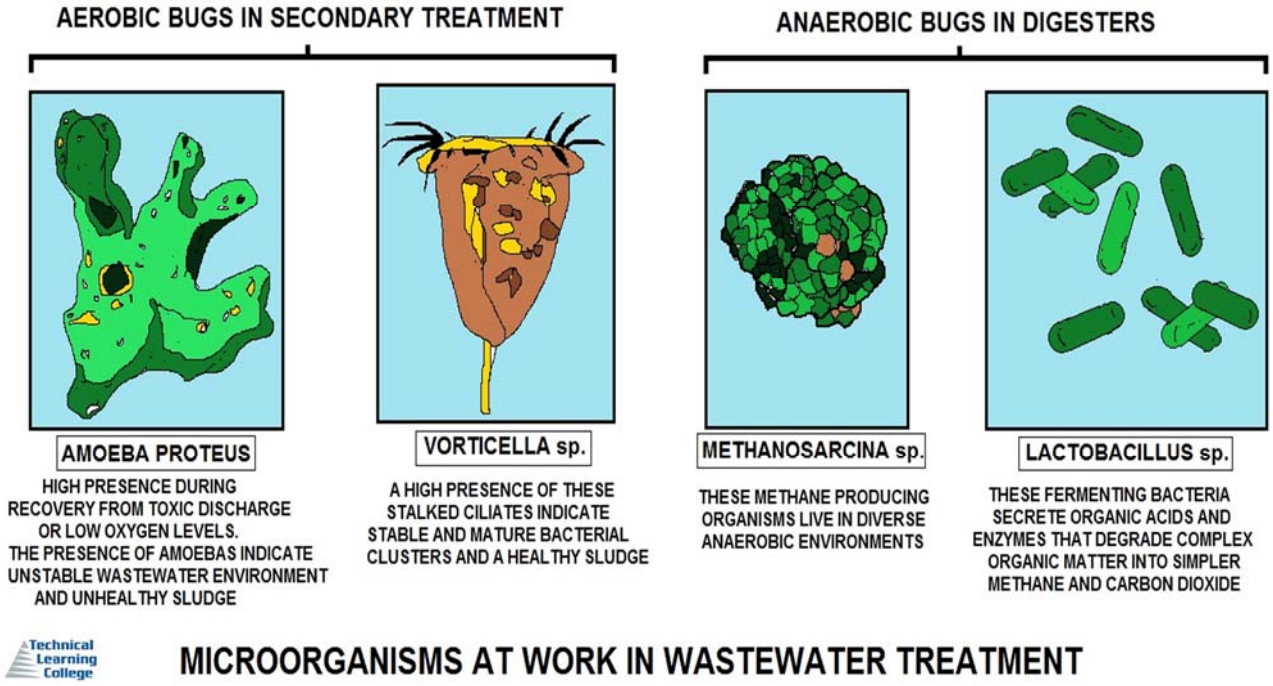
Anaerobic bacteria are used in wastewater treatment on a normal basis. The main role of these bacteria in sewage treatment is to reduce the volume of sludge and produce methane gas from it.

The great thing about this type of bacteria and why it's used more frequently than aerobic bacteria is that the methane gas, if cleaned and handled properly, can be used as an alternative energy source. This is a huge benefit considering the already high wastewater treatment energy consumption levels.

Unlike aerobic bacteria, these anaerobic bacteria are able to get more than enough energy from its food source by fermentation and do not require adding oxygen to help do its job. These highly designed creatures may react negatively or even die if free oxygen is present. Phosphorus removal from wastewater is another benefit of anaerobic microbes used in sewage treatment.

Facultative Microorganisms

Facultative microorganisms in sewage treatment are bacteria that can change between aerobic and anaerobic depending on the environment they are in. Note that these bacteria normally prefer to be in an aerobic condition.



Major Groups of Microorganisms

Five significant groups of wastewater microorganisms are in the aeration basin of the activated sludge process; they are:

Algae and fungi – present with pH changes and older sludge

Metazoa – dominate more extended age systems, including lagoons

Bacteria – primarily responsible for removing organic nutrients from wastewater

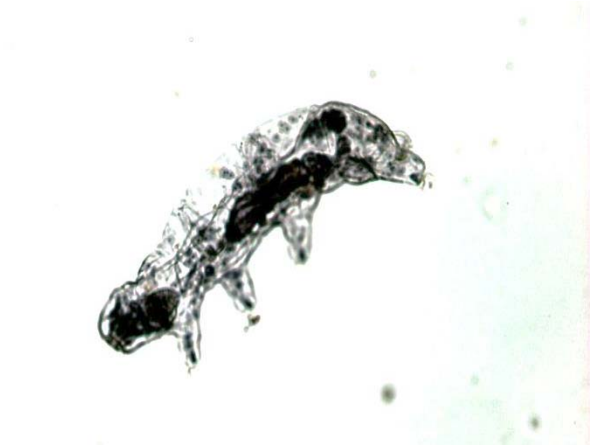
Protozoa – a critical role in wastewater treatment, these microorganisms remove and digest free-swimming dispersed bacteria and other suspended particles. They also improve the clarity of wastewater effluent. Like bacteria, some require very little oxygen while others need oxygen to survive. Some protozoa can even survive without oxygen.

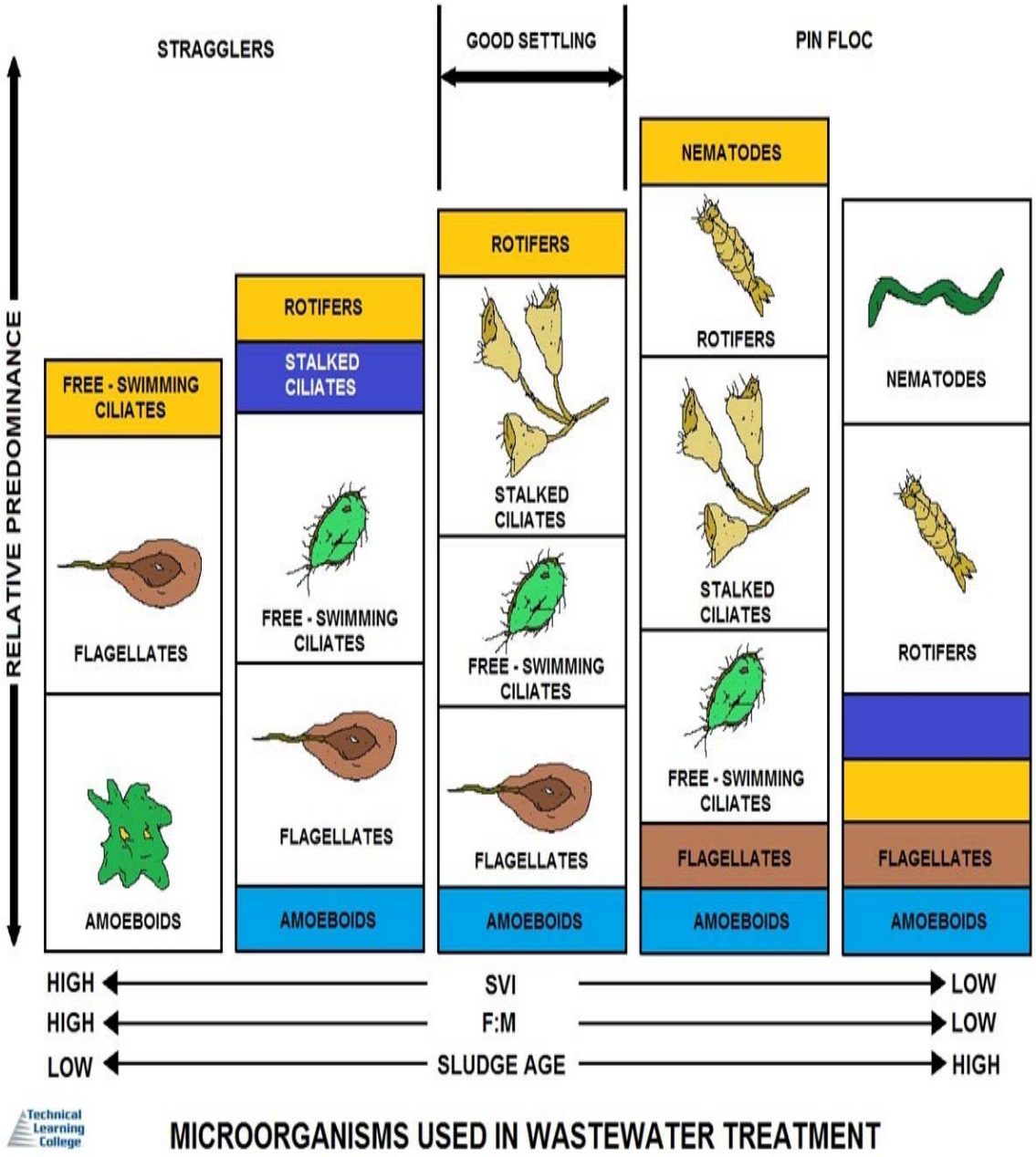
Filamentous bacteria – normal components of activated sludge biomass. The existence of some filamentous bacteria is important and helpful for good floc formation to a biomass. Since filamentous bacteria grow in long thread-like strands, cells do not separate from each other after cell division and therefore grow in the form of filaments. They then connect with each other to form a mesh, which is the most important part in floc formation and causes the separation of a fluid or removal of sediment from a fluid.

Water Bear Tardigrade

This creepy "water bear" has forced scientists to reconsider their definition of what's "alive." When unable to find water, this insect like critter (which is the size of a grain of sand) stops moving, breathing, and eating. Even its cells shut down. Dead as a doornail, right? Wrong! Add water and the critter springs back to life. Scientists have exposed dried-up water bears to extreme heat, bitter cold, and even massive doses of radiation -- and the teeny animals still revived.

The key to the critters' survival may be a sugar they produce as they dry out. By coating structures inside and between the critters' cells, the sugar keeps the cells from sticking together and breaking. When water is added, the sugar dissolves -- and the creepy crawlies burst back into action.




STRAGGLERS
GOOD SETTLING
PIN FLOC
RELATIVE PREDOMINANCE
FREE - SWIMMING CILIATES
FLAGELLATES
AMOEBOIDS
ROTIFERS
STALKED CILIATES
FREE - SWIMMING CILIATES
FLAGELLATES
AMOEBOIDS
ROTIFERS
STALKED CILIATES
FREE - SWIMMING CILIATES
FLAGELLATES
AMOEBOIDS
NEMATODES
ROTIFERS
STALKED CILIATES
FREE - SWIMMING CILIATES
FLAGELLATES
AMOEBOIDS
NEMATODES
ROTIFERS
FLAGELLATES
AMOEBOIDS
HIGH SVI LOW
HIGH F:M LOW
LOW SLUDGE AGE HIGH
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MICROORGANISMS USED IN WASTEWATER TREATMENT

System Components of Activated Sludge

In the basic "activated" sludge process, emphasis on *activated*, the wastewater enters an aerated tank (the dome) where previously developed biological floc particles are brought into contact with the organic matter (foot-long hot dogs) of the wastewater.

The organic matter is a carbon and an energy source for the bug's cell growth and is converted into cell tissue. The oxidized end product is mainly carbon dioxide, CO_2. The substance in the sports dome is referred to as mixed liquor. The stuff in the mixed liquor is suspended solids and consists mostly of microorganisms, suspended matter, and non-biodegradable suspended matter (*MLVSS*).

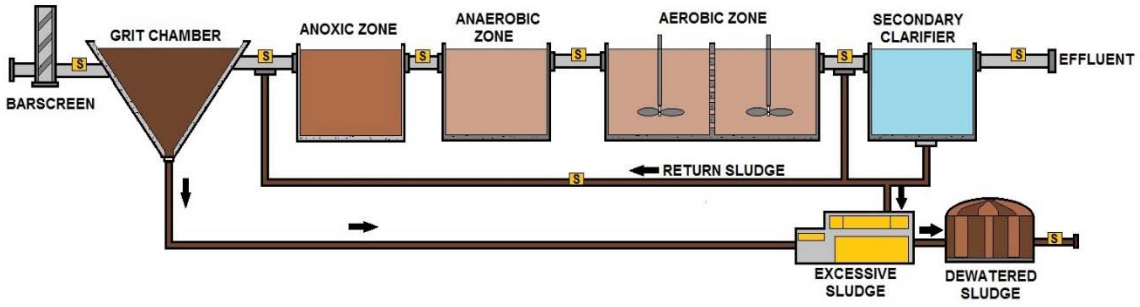
The make-up of the microorganisms is around 70 to 90% organic and 10 to 30% inorganic matter. The makeup of cells varies depending on the chemical composition of the wastewater and the specific characteristics of the organisms in the biological mass. The picture below shows the basic outline of an aeration tank. Just remember that pretreatment is crucial prior to the activated sludge process.

Before we dive into the tank, in the space provided, list three key components of pretreatment (headworks) and how each benefits the process.

1.

2.

3.



BASIC WASTEWATER TREATMENT PLANT AND SAMPLING POINTS

Mixed Liquor

Back to the mixed liquor, as it leaves the aeration tank, it usually goes to a clarifier to separate the suspended solids (SS) from the treated wastewater. The concentrated biological solids are then recycled back to the aeration tank, as returned activated sludge (RAS), to maintain a concentrated population of bugs (the team players) to treat the wastewater. *More on this in the Laboratory Produce Section in the rear of the book.*

Before we start the game, we need to make sure we have a stadium and all components are in place and operating properly. In the space provided, define the following terms:

See Glossary in Rear.

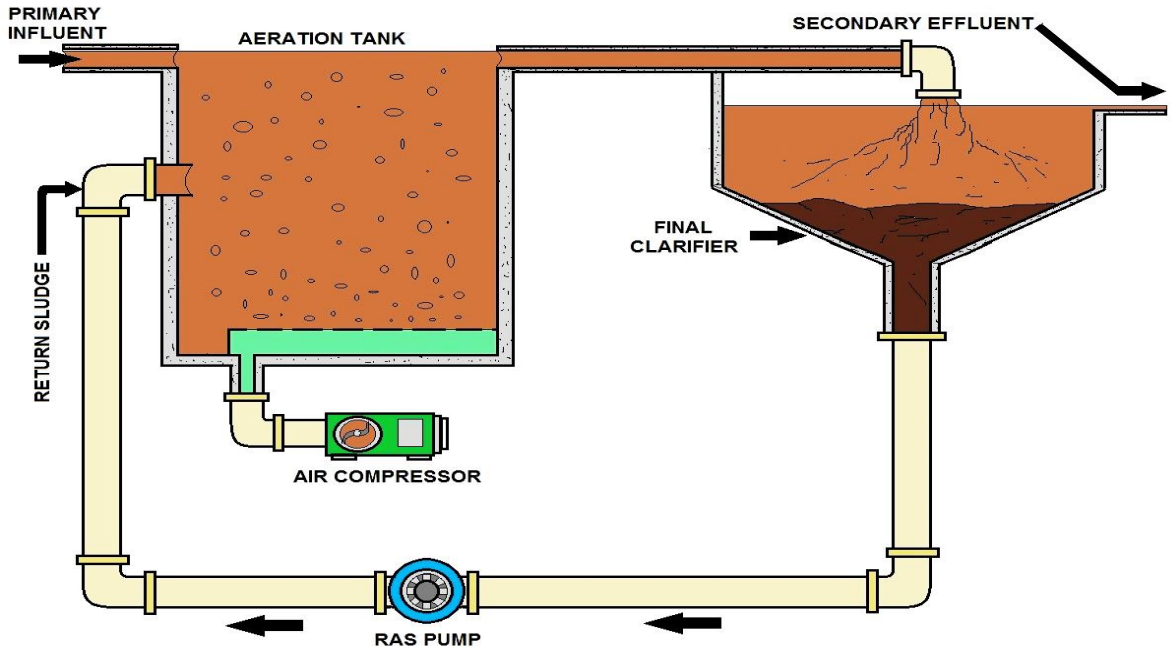
Anaerobic:

Aerobic:

DO:

BOD:

COD:



ACTIVATED SLUDGE PROCESS

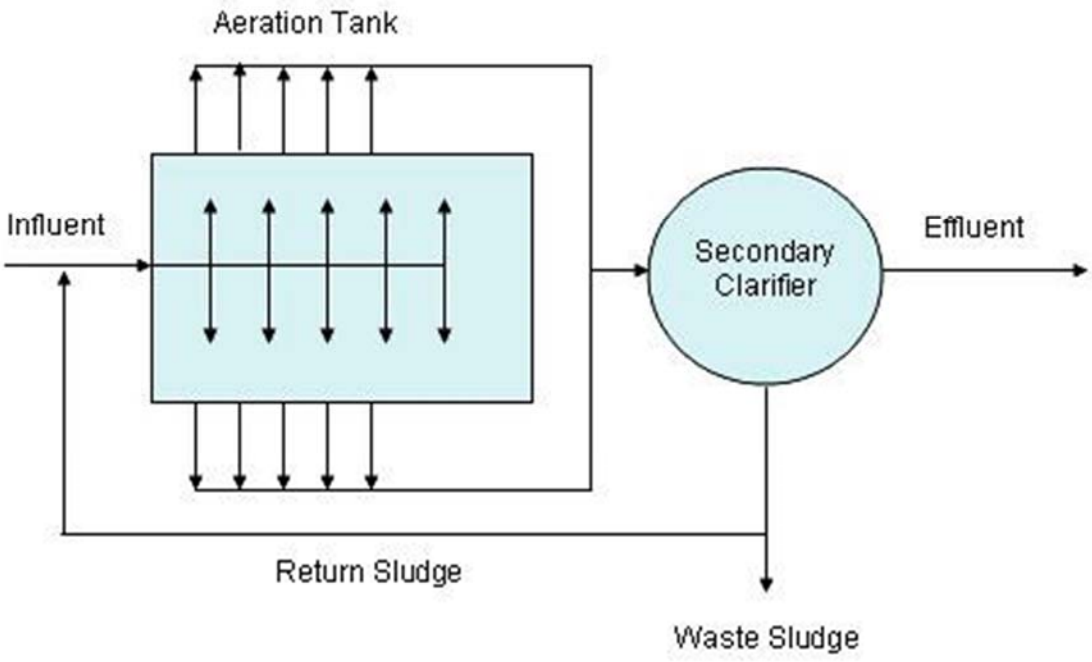
Complete Mix Activated Sludge Process

In a complete mix activated sludge process, the mixed liquor is similar throughout the aeration tank. The operating characteristics measured in terms of solids, oxygen uptake rate (OUR), MLSS, and soluble BOD 5 concentration are identical throughout the tank.

Because the entire tank contents are the same quality as the tank effluent, there is a very low level of food available at any time to a large mass of microorganisms.

This is the major reason why the complete mix modification can handle surges in the organic loading without producing a change in effluent quality. The type of air supply used could be either diffused air or a mechanical aerator.

Complete mix process may be resistant to shock loads but is susceptible to filamentous growths.

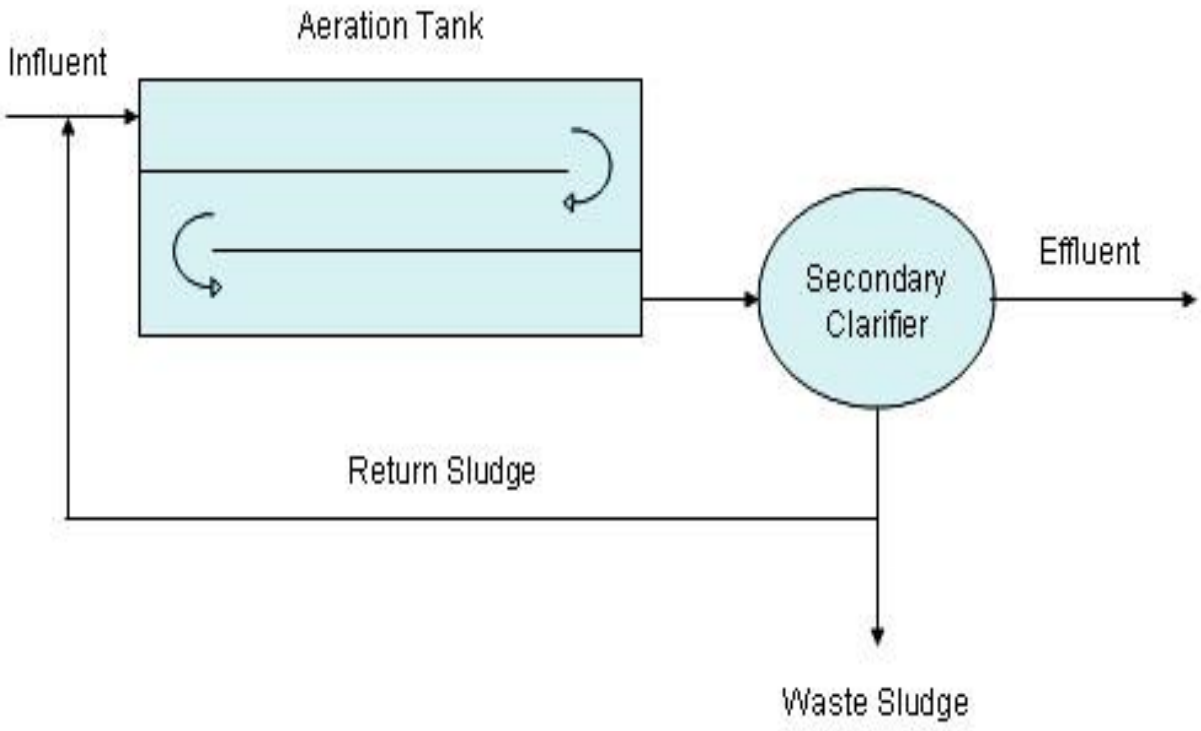


Plug Flow Activated Sludge Process

Plug flow tanks are the oldest and most common form of aeration tank. They were designed to meet the mixing and gas transfer requirements of diffused aeration systems. One characteristic of the plug flow configuration is a very high organic loading on the MLSS in the initial part of the tank. The loading is then reduced and the organic material in the raw wastewater is oxidized.

At the end of the tank, depending on detention time, the oxygen consumption may primarily be the result of endogenous respiration or nitrification, which we will talk more about later on. The same characteristics are present when the aeration tank is partitioned into a series of compartments.

Each compartment must have the oxygen supply and design to meet the individual compartment needs. Plug flow configurations have the ability to avoid **"***bleed through,*" the passage of untreated organics during peak flow. These configurations are often preferred when high effluent DO's are sought because only a small section of the tank will operate at a high DO. In a complete mix configuration, the entire tank must operate at the elevated DO.



Contact Stabilization Activated Sludge Process

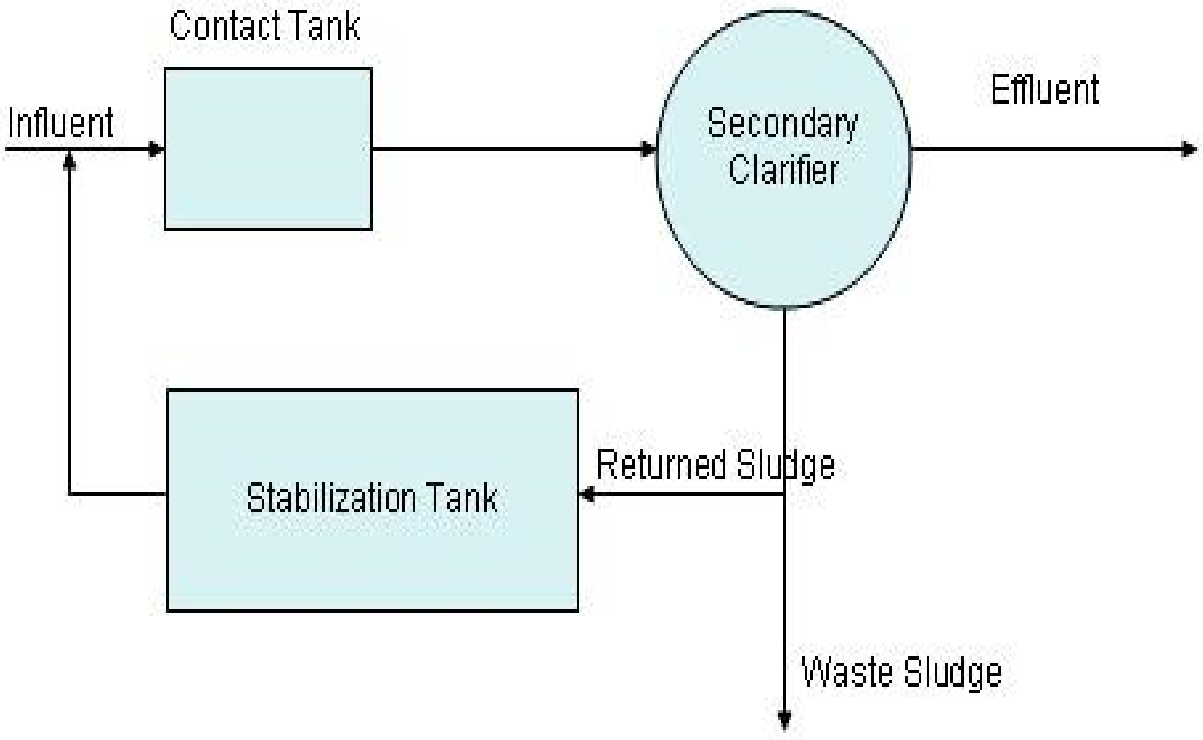
Contact stabilization activated sludge is both a process and a specific tank configuration. The contact stabilization encompasses a short-term contact tank, secondary clarifier, and a sludge stabilization tank with about six times the detention time used in the contact tank.

Contact stabilization is best for smaller flows in which the MCRT desired is quite long.

Therefore, aerating return sludge can reduce tank requirements by as much as 30 to 40 % versus that required in an extended aeration system. The volumes for the contact and stabilization tanks are often equal in size and secondary influent arrangements.

What does this all mean?

They can be operated either in parallel as an extended aeration facility or as a contact stabilization unit. This flexibility makes them suitable for future expansion to conventional activated sludge, without increasing the aeration tank, by merely adding more clarification capacity.



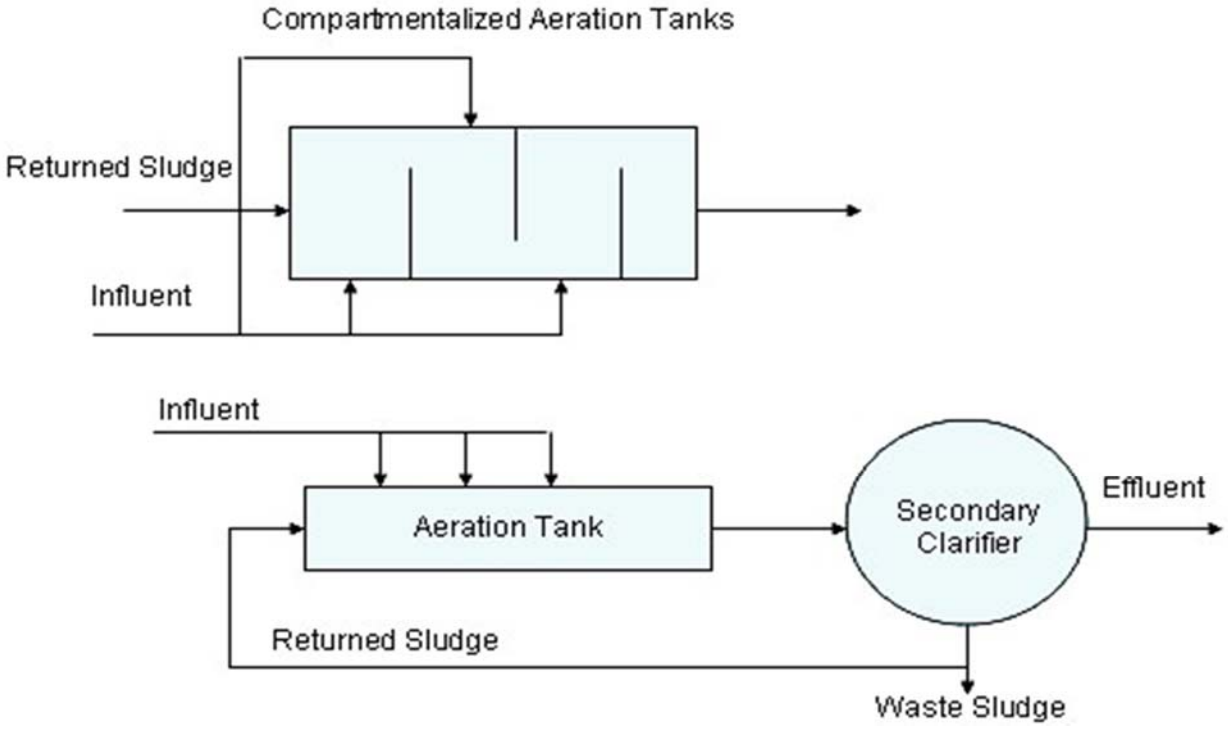
Step Feed Activated Sludge Process

Step feed is a modification of the plug flow configuration in which the secondary influent is fed at two or more points along the length of the aeration tank.

With this arrangement, oxygen uptake requirements are relatively even and the need for tapered aeration is eliminated.

Step feed configurations generally use diffused aeration equipment. The step feed tank may be either the long rectangular or the folded design. Secondary influent flow is added at two or more points to the aeration tank, usually in the first 50 to 75% of the length.

It is also possible to use the same process approach by compartmentalizing the tank and directing flow lengthwise through the compartments. Usually, the last compartment does not receive any raw waste.



Extended Aeration Activated Sludge Process

The extended aeration process uses the same flow scheme as the complete mix or plug flow processes but retains the wastewater in the aeration tank for 18 hours or more.

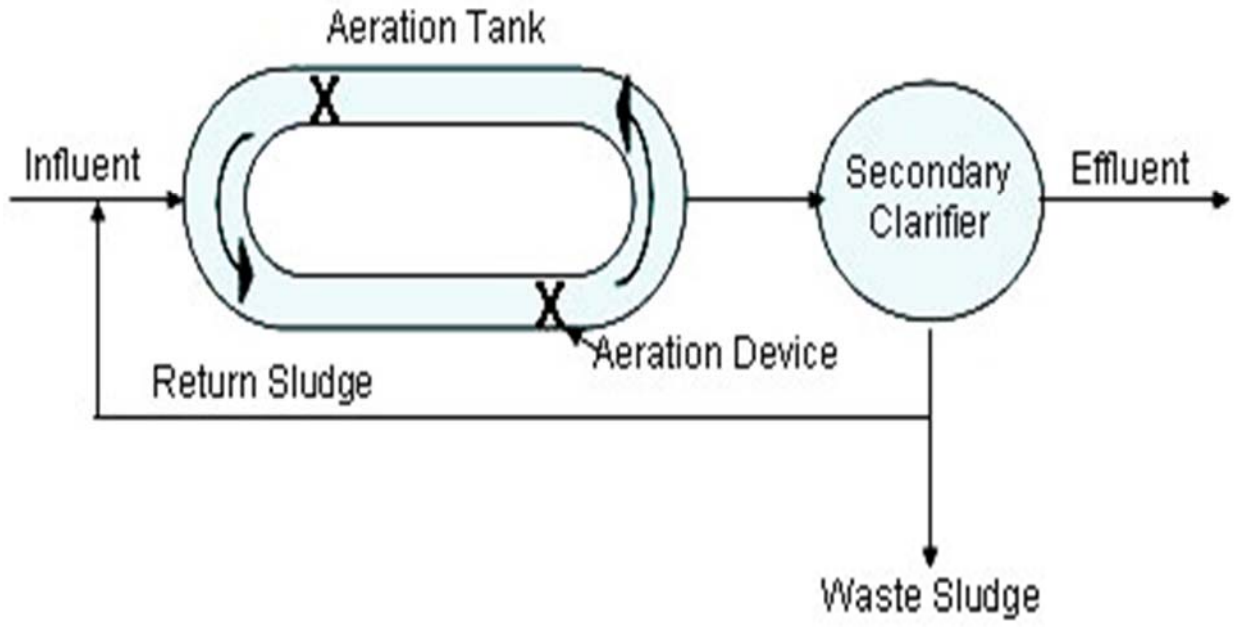
This process operates at a high MCRT (low F/M), resulting in a condition where there is not enough food in the system to support all of the microorganisms present. The microorganisms therefore compete very actively for the remaining food and even use their own cell structure for food.

This highly competitive situation results in a highly treated effluent with low sludge production. (Many extended aeration systems do not have primary clarifiers and they are package plants used by small communities.)

The main disadvantages of this system are the large oxygen requirements per unit of waste entering the plant and the large tank volume needed to hold the wastes for the extended period.

Oxidation Ditch Activated Sludge Process
The oxidation ditch is a variation of the extended aeration process. The wastewater is pumped around a circular or oval pathway by a mechanical aerator/pumping device at one or more points along the flow pathway. In the aeration tank, the mixed liquor velocity is maintained between 0.8 and 1.2 fps in the channel to prevent solids from settling.

Oxidation ditches use mechanical brush disk aerators, surface aerators, and jet aerator devices to aerate and pump the liquid flow. Combination diffused aeration and pumping devices are commonly used in Europe.



High Purity Oxygen Activated Sludge Process

The most common high purity oxygen activated sludge process uses a covered and staged aeration tank configuration. The wastewater, return sludge, and oxygen feed gas enter the first stage of this system and flow concurrently through the tank.

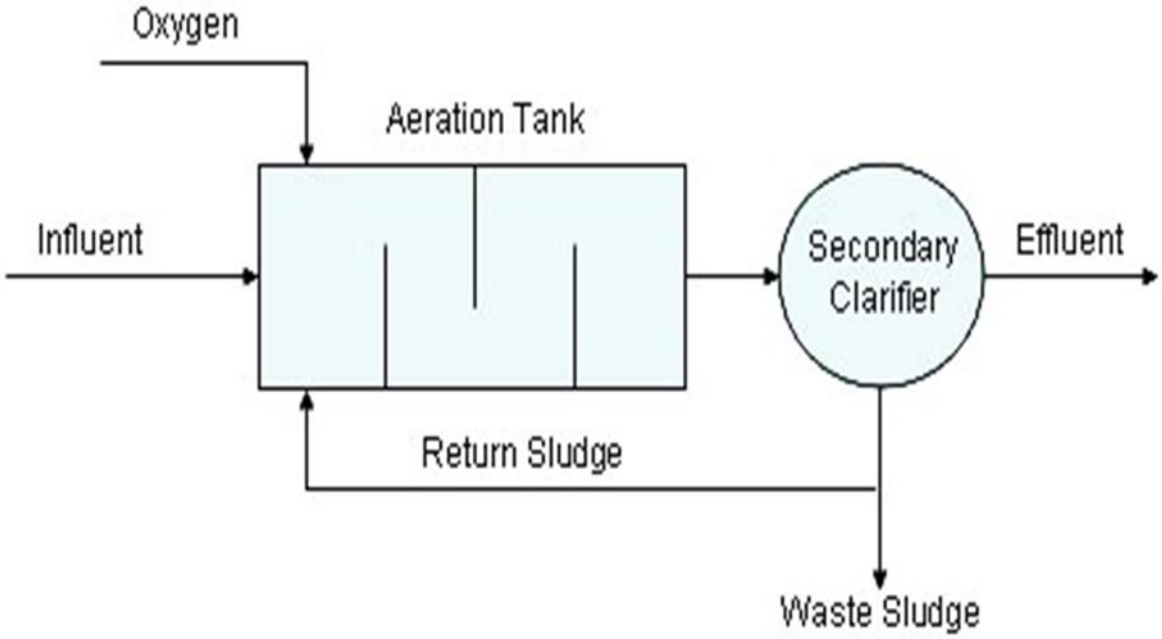
The tanks in this system are covered to retain the oxygen gas and permit a high degree of oxygen use. A prime advantage of the staged reactor configuration of the oxygenation system is the system's ability to match the biological uptake rate with the available oxygen gas purity.

The dissolution of oxygen and the mixing of the biological solids within each stage of the system are accomplished with either surface aeration devices or with submerged turbine-aeration systems. The selection of either of these two types of dissolution systems largely depends on the aeration tank geometry selected.

The particular configuration of oxygenation tank selected for a given system, that is, size of each stage, number of stages per aeration tank, and number of parallel aeration tanks, is determined by several parameters including waste characteristics, plant size, land availability, and treatment requirements.

Aside from the aeration tank, the other key factor in an oxygen activated sludge system is the oxygen gas source. There are three sources of oxygen supply: liquid oxygen storage, cryogenic oxygen generation, and pressure-swing adsorption generation.

The first of these requires no mechanical equipment other than a storage tank that is replenished by trucked-in liquid oxygen. This method is economically feasible for small (less than 4 mgd) or temporary installations.



Organic Loading Methods

We have some wastewater treatment plants that grow the microorganisms (Bugs) in large tanks. To have enough oxygen in the tanks we add oxygen by blowing air into the tank full of wastewater and microorganisms.

Air is added to the water creating small bubbles and mixes *"the bugs,"* food and oxygen together. When we treat wastewater this way, we call it the activated sludge method. With all of this food and air, the microbes grow and multiply very rapidly.

Pretty soon the population of bugs gets too large and some of them need to be removed to make room for new bugs to grow. We remove the excess bugs by sedimentation in the same kind of tanks used for primary treatment. In the tank, the bugs sink to the bottom and we remove them. The settled bugs are also called waste activated sludge.

The waste sludge is treated separately, and the remaining wastewater is now much cleaner. In fact, after primary and secondary treatment, about 85% or more of all pollutants in the wastewater has been removed and it goes on to Disinfection. These systems created in the early 1900's and earned their name because a "sludge" (mass of microbes) is produced which aerobically degrades and stabilizes the organic load of a wastewater. Below diagram shows the layout of a typical activated sludge system.

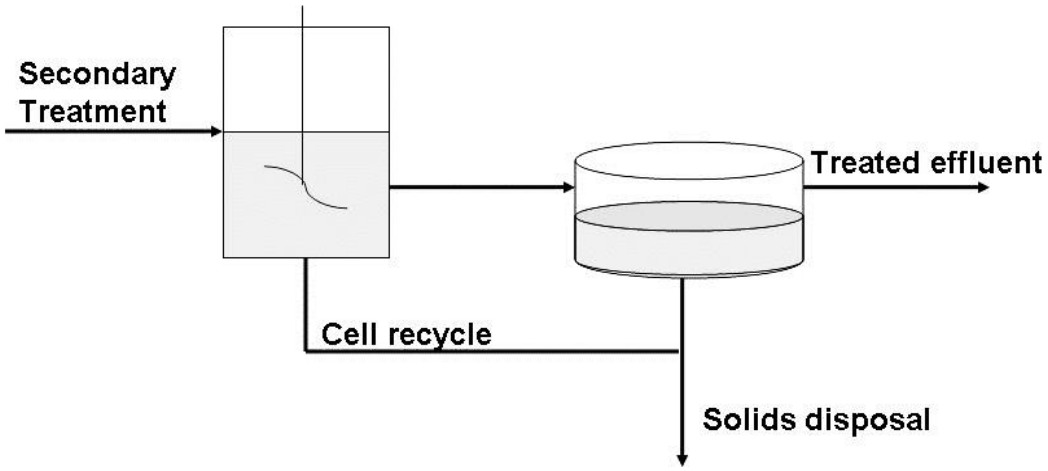


Diagram of a simple activated sludge system.

For larger systems, especially when high variability is expected, the design involves the use of multiple aeration tanks and multiple settling tanks. The number of units employed depends on the flow of wastewater being generated.

Organic Load
Organic loading (this is typically from the primary clarifiers or flotation devices) enters the reactor where the active microbial population (activated sludge) is present. The reactor must be continuously aerated. The mixture then passes to a secondary settling tank where the cells are settled.

The treated wastewater is generally discharged after disinfection while the settled biomass is recycled in part to the aeration basin. The cells must be recycled in order to maintain sufficient biomass to degrade the organic load as quickly as possible.

The amount that is recirculated depends on the need to obtain a high degradation rate and on the need for the bacteria to flocculate properly so that the secondary settling separates the cells satisfactorily. As the cells are retained longer in the system, the flocculating characteristics of the cells improve since they start to produce extra cellular slime which favors flocculating.

Common Types

The most common types of activated sludge are the conventional and the continuous flow settling tank, in which the contents are completely mixed. In the conventional process, the wastewater is circulated along the aeration tank, with the flow being arranged by baffles in plug flow mode. The oxygen demand for this arrangement is maximum at the inlet as is the organic load concentration.

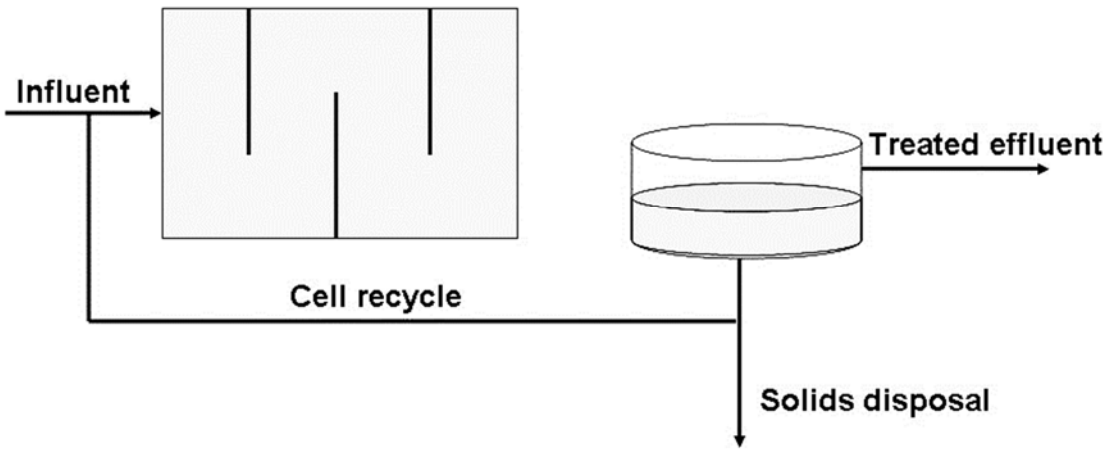


Diagram of a conventional activated sludge process.

In the completely mixed process the inflow streams are usually introduced at several points to facilitate the homogeneity of the mixing; if the mixing is complete, the properties are constant throughout the reactor. This configuration is inherently more stable to perturbations because mixing causes the dilution of the incoming stream into the tank.

In fisheries wastewaters the perturbations that may appear are peaks of concentration of organic load or flow peaks. The flow peaks can be damped in the primary treatment tanks. The conventional configurations would require less reactor volume if smooth plug flow could be assured, which usually does not occur.

Other versions of activated sludge systems (e.g., extended aeration, contact stabilization, step aeration and pure oxygen processes) are used in other kinds of wastewaters but are not known to be applied to treat fisheries wastewaters.

They are discussed elsewhere (Metcalf and Eddy Inc., 1979; Eckenfelder, 1980).

In all activated sludge systems, the cells are separated from the liquid and partially returned to the system to have a relatively high concentration of cells that degrade the organic load in a relatively short time.

Consequently, two different resident times are characteristic:

the hydraulic residence time ($\theta_{H)}$ given by the ratio of reactor volume (V) to flow of wastewater (Q):

$$\theta_H = V/Q$$

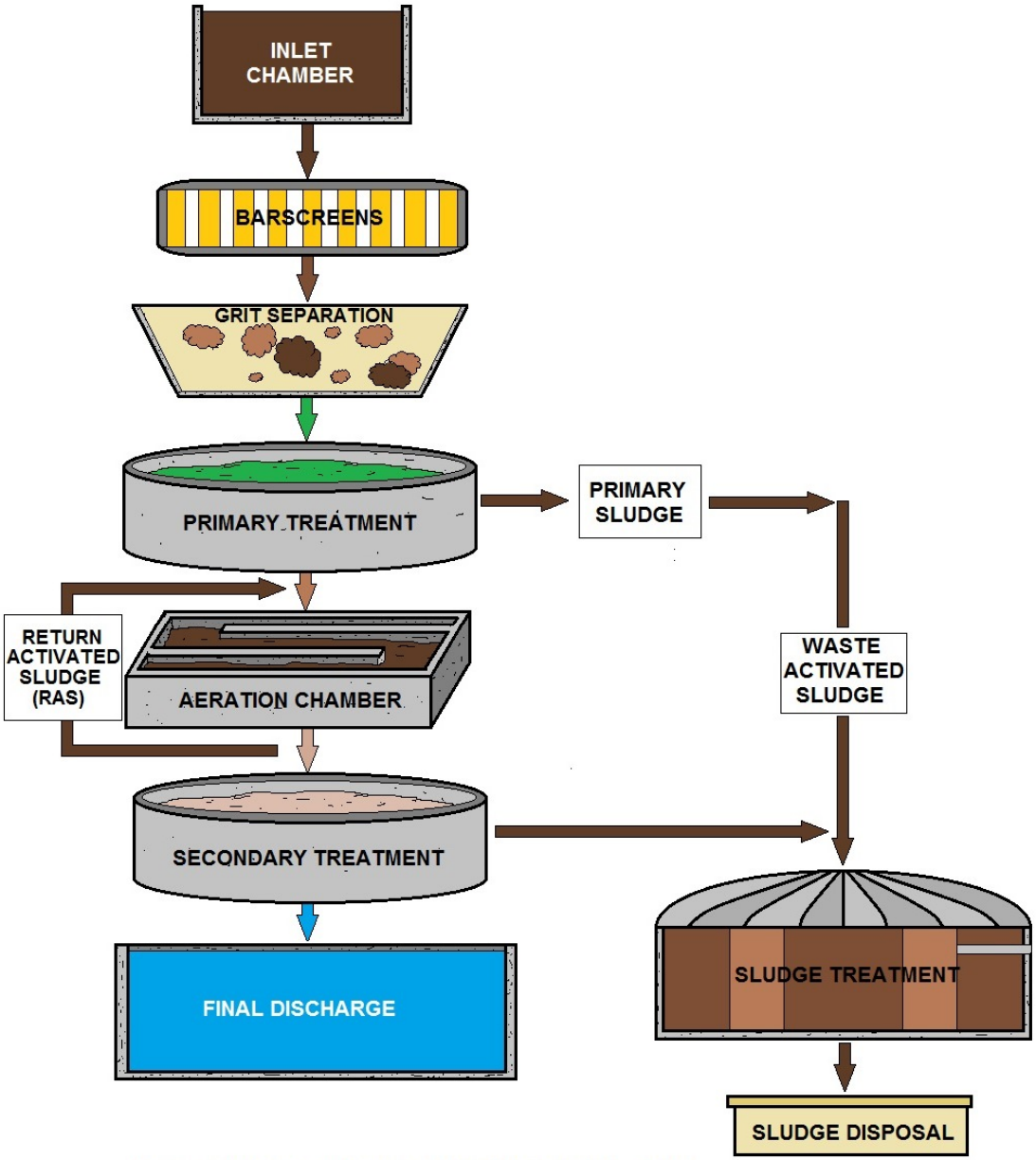
and the cell residence time (θc) given by the ratio of cells present in the reactor to the mass of cells wasted per day.

Typical θ_H values are in the order of 3-6 hours, while θc fluctuates between 3 and 15 days. Such difference in resident times is obtained by discharging the clarified effluent but wasting only a small fraction of the sludge.

This in turn can be accomplished by discarding a portion of the sludge from the settling tank or by wasting a fraction of the outlet of the reactor before entering the settling tank. In activated sludge systems, organic load removals of 85-95% are the most common.

A key factor in the success of these systems is its proper operation, which requires trained manpower.

Although used by some large fisheries which operate on a year-round basis, activated sludge may not prove to be economical or feasible for small seafood processors who operate seasonally because of the need to have a fairly constant supply of wastewater to maintain the microorganisms.



WASTEWATER TREATMENT PLANT
(SLUDGE REMOVAL BASICS)

POOR SETTLING SLUDGE CAUSES

Filamentous bulking and polysaccharide (slime) bulking are common causes of poor settling sludge. Other possibilities for poor settling may include hindered settling due to **denitrification** (one example: there is an upward force working against settling in which nitrogen gas wants to float the sludge), or hindered settling due to the mixed liquor concentration being too high.

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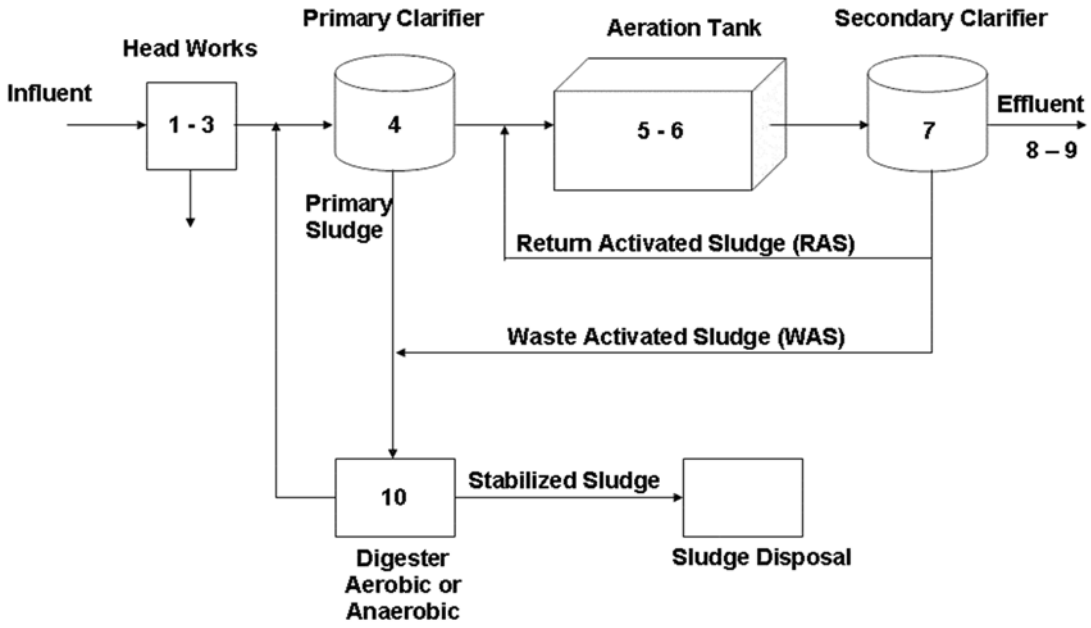
Rectangular Clarifiers Notice the weirs are covered and protected from Sunlight; the Sun helps the algae to grow on the weirs. See numbers 4 and 7 on the diagram on following page.


Primary Clarifier
Aeration Tank
Secondary Clarifier
Head Works
Influent
1 - 3
4
5 - 6
7
Effluent
8 – 9
Primary
Sludge
Return Activated Sludge (RAS)
Waste Activated Sludge (WAS)
10
Stabilized Sludge
Digester
Aerobic or
Anaerobic
Sludge Disposal

Sludge Problems and Solutions Section

Sludge Age

Activated sludge (RAS) is recycled back through the aeration basins by returning settled sludge in the final clarifiers and thus remains in the activated sludge system for a number of days. For effective treatment, a specific sludge age is desired for the type of activated sludge system.

For conventional activated sludge, a sludge age of 3-10 days is typical. For extended aeration activated sludge, older sludge ages of 15-30 days are common. F/M ratio and sludge age is inversely related (1 divided by the sludge age approximates the F/M ratio). The older the sludge, the lower the F/M ratio; conversely, the younger the sludge, the higher the F/M ratio. All three-process control methods are regulated by WAS. It is the key to controlling the activated sludge process. The operator should monitor MLSS, F/M ratio and sludge age to waste accordingly and thus ensure optimal operations and process stability.

Excess Solids

Solids are generated by microorganism growth and reproduction. The influent BOD supplies the food for the growth and reproduction. As microorganisms' populations multiply, excess solids (microorganisms) must be removed (wasted). If excess solids are not removed, the mixed liquor suspended solids (MLSS) and sludge age will increase and process efficiency will be lowered. Sludge settling rates are affected. Eventually, if excess solids do not get wasted, they can overflow the clarifier weirs and into the receiving water.

Wasting Sludge

Wasting sludge is the most important operational process control of the activated sludge process. By wasting sludge on a consistent basis, preferably daily, the biomass within the aeration tank will remain healthy and at a consistent MLSS level.

Wasting Rates

The concentration of WAS has a direct bearing on how much to waste and the volume wasted. On a volume basis, a thicker waste activated sludge (high WAS concentration) will require less amount of wasting than a thinner waste activated sludge (low WAS concentration).

Clarifier Sludge Blanket

Solids settle and concentrate in the final clarifiers forming a sludge blanket. The sludge blanket can increase or decrease depending on the RAS flow rate. The proper RAS flow rate allows for a desired sludge blanket.

Young Sludge

Young sludge consists of sludge that has not yet reached a high enough sludge age to be most effective in a particular activated sludge process. Billowing whitish foam is an indicator that the sludge age is too low. Young sludge will often have poor settling characteristics in the clarifier, and can leave straggler floc in the clarifier effluent. Young sludge is often associated with a high F/M. To correct for young sludge, it is necessary to decrease wasting rates. This will increase the amount of solids under aeration, reduce the F/M ratio, and increase the sludge age.

Old Sludge
Old sludge consists of sludge in which the sludge age is too high to be most effective in a particular activated sludge process. Dark brown foam and a somewhat greasy or scummy appearance is an indicator of old sludge. Settling in the clarifier is rapid, but pin floc can be present in the effluent and the effluent is hazy. Old sludge is often associated with a low F/M ratio. To correct for old sludge, it is necessary to increase wasting rates and return less sludge to the aeration basin. This will reduce the amount of solids under aeration, increase the F/M ratio and decrease the sludge age.

RAS Concentration
Varying the RAS flow rate will affect the concentration and detention time of clarified solids. Adjusting the RAS pumping rate allows the return of more or less concentrated solids while also increasing or decreasing the depth of the sludge blanket. RAS flow rates can be paced off influent flow rates.

Final Clarifier Solids Loading Rate (SLR)
The rate at which the activated sludge is returned from the final clarifiers to the aeration basins, along with the influent flow, effects the flow of solids into the clarifiers. Aeration basin mixed liquor suspended solids must have sufficient time to settle and be returned or wasted in the activated sludge system. Clarifiers are designed for certain solids loading rates that should not be exceeded.

Hydraulic Overloads
Solids washouts
If the flow is too high through the final clarifier, the solids will not have enough time to settle and can wash out over the weirs. This can result in a loss of solids from the system and effluent permit violations.

Reduced treatment efficiency
High flows can reduce the detention time in the aeration basins and thus reduce treatment efficiency. If too many solids also flow out of the clarifier, there may not be enough biomass to effectively treat the incoming organic load.

Denitrification
When RAS flow rates are too low, thick sludge blankets in the final clarifier can result. The operator will see gas bubbles (from nitrogen gas) and rising/floating sludge clumps on the clarifier surface.

Controlling dissolved oxygen levels in diffused air systems
1. By controlling air valves
2. By controlling the blower output such as using VFDs
3. By increasing or decreasing the number of blowers in operation
4. Cleaning or replacing diffusers
5. Changing the number of diffusers
6. Process control (ex. MLSS levels)

Controlling dissolved oxygen levels in mechanical aeration systems
1. By increasing or decreasing the aerator speed by using VFDs
2. By increasing or decreasing the aerator submergence by adjusting the tank water level
3. By increasing or decreasing the number of aerators in operation
4. Process control (ex. MLSS levels)

[Note: Throttling air valves with a positive displacement blower will not reduce airflow output but will raise operating pressure of the blower with high electric cost as the result. Throttling an inlet air valve on a centrifugal blower will reduce air discharge flow.]

Filamentous Bulking Sludge
The sludge blanket in the final clarifier will be near the surface, often with solids going over the weirs. Confirm by microscopic examination.

Nocardia Filaments Present
Thick, greasy, dark tan foam on aeration basins and possibly on final clarifiers. Confirm by microscopic examination.

Return Rates Too Low
Thin mixed liquor suspended solids and a sludge blanket build-up of solids. Rising clumps of sludge or gas bubbles may occur in the final clarifier.

Return Rates Too High
No sludge blanket in the final clarifier and a thin return activated sludge.

Denitrification in Final Clarifier
In the absence of oxygen, a sludge blanket that is too thick and remains in the clarifier too long can denitrify. Nitrates in the sludge will be converted to nitrogen gas. The release of nitrogen gas will cause small gas bubbles that will be observed at the clarifier surface. Clumps of sludge may also rise to the surface.

Low DO in an Aeration Basin
Problem: Dissolved Oxygen Meter/probes
Solution: Check the calibration of DO monitoring equipment. Clean probes and monitoring equipment regularly to ensure accurate DO measurements
or
Problem: Inadequate air supply
Solution: Increase air supply.
or
Problem: Excessive Organic Loading
Solution: Reduce influent loading through enforcement of the sewer use ordinance; a pretreatment program; equalization basins or bringing additional aeration basins on-line if available.

Clarifier Settling Problems and Solutions
Problem: Excessive filamentous organisms
Solution: Adjust the environmental conditions to support a healthier biomass.
or
Problem: Sludge age. Too young or too old a sludge can result in a poor settling sludge.
Solution: Adjust wasting to achieve the proper sludge age.
or
Problem: Clarifier washouts due to high flows
Solution: Develop and implement a collection system CMOM Program to reduce infiltration/inflow (I/I)
or

Problem: Too many solids in the system
Solution: Waste regularly to maintain proper MLSS, F/M ratio and sludge age for influent organic loads

Foaming Problems
Problem: Young sludge (white billowing foam)
Solution: Increase sludge age
or
Problem: Filamentous foaming organisms (Nocardia, Microthrix)
Solution: Adjust environmental conditions. Adjust F/M ratio, sludge age and dissolved oxygen. Reducing incoming grease is one of the most important factors to control surface filamentous forming organisms.
or
Problem: Industrial/chemical discharges (surfactants, phosphates, etc.)
Solution: Enforce sewer use ordinance

Lack of Nitrification
Problem: Improper environmental conditions
Solution: Nitrifying bacteria are very sensitive to environmental factors, such as very low dissolved oxygen, alkalinity, and temperatures. An older sludge (> 8 days) is usually needed for their growth. Adjust these environmental conditions, as you can, to support the growth of nitrifying bacteria.

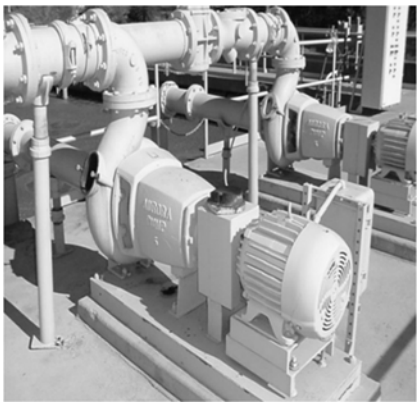
Course Bubble Aeration Systems
1. Aeration basins shall be drained annually
2. Remove excess settled solids that have accumulated
3. Clean diffusers and piping assemblies as needed
4. Inspect all hardware and components
5. Repair, replace, and tighten components as needed
6. Refill aeration tank following startup procedures

Fine Bubble Aeration Systems
1. Aeration basins shall be drained annually
2. Drain aeration basin and leave air on
3. Remove excess settled solids that have accumulated
4. With air on, hose off and wash each diffuser with clean water
5. With air off, if needed scrub each diffuser with either a soft bristle brush or rag.
6. Turn air back on and repeat hosing procedure for each diffuser
7. Inspect all hardware and components
8. Repair, replace, and tighten components as needed
9. Refill aeration tank following startup procedures

Summary

The RAS system pumps the settled sludge from the secondary clarifier back to the aeration tank. It is important that this system returns the RAS to the aeration tank before the microorganisms deplete the entire DO. The RAS must also be as concentrated as possible and the flow must be accurately measured and controlled.

To accomplish this, the RAS pumping system must have a positive variable flow control device and the RAS flow must be adjustable between the minimum and maximum range for proper process control. The desired return flow to the aeration tank could also be automatically paced to secondary influent flow.



All activated sludge processes must have a WAS system to remove excess microorganisms. This is necessary to control the F/M and MCRT. If the process is to reliably meet discharge requirements, this system must provide a positive, flexible, and reliable means of removing excess microorganisms.

It is essential for the system to have flow-metering and pumping equipment that function completely independent of other activated sludge control devices. The most positive and flexible system will include an independent pumping system with flow adjustability (for example, variable speed drive) and a flow meter that provides feedback into a flow-control device.

Such a system can be set for a given wasting rate with complete assurance that variable system head or concentration conditions will not affect its ability to remove the microorganisms required. WAS systems must have sufficient capacity to deal with both the hydraulic and/or organic load changes and process changes.

Aeration and DO Control

The purpose of aeration is two-fold: oxygen must be dissolved in the liquid in sufficient quantities to maintain the organisms and the contents of the tank must be sufficiently mixed to keep the sludge in suspension.

Mixing energy and oxygen transfer are provided through mechanical or diffused aeration. The amount of oxygen that has to be transferred by the aeration system is theoretically equal to the amount of oxygen required by the organisms in the system to oxidize the organic material.

The DO concentration in the aeration tank must be sufficient to sustain at all times the desirable microorganisms in the aeration tank, clarifier, and return sludge line back to the aeration tank.

When oxygen limits the growth of microorganisms, filamentous organisms may predominate and the settleability and quality of the activated sludge may be poor.

On the other hand, over aeration can create excess turbulence and may result in the breakup of the biological floc and waste energy.

Poor settling and high effluent solids will result. For these reasons, it is very important to periodically monitor and adjust the aeration tank DO levels and, for diffused air systems, the air flow rates.

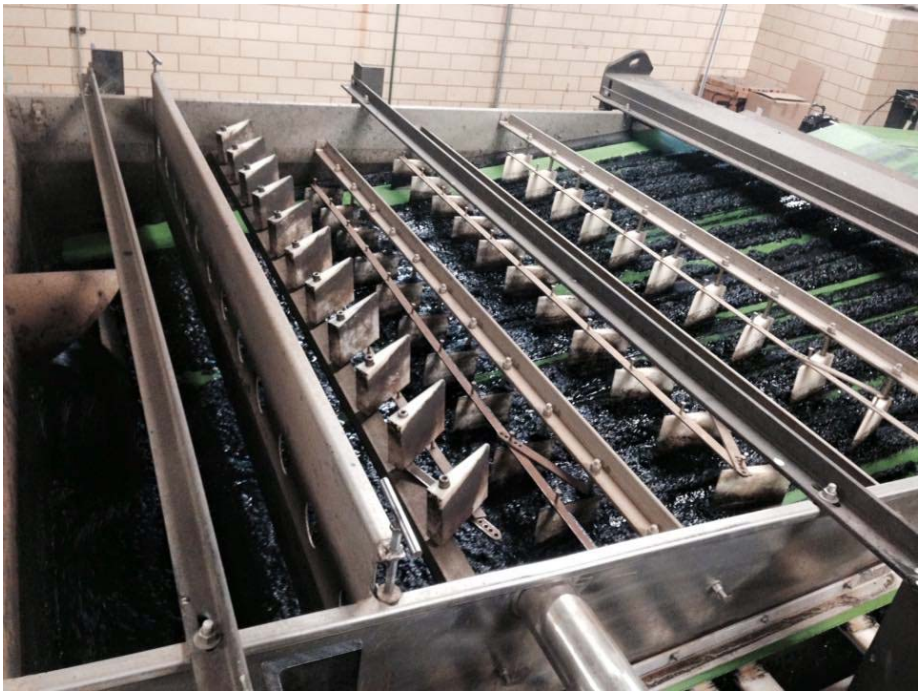
In practice, the DO concentration in the aeration tank should normally be maintained at about 1.5 to 4 mg/L in all areas of the aeration tank at all times for adequate microorganism activity. Poor sludge settling as a result of filamentous organisms has been associated with mixed liquor DO concentrations below 0.5 mg/L. Above 4 mg/L, treatment usually does not significantly improve but power usage increases aeration costs considerably.

RAS Control

To properly operate the activated sludge process, a good settling mixed liquor must be achieved and maintained. The MLSS are settled in a clarifier and then returned to the aeration tank as the RAS. This keeps a sufficient concentration of activated sludge in the aeration tanks so that the required degree of treatment can be obtained in the allotted time period. The return of activated sludge from the secondary clarifier to the aeration tank is a key control parameter of the process.

The secondary clarifiers have two basic functions:

- to clarify the secondary effluent through solids/liquid separation; and
- to rapidly collect and thicken the settled solids for return to the aeration tanks or wasting to the sludge processing facilities.



Example of a Sludge Press.

Topic 4 - Activated Sludge Process Section Post Quiz

True or False

1. Activated sludge is recycled back through the aeration basins by returning settled sludge in the final clarifiers and thus remains in the activated sludge system for a number of days. True or False

2. For conventional activated sludge, a sludge age of 30-40 days is typical.
True or False

3. For extended aeration activated sludge, younger sludge ages of 1-3 days are common.
True or False

4. F/M ratio and sludge age is inversely related (1 divided by the sludge age approximates the F/M ratio). The older the sludge, the lower the F/M ratio; conversely, the younger the sludge, the higher the F/M ratio. True or False

5. The operator should monitor MLSS, F/M ratio and sludge age to waste accordingly and thus ensure optimal operations and process stability. True or False

6. Solids are generated by microorganism growth and reproduction. The influent BOD supplies the food for the growth and reproduction. As microorganisms' populations multiply, excess solids (microorganisms) must be removed (wasted).
True or False

7. If excess solids are not removed, the mixed liquor suspended solids (MLSS) and sludge age will increase and process efficiency will be lowered. Sludge settling rates are affected.
True or False

8. If excess solids do not get wasted, they can overflow the clarifier weirs and into the receiving water. True or False

9. Wasting sludge is the least important operational process control of the activated sludge process. By wasting sludge on a consistent basis, preferably monthly, the biomass within the aeration tank will remain healthy and at a consistent MLSS level.
True or False

10. The concentration of RAS has a direct bearing on how much to waste and the volume wasted. On a volume basis, a thicker waste activated sludge (high WAS concentration) will require greater amount of wasting than a thicker waste activated sludge (low RAS concentration). True or False

11. Solids will not settle and concentrate in the final clarifiers thus forming a sludge blanket. The sludge blanket cannot increase or decrease depending on the RAS flow rate. The proper RAS flow rate allows for a desired sludge blanket. True or False

12. Old sludge consists of sludge which has not yet reached a high enough sludge age to be most effective in a particular activated sludge process. Billowing whitish foam is an indicator that the sludge age is too high. True or False

13. Young sludge is often associated with a high F/M. To correct for young sludge, it is necessary to decrease wasting rates. This will increase the amount of solids under aeration, reduce the F/M ratio, and increase the sludge age. True or False

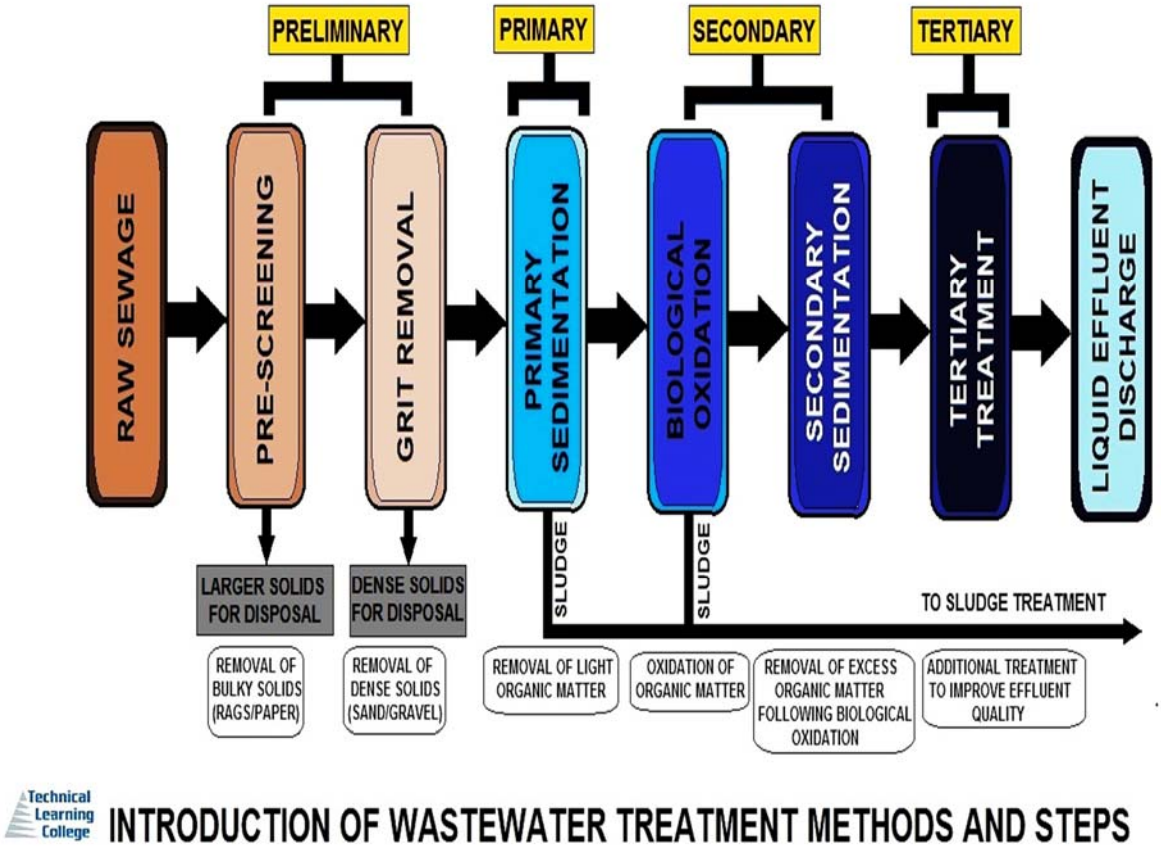
14. Old sludge consists of sludge in which the sludge age is too high to be most effective in a particular activated sludge process. True or False

15. Dark brown foam and a somewhat greasy or scummy appearance is an indicator of old sludge. Settling in the clarifier is rapid, but pin floc can be present in the effluent and the effluent is hazy. True or False

Topic 5 - Advanced Wastewater Treatment Section

Topic 5 - Section Focus: You will learn the basics of advanced wastewater treatment methods. At the end of this section, you the student will be able to understand and describe various tertiary treatment including microfiltration. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Topic 5 – Scope/Background: The goal of tertiary treatment is to remove unwanted elements such as SS, COD (solid and colloidal), phosphorus and specific compounds (pesticides, metals, detergents, and so on). It is designed to improve the quality of purified water so that it can be discharged into the natural environment or re-used. In wastewater treatment, membrane technology is becoming increasingly important. With the help of ultra/microfiltration it is possible to remove particles, colloids and macromolecules, so that waste-water can be disinfected in this way. This is needed if waste-water is discharged into sensitive waters especially those designated for contact water-sports and recreation



Technical Learning College **INTRODUCTION OF WASTEWATER TREATMENT METHODS AND STEPS**

Above, the diagram shows the steps typically used at a facilities using Advanced Treatment. The effluent or reclaimed water is typically reused for many applications such as golf courses or lakes.

TREATMENT METHODS	REMOVAL CAPABILITIES
FILTRATION AIR / STEAM STRIPPING	SUSPENDED SOLID PARTICLES DISSOLVED AMMMONIA VOLATILE ORGANIC COMPOUNDS (VOC's)
ADSORPTION	DISSOLVED ORGANICS, TO INCLUDE VOC's COLOURING ODORIFEROUS COMPOUNDS
BIOLOGICAL PROCESSES	NITROGENOUS & PHOSPHOROUS COMPOUNDS
MEMBRANE SEPARATION PROCESS SUCH AS MICROFILTRATION, ULTRA FILTRATION, NANOFILTRATION & REVERSE OSMOSIS (RO)	DISSOLVED ORGANICS AND INORGANICS
ION-EXCHANGE PROCESS	DISSOLVED ANIONS AND CATIONS
PRECIPITATION	HEAVY METAL IONS AND OTHER IONIC SUBSTANCES
OXIDATION - REDUCTION	ORGANICS & SOME INORGANICS
DISINFECTION	MICRO - ORGANISMS TO INCLUDE VIRUS

Technical Learning College TERTIARY METHODS AND THEIR EFFECTIVENESS IN TREATMENT

Tertiary Treatment Purpose

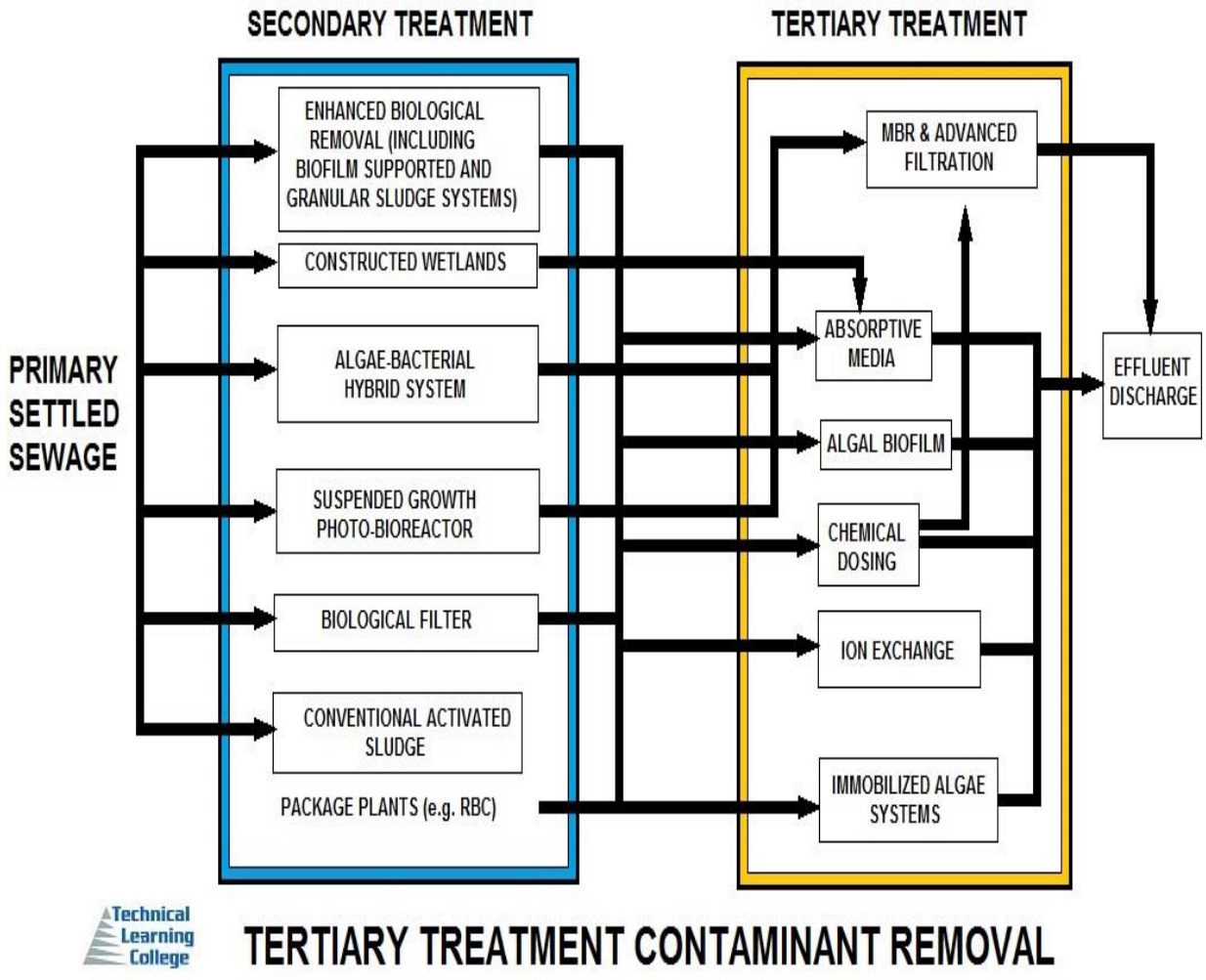
Tertiary treatment methods, considered as Advanced Treatment as seen above, use different methods to achieve targeted removal for water quality.

Another way to classify advanced wastewater treatment is to differentiate on the basis of desired treatment goals.

Advanced wastewater treatment is used for:

1. Additional organic and suspended solids removal
2. Removal of nitrogenous oxygen demand (NOD)
3. Nutrient removal
4. Removal of toxic materials

Advanced Treatment Methods Introduction

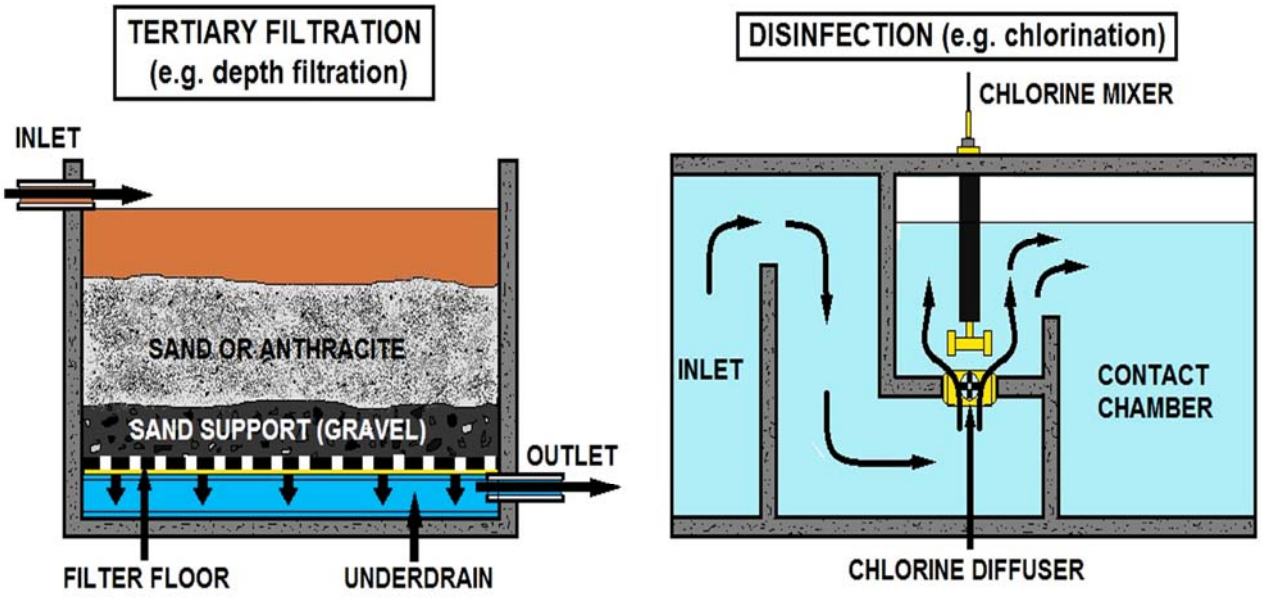


In advanced wastewater treatment, methods are dependent upon the characteristics of effluent to be obtained after secondary treatment to satisfy further use or disposal of treated wastewater. The diagram above list different methods depending on the removal of BOD, TSS and minor portions of nitrogen, phosphorus, and heavy metals achieved during secondary treatment.

Different methods are used in advanced waste treatment to satisfy any of the several specific goals, which include the removal of:

1. Suspended Solids
2. BOD
3. Plant nutrients
4. Dissolved solids
5. Toxic substances

These methods may be introduced at any stage of the total treatment process as in the case of industrial waterways or may be used for complete removal of pollutants after secondary treatment.



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TERTIARY TREATMENT (Filtration / Disinfection)

The diagram above, a simpler form of tertiary treatment that requires disinfection to kill harmful waterborne diseases. This stage is similar to the one used by drinking water treatment plants which clean raw water for drinking purposes.

The tertiary treatment stage has the ability to remove up to 99 percent of the impurities from the wastewater. This produces effluent water that is close to drinking water quality. Unfortunately, this process tends to be a bit expensive as it requires special equipment, well trained and highly skilled equipment operators, chemicals and a steady energy supply.

Types of Conventional Wastewater Filters
New environmental wastewater treatment standards are more stringent and require lower levels of BOD, TSS and ammonia. Because of these standards, the following are a few of the tertiary filtration systems.

Conventional Down-flow Filters
These filters consist of fixed-media beds typically up to 3 feet in depth and are similar to filters used to treat drinking water.

Media can be single media, dual media, or multi media. Single media is typically sand or anthracite.

Dual media combines anthracite and sand. Multi-media filters include a layer of garnet or limonite. Flow in these filters is by gravity from the top down. Most of the removal occurs in the top few inches of the media. The filter must be taken off-line periodically to backwash the filter to prevent clogging and too high of a pressure loss.

Deep-bed Down-flow Filters
These filters are similar to conventional down-flow filters but have deeper beds and larger media size. This gives the advantage of longer run times between backwashes. The size of the media is limited by the ability to backwash the filter. Because these filters are more difficult to backwash, air scour is necessary to fully clean the filter bed.

Continuous Backwashing Upflow Sand Filters
During operation of the continuous backwashing upflow filter, water is introduced through risers at the bottom of a deep sand bed. Water flows upward through the sand bed and over an overflow weir. Sand and trapped solids flow downward through the filter and are drawn into the suction of an airlift pipe in the center of the filter. As the sand travels up the airlift pipe, energy from the air scours the particles and separates the sand from filtered solids. At the top of the airlift pipe, the clean sand settles back onto the top of the filter and the solids are carried away into a reject line.

These filters have the advantage of having no moving parts other than the air compressor and requiring less energy and maintenance than traditionally backwashed filters. They are sometimes referred to by the trade name Dynasand.

Pulsed Bed Filters
Pulsed bed filters are shallow filters with an unstratified fine sand media. An air pulse disturbs the media and allows penetration of solids into media bed, allowing the entire filter bed to be used for removal of solids. The pulse is designed to expand the filter operation and reduce the number of backwash cycles, although the filter must still be periodically backwashed to remove the solids.

Traveling-Bridge Filters
Traveling-bridge filters consist of long shallow beds of granular media. Wastewater is applied to the top of the media and flows downward. Each cell is individually backwashed by a traveling-bridge while the other cells continue to operate. The bridge uses filtered water to backwash the filters and includes surface wash to breakup matted solids or clumps of solids.

Fuzzy Filters
The fuzzy filter uses a proprietary synthetic filter media that is highly porous. Water flows not only around the media but also through it, allowing much higher filtration rates. The media is held in place by a metal plate and flow is from the bottom of the bed upwards. The filter is backwashed by raising the plate and introducing a horizontal air stream from alternating sides causing the media to roll back and forth. The effluent is returned to the plant.

Discfilters
Discfilters are a series of parallel mounted disks used to support a cloth filter media. Water enters a central tube and flows out between the two layers of cloth in each disk. The disks rotate and are normally 60 to 70 percent submerged. The portion above the water is backwashed using spray nozzles.

Cloth Media Disk Filters
The cloth media disk filter is similar to the discfilter listed above. In this case the water flows from the outside of the partially submerged cloth disks and into a center pipe. Disks continue to rotate during backwash and water is sucked into the disc using suction heads.

Membranes
Membrane systems use a pressure head to drive water through a permeable membrane. Membrane filters are typically classified by their pore size which in turn determines the size of the particles they exclude. Microfiltration, ultrafiltration, nanofiltration, and reverse osmosis (RO) remove increasingly smaller particles.

Microfiltration and ultrafiltration remove 3 to 6 logs of bacteria, 95 percent or more BOD, along with most particles (WEF, 2006). Nanofiltration removes nearly all particles including some viruses. RO removes all particles as well as most large dissolved constituents. The energy cost for applying the pressure head and the need to replace membranes make membrane filtration a more expensive technology. It can achieve very low concentrations of nutrients and other contaminants, however, and is common in water re-use projects.

Membranes can be configured a number of ways including hollow fiber, spiral wound, plate and frame, cartridge, or in pressure vessels. Membranes can foul from organics, biological activity, or metals in the wastewater. Typically, the water must be pre-treated before using these membranes. Pretreatment could be conventional filters, cartridge filters, or larger membrane filters. Disinfection may also be required to prevent biological fouling.

Blue PROTM Process
The Blue PROTM process uses a continuous backwashing filter that is designed to remove phosphorus. Filters can be run in series for even greater removal. The filter media (sand) is coated with a hydrous ferric oxide coating, which enhances phosphorus removal through adsorption. A ferric salt is added prior to the filter to aid in coagulation and to replace the ferric coating which is abraded from the sand. Water flows up through the filter while the sand travels down. An airlift tube at the bottom of the filter carries the sand upward. Turbulence from the compressed air knocks accumulated iron and phosphorus along with any solids off the particle as it travels upward. The iron, phosphorus, and particles are wasted, while the clean sand is deposited on the top of the bed. The filters can be run biologically active to achieve denitrification.

The Blu-CAT process combines the Blu-Pro process with addition of advanced oxidants. Early pilot tests show that this process is capable of removing other emerging contaminants along with phosphorus and microorganisms (USEPA, 2008a).

Pressure Filters
Pressure filters are similar to conventional media filters except they are contained in closed containers and are filtered under pressure. The increased pressure creates a greater head loss and allows longer times between backwashes.

Design and Operating Principles
Filtration is mainly affected by the concentration and size distribution of particles entering the filter. Turbidity is often used as a surrogate for particle concentration. The concentration of particles will affect run-time in filters and will also affect the required surface area to achieve the desired filtration. The size distribution of the particles and its relevance to pore size of the granular or membrane filters will affect the removal mechanisms. Filtration rate is also an important design parameter. Too fast of a filtration rate can cause floc to break up and pass through the filter. The optimal filtration rate depends on floc strength, which in turn depends on the biological treatment processes prior to filtration (e.g., Higher SRTs lead to weaker flocs).

The filtration rate, along with the loading rate will determine the area of the filter required. The higher the loading rate, the more frequent backwashes will be required and the greater the head loss across the filters. Typical filtration rates are 15-50 feet (5 to 15 meters) of flow per hour for gravity filters and up to 65-70 feet (20 meters) per hour for pressure filters (WEF and ASCE, 1998). Equipment filtration is based on surface area loading.

Addition of polymers or other coagulant aids can greatly aid filtration. Typical doses for filter influent are 0.05 to 0.15 mg/L of organic polyelectrolyte (WEF and ASCE, 1998), although jar tests are conducted to determine the proper dose. Too low a dose can allow uncoagulated particles through the filter and too high a dose can lead to mudballs and filter clogging.

There are several ways the flow rate can be controlled in filters. Constant-rate fixed head filtration maintains a constant flow through the filter. This will lead to an increased head above the filter as the filter run progresses. In constant-rate variable head filtration the rate is kept the same and the filter is backwashed when the head reaches a certain value. In variable-rate filtration, the rate of filtration decreases throughout the filter run until it reaches a minimum value and is backwashed. Variable-rate filtration is less common than constant-rate filtration.

Proper backwashing is also important to filter operation. Without proper backwashing there can be breakthrough of particles and turbidity. Lack of a proper backwash can also lead to accumulation of materials on the surface of the filter that can form mudballs and cracks, which can allow solids to pass through the filter. A surface wash or air scour may also be helpful to prevent accumulation of mudballs or grease. Surface wash or air scour is also helpful for traveling bridge filters. Without surface wash traveling bridge filters are limited to an influent TSS concentration of 40 to 50 mg/L (WEF and ASCE, 1998).

If membrane filters are used, fouling can be an important consideration. Cellulose acetate membranes can be damaged by biological activity. Disinfection is often used to prevent biological fouling of the membranes. Some membrane materials such as polyacramides, however, can be damaged by chlorine. This can be avoided by using an alternative disinfectant, a different membrane material, or by de-chlorination.

Lowering the pH can help to prevent mineral fouling of nanofiltration or reverse osmosis membranes. Besides pre-treatment, chemical cleaning of the membranes may also be required periodically. Monitoring of effluent quality and pressure differential can be important to help identify membrane fouling or failure.

Ongoing Research and Emerging Technologies

The use of membranes as tertiary filtration is an area that has recently expanded. Research continues on various membrane configurations along with topics such as pre-treatment, membrane cleaning, and removal of emerging contaminants. Fuzzy filters are also an innovative technology that is beginning to be established in the wastewater community with several full scale projects.

Other research has focused on enhancements to existing technology. For example, the Blue-Pro system combines continuous backwashing filters, a well-known technology, with a hydrous ferric oxide coating and ferric salt addition to remove phosphorus by adsorption as well as filtration.

Mathematical Modeling
The Need for Models
WWTPs are complex systems that depend on numerous biological, chemical, and physical processes to achieve effluent goals. Because of the complex behavior of the processes and the variability in wastewater characteristics, biological populations, and plant design, it is not always possible to predict how changing any one variable will affect the effluent quality.

Plant designs that work for one influent wastewater and climate may not perform well in different conditions. Pilot scale or full scale trials can help to determine the effect of various parameters, but costs and time to cover all possibilities may be prohibitive. Therefore, models fill an important need by enabling simulation of a process and estimating the impact that changing parameters will have on the treatment effectiveness.

Models can be used for a number of purposes including the design of new WWTPs, the design of retrofits or upgrades to existing plants, determining how changes in operations may affect effluent concentrations of permitted contaminants, determining how plants will respond to changes in influent quality or flow, and for training operators. Not all models can achieve all of these purposes, so models should be selected with the desired use in mind. There is some disagreement in the literature in the use of the term model.

Some references use the term to refer to sets of mathematical equations that characterize a process, other references use model to refer to the computer program used to solve these equations. This section will use the former and will use the term “simulator” to describe the computer program.

As you have previously read, depending on the design and operation of the process, activated sludge has several interrelated components:

1. Single aeration tank or multiple aeration tanks designed for completely mixed or plug flow.

2. An aeration source to provide adequate oxygen and mixing: sources can be compressed air, mechanical aeration, or pure oxygen.

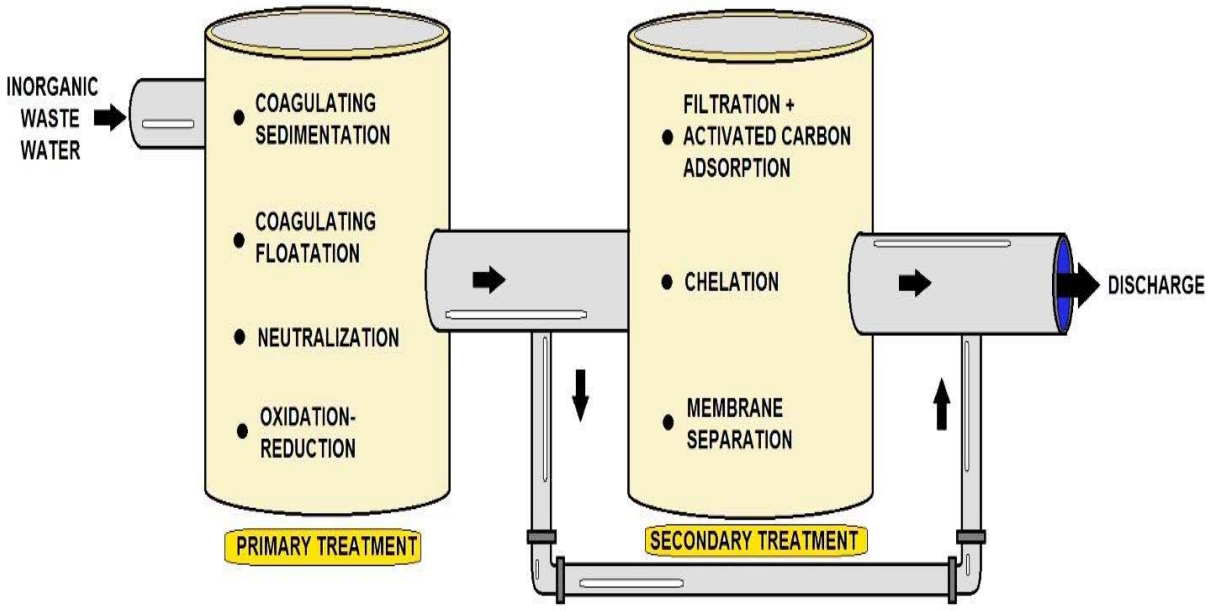
3. A clarifier to separate the biological solids (activated sludge) from the treated wastewater.

4. A means of collecting the biological solids in the clarifier and recycling most of them (return activated sludge, RAS) to the aeration tank.

5. A means of removing or wasting excess biological solids (waste activated sludge, WAS) from the system.

Goal of Advanced Wastewater Treatment

The goal of tertiary treatment is to remove unwanted elements such as SS, COD (solid and colloidal), phosphorus and specific compounds (pesticides, metals, detergents, and so on). It is designed to improve the quality of purified water so that it can be discharged into the natural environment or re-used.



PROCESS OF REMOVING INORGANIC WASTE (Flow Diagram)

Advanced Wastewater Treatment may be broken into three major categories by the type of process flow scheme utilized:

1. Tertiary Treatment
2. Physical-Chemical Treatment
3. Combined Biological-Physical Treatment

Tertiary treatment may be defined as any treatment process in which unit operations are added to the flow scheme following conventional secondary treatment.

Additions to conventional secondary treatment could be as simple as the addition of a filter for suspended solids removal or as complex as the addition of many unit processes for organic, suspended solids, nitrogen and phosphorous removal.

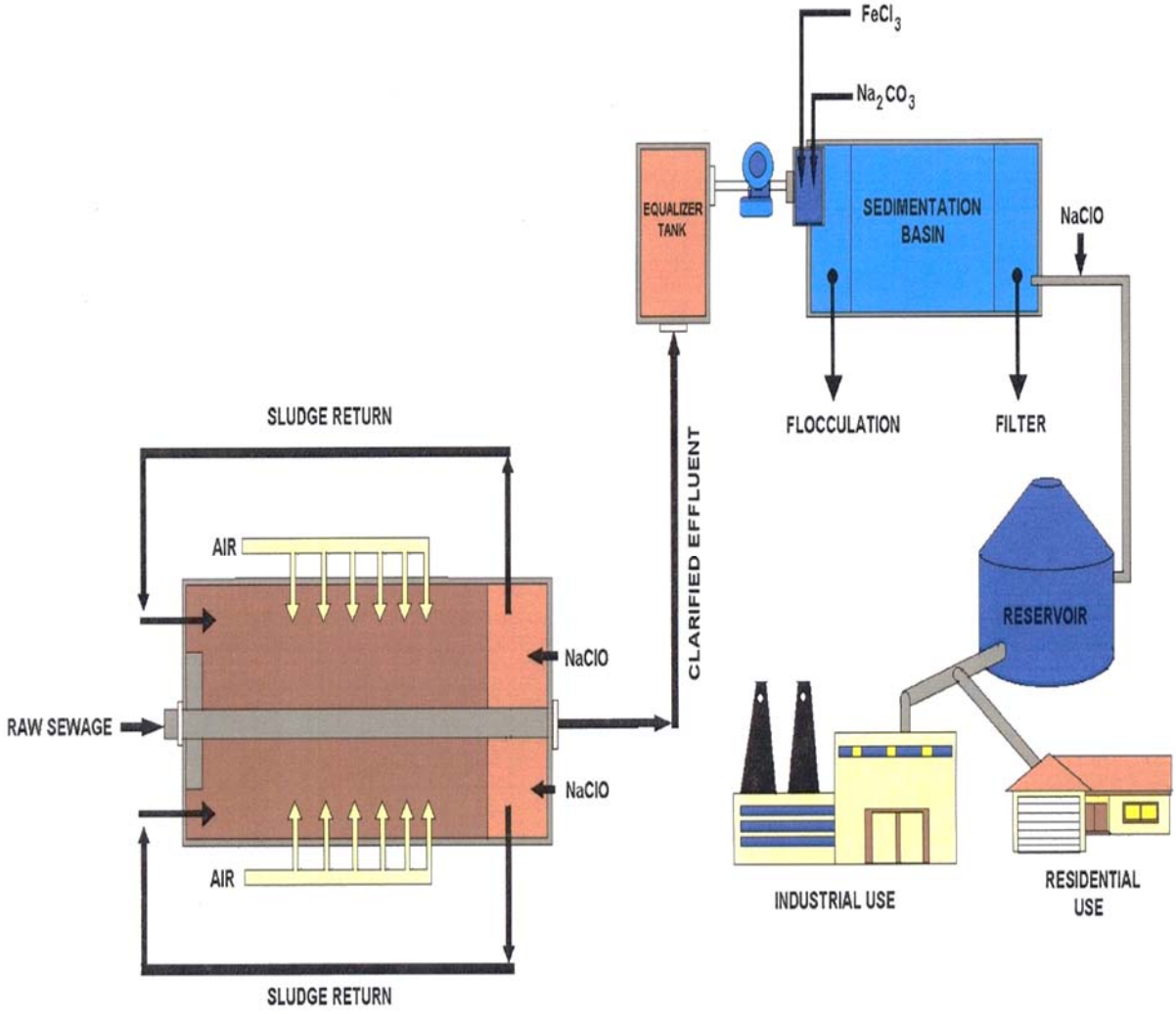
Physical-chemical treatment is defined as a treatment process in which biological and physical-chemical processes are intermixed to achieve the desired effluent.

Combined biological-physical-chemical treatment is differentiated from tertiary treatment in that in tertiary treatment any unit processes are added after conventional biological

treatment, while in combined treatment, biological and physical-chemical treatment are mixed.

Need of Tertiary Treatment

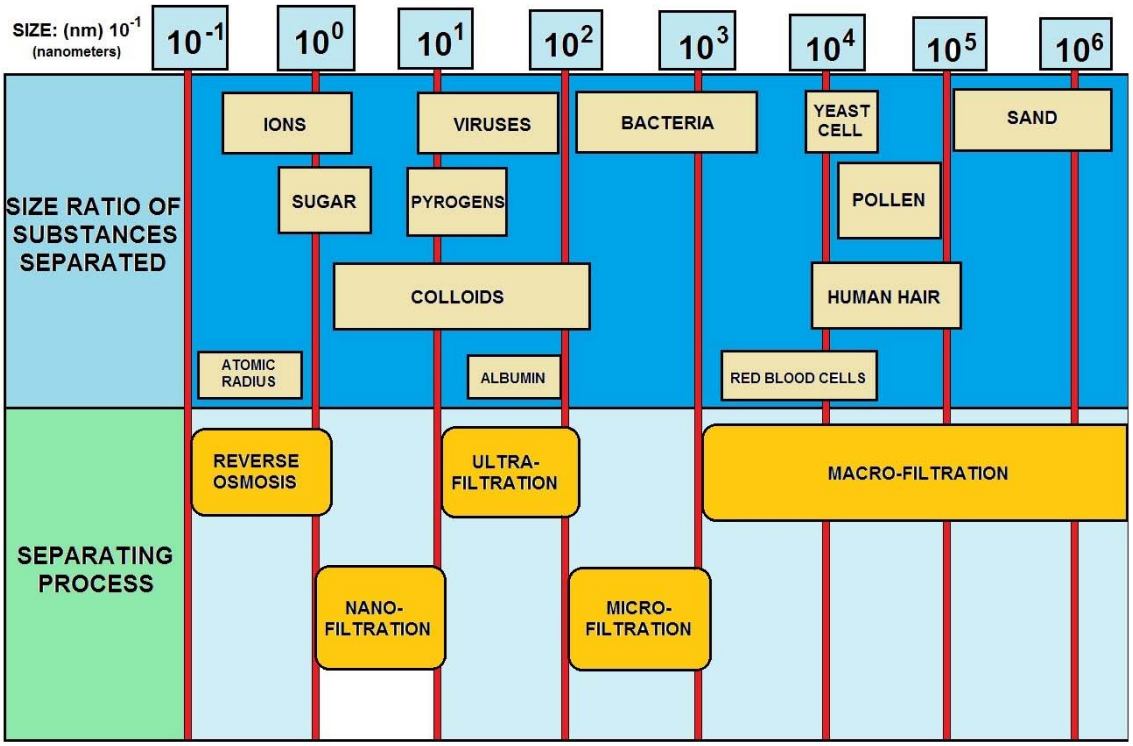
- To remove total suspended solids and organic matter those are present in effluents after secondary treatment.
- To remove specific organic and inorganic constituents from industrial effluent to make it suitable for reuse.
- Tertiary treatment removes the load of nitrogen and phosphorus present in the water. It includes processes like filtration, ion exchange, activated carbon adsorption, electro dialysis, nitrification, and denitrification.



MICROBIOLOGICAL AND CHEMICAL PROCESS TO OBTAIN RE-USE WATER

Microfiltration Sub-Section

Filtration is the separation of two or more components from a fluid stream. A filtration membrane acts as a selective barrier, allowing the passage of certain components and retaining others components of a mixture. The most common membrane processes are microfiltration, ultrafiltration, and hyperfiltration (reverse osmosis).



FILTRATION SPECTRUM

Types of Processes

Membrane separation processes operate without heating and therefore use less energy than conventional thermal separation processes such as distillation, sublimation or crystallization. The separation process is purely physical and both fractions (permeate and retentate) can be used.

Cold separation using membrane technology is widely used in the food technology, biotechnology and pharmaceutical industries. Using membranes enables separations to take place that would be impossible using thermal separation methods. For example, it is impossible to separate the constituents of azeotropic liquids or solutes which form isomorphic crystals by distillation or recrystallization but such separations can be achieved using membrane technology.

Depending on the type of membrane, the selective separation of certain individual substances or substance mixtures is possible. Important technical applications include the production of drinking water by reverse osmosis (worldwide approximately 7 million cubic meters annually), filtrations in the food industry, the recovery of organic vapors such as petro-chemical vapor recovery and the electrolysis for chlorine production.

In wastewater treatment, membrane technology is becoming increasingly important. With the help of ultra/microfiltration it is possible to remove particles, colloids and macromolecules, so that waste-water can be disinfected in this way. This is needed if waste-water is discharged into sensitive waters especially those designated for contact water-sports and recreation.

Azeotropes

An **azeotrope** or a **constant boiling mixture** is a mixture of two or more liquids whose proportions cannot be altered by simple distillation. This happens because when an azeotrope is boiled, the vapor has the same proportions of constituents as the unboiled mixture.

Because their composition is unchanged by distillation, azeotropes are also called (especially in older texts) **constant boiling mixtures**. The word *azeotrope* is derived from the Greek words ζέειν (boil) and τρόπος (turning) combined with the prefix α- (no) to give the overall meaning, "no change on boiling".

The term "azeotrope" was coined in 1911 by English chemist John Wade (1864–1912) and Richard William Merriman.

Many azeotropic mixtures of pairs of compounds are known, and many azeotropes of three or more compounds are also known. In such a case it is not possible to separate the components by fractional distillation. There are two types of azeotropes: minimum boiling azeotrope and maximum boiling azeotrope.

A solution that shows greater positive deviation from Raoult's law forms a minimum boiling azeotrope at a specific composition. For example, an ethanol-water mixture (obtained by fermentation of sugars) on fractional distillation yields a solution containing approximately 95% by volume of ethanol.

Once this composition has been achieved, the liquid and vapor have the same composition, and no further separation occurs. A solution that shows large negative deviation from Raoult's law forms a maximum boiling azeotrope at a specific composition.

Nitric acid and water is an example of this class of azeotrope. This azeotrope has an approximate composition of 68% nitric acid and 32% water by mass, with a boiling point of 393.5 K.

Understanding Membrane Filtration Processes

In 1748, the French physicist Nollet first noted that water would diffuse through a pig bladder membrane into alcohol. This was the discovery of osmosis, a process in which water from a dilute solution will naturally pass through a porous membrane into a concentrate solution. Over the years, scientists have attempted to develop membranes that would be useful in industrial processes, but it wasn't until the late 1950s that membranes were produced that could be used for what is known as reverse osmosis. In reverse osmosis, water is forced to move through a membrane from a concentrate solution to a dilute solution.

Since that time, continual improvements and new developments have been made in membrane technology, resulting in ever-increasing uses in many industries. In potable water treatment, membranes have been used for desalinization, removal of dissolved inorganic and organic chemicals, water softening, and removal of the fine solids.

In particular, membrane technology enables some water systems having contaminated water sources to meet new, more stringent regulations. In some cases, it can also allow secondary sources, such as brackish groundwater, to be used. There is great potential for the continuing wide use of membrane filtration processes in potable water treatment, especially as technology improves and costs are reduced.

Description of Membrane Filtration Processes

In the simplest membrane processes, water is forced through a porous membrane under pressure, while suspended solid, large molecules, or ions are held back or rejected.

Types of Membrane Filtration Processes

The two general classes of membrane processes, based on the driving force used to make the process work, are:

- Pressure-driven processes
- Electric-driven processes

Pressure-Driven Processes

The four general membrane processes that operate by applying pressure to the raw water are:

- Microfiltration
- Ultrafiltration
- Nanofiltration
- Reverse Osmosis

Short Summaries, we will cover these in detail later….

Microfiltration
Microfiltration (**MF**) is a process in which water is forced under pressure through a porous membrane. Membranes with a pore size of 0.45 µm are normally used; this size is relatively large compared with the other membrane filtration processes. This process has not been generally applicable to drinking water treatment because it either does not remove substances that require removal from potable water, or the problem substances can be removed more economically using other processes. The current primary use of MF is by industries to remove very fine particles from process water, such as in electronic manufacturing. In addition, the process has also been used as a pretreatment for other membrane processes. In particular, RO membranes are susceptible to clogging or filter binding unless the water being processed is already quite clean.

However, in recent years, microfiltration has been proposed as a filtering method for particles resulting from the direct filtration process. Traditionally, this direct filtration process has used the injection of coagulants such as alum or polymers into the raw water stream to remove turbidity such as clay or silts. The formed particles were then removed by rapid sand filters. The use of filter aids to improve filtering efficiency, especially for small particles that could contain bacterial and protozoan life are recommended.

Ultrafiltration
Ultrafiltration (**UF**) is a process that uses a membrane with a pore size generally below 0.1 µm. The smaller pore size is designed to remove colloids and substances that have larger molecules, which are called high-molecular-weight materials. UF membranes can be designed to pass material that weigh less than or equal to a certain molecular weight. This weight is called the molecular weight cutoff (**MWC**) of the membrane. Although UF does not generally work well for removal of salt or dissolved solids, it can be used effectively for removal or most organic chemicals.

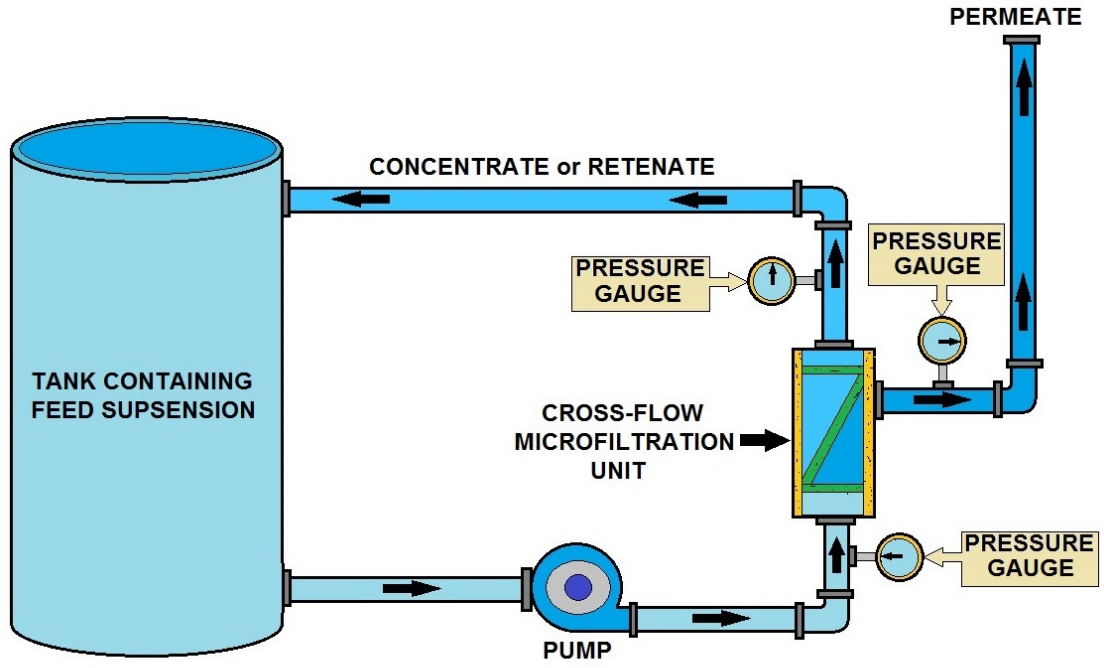
Nanofiltration
Nanofiltration (**NF**) is a process using membranes that will reject even smaller molecules that UF. The process has been used primarily for water softening and reduction of total dissolved solids (**TDS**). NF operates with less pressure that reverse osmosis and is still able to remove a significant proportion of inorganic and organic molecules. This capability will undoubtedly increase the use of NF for potable water treatment.

Reverse Osmosis
Reverse Osmosis (**RO**) is a membrane process that has the highest rejection capability of all the membrane processes. These RO membranes have very low MWC pore size that can reject ions at very high rates, including chloride and sodium. Water from this process is very pure due to the high reject rates.

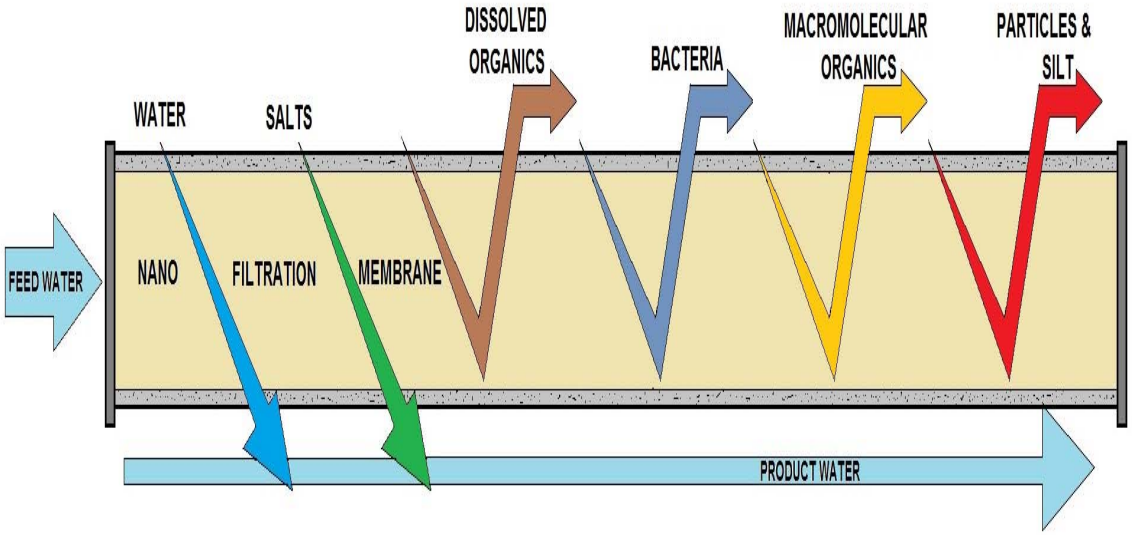
The process has been used primarily in the water industry for desalinization of seawater because the capital and operating costs are competitive with other processes for this service.

The RO also works most organic chemicals, and radionuclides and microorganisms. Industrial water uses such as semiconductor manufacturing is also an important RO process.

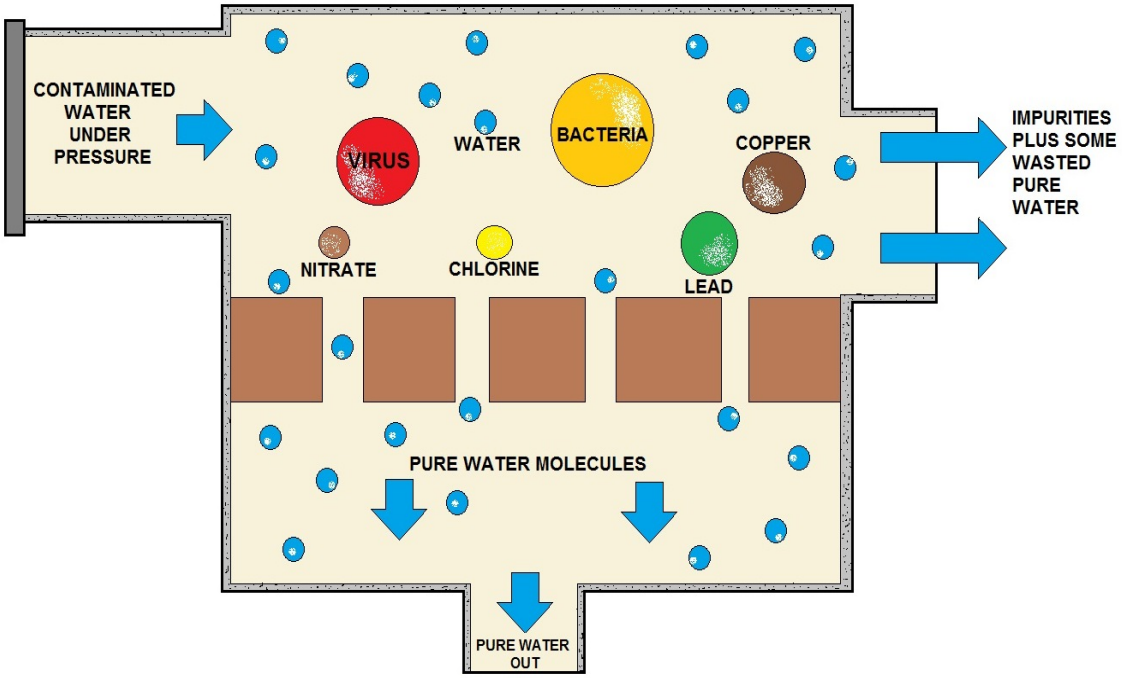
Microfiltration Diagrams



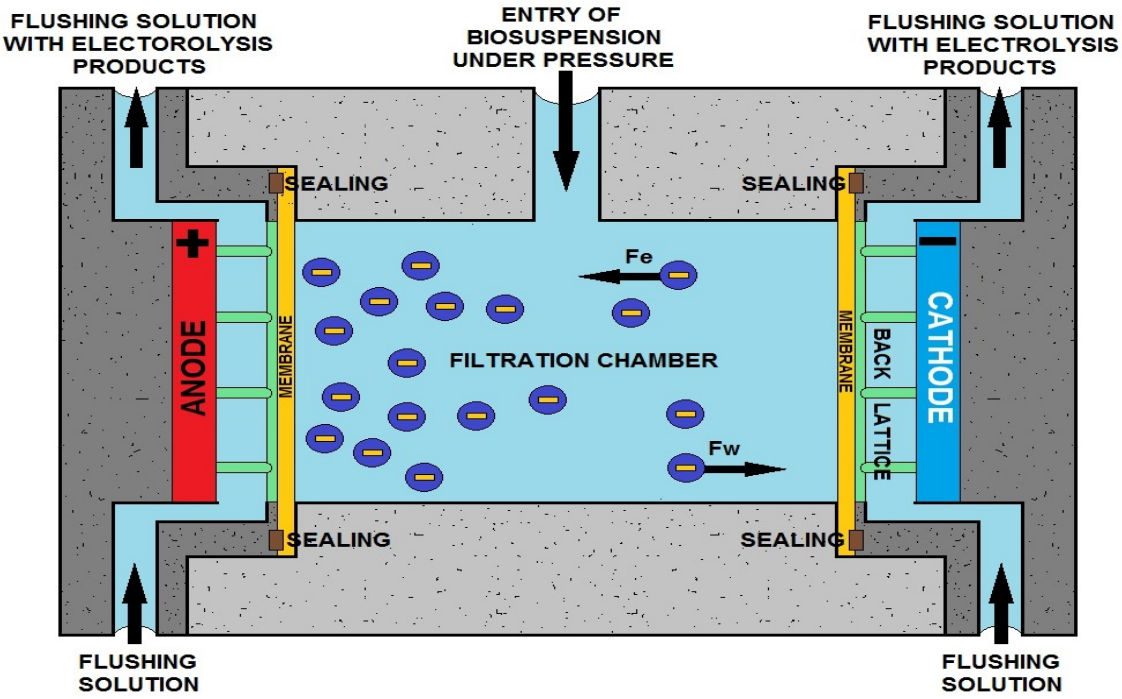
MICROFILTRATION SYSTEM



NANOFILTRATION



REVERSE OSMOSIS SYSTEM BASIC DESIGN



ELECTROFILTRATION CHAMBER

Common Membrane Filtration Operations

According to the driving force of the operation it is possible to distinguish:

- **Pressure driven operations**
  - microfiltration
  - ultrafiltration
  - nanofiltration
  - reverse osmosis
- **Concentration driven operations**
  - dialysis
  - pervaporation
  - forward osmosis
  - artificial lung
  - gas separation
- **Operations in an electric potential gradient**
  - electrodialysis
  - membrane electrolysis e.g. chloralkali process
  - electrodeionization
  - electrofiltration
  - fuel cell
- **Operations in a temperature gradient**
  - membrane distillation

Pore Size and Selectivity

Pore size	Molecular mass	Process	Filtration	Removal of
> 10		"Classic" filter		
> 0.1 µm	> 5000 kDa	microfiltration	< 2 bar	larger bacteria, yeast, particles
100-2 nm	5-5000 kDa	ultrafiltration	1-10 bar	bacteria, macromolecules, proteins, larger viruses
2-1 nm	0.1-5 kDa	nanofiltration	3-20 bar	viruses, 2- valent ions
< 1 nm	< 100 Da	reverse osmosis	10-80 bar	salts, small organic molecules

Filter membranes are divided into four classes according to pore size:

- The pore distribution of a fictitious ultrafiltration membrane with the nominal pore size and the D_{90}
- The pore sizes of technical membranes are specified differently depending on the manufacturer. One common distinction is by *nominal pore size*. It describes the maximum pore size distribution and gives only vague information about the retention capacity of a membrane. The exclusion limit or "cut-off" of the membrane is usually specified in the form of *NMWC* (nominal molecular weight cut-off, or *MWCO*, molecular weight cut off, with units in Dalton). It is defined as the minimum molecular weight of a globular molecule that is retained to 90% by the membrane. The cut-off, depending on the method, can be converted to so-called D_{90}, which is

then expressed in a metric unit. In practice the MWCO of the membrane should be at least 20% lower than the molecular weight of the molecule that is to be separated.

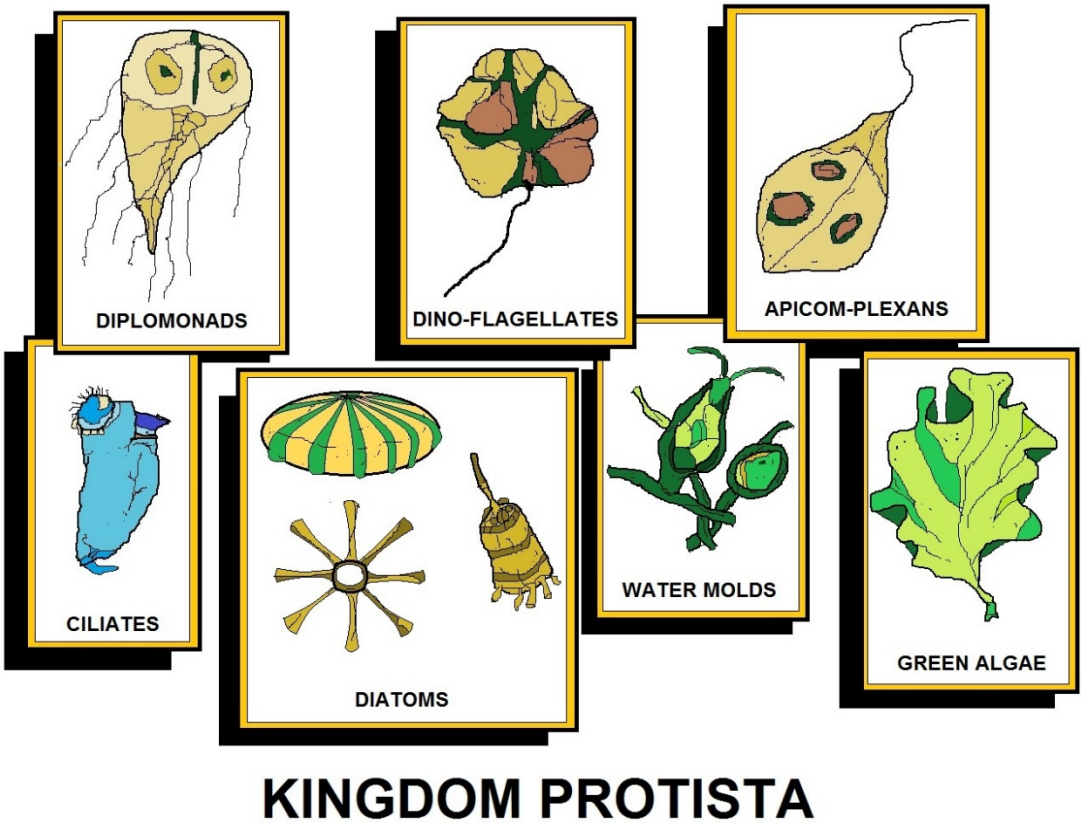
- The form and shape of the membrane pores are highly dependent on the manufacturing process and are often difficult to specify. Therefore, for characterization, test filtrations are carried out and the pore diameter refers to the diameter of the smallest particles which could not pass through the membrane.
- The rejection can be determined in various ways and provides an indirect measurement of the pore size. One possibility is the filtration of macromolecules (often dextran, polyethylene glycol or albumin), another is measurement of the cut-off by gel permeation chromatography. These methods are used mainly to measure membranes for ultrafiltration applications. Another testing method is the filtration of particles with defined size and their measurement with a particle sizer or by laser induced breakdown spectroscopy (LIBS). A vivid characterization is to measure the rejection of dextran blue or other colored molecules. The retention of bacteriophage and bacteria, the so-called "bacteria challenge test", can also provide information about the pore size.
- To determine the pore diameter, physical methods such as porosimetry (mercury, liquid-liquid porosimetry and Bubble Point Test) are also used, but a certain form of the pores (such as cylindrical or concatenated spherical holes) is assumed. Such methods are used for membranes whose pore geometry does not match the ideal, and we get "nominal" pore diameter, which characterizes the membrane, but does not necessarily reflect its actual filtration behavior and selectivity.
- The selectivity is highly dependent on the separation process, the composition of the membrane and its electrochemical properties in addition to the pore size. With high selectivity, isotopes can be enriched (uranium enrichment) in nuclear engineering or industrial gases like nitrogen can be recovered (gas separation). Ideally, even racemics can be enriched with a suitable membrane.
- When choosing membranes selectivity has priority over a high permeability, as low flows can easily be offset by increasing the filter surface with a modular structure. In gas phase filtration different deposition mechanisms are operative, so that particles having sizes below the pore size of the membrane can be retained as well.

Microfiltration Specific Process

Microfiltration (commonly abbreviated to MF) is a type of physical filtration process where a contaminated fluid is passed through a special pore-sized membrane to separate microorganisms and suspended particles from process liquid. It is commonly used in conjunction with various other separation processes such as ultrafiltration and reverse osmosis to provide a product stream which is free of undesired contaminants.

Microfiltration usually serves as a pre-treatment for other separation processes such as ultrafiltration, and a post-treatment for granular media filtration. The typical particle size used for microfiltration ranges from about 0.1 to 10 µm. In terms of approximate molecular weight these membranes can separate macromolecules of molecular weights generally less than 100,000 g/mol.

The filters used in the microfiltration process are specially designed to prevent particles such as, sediment, algae, protozoa or large bacteria from passing through a specially designed filter.



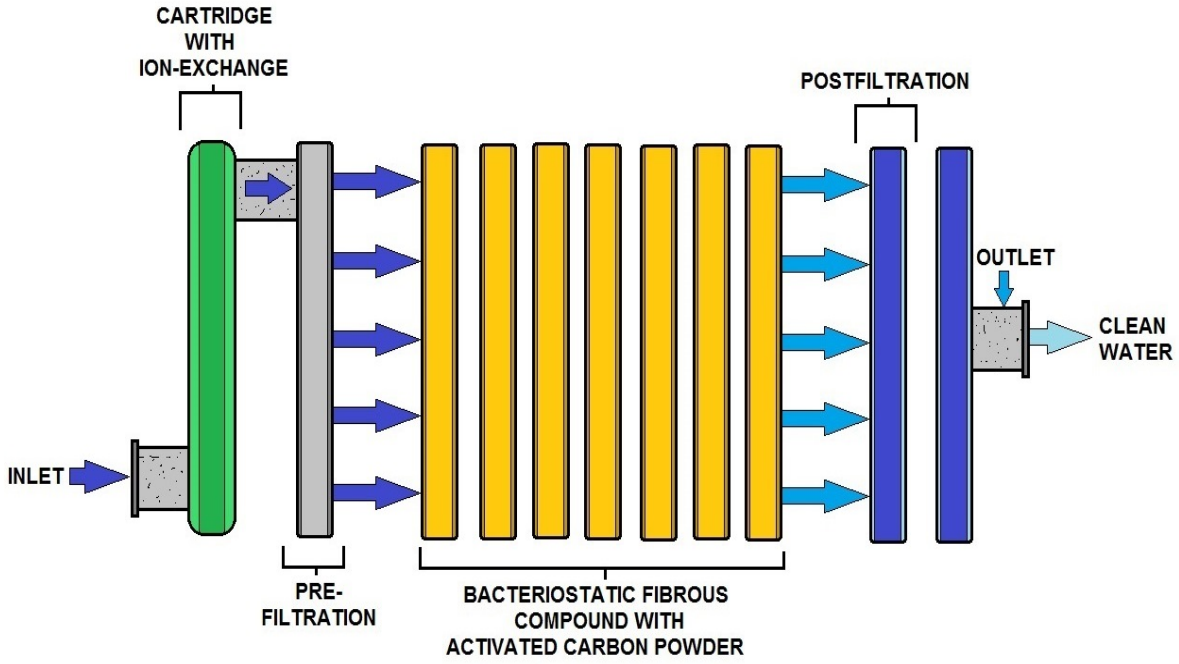
More microorganism information in the Appendix.

More microscopic, atomic or ionic materials such as water (H_2O), monovalent species such as Sodium (Na^+) or Chloride (Cl^-) ions, dissolved or natural organic matter, and small colloids and viruses will still be able to pass through the filter.

The suspended liquid is passed though at a relatively high velocity of around 1–3 m/s and at low to moderate pressures (around 100-400 kPa) parallel or tangential to the semi-permeable membrane in a sheet or tubular form.

A pump is commonly fitted onto the processing equipment to allow the liquid to pass through the membrane filter. There are also two pump configurations, either pressure driven or vacuum.

A differential or regular pressure gauge is commonly attached to measure the pressure drop between the outlet and inlet streams. The most abundant use of microfiltration membranes are in the water, beverage and bio-processing industries. The exit process stream after treatment using a micro-filter has a recovery rate which generally ranges to about 90-98 %



MICROFILTRATION
(VARIATION OF FILTER)

Common Applications

Water Treatment Process
Perhaps the most prominent use of microfiltration membranes pertains to the treatment of potable water supplies. The membranes are a key step in the primary disinfection of the uptake water stream. Such a stream might contain pathogens such as the protozoa Cryptosporidium and Giardia lamblia which are responsible for numerous disease outbreaks. Both species show a gradual resistance to traditional disinfectants (i.e. chlorine).

The use of MF membranes presents a physical means of separation (a barrier) as opposed to a chemical alternative. In this sense, both filtration and disinfection take place in a single step, negating the extra cost of chemical dosage and the corresponding equipment (needed for handling and storage).

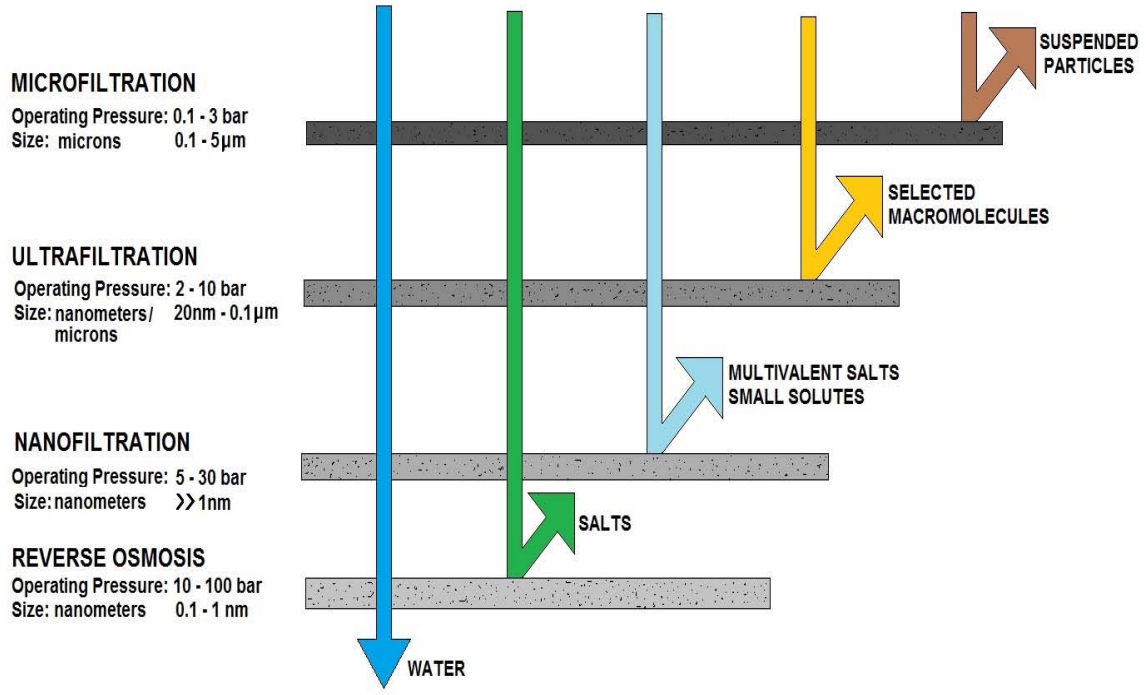
Similarly, the MF membranes are used in secondary wastewater effluents to remove turbidity but also to provide treatment for disinfection. At this stage, coagulants (iron or aluminum) may potentially be added to precipitate species such as phosphorus and arsenic which would otherwise have been soluble.

Sterilization
Another crucial application of MF membranes lies in the cold sterilization of beverages and pharmaceuticals. Historically, heat was used to sterilize refreshments such as juice, wine and beer in particular, however a palatable loss in flavor was clearly evident upon heating. Similarly, pharmaceuticals have been shown to lose their effectiveness upon heat addition. MF membranes are employed in these industries as a method to remove bacteria and other undesired suspensions from liquids, a procedure termed as ‘cold sterilization’, which negate the use of heat.

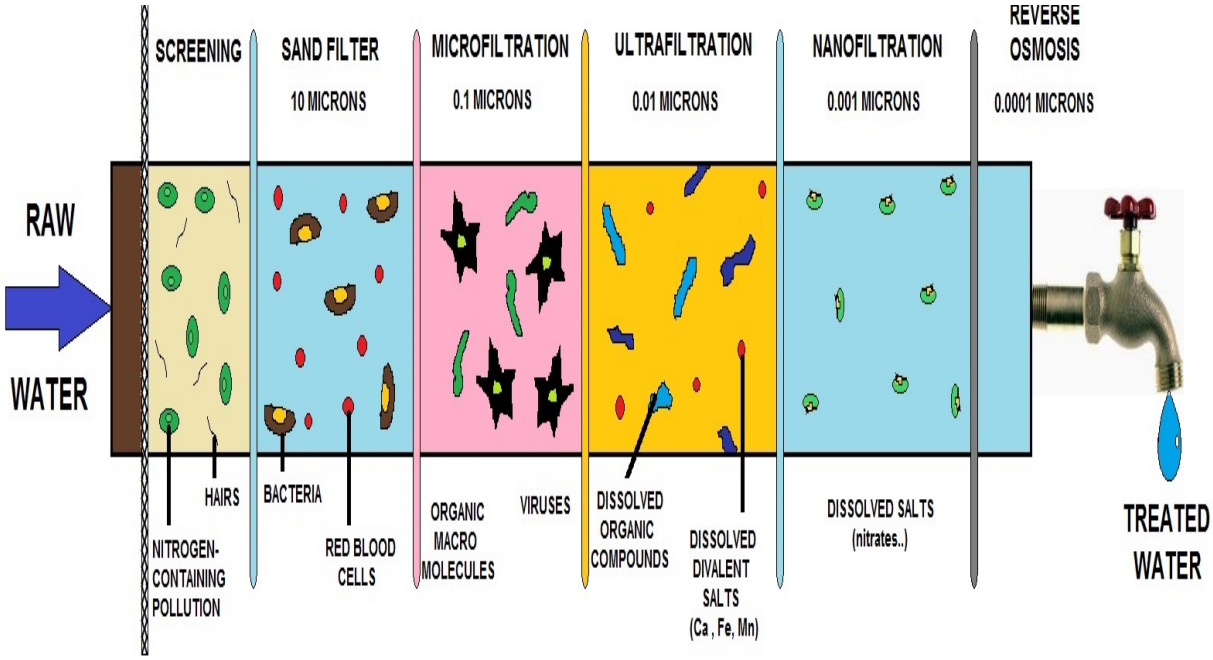
Driving Force, Retentate Stream and Permeate Streams
Membrane filtration processes can be distinguished by three major characteristics; Driving force, retentate stream and permeate streams. The microfiltration process is pressure driven with suspended particles and water as retentate and dissolved solutes plus water as permeate. The use of hydraulic pressure accelerates the separation process by increasing the flow rate (flux) of the liquid stream but does not affect the chemical composition of the species in the retentate and product streams.

Fouling
A major characteristic that limits the performance of microfiltration or any membrane technology is a process known as fouling. Fouling describes the deposition and accumulation of feed components such as suspended particles, impermeable dissolved solutes or even permeable solutes, on the membrane surface and or within the pores of the membrane.

Fouling of the membrane during the filtration processes decreases the flux and thus overall efficiency of the operation. This is indicated when the pressure drop increases to a certain point. It occurs even when operating parameters are constant (pressure, flow rate, temperature and concentration) Fouling is mostly irreversible although a portion of the fouling layer can be reversed by cleaning for short periods of time.



FILTRATION TYPE COMPARISONS



FILTRATION METHODS AND REMOVAL SIZES

Microfiltration Membrane Configurations

Cross-flow Filtration
Where the fluid is passed through tangentially with respect to the membrane. Part of the feed stream containing the treated liquid is collected below the filter while parts of the water are passed through the membrane untreated. Cross flow filtration is understood to be a unit operation rather
than a process.

Dead-end Filtration
All of the process fluid flows and all particles larger than the pore sizes of the membrane are stopped at its surface. All of the feed water is treated at once subject to cake formation. This process is mostly used for batch or semi-continuous filtration of low concentrated solutions.

Process and Equipment Design
The major issues which influence the selection of the membrane include:

Site Specific Issues (Unique to the site where the plant is located)
- Capacity and demand of the facility.
- Percentage recovery and rejection.
- Fluid characteristics (viscosity, turbidity, density)
- Quality of the fluid to be treated
- Pre-treatment processes

Membrane Specific Issues (Unique to the manufacturer or supplier)
- Cost of material procurement and manufacture
- Operating temperature
- Trans-membrane pressure
- Membrane flux
- Handling fluid characteristics (Viscosity, Turbidity, Density)
- Monitoring and maintenance of the system
- Cleaning and treatment
- Disposal of process residuals

Process Design Variables (Regarding proper membrane selection)
- Operation and control of all processes in the system,
- Materials of construction
- Equipment and instrumentation (controllers, sensors) and their cost.

Fundamental Design Heuristics
- When treating raw contaminated fluids, hard sharp materials can wear and tear the porous cavities in the micro-filter, rendering it ineffective. Liquids must be subjected to pre-treatment before passage through the micro-filter. This may be achieved by a variation of macro separation processes such as screening, or granular media filtration.
- When undertaking cleaning regimes the membrane must not dry out once it has been contacted by the process stream. Thorough water rinsing of the membrane modules, pipelines, pumps and other unit connections should be carried out until the end water appears clean.

- Microfiltration modules are typically set to operate at pressures of 100 to 400 kPa. These pressures allow removal of materials such as sand, slits and clays, and also bacteria and protozoa.
- When the membrane modules are being used for the first time, i.e. during plant start-up, conditions need to be well devised. Generally, a slow-start is required when the feed is introduced into the modules, since even slight perturbations above the critical flux will result in irreversible fouling.

Like any other membranes Microfiltration membranes are prone to fouling. It is therefore necessary that regular maintenance be carried out to prolong the life of the membrane module.

- Routine 'backwashing', is used to achieve this. Depending on the specific application of the membrane, backwashing is carried out in short durations (typically 3 to 180 s) and in moderately frequent intervals (5 min to several hours). Turbulent flow conditions with Reynolds numbers greater than 2100, ideally between 3000 - 5000 should be used. This should not however be confused with 'backflushing', a more rigorous and thorough cleaning technique, commonly practiced in cases of particulate and colloidal fouling.
- When major cleaning is needed to remove entrained particles, a CIP (Clean In Place) technique is used. Cleaning agents/detergents, such as sodium hypochlorite, citric acid, caustic soda or even special enzymes are typically used for this purpose. The concentration of these chemicals is dependent on the type of the membrane (its sensitivity to strong chemicals), but also the type of matter (e.g. scaling due to the presence of calcium ions) to be removed.
- Another method to increase the lifespan of the membrane may be feasible to design two microfiltration membranes in series. The first filter would be used for pre-treatment of the liquid passing though the membrane, where larger particles and deposits are captured on the cartridge. The second filter would act as an extra "check" for particles which are able to pass through the first membrane as well as provide screening for particles on the lower spectrum of the range.

Design Economics

The cost to design and manufacture a membrane per unit of area are about 20% less compared to the early 1990s and in a general sense are constantly declining. Microfiltration membranes are more advantageous in comparison to conventional systems. Microfiltration systems do not require expensive extraneous equipment such as flocculates, addition of chemicals, flash mixers, settling and filter basins.

However, the cost of replacement of capital equipment costs (membrane cartridge filters etc.) might still be relatively high as the equipment may be manufactured specific to the application. Using the design heuristics and general plant design principles (mentioned above), the membrane life-span can be increased to reduce these costs.

Through the design of more intelligent process control systems and efficient plant designs some general tips to reduce operating costs are listed below.

- Running plants at reduced fluxes or pressures at low load periods (winter)
- Taking plant systems off-line for short periods when the feed conditions are extreme.
- A short shutdown period (approximately 1 hour) during the first flush of a river after rainfall (in water treatment applications) to reduce cleaning costs in the initial period.

- The use of more cost effective cleaning chemicals where suitable (sulfuric acid instead of citric/ phosphoric acids.)
- The use of a flexible control design system. Operators are able to manipulate variables and set-points to achieve maximum cost savings.

Microfiltration Summary
Membrane configuration can vary between manufacturers, but the "hollow fiber" type is the most commonly used. Membranes in the hollow fiber type are cast into small diameter tubes or straws, nominally one meter in length.

Thousands of these straws are bundled together and the ends are bonded into an epoxy bulkhead or "potting." The ends of potting are cut off to allow access to the inside of the fibers from the end of the potting. The bundles are then sealed into a housing which is usually PVC or stainless steel. The sealed potting creates a separate, sealed space in the module that isolates access to the inside of the fibers from access to the outside. This membrane and housing combination is called a module. It allows water to be forced through the fiber walls without short-circuiting.

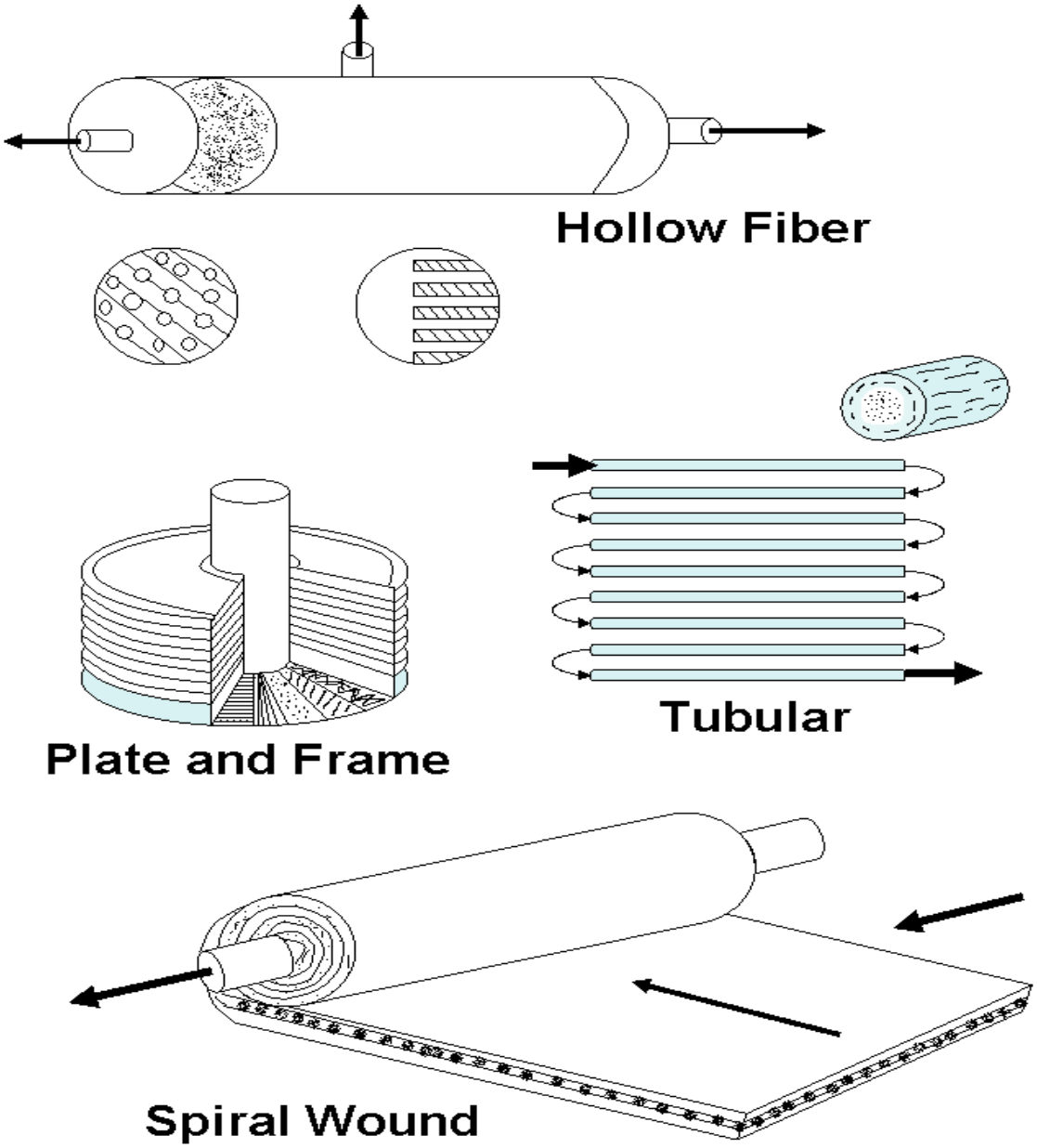
System design is done once the desired flow rate and water conditions are known and a pilot has been performed to determine the required number of modules. The modules are then piped together in a manner which will allow water to be forced from one side of the fibers through the membrane wall and collected from the filtrate side of the modules.

Typically, the water is pumped from the outside of the fibers, and the clean water is collected from the inside of the fibers. This is called "outside-to-inside" flow. This flow direction is sometimes reversed depending on manufacturer and membrane configuration.

Microfiltration membranes used in potable water applications usually operate in the "dead-end" flow regime. In dead-end flow, all of the water fed to the membrane is filtered through the membrane.

A filter cake that must be periodically backwashed from the membrane surface forms. Recovery rates are normally greater than 90 percent on sources which have fairly high quality, low turbidity feeds.

Membrane Configurations



Electric-Driven Processes

There are two membrane processes that purify a water stream by using an electric current to move ions across a membrane. These processes are:

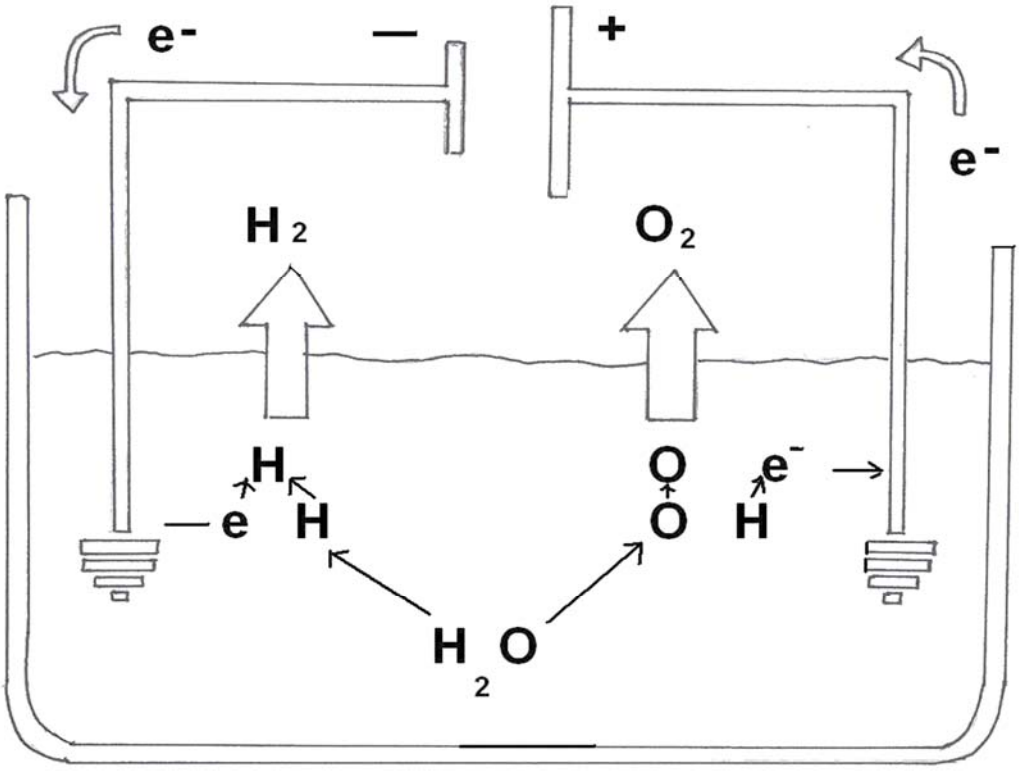
- Electrodialysis
- Electrodialysis reversal

Electrodialysis Sub-Section

Electrodialysis (**ED**) is a process in which ions are transferred through a membrane as a result of direct electric current applied to the solution. The current carries the ions through a membrane from the less concentrated solution to the more concentrated one.

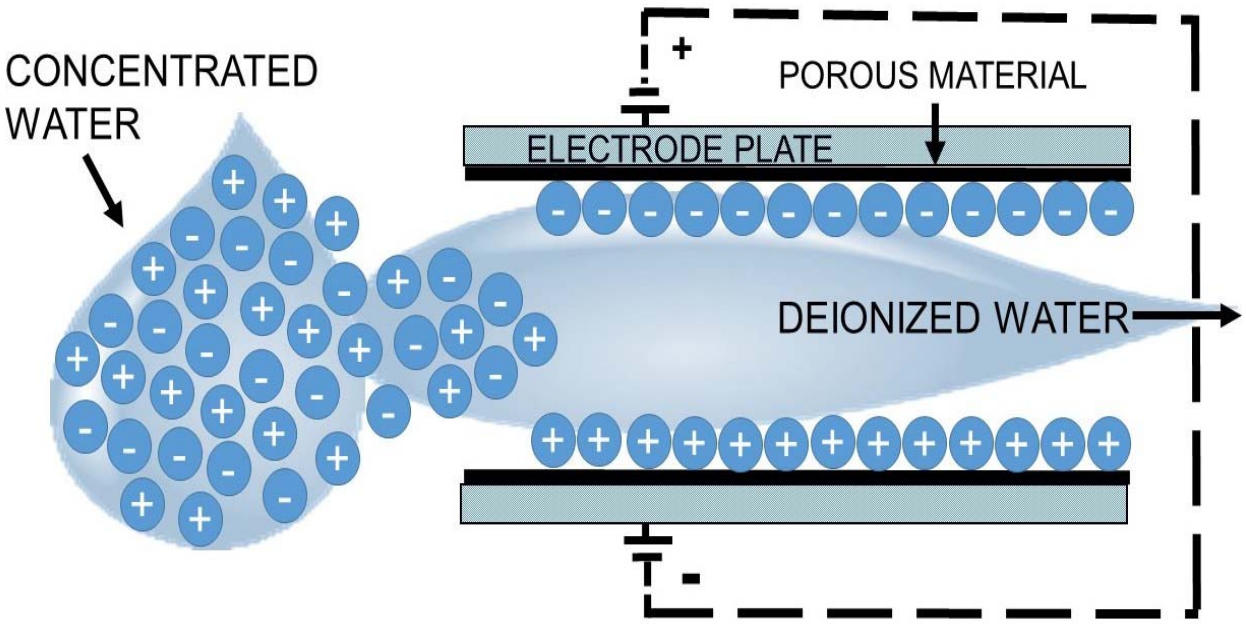
Electrodialysis Reversal
Electrodialysis Reversal (**EDR**) is a process similar to ED, except that the polarity of the direct current is periodically reversed. The reversal in polarity reverses the flow of ions between demineralizing compartments, which provides automatic flushing of scale-forming materials from the membrane surface.

As a result, EDR can often be used with little or no pretreatment of feedwater to prevent fouling. So far, ED and EDR have been used at only a few locations for drinking water treatment.



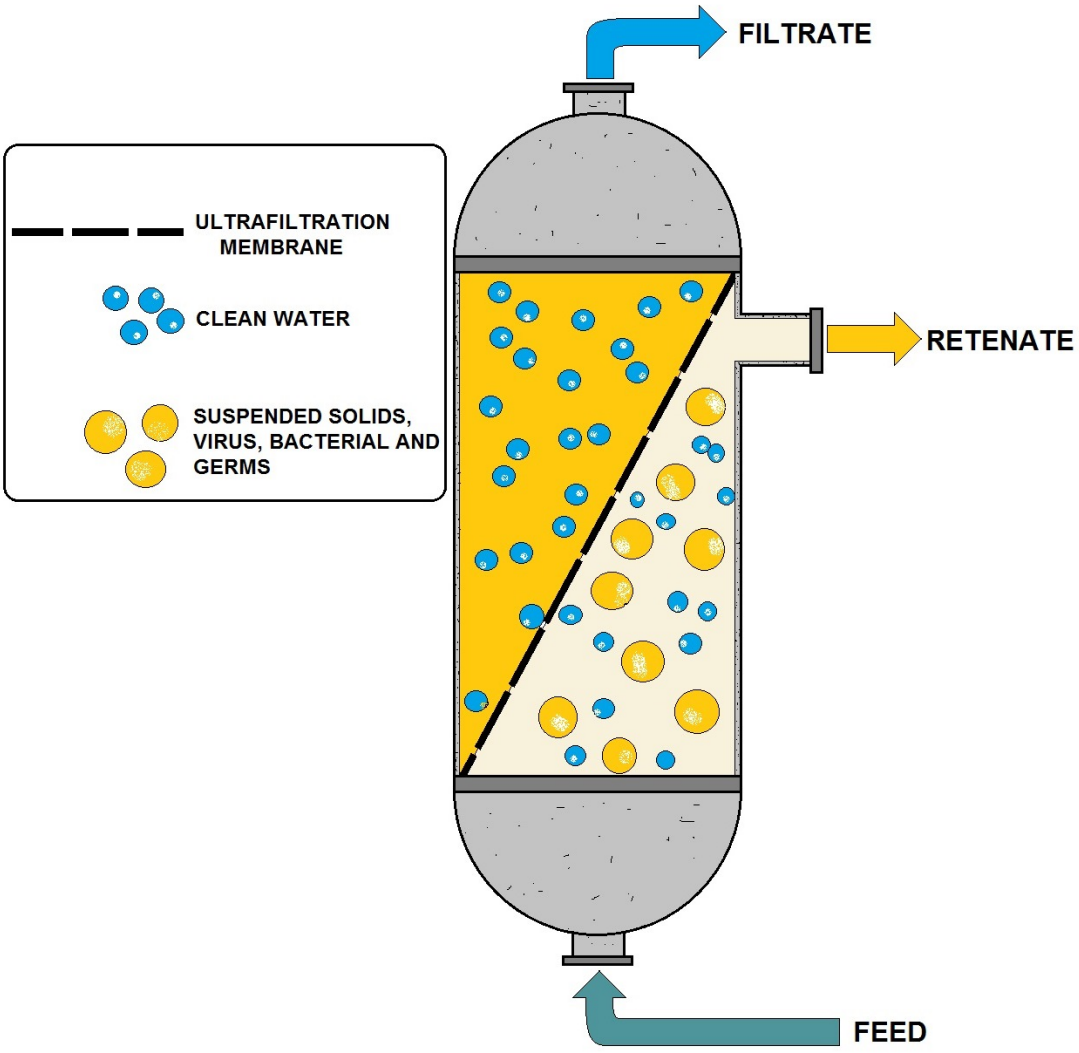
ELECTROLYSIS

(SPLITTING OF H2O WITH ELECTRICITY TO PRODUCE H2 & O2)



CAPACITIVE DEIONIZATION PROCESS

Ultrafiltration (UF) Sub-Section



ULTRAFILTRATION MEMBRANE SYSTEM

Introduction

Ultrafiltration (UF) is a variety of membrane filtration in which forces like pressure or concentration gradients lead to a separation through a semipermeable membrane.

Suspended solids and solutes of high molecular weight are retained in the so-called retentate, while water and low molecular weight solutes pass through the membrane in the permeate. This separation process is used in industry and research for purifying and concentrating macromolecular (10^3 - 10^6 Da) solutions, especially protein solutions.

Ultrafiltration is not fundamentally different from microfiltration. Both of these separate based on size exclusion or particle capture. It is fundamentally different from membrane gas separation, which separate based on different amounts of absorption and different rates of diffusion.

Ultrafiltration membranes are defined by the molecular weight cut-off (MWCO) of the membrane used. Ultrafiltration is applied in cross-flow or dead-end mode.

An ultrafiltration (UF) membrane removes undissolved, suspended or emulsified solids from water supplies without requiring coagulation.

The particles that UF retains have a molecular weight of 1000 to 1,000,000. It is most generally used in specialized applications requiring extremely high purity water, as pretreatment prior to reverse osmosis or for removal of colloidal silica from boiler feed water. Removal includes colloidal silica, synthetic and natural organics, including taste and odor causing compounds, SOCs and natural organic compounds that can serve as precursors to trihalomethanes and other DBPs.

Ultrafiltration generally works by pumping the feeding solution under pressure over the surface of a suitably supported membrane. The pressure gradient forces solvent and smaller species through the pores of the membrane, while the larger molecules are retained. The membranes are cleaned either by backflushing alone or with the addition of a chlorine solution, which restores the original porosity and allows continuous use for indefinite periods.

There are advantages and disadvantages to types of ultrafiltration membranes and the applications they are used for.

Applications
Industries such as chemical and pharmaceutical manufacturing, food and beverage processing, and waste water treatment, employ ultrafiltration in order to recycle flow or add value to later products.

Drinking Water
UF can be used for the removal of particulates and macromolecules from raw water to produce potable water. It has been used to either replace existing secondary (coagulation, flocculation, sedimentation) and tertiary filtration (sand filtration and chlorination) systems employed in water treatment plants or as standalone systems in isolated regions with growing populations. When treating water with high suspended solids, UF is often integrated into the process, utilizing primary (screening, flotation, filtration) and some secondary treatments as pre-treatment stages. UF processes are currently preferred over traditional treatment methods for the following reasons:

- No chemicals required (aside from cleaning)
- Constant product quality regardless of feed quality
- Compact plant size
- Capable of exceeding regulatory standards of water quality, achieving 90-100% pathogen removal

UF processes are currently limited by the high cost incurred due to membrane fouling and replacement. Additional pretreatment of feed water is required to prevent excessive damage to the membrane units.

In many cases UF is used for pre filtration in reverse osmosis (RO) plants to protect the RO membranes.

Compared to traditional methods, UF processes used for this application:

- Are more energy efficient
- Have consistent product quality, 35-80% protein product depending on operating conditions
- Do not denature proteins as they use moderate operating conditions

The potential for fouling is widely discussed, being identified as a significant contributor to decline in productivity.

Concentration Polarization

When filtration occurs the local concentration of rejected material at the membrane surface increases and can become saturated. In UF, increased ion concentration can develop an osmotic pressure on the feed side of the membrane. This reduces the effective TMP of the system, therefore reducing permeation rate.

The increase in concentrated layer at the membrane wall decreases the permeate flux, due to increase in resistance which reduces the driving force for solvent to transport through membrane surface. CP affects almost all the available membrane separation process.

In RO, the solutes retained at the membrane layer results in higher osmotic pressure in comparison to the bulk stream concentration. So the higher pressures are required to overcome this osmotic pressure.

Concentration polarization plays a dominant role in ultrafiltration as compared to microfiltration because of the small pore size membrane. It must be noted that concentration polarization differs from fouling as it has no lasting effects on the membrane itself and can be reversed by relieving the TMP. It does however have a significant effect on many types of fouling.

Types of Fouling

Particulate Deposition

The following models describe the mechanisms of particulate deposition on the membrane surface and in the pores:

- *Standard blocking*: macromolecules are uniformly deposited on pore walls
- *Complete blocking*: membrane pore is completely sealed by a macromolecule
- *Cake filtration*: accumulated particles or macromolecules form a fouling layer on the membrane surface, in UF this is also known as a gel layer
- *Intermediate blocking*: when macromolecules deposit into pores or onto already blocked pores, contributing to cake formation

Scaling

As a result of concentration polarization at the membrane surface, increased ion concentrations may exceed solubility thresholds and precipitate on the membrane surface. These inorganic salt deposits can block pores causing flux decline, membrane degradation and loss of production. The formation of scale is highly dependent on factors affecting both solubility and concentration polarization including pH, temperature, flow velocity and permeation rate.

Biofouling

Microorganisms will adhere to the membrane surface forming a gel layer – known as biofilm. The film increases the resistance to flow, acting as an additional barrier to permeation. In spiral-wound modules, blockages formed by biofilm can lead to uneven flow distribution and thus increase the effects of concentration polarization.

Membrane Arrangements

Depending on the shape and material of the membrane, different modules can be used for ultrafiltration process. Commercially available designs in ultrafiltration modules vary according to the required hydrodynamic and economic constraints as well as the mechanical stability of the system under particular operating pressures. The main modules used in industry include:

Tubular Modules

The tubular module design uses polymeric membranes cast on the inside of plastic or porous paper components with diameters typically in the range of 5 – 25 mm with lengths from 0.6 - 6.4 m. Multiple tubes are housed in a PVC or steel shell. The feed of the module is passed through the tubes, accommodating radial transfer of permeate to the shell side. This design allows for easy cleaning however the main drawback is its low permeability, high volume hold-up within the membrane and low packing density.

Hollow Fiber

This design is conceptually similar to the tubular module with a shell and tube arrangement. A single module can consist of 50 to thousands of hollow fibers and therefore are self-supporting unlike the tubular design. The diameter of each fiber ranges from 0.2 – 3 mm with the feed flowing in the tube and the product permeate collected radially on the outside.

The advantage of having self-supporting membranes as the ease at which it can be cleaned due to its ability to be backflushed. Replacement costs however are high, as one faulty fiber will require the whole bundle to be replaced. Considering the tubes are of small diameter, using this design also makes the system prone to blockage.

Spiral-wound Modules
Are composed of a combination of flat membrane sheets separated by a thin meshed spacer material which serves as a porous plastic screen support. These sheets are rolled around a central perforated tube and fitted into a tubular steel pressure vessel casing. The feed solution passes over the membrane surface and the permeate spirals into the central collection tube.

Spiral-wound modules are a compact and cheap alternative in ultrafiltration design, offer a high volumetric throughput and can also be easily cleaned. However, it is limited by the thin channels where feed solutions with suspended solids can result in partial blockage of the membrane pores.

Plate and Frame
This uses a membrane placed on a flat plate separated by a mesh like material. The feed is passed through the system from which permeate is separated and collected from the edge of the plate.

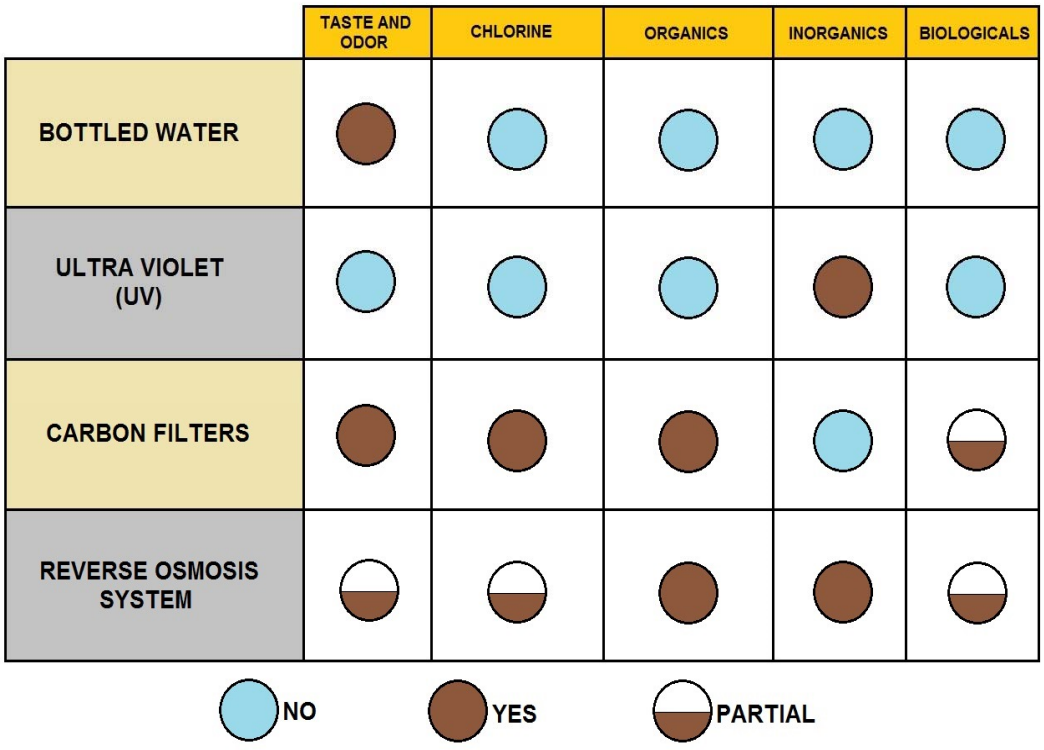
Channel length can range from 10 – 60 cm and channel heights from 0.5 – 1 mm. This module provides low volume hold-up, relatively easy replacement of the membrane and the ability to feed viscous solutions because of the low channel height, unique to this particular design.

Factor	Hollow Fiber	Spiral-wound	Ceramic Tubular
pH	2-13	2-11	3-7
Feed Pressure (psi)	9-15	<30-120	60-100
Backwash Pressure (psi)	9-15	20-40	10-30
Temperature (°C)	5-30	5-45	5-400
Total Dissolved Solids (mg/L)	<1000	<600	<500
Total Suspended Solids (mg/L)	<500	<450	<300
Turbidity (NTU)	<15	<1	<10
Iron (mg/L)	<5	<5	<5
Oils and Greases (mg/L)	<0.1	<0.1	<0.1
Solvents, phenols (mg/L)	<0.1	<0.1	<0.1

Process Characteristics
The process characteristics of a UF system are highly dependent on the type of membrane used and its application. Manufacturers' specifications of the membrane tend to limit the process to the following typical specifications:

Process Design Considerations
When designing a new membrane separation facility or considering its integration into an existing plant, there are many factors which must be considered. For most applications a heuristic approach can be applied to determine many of these characteristics to simplify the design process. Some design areas include:

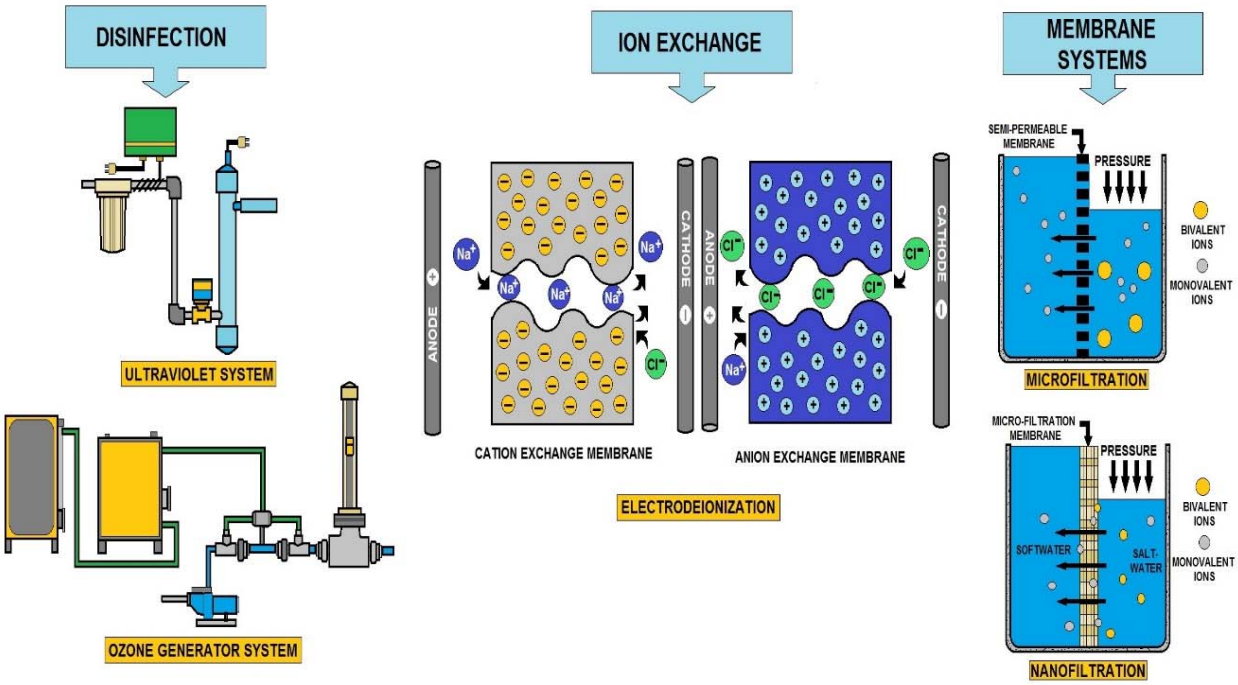
Pre-treatment
Treatment of feed prior to the membrane is essential to prevent damage to the membrane and minimize the effects of fouling which greatly reduce the efficiency of the separation. Types of pre-treatment are often dependent on the type of feed and its quality. For example, in wastewater treatment, household waste and other particulates are screened. Other types of pre-treatment common to many UF processes include pH balancing and coagulation. Appropriate sequencing of each pre-treatment phase is crucial in preventing damage to subsequent stages. Pre-treatment can even be employed simply using dosing points.



TYPES OF WATER QUALITY FILTRATION TECHNOLOGIES AND EFFECTIVE USES

	CHLORINE AS A DISINFECTANT	ULTRAVIOLET GERMICIDAL IRRADIATION (UV) AS A DISINFECTANT
DISINFECTION BYPRODUCTS (DBPs)	X	No
CHEMICAL RESIDUE	X	No
NON-CORROSIVE	X	No
COMMUNITY SAFETY RISKS	X	No
EFFECTIVE AGAINST CRYPTOSPORIDIUM AND GIARDIA	X	Yes
WELL-SUITED FOR CHANGING REGULATIONS	X	Yes

CHLORINE vs. UV FOR DISINFECTION



WATER QUALITY EQUIPMENT

Membrane Specifications

Material
Most UF membranes use polymer materials (polysulfone, polypropylene, cellulose acetate, polylactic acid) however ceramic membranes are used for high temperature applications.

Pore Size
A general rule for choice of pore size in a UF system is to use a membrane with a pore size one tenth that of the particle size to be separated. This limits the number of smaller particles entering the pores and adsorbing to the pore surface. Instead they block the entrance to the pores allowing simple adjustments of cross-flow velocity to dislodge them.

Operation Strategy
Flow Type
UF systems can either operate with cross-flow or dead-end flow. In dead-end filtration the flow of the feed solution is perpendicular to the membrane surface. On the other hand, in cross flow systems the flow passes parallel to the membrane surface.

Dead-end configurations are more suited to batch processes with low suspended solids as solids accumulate at the membrane surface therefore requiring frequent backflushes and cleaning to maintain high flux. Cross-flow configurations are preferred in continuous operations as solids are continuously flushed from the membrane surface resulting in a thinner cake layer and lower resistance to permeation.

Flow Velocity
Flow velocity is especially critical for hard water or liquids containing suspensions in preventing excessive fouling. Higher cross-flow velocities can be used to enhance the sweeping effect across the membrane surface therefore preventing deposition of macromolecules and colloidal material and reducing the effects of concentration polarization. Expensive pumps are however required to achieve these conditions.

Flow Temperature
To avoid excessive damage to the membrane, it is recommended to operate a plant at the temperature specified by the membrane manufacturer. In some instances, however temperatures beyond the recommended region are required to minimize the effects of fouling. Economic analysis of the process is required to find a compromise between the increased cost of membrane replacement and productivity of the separation.

Pressure
Pressure drops over multi-stage separation can result in a drastic decline in flux performance in the latter stages of the process. This can be improved using booster pumps to increase the TMP in the final stages. This will incur a greater capital and energy cost which will be offset by the improved productivity of the process.

With a multi-stage operation, retentate streams from each stage are recycled through the previous stage to improve their separation efficiency.

Multi-Stage, Multi-Module
Multiple stages in series can be applied to achieve higher purity permeate streams. Due to the modular nature of membrane processes, multiple modules can be arranged in parallel to treat greater volumes.

Post-treatment
Post-treatment of the product streams is dependent on the composition of the permeate and retentate and its end-use or government regulation. In cases such as milk separation both streams (milk and whey) can be collected and made into useful products.

Additional drying of the retentate will produce whey powder. In the paper mill industry, the retentate (non-biodegradable organic material) is incinerated to recover energy and permeate (purified water) is discharged into waterways. It is essential for the permeate water to be pH balanced and cooled to avoid thermal pollution of waterways and altering its pH.

Cleaning
Cleaning of the membrane is done regularly to prevent the accumulation of foulants and reverse the degrading effects of fouling on permeability and selectivity. Regular backwashing is often conducted every 10 min for some processes to remove cake layers formed on the membrane surface. By pressurizing the permeate stream and forcing it back through the membrane, accumulated particles can be dislodged, improving the flux of the process.

Backwashing is limited in its ability to remove more complex forms of fouling such as biofouling, scaling or adsorption to pore walls.

These types of foulants require chemical cleaning to be removed. The common types of chemicals used for cleaning are:

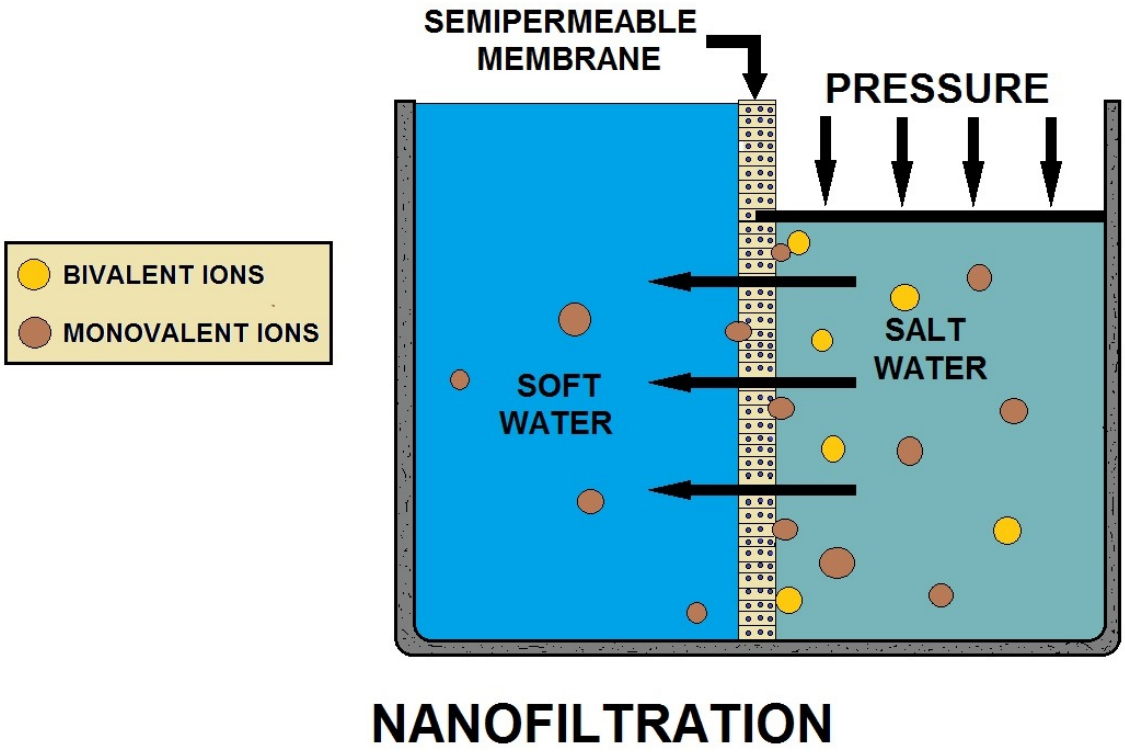
- Acidic solutions for the control of inorganic scale deposits
- Alkali solutions for removal of organic compounds
- Biocides or disinfection such as Chlorine or peroxide when bio-fouling is evident

Cleaning Time
Adequate time must be allowed for chemicals to interact with foulants and permeate into the membrane pores. However, if the process is extended beyond its optimum duration it can lead to denaturation of the membrane and deposition of removed foulants. The complete cleaning cycle including rinses between stages may take as long as 2 hours to complete.

Aggressiveness of Chemical Treatment
With a high degree of fouling it may be necessary to employ aggressive cleaning solutions to remove fouling material. However, in some applications this may not be suitable if the membrane material is sensitive, leading to enhanced membrane ageing.

Disposal of Cleaning Effluent
The release of some chemicals into wastewater systems may be prohibited or regulated therefore this must be considered. For example, the use of phosphoric acid may result in high levels of phosphates entering water ways and must be monitored and controlled to prevent eutrophication.

Nanofiltration (NF) Sub-Section



In this section, the student will understand and explain Nanofiltration treatment methods and terminology.

a. Range of Application
b. Spiral Wound Module
c. Performance Parameters
d. Van der waals
e. Anisotropic

Nanofiltration Introduction

Nanofiltration is a relatively recent membrane filtration process used most often with low total dissolved solids water such as surface water and fresh groundwater, with the purpose of softening (polyvalent cation removal) and removal of disinfection by-product precursors such as natural organic matter and synthetic organic matter.

Nanofiltration is also becoming more widely used in food processing applications such as dairy, for simultaneous concentration and partial (monovalent ion) demineralization.

Nanofiltration is a membrane filtration-based method that uses nanometer sized cylindrical through-pores that pass through the membrane at 90°.

Nanofiltration membranes have pore sizes from 1-10 nanometers, smaller than that used in **microfiltration** and **ultrafiltration**, but just larger than that in reverse osmosis. Membranes used are predominantly created from polymer thin films. Materials that are commonly use include polyethylene terephthalate or metals such as aluminum. Pore dimensions are controlled by pH, temperature and time during development with pore densities ranging from 1 to 106 pores per cm^2.

Membranes made from polyethylene terephthalate and other similar materials, are referred to as “track-etch” membranes, named after the way the pores on the membranes are made.

“Tracking” involves bombarding the polymer thin film with high energy particles. This results in making tracks that are chemically developed into the membrane, or “etched” into the membrane, which are the pores. Membranes created from metal such as alumina membranes, are made by electrochemically growing a thin layer of aluminum oxide from aluminum metal in an acidic medium.

Range of Applications
Historically, nanofiltration and other membrane technology used for molecular separation was applied entirely on aqueous systems. The original uses for nanofiltration were water treatment and in particular water softening. Nanofilters can “soften” water by retaining scale-forming, hydrated divalent ions (e.g. Ca^{2+}, Mg^{2+}) while passing smaller hydrated monovalent ions.

In recent years, the use of nanofiltration has been extended into other industries such as milk and juice production. Research and development in solvent-stable membranes has allowed the application for nanofiltration membranes to extend into new areas such as pharmaceuticals, fine chemicals, and flavor and fragrance industries. Development in organic solvent nanofiltration technology and commercialization of membranes used has extended possibilities for applications in a variety of organic solvents ranging from non-polar through polar to polar aprotic.

Advantages and Disadvantages
One of the main advantages of nanofiltration as a method of softening water is that during the process of retaining calcium and magnesium ions while passing smaller hydrated monovalent ions, filtration is performed without adding extra sodium ions, as used in ion exchangers.

Many separation processes do not operate at room temperature (e.g. distillation), which greatly increases the cost of the process when continuous heating or cooling is applied. Performing gentle molecular separation is linked with nanofiltration that is often not included with other forms of separation processes (centrifugation). These are two of the main benefits that are associated with nanofiltration.

Nanofiltration has a very favorable benefit of being able to process large volumes and continuously produce streams of have a Nanofiltration is the least used method of membrane filtration in industry as the membrane pores sizes are limited to only nanometers. Anything smaller, reverse osmosis is used and anything larger is used for ultrafiltration.

Ultrafiltration can also be used in cases where nanofiltration can be used, due to it being more conventional. A main disadvantage associated with nanotechnology, as with all membrane filter technology, is the cost and maintenance of the membranes used.

Nanofiltration membranes are an expensive part of the process. Repairs and replacement of membranes is dependent on total dissolved solids, flow rate and components of the feed. With nanofiltration being used across various industries, only an estimation of replacement frequency can be used. This causes nanofilters to be replaced a short time before or after their prime usage is complete.

Design and Operation
Industrial applications of membranes require hundreds to thousands of square meters of membranes and therefore an efficient way to reduce the footprint by packing them is required. Membranes first became commercially viable when low cost methods of housing in ‘modules’ were achieved. Membranes are not self-supporting. They need to be stayed by a porous support that can withstand the pressures required to operate the NF membrane without hindering the performance of the membrane.

To do this effectively, the module needs to provide a channel to remove the membrane permeation and provide appropriate flow condition that reduces the phenomena of concentration polarization. A good design minimizes pressure losses on both the feed side and permeate side and thus energy requirements. Leakage of the feed into the permeate stream must also be prevented. This can be done through either the use of permanent seals such as glue or replaceable seals such as O-rings.

Concentration Polarization
Concentration polarization describes the accumulation of the species being retained close to the surface of the membrane which reduces separation capabilities. It occurs because the particles are convected towards the membrane with the solvent and its magnitude is the balance between this convection caused by solvent flux and the particle transport away from the membrane due to the concentration gradient (predominantly caused by diffusion.) Although concentration polarization is easily reversible, it can lead to fouling of the membrane.

Spiral Wound Module
Spiral wound modules are the most commonly used style of module and are ‘standardized’ design, available in a range of standard diameters (2.5”, 4” and 8”) to fit standard pressure vessel that can hold several modules in series connected by O-rings.

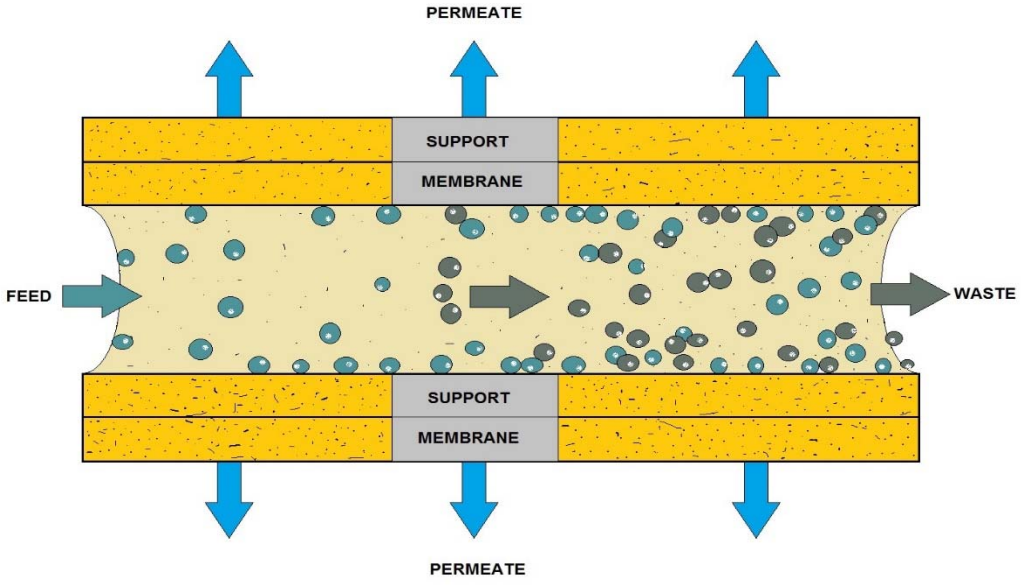
The module uses flat sheets wrapped around a central tube. The membranes are glued along three edges over a permeate spacer to form ‘leaves’.

The permeate spacer supports the membrane and conducts the permeate to the central permeate tube. Between each leaf, a mesh like feed spacer is inserted. The reason for the mesh like dimension of the spacer is to provide a hydrodynamic environment near the surface of the membrane that discourages concentration polarization.

Once the leaves have been wound around the central tube, the module is wrapped in a casing layer and caps placed on the end of the cylinder to prevent ‘telescoping’ that can occur in high flow rate and pressure conditions.

Tubular Module
Tubular modules look similar to shell and tube heat exchangers with bundles of tubes with the active surface of the membrane on the inside. Flow through the tubes is normally turbulent, ensuring low concentration polarization but also increasing energy costs. The tubes can either be self-supporting or supported by insertion into perforated metal tubes. This module design is limited for nanofiltration by the pressure they can withstand before bursting, limiting the maximum flux possible.

Due to both the high energy operating costs of turbulent flow and the limiting burst pressure, tubular modules are more suited to 'dirty' applications where feeds have particulates such as filtering raw water to gain potable water in the Fyne process. The membranes can be easily cleaned through a 'pigging' technique with foam balls are squeezed through the tubes, scouring the caked deposits.



TUBULAR MEMBRANE FILTRATION

Flux Enhancing Strategies
These strategies work to reduce the magnitude of concentration polarization and fouling. There is a range of techniques available however the most common is feed channel spacers as described in spiral wound modules. All of the strategies work by increasing eddies and generating a high shear in the flow near the membrane surface. Some of these strategies include vibrating the membrane, rotating the membrane, having a rotor disk above the membrane, pulsing the feed flow rate and introducing gas bubbling close to the surface of the membrane.

Characterization
Many different factors must be taken into account in the design of NF membranes, since they vary so much in material, separation mechanisms, morphology and thus application. Two important parameters should be investigated during preliminary calculations, performance and morphology parameters.

Performance Parameters
Retention of both charged and uncharged solutes and permeation measurements can be categorized into performance parameters since the performance under natural conditions of a membrane is based on the ratio of solute retained/ permeated through the membrane.

For charged solutes, the ionic distribution of salts near the membrane-solution interface plays an important role in determining the retention characteristic of a membrane.

If the charge of the membrane and the composition and concentration of the solution to be filtered is known, the distribution of various salts can be found. This in turn can be combined with the known charge of the membrane and the Gibbs–Donnan effect to predict the retention characteristics for that membrane.

Uncharged solutes cannot be characterized simply by Molecular Weight Cut Off (MWCO,) although in general an increase in molecular weight or solute size leads to an increase in retention. The chemical structure, functional end-groups as well as pH of the solute, all play an important role in determining the retention characteristics and as such detailed information about the solute molecule characteristics must be known before implementing a NF design.

Molecular weight cut-off or **MWCO** refers to the lowest molecular weight solute (in daltons) in which 90% of the solute is retained by the membrane, or the molecular weight of the molecule (e.g. globular protein) that is 90% retained by the membrane.

This definition is not however standardized, and MWCOs can also be defined as the molecular weight at which 80% of the analytes (or solutes) are prohibited from membrane diffusion. Commercially available microdialysis probes typically have molecular weight cutoffs that range from 1,000 to 300,000 Da, and larger thresholds of filtration are measured in μm.

Morphology Parameters
The morphology of a membrane must also be known in order to implement a successful design of a NF system, and this is usually done by microscopy. Atomic force microscopy (AFM) is one method used to characterize the surface roughness of a membrane by passing a small sharp tip (<100 Ă) across the surface of a membrane and measuring the resulting Van der Waals force between the atoms in the end of the tip and the surface. This is useful as a direct correlation between surface roughness and colloidal fouling has been developed.

Correlations also exist between fouling and other morphology parameters, such as hydrophobe, showing that the more hydrophobic a membrane is, the less prone to fouling it is. Methods to determine the porosity of porous membranes have also been found via permporometry, making use of differing vapor pressures to characterize the pore size and pore size distribution within the membrane.

Initially all pores in the membrane are completely filled with a liquid and as such no permeation of a gas occurs, but after reducing the relative vapor pressure some gaps will start to form within the pores as dictated by the Kelvin equation. Polymeric (non-porous) membranes cannot be subjected to this methodology as the condensable vapor should have a negligible interaction within the membrane

Van der Waals
Van der Waals forces include attraction and repulsions between atoms, molecules, and surfaces, as well as other intermolecular forces. They differ from covalent and ionic bonding in that they are caused by correlations in the fluctuating polarizations of nearby particles (a consequence of quantum dynamics).

Intermolecular forces have four major contributions:

1. A repulsive component resulting from the Pauli exclusion principle that prevents the collapse of molecules.
2. Attractive or repulsive electrostatic interactions between permanent charges (in the case of molecular ions), dipoles (in the case of molecules without inversion center), quadrupoles (all molecules with symmetry lower than cubic), and in general between permanent multipoles. The electrostatic interaction is sometimes called the Keesom interaction or Keesom force after Willem Hendrik Keesom.
3. Induction (also known as polarization), which is the attractive interaction between a permanent multipole on one molecule with an induced multipole on another. This interaction is sometimes called Debye force after Peter J.W. Debye.
4. Dispersion (usually named after Fritz London), which is the attractive interaction between any pair of molecules, including non-polar atoms, arising from the interactions of instantaneous multipoles.

Returning to nomenclature, different texts refer to different things using the term "van der Waals force." Some texts describe the van der Waals force as the totality of forces (including repulsion); others mean all the attractive forces (and then sometimes distinguish van der Waals-Keesom, van der Waals-Debye, and van der Waals-London).

Anisotropic
All intermolecular/van der Waals forces are anisotropic (except those between two noble gas atoms), which means that they depend on the relative orientation of the molecules. The induction and dispersion interactions are always attractive, irrespective of orientation, but the electrostatic interaction changes sign upon rotation of the molecules. That is, the electrostatic force can be attractive or repulsive, depending on the mutual orientation of the molecules.

When molecules are in thermal motion, as they are in the gas and liquid phase, the electrostatic force is averaged out to a large extent, because the molecules thermally rotate and thus probe both repulsive and attractive parts of the electrostatic force. Sometimes this effect is expressed by the statement that "random thermal motion around room temperature can usually overcome or disrupt them" (which refers to the electrostatic component of the van der Waals force).

Clearly, the thermal averaging effect is much less pronounced for the attractive induction and dispersion forces. The Lennard-Jones potential is often used as an approximate model for the isotropic part of a total (repulsion plus attraction) van der Waals force as a function of distance.

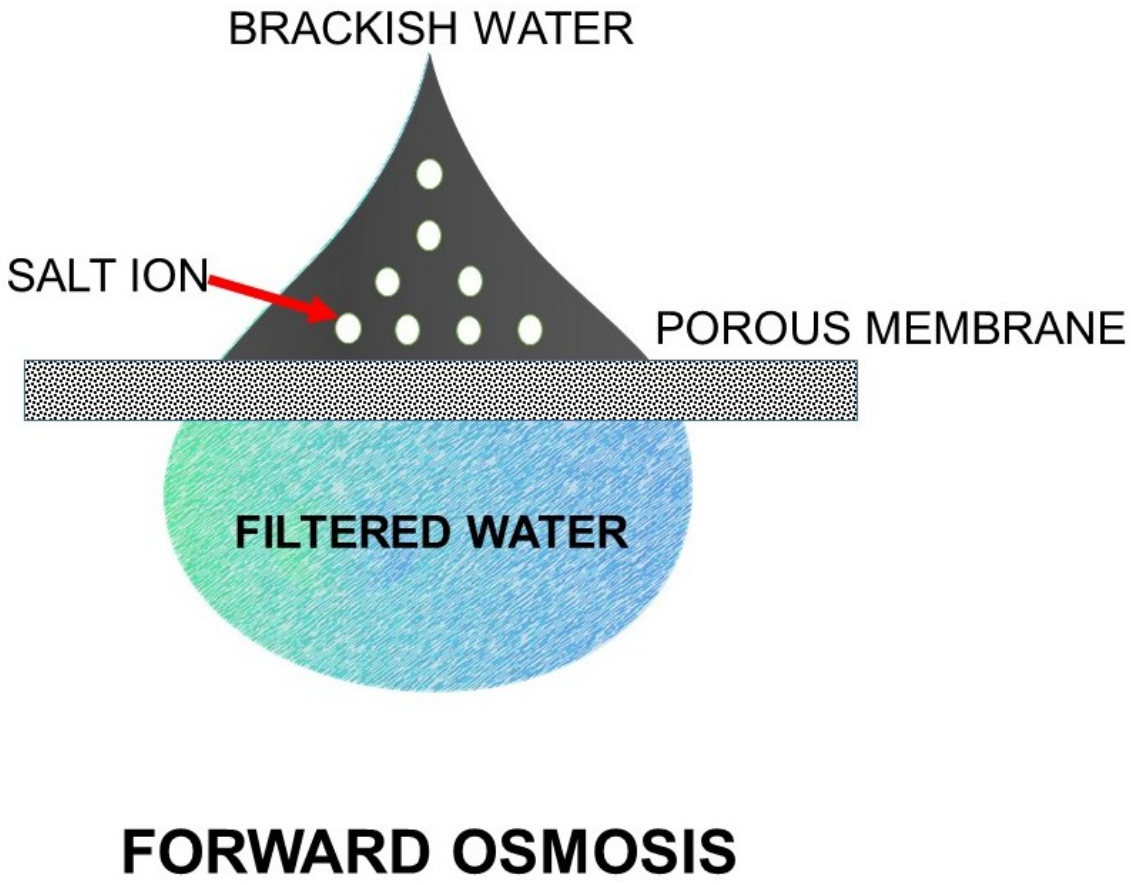
Van der Waals forces are responsible for certain cases of pressure broadening (van der Waals broadening) of spectral lines and the formation of van der Waals molecules. The London-van der Waals forces are related to the Casimir effect for dielectric media, the former being the microscopic description of the latter bulk property.

The first detailed calculations of this were done in 1955 by E. M. Lifshitz. A more general theory of van der Waals forces has also been developed.

The main characteristics of van der Waals forces are:

- They are weaker than normal covalent ionic bonds.
- Van der Waals forces are additive and cannot be saturated.
- They have no directional characteristic.
- They are all short-range forces and hence only interactions between nearest need to be considered instead of all the particles. The greater is the attraction if the molecules are closer due to Van der Waals forces.
- Van der Waals forces are independent of temperature except dipole - dipole interactions.

Osmotic Processes Sub-Section



In this section, the student will understand and explain Forward and Reverse Osmosis treatment methods and terminology.

a. Forward Osmosis
b. Reverse Osmosis
c. Brine Channel
d. R/O Components
e. Clean-in-place System

Forward Osmosis (FO) Introduction

Osmotic processes manipulate osmotic pressure gradient between solutions. Osmotic processes include reverse osmosis (RO), forward osmosis (FO), pressure enhanced osmosis (PEO) and pressure retarded osmosis (PRO).

Forward osmosis (FO) is an osmotic process that, like reverse osmosis (RO), uses a semi-permeable membrane to effect separation of water from dissolved solutes.

The driving force for this separation is an osmotic pressure gradient, such that a "draw" solution of high concentration (relative to that of the feed solution), is used to induce a net flow of water through the membrane into the draw solution, thus effectively separating the feed water from its solutes.

In contrast, the reverse osmosis process uses hydraulic pressure as the driving force for separation, which serves to counteract the osmotic pressure gradient that would otherwise favor water flux from the permeate to the feed. Hence significantly more energy is required for reverse osmosis compared to forward osmosis.

In FO processes we may have solute diffusion in both directions depending on the composition of the draw solution and the feed water. This does two things; the draw solution solutes may diffuse to the feed solution and the feed solution solutes may diffuse to the draw solution.

Clearly this phenomenon has consequences in terms of the selection of the draw solution for any particular FO process. For instance, the loss of draw solution may affect the feed solution perhaps due to environmental issues or contamination of the feed stream, such as in osmotic membrane bioreactors.

An additional distinction between the reverse osmosis (RO) and forward osmosis (FO) processes is that the permeate water resulting from an RO process is in most cases fresh water ready for use. In the FO process, this is not the case. The membrane separation of the FO process in effect results in a "trade" between the solutes of the feed solution and the draw solution.

Depending on the concentration of solutes in the feed (which dictates the necessary concentration of solutes in the draw) and the intended use of the product of the FO process, this step may be all that is required.

The forward osmosis process is also known as osmosis or in the case of a number of companies who have coined their own terminology 'engineered osmosis' and 'manipulated osmosis'.

Forward Osmosis Summary

Forward osmosis (FO) is an osmotic process that uses a semi-permeable membrane to effect separation of water from dissolved solutes. The driving force for this separation is an osmotic pressure gradient between a solution of high concentration, often referred to as a "draw" and a solution of lower concentration, referred to as the "feed".

The osmotic pressure gradient is used to induce a net flow of water through the membrane into the draw, thus effectively concentrating the feed. The draw solution can consist of a single or multiple simple salts or can be a substance specifically tailored for forward osmosis applications. The feed solution can be a dilute product stream, a waste stream or seawater.

Most of the applications of FO, thus fall into three broad categories: product concentration, waste concentration or production of clean water as a bi-product of the concentration process. The most efficient FO applications combine all three. At its best, FO can concentrate waste, turning waste into a product all while producing clean water.

The Forward Osmosis process has applications in many different industries, including but not limited to: Water Reuse and Desalination; Food and Beverage; Mining; Oil and Gas; and the Power Industry.

FO Applications in Different Industries:

- ✓ Water Reuse
- ✓ Water Desalination
- ✓ Brine Concentration
- ✓ Product concentration (examples: juice, chemicals)
- ✓ Produced water treatment

RO produces clean water, FO produces clean draw, while PRO produces power.

Distinction Between RO and FO Processes

A major distinction between the RO and FO processes is that the water permeating the RO process is, in most cases, fresh water ready for use. In the FO process, this is not the case.

The membrane separation of the FO process in effect results in a "trade" between the solutes of the feed solution and the draw solution.

- ✓ Pressure Retarded Osmosis (PRO) may be used to convert salinity gradient into power.
- ✓ Forward osmosis is not a replacement for reverse osmosis.

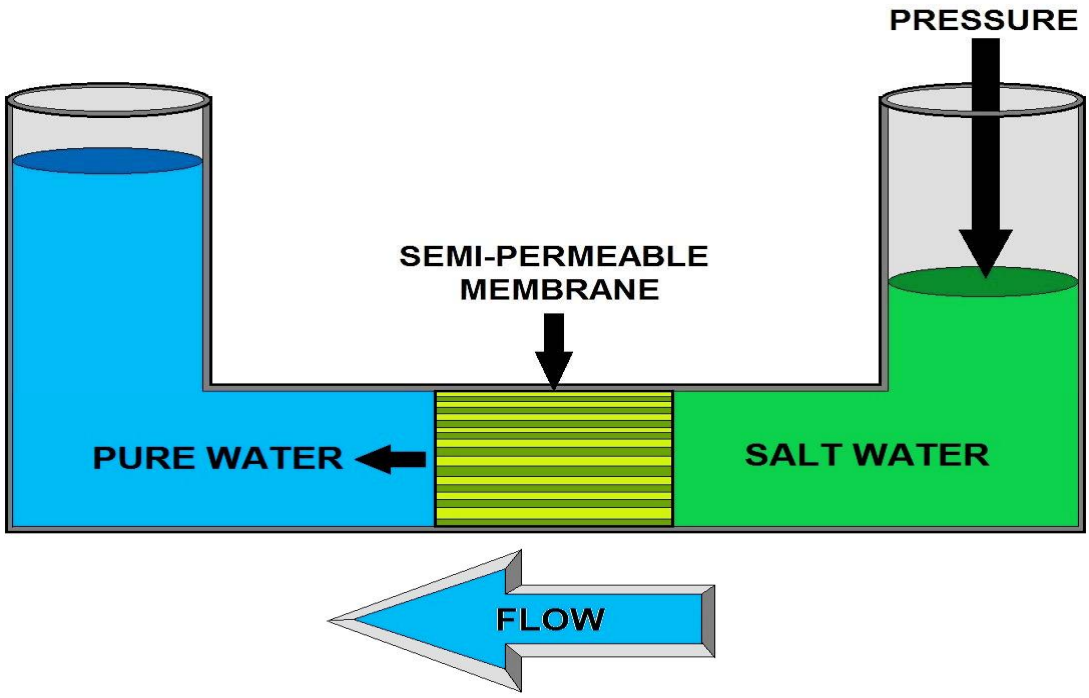
In some applications FO complements RO. In others, specialized draw or salt is concentrated using different technologies. FO can also be used without the draw concentration step as an FO Concentrator if a brine stream with high osmotic pressure is available.

FO can concentrate waters with higher total dissolved solids (TDS) than RO using a high osmotic draw.

- ✓ Membranes used for RO do not work well for FO.

- ✓ Different materials and membrane structure are required to achieve good membrane productivity.
- ✓ FO fouls less than RO.

In contrast with forward osmosis, the reverse osmosis process uses hydraulic pressure as the driving force for separation, which serves to counteract the osmotic pressure gradient that would otherwise favor water flux from the permeate to the feed. One of the reasons that FO membranes are considerably less prone to fouling than membranes used in pressure driven processes is the absence of external pressure which compacts foulants into the membrane surface restricting flow.



REVERSE OSMOSIS

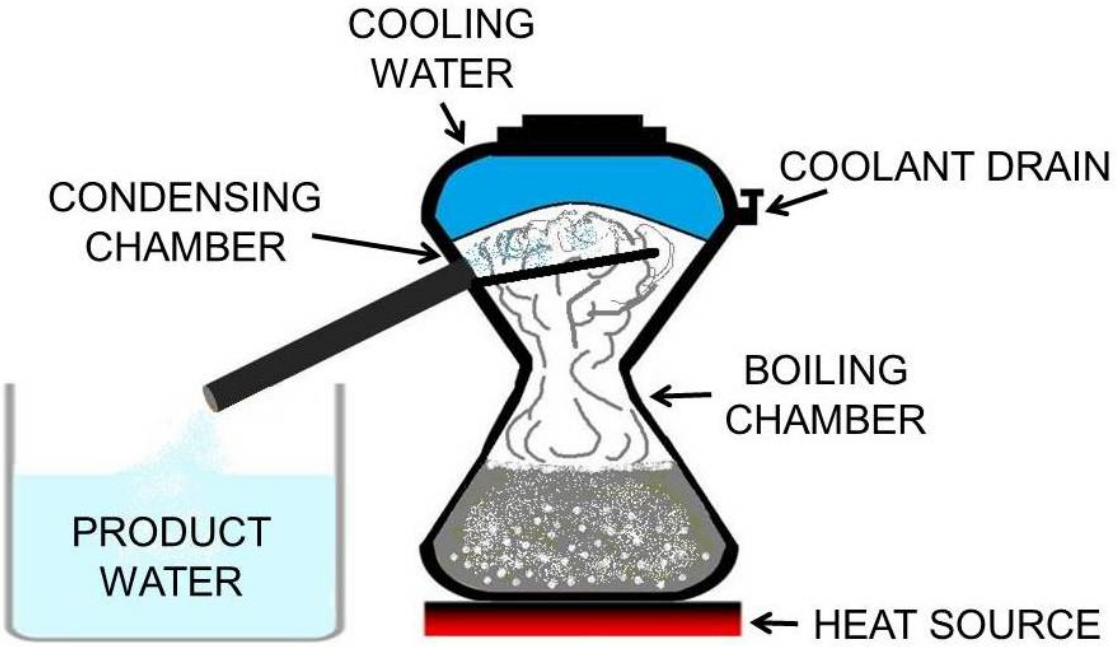
Reverse Osmosis and Nanofiltration processes work in a similar way to an extremely fine filter but use a *"membrane"* to remove atoms which are larger than water molecules.

The mechanism requires sophisticated pumping and control. RO is therefore used to remove a wide range of contaminants, typically salts, hardness and large organic molecules where a very high level of purity is required. It is, of course, more expensive than conventional filtration and is used only where high purity is essential.

Disadvantages of using ultrafiltration, nanofiltration or reverse osmosis to treat water?

Reverse osmosis removes a number of healthy minerals from water, in addition to the harmful minerals and particles. The removal of these minerals, including calcium and magnesium, can actually make water unhealthy, especially for people with inadequate diets and people who live in hot climates, as water can provide these necessary minerals. The addition of calcium and magnesium, as described above, can resolve these concerns.

Desalination Sub-Section



DESALINATION - DISTILLATION

Desalinated water can be produced from the diluted draw / osmotic agent solution, using a second process. This may be by membrane separation, thermal method, physical separation or a combination of these processes. The process has the feature of inherently low fouling because of the forward osmosis first step, unlike conventional reverse osmosis desalination plants where fouling is often a problem.

One other application developed, where only the forward osmosis step is used, is in evaporative cooling make-up water. In this case the cooling water is the draw solution and the water lost by evaporation is simply replaced using water produced by forward osmosis from a suitable source, such as seawater, brackish water, treated sewage effluent or industrial waste water. Thus in comparison with other 'desalination' processes that may be used for make-up water the energy consumption is a fraction of these with the added advantage of the low fouling propensity of a forward osmosis process.

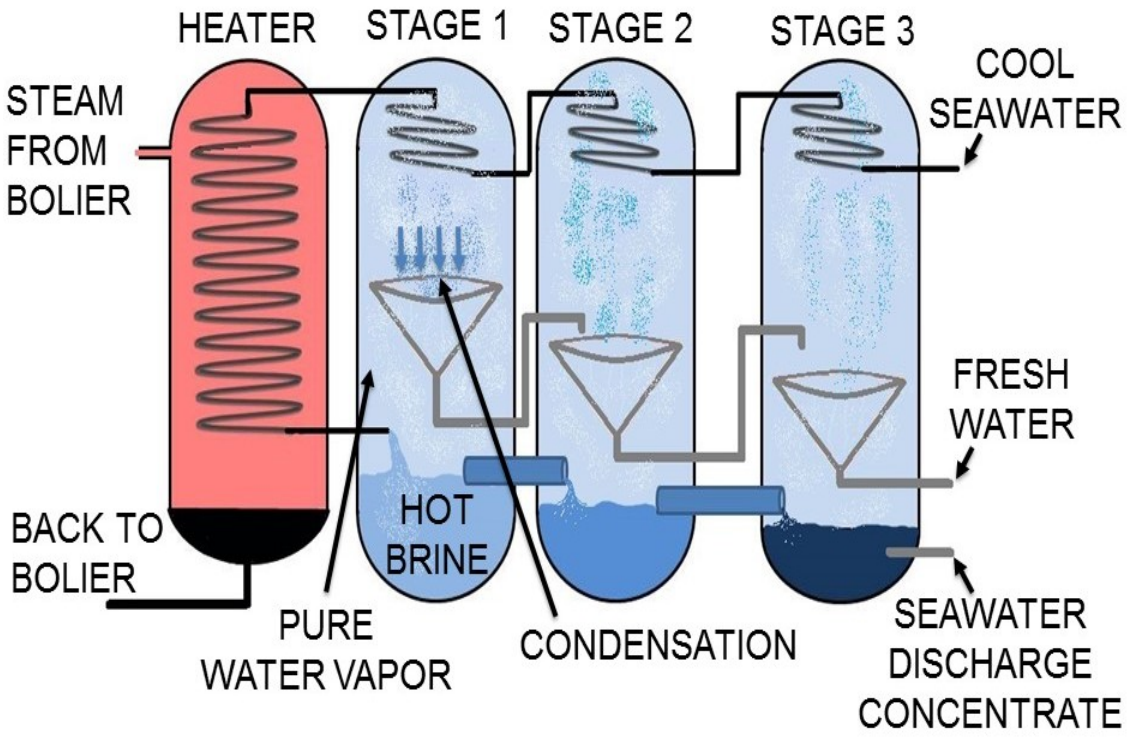
Landfill Leachate Treatment

In the case where the desired product is fresh water which does not contain draw solutes, a second separation step is required. The first separation step of FO, driven by an osmotic pressure gradient, does not require a significant energy input (only unpressurized stirring or pumping of the solutions involved). The second separation step, however does typically require energy input. One method used for the second separation step is to employ RO. This approach has been used, for instance, in the treatment of landfill leachate. An FO membrane separation is used to draw water from the leachate feed into a saline (NaCl) brine. The diluted brine is then passed through a RO process to produce fresh water and a reusable brine concentrate.

The advantage of this method is not a savings in energy, but rather in the fact that the FO process is more resistant to fouling from the leachate feed than a RO process alone.

Brine Concentration

Brine concentration using forward osmosis may be achieved using a high osmotic pressure draw solution with a means to recover and regenerate it. One unexploited application is to 'soften' or pre-treat the feedwater to multi stage flash (MSF) or multiple effect distillation (MED) plants by osmotically diluting the recirculating brine with the cooling water. This reduces the concentrations of scale forming calcium carbonate and calcium sulfate compared to the normal process, thus allowing an increase in top brine temperature (TBT), output and gained output ratio (GOR). Darwish et al. showed that the TBT could be raised from 110 °C to 135 °C whilst maintaining the same scaling index for calcium sulfate.

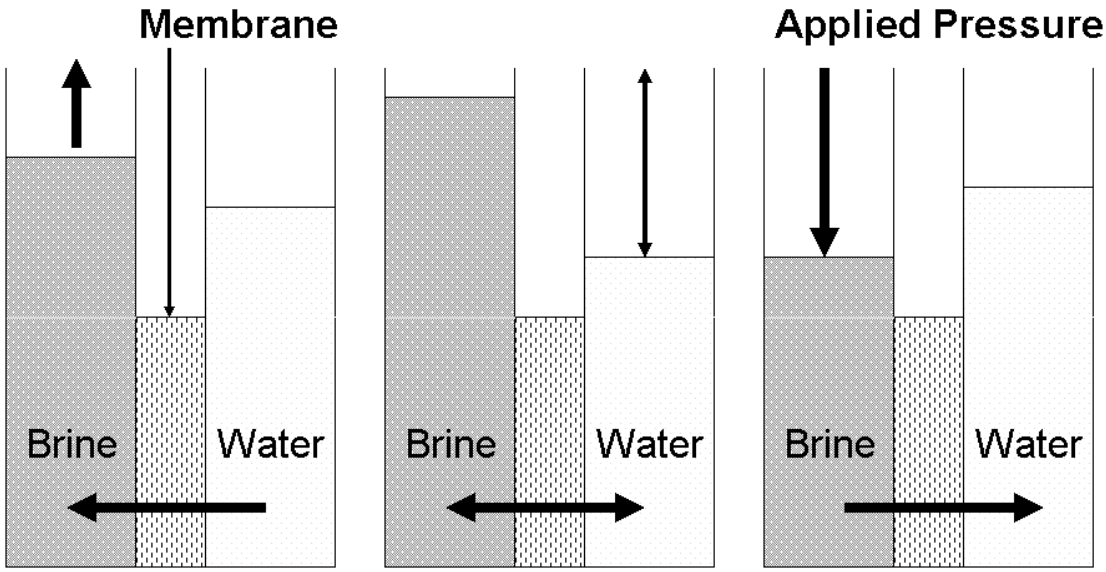


MULTISTAGE FLASH DISTILLATION

Detailed Reverse Osmosis Process Sub-Section

Osmosis is a natural phenomenon in which a liquid - water in this case - passes through a semi-permeable membrane from a relatively dilute solution toward a more concentrated solution. This flow produces a measurable pressure, called osmotic pressure. If pressure is applied to the more concentrated solution, and if that pressure exceeds the osmotic pressure, water flows through the membrane from the more concentrated solution toward the dilute solution.

This process, called reverse osmosis, or RO, removes up to 98% of dissolved minerals, and virtually 100% of colloidal and suspended matter. RO produces high quality water at low cost compared to other purifications processes.



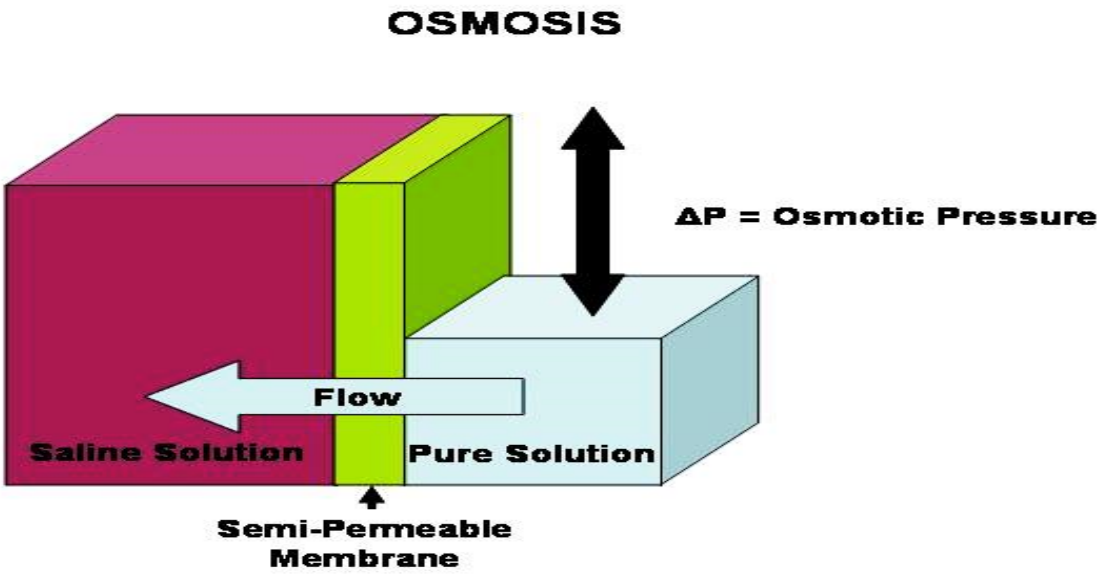
The membrane must be physically strong to stand up to high osmotic pressure - in the case of sea water, 2500 kg/m. Most membranes are made of cellulose acetate or polyamide composites cast into a thin film, either as a sheet or fine hollow fibers. The membrane is constructed into a cartridge called a reverse osmosis module.

After filtration to remove suspended particles, incoming water is pressurized with a pump to 200 - 400 psi (1380 - 2760 kPa) depending on the RO system model. This exceeds the water's osmotic pressure.

A portion of the water (**permeate**) diffuses through the membrane leaving dissolved salts and other contaminants behind with the remaining water where they are sent to drain as waste (**concentrate**).

Pretreatment is important because it influences permeate quality and quantity. It also affects the module's life because many water-borne contaminants can deposit on the membrane and foul it. Generally, the need for pretreatment increases as systems become larger and operate at higher pressures, and as permeate quality requirements become more demanding. Because reverse osmosis is the principal membrane filtration process used in water treatment, it is described here in greater detail.

To understand Reverse Osmosis, one must begin by understanding the process of osmosis, which occurs in nature. In living things, osmosis is frequently seen. The component parts include a pure or relatively pure water solution and a saline or contaminated water solution, separated by a semi-permeable membrane, and a container or transport mechanism of some type.



The semi-permeable membrane is so designated because it permits certain elements to pass through, while blocking others. The elements that pass through include water, usually smaller molecules of dissolved solids, and most gases. The dissolved solids are usually further restricted based on their respective electrical charge.

In osmosis, naturally occurring in living things, the pure solution passes through the membrane until the osmotic pressure becomes equalized, at which point osmosis ceases. The osmotic pressure is defined as the pressure differential required to stop osmosis from occurring. This pressure differential is determined by the total dissolved solids content of the saline solution, or contaminated solution on one side of the membrane.

The higher the content of dissolved solids, the higher the osmotic pressure. Each element that may be dissolved in the solution contributes to the osmotic pressure, in that the molecular weight of the element affects the osmotic pressure.

Generally, higher molecular weights result in higher osmotic pressures. Hence the formula for calculating osmotic pressure is very complex. However, approximate osmotic pressures are usually sufficient to design a system.

Common tap water as found in most areas may have an osmotic pressure of about 10 PSI (Pounds per Square Inch), or about 1.68 Bar. Seawater at 36,000 PPM typically has an osmotic pressure of about 376 PSI (26.75 Bar).

Thus, to reach the point at which osmosis stops for tap water, a pressure of 10 PSI would have to be applied to the saline solution, and to stop osmosis in seawater, a pressure of 376 PSI would have to be applied to the seawater side of the membrane.

Several decades ago, U.S. Government scientists had the idea that the principles of osmosis could be harnessed to purify water from various sources, including brackish water and seawater. In order to transform this process into one that purifies water, osmosis would have to be reversed, and suitable synthetic membrane materials would have to be developed. Additionally, ways of configuring the membranes would have to be engineered to handle a continuous flow of raw and processed water without clogging or scaling the membrane material.

These ideas were crystallized, and fueled by U.S. Government funding, usable membrane materials and designs resulted. One of the membrane designs was the spiral wound membrane element. This design enabled the engineers to construct a membrane element that could contain a generous amount of membrane area in a small package, and to permit the flow of raw water to pass along the length of the membrane. This permits flows and pressures to be developed to the point that ample processed or purified water is produced, while keeping the membrane surface relatively free from particulate, colloidal, bacteriological or mineralogical fouling.

The design features a perforated tube in the center of the element, called the product or permeate tube. Wound around this tube are one or more "**envelopes**" of membrane material, opening at the permeate tube.

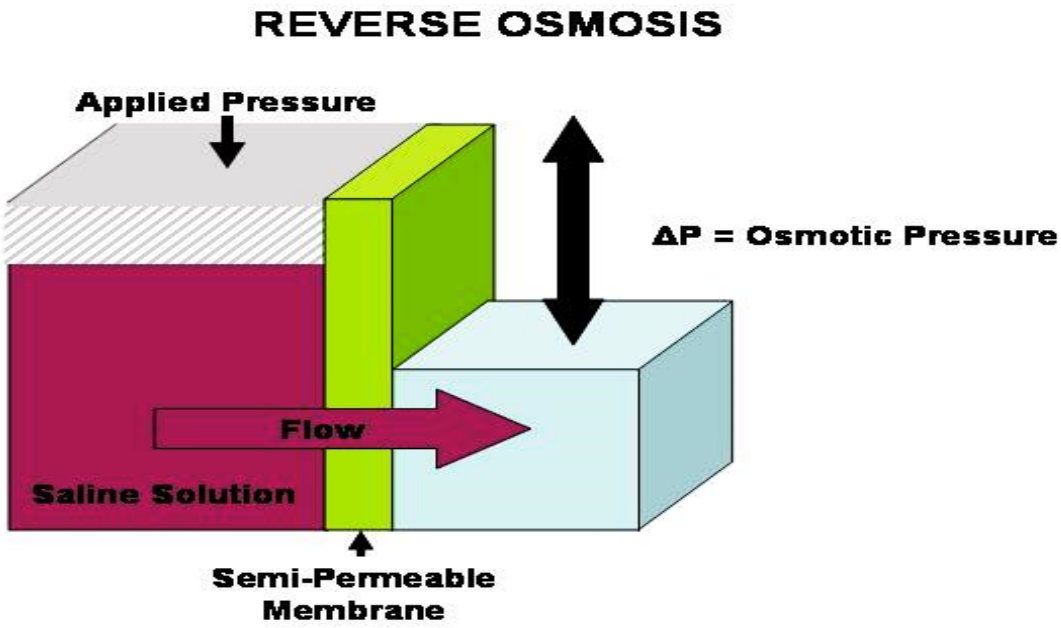
Each envelope is sealed at the incoming and exiting edge. Thus, when water penetrates or permeates though the membrane, it travels, aided by a fine mesh called the permeate channel, around the spiral and collects in the permeate tube. The permeate or product water is collected from the end of each membrane element, and becomes the product or result of the purification process.

Brine Channel

Meanwhile, as the raw water flows along the "**brine channel**" or coarse medium provided to facilitate good flow characteristics, it gets more and more concentrated. This concentrated raw water is called the reject stream or concentrate stream. It may also be called brine if it is coming from a salt water source. The concentrate, when sufficient flows are maintained, serves to carry away the impurities removed by the membrane, thus keeping the membrane surface clean and functional. This is important, as buildup on the membrane surface, called fouling, impedes or even prevents the purification process.

The membrane material itself is a special thin film composite (**TFC**) polyamide material, cast in a microscopically thin layer on another, thicker cast layer of Polysulfone, called the microporous support layer. The microporous support layer is cast on sheets of paper-like material that are made from synthetic fibers such as polyester, and manufactured to the required tolerances.

Each sheet of membrane material is inspected at special light tables to ensure the quality of the membrane coating, before being assembled into the spiral wound element design.



To achieve Reverse Osmosis, the osmotic pressure must be exceeded, and to produce a reasonable amount of purified water, the osmotic pressure is generally doubled. Thus with seawater osmotic pressure of 376 PSI, a typical system operating pressure is about 800 PSI. Factors that affect the pressure required include raw water temperature, raw water TDS (Total Dissolved Solids), membrane age, and membrane fouling. The effect of temperature is that with higher temperatures, the salt passage increases, flux (permeate flow) increases, and operating pressure required is lower. With lower temperatures, the inverse occurs, in that salt passage decreases (reducing the TDS in the permeate or product water), while operating pressures increase. Or, if operating pressures do not increase, then the amount of permeate or product water is reduced.

In general, Reverse Osmosis (R/O) systems are designed for raw water temperatures of 25° C (77° F). Higher temperatures or lower temperatures can be accommodated with appropriate adjustments in the system design.

Membranes are available in "*standard rejection*" or "*high rejection*" models for seawater and brackish water. The rejection rate is the percentage of dissolved solids rejected, or prevented from passing through the membrane. For example, a membrane with a rejection rate of 99% (usually based on Na (Sodium)) will allow only 1% of the concentration of dissolved solids to pass through into the permeate. Hence, product water from a source containing 10,000 PPM would have 100 PPM remaining.

Of course, as the raw water is processed, the concentrations of TDS increase as it passes along the membrane's length and usually multiple membranes are employed, with each membrane in series seeing progressively higher dissolved solids levels.

Typically, starting with seawater of 36,000 PPM, standard rejection membranes produce permeate below 500 PPM, while high rejection membranes under the same conditions produce drinking water TDS of below 300 PPM.

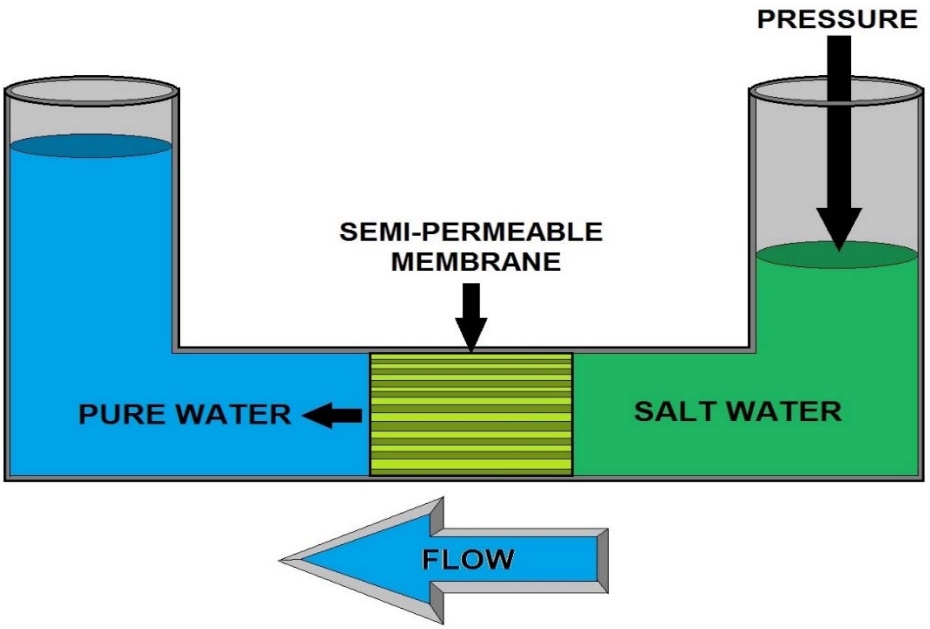
There are many considerations when designing R/O systems that competent engineers are aware of. These include optimum flows and pressures, optimum recovery rates (the percentage of permeate from a given stream of raw water), prefiltration and other pretreatment considerations, and so forth.

Membrane systems in general cannot handle the typical load of particulate contaminants without prefiltration. Often, well designed systems employ multiple stages of prefiltration, tailored to the application, including multi-media filtration and one or more stages of cartridge filtration. Usually the last stage would be 5m or smaller, to provide sufficient protection for the membranes.

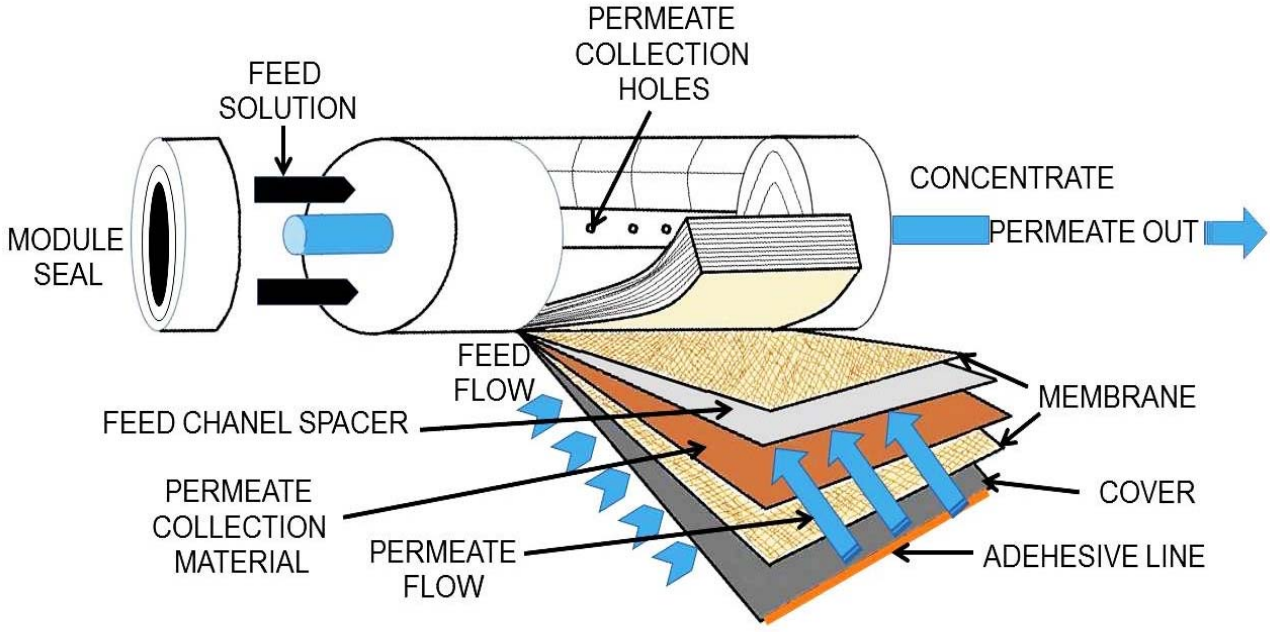
Components
R/O systems typically have the following components: A supply pump or pressurized raw water supply, prefiltration in one or more stages, chemical injection of one or more pretreatment agents may be added, a pressure pump suited to the application, sized and driven appropriately for the flow and pressure required, a membrane array including one or more membranes installed in one or more pressure tubes (also called pressure vessels, R/O pressure vessels, or similar), various gauges and flow meters, a pressure regulating valve, relief valve(s) and/or safety pressure switches, and possibly some form of post treatment.

Post treatment should usually include a form of sterilization such as Chlorine, Bromine, Ultra-Violet (UV), or Ozone. Other types of post treatment may include carbon filters, pH adjustment, or mineral injection for some applications.

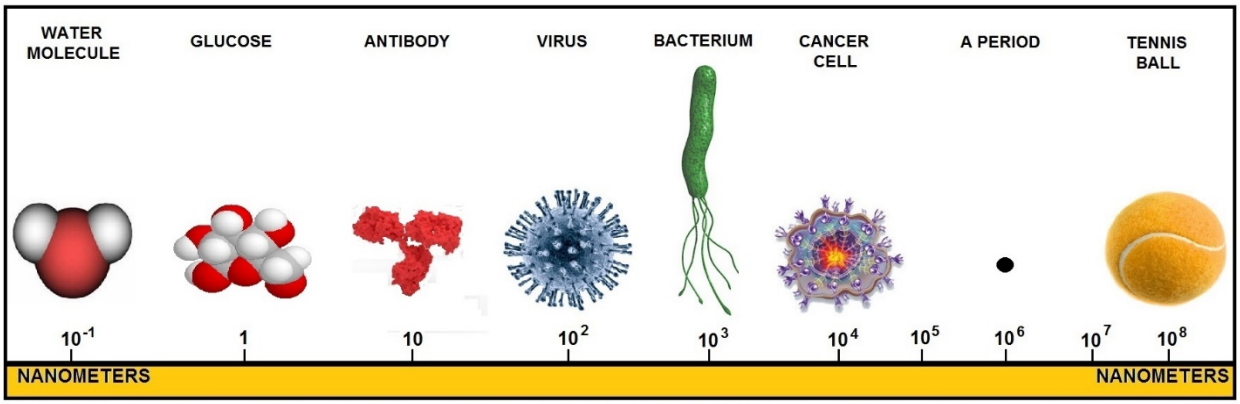
RO Simple Operation and Membrane Diagrams



REVERSE OSMOSIS



REVERSE OSMOSIS MEMBRANE



SIZE COMPARISON
HOW SMALL IS SMALL ?

Clean-In-Place" (CIP) System Introduction

Some very low cost R/O systems may dispense with most of the controls and instruments. However, systems installed in critical applications should be equipped with a permeate or product flow meter, a reject, concentrate or brine flow meter, multiple pressure gauges to indicate the pressure before and after each filtration device, and the system operation pressure in the membrane loop, preferably both before and after the membrane array. Another feature found in better systems is a provision to clean the membranes in place, commonly known as a "*Clean In Place*" (CIP) system. Such a system may be built right into the R/O system or may be provided as an attachment for use as required.

Reverse Osmosis has proved to be the most reliable and cost effective method of desalinating water, and hence its use has become more and more widespread. Energy consumption is usually some 70% less than for comparable evaporation technologies. Advancements have been made in membrane technology, resulting in stable, long lived membrane elements.

Component parts have been improved as well, reducing maintenance and down time. Additional advancements in pretreatment have been made in recent years, further extending membrane life and improving performance. Reverse Osmosis delivers product water or permeate having essentially the same temperature as the raw water source (an increase of 1° C or 1.8° F may occur due to pumping and friction in the piping). This is more desirable than the hot water produced by evaporation technologies. R/O Systems can be designed to deliver virtually any required product water quality. For these and other reasons, R/O is usually the preferred method of desalination today.

Reverse osmosis, also known as hyperfiltration, is the finest filtration known. This process will allow the removal of particles as small as ions from a solution. Reverse osmosis is used to purify water and remove salts and other impurities in order to improve the color, taste, or properties of the fluid. It can be used to purify fluids such as ethanol and glycol, which will pass through the reverse osmosis membrane, while rejecting other ions and contaminants from passing. The most common use for reverse osmosis is in purifying water. It is used to produce water that meets the most demanding specifications that are currently in place.

Reverse osmosis uses a membrane that is semi-permeable, allowing the fluid that is being purified to pass through it, while rejecting the contaminants that remain. Most reverse osmosis technology uses a process known as cross-flow to allow the membrane to continually clean itself. As some of the fluid passes through the membrane the rest continues downstream, sweeping the rejected species away from the membrane. The process of reverse osmosis requires a driving force to push the fluid through the membrane, and the most common force is pressure from a pump. The higher the pressure, the larger the driving force. As the concentration of the fluid being rejected increases, the driving force required to continue concentrating the fluid increases.

Reverse osmosis is capable of rejecting bacteria, salts, sugars, proteins, particles, dyes, and other constituents that have a molecular weight of greater than 150-250 daltons. The separation of ions with reverse osmosis is aided by charged particles. This means that dissolved ions that carry a charge, such as salts, are more likely to be rejected by the

membrane than those that are not charged, such as organics. The larger the charge and the larger the particle, the more likely it will be rejected.

A Reverse Osmosis System removes virtually all: bad taste, odor, turbidity, organic compounds, herbicides, insecticides, pesticides, chlorine and THM's, bacteria, virus, cysts, parasites, arsenic, heavy metals, lead, cadmium, aluminum, dissolved solids, sodium, calcium, magnesium, inorganic dead dirt minerals, fluoride, sulfates, nitrates, phosphates, detergents, radioactivity and asbestos.

Nanofiltration and Reverse Osmosis Comparisons

Nanofiltration and Reverse Osmosis are both techniques to bring into action univalent and bivalent ions.

Nanofiltration
Nanofiltration is a technique that has prospered over the past few years. Today, nanofiltration is mainly applied in drinking water purification process steps, such as water softening, decoloring and micro pollutant removal. During industrial processes nanofiltration is applied for the removal of specific components, such as coloring agents. Nanofiltration is a pressure related process, during which separation takes place, based on molecule size. Membranes bring about the separation. The technique is mainly applied for the removal of organic substances, such as micro pollutants and multivalent ions. Nanofiltration membranes have a moderate retention for univalent salts.

Other applications of nanofiltration are:
- ✓ The removal of pesticides from groundwater
- ✓ The removal of heavy metals from wastewater
- ✓ Wastewater recycling in laundries
- ✓ Water softening
- ✓ Nitrates removal

Reverse Osmosis (RO)
Reverse Osmosis is based upon the fundamental pursuit for balance. Two fluids containing different concentrations of dissolved solids that come in contact with each other will mix until the concentration is uniform. When these two fluids are separated by a semi permeable membrane (which lets the fluid flow through, while dissolved solids stay behind), a fluid containing a lower concentration will move through the membrane into the fluids containing a higher concentration of dissolved solids. (Binnie e.a., 2002)

After a while the water level will be higher on one side of the membrane. The difference in height is called the osmotic pressure.

By pursuing pressure upon the fluid column, which exceeds the osmotic pressure, one will get a reversed effect. Fluids are pressed back through the membrane, while dissolved solids stay behind in the column.

Using this technique, a larger part the salt content of the water can be removed.

1. Water flows from a column with a low dissolved solids content to a column with a high dissolved solids content
2. Osmotic pressure is the pressure that is used to stop the water from flowing through the membrane, in order to create balance
3. By pursuing pressure that exceeds the osmotic pressure, the water flow will be reversed; water flows from the column with a high dissolved solids content to the column with a low dissolved solids content

Reverse Osmosis is a technique that is mainly applied during drinking water preparation. The process of drinking water preparation from salty seawater is commonly known. Besides that, Reverse Osmosis is applied for the production of ultra-pure water and boiler feed water.

It is also applied in the food sector (concentration of fruit juice, sugar and coffee), in the galvanic industry (concentration of wastewater) and in the dairy industry (concentration of milk for cheese production).

Summarized, the applications of Reverse Osmosis application are:

- ✓ Water softening
- ✓ Drinking water production
- ✓ Process water production
- ✓ Ultra-pure water production (electronic industries)
- ✓ Concentration of molecular solvents for food and dairy industries

The pre-treatment of feed water for nanofiltration or Reverse Osmosis installations greatly influences the performance of the installation. The required form of pre-treatment depends on the feed water quality. The purpose of pre-treatment is reducing the organic matter content and the amount of bacteria, as well as lowering the MFI.

The organic matter content and the amounts of bacteria should be as low as possible to prevent the so-called biofouling of membranes.

The application of a pre-treatment has several benefits:

- ✓ Membranes have a longer life-span when pre-treatment is performed
- ✓ The production time of the installation is extended
- ✓ The management tasks become simpler
- ✓ The employment costs are lower

Next to pre-treatment one can perform a chemical dosage (acid, anti-scalent), to prevent scaling and precipitation of insoluble solids, such as calcium carbonate and barium sulfate on the membrane surface.

The applied acids are hydrochloric acid (HCl) and sulfuric acid (H_2SO_4).

Sulfuric acid is the most widely used chemical for this purpose. However, hydrochloric acid is applied more and more because sulfuric acid can negatively influence the fouling speed of a membrane. When the feed water contains high amounts of sulfate ions, hydrochloric acid replaces sulfuric acid. The dosage of sulfuric acid would enhance the chances of scaling by sulfate ions on the membranes in this case. (Baker, 2000)

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Topic -5 Advanced Treatment Section Post Quiz

Microfiltration Section

1. Filtration is the separation of two or more components from a fluid stream. _____acts as a selective barrier, allowing the passage of certain components and retaining others components of a mixture.

Types of Processes

2. _____ operate without heating and therefore use less energy than conventional thermal separation processes such as distillation, sublimation or crystallization. The separation process is purely physical and both fractions (permeate and retentate) can be used.

3. It is impossible to separate the constituents of azeotropic liquids or solutes which form isomorphic crystals by distillation or recrystallization but such separations can be achieved using _____.

4. In wastewater treatment, membrane technology is becoming increasingly important. With the help of _____ it is possible to remove particles, colloids and macromolecules, so that waste-water can be disinfected in this way.

5. Ultrafiltration (**UF**) is a process that uses a membrane with a pore size generally below 0.1 μm. The smaller pore size is designed to remove colloids and substances that have larger molecules, which are called_____.

6. Nanofiltration is also becoming more widely used in food processing applications such as dairy, for _____and partial (monovalent ion) demineralization.

7. Materials that are commonly use include polyethylene terephthalate or metals such as aluminum. _____ are controlled by pH, temperature and time during development with pore densities ranging from 1 to 106 pores per cm^2.

8. One of the main advantages of nanofiltration as a method of softening water is that during the process of retaining calcium and magnesium ions while passing smaller hydrated monovalent ions, filtration is performed without adding extra sodium ions, as used in_____ .

9. _____has a very favorable benefit of being able to process large volumes and continuously produce streams of have a Nanofiltration is the least used method of membrane filtration in industry.

10. Anything smaller, reverse osmosis is used and anything larger is used for _____.

Reverse Osmosis Process Section

11. Osmosis is a natural phenomenon in which a liquid - water in this case - passes through a semi-permeable membrane from a relatively dilute solution toward a more concentrated solution. This flow produces a_____, called osmotic pressure.

12. Meanwhile, as the raw water flows along the "brine channel" or coarse medium provided to facilitate good flow characteristics, it gets more and more concentrated. This concentrated raw water is called the reject stream or concentrate stream. It may also be called brine if it is coming from a_____.

13. _____, when sufficient flows are maintained, serves to carry away the impurities removed by the membrane, thus keeping the membrane surface clean and functional.

14. R/O Systems can be designed to deliver virtually any_____. For these and other reasons, R/O is usually the preferred method of desalination today.

15. Reverse osmosis is capable of rejecting bacteria, salts, _____, proteins, particles, dyes, and other constituents that have a molecular weight of greater than 150-250 daltons.

16. The separation of ions with reverse osmosis is aided by_____. This means that dissolved ions that carry a charge, such as salts, are more likely to be rejected by the membrane than those that are not charged, such as organics.

17. A Reverse Osmosis System removes virtually all: bad taste, odor, turbidity, organic compounds, herbicides, insecticides, pesticides, chlorine and THM's, bacteria, virus, cysts, parasites, arsenic, heavy metals, lead, cadmium, aluminum, dissolved solids, sodium, calcium, magnesium, _____, fluoride, sulfates, nitrates, phosphates, detergents, radioactivity and asbestos.

Topic 6 – Nutrient Section

Topic 6 – Section Focus: You will learn the basics of wastewater nutrients, including nitrogen, phosphorus and removal procedures. At the end of this section, you the student will be able to understand and describe various wastewater nutrients and removal methods. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.
Topic 6 – Scope/Background: This section provides information on a number of different technologies that can reduce nitrogen and phosphorus levels. The actual technology selected will be site-specific and dependent on many factors including soil conditions, influent water quality, required effluent levels, disposal options, availability of land, cost, etc.

Excess nutrients discharged into receiving waters.

Wastewater contains nitrogen and phosphorus from human waste, food and certain soaps and detergents. Once the water is cleaned to standards set and monitored by state and federal officials, it is typically released into a local water body, where it can become a source of nitrogen and phosphorus pollution.

Some wastewater treatment plants are able to remove more nitrogen and phosphorus from their discharges than others depending on their equipment and how they treat wastewater.

Enhanced treatment systems enable some wastewater plants to produce discharges that contain less nitrogen than plants using conventional treatment methods. Upgrading wastewater treatment systems is often expensive for municipalities and rate payers, but upgrades can pay for themselves or end up saving a plant money. Various strategies to reduce nitrogen and phosphorus loads from wastewater treatments plants are being pursued across the country. Credit to US EPA

Key Information

NITROGEN CYCLE

The **wastewater nitrogen cycle** incorporates the significant inorganic and organic nitrogenous compounds that enter the activated sludge process, are produced in the activated sludge process and leave the activated sludge process. The impact of these compounds upon the activated sludge process also is presented.

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NITROGEN

Nitrogen is an important nutrient for plant and animal growth. Atmospheric nitrogen is less biologically available than dissolved nitrogen in the form of ammonia and nitrates. Availability of dissolved nitrogen may contribute to algal blooms.

Ammonia and organic forms of nitrogen are often measured as **Total Kjeldahl Nitrogen (TKN)**, and analysis for inorganic forms of nitrogen may be performed for more accurate estimates of total nitrogen content.

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Nutrient Introduction

NUTRIENTS

Nutrients are components in foods that an organism uses to survive and grow. Macronutrients provide the bulk energy an organism's metabolic system needs to function while micronutrients provide the necessary cofactors for metabolism to be carried out. Both types of nutrients can be acquired from the environment.

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Nutrients
Let us look at nutrients found in wastewater. Most are chemical elements or compounds vital for both plant and animal growth. Nutrient include ammonia, organic nitrogen, Kjeldahl nitrogen, nitrate nitrogen (water only) and total phosphorus. High amounts of nutrients have been related with eutrophication, or over-fertilization of a water body, while low levels of nutrients can reduce plant growth and starve higher-level organisms that consume phytoplankton.

The purpose of this section is to provide an overview of the major factors driving decisions to enhance nutrient removal at WWTPs. This section characterizes the industry based on U.S. Environmental Protection Agency (EPA) survey information. This section describes the negative impacts of nutrient enrichment, highlighting the history of water quality changes in key regions of the country. EPA and State initiatives to reduce nutrient pollution from wastewater treatment discharges are summarized in this training course. Lastly, we will highlight several barriers to enhancing nutrient removal at wastewater plants.

Status of Wastewater Treatment in the U.S.
The 1972 Amendments to the Federal Water Pollution Control Act (FWPCA)(Public Law 92-500), also known as the Clean Water Act (CWA), established the foundation for wastewater discharge control in the U.S. The CWA's primary objective is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters."

The CWA established a program to ensure clean water by requiring permits that limit the amount of pollutants discharged by all municipal and industrial dischargers into receiving waters. Discharges are regulated under the National Pollutant Discharge Elimination System (NPDES) permit program. As of 2004, there were 16,583 municipal wastewater utilities [also known as Publicly Owned Treatment Works (POTWs)] regulated under the CWA, serving approximately 75 percent of the Nation's population (U.S. Public Health Service and USEPA, 2008) with the remaining population served by septic or other onsite systems.

Wastewater treatment has generally been defined as containing one or more of the following four processes: (1) preliminary, (2) primary, (3) secondary, and (4) advanced - also known as tertiary treatment.

Preliminary treatment consists of grit removal, which removes dense inert particles and screening to remove rags and other large debris. Primary treatment involves gravity settling tanks to remove settleable solids, including settleable organic solids.

The performance of primary settling tanks can be enhanced by adding chemicals to capture and flocculate smaller solid particles for removal and to precipitate phosphorus. Secondary treatment follows primary treatment in most plants and employs biological processes to remove colloidal and soluble organic matter. Effluent disinfection is usually included in the definition of secondary treatment.

EPA classifies advanced treatment as “a level of treatment that is more stringent than secondary or produces a significant reduction in conventional, non-conventional, or toxic pollutants present in the wastewater” (U.S. Public Health Service and USEPA, 2008). Other technical references subdivide advanced treatment, using the terms “secondary with nutrient removal” when nitrogen, phosphorus, or both are removed and “tertiary removal” to refer to additional reduction in solids by filters or microfilters (Tchobanoglous et al, 2003).

Effluent filtration and nutrient removal are the most common advanced treatment processes. The CWA requires that all municipal wastewater treatment plant discharges meet a minimum of secondary treatment. Based on data from the *2004 Clean Watersheds Needs Survey*, 16,543 municipal WWTPs (99.8 percent of plants in the country) meet the minimum secondary wastewater treatment requirements.

Of those that provide at least secondary treatment, approximately 44 percent provide some kind of advanced treatment (U.S. Public Health Service and USEPA, 2008).

Nutrient Impairment of U.S. Waterways

The harmful effects of eutrophication due to excessive nitrogen and phosphorus concentrations in the aquatic environment have been well documented. Algae and phytoplankton growth can be accelerated by higher concentrations of nutrients as they can obtain sufficient carbon for growth from carbon dioxide. In addition to stimulating eutrophication, nitrogen in the form of ammonia can exert a direct demand on dissolved oxygen (DO) and can be toxic to aquatic life.

Even if a treatment plant converts ammonia to nitrate by a biological nitrification process, the resultant nitrate can stimulate algae and phytoplankton growth. Phosphorus also contributes to the growth of algae. Either nitrogen or phosphorus can be the limiting nutrient depending on the characteristics of the receiving water.

Nitrogen is typically limiting in estuarine and marine systems and phosphorus in fresh water systems. According to the 2007 report *Effects of Nutrient Enrichment in the Nation’s Estuaries: A Decade of Change*, increased nutrient loadings promote a progression of symptoms beginning with excessive growth of phytoplankton and macroalgae to the point where grazers cannot control growth (Bricker et al., 2007).

These blooms may be problematic, potentially lasting for months at a time and blocking sunlight to light-dependent submerged aquatic vegetation (SAV). In addition to increased growth, changes in naturally occurring ratios of nutrients may also affect which species dominate, potentially leading to nuisance/toxic algal blooms.

These blooms may also lead to other more serious symptoms that affect biota, such as low DO and loss of SAV. Once water column nutrients have been depleted by phytoplankton and macroalgae and these blooms die, the bacteria decomposing the algae then consume oxygen, making it less available to surrounding aerobic aquatic life.

Consequently, fish and invertebrate kills may occur due to hypoxia and anoxia, conditions of low to no DO. Eutrophic conditions may also cause risks to human health, resulting from consumption of shellfish contaminated with algal toxins or direct exposure to waterborne toxins. Eutrophication can also create problems if the water is used as a source of drinking water. Chemicals used to disinfect drinking water will react with organic compounds in source water to form disinfection byproducts, which are potential carcinogens and are regulated by EPA.

Advanced eutrophic conditions can lead to “dead zones” with limited aquatic life, which describes the hypoxia condition that exists in the Northern Gulf of Mexico. A recent U.S. Geological Survey (USGS) report titled *Differences in Phosphorus and Nitrogen Delivery to the Gulf of Mexico from the Mississippi River Basin* documents the contribution of nitrogen and phosphorus from agricultural and non-agricultural sources in the Mississippi River basin (Alexander et al., 2008).

On June 16, 2008 the joint federal-state Mississippi River/Gulf of Mexico Watershed Nutrient Task Force released its *2008 Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico and Improving Water Quality in the Mississippi River Basin,* which builds upon its 2001 plan by incorporating emerging issues, innovative approaches, and the latest science, including findings from EPA’s Science Advisory Board.

Improvements include more accountability through an Annual Operating Plan, better tracking of progress, state and federal nutrient reduction strategies, and a plan to increase awareness of the problem and implementation of solutions (USEPA, 2008b). Nutrient pollution has also caused significant problems in the Chesapeake Bay. Elevated levels of both nitrogen and phosphorus are the main cause of poor water quality and loss of aquatic habitats in the Bay. Significant algae blooms on the water surface block the sun’s rays from reaching underwater bay grasses. Without sunlight, bay grasses cannot grow and provide critical food and habitat for blue crabs, waterfowl, and juvenile fish.

The Chesapeake Bay Program estimates that 22 percent of the phosphorus loading and 19 percent of the nitrogen loading in the Bay comes from municipal and industrial wastewater facilities (Chesapeake Bay Program, 2008). The first national attention to nutrient contamination occurred in the Great Lakes.

In the 1960s Lake Erie was declared “dead” when excessive nutrients in the Lake fostered excessive algae blooms that covered beaches and killed off native aquatic species due to oxygen depletion. At that time, phosphorus was the primary nutrient of concern due to the advent of phosphate detergents and inorganic fertilizers. With the enactment of the CWA and the Great Lakes Water Quality Agreement in 1972, a concerted effort was undertaken to reduce pollutant loadings, including phosphorus in the Lake.

Although the health of the Lake improved dramatically, in recent years, there has been renewed attention to the re-emergence of a “dead” zone in Lake Erie, again due to nutrient loadings.

Recent studies by scientists and the National Oceanic and Atmospheric Administration (NOAA) have also hypothesized a relationship between excessive nutrients in the Lake and the presence of two aquatic invasive species – the zebra mussel and the quagga mussel (Vanderploeg et al., 2008). Development and population increases in the Long Island Sound Watershed have resulted in a significant increase in nitrogen loading to the Sound.

The increased nitrogen loads have stimulated plant growth, increased the amount of organic matter settling to the benthic zone, lowered DO levels, and changed habitats.

The primary concerns in the Sound include hypoxia, the loss of sea grass, and alterations in the food web. Management efforts are currently underway to reduce nitrogen pollution by more than half with a focus on upgrading WWTPs with new technologies and removing nitrogen by reducing polluted run-off through best management practices on farms and suburban areas (Long Island Sound Study, 2004).

The above represent four examples of impaired large water bodies impacted by nutrient loadings. There are more than 80 additional estuaries and bays, and thousands of rivers, streams, and lakes that are also impacted by nutrients in the U.S. In fact, all but one state and two territories have CWA section 303(d) listed1 water body impairments for nutrient pollution. Collectively, states have listed over 10,000 nutrients and nutrient–related impairments.

Climate change may also be a significant influence on the development of future eutrophic symptoms. According to the report *Effects of Nutrient Enrichment in the Nation's Estuaries: A Decade of Change*, the factors associated with climate change that are expected to have the greatest impacts on coastal eutrophication are:

- Increased temperatures
- Sea level rise
- Changes in precipitation and freshwater runoff

Increased temperatures will have several effects on coastal eutrophication. Most coastal species are adapted to a specific range of temperatures. Increases in water temperatures may lead to expanded ranges of undesirable species. Higher temperatures may also lead to increased algal growth and longer growing seasons, potentially increasing problems associated with excessive algal growth and nuisance/toxic blooms. Additionally, warmer waters hold less DO, therefore potentially exacerbating hypoxia. Temperature-related stratification of the water column may also worsen, having a further negative effect on DO levels.

Climate change models predict increased melting of polar icecaps and changes in precipitation patterns, leading to sea level rise and changes in water balance and circulation patterns in coastal systems. Sea level rise will gradually inundate coastal lands, causing increased erosion and sediment delivery to water bodies, and potentially flooding wetlands.

The increased sediment load and subsequent turbidity increase may cause SAV loss. The positive feedback between increased erosion and algal growth (as erosion increases, sediment associated nutrients also increase, stimulating growth) may also increase turbidity. The loss of wetlands, which act as nutrient sinks, will further increase nutrient delivery to estuaries.

Another report titled *Aquatic Ecosystems and Global Climate Change – Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States* notes that climate change of the magnitude projected for the U.S. over the next 100 years will cause significant changes to temperature regimes and precipitation patterns across the U.S. (Poff et al., 2002).

Such alterations in climate pose serious risks for inland freshwater ecosystems (lakes, streams, rivers, wetlands) and coastal wetlands, and may adversely affect numerous critical services provided to human populations.

These conclusions indicate climate change is a significant threat to the species composition and function of aquatic ecosystems in the U.S. However, critical uncertainties exist regarding the manner in which specific species and whole ecosystems will respond to climate change. These arise both from uncertainties about how regional climate will change and how complex ecological systems will respond.

Indeed, as climate change alters ecosystem productivity and species composition, many unforeseen ecological changes are expected that may threaten the goods and services that these systems provide to humans.

Required by Section 303(d) of the CWA, the 303(d) list is a list of state's water bodies that do not meet or are not expected to meet applicable Water Quality Standards with technology-based controls alone.

CONVENTIONAL POLLUTANTS

POTWs are designed to treat typical household wastes and biodegradable commercial and biodegradable industrial wastes. The Clean Water Act defines the contaminants from these sources as **conventional pollutants**. **Conventional pollutants** are biological oxygen demand (BOD), total suspended solids (TSS), fecal coliform, oil and grease, and pH**.**

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Nitrogen Introduction

Because of the importance of nutrient control, we need to mention nitrogen and we will return to this subject later.

Nitrogen

Nitrogen is an essential nutrient for plants and animals. Approximately 80 percent of the earth's atmosphere is composed of nitrogen and it is a key element of proteins and cells. The major contributors of nitrogen to wastewater are human activities such as food preparation, showering, and waste excretion. The per capita contribution of nitrogen in domestic wastewater is about 1/5th of that for BOD.

Total nitrogen in domestic wastewater typically ranges from 20 to 70 mg/L for low to high strength wastewater (Tchobanoglous et al., 2003). Factors affecting concentration include the extent of infiltration and the presence of industries. Influent concentration varies during the day and can vary significantly during rainfall events, as a result of inflow and infiltration to the collection system.

The most common forms of nitrogen in wastewater are:

- Ammonia (NH_3)
- Ammonium ion (NH_4+)
- Nitrite (NO_2-)
- Nitrate (NO_3-)
- Organic nitrogen

Nitrogen in domestic wastewater consists of approximately 60 to 70 percent ammonia-nitrogen and 30 to 40 percent organic nitrogen (Tchobanoglous et al., 2003; Crites and Tchobanoglous, 1998). Most of the ammonia-nitrogen is derived from urea, which breaks down rapidly to ammonia in wastewater influent.

EPA approved methods for measuring ammonia, nitrate, and nitrite concentration use colorimetric techniques. Organic nitrogen is approximated using the standard method for Total Kjeldahl Nitrogen (TKN) (APHA, AWWA, and WEF, 1998).

Nitrogen (N_2) is present in domestic, commercial and industrial wastewater, it is usually not removed by secondary treatment. If discharged into lakes and streams or estuary waters, nitrogen in the form of ammonia (NH_3) can consume oxygen or encourage the excessive growth of algae. Ammonia in wastewater effluent can be toxic to aquatic life in certain instances. By providing additional biological treatment beyond the secondary stage, nitrifying bacteria present in wastewater treatment can biologically convert ammonia to the non-toxic nitrate through a process known as nitrification.

The nitrification process is normally sufficient to remove the toxicity associated with ammonia in the effluent. Since nitrate is also a nutrient, excess amounts can contribute to increased levels of algae growth. In situations where nitrogen must be removed from effluent discharge, additional biological process can be added to the system to convert the nitrate (NO_3^-) to nitrogen gas. We will cover this in much more detail in a few more pages.

Conversion of Nitrate to Nitrogen Gas
The conversion of nitrate to nitrogen gas is accomplished by bacteria in a process known as denitrification. Effluent with nitrogen in the form of nitrate is retained in a tank that lacks oxygen, where carbon-containing chemicals, such as methanol, are added or a small stream of raw wastewater is mixed in with the nitrified effluent.

In this oxygen free environment, bacteria use the oxygen attached to the nitrogen that is in the nitrate form, then the nitrogen gas is released. Because nitrogen contains almost 80 percent of the earth's atmosphere, the release of nitrogen into the atmosphere does not cause any known environmental harm.

DENTRIFICATION FILTER

The nitrogen gas forms small gas bubbles within the filter. The media and down flow of the liquid prevent the nitrogen gas bubbles from rising to the surface and escaping into the atmosphere. **The nitrogen release cycle is a short backwash cycle to release the nitrogen gas which becomes trapped in the filter media.** Generally, the nitrogen release cycle backwash is done at 4 to 6 hour intervals. If the nitrogen release backwash cycle is not performed at the required interval, the nitrogen gas will continue to accumulate and the head loss through the filter will increase just as in a dirty filter. The flow rate through the affected filter will be reduced. Automatic controls are arranged to provide an adjustable duration water backwash, in sequence, to each group.

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Biological Phosphorus Control

We will cover Phosphorus in greater detail in a few more pages.
Like nitrogen, phosphorus is also a necessary nutrient for the growth of algae. Phosphorus reduction is often needed to prevent excessive algal growth before discharging effluent into lakes, reservoirs and estuaries.

Phosphorus removal can be achieved through chemical addition and a coagulation-sedimentation process discussed in the following section. Some biological treatment processes called biological nutrient removal (BNR) can also achieve nutrient reduction, removing both nitrogen and phosphorus.

Most of the BNR processes involve modifications of suspended growth treatment systems so that the bacteria in these systems also convert nitrate nitrogen to inert nitrogen gas and trap phosphorus in the solids that are removed from the effluent.

Coagulation-Sedimentation Process

A process known as chemical coagulation-sedimentation is used to increase the removal of solids from effluent after primary and secondary treatment.

Solids heavier than water settle out of wastewater by gravity. With the addition of specific chemicals, solids can become heavier than water and will settle.

Alum, lime, or iron salts are chemicals added to the wastewater to remove phosphorus. With these chemicals, the smaller particles 'floc' or clump together into large masses.

The larger masses of particles will settle faster when the effluent reaches the next step the sedimentation tank.

This process can reduce the concentration of phosphate by more than 95 percent.

Although used for years in the treatment of industrial wastes and in water treatment, coagulation-sedimentation is considered an advanced process because it is not routinely applied to the treatment of municipal wastewater. In some cases, the process is used as a necessary pretreatment step for other advanced techniques. This process produces a chemical sludge, and the cost of disposing of this material can be significant.

Results after settling.

PHOSPHORUS LOADING

Phosphorus concentrations can be very high for limited periods but turbulent conditions, short residence times, and shading from sediment often prevent excess algae growth. At low flow, the proportion of effluent to stream flow can be much higher. Point sources like wastewater treatment facilities can dominate in-stream phosphorus loading. Low flow conditions often occur in late summer months when temperatures are higher and water is moving slower, all of which tend to encourage algae growth.

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PHOSPOROUS CONTROL

Controlling **phosphorous** discharged from municipal and industrial wastewater treatment plants is a key factor in preventing eutrophication of surface waters. **Phosphorous** is one of the major nutrients contributing in the increased eutrophication of lakes and natural waters.

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FINAL CLARIFER SOLIDS LOADING RATE (SLR)

The rate at which the activated sludge is returned from the final clarifiers to the aeration basins, along with the influent flow, effects the flow of solids into the clarifiers. Aeration basin mixed liquor suspended solids must have sufficient time to settle and be returned or wasted in the activated sludge system. Clarifiers are designed for certain solids loading rates that should not be exceeded.

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Carbon Adsorption

Carbon adsorption technology can remove organic materials from wastewater that resist removal by biological treatment. These resistant, trace organic substances can contribute to taste and odor problems in water, taint fish flesh, and cause foaming and fish kills.

Carbon adsorption consists of passing the wastewater effluent through a bed or canister of activated carbon granules or powder which remove more than 98 percent of the trace organic substances. The substances adhere to the carbon surface and are removed from the water. To help reduce the cost of the procedure, the carbon granules can be cleaned by heating and used again.

Granular Carbon

GAC vessel

Nitrification and Nutrient Removal Section

NITRIFYING BACTERIA

Nitrifying bacteria are chemolithotrophic organisms that include species of the genera **Nitrosomonas**, **Nitrosococcus**, **Nitrobacter** and **Nitrococcus**. These bacteria get their energy by the oxidation of inorganic nitrogen compounds. Types include ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB).

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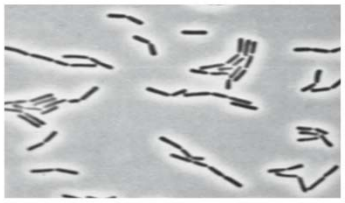
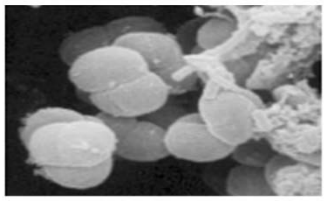
It was once thought that only two bacteria were involved in nitrification: Nitrosomonas europaea, which oxidizes ammonia to nitrite, and Nitrobacter winogradskyi, which oxidizes nitrite to nitrate. It is now known that at least 5 genera of bacteria oxidize ammonia and at least three genera of bacteria oxidize nitrite (Holt et al., 1994). Besides oxygen, these nitrifying bacteria require a neutral pH (7-8) and substantial alkalinity (these autotrophs use CO2 as a carbon source for growth).

This indicates that complete nitrification would be expected at pond pH values between pH 7.0 and 8.5. Nitrification ceases at pH values above pH 9 and declines markedly at pH values below 7. This results from the growth inhibition of the nitrifying bacteria. Nitrification, however, is not a major pathway for nitrogen removal in lagoons. Nitrifying bacteria exists in low numbers in lagoons. They prefer attached growth systems and/or high MLSS sludge systems.



Lactobacillus sp.

One of the key bacteria used in digesters that release organic acids and enzymes that reduce organic matter.



Methanosarcina sp.

This single cell organism is known for producing methane from carbon dioxide and hydrogen gas.

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ANAEROBIC DIGESTER BUGS

Anaerobic Bacteria

Anaerobic, heterotrophic bacteria that commonly occur in lagoons are involved in methane formation (acid-forming and methane bacteria) and in sulfate reduction (sulfate reducing bacteria). Anaerobic methane formation involves three different groups of anaerobic bacteria that function together to convert organic materials to methane via a three-step process.

General anaerobic degraders - many genera of anaerobic bacteria hydrolyze proteins, fats, and polysaccharides present in wastewater to amino acids, short-chain peptides, fatty acids, glycerol, and mono- and di-saccharides. These have a wide environmental tolerance in pH and temperature.

Photosynthetic Organisms

Acid-Forming Bacteria

This highly designed diverse group of bacteria converts products from above under anaerobic conditions to simple alcohols and organic acids such as acetic, propionic, and butyric. These bacteria are hardy and occur over a wide pH and temperature range.

Methane Forming Bacteria

These bacteria convert formic acid, methanol, methylamine, and acetic acid under anaerobic conditions to methane. Methane is derived in part from these compounds and in part from CO_2 reduction. Methane bacteria are environmentally sensitive and have a narrow pH range of 6.5-7.5 and require temperatures > 14^{o} C.

Note that the products of the acid formers (principally acetic acid) become the substrate for the methane producers.

A problem exists at times where the acid formers overproduce organic acids, lowering the pH below where the methane bacteria can function (a pH < 6.5). This can stop methane formation and lead to a buildup of sludge in a lagoon with a low pH. In an anaerobic fermenter, this is called a "stuck digester".

In addition, methane fermentation ceases at cold temperature, probably not occurring in most lagoons in the wintertime in cold climates. A number of anaerobic bacteria (14 genera reported to date (Bolt et al., 1994)) called sulfate reducing bacteria can use sulfate as an electron acceptor, reducing sulfate to hydrogen sulfide.

This occurs when BOD and sulfate are present and oxygen is absent. Sulfate reduction is a major cause of odors in ponds.

Anaerobic, photosynthetic bacteria occur in all lagoons and are the predominant photo-synthetic organisms. In anaerobic lagoons, the anaerobic sulfur bacteria, generally grouped into the red and green sulfur bacteria and represented by about 28 genera (Ehrlich, 1990), oxidize reduced sulfur compounds (H_2S) using light energy to produce sulfur and sulfate.

Here, H_2S is used in place of H_2O as used by algae and green plants, producing $S0_4$- instead of O_2. All are either strict anaerobes or microaerophilic. Most common are Chromatium, Thiocystis, and Thiopedia, which can grow in profusion and give a lagoon a pink or red color.

Finding them is most often an indication of organic overloading and anaerobic conditions in an intended aerobic system. Conversion of odorous sulfides to sulfur and sulfate by these sulfur bacteria is a significant odor control mechanism in facultative and anaerobic lagoons, and can be desirable.

Initiatives to Reduce Nutrient Pollution

NPDES Permitting

Established by the FWPCA Amendment of 1972, EPA's NPDES permit program has been the primary mechanism for controlling pollution from point sources. Point sources are discrete conveyances such as pipes or man-made ditches. Individual homes that are connected to a municipal system, use a septic system, or do not have a surface discharge do not need an NPDES permit; however, POTWs and other facilities must obtain permits if they discharge directly to surface waters.

NPDES permits for wastewater discharges contain, among other information, effluent limits for "conventional" pollutants such as biochemical oxygen demand (BOD), total suspended solids (TSS), and pH as well as limits for specific toxicants including various organic and inorganic chemicals. Permits may also include effluent limits for "non-conventional" pollutants such as nitrogen and phosphorus.

Effluent limits can be technology-based and/or water-quality based. EPA has established technology-based, secondary treatment effluent limits for BOD as 5-day biochemical oxygen demand (BOD5), TSS, and pH.

Water-quality based effluent limits are set if the technology-based limits are not sufficient to maintain the water quality standards (WQS) of the receiving water.

Federal and State regulations related to WQSs and Total Maximum Daily Loads (TMDLs) are expected to drive down NPDES effluent limits for nitrogen and phosphorus. WQS define the goals for a water body by designating its uses, setting criteria to protect those uses, and establishing provisions to protect water bodies from pollutants. Criteria can be narrative or numeric.

Regulatory agencies can adopt *nutrient criteria* to protect a water body against nutrient over-enrichment and eutrophication caused by nitrogen and phosphorus. In June 1998, EPA issued a *National Strategy for the Development of Regional Nutrient Criteria.*

This was followed by publication of recommended nutrient criteria for most streams and lakes in 2001. In a January 9, 2001 *Federal Register* notice, EPA recommended that states and other regulatory agencies develop a nutrient criteria plan to outline their process for adopting such nutrient criteria (*Federal Register*, 2001).

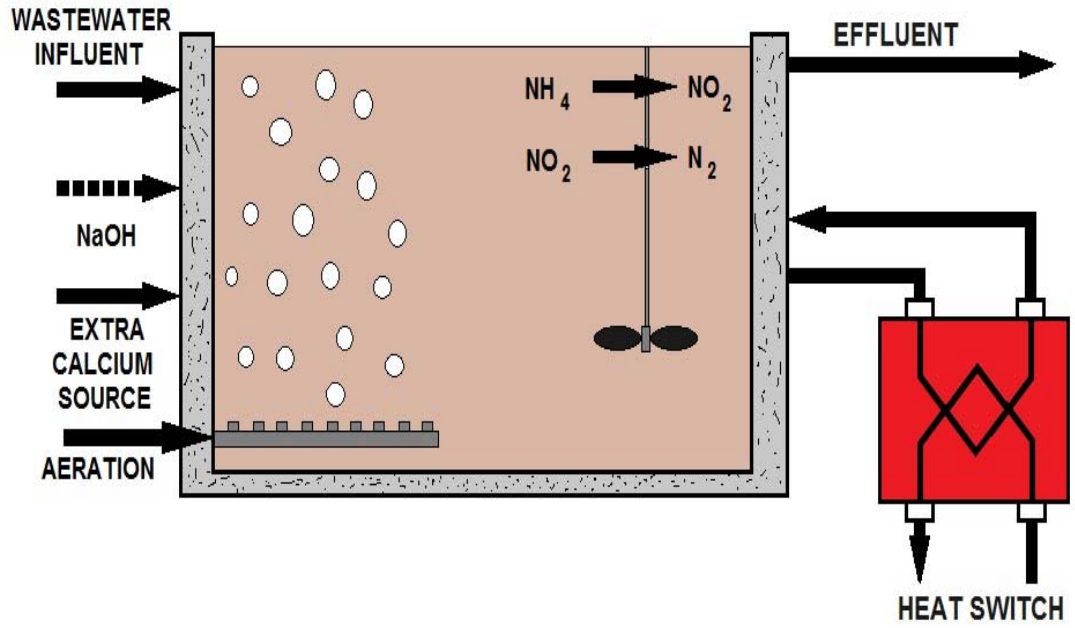
As of May 2007, only a handful of States and Territories had adopted nutrient criteria for nitrogen and phosphorus (USEPA, 2007a), although many have made progress in criteria development. In a memo dated May 25, 2007, EPA encouraged all regulatory agencies to "…*accelerate their efforts and give priority to adopting numeric nutrient standards or numeric translators for narrative standards for all waters in States and Territories that contribute nutrient loadings to our waterways" (USEPA, 2007b).*

CWA Section 303(d) requires states to develop TMDLs for water bodies on the 303(d) list of impaired waters. A TMDL is a calculation of the maximum amount of a pollutant a water body can receive and still meet WQS.

TMDLs serve as a tool for implementing WQS. The TMDL targets or endpoints represent a number where the applicable WQS and designated uses (e.g., such as public water supply, contact recreation, and the propagation and growth of aquatic life) are achieved and maintained in the water body of concern.

TMDLs identify the level of pollutant control necessary to meet WQS and support the designated uses of a water body. Once a TMDL is set, the total load is allocated among all existing sources.

The allocation is divided into two portions - a load allocation representing natural and non-point sources and a waste load allocation representing NPDES permitted point source discharges. In many regions, water bodies have a poor ability to assimilate nutrients or water bodies are already impaired from past pollution and the water body cannot handle large loads of additional nutrients. In these cases, TMDLs may require nutrient permit levels to be even lower than what might be allowed otherwise by nutrient criteria.



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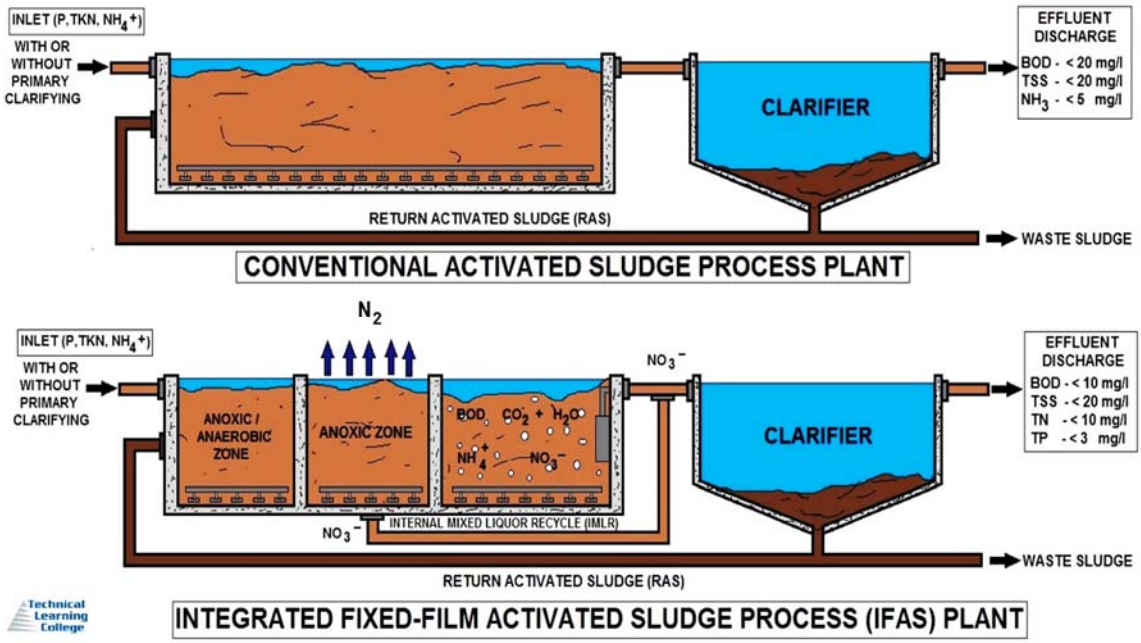
PROCESS FOR NITROGEN (N_2) REMOVAL

Nitrogen and Phosphorus Removal Technologies (Credit EPA)

Introduction

This section provides information on a number of different technologies that can reduce nitrogen and phosphorus levels. The actual technology selected will be site-specific and dependent on many factors including soil conditions, influent water quality, required effluent levels, disposal options, availability of land, cost, etc. In some cases, a combination of technologies may be necessary to effectively remove all the contaminants of concern. Small system owners and operators should work closely with their state onsite and decentralized program staff as well as engineers to ensure that the technologies selected will work effectively in combination to achieve the effluent goals.



Nutrient Removal Technologies

Fixed-Film Systems - Aerobic/anaerobic Trickling Filter Package Plant

Fixed-film systems (FFSs) are biological treatment processes that employ a medium such as rock, plastic, wood, or other natural or synthetic solid material that will support biomass on its surface and within its porous structure (USEPA, 2008c). Trickling filter FFSs are typically constructed as beds of media through which wastewater flows. Oxygen is normally provided by natural or forced ventilation.

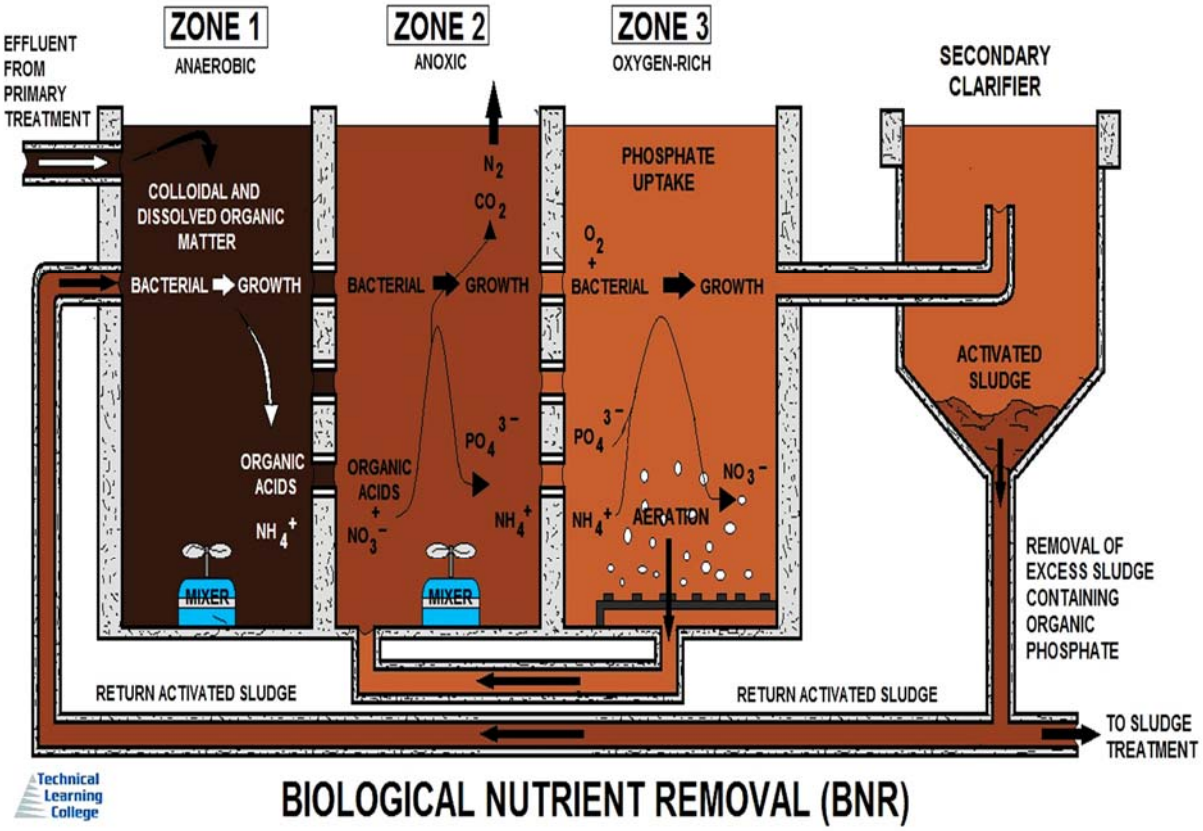
Commercial on-site systems use synthetic media and receive wastewater from overlying sprayheads for aerobic treatment and nitrification. Nitrified effluent returns to the anoxic zone to mix with either septic tank contents or incoming septic tank effluent for denitrification.

A portion of the denitrified effluent is discharged for disposal or further treatment. Aerobic tanks are available in residential or small community sizes. Typical trickling filters systems currently available are capable of producing effluent BOD and TSS concentrations of 5 to 40 mg/L.

Nitrogen removal typically varies from 0 to 35 percent although removal percentages as high as 65% have been demonstrated through USEPA's Environmental Technology Verification (ETV) program. Phosphorus removal is typically 10 to 15 percent.

Higher removal occurs at low loading rates in warm climates. Systems can be configured for single-pass use where the treated water is applied to the trickling filter once before being disposed of, or for multi-pass use where a portion of the treated water is cycled back to the septic tank and re-treated via a closed loop.

Multi-pass systems result in higher treatment quality and assist in removing Total Nitrogen (TN) levels by promoting nitrification in the aerobic media bed and denitrification in the anaerobic septic tank. Factors affecting performance include influent wastewater characteristics, hydraulic and organic loading, medium type, maintenance of optimal DO levels, and recirculation rates.



Sequencing Batch Reactor (SBR) Section

The SBR process is a sequential suspended growth (activated sludge) process in which all major steps occur in the same tank in sequential order (USEPA, 2008d). The SBR system is typically found in packaged configurations for onsite and small community or cluster applications. The major components of the package include the batch tank, aerator, mixer, decanter device, process control system (including timers), pumps, piping, and appurtenances.

Aeration may be provided by diffused air or mechanical devices. SBRs are often sized to provide mixing as well and are operated by the process control timers. Mechanical aerators have the added value of potential operation as mixers or aerators.

The decanter is a critical element in the process. Several decanter configurations are available, including fixed and floating units. At least one commercial package employs a thermal processing step for the excess sludge produced and wasted during the “idle” step. The key to the SBR process is the control system, which consists of a combination of level sensors, timers, and microprocessors which can be configured to meet the needs of the system.

SBRs can be designed and operated to enhance removal of nitrogen, phosphorus, and ammonia, in addition to removing TSS and BOD. Package plant SBRs are suitable for areas with little land, stringent treatment requirements, and small wastewater flows such as RV parks or mobile homes, campgrounds, construction sites, rural schools, hotels, and other small applications. These systems are also useful for treating pharmaceutical, brewery, dairy, pulp and paper, and chemical wastes (USEPA, 2000d).

Intermittent Sand Filters (ISF)
ISF is used to describe a variety of packed-bed filters of sand or other granular materials available on the market (USEPA, 2008g). Sand filters provide advanced secondary treatment of settled wastewater or septic tank effluent. They consist of a lined (e.g., impervious PVC liner on sand bedding) excavation or structure filled with uniform washed sand that is placed over an underdrain system. The wastewater is directed onto the surface of the sand through a distribution network and allowed to percolate through the sand to the underdrain system. The underdrain system collects the filter effluent for further processing or discharge.

Sand filters are aerobic, fixed-film bioreactors. Bioslimes from the growth of microorganisms develop as films on the sand particle surfaces. The microorganisms in the slimes capture soluble and colloidal waste materials in the wastewater as it percolates over the sand surfaces. The captured materials are metabolized into new cell mass or degraded under aerobic conditions to carbon dioxide and water.

Most biochemical treatment occurs within approximately 6 inches of the filter surface. Other treatment mechanisms that occur in sand filters include physical processes, such as straining and sedimentation, to remove suspended solids within the pores of the media. Most suspended solids are strained out at the filter surface.

Chemical adsorption can occur throughout the media bed. Adsorption sites in the media are usually limited, however.

The capacity of the media to retain ions depends on the target constituent, the pH, and the mineralogy of the media. Phosphorous is one element of concern in wastewater that can be removed in this manner, but the number of available adsorption sites is limited by the characteristics of the media.

Sand filters can be used for a broad range of applications, including single-family residences, large commercial establishments, and small communities. Sand filters are frequently used to pretreat septic tank effluent prior to subsurface infiltration onsite where the soil has insufficient unsaturated depth above ground water or bedrock to achieve adequate treatment.

They are also used to meet water quality requirements (with the possible exception of fecal coliform removal) before direct discharge to surface water. Sand filters are used primarily to treat domestic wastewater, but they have been used successfully in treatment trains to treat wastewaters high in organic materials such as those from restaurants and supermarkets.

Single-pass ISF filters are most frequently used for smaller applications and sites where nitrogen removal is not required. However, they can be combined with anoxic processes to significantly increase nitrogen removal.

Recirculating Sand Filters (RSF)

Recirculating filters using sand, gravel, or other media provide advanced secondary treatment of settled wastewater or septic tank effluent (USEPA, 2008h). They consist of a lined (e.g., impervious PVC liner on sand bedding) excavation or structure filled with uniform washed sand that is placed over an underdrain system.

The wastewater is directed onto the surface of the sand through a distribution network and allowed to percolate through the sand to the underdrain system. The underdrain system collects and recycles the filter effluent to the recirculation tank for further processing or discharge.

The basic components of recirculating filters include a recirculation/dosing tank, pump and controls, distribution network, filter bed with an underdrain system, and a return line.

The return line or the underdrain must split the flow to recycle a portion of the filtrate to the recirculation/dosing tank. A small volume of wastewater and filtrate is dosed to the filter surface on a timed cycle 1 to 3 times per hour.

Recirculation ratios are typically between 3:1 and 5:1. In the recirculation tank, the returned aerobic filtrate mixes with the anaerobic septic tank effluent before being reapplied to the filter. RSFs can be used for a broad range of applications, including single-family residences, large commercial establishments, and small communities. They produce a high quality effluent with approximately 85 to 95 percent BOD and TSS removal. In addition, almost complete nitrification is achieved.

Denitrification also has been shown to occur in RSFs. Depending on modifications in design and operation, 50 percent or more of applied nitrogen can be removed (USEPA, 1999). To enhance this capability, they can be combined with a greater supply of biodegradable organic carbon, time, and mixing than is normally available from the conventional recirculation tank.

Natural Systems

The natural systems described here include constructed wetlands and floating aquatic plant treatment systems.

Wetland systems are typically described in terms of the position of the water surface and/or the type of vegetation grown.

Most natural wetlands are free water surface (FWS) systems where the water surface is exposed to the atmosphere; these include bogs (primary vegetation mosses), swamps (primary vegetation trees), and marshes (primary vegetation grasses and emergent macrophytes) (USEPA, 2000e). subsurface flow (SF) wetlands are specifically designed to treat or polish wastewater and are typically constructed as a bed or channel containing appropriate media.

Constructed wetlands treat wastewater by bacterial decomposition, settling, and filtering. As in tank designs, bacteria break down organic matter in the wastewater, aerobically, anoxically and anaerobically. Oxygen for aerobic decomposition is supplied by the plants growing in the wetland.

Solids are filtered and finally settle out of the wastewater within the wetland. After about two weeks in the wetland, effluent is usually discharged by gravity to an unlined wetland bed. If these systems discharge effluent to surface ditches, they require a NPDES permit.

The submerged plant roots do provide substrate for microbial processes. However, the amount of oxygen that emergent macrophytes can transmit from the leaves to their roots is negligible compared to the oxygen demand of wastewater. Therefore, subsurface flow wetlands are devoid of oxygen.

The lack of oxygen in these subsurface flow systems means that ammonia oxidation via biological nitrification will not occur without the use of an additional unit process, such as a gravel trickling filter for nitrification of the wastewater ammonia.

Vertical flow wetland beds are a modification of subsurface flow wetlands which contain gravel or coarse sand and are loaded intermittently at the top surface.

Unlike ammonia oxidation, nitrate removal in a subsurface flow wetland can be rapid and effective because the anoxic conditions and carbon sources necessary to support the treatment reactions occur naturally in these systems.

FWS wetlands with long detention times can remove minor amounts of phosphorus through plant uptake, adsorption, complexation, and precipitation.

NITROGEN CYCLE

The **wastewater nitrogen cycle** incorporates the significant inorganic and organic nitrogenous compounds that enter the activated sludge process, are produced in the activated sludge process and leave the activated sludge process. The impact of these compounds upon the activated sludge process also is presented.

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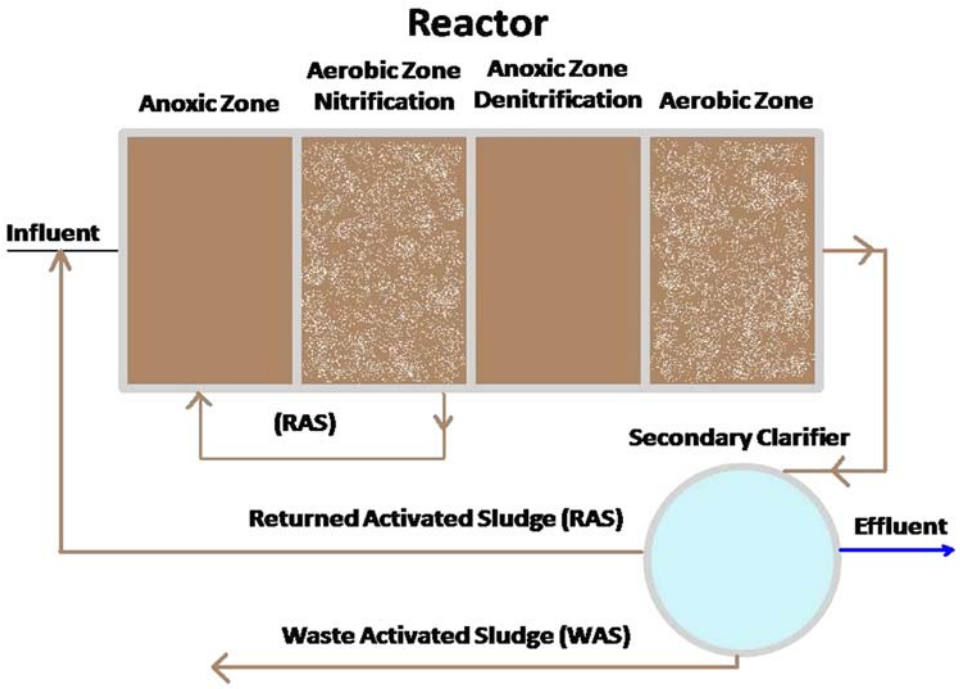

A nitrification-denitrification four-stage Bardenpho flow diagram

Nitrification is a process of nitrogen compound oxidation (effectively, loss of electrons from the nitrogen atom to the oxygen atoms):

1. $2\ NH_3 + 3\ O_2 \rightarrow 2\ NO_2^- + 2\ H_2O + 2\ H^+$ (Nitrosomonas)

2. $2\ NO_2^- + 1\ O_2 \rightarrow 2\ NO_3^-$ (Nitrobacter, Nitrospina)

3. $NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^-$

4. $NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^-$

DENITRIFICATION PROCESS

Denitrification is the reduction of nitrates back into nitrogen gas (N_2), completing the nitrogen cycle. This process is performed by bacterial species such as **Pseudomonas and Clostridium** in anaerobic conditions. They use the nitrate as an electron acceptor in the place of oxygen during respiration. These facultative anaerobic bacteria can also live in aerobic conditions.

Denitrification happens in anaerobic conditions e.g. waterlogged soils. The denitrifying bacteria use nitrates in the soil to carry out respiration and consequently produce nitrogen gas, which is inert and unavailable to plants.

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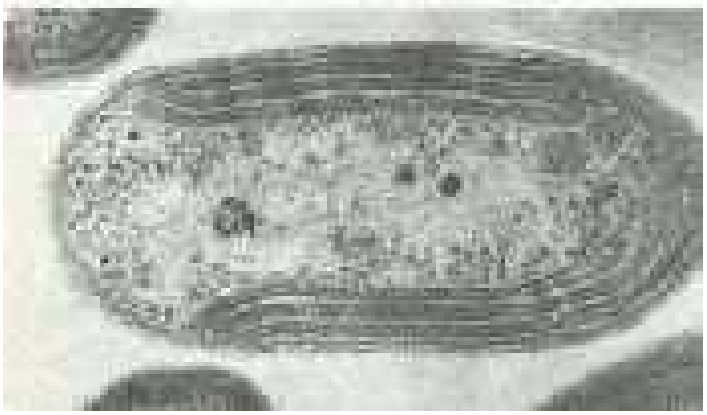
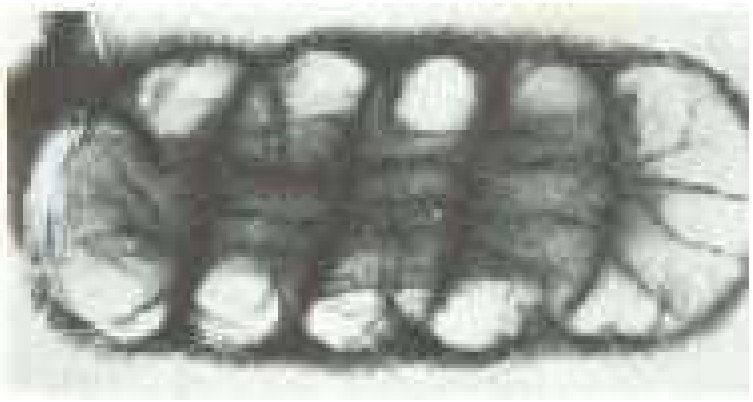


Nitrobacter winogradskyi



Nitrospira gracilis

DENITRIFICATION PROCESS

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When sludge denitrifies, it will rise to the top of the Settleometer.

Water Quality Trading Section

What is “Water quality trading”? It is a market-based approach to improve and preserve water quality.

Trading can provide greater efficiency in achieving water quality goals by allowing one source to meet its regulatory obligations by using pollutant reductions created by another source that has lower pollution control costs.

For example, under a water quality-trading program, a POTW could comply with discharge requirements by paying distributed sources to reduce their discharges by a certain amount. The use of geographically-based trading ratios provides an economic incentive, encouraging action toward the most cost effective and environmentally beneficial projects.

EPA issued a Water Quality Trading Policy in 2003 to provide guidance to States and Tribes on how trading can occur under the CWA and its implementing regulations. The policy discusses CWA requirements that are relevant to water quality trading including: requirements to obtain permits, anti-backsliding provisions, development of WQSs including an anti-degradation policy, NPDES permit regulations, TMDLs and water quality management plans.

EPA also developed a number of tools and guidance documents to assist states, permitted facilities, non-point sources, and stakeholders involved in the development of trading programs.

Recently, the U.S. Department of Agriculture (USDA) National Resources Conservation Service released a Nitrogen Trading Tool (NTT) prototype for calculating nitrogen credits based on the Nitrogen Loss and Environmental Assessment Package Model (Gross et al., 2008).

Water quality trading programs have been successfully implemented in several states and individual watersheds across the county. For example, nitrogen pollution from point sources into the Long Island Sound was reduced by nearly 25 percent using an innovative Nitrogen Credit Trading Program.

In Connecticut, the program was implemented among 79 sewage treatment plants in the state. Through the Nitrogen Credit Exchange, established in 2002, the Connecticut program has a goal of reducing nitrogen discharges by 58.5 percent by 2014.

A recent American Society of Civil Engineers journal article points out that regulatory frameworks for water quality trading programs have yet to be adopted by the majority of States.

Barriers to adopting such programs include uncertainty in:
(1) the mechanisms for determining appropriate credits and ratios between point sources and distributed sources; and
(2) approaches to ensure that promised reductions actually occur (Landers, 2008).

These photographs are of an operator taking mixed liquor samples in an oxidation ditch. Always wear latex gloves, many operators quit wearing gloves after a short period because they feel immune to disease.

Nutrient Constituents and Measurement Methods

This section provides an overview of the sources, forms, and measurement methods for nitrogen and phosphorus in wastewater.

NITROGEN

Nitrogen is an important nutrient for plant and animal growth. Atmospheric nitrogen is less biologically available than dissolved nitrogen in the form of ammonia and nitrates. Availability of dissolved nitrogen may contribute to algal blooms.

Ammonia and organic forms of nitrogen are often measured as **Total Kjeldahl Nitrogen (TKN)**, and analysis for inorganic forms of nitrogen may be performed for more accurate estimates of total nitrogen content.

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NUTRIENT TESTING CONCEPT (TKN)

Nutrients are substances that are required for the growth of living plants and animals. Major nutrients include **nitrogen (N)** and **phosphorous (P)**. Both are found in wastewater in various forms. Nitrogen is typically present in the influent in the forms of ammonia (NH_3) and organically bound nitrogen. Both nitrogen compounds can be measured by the **Total Kjeldahl Nitrogen (TKN)** test.

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The TKN method has three major steps:

(1) digestion to convert organic nitrogen to ammonium sulfate;
(2) conversion of ammonium sulfate into condensed ammonia gas through addition of a strong base and boiling; and
(3) measurement using colorimetric or titration methods. Because the measured concentration includes ammonia, the ammonia-nitrogen concentration is subtracted from the TKN to determine organic nitrogen.

Nitrogen components in wastewater are typically reported on an “as nitrogen” basis so that the total nitrogen concentration can be accounted for as the influent nitrogen components are converted to other nitrogen compounds in wastewater treatment.

WWTPs designed for nitrification and denitrification can remove 80 to 95 percent of inorganic nitrogen, but the removal of organic nitrogen is typically much less efficient (Pehlivanoglu-Mantas and Sedlak, 2006). Domestic wastewater organic nitrogen may be present in particulate, colloidal or dissolved forms and consist of proteins, amino acids, aliphatic N compounds, refractory natural compounds in drinking water (e.g. Humic substances), or synthetic compounds (e.g. ethylene Diamine tetraacetic acid (EDTA)).

Organic nitrogen may be released in secondary treatment by microorganisms either through metabolism or upon death and lysis.

Some nitrogen may be contained in recondensation products. Hydrolysis of particulate and colloidal material by microorganisms releases some organic nitrogen as dissolved, biodegradable compounds.

Amino acids are readily degraded during secondary biological treatment, with 90 to 98 percent removal in activated sludge systems and 76 to 96 percent removal in trickling filters. However, other forms of organic nitrogen may be more persistent in wastewater treatment processes.

The importance of organic nitrogen has increased as effluent limits on nitrogen have become more stringent. With more impaired waterways from nutrient loads, effluent limits for total nitrogen (TN) concentrations of 3.0 mg/L or less are becoming more common.

The dissolved organic nitrogen (DON) concentration in the effluent from biological nutrient removal treatment facilities was found to range from 0.50 to 1.50 mg/L in 80 percent of 188 plants reported by Pagilla (STAC-WERF, 2007) and values as high as 2.5 mg/L were observed.

Thus, for systems without effluent filtration or membrane bioreactors (MBRs) that are trying to meet a TN treatment goal of 3.0 mg/L, the effluent DON contribution can easily be 20 to 50 percent of the total effluent nitrogen concentration, compared to only about 10 percent for conventional treatment (Pehlivanoglu-Mantas and Sedlak, 2004).

The chemical composition of DON in wastewater effluents is not completely understood. Sedlak (2007) has suggested that only about 20 percent of the DON has been identified as free and combined amino acids, EDTA, and other trace nitrogen compounds.

About 45 percent may be unidentified low molecular weight compounds and the other 35 percent as unidentified high molecular weight compounds containing Humic acids and amides. Similar results were found by Khan (2007). Early work by Parkin and McCarty (1981) suggested that 40 to 60 percent of effluent DON is non-bioavailable. The non-bioavailable portion is also referred to as recalcitrant DON (rDON).

NITROGEN REMOVAL

Nitrogen is removed through the biological **oxidation** of nitrogen from **ammonia** to **nitrate (nitrification)**, followed by **denitrification**, the reduction of nitrate to nitrogen gas. Nitrogen gas is released to the atmosphere and thus removed from the water.

Nitrification itself is a two-step aerobic process, each step facilitated by a different type of bacteria. The oxidation of ammonia (NH_3) to nitrite.

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Denitrification Bacteria Section

In municipal and industrial wastewater treatment processes, denitrification is the biological reduction of nitrate or nitrite to nitrogen gas (N2) as indicated by equation below.

$$6NO_3^- + 5CH_3OH \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH$$

This is accomplished by a variety of common heterotrophic microorganisms that are normally present in aerobic biological processes. Most are facultative aerobic bacteria with the ability to use elemental oxygen, nitrate, or nitrite as their terminal electron acceptors for the oxidation of organic material.

Heterotrophic bacteria capable of denitrification include the following genera: *Achromobacter, Acinetobacter, Agrobacterium, Alcaligenes, Arthrobacter, Bacillus, Chromobacterium, Corynebacterium, Flavobacterium, Hypomicrobium, Moraxella, Nesseria, Paracoccus, Propionibacteria, Pseudomonas, Rhizobium, Rhodopseudmonas, Spirillum and Vibrio* (Tchobanoglous et al., 2003).

Recent research has shown that nitrite reduction is accomplished by a much more specialized group of heterotrophic bacteria than those performing the conversion of nitrate to nitrite (Katehis, 2007).

Denitrification by heterotrophic nitrifying bacteria and by autotrophic bacteria has also been observed. An example of a heterotrophic nitrifying bacteria that can denitrify is *Parococcus pantotropha*, which obtains energy by nitrate or nitrite reduction while oxidizing ammonia under aerobic conditions.

A readily available carbon source, such as acetate, is needed (Robertson and Kuenen, 1990). The conditions required for this form of denitrification are not practical in biological wastewater treatment.

An autotrophic denitrifying bacteria of practical significance in wastewater treatment is that in the Anammox process used to remove nitrogen in return streams from anaerobic digestion sludge dewatering filtrate or centrate. These bacteria have been identified as a member of bacteria in the order *Planctomycetales* (Strous et al, 1999).

Under anaerobic conditions, ammonia is oxidized with the reduction of nitrite with the final product as nitrogen gas. The reaction is best accomplished at temperatures above 25°C and they are slow growing organisms.

Facultative Denitrifying Bacteria
Facultative denitrifying bacteria will preferentially use oxygen instead of nitrate. In the absence of oxygen, however, they will carry out nitrite and/or nitrate reduction. Microbiologists generally use the term anaerobic to describe biological reactions in the absence of oxygen.

To distinguish anaerobic conditions for which the biological activity occurs mainly with nitrate or nitrite as the electron acceptor, the term “anoxic” has been applied.

Although oxygen is known to inhibit denitrification, denitrification has been observed in activated sludge and fixed film systems in which the bulk liquid DO concentration is positive. This is due to the establishment of an anoxic zone within the floc or biofilm depth. Hence, a single system can carry out simultaneous nitrification and denitrification.

The DO concentration that is possible for simultaneous nitrification and denitrification depends on a number of factors including the mixed liquor concentration, temperature, and substrate loading. The DO concentration above which denitrification is inhibited may vary from 0.10 to 0.50 mg/L (WEF and ASCE, 2006; Tchobanoglous et al., 2003; Barker and Dold, 1997).

The organic carbon source for denitrifying bacteria can be in the form of:

- Soluble degradable organics in the influent wastewater
- Soluble organic material produced by hydrolysis of influent particulate material
- Organic matter released during biomass endogenous decay

A general rule of thumb is that 4 g of wastewater influent BOD is needed per g of NO3-N to be removed through biological treatment (Tchobanoglous et al., 2003). When denitrification occurs after secondary treatment, there is little BOD remaining so a supplemental carbon source is often needed.

Methanol

The most common exogenous carbon source in use is methanol; however, due to issues regarding its safety, cost, and availability, some wastewater systems are using alternative carbon sources such as acetic acid, ethanol, sugar, glycerol, and proprietary solutions depending on the needs of their particular facility (deBarbadillo et al., 2008).

Biological denitrification reactions produce alkalinity and heterotrophic biomass. Based on the stoichiometry of the reactions, denitrification will produce a 3.57 mg/L of alkalinity as CaCO3 for each mg/L of $NO3^{-}-N$ consumed. Heterotrophic biomass produced can be estimated as 0.4 g volatile suspended solids (VSS) produced for every gram of COD consumed.

Growth kinetics for denitrifiers are dependent on a number of factors including carbon substrate type and concentration, DO concentration, alkalinity, pH, and temperature, with carbon source being the most important.

Current Configurations

Biological nitrogen removal can be accomplished by a variety of treatment configurations using suspended growth, attached growth, or combined systems. In the past, some WWTPs were required to only remove ammonia-nitrogen in wastewater to reduce toxicity to aquatic organisms with no limits on nitrate or total nitrogen.

However, most treatment plants are now required to remove nitrogen because both ammonia-nitrogen and nitrate-nitrogen can stimulate algae and phytoplankton growth and lead to eutrophication of U.S. waterways. For biological nitrogen removal, it is essential that nitrification occur first followed by denitrification.

Biological Nitrogen Removal Process Configurations
Biological nitrogen removal systems achieve nitrification and denitrification along with BOD reduction in bioreactors followed by secondary clarification. Processes can be either suspended growth or hybrid systems that use a combination of attached growth (biofilms) and suspended growth technologies.

Configurations within each of these classifications will be discussed. Note that biological processes that removal both nitrogen and phosphorus are discussed later in this manual.

Suspended Growth Systems Modified Ludzck Ettinger (MLE) process
The most common nitrogen removal process used at WWTPs is the Modified Ludzck Ettinger (MLE) process, which is considered a pre-denitrification, single sludge system. The process includes an initial anoxic zone, followed by an aerobic zone.

In the anoxic zone, nitrate produced in the aerobic zone is reduced to nitrogen gas. This process uses some of the BOD in the incoming waste.

Nitrification occurs in the aerobic zone along with the removal of most of the remaining BOD. At the end of the aerobic zone, pumps recycle the nitrate-rich mixed liquor to the anoxic zone for denitrification.

Total nitrogen removal for the MLE process is typically 80 percent, and the process achieves total effluent nitrogen concentrations ranging from approximately 5 to 8 mg/L with internal nitrate recycle ratios of 2 to 4 based on the influent flowrate (2-4Q).

Four-Stage Bardenpho Process
The four-stage Bardenpho process builds on the MLE process, with the first two stages being identical to the MLE system (anoxic zone followed by an aeration zone with a nitrate-rich recycle from the aeration to the anoxic zone).

The third stage is a secondary anoxic zone to provide denitrification to the portion of the flow that is not recycled to the primary anoxic zone.

Methanol or another carbon source can be added to this zone to enhance denitrification.

The fourth and final zone is a re-aeration zone that serves to strip any nitrogen gas and increase the DO concentration before clarification. Some configurations have used an oxidation ditch instead of the first two stages. This process can achieve effluent TN levels of 3 to 5 mg/L.

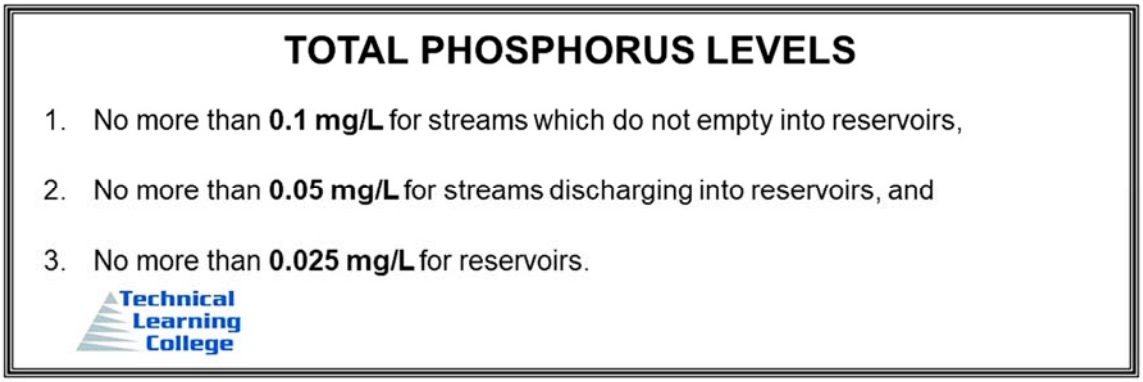
The four-stage Bardenpho which includes fermentation.

Phosphorus Section

Total phosphorus (TP) in domestic wastewater typically ranges between 4 and 8 mg/L but can be higher depending on industrial sources, water conservation, or whether a detergent ban is in place. Sources of phosphorus are varied. Some phosphorus is present in all biological material, as it is an essential nutrient and part of a cell's energy cycle. Phosphorus is used in fertilizers, detergents, and cleaning agents and is present in human and animal waste.

Phosphorus in wastewater is in one of three forms:

- Phosphate (also called Orthophosphate)
- Polyphosphate, or
- Organically bound phosphorus.



The orthophosphate fraction is soluble and can be in one of several forms (e.g., phosphoric acid, phosphate ion) depending on the solution pH. Polyphosphates are high-energy, condensed phosphates such as pyrophosphate and trimetaphosphate. They are also soluble but will not be precipitated out of wastewater by metal salts or lime. They can be converted to phosphate through hydrolysis, which is very slow, or by biological activity.

Organically bound phosphorus can either be in the form of soluble colloids or particulate. It can also be divided into biodegradable and non-biodegradable fractions.

Particulate organically bound phosphorus is generally precipitated out and removed with the sludge. Soluble organically bound biodegradable phosphorus can be hydrolyzed into orthophosphate during the treatment process. Soluble organically bound non-biodegradable phosphorus will pass through a wastewater treatment plant. A typical wastewater contains 3 to 4 mg/L phosphorus as phosphate, 2 to 3 mg/L as polyphosphate, and 1 mg/L as organically bound phosphorus (WEF and ASCE, 2006).

Phosphorus content in wastewater can be measured as

- Orthophosphate
- Dissolved orthophosphate
- Total phosphorus
- Total dissolved phosphorus (i.e., all forms except particulate organic phosphorus)

EPA approved laboratory methods rely on colorimetric analysis. Colorimetric analysis measures orthophosphate only, so a digestion step is needed to convert polyphosphate and organic phosphorus to orthophosphate to measure TP.

TOTAL PHOSPHORUS AND PHOSPHATE

Phosphates enter the water ways through both non-point sources and point sources. Non-point source (NPS) pollution refers to water pollution from diffuse sources. Nonpoint source pollution can be contrasted with point source pollution, where discharges occur to a body of water at a single location.

The non-point sources of phosphates include: natural decomposition of rocks and minerals, storm water runoff, agricultural runoff, erosion and sedimentation, atmospheric deposition, and direct input by animals/wildlife; whereas: point sources may include: waste water treatment plants and permitted industrial discharges.

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The persulfate method is reported to be the most common and easiest method (WEF and ASCE, 2006). To determine dissolved phosphorus (either total dissolved phosphorus or total dissolved orthophosphate), the sample is first filtered through a 0.45 micron filter.

USEPA approved colorimetric methods are routinely used to measure phosphorus levels as low as 0.01 mg/L. On-line analyzers that use the colorimetric method are available from vendors (e.g., the Hach PhosphaxTM SC phosphate analyzer).

Ion chromatography is a second common technique used to measure orthophosphate in wastewater. As with colorimetric methods, digestion is required for TP measurement, with persulfate digestion recommended (WEF and ASCE, 2006).

PHOSPHORUS LOADING

Phosphorus concentrations can be very high for limited periods but turbulent conditions, short residence times, and shading from sediment often prevent excess algae growth. At low flow, the proportion of effluent to stream flow can be much higher. Point sources like wastewater treatment facilities can dominate in-stream phosphorus loading. Low flow conditions often occur in late summer months when temperatures are higher and water is moving slower, all of which tend to encourage algae growth.

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Phosphorus Removal by Chemical Addition

The purpose of this section is to describe techniques for phosphorus removal by chemical addition. It summarizes issues associated with chemical feed location, mixing, and sludge production. An overview of advanced solids separation processes is also provided.

Principles

Chemical precipitation for phosphorus removal is reliable wastewater treatment method that has not significantly changed over the years. To achieve removal, coagulant aids such as iron salts are added to wastewater where they react with soluble phosphates to form precipitates. The precipitates are removed using a solids separation process, most commonly clarification. Chemical precipitation is typically accomplished using either lime or a metal salt such as aluminum sulfate (alum) or as mentioned iron salts such as ferric chloride. The addition of polymers and other substances can further enhance floc formation and solids settling. Plant operators can use existing secondary clarifiers or retrofit primary clarifiers for removal of sludge.

Aluminum and Iron Salts

Alum and ferric or ferrous salts are commonly used as coagulant and settling aids in both the water and wastewater industry. Alum is less corrosive than Ferric without drastic changes to pH, creates less sludge, and is more popular with operators when compared to lime which increases the pH. Alum is available in liquid or dry form, can be stored on site in steel or mild concrete, and has a near unlimited shelf life.

Ferric chloride is similar although care is needed during handling because of corrosivity. If an industrial source is available such as waste pickle liquor, ferrous chloride or ferrous sulfate have been used for phosphorus removal. Ferrous forms should be added directly to aerobic reactors rather than to anaerobic reactors such as primary settling basins because the ferrous iron needs to oxidize to ferric iron for best results.

The molar ratio of aluminum to phosphorus required for phosphorus removal ranges from about 1.38:1 for 75 percent removal, 1.72:1 for 85 percent removal, and 2.3:1 for 95 percent removal.

For iron compounds, a ratio of about 1:1 is required, with a supplemental amount of iron (10 mg/L) added to satisfy the formation of hydroxide (WEF and ASCE, 1998). For additional removal of phosphorus with aluminum and iron salts, a ratio of between 2 and 6 parts metal salt to 1-part phosphorus may be required for adequate phosphorus removal.

To supplement stoichiometry calculations, designers should consider jar tests and, in some cases, full-scale pilot tests to gauge the effects on the required dose of competing reactions; the influence of pH and alkalinity, adsorption, and co-precipitation reactions; and the interaction with polymers that are added to increase coagulation and flocculation (WEF and ASCE, 1998; Bott et al. 2007).

Aluminum or ferric iron salts can be added to the primary clarifier, secondary clarifier, tertiary clarifier, or directly into the activated sludge aeration tank. Multiple additions can increase phosphorus removal efficiency. Ferrous salts can only be added to the aeration basin since it needs to be oxidized to ferric to precipitate the phosphorus.

The solubility of aluminum and iron salts is a function of pH.

The optimum solubility for alum was previously reported to occur at a pH range of 5.5 to 6.5, significantly lower than most influent wastewater. Recent studies (Szabo et al., 2008) showed that the range for both iron and alum is between 3.5 and 7.5 with the highest efficiency between pH 5.5 and 7.

Chemicals such as lime compounds, caustic soda, and soda ash can be used to raise the pH of the waste stream prior to biological treatment processes or discharge. It is important to understand that alkalinity is consumed during the precipitation reactions, and precipitation will be incomplete if insufficient alkalinity is present.

Lime

Although lime had lost favor due to issues associated with chemical handling, sludge production, and re-carbonation, it has recently been considered more often because of its ability to reduce phosphorus to very low levels when combined with effluent filtration and the microbial control properties associated with its high pH.

When lime is added to wastewater, it first reacts with the bicarbonate alkalinity to form calcium carbonate (CaCO3). As the pH increases to more than 10, excess calcium ions will react with phosphate to precipitate hydroxylapatite [CA5(OH)(PO4)3].

Because it reacts first with alkalinity, the lime dose is essentially independent of the influent phosphorus concentration. Tchobanoglous et al. (2003) estimates the lime dose to typically be 1.4 to 1.6 times the total alkalinity expressed as CaCO3.

The molar ratio required for phosphorus precipitation with lime is approximately 5:3, but can vary from between 1.3 to 2, depending on the composition of the wastewater. As with iron and aluminum salts, jar tests can be used to determine correct doses for a specific wastewater stream (WEF,1998).

Lime addition can raise the pH to greater than 11. Because activated sludge processes require pH levels below 9, lime cannot be added directly to biological treatment processes or it will cause process upsets. Lime can be added to primary sedimentation tanks and removed with the primary sludge or it can be added as a tertiary treatment process after biological treatment.

When added to primary tanks, it will also result in the removal of colloidal material through coagulation and settling, with a concomitant removal of TSS up to 80 percent and chemical oxygen demand (COD) up to 60 percent.

In either case, pH adjustment is needed and typically accomplished by adding CO2 or a liquid acid such as sulfuric acid, nitric acid, or hypochlorite (Tchobanoglous et al., 2003; USEPA, 1999a).

Hortskotte et al. (1974) showed that when the primary effluent is discharged directly to a nitrifying activated sludge plant, the hydrogen ions produced may neutralize the high pH. However, when denitrification is practiced and the operator wishes to make use of the soluble COD in the primary effluent, the effluent must be neutralized before discharging it to the anoxic zone.

Chemical Feed and Mixing Overview

Lime or metal salts can be added at several locations throughout the treatment plant to remove phosphorus.

“Pre-precipitation” is when chemicals are added to raw water to precipitate phosphorus in the primary sedimentation basins.

“Co-precipitation” involves adding chemicals to form precipitates that can be removed with biological sludge.

“Post-precipitation” is when chemicals are added after secondary sedimentation and precipitants are removed in a tertiary process such as sedimentation or filtration (Tchobanoglous et al., 2003). Because it requires a high pH to achieve a low phosphorus concentration, lime cannot be added directly to biological reactors or to the secondary clarifiers.

Multipoint additions of iron or aluminum salts have been very effective and can typically remove more phosphorus than single-point applications.

There are several advantages to post-precipitating phosphorous using a tertiary treatment technique (after biological processes in a separate reactor):

• Microorganisms rely on phosphorus as a food source. If too much phosphorus is removed prior to biological treatment, biological processes may suffer. For activated sludge, the minimum ratio of phosphorus to BOD5 for a rapidly growing (low solids retention time (SRT)) system is typically about 1:100 (WEF and ASCE, 1998).

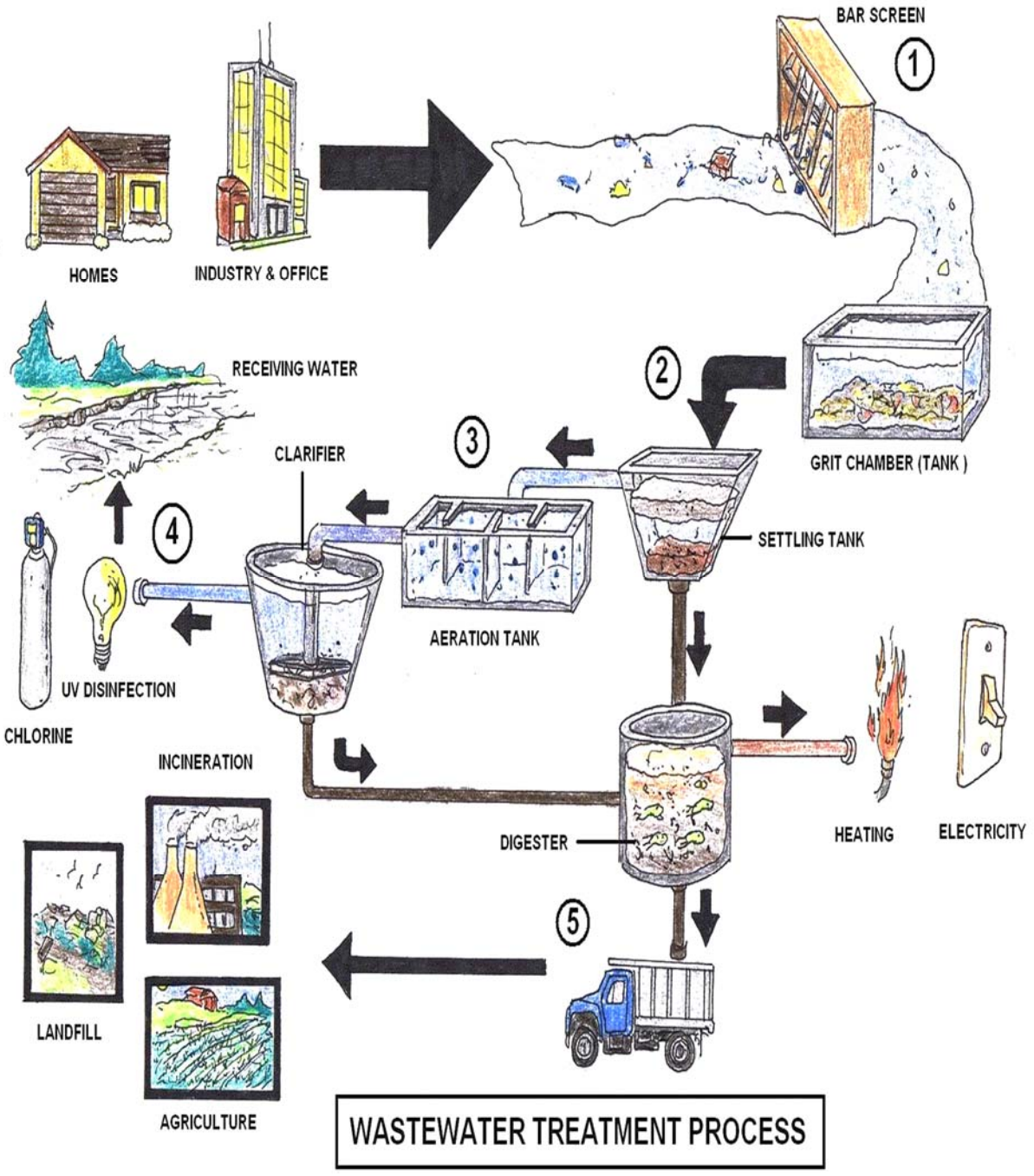
• Competing chemicals in the primary sedimentation basins can increase the required dose.

• Phosphorus enters the treatment plant as soluble orthophosphate, soluble polyphosphates, and organically bound phosphorus. Most of the polyphosphates and much of the organically bound phosphorus are converted to more simple orthophosphates during biological treatment. If the influent contains significant polyphosphates and/or organically bound phosphorus, locating chemical treatment after biological processes would be more efficient and achieve lower effluent levels.

• The removal of carbonate alkalinity and phosphorus by lime prior to biological treatment can have a negative impact on nitrification processes (WEF and ASCE, 1998). Also, removing phosphorus to very low concentrations upstream of denitrification filters can negatively affect the denitrification process. Previous studies showed that the hydroxide alkalinity can be balanced by the hydrogen ions produced during nitrification.

• Sludge recalcification can be used to achieve high removal efficiencies using lime in tertiary treatment. One potential advantage to adding chemicals during primary treatment instead of tertiary treatment is reduced capital costs and space requirements as a result of removing additional BOD and TSS and reducing the load to downstream processes, thereby reducing the size of the subsequent activated sludge basins and the amount of oxygen transfer needed.

Chemicals should be well mixed with the wastewater to ensure reaction with soluble phosphates and formation of precipitates. Chemicals may either be mixed in separate tanks or can be added at a point in the process where mixing already occurs. Bench-scale and pilot scale tests are often used to determine the correct mixing rate for a given composition of wastewater and chemicals used, including polymer (USEPA, 1999a).



Chemicals can be added in the clarifier.

Ammonia

Ammonia is a nutrient that contains nitrogen and hydrogen. Its chemical formula is NH3 in the un-ionized state and NH4+ in the ionized form.

Total ammonia is the sum of both NH3 and NH4+ . Total ammonia is what is measured analytically in water.

Ammonia (CAS # 7664-41-7, atomic mass 17.03) is a colorless alkaline gas which has a pungent suffocating odor at ambient temperature and pressure (WHO 1986; CCREM 1987). It freezes at -77.8oC and boils at -33.35oC, and is often stored or shipped in liquefied form (Geadah 1985).

Ammonia is an important component of the nitrogen cycle and because it is oxidized in the environment by microorganisms (i.e., nitrification), it is a large source of available nitrogen in the environment (Raven & Johnson 1989).

The complexity of the nitrogen cycle, various rate determining environmental conditions for nitrification (e.g., pH, temperature), and the physical behavior of ammonia (e.g., volatilization, adsorption) make determining the fate of ammonia in the environment extremely complex.

Ammonia can form explosive mixtures with air at concentrations between 16 and 27% by volume, but is generally regarded as non-flammable (WHO 1986; Geadah 1980). Ionized ammonium salts form when ammonia dissolves in dilute acids. Some of these salts are found in nature (water, soil, atmosphere) (WHO 1986).

Ammonia is the preferred nitrogen-containing nutrient for plant growth.

Ammonia can be converted to nitrite (NO2) and nitrate (NO3) by bacteria, and then used by plants. Nitrate and ammonia are the most common forms of nitrogen in aquatic systems.

Nitrate predominates in unpolluted waters.

Nitrogen can be an important factor controlling algal growth when other nutrients, such as phosphate, are abundant. If phosphate is not abundant it may limit algal growth rather than nitrogen.

Ammonia is excreted by animals and produced during decomposition of plants and animals, thus returning nitrogen to the aquatic system.

Ammonia is also one of the most important pollutants because it is relatively common but can be toxic, causing lower reproduction and growth, or death. The neutral, unionized form (NH3) is highly toxic to fish and other aquatic life.

Ammonia is analyzed by chemical titration. The method used in most test kits is called the salicylate method.

Always measure pH and temperature when you measure ammonia. Without these other measurements it will be difficult to know the toxicity of the ammonia.

The careful reporting of ammonia test results is very important. Do not simply tabulate your results as "NH3" because this abbreviation is used for both total and unionized ammonia. Be sure you indicate which you are reporting.

Results can be expressed as: total ammonia (mg/l), un-ionized ammonia (mg/l), total ammonia (as N, mg/l), un-ionized ammonia (as N, mg/l).

Advanced Solids Separation Processes (TP) Section

The effectiveness of phosphorus removal by chemical addition is highly dependent on the solids separation process following chemical precipitation.

Direct addition of metal salts to activated sludge processes followed by conventional clarification can typically remove TP to effluent levels between 0.5 and 1.0 mg/L (Bott et al., 2007). Tertiary processes (post-secondary treatment) can be used to remove phosphorus to very low (< 0.1 mg/L) concentrations. For example, Reardon (2005) reports that four WWTP with tertiary clarifiers achieved TP levels of between 0.032 and 0.62 mg/L.

Two common tertiary processes are clarification and effluent filtration. These approaches can be used separately or in combination. The next section presents a detailed discussion of effluent filtration. Advances in tertiary clarification processes are discussed below.

The types of clarifiers used for tertiary processes include conventional, one or two-stage lime, solids-contact, high-rate, and ballasted high-rate (BHRC). Several patented BHRC using different types of ballast such as recycled sludge, microsand, and magnetic ballast (USEPA, 2008a) have been developed in recent years.

The advantages of high-rate clarification are that the clarifiers have a smaller footprint and are able to treat larger quantities of wastewater in a shorter period of time. In addition, as an add-on during wet weather, they can help prevent sanitary sewer overflows (SSOs) and combined sewer overflows (CSOs).

The following patented processes are examples of high rate clarification including performance estimates:

- DensaDeg® uses a coagulant in a rapid mix basin to destabilize suspended solids. The water flows into a second tank where polymer (for aiding flocculation) and sludge are added. The sludge acts as the “seed” for formation of high density floc. This floc is removed in settling tubes (USEPA, 2008). The main advantages of this process are a smaller footprint and denser sludge which is easier to dewater. Pilot testing for City of Fort Worth, Texas found a phosphorus removal rate of 88-95% for DensaDeg® (USEPA, 2003).

- Actiflo® uses a coagulant in a rapid mix basin to destabilize suspended solids. The water flows to a second tank where polymer (for aiding flocculation) and microsand are added. Microsand provides a large surface onto which suspended solids attach, creating a dense floc that settles out quickly. Clarification is assisted by lamella settling. Product pilot testing in Fort Worth, Texas showed a phosphorus removal efficiency of 92-96% for Actiflo®(USEPA, 2003).

- The CoMag process uses the addition of magnetic ballast with metal salts to promote floc formation. Settling is followed by high gradient magnetic separation for effluent polishing and recovery of the magnetic ballast (USEPA, 2008a). CoMag is currently in operation at a 4.0 million gallons per day (MGD) wastewater treatment plant in Concord, Massachusetts. The vendor has guaranteed an effluent phosphorus concentration not to exceed 0.05 mg/L (EPA Region 10, 2007).

Other Design and Operational Issues
Phosphorus removal by chemical addition is limited to the soluble phosphates in the waste stream.

Organically bound phosphorus and polyphosphates will not be removed by chemical treatment unless they are coagulated with the chemicals and removed in the sludge. Chemicals can be added after biological treatment to capitalize on the conversion of polyphosphates and organically bound phosphorus to phosphates by microorganisms in activated sludge.

The success of phosphorus removal by chemical addition depends on proper instrumentation and control. Dosage control typically takes the form of manual operation (for small systems), adjustments based on automatic flow measurements, or the more advanced on-line analyzers with computer-assisted dosage control.

Chemical properties of any water used for making solutions should be considered – tap water high in suspended solids could cause sludge to form when mixed with coagulants (WEF and ASCE, 1998) and could lead to clogging of chemical feed lines. Smith et al. (2008) found that factors such as pH, complexation, mixing, and the coagulant used can limit the removal of phosphorus, especially in the range of <0.1 mg/L.

Impacts on Sludge Handling and Production
Sludge handling and production is generally considered to be one of the main downsides of chemical addition. Chemical precipitation methods always produce additional solids due to generation of metal- or calcium- phosphate precipitates and additional suspended solids (WEF and ASCE, 1998). Chemically treated sludge has a higher inorganic content compared to primary and activated sludge and will increase the required size of aerobic and anaerobic digesters. Additional sludge production can be estimated using reaction equations. The use of metal salts can result in increased inorganic salts (salinity) in the sludge and in the effluent.

Salinity can create problems when biosolids are land applied or when the effluent is returned to existing water supply reservoirs. Biological phosphorus removal was developed in South Africa due to the high rate of indirect recycling of wastewater effluent which led to excessive total dissolved solids (TDS) during dry periods. High total salts can reduce germination rates for crops and negatively affect the soil structure.

Lime traditionally produces a higher sludge volume compared to metal salts because of its reaction with natural alkalinity. An advantage of lime sludge is that some stabilization can occur due to the high pH levels required. One disadvantage is that lime can cause scaling in mechanical thickening and dewatering systems. There are also differences in the amount and characteristics of sludge generated by alum versus ferric salts. Although alum tends to produce less sludge than do ferric salts, alum sludge can be more difficult to concentrate and dewater compared to ferric sludge.

Biological Nitrogen Removal
This section provides an overview of the principles behind biological nitrogen removal and describes the common design configurations in use today. It identifies key operational and design issues (including impacts on sludge handling and production), provides general guidelines on process selection, and summarizes ongoing research efforts in this area.

Process configurations that are designed to remove both nitrogen and phosphorus are described latter.

Principles
In wastewater treatment, nitrogen removal occurs in two sequential processes: nitrification and denitrification. An overview of each process is provided below.

Nitrification
Nitrification is an aerobic process in which autotrophic bacteria oxidize ammonia or nitrite for energy production. Nitrification is normally a two-step aerobic biological process for the oxidation of ammonia to nitrate. Ammonia-nitrogen (NH3-N) is first converted to nitrite (NO2 -) by ammonia oxidizing bacteria (AOB). The nitrite produced is then converted to nitrate (NO3-) by nitrite oxidizing bacteria (NOB). Both reactions usually occur in the same process unit at a wastewater treatment plant (e.g. activated sludge mixed liquor or fixed film biofilm).

The group of AOB most associated with nitrification is the *Nitrosomonas* genus, although other AOB such as *Nitrosococcus* and *Nitrosospira* can contribute to the process. *Nitrobacter* are the NOB most associated with the second step, although other bacteria including *Nitrospina*, *Nitrococcus*, and *Nitrospira* have been found to also oxidize nitrite (Tchobanoglous et al., 2003; USEPA, 2007c).

AOB and NOB are classified as autotrophic bacteria because they derive energy from the oxidation of reduced inorganic compounds (in this case, nitrogenous compounds) and use inorganic carbon (CO2) as a food source.

Nitrifying bacteria require a significant amount of oxygen to complete the reactions, produce a small amount of biomass, and cause destruction of alkalinity through the consumption of carbon dioxide and production of hydrogen ions. For each gram (g) of NH3-N converted to nitrate, 4.57 g of oxygen are used, 0.16 g of new cells are formed, 7.14 g of alkalinity are removed, and 0.08 g of inorganic carbon are utilized in formation of new cells (Tchobanoglous et al., 2003).

Nitrifying bacteria grow slower and have much lower yields as a function of substrate consumed, compared to the heterotrophic bacteria in biological treatment processes.

The maximum specific growth rate of the nitrifying bacteria is 10 to 20 times less than the maximum specific growth rate of heterotrophic bacteria responsible for oxidation of carbonaceous organic compounds in wastewater treatment. Thus, the nitrification process needs a significantly higher SRT to work compared to conventional activated sludge processes.

The SRT needed for nitrification in an activated sludge process is a function of the maximum specific growth rate (which is related to temperature), the reactor dissolved oxygen concentration, and pH.

Nitrification rates decline as the DO concentration decreases below 3.0 mg/L and the pH decreases below 7.0 mg/L. With sufficient DO and adequate pH, typical nitrification design SRTs range from 10 to 20 days at 10^{o}C and 4 to 7 days at 20^{o}C (Randall et al.,1992).

Biological Phosphorus Removal and Combination Processes

This abstract provides an overview of the principles behind biological phosphorus removal (BPR). It describes existing configurations that can achieve phosphorus removal and in many cases, simultaneous nitrogen removal. Key operational issues, impacts on sludge handling, and a summary of ongoing research related to BPR removal are also provided.

Principles
Biological phosphorus removal is achieved by contacting phosphorus accumulating organisms (PAOs) in the RAS with feed, containing volatile fatty acids (VFA), in a zone free of nitrates and DO (anaerobic zone).

Phosphorus is released in this zone providing energy for uptake of VFAs that are polymerized and stored inside the PAO cells. The anaerobic zone is followed by an aeration zone where the polymerized VFAs are metabolized and phosphorus is taken up again to store excess energy from the metabolism.

The phosphorus content of the mixed liquor suspended solids (MLSS) would be similar to that of the waste activated sludge (WAS). When nitrification occurs in the aeration basin, nitrates will be present in the RAS, resulting in some metabolism of the VFA before storage, thereby reducing subsequent phosphorus uptake.

Some form of denitrification (anoxic zones) must be used to reduce/remove the nitrates from the RAS. The process flow sheets now known as Pho-redox (A/O) and 3 Stage Pho-redox (A2/O) as well as the modified Bardenpho process were first published by Barnard (1975) as the Pho-redox flow sheets for the removal of phosphorus. The theory for the functioning of the PAO was first suggested by Fuhs & Chen (1975).

Fuhs & Chen Theory
PAOs have the ability to store a large mass of phosphorus in their cells in the form of polyphosphates. Polyphosphates are formed by a series of high-energy bonds. The organisms can subsequently get energy from breaking these bonds. The polyphosphate globules within the cells function just like energy storage batteries.

The storage of polyphosphates (energy), takes place in the aeration zone. In the anaerobic zone, these obligate aerobic bacteria can take up short chain VFA such as acetate and propionate and store them in the form of intermediate products such as poly-β-hydroxybutyrate (PHB).

The energy for transferring the food across the cell membranes in the anaerobic zone is derived from breaking phosphorus bonds. Excess phosphates are released to the liquid in the anaerobic zone.

Some magnesium and potassium ions are co-transported across the cell walls with phosphates. PAOs can only get energy from the food they have taken up in the anaerobic zone when they pass to the aerobic zone where oxygen is available. They use oxygen to metabolize the stored products, deriving enough energy to take up all the released phosphates as well as those in the influent, and store them in the cells. The WAS will contain sufficient phosphate-enriched PAOs to remove most of the phosphorus from the waste steam once enhanced BPR is established.

The right carbon source, in this case a combination of acetates and propionates, is essential for BPR. The wastewater characteristics are thus important. In general, it can be said that you need at least 40:1 COD:TP or about 18:1 BOD5:TP in the process influent wastewater to reduce effluent phosphorus to less than 1.0 mg/L.

In addition, some of the COD should consist of short chain VFAs. More COD may be required if nitrates must also be denitrified.

Biological phosphorus removal can work in with or without nitrification. When nitrification occurs, denitrification within the process is important to reduce the nitrates that may be returned with the RAS.

While the anaerobic zone serves mostly as a contact zone for VFAs and PAOs, some fermentation of easily biodegradable carbon compounds (rbCOD) to acetate and propionate may take place. In most plants the readily biodegradable material is in short supply and must be reserved for the PAOs.

When nitrate or oxygen is discharged to the anaerobic zone, two things may happen, both undesirable:

- They will prevent fermentation of rbCOD to acetic and propionic acid.
- Nitrates or DO could serve as electron acceptors for PAOs and other organisms that will metabolize the VFA and so deprive the PAOs of the substance that they need to store for growth and phosphorus removal.

In the absence of electron acceptors such as DO and nitrates in the anaerobic zone, PAOs are favored to grow since they can take up and store the VFA under anaerobic conditions, thereby making it unavailable for other aerobic and facultative heterotrophs in the aerobic zone.

Biological removal of both nitrogen and phosphorus at the same WWTP is common. Both funct-ions require a carbon source. While denitrification organisms can feed on quite a number of easily degradable materials such as methanol, sugar, glucose, acetate and propionate, PAOs are restricted to the latter two for polymerization and storage (e.g. adding methanol to the anaerobic zone will reduce nitrates but not assist in the removal of phosphorus).

Current Configurations

The basic design of anaerobic, anoxic, and aerobic zones, in that order, has been achieved in many different configurations. The configurations vary in the number of stages, the nature and location of recycles, and the operation of the process.

Each process was modified from the standard biological activated sludge design in order to accomplish various design goals (e.g., protection of the anaerobic zone from excess nitrate recycle). The primary processes are listed below.

Of these, all will also biologically remove nitrogen except for the Pho-redox process.

- Pho-redox (A/O)
- 3 Stage Pho-redox (A2/O)
- Modified Bardenpho
- University of Capetown (UCT) and Modified UCT (MUCT)
- Johannesburg (JHB), Modified Johannesburg, and Westbank
- Orange Water and Sewer Authority (OWASA)
- Oxidation ditches with anaerobic zones or phases added
- SBR operated with an anaerobic phase
- Hybrid chemical/biological processes

The performance of these technologies depends on many site specific factors, including but not limited to temperature, hydraulic and organic loading, recycle rates, and return streams.

The technologies described in this section are generally capable of phosphorus removal to effluent levels between 0.5 and 1.0 mg/L.

Operating strategies that can be used to enhance biological treatment and achieve these and, in some cases, even lower effluent levels.

Biological phosphorus removal can be combined with other technologies to achieve very low effluent concentrations (< 0.2 mg/L).

Chemical addition combined with biological removal of phosphorus has been used to consistently achieve low levels.

WEF and ASCE (1998) recommend that WWTPs have chemical addition capabilities even for well operating BPR plants to provide backup phosphorus removal in the event of power outages, pipe breaks, or other unforeseen events.

Solids removal can also be a limiting factor in achieving phosphorus removal below 0.2 mg/L. Very low phosphorus levels generally require a TSS level of less than 5 mg/L.

Tertiary filtration (see membrane bioreactors), and advanced clarification processes can achieve TSS levels less than 5 mg/L.

Pho-Redox (A/O) and 3 Stage Pho-Redox (A2/O)

The Pho-redox (A/O) process is a conventional activated sludge system with an anaerobic zone at the head of the aeration basin. The RAS is pumped from the clarifier to the anaerobic zone. It is a low SRT process, operated to avoid nitrification. With no nitrates in the RAS the process is reliable and easy to operate except at temperatures in excess of 25°C when nitrification is difficult to avoid. The 3 Stage Pho-redox (A2/O) process adds an anoxic zone after the anaerobic zone to achieve de-nitrification.

In addition, a nitrate rich liquor is recycled from the end of the aerobic zone to the head of the anoxic zone to enhance de-nitrification. A shortcoming of the 3 Stage Pho-redox process is that there will be nitrates present in the RAS, potentially making the process unreliable.

Modified Bardenpho
The Bardenpho process removes nitrogen to low concentrations. The addition of an anaerobic zone at the head of the process enables phosphorus removal as well. The process consists of 5 stages: an anaerobic stage followed by alternating anoxic and aerobic stages. A nitrate-rich liquor is recycled from the first aerobic stage, designed for complete nitrification, to the first anoxic stage.

The RAS is recycled from the clarifier to the beginning of the anaerobic zone. Since the nitrates in the RAS ranges from 1 to 3 mg/L, it does not seriously interfere with the mechanism for phosphorus removal as can happen in the 3 Stage Pho-redox process.

University of Cape Town (UCT) and Modified UCT (MUCT)
The UCT process was designed to reduce nitrates to the anaerobic zone when high removal of nitrates in the effluent is not required. It consists of three stages: an anaerobic stage, an anoxic stage, and an aerobic stage. The RAS is returned from the clarifier to the anoxic zone instead of the anaerobic zone to allow for denitrification and to avoid interference from nitrate with the activation of the PAOs in the anaerobic stage.

A nitrate rich stream is recycled from the aerobic zone to the anoxic zone. Denitrified mixed liquor is recycled from the anoxic zone to the anaerobic zone. Several modifications of the process exist. Sometimes it can be difficult to achieve the level of denitrification in the anoxic zone required to protect the anaerobic zone from nitrates when the zone is receiving both RAS and high internal nitrate recycle flows.

This problem led to the development of the modified UCT process, which splits the anoxic zone into two stages. The nitrate rich recycle from the aerobic zone is recycled to the head of the second anoxic stage. The nitrate containing RAS is recycled to the first anoxic stage where it is denitrified. Next, the denitrified RAS is recycled from the end of the first anoxic stage back to the head of the anaerobic stage and mixed with the incoming wastewater.

Johannesburg (JHB), Modified Johannesburg and Westbank
The JHB process is similar to the 3 Stage Pho-redox process, but has a pre-anoxic tank ahead of the anaerobic zone to protect the zone from nitrates when low effluent nitrates are not required. The low COD of the wastewater limited the de-nitrification capacity in the original plant (Northern Works), resulting in nitrates in the RAS.

This reduced BPR so much that a pre-anoxic tank was included on the RAS line to remove the nitrates from the RAS flow using endogenous respiration, before the flow entered the anaerobic zone. The modified JHB process adds a recycle from the end of the anaerobic zone to the head of the pre-anoxic zone to provide residual, readily biodegradable compounds for denitrification.

The Westbank process is similar to the JHB process but adds some primary effluent to the anaerobic zone to assist in denitrification with the remainder of the primary effluent being discharged to the anaerobic zone. During storm flows, excess flow is passed directly to the main anoxic zone. VFA obtained from acid fermentation of the primary sludge is passed to the anaerobic zone.

Oxidation Ditches

There are several oxidation ditch designs that can remove phosphorus. They normally consist of an anaerobic zone ahead of the oxidation ditch whereas simultaneous nitrification and denitrification takes place within the ditches.

Oxidation ditches typically operate as racetrack configurations around a central barrier, with forward mixed liquor flows of approximately 1 foot per second or more. It is possible, by manipulating the DO transferred to the mixed liquor, to establish both anoxic, aerobic and near anaerobic zones within the racetrack configuration, even though the high flow velocities accomplish complete mixing of the wastewater with the RAS.

There are many forms of oxidation ditches, such as the Carousel, the Pasveer Ditch and the Orbal process. The Orbal process creates anaerobic and anoxic zones in the outer of three concentric oval shaped ditches with the RAS recycled from the clarifier to the anoxic zone. It is also possible to introduce an anaerobic tank before the ditch to accomplish BPR in the combined system.

The Pasveer Ditch and the Carousel system also can be used in conjunction with an anaerobic zone to accomplish BPR, in addition to simultaneous nitrification and denitrification within the ditches. Because of the very high internal recycle within the ditches, very low nitrate concentrations can be achieved in the mixed liquor before settling, and anaerobic conditions are easy to maintain in the anaerobic zone, thereby resulting in efficient BPR.

The layout would resemble a Pho-redox process with simultaneous nitrification-denitrification (SND) in the aeration basin. Alternatively, the Carousel or Pasveer Ditch could be used as the aeration stage in either the 3 Stage Pho-redox or the Modified Bardenpho process.

The VT2 process at Bowie, MD, operates two Pasveer ditches in series with dedicated anoxic, near anaerobic and aerobic zones. It also has a side stream anaerobic zone that receives only 30 percent of the influent flow to enhance BPR. Denitrified MLSS for the anaerobic zone are obtained from the end of the near anaerobic zone of the adjacent ditch.

Operated without primary sedimentation, the system consistently obtains very low (<0.25 mg/L) effluent TP without chemicals or effluent filtration. The ditches are operated in series because the plant has limited clarification capacity, and series operation results in lower MLSS concentrations to the clarifiers.

The biodenipho process also uses pairs of ditches. The ditches in the biodenipho process operate in alternating anoxic-aerobic modes. An anaerobic tank is placed before the ditches for BPR and the ditches are alternated between nitrification and denitrification.

Sequencing Batch Reactors (SBR)
SBRs are fill-and-draw reactors that operate sequentially through the various phases by means of adjusting the mixing and aeration. The reactor phases can be set and automated to allow the mixed liquor to go through an anaerobic/anoxic/aerobic progression as is necessary for removal of phosphorus and nitrates.

Because of the fill-and-draw nature of SBRs, it actually is necessary to remove the nitrates remaining from the previous cycle before anaerobic conditions can be established, thus the typical treatment progression becomes anoxic/anaerobic/aerobic.

However, SBRs are almost always operated without primary sedimentation, so they still usually have a favorable BOD5:TP ratio for effluent TP of somewhat less than 1.0 mg/L during the settling phase.

Hybrid Chemical / Biological Processes
The PhoStrip configuration, used mainly in non-nitrifying plants, pulls a side stream off the RAS in a conventional activated sludge plant.

The side stream is concentrated and retained for a day or more in a thickening tank where the solids blanket is deep enough to produce anaerobic conditions and fermentation, resulting in the release of phosphates by the microorganisms. Lime is then added to the supernatant stream to precipitate and remove phosphate.

The thickened, fermented sludge is passed back to the main aeration basin. Existing plants include Seneca Falls, NY; Lansdale, PA; Adrian, MI; Savage, MD; Southtowns, NY; Amherst, NY; and Reno-Sparks, NV.

The Biological Chemical Phosphorus and Nitrogen Removal (BCFS) configuration is similar to the modified UCT process. In this process, a sludge stream is removed from the anaerobic zone.

Ferric chloride is added to the sludge thickener to remove phosphate. This provides an advantage over chemical addition to the secondary clarifier because it does not require the chemical sludge to be recycled. There is an existing plant at Holten in the Netherlands (WEF and ASCE, 2006), but no performance data are available.

Topic 6 – Nutrient Section Post Quiz

Nitrogen and Phosphorus Removal Technologies

1. The actual technology selected will be site-specific and dependent on many factors including_____, influent water quality, required effluent levels, disposal options, availability of land, cost, etc. In some cases, a combination of technologies may be necessary to effectively remove all the contaminants of concern.

Nutrient Removal Technologies

Fixed-film systems - Aerobic/anaerobic trickling filter package plant

2. _____are biological treatment processes that employ a medium such as rock, plastic, wood, or other natural or synthetic solid material that will support biomass on its surface and within its porous structure (USEPA, 2008c).

3. Commercial on-site systems use synthetic media and receive wastewater from overlying sprayheads for aerobic treatment and nitrification. _____returns to the anoxic zone to mix with either septic tank contents or incoming septic tank effluent for denitrification.

4. Typical trickling filters systems currently available are capable of producing effluent _____ concentrations of 5 to 40 mg/L.

5. Higher removal occurs at low loading rates in warm climates. Systems can be configured for single-pass use where the _____is applied to the trickling filter once before being disposed of, or for multi-pass use where a portion of the treated water is cycled back to the septic tank and re-treated via a closed loop.

6. Factors affecting performance include influent wastewater characteristics, hydraulic and organic loading, medium type, maintenance of optimal DO levels, and_____.

Sequencing batch reactor (SBR)

7. The major components of the package include the batch tank, aerator, mixer, decanter device, process control system (including timers), pumps, piping, and appurtenances. _____may be provided by diffused air or mechanical devices.

8. The key to the _____ is the control system, which consists of a combination of level sensors, timers, and microprocessors which can be configured to meet the needs of the system.

9. _____are suitable for areas with little land, stringent treatment requirements, and mall wastewater flows such as RV parks or mobile homes, campgrounds, construction sites, rural schools, hotels, and other small applications. These systems are also useful for treating pharmaceutical, brewery, dairy, pulp and paper, and chemical wastes (USEPA, 2000d).

Intermittent sand filters (ISF)

10. _____provide advanced secondary treatment of settled wastewater or septic tank effluent. They consist of a lined (e.g., impervious PVC liner on sand bedding) excavation or structure filled with uniform washed sand that is placed over an underdrain system.

11. Most biochemical treatment occurs within approximately 6 inches of the filter surface. Other treatment mechanisms that occur in sand filters include physical processes, such as straining and sedimentation, to remove suspended solids within the pores of the media. _____are strained out at the filter surface.

12. Phosphorous is one element of concern in wastewater that can be removed in this manner, but the number of available adsorption sites is limited by the_____.

13. Sand filters are frequently used to pretreat septic tank effluent prior to _____where the soil has insufficient unsaturated depth above ground water or bedrock to achieve adequate treatment.

Recirculating sand filters (RSF)

14. Recirculating filters using _____provide advanced secondary treatment of settled wastewater or septic tank effluent (USEPA, 2008h).

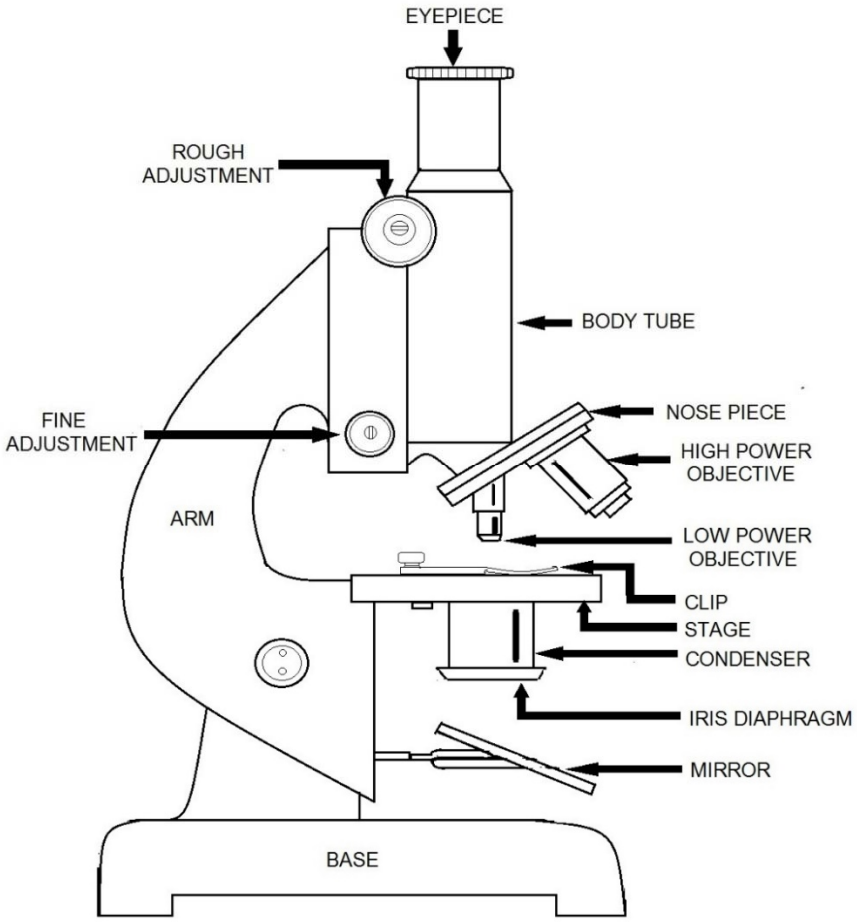
Natural Systems

15. The natural systems described here include constructed wetlands and floating aquatic plant treatment systems. _____are typically described in terms of the position of the water surface and/or the type of vegetation grown.

Topic 7- Wastewater Microbiology Section

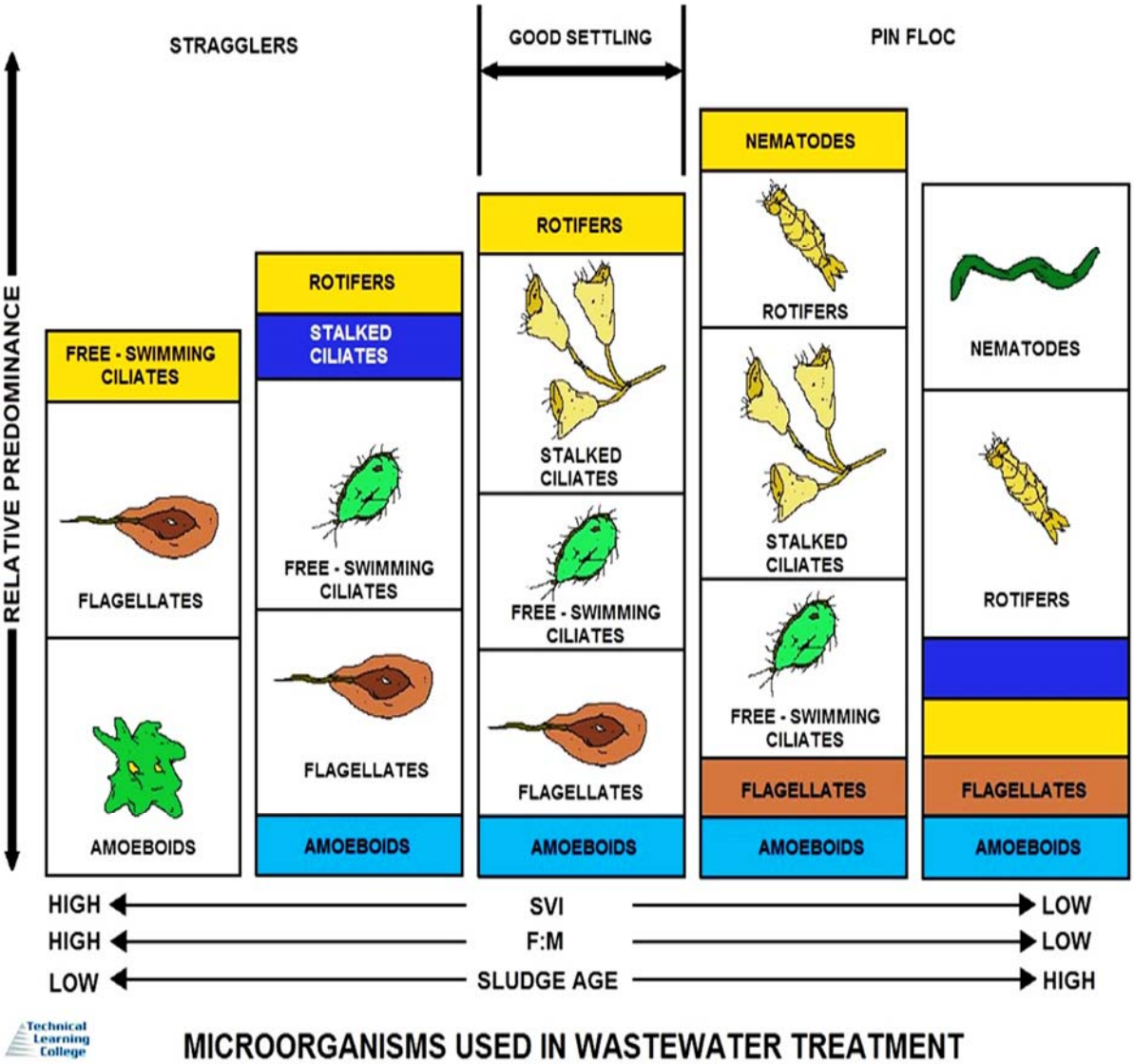
Topic 7 - Section Focus: You will learn the basics of the Microlife that lives in wastewater. At the end of this section, you the student will be able to understand and describe various wastewater Microlife and bacteria. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Topic 7 – Scope/Background: Wastewater Microbiology focuses on microbial contaminants found in wastewater, methods of detection for these contaminants, and methods of disinfecting water of microbial contamination. Microbiological analysis of activated sludge systems, lagoons, filters or any biological treatment process is an invaluable tool for troubleshooting and suggesting effective remedial actions for wastewater treatment issues.



Microscopic Analysis

Operators perform microscopic analysis of wastewater bugs from activated sludge and lagoon systems to provide detailed reports identifying filament(s) and other indicator organisms that are present. This information is then used to give likely causes for the presence of filaments and suggestions for their control.



Technical Learning College

MICROORGANISMS USED IN WASTEWATER TREATMENT

Biological Criteria Introduction

Many types of microscopic plants and animals, such as plankton, water beetles, and insects that live in or on the water, serve as food for small fish. Small fish are eaten by larger fish which, in turn, are consumed by even larger fish. These large fish may ultimately be consumed by humans. All life along the food chain is dependent on the water environment and it is for this reason that the quality of the nation's surface waters must be protected.

The Clean Water Act directs the EPA to develop criteria for water quality that accurately reflect the latest scientific knowledge about the effects of pollutants on aquatic life and human health.

In developing these criteria, the EPA examines the effects of specific pollutants on plankton, fish, shellfish, wildlife, plant life, aesthetics, and recreation in any body of water. This includes specific information on the concentration and dispersal of pollutants through biological, physical, and chemical processes as well as the effects of pollutants on biological communities as a whole.

States may use the criteria that are developed by the EPA to help set water quality standards that protect the uses of their waters or they may develop their own water quality criteria. The EPA publishes human health and aquatic life criteria and is currently developing sediment and biological criteria. These criteria are complementary; each is designed to protect specific types of living organisms or ecological systems from the adverse effects of pollution.

Human Health Criteria
People can potentially be exposed to water pollutants when they drink untreated surface water or eat fish, shellfish, or wildlife that have been contaminated by pollutants in surface waters. To reduce the risk to humans from these sources, the EPA scientists research information to determine the levels at which specific chemicals are not likely to adversely affect human health.

The EPA publishes these levels as human health criteria that the states use, along with other information, to set allowable concentrations of pollutants in their water quality standards. In this way, the EPA and the states work together to protect people from exposure to harmful pollutants in surface waters.

Aquatic Life Criteria
Aquatic life criteria provide protection for plants and animals that are found in surface waters. The EPA develops these criteria as numeric limits on the amounts of chemicals that can be present in river, lake, or stream water without harm to aquatic life.

Aquatic life criteria are designed to provide protection for both freshwater and saltwater aquatic organisms from the effects of acute (short term) and chronic (long term) exposure to potentially harmful chemicals.

Aquatic life criteria are based on toxicity information and are developed to protect aquatic organisms from death, slower growth, reduced reproduction, and the accumulation of harmful levels of toxic chemicals in their tissues that may adversely affect consumers of such organisms.

Sediment Quality Criteria Guidance
In a healthy aquatic community, sediments provide a habitat for many living organisms. Worms, plants, and tiny microorganisms living in or on the sediment sustain the fish and shellfish that, in turn, nourish larger fish, wildlife, and man.

Pollutants in the Sediment
Controlling the concentration of pollutants in the sediment helps to protect bottom dwelling species and prevents harmful toxins from moving up the food chain and accumulating in the tissue of animals at progressively higher levels. This is particularly important at the lower levels of the food chain because the concentration of many pollutants may increase at each link in the food chain. A pollutant level in the sediment that does not harm snails of small fish may bioaccumulate in the food chain and become very harmful to larger fish, birds, mammals, wildlife, and people.

The EPA develops sediment quality criteria guidance on the concentrations or amounts of individual chemicals that can be present in river, lake, or stream sediments and still protect sediment-dwelling organisms and ultimately animals higher in the food chain from the harmful effects of toxic pollutants.

Biological Criteria
A water body in its natural condition is free from the harmful effects of pollution, habitat loss, and other negative stressors. It is characterized by a particular biological diversity and abundance of organisms. This biological integrity--or natural structure and function of aquatic life--can be dramatically different in various types of water bodies in different parts of the country. Because of this, the EPA is developing methodologies that states can use to assess the biological integrity of their waters and, in so doing, set protective water quality standards. These methodologies will describe scientific methods for determining a particular aquatic community's health and for maintaining optimal conditions in various bodies of water.

Standard Total Coliform Fermentation Technique

We will cover the fecal test in the Laboratory procedure and the Appendix section in the rear of this book.

Goal Summary
The goal of all biological wastewater treatment systems is to remove the non-settling solids and the dissolved organic load from the effluents by using microbial populations. Biological treatments are generally part of secondary treatment systems. The microorganisms used are responsible for the degradation of the organic matter and the stabilization of organic wastes. With regard to the way in which they utilize oxygen, they can be classified into aerobic (require oxygen for their metabolism), anaerobic (grow in absence of oxygen) and facultative (can proliferate either in absence or presence of oxygen although using different metabolic processes).

Most of the microorganisms present in wastewater treatment systems use the organic content of the wastewater as an energy source to grow, and are thus classified as heterotrophes from a nutritional point of view. The population active in a biological wastewater treatment is mixed, complex and interrelated.

Genera
By example, in a single aerobic system, members of the genera *Pseudomonas, Nocardia, Flavobacterium, Achromobacter and Zooglea* may be present, together with filamentous organisms *(Beggioata* and *Spaerotilus* among others).

In a well-functioning system, protozoas and rotifers are usually present and are useful in consuming dispersed bacteria or non-settling particles. More extensive description and treatment of the microbiology of wastewater treatment systems are given elsewhere (Stanier, 1976).

The organic load present is incorporated in part as biomass by the microbial populations, and almost all the rest is liberated as gas (carbon dioxide (CO_2) if the treatment is aerobic, or carbon dioxide plus methane (CH_4) if the process is anaerobic) and water. In fisheries wastewaters the non- biodegradable portion is very low.

Unless the cell mass formed during the biological treatment is removed from the wastewater (e.g., by sedimentation or other treatment described in the previous section), the treatment is largely incomplete, because the biomass itself will appear as organic load in the effluent and the only pollution reduction accomplished is that fraction liberated as gases.

The biological treatment processes used for wastewater treatment are broadly classified as aerobic in which aerobic and facultative microorganisms predominate or anaerobic which use anaerobic microorganism.

If the microorganisms or Bugs are suspended in the wastewater during biological operation, the operations are called "suspended growth processes", while the microorganisms that are attached to a surface over which they grow are called "attached growth processes".

This section explains the principles and main characteristics of the most common processes in each case.

Credit to the USEPA for text.

WASTEWATER FOOD

Incoming wastewater to a treatment plant provides the food that microorganisms need for their growth and reproduction. This food is mostly organic material. The more soluble the organic material is, the more easily microorganisms can use it. Since the amount and type of organic loading in the treatment plant affects the growth of the microorganisms, influent total BOD and soluble BOD are measurements an operator can make to determine the amount and type of incoming food for the microorganisms.

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ACTIVATED SLUDGE MICROORGANISMS

The principle role microorganisms have in the activated sludge process is to convert dissolved and particulate organic matter, measured as biochemical oxygen demand (BOD), into cell mass. In a conventional activated sludge process, microorganisms use oxygen to break down organic matter (food) for their growth and survival. Over time and as wastewater moves through the aeration basin, food (BOD) decreases with a resultant increase in cell mass (MLSS concentration).

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Microlife Food to Mass Introduction

We talked about the basic components and designs of wastewater treatment now let's look at the main "Team Players". Your process will respond to whatever direction you give it. You can run your plant (the team) to always try for the better or be content with the way it is. To get the best, it takes work!

Most activated sludge processes are used to degrade carbonaceous BOD. It is also possible to design and/or operate the basic system to oxidize ammonia (nitrification).

Many plants are now designed to achieve nitrification. Other system modifications include phosphorus removal and biological denitrification. Activated sludge plants are usually designed from pilot plant and laboratory studies.

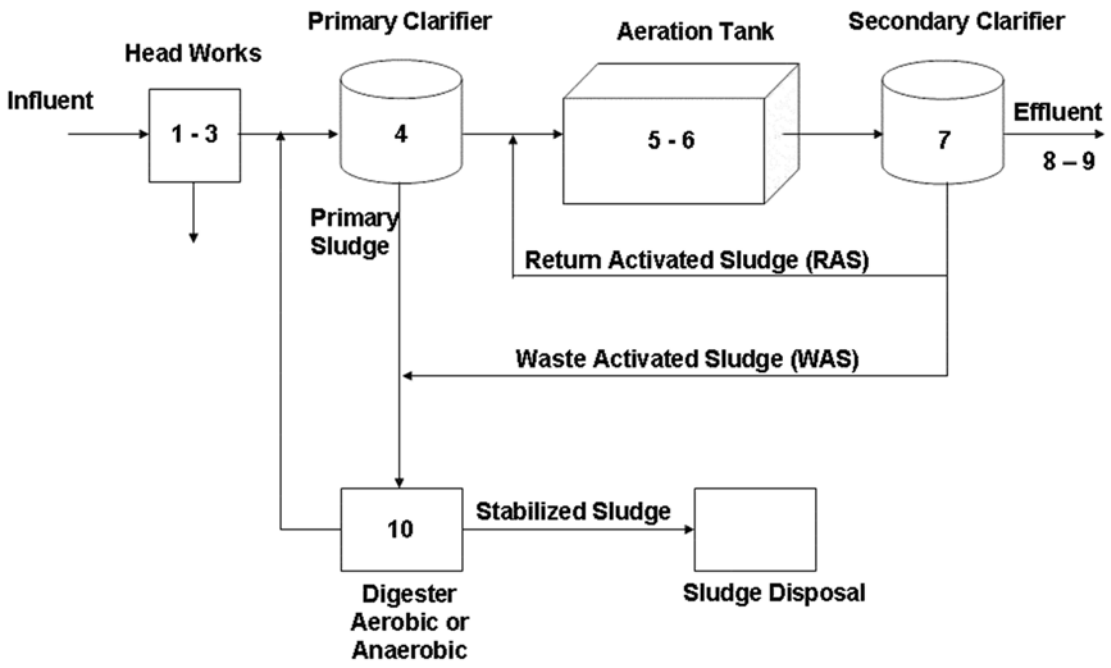
From this approach, it is possible to design a process based on the amount of time the sludge spends in the system, generally termed mean cell residence time (MCRT), or on the amount of food provided to the bacteria in the aeration tank (the food-to-microorganism ratio, F/M). What does this mean?

Suppose a person ate 10 pounds of hot dogs (BOD) and weighed 200 pounds (MLSS).

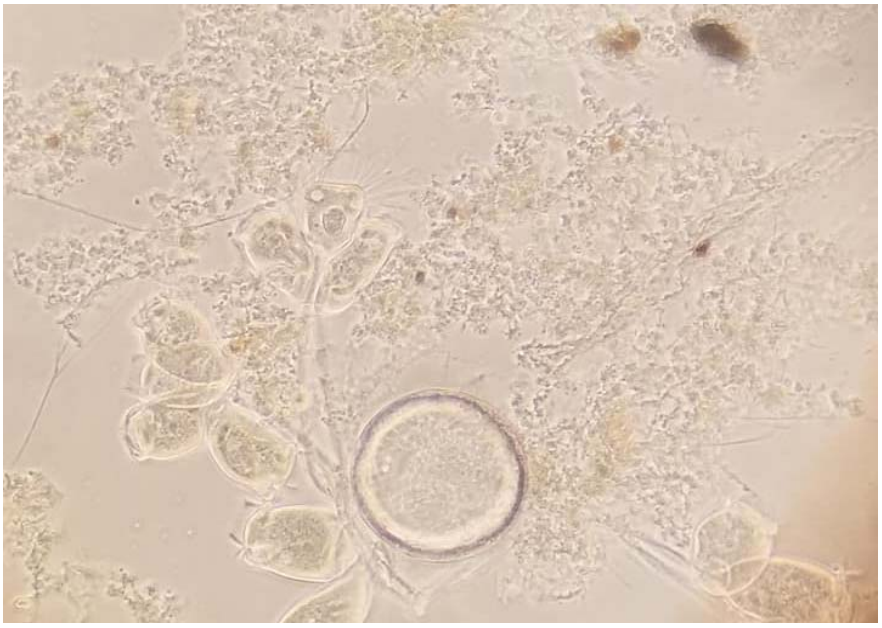
What is the ratio of food to weight?

It would be 10 lbs. to 200 lbs. If we divide 200 into 10, the ratio is .05 or 5%.

Activated Sludge Aeration Basin, identify by the bubbles.



Microlife' s health is essential for the proper operation of box 5, 6, 7 and 10. Box 4 is for settling of the solids.



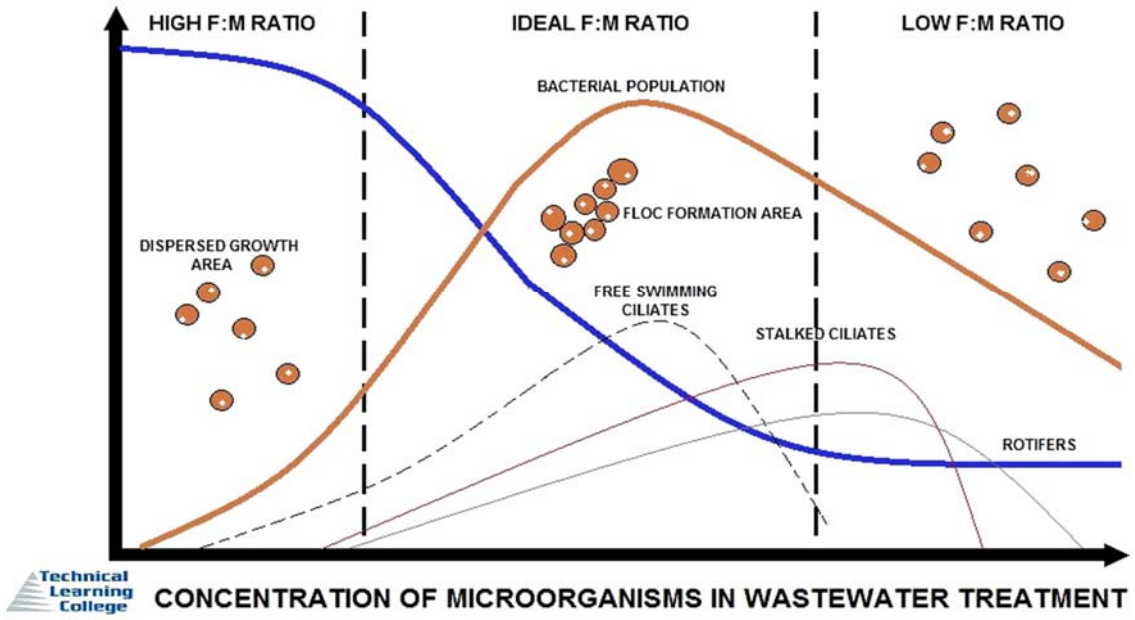
Suctoria between Vorticella

F/M Ratio

The following are some general statements about F/M and MCRT assuming that the environmental conditions are properly controlled.

a. The optimum operating point of either helps obtain the desired effluent concentration.
b. Both provide a means for maintaining the best effluent and sludge quality.
c. Both techniques attempt to regulate rate of growth, metabolism, and stabilization of food matter.
d. Both techniques indicate the solids level needed to stabilize the food and attain sludge quality.
e. The desired solids level is controlled by wasting.
    1. To maintain – waste amount of net daily
    2. To increase – decrease waste rate
    3. To decrease – increase waste rate
f. They are interrelated so changing one control generally changes the other.
g. Once the control point is set, it should remain constant until change in effluent or sludge quality requires a change.

The operating control point is that point when the best effluent and sludge quality is obtained for the existing conditions.



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F/M RATIO

The food to mass or microorganism (**F/M ratio**) is a **process control number that helps you to determine the proper number of microorganisms** for your system. To do this calculation, you will need the following information: Influent Flow into your activated sludge system (Flow MGD) Influent CBOD (mg/l) concentration into your aeration tank.

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OLD SLUDGE

Old sludge consists of sludge in which the sludge age is too high to be most effective in a particular activated sludge process. Dark brown foam and a greasy or scummy appearance is an indicator of old sludge. Settling in the clarifier is rapid, but pin floc can be present in the effluent and the effluent is hazy. **Old sludge** is often associated with a low F/M ratio. To correct for old sludge, it is necessary to increase wasting rates and return less sludge to the aeration basin. This will reduce the amount of solids under aeration, increase the F/M ratio and decrease the sludge age.

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Dissolved Oxygen Concentrations Introduction

We will cover DO and MCRT in great detail in the Laboratory Section

Dissolved oxygen concentrations may be measured directly in wastewater, but the amount of oxygen potentially required by other chemicals in the wastewater is termed as oxygen demand.

Dissolved or suspended oxidizable organic material in wastewater will be used as a food source.

Oxygen is needed by living organisms as they oxidize wastes to obtain energy for growth. Therefore, controlling oxygen is required for secondary or biological treatment of wastewater.

Indicators of low dissolved-oxygen conditions include substantial presence of low dissolved-oxygen filamentous bacteria in the activated sludge, turbid effluent, or dark gray or black-colored mixed liquor (often with a putrid odor).

The first indicator of low dissolved-oxygen conditions will be the growth of low dissolved-oxygen filamentous microorganisms.

As the dissolved oxygen drops, the quantity of these filamentous microorganisms increases, adversely affecting the settle-ability of the activated sludge.

As an operator, it is important to recognize these early warning signs and make corrections to dissolved-oxygen levels before the quality of the effluent deteriorates.

If dissolved oxygen continues to drop, even low dissolved-oxygen filamentous microorganisms will not be present in the mixed liquor, and treatment efficiencies will be seriously affected. At this point, effluent turbidity will increase and treatment will deteriorate rapidly.

Under severe conditions, mixed liquor may turn a dark gray or even black color and putrid odors may also be present.

Visual observations are good as indicators, but actual measurements of both activated sludge dissolved oxygen and effluent water quality should be taken before a determination of cause is made; for example, the black color may be the result of a dye from an industrial discharger.

The key to avoiding low dissolved-oxygen conditions is to properly monitor your aeration system.

A properly monitored aeration system includes a dissolved-oxygen profile of the entire aeration system. A profile merely means measuring the dissolved oxygen in different locations and at different depths throughout the aeration system.

Mean Cell Residence Time (MCRT)

An expression of the average time (days) that a microorganism will spend in the activated sludge process.

Operators at different plants can calculate the Total Suspended Solids (TSS) in the Activated Sludge Process, lbs. (kg), by three different methods:
1. TSS in the Aeration Basin or Reactor Zone, lbs. (kg)
2. TSS in the Aeration Basin and Secondary Clarifier, lbs. (kg)
3. TSS in the Aeration Basin and Secondary Clarifier Sludge Blanket, lbs. (kg)

These methods make it difficult to compare MCRTs in days among different plants unless everyone uses the same method.

Solids Retention Time (SRT)
SRT is sometimes used as a synonym for MCRT. These generally mean the same thing, but they may be calculated using different pieces of data. SRT can be viewed as the total mass of the solids in the treatment system, whereas MCRT is the mass of the bacteria in the system.

SRT can also be expressed in days. In essence, MCRT would be calculated with the volatile suspended solids (VSS) values (for example, mixed liquor VSS, effluent VSS, waste sludge VSS), whereas SRT would be calculated using the total suspended solids (TSS) values (for example, mixed liquor TSS, effluent TSS, waste sludge TSS).

Solids Retention Time (SRT) is a critical activated sludge design and operating parameter. The selection of an SRT has many consequences related to process performance, sludge production, and oxygen requirements.

DSRT is the acronym for dynamic solids retention time.

MLVSS

Mixed Liquor Volatile Suspended Solids is generally defined as the microbiological suspension in the aeration tank of an activated-sludge biological wastewater treatment plant.

The biomass solids in a biological waste water reactor are usually indicated as **total suspended solids (TSS)** and **volatile suspended solids (VSS).** The mixture of solids resulting from combining recycled sludge with influent wastewater in the bioreactor is termed **mixed liquor suspended solids (MLSS)** and **mixed liquor volatile suspended solids (MLVSS).** The solids are comprised of biomass, **nonbiodegradable volatile suspended solids (nbVSS),** and inert **inorganic total suspended solids (iTSS).**

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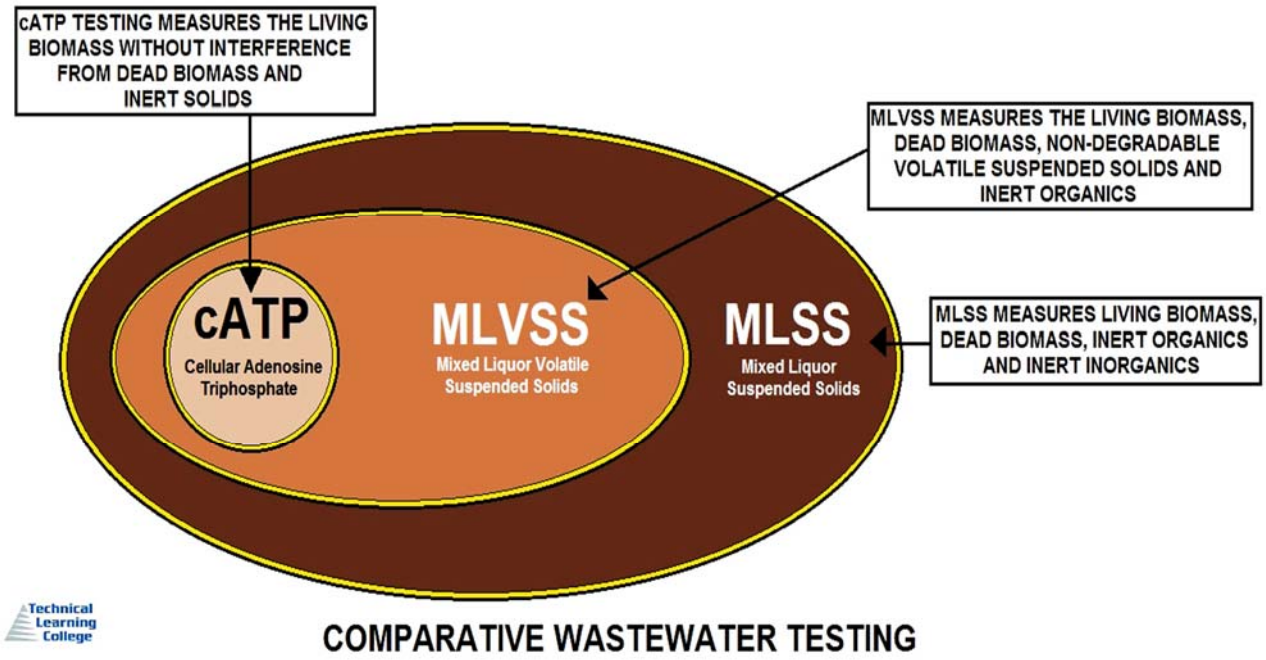

ATP and MLSS

Conventional wastewater measurements such as mixed-liquor suspended solids (MLSS) or mixed liquor volatile suspended solids (MLVSS) can provide misleading information about the amount of viable biomass in the reactors.

Furthermore, these measurements do not distinguish between living and dead cells. Because ATP is produced only by living cells, its measurement can overcome these difficulties and provide an opportunity for superior control of such fundamental operating issues such as food to microorganism ratio, sludge age, and nutrient feed.

Although ATP is vital to all wastewater treatment microorganisms and the measurement process described is simple, ATP has not been routinely adopted as a process parameter in operating wastewater treatment plants. Possible reasons for lack of routine use include the following:

- Instability of reagents;
- Ineffective or cumbersome ATP extraction techniques for wastewater treatment samples;
- Lack of test protocols optimized for wastewater treatment applications;
- Insufficient monitoring guidelines.

WASTEWATER FOAM DESCRIPTION	CAUSE(s) OF FOAM
WHITE TO GRAY COLOR / THIN FOAM	"YOUNG SLUDGE" / LOW CELL RESIDENCE TIME
WHITE, FROTHY / BILLOWING FOAM	SEEN WITH LOW ACTIVE BIOMASS AND HIGH F/M. NON-BIODEGRADABLE DETERGENTS (rare) FOAM
PUMICE-LIKE, GRAY / ASHY FOAM	EXCESSIVE RECYCLING FROM DIGESTERS AND PRESSSES THAT LEAD UP TO BUILDUP OF "FINES"
A THICK SLUDGE BLANKET FLOATING IN FINAL CLARIFIER. STIRRING OF SLUDGE RELEASES SMALL BUBBLES.	SLUDGE BLANKET KEPT TOO LONG IN CLARIFIER WHERE THE SLUDGE HAS NITRATE PRESENT ; DENITRIFICATION
GRAY TO BROWN COLOR / THICK, SLIMY FOAM	EASILY DIAGNOSED WITH INDIA INK STAIN. NUTRIENT DEFICIENCY CAUSE EXCESS POLY SACCHARIDE PRODUCTION
BROWN COLOR / THICK, STABLE FOAM (with Filaments)	FOAMING INDUCED BY FILAMENT CAUSED BY NOCARDIA sp., MICROTHIS PARVACELLA, or TYPE 1863
BROWN FLOATING SCUM BUILDUP ON CLARIFIERS / FOAM HAS BROWN-BLACK STREAKS	GREASE & OIL

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DESCRIPTION AND CAUSES OF FOAMING IN WASTEWATER TREATMENT

Foaming Sludge

Foaming in activated sludge process is a common operational problem in many wastewater treatment plants. The foam can occur in aeration tank, secondary clarifier, as well as in anaerobic digester.

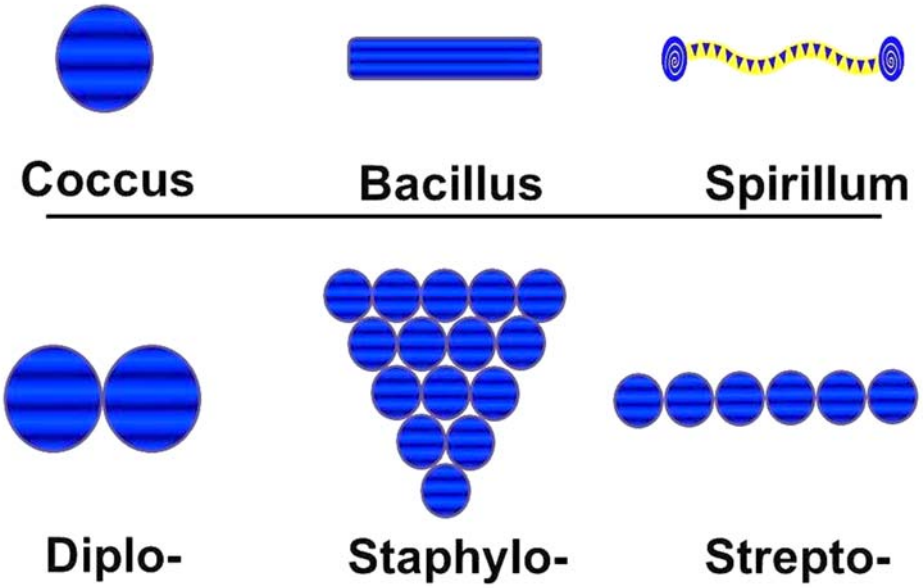
Foam in WWTP is normally sticky, viscous and brown in color. It floats and accumulates on top of the tanks, and can take up a large fraction of solids inventory and reactor volume, thus decreasing the effluent quality and control of sludge retention time (SRT).

Bacteria Section **(More information in the Appendix)**

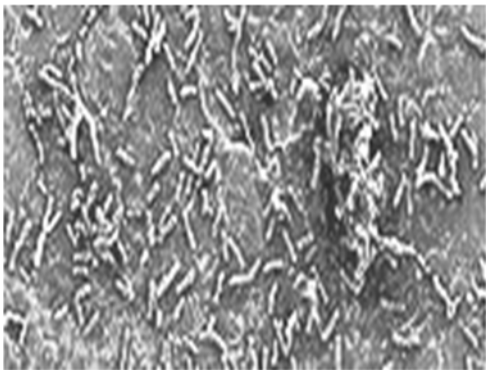
Bacteria are highly designed creatures formed in a variety of shapes. The simplest shape is a round sphere or ball.

Bacteria formed like this are called cocci (singular coccus). The next simplest shape is cylindrical.

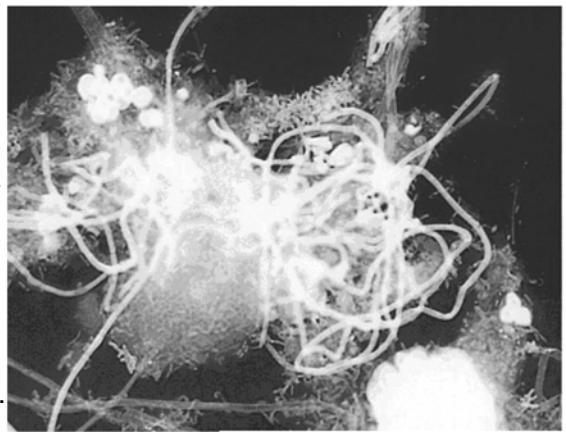
Cylindrical bacteria are called rods (singular rod). Some bacteria are basically rods but instead of being straight they are twisted, bent or curved, sometimes in a spiral. These bacteria are called spirilla (singular spirillum). Spirochaetes are tightly coiled up bacteria.



Bacteria tend to live together in clumps, chains or planes. When they live in chains, one after the other, they are called filamentous bacteria - these often have long thin cells. When they tend to collect in a plane or a thin layer over the surface of an object, they are called a biofilm. Many bacteria exist as a biofilm and the study of biofilms is very important. Biofilm bacteria secrete sticky substances that form a sort of gel in which they live. The plaque on your teeth that causes tooth decay is a biofilm.



Filamentous Bacteria



Filamentous Bacteria are a type of bacteria that can be found in a wastewater treatment system.

They function similar to floc forming bacteria since they degrade BOD quite well. In small amounts, they are quite good to a biomass. They can add stability and a backbone to the floc structure that keeps the floc from breaking up or shearing due to turbulence from pumps, aeration or transfer of the water.

In large amounts they can cause many problems. Filaments are bacteria and fungi that grow in long thread-like strands or colonies.

Site Specific Bacteria

Aeration and biofilm building are the key operational parameters that contribute to the efficient degradation of organic matter (BOD/COD removal). Over time, the application-specific bacteria become site-specific as the biofilm develops and matures and is even more efficient in treating the site-specific waste stream.

Facultative Bacteria

Most of the bacteria absorbing the organic material in a wastewater treatment system are facultative in nature. This means they are adaptable to survive and multiply in either anaerobic or aerobic conditions. The nature of individual bacteria is dependent upon the environment in which they live.

Usually, facultative bacteria will be anaerobic unless there is some type of mechanical or biochemical process used to add oxygen to the wastewater. When bacteria are in the process of being transferred from one environment to another, the metamorphosis from anaerobic to aerobic state (and vice versa) takes place within a couple of hours.

Anaerobic Bacteria

Anaerobic bacteria live and reproduce in the absence of free oxygen. They utilize compounds such as sulfates and nitrates for energy and their metabolism is substantially reduced. In order to remove a given amount of organic material in an anaerobic treatment system, the organic material must be exposed to a significantly higher quantity of bacteria and/or detained for a much longer period of time.

A typical use for anaerobic bacteria would be in a septic tank. The slower metabolism of the anaerobic bacteria dictates that the wastewater be held several days in order to achieve even a nominal 50% reduction in organic material. That is why septic tanks are always followed by some type of effluent treatment and disposal process. The advantage of using the anaerobic process is that electromechanical equipment is not required. Anaerobic bacteria release hydrogen sulfide as well as methane gas, both of which can create hazardous conditions.

Even as the anaerobic action begins in the collection lines of a sewer system, deadly hydrogen sulfide or explosive methane gas can accumulate and be life threatening.

Aerobic Bacteria
Aerobic bacteria live and multiply in the presence of free oxygen. Facultative bacteria always achieve an aerobic state when oxygen is present. While the name "aerobic" implies breathing air, dissolved oxygen is the primary source of energy for aerobic bacteria. The metabolism of aerobes is much higher than for anaerobes. This increase means that 90% fewer organisms are needed compared to the anaerobic process, or that treatment is accomplished in 90% less time. This provides a number of advantages including a higher percentage of organic removal. The by-products of aerobic bacteria are carbon dioxide and water.

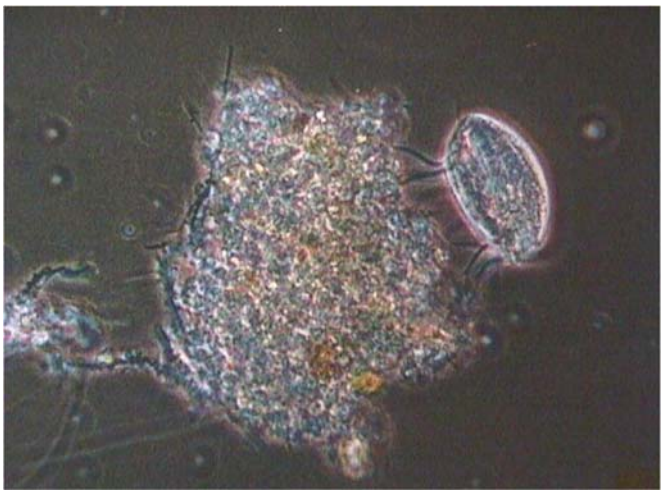
Aerobic bacteria live in colonial structures called floc and are kept in suspension by the mechanical action used to introduce oxygen into the wastewater. This mechanical action exposes the floc to the organic material while treatment takes place. Following digestion, a gravity clarifier separates and settles out the floc. Because of the mechanical nature of the aerobic digestion process, maintenance and operator oversight are required.

Protozoans and Metazoans

In a wastewater treatment system, the next higher life form above bacteria is protozoans. These single-celled animals perform three significant roles in the activated sludge process. These include floc formation, cropping of bacteria and the removal of suspended material.

Protozoans are also indicators of biomass health and effluent quality. Because protozoans are much larger in size than individual bacteria, identification and characterization is readily performed. Metazoans are very similar to protozoans except that they are usually multi-celled animals. Macroinvertebrates, such as nematodes and rotifers, are typically found only in a well-developed biomass.

The presence of protozoans and metazoans and the relative abundance of certain species can be a predictor of operational changes within a treatment plant. In this way, an operator is able to make adjustments and minimize negative operational effects simply by observing changes in the protozoan and metazoan population.



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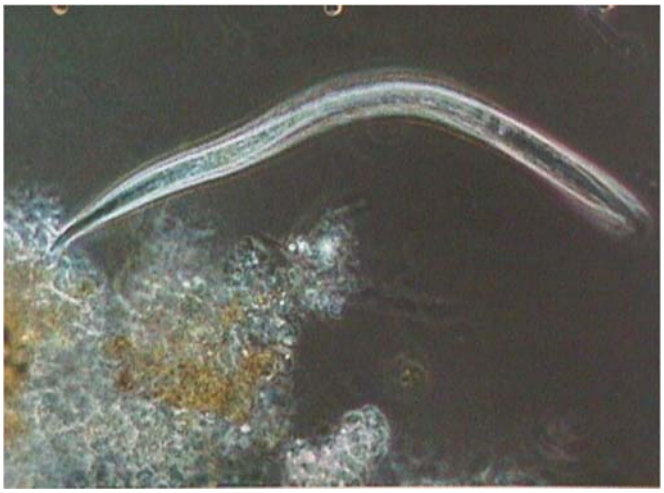


Nematode

Dispersed Growth
Dispersed growth is material suspended within the activated sludge process that has not been adsorbed into the floc particles. This material consists of very small quantities of colloidal (too small to settle out) bacteria as well as organic and inorganic particulate material. While a small amount of dispersed growth between the floc particles is normal, excessive amounts can be carried through a secondary clarifier. When discharged from the treatment plant, dispersed growth results in higher effluent solids.

Taxonomy
Taxonomy is the science of categorizing life forms according to their characteristics. Eighteen different categories are used to define life forms from the broadest down to the most specific. They are: Kingdom, Phylum, Subphylum, Superclass, Class, Subclass, Cohort, Superorder, Order, Suborder, Superfamily, Family, Subfamily, Tribe, Genus, Subgenus, Species and Subspecies. Identifying the genus is usually specific enough to determine the role of the organisms found in a wastewater treatment system.

Process Indicators
Following taxonomic identification, enumeration and evaluation of the characteristics of the various organisms and structures present in a wastewater sample, the information can be used to draw conclusions regarding the treatment process.

Numerous industry references, such as ***WASTEWATER BIOLOGY: THE MICROLIFE*** by the Water Environment Federation, can be used to provide a comprehensive indication of the conditions within a treatment process. As an example, within most activated sludge processes, the shape of the floc particles can indicate certain environmental or operational conditions.

A spherical floc particle indicates immature floc, as would be found during start-up or a process recovery. A mature floc particle of irregular shape indicates the presence of a beneficial quantity of filamentous organisms and good quality effluent. An excess of dispersed growth could indicate a very young sludge, the presence of toxic material, excess mechanical aeration or an extended period of time at low dissolved oxygen levels.

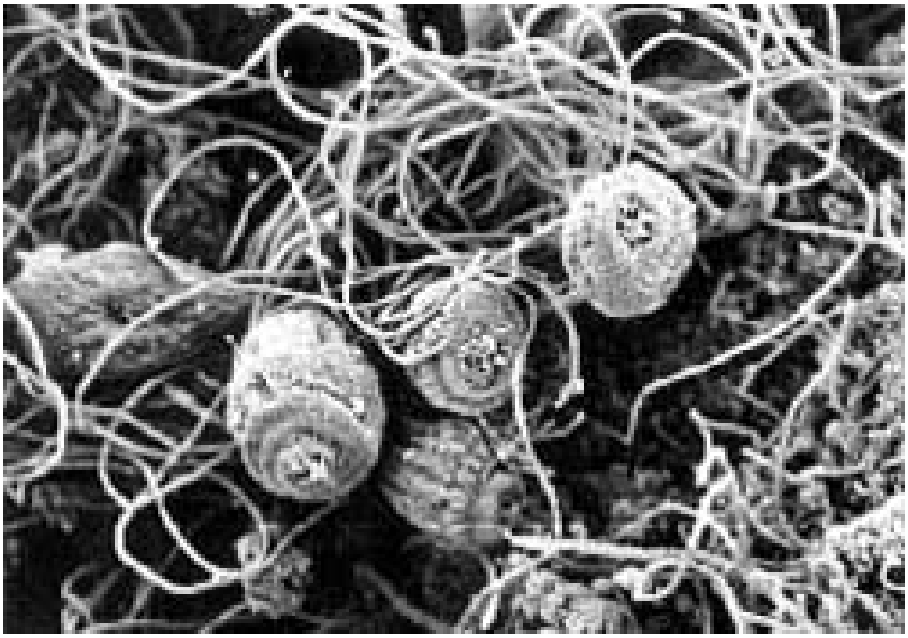
Filamentous Bacteria have Positive aspects:

- ✓ They are very good BOD removers.
- ✓ They add a backbone or rigid support network to the floc structure.
- ✓ Helps the floc structure filter out fine particulate matter that will improve clarifier efficiency.
- ✓ They help the floc settle if in small amounts.
- ✓ They reduce the amount of "pin" floc.

Filamentous Bacteria have Negative aspects:
They can interfere with separation and compaction of activated sludge and cause bulking when predominant.

Filamentous Bacteria

- ✓ They can affect the sludge volume index (SVI).
- ✓ They can cause poor settling if dominant.
- ✓ They can fill up a clarifier and make it hard to settle, causing TSS carryover.
- ✓ They can increase polymer consumption.
- ✓ They can increase solids production and cause solids handling costs to increase significantly.



Filamentous bacteria floc (SEM) or Pin Floc.

FILAMENTOUS BULKING PROBLEM

Filamentous bulking can occur within the floc, where weak and diffuse flocs are created, or as filamentous bacteria bridge the flocs. A phase contrast microscope is necessary in situations where inter-floc bulking is occurring to properly view these filaments.

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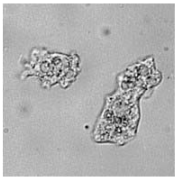
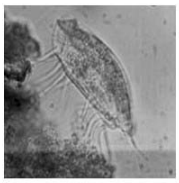


AMOEBAE



FREE SWIMMING CILIATE

ROTIFER

RETENTION TIME

FLAGELLATE

STALKED CILATES

WORM

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WASTEWATER INDICATOR ORGANISMS

BULKING

An activated sludge that does not settle well and may overflow the weirs of the final clarifiers resulting in excess suspended solids in the effluent. It is usually caused by filamentous.

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Bacteria Growth Terms

Lag-Phase
During the lag-phase, bacteria are becoming acclimated to their new environment. They are digesting food and are developing the enzymes needed to break down the types of nutrients that the bacteria have detected. Growth does not occur during this phase.

Accelerated Growth-phase
Bacteria begin to grow at a rapid rate because of the excess amount of food that is available. The cells are mostly dispersed and active. They are not sticking together to form floc.

Declining Growth-Phase
Reproduction slows down at this phase because there is no long an excess amount of food. There are a large number of bacteria that have to compete for the remaining food. The bacteria begin to lose their flagella.

Stationary-Phase
Because of the lack of food, some bacteria are reproducing but an equal number are also dying. Therefore, the number of bacteria remains relatively constant. They have not lost their flagella and have formed a sticky substance covering the outside of the cell wall which allows them to agglomerate into floc.

Death-Phase
In this phase the death rate increased with little or no growth occurring. The total number of bacteria keeps reducing.

Bacteria in the activated sludge system must be allowed to hang out in the aeration basin until they reach the stationary-phase. If they flow out of the basin too early, they will be active and motile and will not settle out as floc.

Food: Microorganism Ratio
The food to microorganism (F/M) ratio measures the amount of food that is available for the amount of microorganisms present in the aeration basin. The amount of food is determined by the biochemical oxygen demand (BOD) or chemical oxygen demand (COD) test. If there is too much food and not enough microorganism (high F/M ratio), settling problems may occur because in the presence of excess food bacteria are active and multiplying and will not develop into floc.

Factors Affecting Bacteria Growth
It is the responsibility of the operator to provide the best possible environment for the floc-forming bacteria to grow. The operator can control some of the conditions they require and there are some conditions they cannot control. For instance, the operator has no control of the weather and very little control over the types and amount of nutrients entering the treatment plant. Therefore, it is important that the operator understand how the following factors affect the growth of the bacteria.

Oxygen Utilization, Sludge Age, Dissolved Oxygen, Mixing, pH, Temperature, Nutrients

Oxygen Utilization
Actively growing bacteria eat food at a rapid rate therefore using oxygen at a rapid rate. The rate of oxygen use is normally termed the Oxygen Uptake Rate and is measured in mg O2/hr/gm of MLSS. Generally a higher Uptake Rate is associated with a higher F:M ratio and younger sludge ages. A lower Uptake Rate is associated with a lower F:M ratio and older sludge ages.

Sludge Age
As bacteria first begin to develop in the system they grow singularly, in small clumps and chains. They are very active with flagella and do not have a well-developed slime layer. The bacteria are disperse and do not settle well. As the sludge is allowed to age, bacteria lose their flagella and accumulate more slime. The small clumps and chains begin to stick together and form floc large enough to settle.

Dissolved Oxygen
Aerobic bacteria require at least 0.1 - 0.3 mg/L of oxygen to survive. At least 2 mg/L of oxygen must be maintained in the bulk fluid in order for the bacteria in the center of the floc to get 0.1- 0.3 mg/L of oxygen. If not, the bacteria in the center will die and the floc will begin to break up.

Mixing
Mixing is required to bring the bacteria, oxygen and nutrients in contact with each other. Remember, once food is limited the bacteria lose their flagella and can no longer swim. Without sufficient mixing, the bacteria will not bump into each other to form floc and proper treatment will not take place.

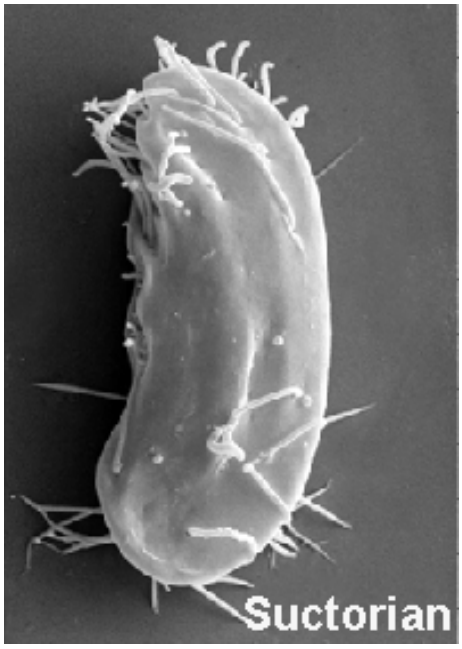
pH
It is the bacterial enzymes that are very pH dependent. Their optimal pH is between 7.0 and 7.5. Rapid pH changes should be avoided.

Temperature
Biochemical reactions are temperature dependent. Reactions are slower in colder temperatures so the system will require more organisms to do the work. Reactions are faster in warmer temperatures therefore fewer bacteria are required to do the same job during the summer months.

Nutrients
Bacteria require basic nutrients for growth (carbon, nitrogen, phosphorus as well as trace amounts of sodium, potassium, magnesium and iron. All these are present in normal domestic sewage. Generally, industrial wastes do not contain sufficient nutrients and must be supplemented.

Activated Sludge Bugs

We will look at four groups of microorganisms "bugs" that do the greatest amount of "chowing down" in the activated sludge process. The first group is the bacteria which eat the dissolved organic compounds. The second and third groups of bugs are microorganisms known as the free-swimming and stalked ciliates. These larger bugs eat the bacteria and are heavy enough to settle by gravity. The fourth group is a microorganism, known as Suctoria, which feeds on the larger bugs and assists with settling.



The interesting thing about the bacteria that eat the dissolved organics is they have no mouths. The bacteria have an interesting property, their "fat reserves" are stored on the outside of their bodies. This fat layer is sticky and is what the organics adhere to.

Once the bacteria have "contacted" their food, they start the digestion process. A chemical enzyme is sent out through the cell wall to break up the organic compounds.

This enzyme, known as hydrolytic enzyme, breaks the organic molecules into small units which are able to pass through the cell wall of the bacteria.

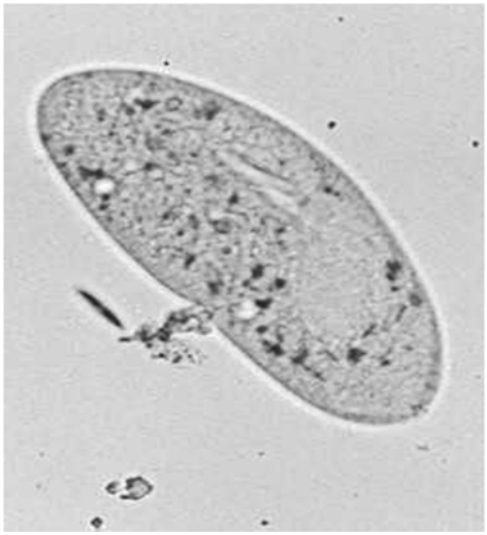
In wastewater treatment, this process of using bacteria-eating bugs in the presence of oxygen to reduce the organics in water is called activated sludge. The first step in the process, the contact of the bacteria with the organic compounds, takes about 20 minutes. The second step is the breaking up, ingestion and digestion processes, which takes four to 24 hours.

The fat storage property of the bacteria is also an asset in settling. As the bugs "bump" into each other, the fat on each of them sticks together and causes flocculation of the non-organic solids and biomass.

From the aeration tank, the wastewater, now called mixed liquor, flows to a secondary clarification basin to allow the flocculated biomass of solids to settle out of the water.

The solids biomass, which is the activated sludge, contains millions of bacteria and other microorganisms, is used again by returning it to the influent of the aeration tank for mixing with the primary effluent and ample amounts of air.

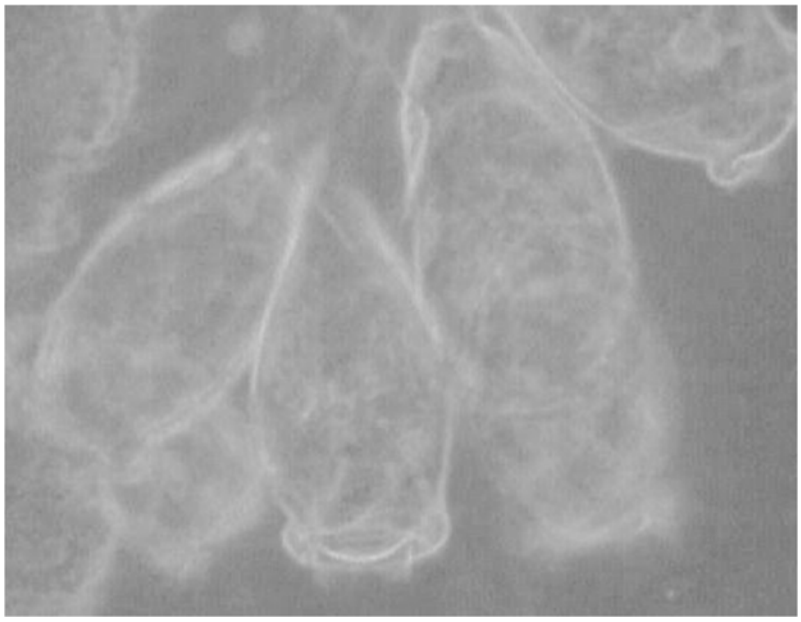
Paramecium sp.



Paramecium is a medium to large size (100-300 µm) swimming ciliate, commonly observed in activated sludge, sometimes in abundant numbers. The body is either foot-shaped or cigar-shaped, and somewhat flexible. Paramecium is uniformly ciliated over the entire body surface with longer cilia tufts at the rear of the cell.

Paramecium swims with a smooth gliding motion. It may also be seen paired up with another Paramecium which makes a good diagnostic key. The cell has either one or two large water cavities which are also identification tools. This swimmer moves freely in the water column as it engulfs suspended bacteria. It has a large feeding groove used to trap bacteria and form the food cavities that move throughout the body as digestion occurs. Paramecium is described as a filter-feeding ciliate because its cilia move and filter bacteria from the water.

Vorticella sp.



Vorticella is a stalked ciliate. There are at least a dozen species found in activated sludge ranging in length from about 30 to 150 µm. These organisms are oval to round shaped, have a contractile stalk, a domed feeding zone, and a water vacuole located near the terminal end of the feeding cavity.

One organism is found on each stalk except during cell division. After reproducing, the offspring develops a band of swimming cilia and goes off to form its own stalk.

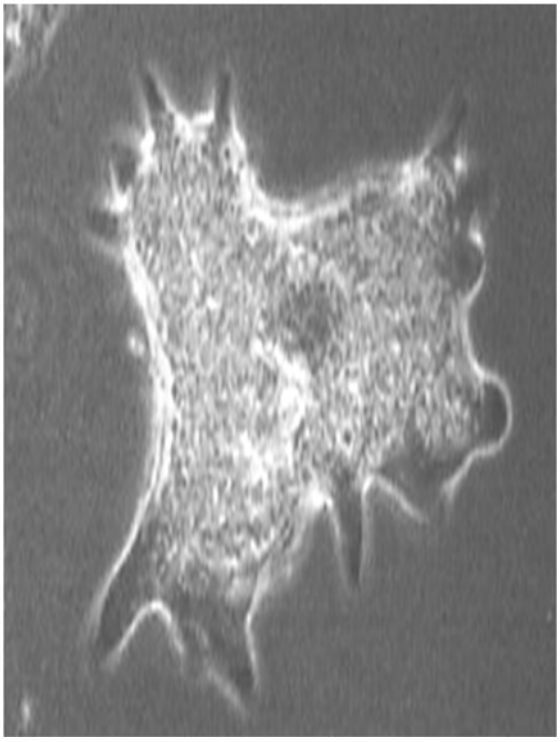
The expelled organism is called a "***swarmer***."

Vorticella feeds by producing a vortex with its feeding cilia. The vortex draws bacteria into its gullet. Vorticella's principal food source is suspended bacteria. The contracting stalk provides some mobility to help the organism capture bacteria and avoid predators.

The stalk resembles a coiled spring after its rapid contraction.

Indicator: If treatment conditions are bad, for example low DO or toxicity, Vorticella will leave their stalks. Therefore, a bunch of empty stalks indicates poor conditions in an activated sludge system. Vorticella sp. are present when the plant effluent quality is high.

Euglypha sp.

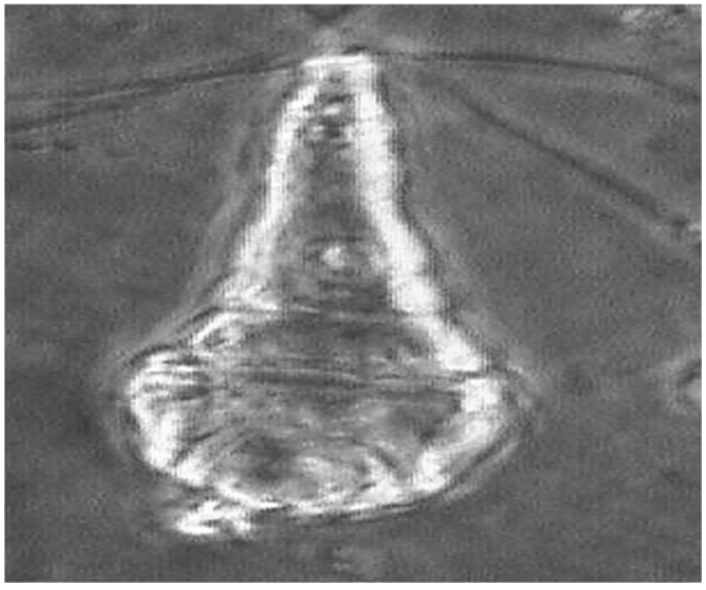


Euglypha (70-100 µm) is a shelled (testate) amoeba. Amoebas have jelly-like bodies. Motion occurs by extending a portion of the body (pseudopodia) outward. Shelled amoebas have a rigid covering which is either secreted or built from sand grains or other extraneous materials. The secreted shell of this Euglypha sp. consists of about 150 oval plates. Its spines project backward from the lower half of the shell. Euglypha spines may be single or in groups of two or three. The shell has an opening surrounded by 8-11 plates that resemble shark teeth under very high magnification.

The shell of Euglypha is often transparent, allowing the hyaline (watery) body to be seen inside the shell. The pseudopodia extend outward in long, thin, rays when feeding or moving. Euglypha primarily eats bacteria.

Indicator: Shelled amoebas are common in soil, treatment plants, and stream bottoms where decaying organic matter is present. They adapt to a wide range of conditions and therefore are not good indicator organisms.

Euchlanis sp.



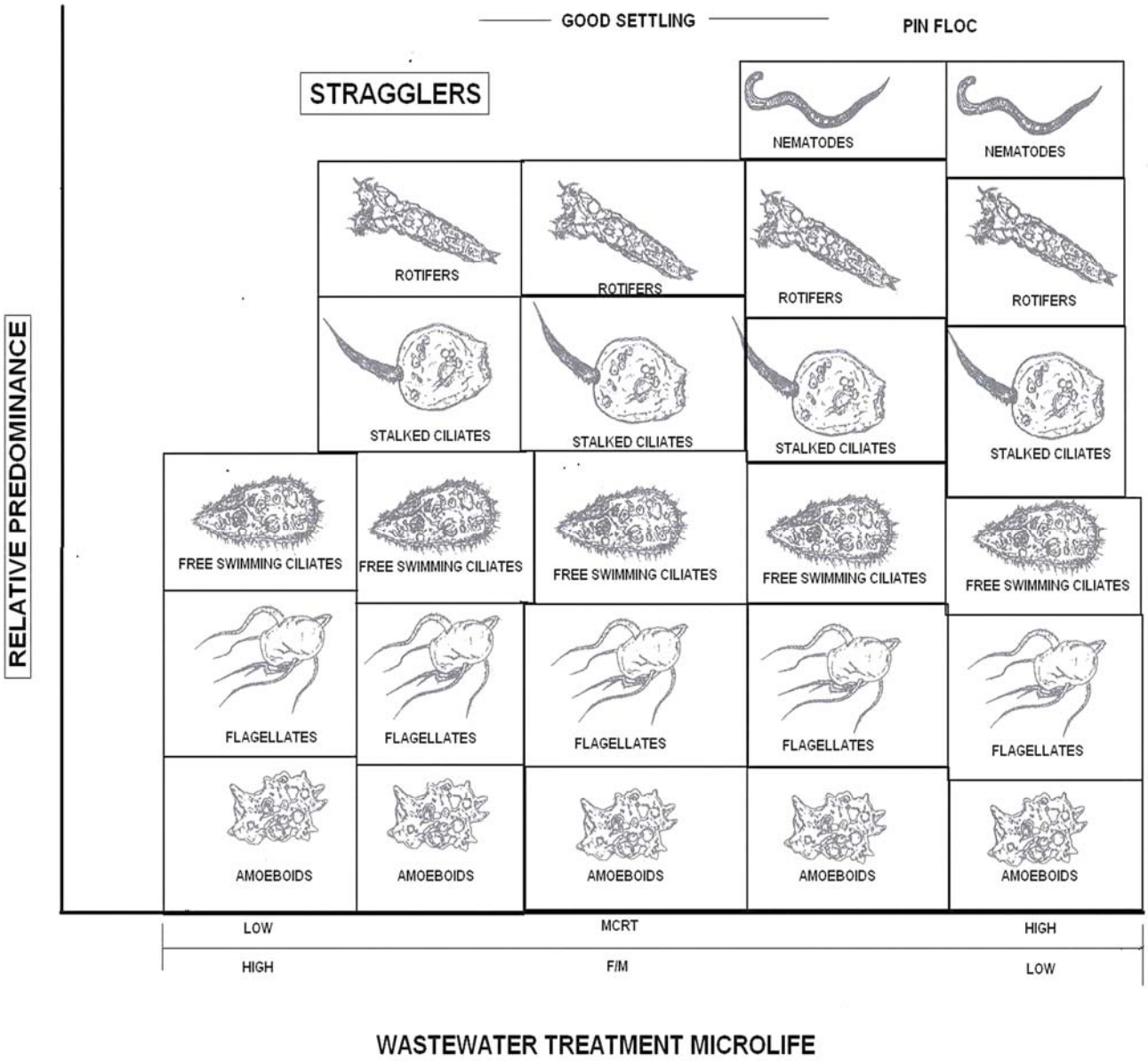
This microscopic animal is a typical rotifer. Euchlanis is a swimmer, using its foot and cilia for locomotion. In common with other rotifers, it has a head rimmed with cilia, a transparent body, and a foot with two strong swimming toes.

The head area, called the "corona," has cilia that beat rhythmically, producing a strong current for feeding or swimming. Euchlanis is an omnivore, meaning that its varied diet includes detritus, bacteria, and small protozoa.

Euchlanis has a glassy shell secreted by its outer skin. The transparent body reveals the brain, stomach, intestines, bladder, and reproductive organs.

A characteristic of rotifers is their mastax, which is a jaw-like device that grinds food as it enters the stomach. At times the action of the mastax resembles the pulsing action of a heart. Rotifers, however, have no circulatory system.

Indicator: Euchlanis is commonly found in activated sludge when effluent quality is good. It requires a continual supply of dissolved oxygen, evidence that aerobic conditions have been sustained.

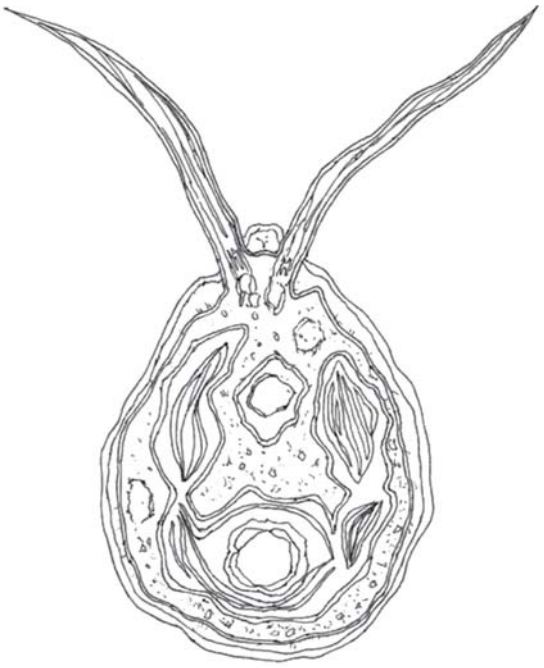


WASTEWATER TREATMENT MICROLIFE

Indicator Organisms - More information in the Appendix

AMOEBOID

"Amoeboid" and "amoeba" are used interchangeably. Amoeboids move using pseudopodia, which are bulges of cytoplasm. Amoebas breathe using their entire cell membrane that is constantly immersed in water. Excess water can cross into the cytosol. Amoebas have a contractile vacuole to expel excess water.



CHLAMYDOMONAS

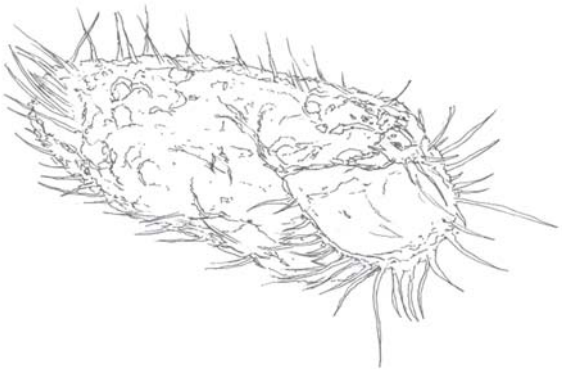
Chlamydomonas reinhardtii is known to remove nitrogen and phosphorus from wastewater.

ROTIFER EUCHLANIS

Euchlanis is commonly found in activated sludge when effluent quality is good. It requires a continual supply of dissolved oxygen, evidence that aerobic conditions have been sustained.

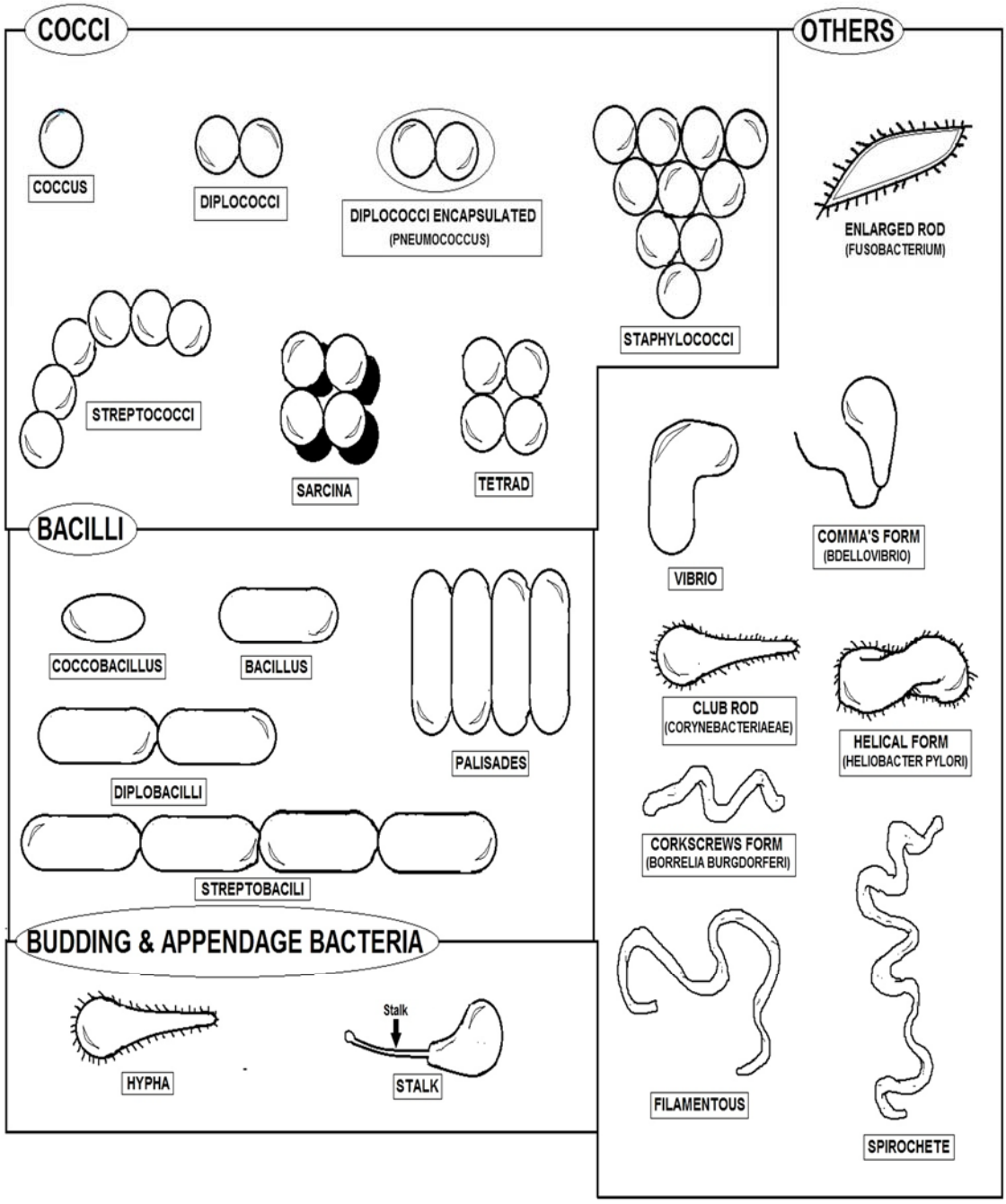
ROTIFER CALYCIFLORUS

This particular Rotifer is a great indicator bug for fresh and brackish water. With the increasing use of antibiotics, wastewater facilities are noticing passage through the treatment process. The toxicity effects the reproduction of the organisms in the water.

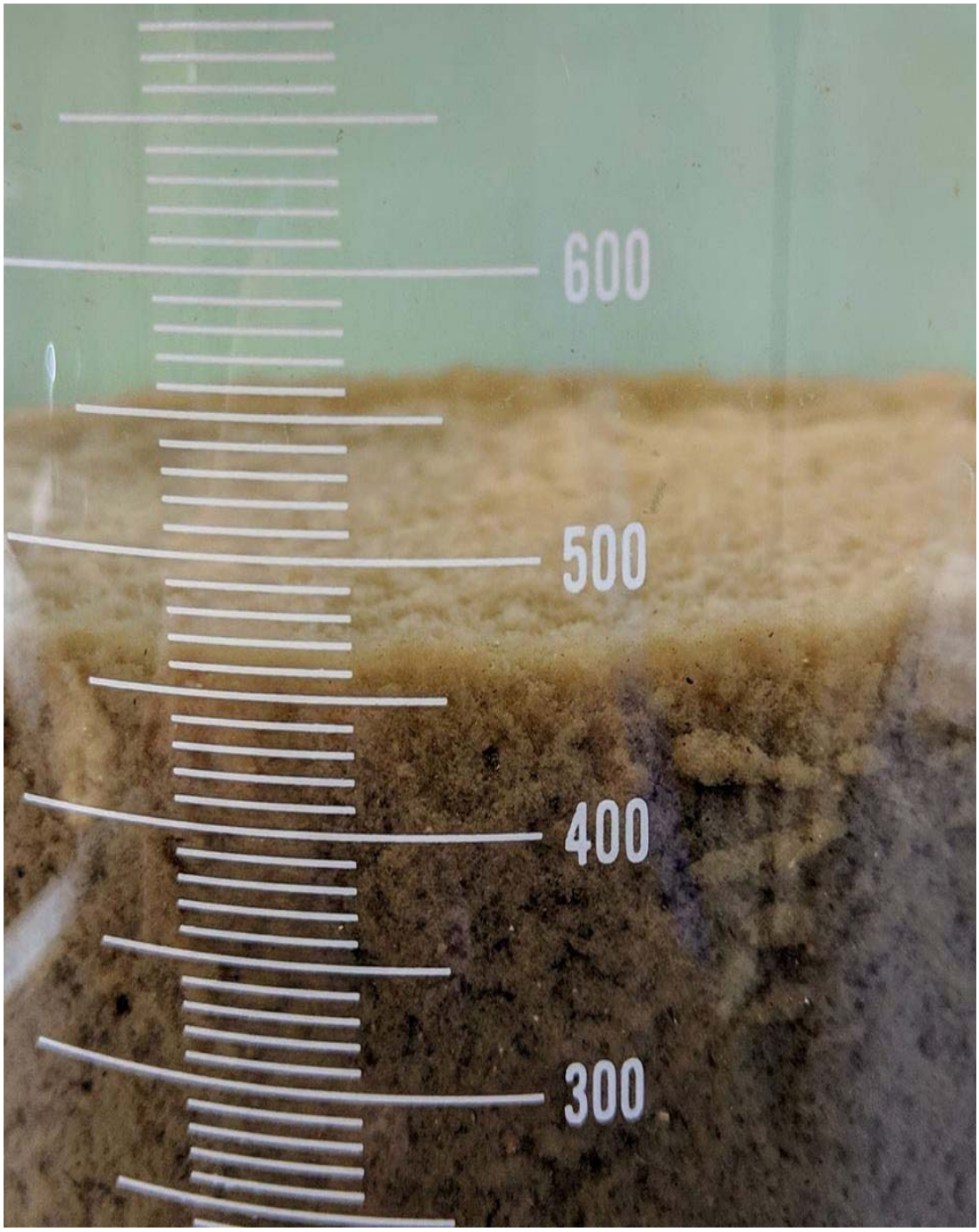


STYLONYCHIA MYTILUS

This ciliate is heavy metal resistant, Stylonychia mytilus, isolated from industrial wastewater has been shown to be potential bioremediator of contaminated wastewater. The ability of Stylonychia to take up variety of heavy metals from the medium could be exploited for metal detoxification and environmental clean-up operations.



BACTERIA SHAPES



The photo above is showing microorganisms (bugs) doing their job.

Activated Sludge Aerobic Flocs

Aerobic flocs in a healthy state are referred to as activated sludge. While aerobic floc has a metabolic rate approximately 10 times higher than anaerobic sludge, it can be increased even further by exposing the bacteria to an abundance of oxygen.

Compared to a septic tank, which takes several days to reduce the organic material, an activated sludge tank can reduce the same amount of organic material in approximately 4-6 hours. This allows a much higher degree of overall process efficiency. In most cases, treatment efficiencies and removal levels are so much improved that additional downstream treatment components are dramatically reduced or totally eliminated.

Problems may appear during the operation of activated sludge systems, including:

- High solids content in clarified effluent, which may be due to too high or too low solids retention time and to growth of filamentous microorganisms.
- Rising sludge, occurring when sludge that normally settles rises back to the surface after having settled. In most cases, this is caused by the denitrification process, where nitrate present in the effluent is reduced to nitrogen gas, which then becomes trapped in the sludge causing this to float. This problem can be reduced by decreasing the flow from the aeration basin to the settling tank or reducing the sludge resident time in the settler, either by increasing the rate of recycle to the aeration basin, increasing the rate of sludge collection from the bottom, or increasing the sludge wasting rate from the system.
- Bulking sludge, that which settles too slowly and is not compactable, caused by the predominance of filamentous organisms. This problem can be due to several factors of which the most common are nutrient balance, wide fluctuations in organic load, oxygen limitation (too low levels), and an improper sludge recycle rate.
- Insufficient reduction of organic load, probably caused by a low solids retention time, insufficient amount of nutrients such as P or N (rare in fisheries wastewaters), short-circuiting in the settling tank, poor mixing in the reactor and insufficient aeration or presence of toxic substances.
- Odors, caused by anaerobic conditions in the settling tanks or insufficient aeration in the reactor.

Filamentous Organisms

The majority of filamentous organisms are bacteria, although some of them are classified as algae, fungi or other life forms. There are a number of types of filamentous bacteria which proliferate in the activated sludge process. Filamentous organisms perform several different roles in the process, some of which are beneficial and some of which are detrimental. When filamentous organisms are in low concentrations in the process, they serve to strengthen the floc particles. This effect reduces the amount of shearing in the mechanical action of the aeration tank and allows the floc particles to increase in size.

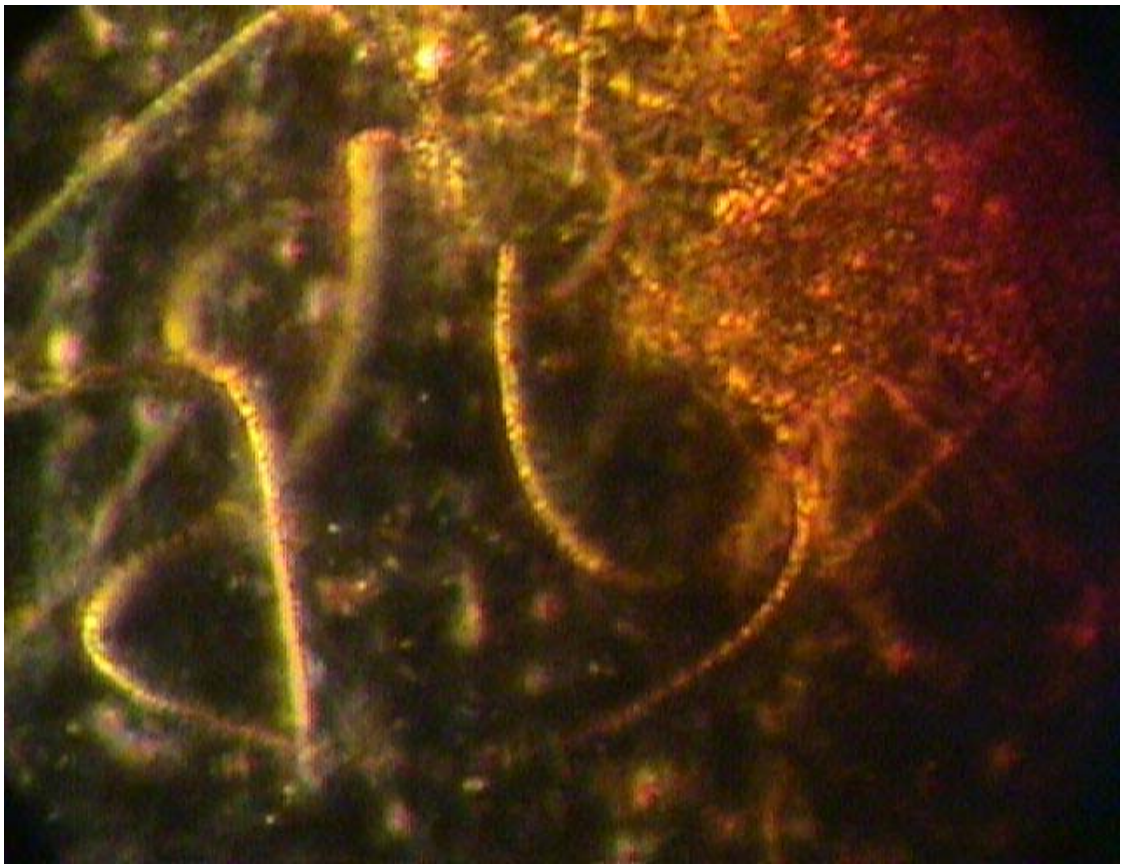
Larger floc particles are more readily settled in a clarifier. Larger floc particles settling in the clarifier also tend to accumulate smaller particulates (surface adsorption) as they settle producing an even higher quality effluent. Conversely, if the filamentous organisms reach too high a concentration, they can extend dramatically from the floc particles and tie one floc particle to another (interfloc bridging) or even form a filamentous mat of extra-large size.

Due to the increased surface area without a corresponding increase in mass, the activated sludge will not settle well. This results in less solids separation and may cause a washout of solid material from the system. In addition, air bubbles can become trapped in the mat and cause it to float, resulting in a floating scum mat.

Due to the high surface area of the filamentous bacteria, once they reach an excess concentration, they can absorb a higher percentage of the organic material and inhibit the growth of more desirable organisms.

Certain protozoans, such as amoebae and flagellates dominate during a system start-up. Free swimming ciliates are indicative of a sludge of intermediate health and an effluent of acceptable or satisfactory quality.

A predominance of crawling ciliates, stalked ciliates and metazoans is an indicator of sludge with excellent health and an effluent of high quality.



Filamentous Bacteria

Filamentous Bacteria Identification Section

Filamentous Bacteria
A problem that often frustrates the performance of activated sludge is bulking sludge due to the growth of filamentous bacteria. Sludge bulking can often be solved by careful process modifications. However, different filamentous bacteria such as Microthrix, Sphaerotilus, Nostocoida, Thiothrix or ”Type 021N” and others cause bulking for very different reasons.

Many filamentous species have not even been given a scientific name yet. Consequently, in order to make the right kind of process modification, knowledge to identify them and experience with the process ecology are required. The potential for instability with activated sludge is an acute problem when strict demands on treatment performance are in place.

Filamentous Identification is a helpful tool to monitor how healthy the biomass is when a filament problem may be suspected.

Filamentous Identification also helps to determine the type of filaments present so that we can find the cause and corrections can be made to the process to improve future problems.

All filamentous bacteria usually have a process control variation related with the type of filament present that can be changed depending on the environment condition. Killing the filaments with chlorine or peroxide will temporarily remove the filaments, but that’s just a quick fix.

A process change must be made or the filaments will return over time. Find out what filaments are present, find out the cause associated with them and make a process change for a lasting fix to the problems.

Filaments, their causes and suggested controls

Low DO Filaments	**Control**
Type 1701 S. natans	Adjust the aeration rates or F/M (based on aeration solids)
H. hydrossis	Long RAS lines or sludge held too long in the clarifier can sometimes cause the growth of low DO filaments even if the aeration basin DO is adequate
Waste with limited Nutrients	**Control**
Thiothrix I & II 021N and N. Limicola III	Nutrient addition BOD ratio of 100:5:1
Low F/M ratios	**Control**
0041, Nocardia	Use of selector, increase RAS
Type 1851, 0961, 0803, 0675	Increase WAS

Some filaments have more than one version of the filament species, with slightly different characteristics for identification.

- N. Limicola I
- N. Limicola II
- N. Limicola III
- Thiothrix I
- Thiothrix II

Filamentous Identification
Filaments can be internal or external, and they can be free of the floc structures or found intertwined in the floc. Most labs think that filaments need to be extending from the floc in order to be a problem. This is not true.

Internal filaments can cause more problems than external filaments. Think of internal filaments causing a structure like a sponge. It will retain water easily and be harder to dewater, will be hard to compress and will take up more space, thereby increasing solids handling costs.

Filaments present in the system do not always mean there is a problem. Some filaments are good if they form a strong backbone and add a rigid network to the floc. They help give the floc more structure and settle faster.

Filaments are good BOD degraders also. They are only a problem when they become dominant. If filament abundance is in the abundant or excessive range, having a Filamentous Identification performed is recommended.

The activated sludge process was invented around 1914 and is today still the most commonly used biological wastewater treatment process. This widespread use is due to the fact that activated sludge can be a rather easy process to implement and one that can attain high treatment efficiency.

Activated sludge is susceptible to process disturbances making it a very problematic technology for many of its users. Problems arise most when the wastewater to be treated varies significantly in composition and/or flow.

Let's do a quick review of the Bugs…. We will go much more into detail later…
Nocardia amarae
Nocardia amarae, a common cause of disruptive foaming in waste treatment plants, is a slow growing, usually gram-positive, chemoautotrophic, filamentous, strict aerobe that produces the biosurfactant trehalose.

Colonies can be brown, pink, orange, red, purple, gray or white, so color alone is not a key to identifying this species. N. amarae, member of the Actinomycetes family, is not motile, so it relies on movement of the water to carry it through the system. It produces catalase, urease and nitrate reductase enzymes, but not casease.

The foam from Nocardia amarae is usually a viscous brown color unless algae are entrapped in it, in which case it appears green and brown.

Nostocoida limicola
Nostocoida limicola is yet another common cause of disruptive foaming in waste treatment plants, motile in its Hormogonia and sometimes Trichome phases. This oxygenic phototrophic species often forms a confluent gel encasing flattened discs or large sheets of cells, forming symbiotic relationships with other species. Staining gram-positive, Nostocoida produces round cells within tight coil formations.

Nostocoida can also be dentified by their starburst effect formations using phase contrast microscopy at 400 to 1000x magnification. After chlorination, a few dead cells sticking out identify stress to this species.

Thiothrix
Thiothrix spp., the second most common cause of disruptive foaming in wastewater treatment plants appears as straight to slightly curved cells with rectangular shape form filaments up to 500 microns in length, in multicellular rigid filaments, staining gram-negative, with obligately aerobic respiration.

Thiothrix are mixotrophic, using several small organic carbons and reduced inorganic sulfur sources for growth and energy. Thiothrix I is one of the largest filament found using phase contrast microscopy at 400 to 1000x magnification. Thiothrix II produces rectangular filaments up to 200 microns in length and is easily identified by their starburst effect formations using phase contrast microscopy at 400 to 1000x magnification.

Microthrix parvicella
Microthrix parvicella is another common cause of disruptive foaming in waste treatment plants, producing filaments up to 400 microns in length, easily visualized by phase contrast microscopy at 400x magnification. This species is usually found outside floc, tangling with structures in the system, but can also be found hanging out of the floc.

Sphaeroliticus natans
Sphaeroliticus natans is another filamentous species, and yet it is reputed to increase settleability by branching between flocs, increasing surface area. Cells are straight to slightly curved, up to 1000 microns in length and stain gram-negative.

These large cells can be easily visualized by phase contrast microscopy at 100x magnification. Certain conditions favor the proliferation of filamentous species.

A low F/M (food to mass) ratio favors filamentous organisms, because their higher ratio of surface area to volume provides them with a selective advantage for securing nutrients in nutrient limited environments.

When a plant runs an extremely long sludge age, the slower growing filaments have a better chance to establish a strong colony. As a strict aerobe, high levels of oxygen are necessary to sustain this species. Mesophilic, Nocardia amarae thrives in temperatures from 17 to 37 deg. C.

The presence of high levels of fats, oils and greases or hydrocarbons and phenols, can encourage this species, particularly when insufficient levels of nitrogen and phosphorus are present to balance these carbon sources.

If you ever experienced an overgrowth of Microthrix parvicella in your activated sludge plant, you will be aware that it can be very difficult to either eradicate or control.

Microthrix is the most common cause of bulking and foaming in activated sludge plants (Rosetti et al. 2002), and it appears either essentially alone or in the company of other filaments.

Microthrix foams appear in many of the photographs of aeration basins and clarifiers I have collected all over the world, and many of the plant tours on the Internet show the same brown stable scums associated with this organism.

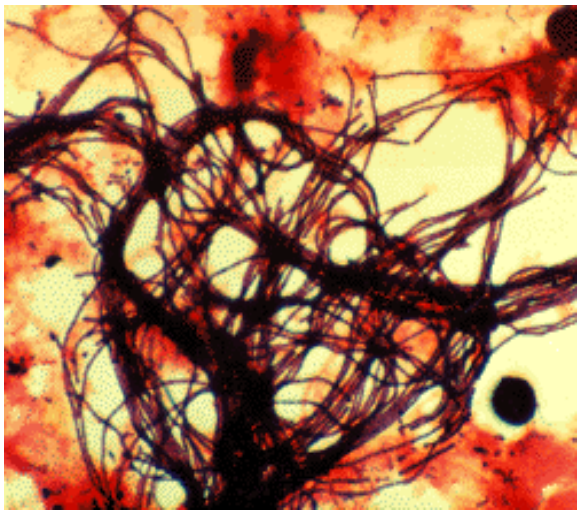


Figure 1.
A micrograph of Microthrix parvicella, gram stain x 1000

Microthrix is your Enemy - *Get to know it!*

Microthrix fits into the filamentous bacterial classification of low F/M, which means that it tends to appear in plants with long sludge ages. Lackay *et al.* (1999) suggested that *M. parvicella* and its low F/M compatriots *Haliscomenobacter hydrossis*, and types 0092, 0041, 1851, 0803 were also encouraged to the point of maximum proliferation by alternating anoxic-aerobic conditions (particularly 30-40% aerobic and 60-70% anoxic) but any alternation of anoxic-aerobic conditions may cause a problem in single reactor, two reactor, or multireactor systems in which nitrate and/or nitrite are present throughout the anoxic period, or in the anoxic reactor just prior to the aerobic reactor. Modern plants incorporating denitrification and/or phosphorus removal are obvious candidates for bulking and foaming due to *Microthrix*.

Figures 1 and 2 show typical views of *Microthrix* by using light microscopy and scanning electron microscopy respectively. It is not difficult to recognize using standard staining and microscopy, giving a positive response to Gram stain and being of fairly easily recognized morphology (Seviour *et al.* 1999). Of all the filaments creating difficulties in activated sludge plants, it is one of the most easily recognized, but there is a commercial test kit available which uses fluorescent situ hybridization (or "FISH") to permit visual identification should one feel the need.

The design of plants can play a significant part in the proliferation of scums and foams and there are many common mistakes in plant design which assist organisms like *Microthrix* by retaining floating masses in dead areas of the plant which have very high MCRT values and continuously reseed the biomass, (Pitman 1996). These should obviously be avoided (Figs 3, 5 and 6).

Similarly poor mixing, poorly designed and inadequate aeration systems, cyclic overloading and low process D.O. levels can contribute to the creation of anoxic and anaerobic zones in what are supposed to be aeration basins.

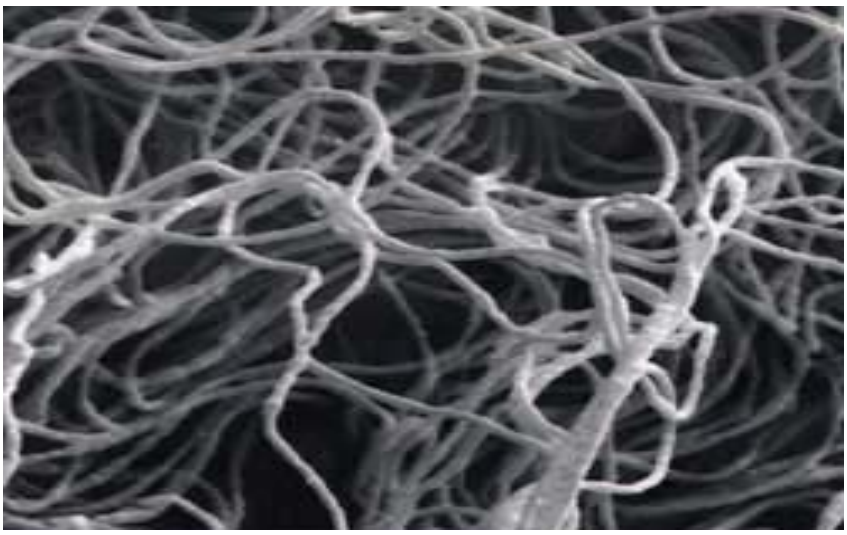


Figure 2. A scanning electron micrograph of Microthrix parvicella

Current Remedial Techniques

Jenkins *et al.* (1993) presented sludge chlorination as a method of choice in the United States to combat filamentous bulking due to any organism. The success of treatment of *Microthrix* in mixed liquor or foams is poor, due it is believed to resistant filamentous bacteria with hydrophobic cell walls such as *M. parvicella* and *Nostocoida limicola*.

Lakay *et al.* (1988) obtained only a partial elimination of *Microthrix parvicella* bacteria at a high chlorine dose. Hwang and Tanaka found in batch tests that *M. parvicella* remained intact at very high chlorine doses, while the microbial flocs were completely destroyed. Saayman *et al.* (1996) examined the use of non-specific chemical treatment in a BNR plant and assessed the effects of biomass settling characteristics and other operational parameters.

Figure 3.
Dry Microthrix parvicella foam trapped in an anoxic zone of a BNR plant. aeration basin.

While chlorine use was the most effective, it was reported to damage the biomass and cause difficulties in the P removal process when dosed at high levels, while ozone and peroxide were less effective in treating settling problems but less of a problem to the biomass.

In recent times the introduction of selectors has been hailed as a major initiative in the control and elimination of filamentous bacteria (bulking and foaming) and the maintenance of moderate biomass SVIs.

Figure 4. Typical dark brown Microthrix parvicella foam on an

Evidence on the performance of selectors in controlling low F/M filaments has been described as both controversial and ambiguous and, in the Netherlands, despite incorporating over 80 selectors in full-scale plants, the percentage of plants with bulking associated with *Microthrix parvicella* was unchanged. Other experiences with the aerobic selector showed only little success in controlling the growth of *M. parvicella* in the presence of long chain fatty acids (LCFA), (Lebek and Rosenwinkel, 2002) and a comparison of anoxic selectors at five plants in the US has demonstrated that performance and effectiveness varied significantly (Marten and Daigger, 1997).

Microthrix Capabilities

Mamais *et al.* 1998 examined the effect of factors such as temperature, substrate type (easily biodegradable in the form of acetate and slowly biodegradable in the form of oleic acid) on Microthrix parvicella growth using complete mix with and without selectors (anoxic and anaerobic) and plug flow reactors. The results indicate that low temperatures and substrates in the form of long chain fatty acids favor the growth of *M. parvicella*.

The plug flow configuration was shown to be quite effective in controlling the growth of *M. parvicella* and producing a sludge with good settling characteristics, while the presence of a selector, either anoxic or anaerobic, had no significant effect on the growth of *M. parvicella*. Maintenance of low sludge ages (5) days has also been reported to eliminate *M. parvicella* because it is a slow growing organism, but this is not always operationally possible.

While it is often convenient to group filaments together, it does appear the *Microthrix* has received special attention because of its ability to proliferate. More selective investigation of *Microthrix* has indicated that it has quite well defined requirements. The nature of *Microthrix* is such that it has the capability of using long chain fatty acids (oleic acid) and their esters (triglycerides of palmitic and stearic acid) (fats and oils) as sources of carbon and energy.

Lipids and LCFA are present in all domestic wastewater streams and often constitute a significant part of it. Values of 25-35% of the incoming COD have been reported, and it can support a substantial biomass production in a treatment plant. LCFA are generally easily consumed in activated sludge, and the consumption rate of LCFA under aerobic or anoxic conditions has been found to be rapid.

Studies indicate that *M.parvicella* consumes exclusively long chain fatty acids (LCFA), and that it is able to take up LCFA not only under aerobic, but also under anaerobic and anoxic conditions (Andreasen, K. and Nielsen, P.H. (2000)). It has been reported that *M. parvicella* is able to out-compete other bacteria particularly well in alternating anaerobic-aerobic and anoxic activated sludge systems. This ability is based on a high uptake and storage capacity for LCFA under anaerobic conditions and a subsequent use of the stored substrate for growth with oxygen (or nitrate) as electron acceptor.

Rosetti *et al.* (2002) carried out an extensive examination of *M. parvicella* and found that it was a very versatile organism which could store organic carbon under anaerobic conditions using stored polyphosphate for energy (like the organisms responsible for phosphorus removal). Once exposed to aerobic conditions it would recover rapidly and resume growing. *Microthrix* has a high storage capacity under all operating conditions (anaerobic, anoxic and anaerobic). It has a high "substrate affinity" or low Ks, which means it competes well at low substrate concentration.

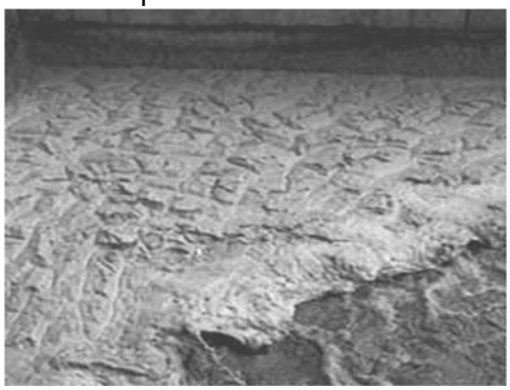


Figure 5.
Microthrix parvicella foam trapped near a mechanical aerator.

Most interestingly, *M. parvicella* has a maximum growth rate near 22° C, zero growth rate at 30° C and is capable of quite reasonably large growth rates at as low as 7° C which gives it a significant advantage in the competition with floc formers during winter in cold climates.

PAX vs. Microthrix parvicella

Microthrix parvicella is well-equipped to survive, compete and dominate in all kinds of activated sludge systems. With all of the above in mind, it is pleasing to find that Microthrix does have a weakness. That weakness is its apparent sensitivity to poly aluminum chloride (PAX) dosing, which seems to attack the ability of Microthrix parvicella to use lipids by reducing the activity of extracellular enzymes (lipases) on the surface of the organism rendering the organism relatively uncompetitive (Nielsen et al. 2003).

Roels *et al.* (2002) reported a loss of surface scum following PAX-14 dosing which was probably due to a loss of hydrophobicity. Full-scale dosages of PAX-14 range from 1.5 to 4.5 g Al^{3+}/kg MLSS/day depending on the sludge retention time (SRT); the lower the SRT, the higher the dosage and certainly lower than 7 g Al^{3+}/kg MLSS. Roels *et al.* (2002) offered the following empirical formula to establish the dose:

60/SRT = #g of Al^{3+}/kg MLSS

They also recommended the removal of the scum layer before dosing to allow the concentration and time of dosage to be kept at a minimum.

Removal of the floating sludge layer from the surface before starting PAX application was necessary to ensure specific and rapid impact of Al-salts on *M. parvicella*.

In fact, the stable floating sludge represents an independent microbial system, into which aluminum can penetrate only at a limited extent. Dosage should be combined with high oxygen concentration in the aeration (i.e. above 2.5 mg/L) and the MLSS concentration low (i.e. under 2.5 g/L) since *M. parvicella* competes well at low oxygen levels.

Figure 6. A heavy build-up of trapped Microthrix parvicella foam during winter.

Of note was that the morphological properties of only Microthrix parvicella changed, apparently leaving the other filaments remaining unaffected.

Paris *et al.* (2003) came to a similar conclusion; by dosing $AlCl_3$ (3.5 mg $mgAl^{3+}$ gMLSS/d), a general improvement of the settling properties of the activated sludge was achieved. As the filamentous population of activated sludge and the occurrence frequency of *M. parvicella* dropped, a decrease of hydrophobicity and floating tendency of activated sludge was observed. With low hydrophobicity the sludge does not tend to float. This has significant relevance for any measure to prevent floating foams.

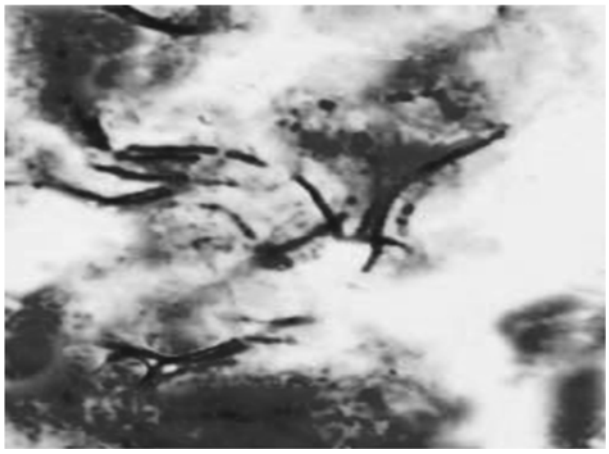


Figure 7. An typical view of Microthrix parvicella (gram stain x 1000) after extended PAX treatment.

It was observed that by adding PAX a morphological modification of the filamentous bacterium *M. parvicella* occurs. The morphological modification is probably the reason why the hydrophobic property of the filaments decreases. Paris *et al.* (2003) included micrographs which indicated that the *Microthrix parvicella* appeared to shorten in length after dosing (Figure 7) and no longer inhabit the zones between flocs.

PAX

PAX (or PAX-14 or polyaluminium chloride) used for *Microthrix* control is a flocculant or coagulant commonly used in water and wastewater treatment. The 14 or other number associated with the name refers to the particular grade of the chemical.

Nielsen *et al.* (2003) report that PAX-14 is $Al_{13}O_4(OH)_{24}$ $(H_2O)_{12}^{7+}$ and it is produced from $Al(OH)_3$ at high temperature and high pressure. PAX-14 and 18 are being used in several countries with good success for controlling *M. parvicella* - in particular Denmark where PAX-14 has been applied successfully in treatment plants with biological N and/or P removal for 91 out of 500 plants in 2002.

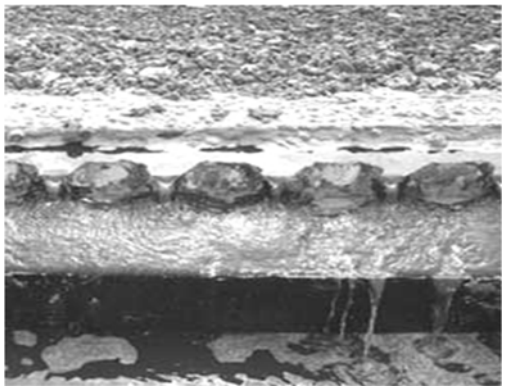


Figure 8.
Foam build-up in a secondary clarifier resulting in solids loss and turbid effluent.

Proposed Treatment Regime
In the fall, to prevent the normal appearance of M. parvicella during the coming winter and to control problems with M. parvicella (winter, spring).

Dosage: 0.5-1.5g Al/kgSS/day usually added to return sludge. PAX should be dosed continuously over the treatment period at the chosen level.

Removal of floating sludge before and during dosing is recommended. Microscopic examination of the biomass and regular testing of biomass settling is also a very good idea and the dosing at the chosen remedial rate until a target SVI or preferably DSVI is reached should be the rule.

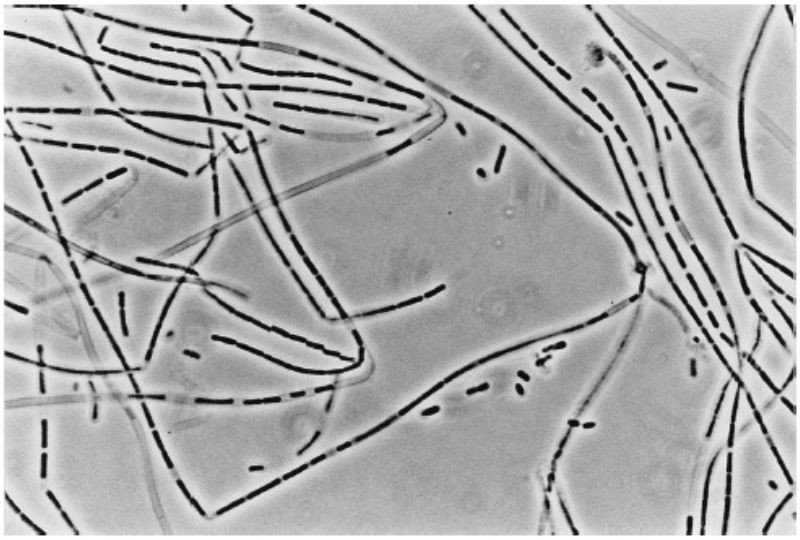
It is not yet fully clear why PAX has the effect that it does, but the research continues. It is known that other Al salts have little effect on surface associated enzymes after 15 min, and no effect on surface hydrophobicity and surface associated enzymes.

Old mixed liquor, the dark color is an indicator of old bugs or upset.

Sphaerotilus natans

Description and Significance

Sphaerotilus natans is a filamentous bacterium that is covered in a tubular sheath and can be found in flowing water and in sewage and wastewater treatment plants. While this bacterium sometimes clogs pipes and causes other similar problems, it does not cause major threat to wastewater treatment plants nor is it known to be pathogenic.

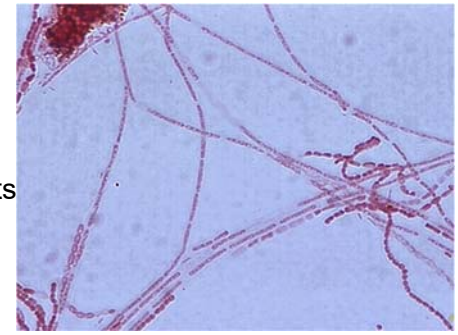


Long unbranched and ensheathed filaments produced by *Sphaerotilus natans* IF4.

Relatively long, non-motile filaments (100-1000 µm). Straight or smoothly curved with tree-like false branching. The cells are round-ended and rod shaped (1.0-1.8 x 1.5-3.0) and are contained in a clear, tightly fitting sheath. **Note:** They can be rectangular when the cells are tightly packed within the sheath. The cell septa are clear and easily observable with indentations.

Filaments radiate outward from the floc surface into the bulk solution and can cause sludge settling interference by inter-floc bridging. The filament is usually Gram negative and Neisser negative. There are no sulfur granules. Poly-ß-hydroxybutric acid (PHB) is frequently observed as dark intracellular granules. In wastewater that is nutrient deficient, an exocellular slime coat may be present. Attached growth is usually uncommon, but may occur when at low growth rate.

This filament is usually found in environments where there is low DO or low nutrients (Nor P).



Control

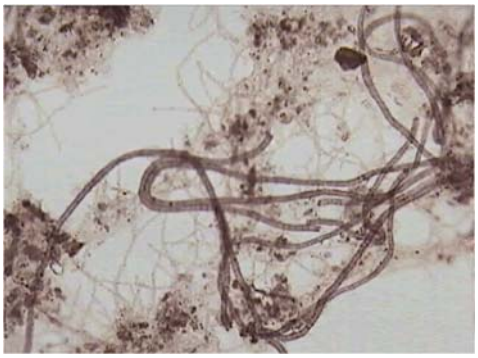
RAS chlorination can be used to get rid of the filaments but process changes should also be made. Cell lysis occurs readily on this type of filament, although the empty sheaths still remain. Sludge wasting is necessary to remove them entirely from the system.

Manipulation of F/M and DO concentration can be used to control the filaments. Nutrient deficient wastes can be checked by effluent values of residual NH^3 and o-PO^4 and should be supplemented if necessary.

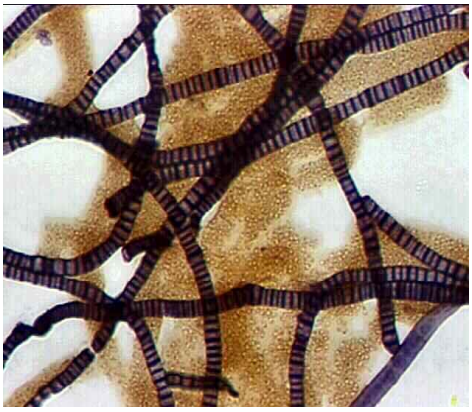
Rank
Sphaerotilus natans ranks 6th in number of predominance. Typically not found in pulp-mills with activated sludge.

Nostocoida limicola *I* and *II*
Nostocoida limicola I is a bent and highly coiled filament. *N. limicola* has cells that are oval (0.6-0.8 µm wide) but are found to be closer to each other and the cell septa are almost indiscernible. The length of the filament can range from 100 to 200 µm and the majority of the time the trichome is found within the floc. *N. limicola* has no sheath and attached growth is rare. It stains Gram positive and Neisser positive.

***Nostocoida limicola II* Identification**
Medium length , non-motile filaments (100-200 µm). Bent and irregularly coiled filaments with incidental true branching. Knots sometimes seen. Cell septa are clear with indentations. Cells are oval or disc shaped (1.2-1.4 µm). Filaments are found within the floc structure but may occur in the bulk solution. The filament staining is variable, it is usually Gram negative but sometimes positive and Neisser positive.



Usually easy to identify due to its Neisser staining properties. Stains entirely purple and looks like stacked discs (or hockey pucks). In industrial wastes, an organism that is Gram negative and Neisser negative occurs. There is no sheath and there are no sulfur granules. Poly-ß-hydroxybutric acid (PHB) granules are frequently observed as dark intracellular granules. Attached growth is usually uncommon. Three subtypes are known. Resembles *M. parvicella* except in its Neisser staining properties.

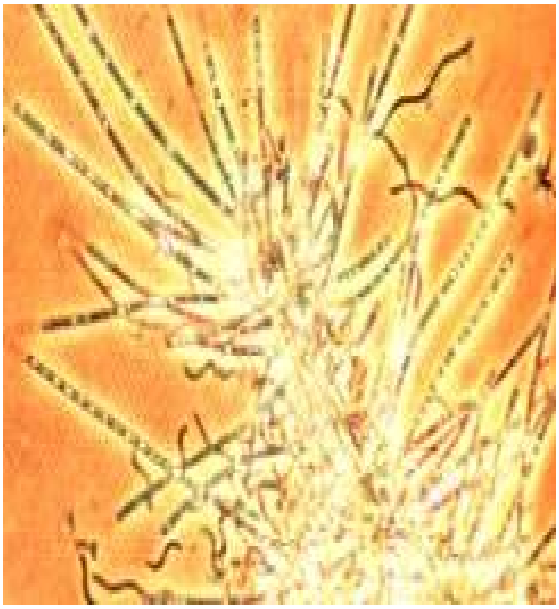


Environment
This filament is usually found in environments where there is low DO or low F/M and the presence of organic wastes. Wastes containing starch seem more selective to this filament. Bulking is more common in industrial wastes. The filament appears to be facultative fermentative, which is unique for most filaments.

Control
Manipulation of F/M (usually an increase) and DO concentration can be used to control the filaments. A selector may be used and chlorination. System changes include changing from a complete mix to plug flow aeration basin configuration.

N. limicola ranks 12th in number of predominance in industry. Typically not found in kraft mills. Common in municipalities.

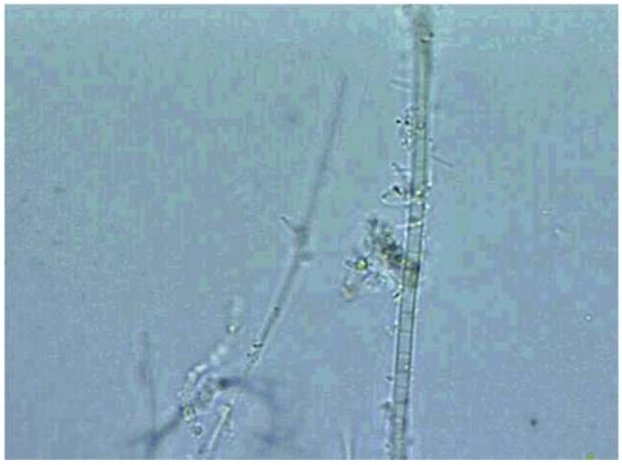
Thiothrix I & II



Thiothrix species consist of two types of Thiothrix and they are Thiothrix I and Thiothrix II. Thiothrix filaments are straight or slightly curved with Thiothrix I having an overall length of 100-500 µm and individual cells having a rectangular shape (1.4-2.5 x 3-5 µm). Thiothrix II has total length varying form 50-200 µm and its cells are rectangular (0.8-1.4 x 1-2 µm).

Both types of Thiothrix are found stretching from the floc surface, there is a noticeable septa between cells. Both species are Gram negative and Neisser negative with cells that on occasions have sulfur granules. There are additional structures on Thiothrix trichomes and they include apical gonidia as well as rosettes and a sheath is present, incidental attached growth may be observed. A holdfast may add to the characteristic of radiating out from a common center, the "starburst effect".

Relatively large, non-motile filaments (100-500 µm). Straight or smoothly curved filaments with no branching. Cells are rectangular (1.4 x 2.5 µm) and a clear cell septa is present without indentations at the septa. Filaments are found radiating outwards from the floc structure causing inter-floc bridging.

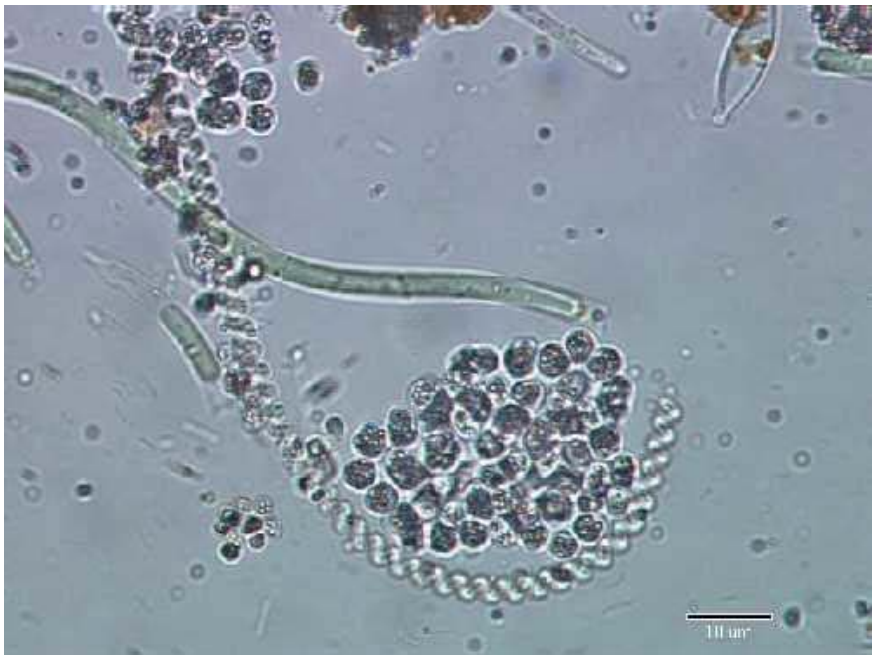


The filament staining is Gram negative or Gram variable when sulfur granules are present and Neisser negative with Neisser positive granules observed frequently.

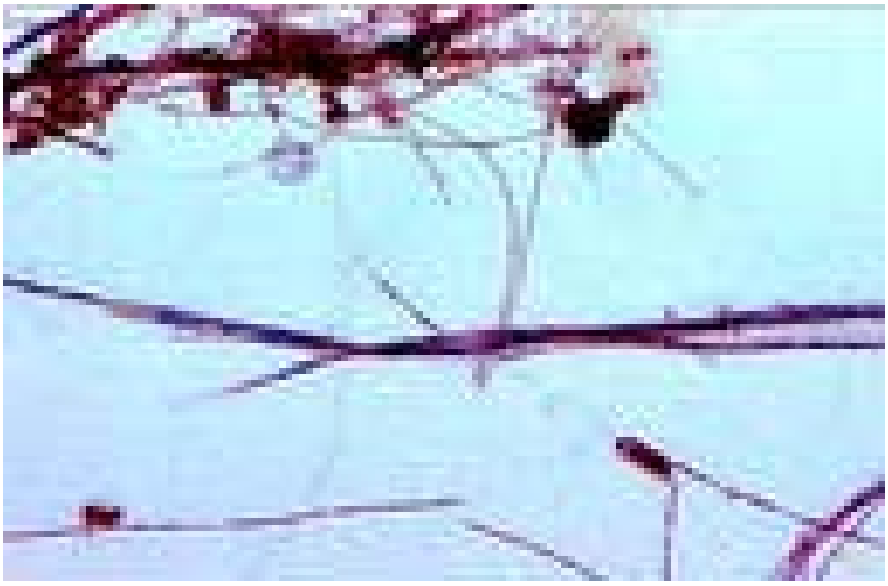
Exhibits bright sulfur granules in the presence of sulfides under phase contrast (use the S-test). Poly-ß-hydroxybutric acid (PHB) is frequently observed as dark intracellular granules. No attached growth when extending into the bulk solution. Can form rosettes and the filaments can have gonidia on the tips. Rosettes are when many filaments radiate outward from a common origin. Prominent heavy sheath. Easy to identify due to its large size.

Similar Organisms
Type 021N is similar when in the bulk solution and with no attached growth, although Type 021N has no sheath.

Environment
This filament is usually found in environments where there are limited nutrients (N or P). It can also be found in wastes containing specific compounds with sulfides and/or organic acids or environments with low DO. Sometimes found in plants with high pH in the aeration system.



Thiothrix II



The common range for sludge age for a conventional activated sludge plant is **between 3 and 15 days**. For extended aeration activated sludge plants the range is between about 15 and 30 days. Generally during the winter months, higher sludge ages are required to maintain a sufficient biological mass.

Topic 7- Wastewater Microbiology Section Post Quiz

True or False

1. Actively growing bacteria eat food at a rapid rate therefore using oxygen at a rapid rate. The rate of oxygen use is normally termed the Oxygen Uptake Rate and is measured in mg O2/hr/gm of MLSS. True or False

2. As bacteria first begin to develop in the system, they grow in large clumps and chains. They are not very active with flagella and have a well-developed slime layer. True or False

3. Aerobic bacteria require at least 0.1 - 0.3 mg/L of oxygen to survive. At least 2 mg/L of oxygen must be maintained in the bulk fluid in order for the bacteria in the center of the floc to get 0.1- 0.3 mg/L of oxygen. True or False

4. Mixing is never required to bring the bacteria, oxygen and nutrients in contact with each other. True or False

5. Bacteria require basic nutrients for growth (carbon, nitrogen, phosphorus as well as trace amounts of sodium, potassium, magnesium and iron. All these are present in normal domestic sewage. True or False

6. The bacteria have an interesting property; their “fat reserves” are stored on the outside of their bodies. This fat layer is sticky and is what the organics adhere to. True or False

7. Once the bacteria have “contacted” their food, they start the digestion process. True or False

8. In wastewater treatment, this process of using bacteria-eating bugs in the presence of oxygen to reduce the organics in water is called “Oxidation”. True or False

9. As the bugs “bump” into each other, the fat on each of them slides off and causes flocculation of the organic solids and biomass. True or False

10. Euglypha is a medium to large size (100-300 µm) swimming ciliate, commonly observed in activated sludge, sometimes in abundant numbers. The body is either foot-shaped or cigar-shaped, and somewhat flexible. True or False

11. Euglypha swims with a smooth gliding motion. It may also be seen paired up with another Paramecium which makes a good diagnostic key. True or False

12. Vorticella is a stalked ciliate. There are at least a dozen species found in activated sludge ranging in length from about 30 to 150 µm. True or False

13. Vorticella are oval to round shaped, have a contractile stalk, a domed feeding zone, and a water vacuole located near the terminal end of the feeding cavity. True or False

14. Euglypha primarily eats viruses. True or False

15. Shelled amoebas are common in soil, treatment plants, and stream bottoms where decaying organic matter is present. They adapt to a wide range of conditions and therefore are not good indicator organisms. True or False

16. Euchlanis is a swimmer, using its foot and cilia for locomotion. In common with other rotifers, it has a head rimmed with cilia, a transparent body, and a foot with two strong swimming toes. True or False

17. Euchlanis is an omnivore, meaning that its varied diet includes detritus, bacteria, and small protozoa. Euchlanis has a glassy shell secreted by its outer skin. The transparent body reveals the brain, stomach, intestines, bladder, and reproductive organs. True or False

18. A characteristic of rotifers is their mastax, which is a jaw-like device that grinds food as it enters the stomach. True or False

19. Rotifers have a circulatory system. True or False

20. Euchlanis is never found in activated sludge when effluent quality is good. It requires a continual supply of dissolved oxygen, evidence that aerobic conditions have been sustained. True or False

Topic 8 -Wastewater Sampling Section

Topic 8 - Section Focus: You will learn the basics of the wastewater sampling program, rules, and sampling procedures. At the end of this section, you the student will be able to understand and describe various sampling regulations and sampling procedures. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Topic 8 – Scope/Background:

The sampler should be thoroughly familiarized with existing safety guidelines and follow your permit and proper sampling procedures, guidelines and practices for any analyte of particular interest. The sampler must always be alert to the possibility of danger, especially in dealing with unknown sites, situations or possible contaminants. Legal samples are necessary for process control and for when there is evidence an individual or company has not complied with wastewater regulatory requirements and there is a potential for laying charges. Legal sampling is conducted under the following circumstances: Any known or suspected violation, Spills or environmental accidents, Previous knowledge about compliance history does not exist or it is unknown. From the standing point of objectivity, continuity of evidence and quality of the results, the collection, handling, transport, analysis, storage and disposal of the legal samples must be defensible.

WASTEWATER CHARACTERISTICS & SPECIFIC SOURCES	
PHYSICAL	
SOLIDS	Domestic - Industrial Wastes / Soil Erosion / Inflow, etc.
COLOR	Industrial - Domestic Wastes / Natural Decaying of Organic Matter
ODOR	Industrial Wastes / Decomposition of Wastewater
CHEMICAL	
PHENOLS	Industrial Wastes
pH	Industrial Wastes
TOXIC COMPOUNDS	Industrial Wastes
HEAVY METALS	Industrial Wastes
PESTICIDES	Run-Off From Agriculture
BIOLOGICAL	/ Open Water Courses / Treatment Units, etc

CHART IDENTIFYING BASIC SOURCES AND CHARACTERISTICS OF WASTEWATER

Collecting Wastewater Samples

The purpose of this section is to understand both general and specific sampling procedures, methods and considerations to be used and observed when collecting wastewater samples for field screening or laboratory analysis.

Common Wastewater Sample Collection Bottles

Above, 625/608, 1657, TTO/Organics, TPH/Oil/Grease
Smaller bottles-TOCs, VOCs, 601/602 and 502.2.

NO_2/NO_3, Fluoride, Sulfide, Metals, BOD-TDS-TSS
Wide-mouth Sludge/Metals bottle.

Safety First

Proper safety precautions must be observed when collecting wastewater samples. Wastewater can contain microbiological disease agents (pathogens), chemical poisons (toxins), and other biological, chemical, and physical components that may cause human health problems or disturb natural aquatic ecosystems. Waterborne pathogens in the sewer collection system are different, and potentially more antibiotic resistant, than decades ago.

Wastewater operators can be exposed to wastewater pathogens and toxins through several pathways:

- respiratory exposure -face shield and masks protect from droplets and aerosols
- dermal exposure -gloves and hand hygiene protect from direct contact
- surface (fomite) exposure - barriers between skin and surfaces protect from wastewater and plant equipment contact

Always check the atmosphere of manholes before sampling or entering.

Refer to Centers for Disease Control and Prevention (CDC) Guidance for Controlling Potential Risks to Workers exposed to Class B Biosolids. DHHS (NIOSH) Publication Number 2002-149. Refer to the SESD* Safety, Health and Environmental Management Program Procedures and Policy Manual and any pertinent site-specific Health and Safety Plans (HASP) for guidelines on safety precautions. These guidelines, however, should only be used to complement the judgment of an experienced professional. Address chemicals that pose specific toxicity or safety concerns and follow any other relevant requirements, as appropriate.

Credit U.S. EPA, Science and Ecosystem Support Division (SESD)

Procedural Precautions

The following precautions should be considered when collecting wastewater samples.

• Special care must be taken not to contaminate samples. This includes storing samples in a secure location to preclude conditions which could alter the properties of the sample. Samples shall be custody sealed during long-term storage or shipment.

• Collected samples are in the custody of the sampler or sample custodian until the samples are relinquished to another party.

• If samples are transported by the sampler, they will remain under his/her custody or be secured until they are relinquished.

• Shipped samples shall conform to all U.S. Department of Transportation (DOT) and/or International Air Transportation Association (IATA) hazardous materials shipping requirements.

• Documentation of field sampling is done in a bound logbook.

• Chain-of-custody documents shall be filled out and remain with the samples until custody is relinquished.

• All shipping documents, such as air bills, bills of lading, etc., shall be retained by the project leader and stored in a secure place.

Special Precautions for Wastewater Sampling

• A clean pair of new, non-powdered, disposable gloves will be worn each time a different location is sampled and the gloves should be donned immediately prior to sampling. The gloves should not come in contact with the media being sampled and should be changed any time during sample collection when their cleanliness is compromised.

• Sample containers for samples suspected of containing high concentrations of contaminants shall be stored separately.

• Sample collection activities shall proceed progressively from the least suspected contaminated area to the most suspected contaminated area. Samples of waste or highly contaminated media must not be placed in the same ice chest as environmental (i.e., containing low contaminant levels) or background/control samples.

• If possible, one member of the field sampling team should take all the notes and photographs, fill out tags, etc., while the other members collect the samples. • Field investigators must use new, verified certified-clean disposable or non-disposable equipment cleaned according to procedures contained in SESD Operating Procedure for Field Equipment Cleaning and Decontamination (SESDPROC-205) for collection of samples for trace metals or organic compound analyses.

Site Selection for Wastewater Sampling

Where applicable, wastewater samples should be collected at the location specified in your NPDES permit (if the source has a permit). In some instances, the sampling location specified in the permit, or the location chosen by the permittee, may not be adequate for the collection of a representative wastewater sample.

In such instances, the investigator is not limited by permit specifications and may collect a sample at a more representative location. When a conflict exists between the permittee and the regulatory agency regarding the most representative sampling location, both sites should be sampled, and the reason for the conflict should be noted in the field notes and the inspection or study report. Recommendations and reasons for a change in sampling locations should be given to the appropriate permitting authority.

Influent Sampling
Influent wastewaters are preferably sampled at locations of highly turbulent flow in order to ensure good mixing; however, in many instances the most desirable location is not accessible. Preferable influent wastewater sampling locations include: 1) the upflow siphon following a comminutor (in absence of grit chamber); 2) the upflow distribution box following pumping from main plant wet well; 3) aerated grit chamber; 4) flume throat; 5) pump wet well when the pump is operating; or 6) downstream of preliminary screening. When possible, influent samples should be collected upstream from sidestream returns.

Effluent Sampling
Effluent samples should be collected at the site specified in the permit, or if no site is specified in the permit, at the most representative site downstream from all entering wastewater streams prior to discharge into the receiving waters. If a conflict exists between the permittee and inspector regarding the source being sampled or the location of the most representative site, follow the procedures and examples described in a few mores pages.

Pond and Lagoon Sampling
Generally, composite effluent wastewater samples should be collected from ponds and lagoons. Even if the ponds or lagoons have long retention times, composite sampling is necessary because ponds and lagoons have the tendency to have flow paths that short circuit, which changes the designed detention time.

Sampling Techniques and Equipment

The wastewater sampling techniques and equipment described in this document are designed to minimize effects on the chemical and physical integrity of the sample. If the procedures in these sections are followed, a representative sample of the wastewater should be obtained.

The variety of conditions at different sampling locations requires that considerable judgment be exercised regarding the methodologies and procedures for the collection of representative samples of wastewater. Each sampling location warrants attention commensurate with its complexity. There are, however, basic rules and precautions generally applicable to sample collection.

Acceptable procedures are generally those outlined in the permit or NPDES Compliance Inspection Manual. Some important considerations for obtaining a representative wastewater sample include:

• The sample should be collected where the wastewater is well mixed. Therefore, the sample should be collected near the center of the flow channel, at approximately 40 to 60 percent of the water depth, where the turbulence is at a maximum and the possibility of solids settling is minimized. Skimming the water surface or dragging the channel bottom should be avoided. However, allowances should be made for fluctuations in water depth due to flow variations.

• In sampling from wide conduits, cross-sectional sampling should be considered. Rhodamine WT dye may be used as an aid in determining the most representative sampling locations.

• If manual compositing is employed, the individual sample portions must be thoroughly mixed before pouring the individual aliquots into the composite container. For manual composite sampling, the individual sample aliquots should be preserved at the time of sample collection.

Sample Handling and Preservation Requirements

1. All sample collection and preservation procedures will comply with the requirements outlined in your permit and/or 40 CFR, Part 136.3 (e), Table II, and Figure 3-1 of the US EPA Region 4 Analytical Support Branch Laboratory Operations and Quality Assurance Manual (ASB LOQAM), Most Recent Version.

2. Wastewater samples will typically be collected either by directly filling the sample container or by using an automatic sampler or other device.

3. During sample collection, if transferring the sample from a collection device, make sure that the device does not come in contact with the sample containers.

4. Place the sample into appropriate, labeled containers. Samples collected for VOC analysis must not have any headspace. All other sample containers must be filled with an allowance for ullage.

5. All samples requiring preservation must be preserved as soon as practically possible, ideally immediately at the time of sample collection. If preserved VOC vials are used, these will be preserved with concentrated hydrochloric acid The adequacy of sample preservation will be checked after the addition of the preservative for all samples, except for the samples collected for VOC analysis. If it is determined that a sample is not adequately preserved, additional preservative should be added to achieve adequate preservation.

6. All samples preserved using a pH adjustment (except VOCs) must be checked, using pH strips, to ensure that they were adequately preserved. This is done by pouring a small volume of sample over the strip. Do not place the strip in the sample. Samples requiring reduced temperature storage should be placed on ice immediately.

Pretreatment Compliance Monitoring

There are two types of sampling activities that are performed as part of your permit and/or compliance monitoring for permitted industries: unscheduled and demand.

Unscheduled sampling is used to determine the compliance status of the user. Instances of noncompliance are often identified during unannounced monitoring visits. No notice is given for this type of sampling. This type of sampling is performed two to four times a year, at each industrial user site, over a two to five-day period to obtain sampling data

Demand sampling is usually initiated in response to a known or suspected violation, discovered as a result of a self-monitoring report, routine sampling visit, public complaint, unusual influent condition at the wastewater treatment plant, or emergency situations (e.g., plant upsets, sewer line blockages, fires, explosions, etc.).

Most often, this type of sampling is conducted to support enforcement actions against an industrial user.

This type of sampling activity is performed on an as needed basis. The length of the sampling program depends on the flow, nature of the wastes, and type of samples (i.e., grab or composite) to be collected. Typically, composite and grab samples are collected at each user site.

Nonpermitted Industrial Users (User Rate Charge Program) Policy Example
On a periodic basis (i.e., once every two to three years), commercial and minor industrial users are sampled to determine discharge concentrations of various pollutants. Typical types of users which may be sampled include: restaurants, photo processing laboratories, laundries, car washes, and printing shops.

A three- to four-day sampling program is usually conducted at each assigned site. Commercial establishments are sampled to establish BOD and SS levels for various groups of users for the POTW's Finance or Utilities Division.

This activity is also helpful in identifying industrial or commercial users which may discharge pollutants of concern.

Wastewater Treatment Plant Sampling Example
POTW samples are collected in accordance with the National Pollutant Discharge Elimination System (NPDES) permit which sets discharge limits for certain pollutants and specifies sampling frequencies and sample types.

The POTW is responsible for coordinating the plant sampling activity with laboratory personnel who prepare any special sampling bottles and laboratory appurtenances necessary (i.e. trip blanks, etc.) to complete the sampling objectives.

Pre-Treatment Monitoring Locations Should:

- be appropriate for waste stream conditions;
- be representative of the discharge;
- have no bypass capabilities; and
- allow for unrestricted access at all times.

Control Authorities should measure flow to allow for collection of flow-proportioned composite samples, which are required, unless flow-proportional sampling is not feasible. Flow-proportional composite samples are preferred over time composite samples particularly where the monitored discharge is intermittent or variable.

Desired analyses dictate the preparation protocols, equipment, and collection bottles to use to avoid contamination of samples or loss of pollutants through improper collection. Sampling for such pollutants as pH, cyanide, oil and grease, flashpoint, and volatile organic compounds require manual collection of grab samples. Similar to composite samples, grab samples must be representative of the monitored discharge and are to be collected from actively flowing wastestreams. Fluctuations in flow or the nature of the discharge may require collection of and hand-compositing of more than one grab sample to accurately access compliance.

To ensure defensibility of data, Control Authorities should develop and implement standard operating procedures and policies detailing sample collection and handling protocols in accordance with 40 CFR Part 136.

Adherence to proper sample collection and handling protocols, 40 CFR Part 136 approved analytical methodologies, and record keeping requirements [40 CFR §403.12(o)(1)] can be verified through review of field measurement records, chain of custodies, and lab reports.

Field measurement records may require information regarding sample location, condition of and programmed settings for sampling equipment, wastewater meter readings, and information for such parameters as pH and temperature which require analysis in the field.

Chain of custody forms serve as a link between field personnel and the laboratory and contain information regarding the sample matrix, type, and handling.

Lab reports should contain the minimum information specified in 40 CFR §403.12(o)(1)(ii-iv) as well as any additional information necessary to demonstrate compliance with 40 CFR Part 136 requirements (e.g., analytical methodology, sample preparation date and time, time of analysis).

Use of standardized forms which prompt recording of information necessary for demonstrating compliance with applicable requirements, will aid in ensuring it can be used as admissible evidence in enforcement proceedings or in judicial actions.

Quality Control Introduction

Equipment blanks should be collected if equipment is field cleaned and re-used on-site or if necessary to document that low-level contaminants were not introduced by the sampling equipment.

Records

Wastewater sampling studies focus primarily on collecting wastewater samples of the influent or effluent at domestic and non-domestic facilities.

Sampling activities are usually conducted for National Pollutant Discharge Elimination System (NPDES) compliance, compliance assistance, civil and criminal investigations, and water quality studies.

Collection of wastewater samples is necessary in order to obtain reliable data that can support your permit's compliance or enforcement activities.

The main considerations in developing a wastewater sampling strategy are:

- Type of study (Compliance Sampling Inspection (CSI), Diagnostic Evaluation (DE), etc.).
- Regulated or target pollutants in the wastewater stream to be sampled.
- Selection of the projected sampling locations to satisfy the study objectives.
- Quality control criteria of the parameters to be sampled (oil and grease samples need to be collected as grab samples, trip blanks are taken into the field for the collection of samples for volatile organic compound analyses, etc.).

Complexity of the sampling program will vary with a number of factors. Some primary factors are:

- The number of sampling stations to be monitored. This will be dependent on NPDES permit requirements and the type of study; for example, Toxic CSIs and DEs require a greater amount of sampling stations than a routine CSI.
- Special handling requirements of the target pollutants (sampling equipment for trace organic compounds require special cleaning procedures, etc.).
- Laboratory conducting the analyses (use of a contract laboratory may require shipping from the field, etc.).
- Accessibility to sampling stations.
- Process and operation criteria of the source generator (e.g., batch operation versus continuous discharge).
- Coordination of participating organizations in the study (e.g., state assistance with the sample collection).
- The length of time for sampling activities will dictate logistical considerations (e.g., shipment of samples, additional supplies, etc.).

Always follow your NPDES permit for proper sampling information.

A normal day for a WWT sampler: She is looking up a flow rate to determine the volume of wastewater that is flowing. Many samplers do not know simple math formulas to determine flow and rely solely upon the electric measuring devices. These measuring devices and auto-samplers can fail or be programmed incorrectly and/or batteries die. Be prepared for the worst case scenarios, unexpected events will happen. Anything can happen from snakes, melted ice, slips and fall hazards, irate customers, and bad air (lack of O_2 or H_2S). Pickle bottle is shown in the middle photograph.

Wastewater Plant Sampling Procedure Example

Set up two-four samplers or equivalent at the plant influent channel and two samplers at the plant effluent channel. Two automatic samplers are used to provide sufficient sample quantity and to minimize sampler failure. All sampling equipment must be prepared and cleaned as established in your permit requirements and/or POTW's procedures. Teflon hose or equivalent is required. Sampling sites are specified in each plants NPDES permit.

Collect the following composite samples at all sites.

(1) Metals Sample - (one 2-liter plastic bottle)

Preserve with 1:1 nitric acid to a pH < 2. Store sample on ice to four degrees Centigrade.

(2) Cyanide Sample - one (2-liter plastic bottle)

Collect the cyanide sample as a composite in accordance with NPDES permit. Check the sample for chlorine. If Cl_2 is present, use ascorbic acid to eliminate chlorine. Add NaOH to a pH > 12. Store samples on ice to four degrees Centigrade.

(3) EPA Test Method 608 and 625 samples are informational samples only. These results are used for local limits data.

608 and 625 samples are collected as composite samples. At the influent channel: Collect one 1-liter amber glass bottle of each sample (608, 625). Check samples for chlorine. At the effluent channel: Collect one 4-liter amber glass bottle of each sample (608, 625). Check samples for chlorine. If Cl_2 is present in the samples, use sodium thiosulfate ($Na_2S_20_3$) to eliminate chlorine. Store samples on ice to four degrees Centigrade.

(4) **625/Phenols** are collected as a grab sample. Collect one 4-liter amber glass bottle at the effluent channel only. Check the sample for chlorine. If Cl_2 is present, use sodium thiosulfate ($Na_2S_20_3$) to eliminate chlorine. Store sample on ice to four degrees Centigrade.

Bio-Solids Sampling Example
Bio-solids (dried activated sludge) samples are collected at POTWs.

Normally, bio-solid samples will be collected from the final storage area for dry sludge. The location of the dried bio-solids may vary based on the individual plants. Sampling frequency will be determined on an as needed basis and to comply with the EPA requirements.

All samples collected are grabs. All samples are collected using a sterile plastic scoop or equivalent in order to avoid any contamination.

The following is a list of samples that are normally collected:

PARAMETER	CONTAINER
Helminth Ova & Enteric Virus	1 Qt. Plastic Bag
Metals +	500 ml Plastic Bottle
Nitrogen (total)	4 oz. Glass Bottle
TOC (Total Organic Carbon)	4 oz. Glass Bottle
Fecal Coliform	(autoclaved from lab)
6 hrs. hold time	500 ml Plastic Bottle

Sample Scheduling Example
An active file is maintained on each sampling location which contains historical data, including past process discharge flow readings, water meter readings, sampling dates, and conditions of sampling site.

Treated Wastewater Effluent River Sampling Activities Example
When developing a sampling plan for river sampling, the following considerations must be observed:

(1) Sampling sites must meet the objectives of your permit requirements and/or program or study.
(2) At the sampling sites the river must be flowing freely and the sample must be as representative as possible of river flow at that site. Consideration of all safety factors must be observed.
(3) Samples must be collected at midstream of the main channel at approximately two-thirds of the depth unless specific depths have been requested.
(4) All safety precautions must be observed during sampling which includes the use of harnesses, waterproof boots and other equipment.

Samples from Sewers *Example*
Sewer system and user rate sampling are conducted in manholes. General guidelines for selection of sampling locations include the following:

(1) Samples should be taken at points of high turbulent flow to ensure good mixing and prevent the deposition of solids.
(2) The sample location should be easily accessible and free of any major safety hazards.
(3) Sample lines should not be located where there is surface scum.
(4) If a flow study or a flow/proportional sampling event is required, make sure that the sewer pipe does not have a curve, a drop in the line or any obstructions. These would cause false readings.

Hand Compositing Example

Hand compositing is a series of time proportional grab samples which are collected and composited by hand. Provided the sample volumes are equal and are collected at even intervals, the results should be the same as if done by an automatic sampler (i.e., flow proportional composite sampling).

A specific instance where this sampling method may be used is in metal plating shops which have batch discharges from the treatment tank. Provided the tank contains a homogeneous mixture, a minimum of four grab samples are taken of equal amounts and at evenly spaced intervals of time during discharge, to accurately represent the entire tank.

This should represent the waste characteristics of the entire batch discharge to the sewer. One hand composite per batch discharge would be equivalent to a 24-hour composite sample taken at other types of facilities. The sampling data would be compared with the average daily categorical standards or local limits where applicable.

Parshall Fume and Ultrasonic Flow Meter. Here is a great short-cut if you do not have a stand for your ultrasonic probe, simply use a reflective street cone to hold your probe. Notice the debris and most POTW's will write a NOV for not maintaining the flume and/or uncleanness.

SAMPLING PLAN

Prior to laboratory analysis a sampling plan should consider the following:

1. Why is the sample being collected?
2. What tests need to be performed?
3. At what location will the sample be taken?
4. Will the sample be analyzed at the location?
5. When and how often must the sample be analyzed?
6. Is it a grab or composite sample?
7. Is it for process control or compliance?

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Grab Samples (Snapshot)
A grab sample consists of a single container or large bucket of wastewater analyzed at one specific time. Grab samples indicate the condition of the wastewater at that specific time and may or may not represent the normal conditions. Grab samples are required when the analysis change rapidly. For instance, grab samples are required for certain tests such as temperature, pH, D.O. (dissolved oxygen), and bacteriological analysis.

Composite Samples
A composite sample consists of several grab samples collected from the same spot over a specific period of time and merged into a single sample. A composite sample is more arduous, complicated and usually inconvenient than a simple grab sample. Collecting a sample every few minutes and adding it to a single bottle is tedious, boring, and costly. To help solve this problem, a 24-hour automatic sampler is often used. The automatic sampler consists of a battery pack, a programmable timer, a pump, and as many as 24 bottles.

The automatic sampler has the capability to be programmed to draw a certain volume of sample every few minutes and deposit each sample into one bottles that are preserved or refrigerated. At the end of the sampling period, the operator can retrieve the bottles, bring them back to the lab and create a single composite sample. Analysis can now be performed on a single composite sample that is more representative of the wastewater quality than a grab sample.

Unweighted Composite
An unweighted composite collects the same sample volume at a constant time interval. For example, the operator collects 100 ml every hour for 6 hours. At the end of the time period, there will be 12 individual bottles representing the wastewater quality over the 6 hour time period. The operator now composites the samples by pouring from each bottle into a large bottle and mixes the composite.

Flow Weighted Composite
A flow meter is connected to the composite sampler and the sampler is programed to draw at different flow intervals. As the flow increases so does the number of samples.

Proper Sample Handling Introduction

The proper handling of water quality samples also includes wearing gloves. Gloves not only protect field personnel, but also prevent potential contamination to the water sample. Always wear powderless, disposable gloves. When sampling for inorganics, wear latex gloves. Nitrile gloves are appropriate for organics.

The following sections provide a field reference for chain of custody procedures, sampling surface water and ground water, and further provides procedures for measuring field parameters and handling water-quality samples.

Use chain-of-custody procedures when coolers and containers are prepared, sealed and shipped. They will remain sealed until used in the field.

When making arrangements with the laboratory, make sure you request enough containers, including those for blank and duplicate samples. Order extra sample bottles to allow for breakage or contamination in the field.

Some samples require low-temperature storage and/or preservation with chemicals to maintain their integrity during shipment and before analysis in the laboratory. The most common preservatives are hydrochloric, nitric, sulfuric and ascorbic acids, sodium hydroxide, sodium thiosulfate, and biocides.

Many laboratories provide pre-preserved bottles filled with measured amounts of preservatives. Although most federal and state agencies allow the use of pre-preserved sample containers, some may require either cool temperatures or added preservatives in the field.

When the containers and preservatives are received from the laboratory, check to see that none have leaked. Be aware that many preservatives can burn eyes and skin, and must be handled carefully. Sampling bottles should be labeled with type of preservative used, type of analysis to be done and be accompanied by a Safety Data Sheet (SDS).

Make sure you can tell which containers are pre-preserved, because extra care must be taken not to overfill them when collecting samples in the field. Check with the laboratory about quality control procedures when using pre-preserved bottles.

Coolers used for sample shipment must be large enough to store containers, packing materials and ice. Obtain extra coolers, if necessary. Never store coolers and containers near solvents, fuels or other sources of contamination or combustion. In warm weather, keep coolers and samples in the shade.

Field Parameters
Measure and record the field parameters of temperature, electrical conductivity, pH and dissolved oxygen in an undisturbed section of stream flow. Other parameters may be measured, if desired.

Sample Station commonly found at most water or wastewater treatment plants. This tap will allow the operator to obtain grab samples for pH, Temperature, COD, Bacterial, ORP, OUP, Organic and Inorganic field parameters for local limits or process sampling.

CONCENTRATION OF HYDROGEN IONS COMPARED TO DISTILLED H2O				EXAMPLES OF SOLUTIONS AND THEIR RESPECTIVE pH
	1/10,000,000	14	LIQUID DRAIN CLEANER CAUSTIC SODA	
	1/1,000,000	13	BLEACHES OVEN CLEANERS	
	1/100,000	12	SOAPY WATER	
	1/10,000	11	HOUSEHOLD AMMONIA (11.9)	
	1/1,000	10	MILK OF MAGNESIUM (10.5)	
	1/100	9	TOOTHPASTE (9.9)	
	1/10	8	BAKING SODA (8.4) / SEA WATER EGGS	
	0	7	"PURE" WATER (7)	
	10	6	URINE (6) / MILK (6.6)	
	100	5	ACID RAIN (5.6) BLACK COFFEE (5)	
	1000	4	TOMATO JUICE (4.1)	
	10,000	3	GRAPEFRUIT & ORANGE JUICE SOFT DRINK	
	100,000	2	LEMON JUICE (2.3) VINEGAR (2.9)	
	1,000,000	1	HYDROCHLORIC ACID SECRETED FROM STOMACH LINING (1)	
	10,000,000	0	BATTERY ACID	

pH Scale

Automatic Samplers Introduction

General

Automatic samplers may be used to collect composite or grab samples when several aliquots are to be collected at frequent intervals or when a continuous sample is required. For composite sampling applications, the automatic samplers may be used to collect time composite or flow proportional samples. In the flow proportional mode, the samplers are activated and paced by a compatible flow meter.

Flow proportional samples can also be collected using an automatic sampler equipped with multiple containers and manually compositing the individual sample portions proportional to the flow.

Automatic samplers must meet the following requirements:

• Sampling equipment must be properly cleaned to avoid cross-contamination which could result from prior use.

• No plastic or metal parts of the sampler shall come in contact with the water or wastewater stream when parameters to be analyzed could be impacted by these materials.

• The automatic sampler must be capable of providing adequate refrigeration during the sampling period. This can be accomplished in the field by using ice.

• The automatic sampler must be able to collect a large enough sample for all parameter analyses.

• The individual sample aliquot must be at least 100 mL if the sampler uses a peristaltic pump.

• The automatic sampler should be capable of providing a lift of at least 20 feet and the sample volume should be adjustable since the volume is a function of the pumping head.

• The pumping velocity must be at least two (2) ft. /sec to transport solids and not allow solids to settle.

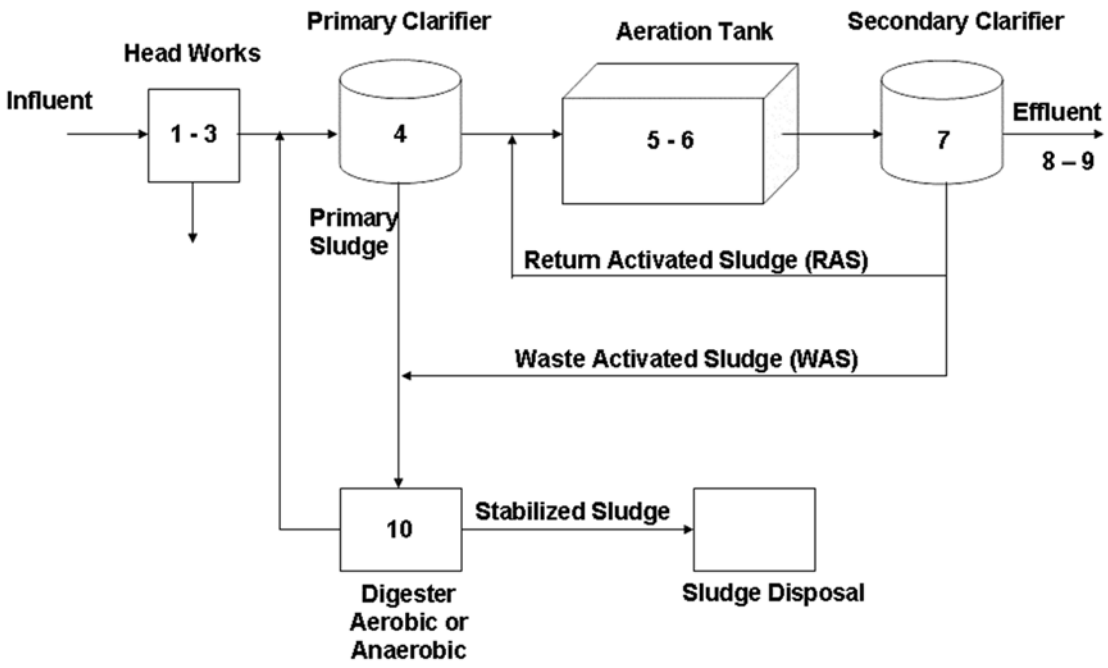
• The intake line leading to the pump must be purged before each sample is collected.

• The minimum inside diameter of the intake line should be 1/4 inch.

• An adequate power source should be available to operate the sampler for the time required to complete the project. Facility electrical outlets may be used if available.

• Facility automatic samplers should only be used if 1) field conditions do not allow for the installation of sampling equipment, and 2) the facility sampling equipment meets all of the requirements detailed above. Specific operating instructions, capabilities, capacities, and other pertinent information for automatic samplers should be included in your POTW's respective operating manuals.

The refrigerated automatic WWT sampler will have a data programmer that will allow you to set the time to collect the sample or samples. This machine can also measure the amount of the sample. These can devices also be used for the collection of composite samples. Sometimes you will see a pH probe with real-time readings sent to the Operator's Command Center or cell phone. These are a common sight at most wastewater plants and SIUs.



Depending upon the process control (compliance and non-compliance sampling requirements) and Local Limits requirements. There can be grab and composite samples taken at each of the above locations including sludge disposal. Sampling may be hourly, daily, 24-48 hour composites.

Automatic Sampler Security

Field investigators should take whatever steps are necessary to prevent tampering with POTW equipment. A lock or custody seal may be placed on the sampler to detect tampering. However, this does not prevent tampering with the sample collection tubing. If necessary, seals may be placed on the sampling pole and tubing line to further reduce tampering possibilities.

Automatic Sampler Maintenance, Calibration and Quality Control

To ensure proper operation of automatic samplers, and thus the collection of representative samples, the following maintenance and calibration procedures should be used and any deviations should be documented in the field logbook.

Prior to being used, the sampler operation should be checked by the field investigator or Field Equipment Center personnel to ensure proper operation. This includes operation (forward, reverse, and automatic) of at least one purge-pump-purge cycle; checking desiccant and replacing if necessary; checking the 12-volt batteries to be used with the sampler; and repairing any item if necessary.

During each field trip, prior to initiating the automatic sampler, the rinse and purge pump-purge cycle shall be checked at least once.

The pumping volume should be checked at least twice using a graduated cylinder or other calibrated container prior to initiating the sampler. For flow proportional sampling, the flow meter that activates the sampler should be checked to ensure that it operates properly.

Upon returning from a field trip, the structural integrity of the sampler should be examined and repaired, if necessary.

The desiccant will be checked and replaced if appropriate. The operation (forward, reverse, automatic, etc.) will be checked and required repairs will be made and documented. The sampler will then be cleaned as outlined in SESD Operating Procedures for Field Equipment Cleaning and Decontamination (SESDPROC-205).

The automatic sampler should be checked against the manufacturer's specifications and documented whenever one or more of the sampler functions appear to be operating improperly.
Manual Sampling

Manual sampling is normally used for collecting grab samples and/or for immediate insitu field analyses. However, it can also be used in lieu of automatic equipment over extended periods of time for composite sampling, especially when it is necessary to evaluate unusual waste stream conditions.

The best method to manually collect a sample is to use the actual sample container which will be used to transport the sample to the laboratory. This eliminates the possibility of contaminating the sample with intermediate collection containers.

If the water or wastewater stream cannot be physically reached by the sampling personnel or it is not safe to reach for the sample, an intermediate collection container may be used, from which the sample can be redistributed to other containers.

If this is done, however, the container used to collect the sample must be properly cleaned according your Field Equipment Cleaning and Decontamination policy) and must be made of a material that meets the requirements of the parameter(s) being investigated.

Samples for oil and grease, bacteria, and most volatile compounds (both organic and inorganic) must always be collected directly into the sample container.

In some cases, it may be best to use a pump, either power or hand operated, to withdraw a sample from the water or wastewater stream. If a pump is used, it is imperative that all components of the pump that come in contact with the sample are properly cleaned according to your POTW’s permit or Operating Procedure for Field Equipment Cleaning and Decontamination policy to ensure the integrity of the sample.

In general, samples are manually collected by first selecting a location in the wastestream that is well mixed then dipping the container in the water or wastewater stream so the mouth of the container faces upstream. The container should not be overfilled if preservatives are present in the container.

Field Equipment Blanks Procedure Example

The purpose of Field Equipment Blanks are to test the procedure for cleaning the sample measuring container to determine if cross contamination between sample sites has occurred. These Blanks are needed only at sites where flow-proportion samples are taken. Follow these steps when collecting a Field Equipment Blank:

1. Collect Field Equipment Blank **AFTER** collecting a sample and **BEFORE** moving to the next sampling location.
2. After collecting sample, triple rinse sample measuring container, usually a graduated cylinder, using High Purity water.
3. Open a sealed bottle of High Purity Water.
4. Pour the High Purity Water into the sample measuring container that was just rinsed.
5. Pour the High Purity water from sample measuring device into sample bottles labeled for the Field Equipment Blanks.
6. Repeat Steps 3 through 5 until all Field Equipment Blank sample bottles have been filled.
7. Process samples using standard procedures and submit to laboratory.

An equipment blank is high purity water which has been collected in a composite sample bottle or a series of discrete bottles from an automatic sampler. Equipment blanks are used to evaluate the reliability of composite samples collected in the field.

The data produced from the equipment blank indicates the performance of the sample collection system, which involves the cleaning of sampling equipment, and accessories, preservation techniques, and handling of samples.

The objective is to demonstrate that the samples are not contaminated by inadequate cleaning of equipment, contaminated preservation additives or sample collection techniques, and to provide documented records on Quality Assurance Practices.

Procedures to be followed in collecting the equipment blanks are outlined below.
(Also see QA/QC check list, example).

(1) The sampler is to be assembled completely in the manner determined by the parameters the crew will be sampling (i.e. if sampling for organics, Teflon suction tubing must be used at that site). The composite jar inside the sampler must always be rinsed out thoroughly with high purity water.

(2) Program the sampler to collect the proper amount of high purity water that is representative of the sample parameters that will be collected at that site. Grab samples are excluded. Pump high purity water through the strainer and intake tubing prior to filling the sampler bottle. Then, place the strainer into as many fresh, uncontaminated bottles of high purity water as needed to collect the necessary volume of sample.

(3) If the sampler is set up in the discrete mode, the crew must then transfer the collected samples into the field composite bottle and shake to mix thoroughly.

(4) Transfer the sample from the field composite bottle into its respective lab sample bottles. Test and preserve the samples as appropriate for the parameters being analyzed.

(5) Follow the chain of custody procedures outlined in SOP for turning the samples in to the laboratory. All paperwork must be completed at this time, and all bottles must be marked accordingly. Custody seals must be used. The crew must note the sampling activity in a logbook that is kept specifically for documenting preparation of equipment blanks and/or any other QA activities.

Wastewater Sampling Procedures/Techniques Example

General Guidelines
In general, the following guidelines should be observed in conducting sampling activities:

(1) Samples being collected must be representative of the wastestream being tested.
(2) Samples shall be collected in uncontaminated containers and preserved properly.
(3) Samples should be of sufficient volume for the required analyses.
(4) Samples should be stored in a manner which does not alter the properties of the sample prior to chain of custody transfer.
(5) Samples should be properly and completely identified by marking them with the proper information.

(6) Sample lines should be as short as possible and the smallest practical diameter to facilitate purging, reduce lag time, and give adequate consideration to maximum transport velocity. Also, they should have sufficient strength to prevent structural failure.
(7) Sample lines should be pitched downward at least 10 percent to prevent settling or separation of solids contained by the sample.
(8) Samples should be delivered as quickly as possible to the laboratory.

Specific Techniques
Sampling techniques in addition to the above general guidelines must also recognize differences in sampling methodology, preservation, and analytical methods.

The following sections specify techniques that differ by pollutant group and discuss such factors as sampling methodology (e.g., composite, grab, etc.), type of container, preservation and holding time.

Always follow your NPDES permit for proper sampling information.

Special Sample Collection Procedures

Organic Compounds and Metals
Trace organic compounds and metals detection limits are usually in the parts per billion or parts per trillion ranges, so extreme care must be exercised to ensure sample integrity. All containers, composite bottles, tubing, etc., used for sample collection for trace organic compounds and metals analyses should be prepared as described in your POTW's Standard Operating Procedure for Field Equipment Cleaning and Decontamination policy.

When possible, the sample should be collected directly into the appropriate sample container. If the material to be sampled cannot be physically reached, an intermediate collection device may be used. This should be a Teflon®, glass or stainless steel (for non-metals only) vessel on a pole or rope, or Teflon® tubing via a peristaltic type pump and a Teflon® vacuum container attachment, which converts a sample container into a vacuum container.

Sample collection for trace-level mercury analysis will be conducted in accordance on EPA Method 1669.

Bacteriological
Samples for bacteriological analyses must always be collected directly into the prepared glass or plastic sample container. The sample container should be kept unopened until it is to be filled.

When the cap is removed, care should be taken not to contaminate the cap or the inside of the bottle. The bottle should be held near the base and filled to within about one inch of the top without rinsing and recapped immediately. During sample collection, the sample container should be plunged with the neck partially below the surface and slightly upward. The mouth should be directed against the current.

When the sample container must be lowered into the waste stream, either because of safety or impracticality (manhole, slippery effluent area, etc.), care must be taken to avoid contamination.

Immiscible Liquids/Oil and Grease
Oil and grease may be present in wastewater as a surface film, an emulsion, a solution or as a combination of these forms.

Since it is very difficult to collect a representative sample for oil and grease analysis, the inspector must carefully evaluate the location of the sampling location. The most desirable sampling location is the area of greatest mixing.

Quiescent areas should be avoided. The sample container should be plunged into the wastewater using a swooping motion with the mouth facing upstream. Care should be taken to ensure that the bottle does not over fill during sample collection.

Because losses of oil and grease will occur on sampling equipment, an automatic sampler should not be used to collect samples for oil and grease analysis. Individual portions collected at prescribed time intervals must be analyzed separately to obtain the average concentrations over an extended period.

Volatile Organic Compounds

Samples to be analyzed for volatile organic compounds (VOCs) should be collected in 40-mL septum vials with screw caps with a Teflon® -lined silicone disk (septum) in the cap to prevent contamination of the sample by the cap. Samples for VOC analysis must be collected using either stainless steel or Teflon® equipment.

When sampling for VOCs, triplicate samples should always be collected from each location. The investigator should determine if the water to be sampled contains chlorine. If the water contains no chlorine, three pre-preserved 40-ml vials should be filled with the sample. The samples may be held for up to 14 days before analysis.

When preservation is not feasible, samples can be held up to seven (7) days before analysis. In the great majority of cases, the preserved vials are used to take advantage of the extended holding time.

In some situations, however, it may be necessary to use the unpreserved vials. For example, if the wastewater sample contains a high concentration of dissolved calcium carbonate, there may be an effervescent reaction between the hydrochloric acid and the water, producing large numbers of fine bubbles. This will render the sample unacceptable. In this case, unpreserved vials should be used and arrangements must be confirmed with the laboratory to ensure that they can accept the unpreserved vials and meet the shorter sample holding times.

If the water contains chlorine, collect the sample in an 8-ounce sampling container with two (2) drops of a 25% ascorbic acid solution (the jar with acid should be obtained from the SESD laboratory prior to sample collection).

Cap and mix thoroughly but gently by swirling to eliminate residual chlorine. Transfer the sample to three pre-preserved 40-ml vials. The ascorbic acid and preservative must be added in this order and in two separate steps.

The 40-mL vials should be completely filled to prevent volatilization, and extreme caution should be exercised when filling each vial to prevent any turbulence which could also produce volatilization. The sample should be carefully poured down the side of the vial to minimize turbulence.

As a rule, it is best to gently pour the last few drops into the vial so that surface tension holds the water in a "convex meniscus." The cap is then applied and some overflow is lost, but air space in the bottle is eliminated.

After capping, turn the bottle over and tap it to check for bubbles. If a bubble or bubbles are present, the vial should be topped off using a minimal amount of sample to re-establish the meniscus.

Care should be taken not to flush any preservative out of the vial during topping off. If, after topping off and capping the vial, bubbles are still present, a new vial should be obtained and the sample re-collected.

Special Process Control Samples and Tests

During diagnostic evaluations, process control tests may be conducted to evaluate and troubleshoot the performance of the biological treatment processes of a municipal or industrial wastewater treatment facility.

The EPA Activated Sludge Process Control Manual is the standard reference used by most inspectors for activated sludge process control testing. The manual includes a complete description of the step-by-step procedures for each test and the interpretation of the results.

The six basic activated sludge process control tests are:

- Sludge settleability (settlometer)
- Centrifuge spins
- Aeration basin Dissolved Oxygen (DO) profiles
- Oxygen uptake rate (OUR) measurements
- Mixed liquor microscopic examinations
- Sludge blanket depth (SBD) measurements

Additional references are available that provide a more comprehensive evaluation of the methods used to conduct a diagnostic evaluation.

Supplementary Data Collection

While conducting wastewater sampling, the following information will be obtained, if applicable:

- Field measurements -- pH, dissolved oxygen, total residual chlorine, conductivity and temperature.

- Flows associated with the samples collected -- continuous flows with composite samples and instantaneous flows with grab samples.

- Photographs of pertinent wastewater associated equipment, such as flow measuring devices, treatment units, etc. (keep photolog as specified in your POTW's Operating Procedure for Logbooks policy.

- Global Positioning System (GPS) data point of the location sampled.

- Diagrams and/or written descriptions of the wastewater treatment systems (if available).

- Process control information on the wastewater treatment process (if applicable).

- Completion of applicable forms required during specific investigations.

All observations, measurements, diagrams, etc., will be entered in bound field logbooks or as specified in your POTW's Operating Procedure for Logbooks policy.

Oil and Grease/TPH Example

EPA Method 1664A–Extraction of Oil and Grease from Water Samples Using Solid-Phase Extraction (SPE) Disk Configuration

Oil and Grease Disc Configuration Method
Acidify each 1L sample to pH < 2 using 6 M of HCl.

Place required number of samples (1–6) in the sample vial rack. Insert sample lines into each sample bottle. Collection Label the collection vials (1–6) and place these into the collection rack. Position the solvent bottles on the left side of the Dionex AutoTrace instrument.

Solvents Add methanol to solvent bottle 1, water (pH 2) to solvent bottle 2, hexane/THF (1:1) to solvent bottle 3, hexane to solvent bottle 4, and water to solvent bottle 5.

Place these solvent bottles to the left side of the Dionex AutoTrace instrument and insert the solvent lines into the corresponding bottle (up to five different solvents can be used with the Dionex AutoTrace instrument).

SPE Media Insert SPE disks onto the Dionex AutoTrace instrument (see Dionex (now part of Thermo Scientific) AutoTrace 280 Operation Manual for details1) and secure the disk into place using the disk holder. The green LED will be illuminated when the disk is locking into place.

BOD/COD/SS Example

(1) 24-hour composite sampling is always used for this test. Agitate the bottle to completely mix the composite sample. Do not allow the solids to settle out before you pour off the sample.

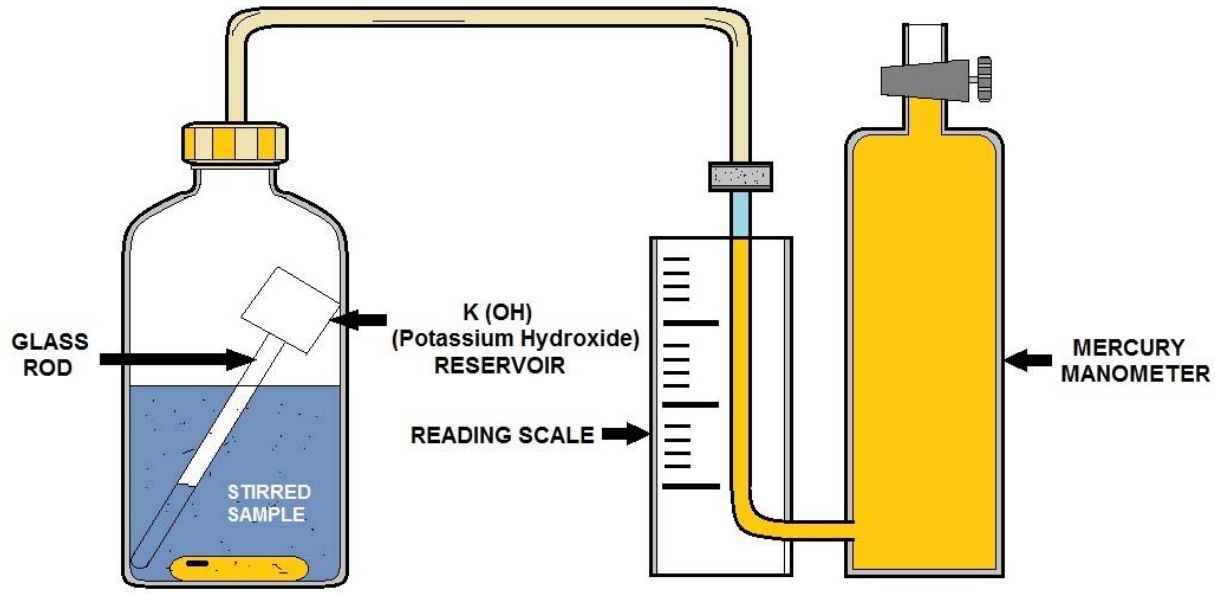
(2) When more than one sample is being taken from a composite bottle, the BOD/COD/SS is taken first. The lab needs 1000 ml if the sample is cloudy or has solids. If the sample is clear, you must collect 2000 ml. Transfer the appropriate volume to the sample bottle.

(3) Take the pH/temperature of the sample with either pH paper and a thermometer, or the pH meter carried on the sampling trucks.

(4) Label the sample bottle and place a custody seal over the lid. Store on ice at four degrees centigrade.

(5) Should split samples be requested, they are given when it is sure there is enough sample for POTW's requirements. Users must provide their own sample containers and allow POTW's staff to pour off samples.

Sequence Batch Reactor
Aeration sequence for an SBR.



MANOMETRIC DEVICE TO ESTIMATE BOD OF WASTEWATER

Older method of testing BOD. Most of us use electronic dissolved oxygen probes to measure the DO in the BOD bottles. These probes usually calibrate to an air setting rather than DO saturated water. If your probe is an air calibration type, calibrate to the barometric pressure in your lab rather than to 760 mm (sea level) or to a calculated air pressure based on your topographic elevation (which is commonly done). Air pressure often changes daily and sometimes hourly. Most likely the air pressure is not the same the day of a BOD setup and five days later when the BODs are read again. This will be important when measuring the BOD blank. Since the DO change of the blank should not exceed 0.2 mg/L, you can see where calibration accuracy would aid in validating the analysis.

Bubbles in a BOD bottle also invalidate that bottle's DO measurement. Algae in a BOD sample and left out on a lab bench exposed to sunlight can be a source of bubbles. Always put the BOD bottle in a dark incubator soon after the initial DO is measured and the bottle sealed. But a more common source of bubbles is from dirty glassware. Even though we should try to fill BOD bottles with sample and dilution water as bubble free as possible, there seems to always be tiny bubbles generated. If the glassware is not thoroughly cleaned, then the bubbles stick to the side of the glass and will eventually collect near the bottle's seal during the five-day incubation period.

Conventional Sampling (Inorganic Parameters)

Conventional sampling includes all inorganic parameters (e.g., BOD5, TSS, COD, nutrients) that can be collected using an automatic sampler.

New tubing (Silastic ®, or equal, in the pump and either Teflon ® or Tygon ®, or equal, in the sample train) will be used for each sampler installation.

Installation procedures for installing tubing on a sampler include cutting the proper length of tubing, positioning it in the wastewater stream, and sampler programming. Protective gloves should be worn to reduce exposure and to maintain the integrity of the sample.

For a time-composite sample, the sampler should be programmed to collect sufficiently sized aliquots (at least 100-milliliter if using a peristaltic pump) at a frequency that provides a representative sample and enough sample volume to conduct all required analyses.

For a flow proportional sample, the sampler should be programmed to collect a minimum of 100 - milliliters for each sample aliquot with the interval predetermined based on the flow of the monitored stream.

At the end of the compositing period, the sample collected should be properly mixed and transferred into the respective containers, followed by immediate preservation, if required. For routine inspections, the permittee should be offered a split sample.

Metals

When an automatic sampler is used for collecting samples for metals analyses, the entire sample collection system is rinsed with organic-free water and an equipment rinse blank is collected. The equipment rinse blank is taken to ensure that metals contamination is not occurring from the sampling equipment, and to check the effectiveness of the decontamination procedures.

To collect an equipment rinse blank approximately one-half gallon of rinse water should be pumped through the sample tubing into the composite container and discarded.

After the purge, another one-half gallon of rinse water is pumped through the sample tubing, into the composite container, and collected as an equipment rinse blank.

Once the equipment rinse blank sample is collected, it must be properly preserved with Nitric acid. The automatic sampler may then be positioned in the appropriate location and the sampler program initiated.

If the automatic sampler tubing is attached to a metal conduit pipe, the intake tubing should be carefully installed upstream and away from the conduit to prevent metals contamination. This can be accomplished by clamping the tubing upstream of the conduit using laboratory clamps and wrapping the submerged portion of conduit pipe with a protective barrier (e.g., duct tape).

Always follow your NPDES permit for proper sampling information.

Extractable Organic Compounds, Pesticides and PCBs
When an automatic sampler is used for collecting samples for the analyses of extractable organic compounds, pesticides and/or PCBs, the installation procedures include cutting the proper length of new Teflon7 tubing, rinsing of the entire sampler collection system with organic-free water and collection of appropriate equipment blanks for organic compounds analysis.

For the organic-free water rinse, approximately one-half gallons is initially pumped into the composite sample container and discarded.

An additional one and one-half gallons (approximate) are then pumped into the composite sample container for distribution into the appropriate blank container. Finally, the collection tubing should be positioned in the wastewater stream and the sampler programmed and initiated.

Parasitological Sampling
Parasitological sampling utilizes the same equipment and techniques as in the virus sampling described above. However, a different type of filter, which is provided by the Lab, is used.

Field Tests *Example*

Sampling Procedures for Hexavalent Chromium (Hach Kit)

(1) Rinse out the two color viewing tubes with a portion of the sample to be tested.
(2) Refill one of the color viewing tubes to the 5 ml mark with a sample (this is the test sample). Using the clippers provided in the test kit, open one ChromaVer three chromium reagent powder pillow. Add the contents of the pillow to the sample. Stopper and shake to mix and put the tube in the color comparator.
(3) Fill the other viewing tube with a sample and put it in the left side of the color comparator (this is the blank).
(4) Let the viewing tubes sit in the color comparator for approximately 5 minutes. The samples should not be exposed to direct sunlight.
(5) Hold the color comparator up to a light source and view the two samples through the two openings in the front. Rotate the dial on the holder until the color appears the same in both samples. Record the results from the dial (which is read in mg/l Cr +6) onto the chain of custody form.

Sampling Techniques for Dissolved Sulfides (Chemetrics, Inc. Kit)

(1) Collect a 25 ml grab sample in the container provided.
(2) Add three drops of activator (amber colored liquid) and mix well.
(3) Break a sulfide chemet Type S glass ampule and add the contents to the 25 ml container.
(4) Let stand five minutes.
(5) Take a reading and record the results on the chain of custody form. If the reading is 0.0 then show the results less than 0.1 mg/l.

Sampling Techniques for Free and Total Chlorine (older colorwheel Hach Kit)

Procedures for determining free chlorine are as follows.

(1) Rinse out the two color viewing tubes with a portion of the sample to be tested.
(2) Refill one of the color viewing tubes to the 5 ml mark with a sample (this is the test sample). Using the clippers provided in the test kit, open one DPD free chlorine reagent powder pillow. Add the contents of the pillow to the sample. Stopper and shake to mix and put the tube in the color comparator. All of the powder does not have to dissolve to obtain correct readings.
(3) Fill the other viewing tube with the original sample and put it in the left side of the color comparator (this is the blank).
(4) Let the viewing tubes sit in the color comparator for approximately 1 minute. The samples should not be exposed to direct sunlight.
(5) Hold the color comparator up to a light source and view the two samples through the two openings in the front. Rotate the dial on the holder until the color appears the same in both samples. Record the results from the dial (which is read in mg/l free chlorine) onto the chain of custody form.

Procedures for determining total chlorine are as follows.

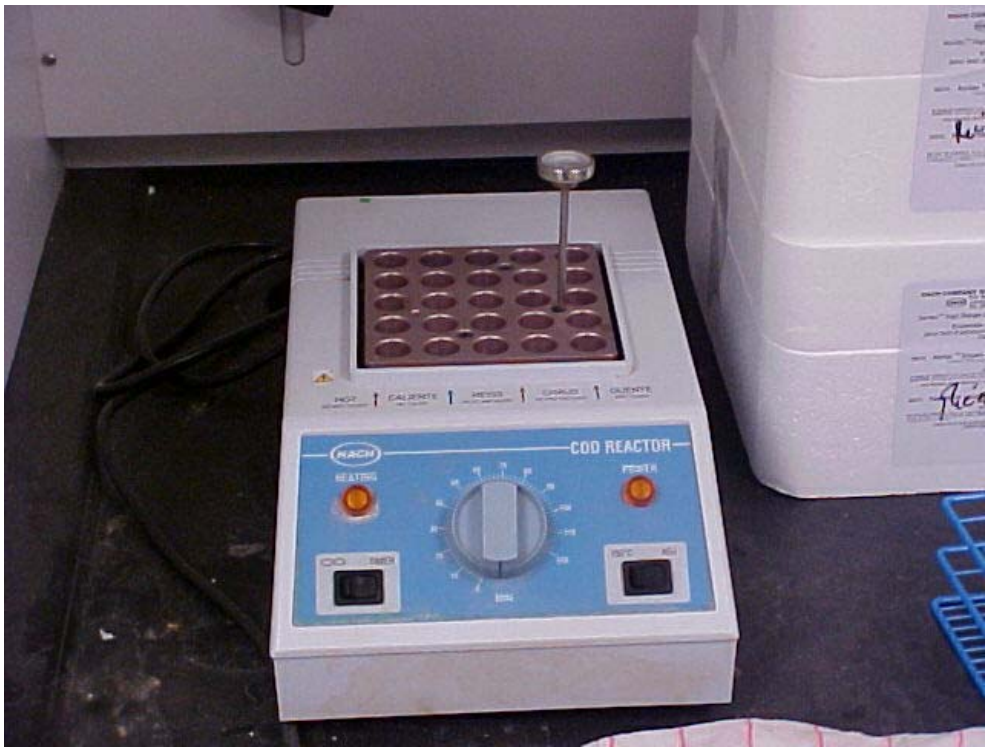
(1) Rinse out the two color viewing tubes with a portion of the sample to be tested.

(2) Refill one of the color viewing tubes to the 5 ml mark with a sample (this is the test sample). Using the clippers provided in the test kit, open one DPD total chlorine reagent powder pillow. Add the contents of the pillow to the sample. Stopper and shake to mix and put the tube in the color comparator. All of the powder does not have to dissolve to obtain correct readings.

(3) Fill the other viewing tube with a sample and put it in the left side of the color comparator (this is the blank).

(4) Let the viewing tubes sit in the color comparator for approximately 3 minutes. The samples should not be exposed to direct sunlight.

(5) Hold the color comparator up to a light source and view the two samples through the two openings in the front. Rotate the dial on the holder until the color appears the same in both samples. Record the results from the dial (which is read in mg/l total chlorine) onto the chain of custody form.



COD Reactor

Pretreatment Key Terms

As Sampler, it is best to know the reason why you need to take samples. Most samples are for process control, while others are for Local Limits or other regulatory purposes. The EPA information is to satisfy the regulatory portion of your training. Credit to the USEPA for this information.

PRETREATMENT OBJECTIVES

The **Pretreatment Program** is to control the pollutants discharged into sewer systems and to **reduce the amount of pollutants released into the environment**. Most POTWs are designed to treat sanitary (domestic) wastes from households, but not to treat toxic pollutants from industrial or commercial facilities. The toxic pollutants from industrial and commercial facilities may cause serious problems at POTWs. These problems may be prevented by recycling, waste minimization, chemical substitution, pretreatment, or other best management practices to reduce or eliminate the pollutants from commercial or industrial facilities.

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CATEGORICAL STANDARDS

Categorical standards are technology-based limitations on pollutant discharges to POTWs, which have been promulgated by U.S. EPA in accordance with Section 307 of the Clean Water Act, and apply to specific process wastewater discharges for thirty-two (32) different industrial categories. (Categorical standards can be found in 40 CFR Parts 405-471.) Categorical standards are similar to federal effluent guidelines (FEGs), with two important distinctions:

- **categorical standards** apply to indirect discharges while FEGs apply only to direct discharges to surface waters; and
- **categorical standards** are developed with the assumption that the POTW will remove at least small amounts of a pollutant, therefore the categorical standard for the pollutant will be less stringent than the corresponding best available technology (BAT) limits for the FEG applied to a direct discharger

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INDUSTRIAL USERS

Industrial users: non-domestic sources of wastewater with discharges large enough to potentially affect a POTW

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LOCAL LIMITS

Delegated POTWs must control SIUs individually and not impose limits on them that may allow violations of the general or specific prohibitions. The POTW generally should impose required local limits (limits imposed by POTW to prevent interference or pass-through) for all SIUs, and is required to when interference or pass-through has occurred and may reoccur. A POTW also must evaluate **local limits** if an SIU causes interference or pass-through without violating a **local limit**. In addition to required local limits, a POTW may set other local limits not required by pretreatment rules. The State can enforce required local limits, but cannot enforce the non-required limits.

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CONVENTIONAL POLLUTANTS

POTWs are designed to treat typical household wastes and biodegradable commercial and biodegradable industrial wastes. The Clean Water Act defines the contaminants from these sources as **conventional pollutants**. **Conventional pollutants** are biological oxygen demand (BOD), total suspended solids (TSS), fecal coliform, oil and grease, and pH**.**

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INTERFERENCE

Interference: a discharge from an industrial user that, alone or in conjunction with other sources a) inhibits or disrupts a POTW plant, its treatment processes or operations, or its sludge processes, use, or disposal, and b) therefore causes a violation including increasing a violation's magnitude or duration of any permit or rule that controls release of pollutants from the POTW.

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Sampling of the entire A/S process including the biosolids and dried sludge is essential component of the plant process control, including compliance, non-compliance sampling and Local Limits. In the ideal world, we would prefer domestic wastewater; however, we need to deal with upsets and contaminants from industrial wastewater that may create pass-through or interference with A/S.

POTW's Wastewater Samples Example

Example
There are at least four types of samples that are collected by the POTW's Sampling Section: the primary are: grab, time proportional composites, flow proportional composites, and hand composites.

The sampling method used depends largely on the types of analyses to be run, and the nature of the wastestream being sampled. Each sampling method is described in this section.

Most POTW's will define the sampling methods which must be used by industrial users (IUs) to obtain representative samples to show compliance with their permits:

Example

(1) A grab sample is an individual sample collected in less than 15 minutes without regard for flow or time of day. pH, cyanide, oil and grease, sulfide, and volatile organics must be collected as grab samples.

(2) 24-hour flow proportional composite samples where feasible. The POTW may waive this requirement if the IU demonstrates that this method is not feasible. Samples would then be taken by means of time proportional composite sampling methods or by hand composite where the IU can demonstrate that this will provide a representative sample of the effluent being discharged.

The volume of sample to be collected by any of these methods is dependent on the number and types of analyses that must be performed.

Wastewater Grab Samples
Grab samples are individual samples collected in less than 15 minutes without regard to flow or time of day.

Grab samples are normally taken manually, but can be pumped. Oil and grease samples and purgeable organics are exceptions and must be taken manually.

A grab sample is usually taken when a sample is needed to:

(1) Provide information about an instantaneous concentration of pollutants at a specific time.
(2) Quantify the pollutants in a non-continuous discharge (e.g., batch discharge).
(3) Corroborate composite samples if the waste is not highly variable.
(4) Monitor parameters not amenable to compositing such as pH, temperature, dissolved oxygen, chlorine, purgeable organics and sulfides, oil and grease, coliform bacteria, and sulfites.

QA/QC Field Procedures for Plant Sampling *Example*

Duplicate Sampling Procedure

The purpose of Duplicate Samples is to check the laboratory's ability to reproduce analytical results. Duplicate Samples are to be collected using these steps:

1. Determine amount of sample needed. If a flow proportion sample is required, then base the amount of sample needed on the current flow reading. If a flow-proportion sample is not required, then use the predetermined amount for the sampling site.
2. Collect sample using a grab type sampler or a sampling head.
3. Measure the amount determined in Step 1 using a graduated cylinder or other accurate measuring device.
4. Pour measured sample into sample container that is not marked as the Duplicate Sample.
5. Measure same amount as in Step 1.
6. Pour second measured quantity into sample container marked for Duplicate Sample.
7. Process both samples using standard procedures and submit both samples to laboratory.

Split Sampling Procedure

The purpose of Split Samples is to check analytical procedures by having the samples analyzed by two different laboratories. Split Samples are to be collected using these steps:

1. Determine amount of sample needed. If a flow proportion sample is required, then base the amount of sample needed on the current flow reading. If a flow-proportion sample is not required, then use the predetermined amount for the sampling site.
2. Collect sample using a grab type sampler or a sampling head.
3. Measure the amount determined in Step 1 using a graduated cylinder or other accurate measuring device.
4. Pour measured sample into sample container that is not marked as the Split Sample.
5. Measure same amount as in Step 1
6. Pour second measured quantity into sample container marked for Split Sample.
7. Process both samples using standard procedures and submit both samples to the laboratory. The laboratory will be responsible for submitting the samples to the outside laboratory that will be analyzing the Split Sample.

Trip Blank Procedure

The purpose of Trip Blanks is to determine if the sample bottles have been adequately cleaned, and if sample contamination occurs between the time sample bottles leave the laboratory to the time that samples are returned to the lab.

Trip blanks are prepared by the laboratory using bottles supplied by the sampler. They are picked up by the person who begins the sampling day. Trip blanks are placed in the cooler which contains the other samples and remain there until the samples are turned into the laboratory.

Always follow your NPDES permit for proper sampling information.

Collecting Procedure for Water/Wastewater Grab Samples
Policy or Permit Example

- Lower dipper or mouth of the bottle into water just below surface. In some cases, you will need to rinse the bottle or dipper three times in the sample before obtaining the sample.
- Retrieve collected sample to clean processing area.
- Rinse the outside of the bottle 3 times to remove contamination.
- Pour the sample into the required laboratory bottle.

Filtering (for ortho-P and NOx samples)
You may need to filter the sample; this is true with some water and wastewater samples. Some surface water virus samples need to be filtered.

- Secure caps tightly.
- Bottle preservation is performed in the truck or lab before sampling.
- Secure sample container caps tightly.
- Label the sample containers and place them in an iced cooler before storage.

Timed Composites Example
Timed samples are usually taken in instances where the intention is to characterize the wastes over a period of time without regard to flow, or where the flow is fairly constant.

Timed composite samples consist of a series of equal volume grab samples taken at regular intervals. Usually the interval is 15 minutes with a maximum sampling duration of 24 hours.

However, other intervals can be used and may be more appropriate under some circumstances. Samplers are available which can take up to 10 discreet samples per bottle, for a total of 240 discreet samples. The sampler may be programmed to take any number of samples into one composite bottle which has a 2.5-gallon capacity.

Flow Proportional Composites Example
Flow proportional composite samples consist of: a series of grab samples whose volumes are equal in size and proportion to the flow at the time of sampling.

Samples are taken at varying time intervals, or continuous samples taken over a period of time based on the flow.

Wherever possible, flow proportional sampling is recommended because it most accurately reflects the nature of the wastestream.

Equal volume samples taken at varying time intervals are most often collected by the sampling inspectors. A flow measuring device should be used in conjunction with the automatic sampler.

This sampling method is used for all sampling activities except for instances where grab samples are required or time proportional sampling is more expedient and can provide the same accuracy as flow proportional sampling (i.e., constant flow levels).

Pre-Sampling Procedures *Example*
To ensure acceptable analytical results, numerous steps must be followed before a sampling program can be initiated:

(1) Sampling equipment must be clean and in good working order.
(2) Sampling site must be selected.
(3) Types of analyses must be determined.
(4) Proper sample containers must be selected and prepared.

Wastewater Sampling Equipment Policy Example
The POTW may use one or more of the following portable samplers, ISCO Ultra-Sonic flow meters, SIGMA Depth Sensor samplers, and SIGMA pH Probe samplers. Safety equipment and other necessary equipment are also used. There are many different manufactures of this type of equipment.

The equipment that is kept in the sampling vehicle is dependent on the types of sampling activities planned each week, while the equipment stored in the storeroom is for back-up needs and future sampling demands.

Each sampling vehicle should be equipped with at least one sampler and one flow meter more than is needed for the particular sampling period. For example, three scheduled flow proportionate sampling sites would require a vehicle to be equipped with four samplers and four flow meters. At least one spare battery for each type of equipment taken into the field should also be placed in the sampling vehicle.

Ancillary equipment, such as supports, harnesses, blowers, etc., that must be carried in each vehicle will depend on the nature of the sampling location.

In order to keep the equipment in good working order, it should be maintained and cleaned on a regular basis. Routine maintenance and cleaning procedures should be written into the procedures.

Sampling Equipment Maintenance Policy Example
Basic maintenance for samplers includes: periodic calibration, general equipment checking, and replacement of the internal desiccant and fuses. Routine cleaning should be done as covered in SOP or equivalence.

Basic maintenance of the flow meters includes: periodic replacement of the internal desiccant, plotter paper, ribbon, fuses, and any broken re-roll spool assemblies. **Note**: on this assembly there are two tabs on the sides of this piece which are extremely thin and easily broken.

It is important to note that charged NiCad batteries, if left unused for a long time, are nevertheless slowly discharging. Voltage readings should be taken **before** the charged batteries are taken into the field to be sure that they still have a full charge.

When a sampler, flow meter, or ancillary equipment needs more specific repairs, the manufacturer representative should be contacted and arrangements made for repair or replacement of the equipment.

Cleaning Automatic Samplers Policy Example

Samplers, sample jars, grab beakers, and all other equipment used in collecting samples must be cleaned between their uses at each site, to avoid the possibility of cross contamination. Latex or nitrile gloves or equivalent should be worn to protect against infections and acid burns. The following steps should be taken to ensure the proper cleaning of the sampling equipment.

(1) Break down the sampler and lay the three components in a row.

(2) Place the strainers and weights in a plastic bucket.

(3) Set the glass composite jars and Teflon caps off to the side, to be cleaned separately from the samplers.

(4) Pour a small amount of diluted (1:128) O-Syl disinfectant and MICRO soap into each sampler component, the bucket containing the strainers and weights, and the composite jars.

(5) To clean the sampler components:

- (a) Partially fill the sampler bases and cover with water.
- (b) Use a brush to scrub the inside and outside of each sampling component. Using a small bottle brush, thoroughly scrub the inside of the intake tube and the float housing of the sampler head (these are critical areas since they come in contact with the sample).
- (c) Rinse off the soap with fresh water.
- (d) Stack each component so that it will dry quickly and thoroughly.
- (e) Reassemble the sampler after the components are dry, and store it in the proper compartment of the sampling van. Leave the sampler lid loose so moisture won't be trapped.
- (f) Clean the strainers and weights in the bucket. Empty the contents of the bucket and rinse the bucket, strainers, and weights. After they have dried, place them in the proper storage areas of the sampling van.
- (g) Drain the wastewater tank of the sampling van into the sewer drain.
- (h) Refill the fresh-water tank on the sampling van with potable water.

Sampler Bottle Cleaning and Preparation Policy Example

(1) Fill each jar with O-Syl (same dilution as used in the sampler disinfection), MICRO soap, and fresh water.

(2) Thoroughly scrub the inside and outside of the jars until they are sparkling clean. Make sure that all oil and grease are removed.

(3) Rinse the jars with fresh water.

(4) Pour a small amount of 1:1 nitric acid into one jar, and securely place the proper Teflon cap on the jar. Swirl the nitric acid throughout the jar, remove the lid, and pour the nitric acid into the next jar. Repeat this procedure until all the bottles have been treated. Rinse bottles with water after the acid wash. **NOTE:** Wear safety glasses or a full-face shield to protect your eyes.

(5) Place jars in the drying oven. If jars are to air dry use Acetone to clean the bottles the same way as stated in (4) above. Let the jars and caps dry completely.

(6) Place the jars, with their caps on loosely, in their respective places on the sampling van.

Selection of Pretreatment Sampling Site

In order to ensure the collection of valid samples, a representative sampling site must be selected. For industrial sampling, the sites are designated in the permit.

Quality Assurance/Quality Control Policy *Example*

Quality Assurance/Quality Control (QA/QC) measures taken by the sampling crew include equipment blanks, trip blanks, split samples and duplicate samples. Equipment blanks and trip blanks are routine QA/QC measures.

Split samples are taken for Local Limits (pretreatment) sampling and when requested by an industry or laboratory. Split samples requested by an industry are analyzed by their lab at their expense.

Duplicate samples should be run when requested by a Supervisor or Project Leader.

The laboratory prepares all trip blanks/travel blanks used by the sampling crews. This is performed in the laboratory rather than in the field in order to assure that there is no field contamination in the blanks.

Any contamination detected in the blanks would result from field exposure which could in turn affect collected samples.

Always follow your NPDES permit for proper sampling information.

Chain-of-Custody Policy Example

Documentation of all pertinent data concerning the collection, preservation and transportation of samples is critical to the overall success of the Wastewater Sampling Program. If sampling is performed for the Pretreatment program, any sampling data may be used as evidence in court proceedings against a noncompliant industrial user. In this case documentation becomes critical. This form is a legal document and is of major importance in a court hearing. Specific procedures with regard to chain of custody are outlined below:

(1) The sampling crew takes a sufficient supply of pre-numbered Industrial Waste Lab Reports, (custody forms) and sample containers into the field.

(2) The sampling crew fills in the sampling form at the time of sample collection, and returns the form to the lab along with the collected sample. Specific information to be completed on the form includes:

(a) CODE: The company ID number assigned by supervisor.

(b) SITE No.: The sampling point ID number assigned by supervisor.

(c) DATE SAMPLED: From - Date sampling began To - Date sample is pulled. If it is a grab sample, only the date the sample was taken will be entered with the other line crossed out.

(d) SUBMITTED BY: This will have a preprinted truck number. The sampling crew will write in their initials on the blank line which follows.

(e) LABEL: A letter is checked and the type of analysis to be performed.

(f) PRESERVATIVE: The method of preservation used. See preservation section to see which preservatives to use.

(g) TYPE OF SAMPLE: Check off whether proportional, timed composite, hand composite, flow or grab sample.

(h) TIME: The time frame needed for collection of the sample. A starting time for sample collection, an ending time, and a total time in hours and quarter hours is recorded, such as 23.25 hours. On a grab sample only, the end time, which is the time the sample was taken, will be entered and the other two lines will be crossed out.

(i) RELINQUISHED BY: This is the signature of person that relinquishes sample to lab personnel, or to any other person taking custody of the sample.

(j) DATE: Date sample is submitted to the laboratory or relinquished to another person.

(k) NOTES TO LAB: Includes any special notes to the lab, such as special analysis required of the sample, a letter code which is assigned to the entity being tested the amount of flow if sample is flow proportional, grab sample pH and temperature, and/or actual sample temperature.

(l) FIELD TEST: Results of any field tests including sample pH, hexavalent chromium, dissolved sulfides, copper, and residual chlorine.

(m) RESULTS: The appropriate box(es) need to be checked to correspond to the label designation chosen above.

(3) When the sampling is completed at a site, the sampling crew labels the bottles with the label letter designation. The samples are sealed with chain of custody seals and placed in an ice chest for transportation to the lab.

(4) The sampling crew submits the samples and the chain of custody form to the laboratory.

(5) The laboratory logs the samples and assigns a Lab Reference Number to the sample. The sample is tracked by means of this number.

(6) Laboratory personnel sign and date the form, and return it to the sampling crew who makes two copies of the form. One copy is for the sampling crew files and the other is for data entry. The original form is returned to the laboratory. It is also important to note that the sampling vehicle should be kept locked at all times when the sampling crew is not in the vehicle, or in full view of the vehicle.

Regular Sampling Maintenance Includes the Following…

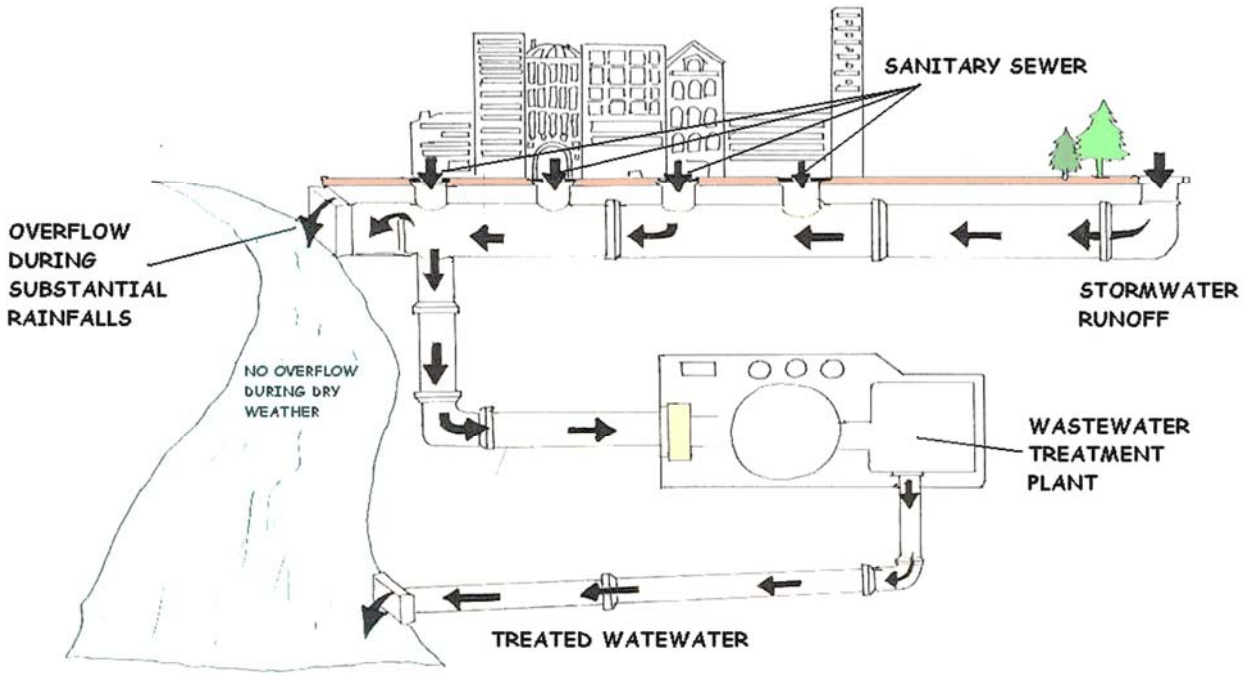
Automatic Sampler

- Washing
- Drying
- Change desiccant
- Check full bottle shut-off float
- Recharge battery

Flowmeter

- Washing
- Drying
- Change plotter paper
- Change printer ribbon
- Change desiccant
- Recharge battery

Record keeping - keep a record of cleaning dates. What was cleaned, and when.



A modern wastewater treatment facility may have up to 10 different sampling sites some are necessary for compliance purposes, some sites are to please certain agendas or for political purposes. These sampling sites may include Local Limits, QA/QC, Influent, Outfall, Chlorine residual, and many more sites to maintain compliance and to ensure that the plant is running efficiently.

Equipment Maintenance Cleaning Techniques Example

It is important to keep all equipment used for sampling clean to reduce the risk of cross contamination.

Is your automatic sampler and equipment clean?

All components of an automatic sampler need to be clean prior to setup, since contamination can occur.

Automatic sampler - Each section should be clean, especially the inlet tube.

Intake tubing - Cleaned or new Tygon or Teflon should be used according to the samples you are collecting.

- Intake line strainer - Clean or stainless steel or Teflon.
- Pump tubing - Clean or new medical grade silicone tubing.

Composite bottle - Generally glass is used for this and it's extremely important that it is clean.

Automatic sampling equipment - all components of an automatic sampler should be cleaned using phosphate free soap and rinsed thoroughly prior to setup.

Follow safety procedures (goggles, gloves, etc...) When cleaning equipment!
Composite bottles used in the automatic sampler need to be cleaned prior to setup.

1. Rinse bottle and cap with tap water to remove any residual contaminants.
2. Wash bottle and cap with a phosphate free soap and tap water.
3. Rinse bottle and cap with tap water to flush off any soap.
4. Add 1:1 nitric acid to bottle, cap and shake to cover entire inside of bottle and cap. Pour out 1:1 nitric acid.
5. Triple rinse bottle and cap with analyte free water.
6. Allow bottle and cap to dry.
7. Store Bottle with cap loosely screwed onto bottle to keep contaminants out.

Tubing - clean or new
Using clean tubing (intake and pump) for each sampling event will eliminate the need to clean the tubing. If tubing is not going to be changed before a sampling event, then the tubing will need to be washed.

1. Pump clean tap water through tubing, using the automatic sampler pump to transfer water from one container to another.
2. Place tubing into another container that has a phosphate free soap in it and pump the soapy water through the tubing 3 or 4 times while catching the discharge in a separate container.
3. Pump clean tap water through tubing to rinse out soap.
4. Add 1:1 nitric acid to clean tap water and pump this solution through tubing 3 or 4 times.
5. Pump analyte-free water through tubing until all residual acid has been removed.
6. Keep tubing in a clean place until next sampling event.

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SESD Operating Procedure for Field Equipment Cleaning and Decontamination, SESDPROC-205, Most Recent Version

SESD Operating Procedure for Field Equipment Cleaning and Decontamination at the FEC, SESDPROC-206, Most Recent Version

SESD Operating Procedure for Field pH Measurement, SESDPROC-100, Most Recent Version

SESD Operating Procedure for Field Sampling Quality Control, SESDPROC-011, Most Recent Version

SESD Operating Procedure for Field Specific Conductance Measurement, SESDPROC101, Most Recent Version

SESD Operating Procedure for Field Temperature Measurement, SESDPROC-102, Most Recent Version

SESD Operating Procedure for Logbooks, SESDPROC-010, Most Recent Version

SESD Operating Procedure for Packaging, Marking, Labeling and Shipping of Environmental and Waste Samples, SESDPROC-209, Most Recent Version

SESD Operating Procedure for Sample and Evidence Management, SESDPROC-005, Most Recent Version

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US EPA. 2000. Activated Sludge Process Control Testing. ESD, Water Compliance Unit, Athens, GA

US EPA. 2001. Environmental Investigations Standard Operating Procedures and Quality Assurance Manual. Region 4 Science and Ecosystem Support Division (SESD), Athens, GA

Topic 8 -Wastewater Sampling Section
Post Quiz

True or False

1. Grab samples indicate the condition of the wastewater at that specific time and always represent the normal conditions. True or False

2. Grab samples are required when the analysis change rapidly. For instance, grab samples are required for certain tests such as temperature, pH, D.O. (dissolved oxygen), and bacteriological analysis. True or False

3. An unweighted composite collects a different sample volume at a constant time interval. True or False

4. A composite sample consists of several grab samples collected from the same spot over a specific period of time and merged into a single sample. True or False

5. A flow meter is connected to the composite sampler and the sampler is programed to draw at different flow intervals. As the flow increases so does the number of samples. True or False

6. A grab sample is more arduous, complicated and usually inconvenient than a simple composite sample. True or False

7. The automatic sampler has the capability to be programmed to draw an unknown volume of sample every few minutes and deposit each sample into one bottles that are preserved or refrigerated. At the end of the sampling period, the operator can retrieve the bottles, bring them back to the lab and create a grab sample. True or False

8. Where applicable, wastewater samples should be collected at the location specified in the NPDES permit (if the source has a permit). True or False

9. In some instances, the sampling location specified in the permit, or the location chosen by the permittee, may be adequate for the collection of a representative wastewater sample. True or False

10. When a conflict exists between the permittee and the regulatory agency regarding the most representative sampling location, both sites should be sampled, and the reason for the conflict should be noted in the field notes and the inspection or study report. True or False

11. Influent wastewaters are preferably sampled at locations of low turbulent flow where the most desirable location is accessible. True or False

12. When possible, influent samples should be collected upstream from sidestream returns. True or False

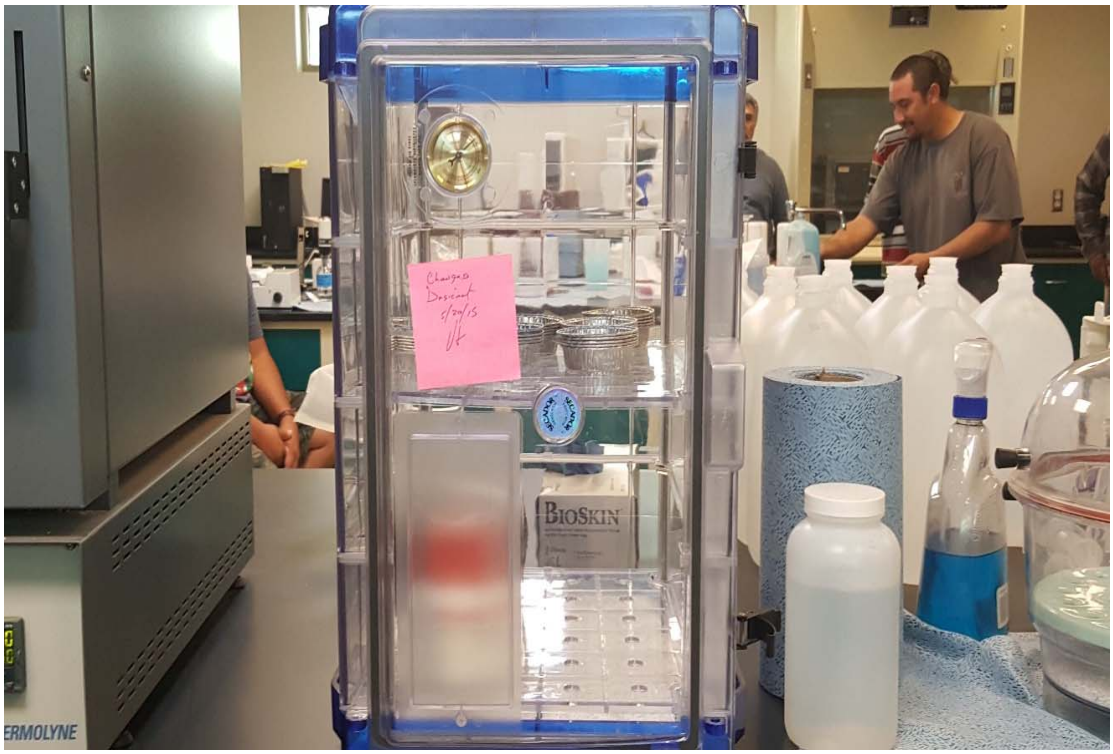
13. Composite effluent wastewater samples should never be collected from ponds and lagoons. True or False

14. Even if the ponds or lagoons have long retention times, composite sampling is necessary because ponds and lagoons have the tendency to have flow paths that short circuit, which changes the designed detention time. True or False

15. Effluent samples do not be collected at the site specified in the permit, or if no site is specified in the permit, at the most representative site upstream from all entering wastewater streams prior to discharge into the receiving waters.
True or False

Topic 9- Laboratory Analysis/ Process Control Section

Topic 9 - Section Focus: You will learn the basics of the wastewater laboratory analysis and process control procedures. At the end of this section, you the student will be able to understand and describe general laboratory analysis procedures. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.
Topic 9 – Scope/Background: Wastewater quality indicators are laboratory analysis methodologies to assess suitability of wastewater for disposal or re-use. Analysis selected and desired test results vary with the intended use or discharge location. Analysis measure physical, chemical, and biological characteristics of the wastewater. The program is important in preventing harm to the environment and to abide with regulations.



Laboratory Tests and Analysis

Wastewater treatment operators run laboratory tests and analysis to monitor the treatment plant operation. These analyses are for testing the process control and indicate how well a particular process is working. Operators will analyze the results and if needed, will make operational adjustments.

In a typical wastewater treatment plant, there are several locations to sample. As wastewater flows through the treatment plant, including the collection system, its characteristics frequently change. By taking samples at different locations throughout the process, the operator has a better understanding of how to treat the flow.

Laboratory duties include some of the following:

- Collect and preserve samples
- Prepare samples for analysis
- Analyze samples and interpret results
- Operate and maintain equipment and instruments
- Handle chemicals and wastes (PPE)
- Quality assurance/quality control (Engineering and Administrative controls)
- Manage laboratory
- Laboratory safety

Quality Assurance (QA)/Quality Control (QC)

Quality Assurance (QA)/Quality Control (QC) is a program designed by the laboratory that specifies the methods and procedures required to produce measurement-based, technically valid, legally defensible and known quality information.

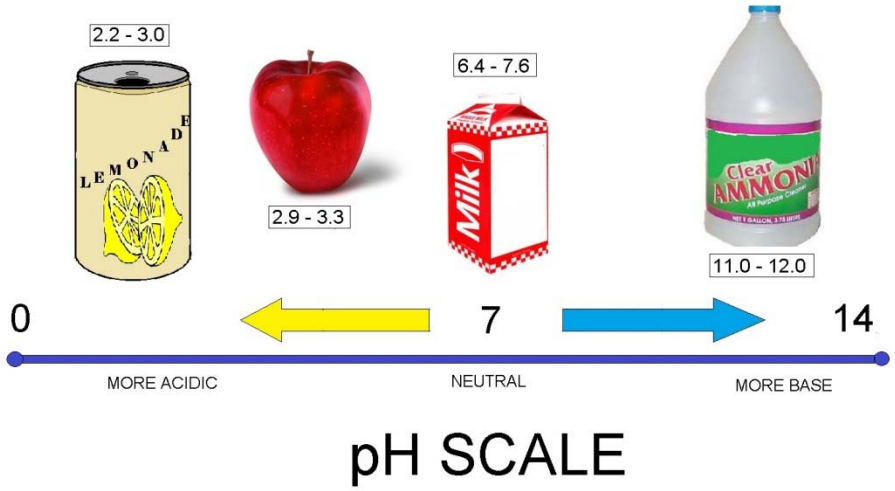
The QA/QC activities are designed to evaluate precision and accuracy of the sample collection and analysis and to ensure that any problems that may occur are quickly identified and rectified.

The QA/QC Program has two components:

1. Quality Assurance (QA) - describes the overall measures that a laboratory uses to ensure the quality of its operations. It is designed to evaluate the precision and accuracy of the sample collection, laboratory analysis and potential sources of contamination encountered during sample collection and delivery to the laboratory.

2. Quality Control (QC) – is part of the overall QA. It consists of operational techniques and activities that are used to fulfil requirements for quality.

pH Testing Section



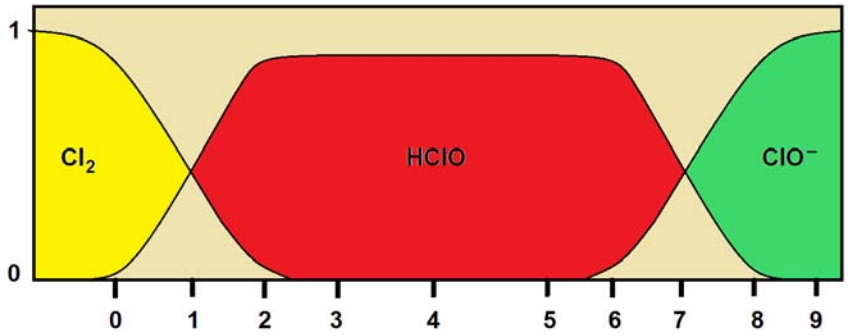
pH SCALE

In water and wastewater processes, **pH** is a measure of the acidity or basicity of an aqueous solution. Solutions with a pH greater than 7 are basic or alkaline and solution or samples with a pH less than 7 are said to be acidic. Pure water has a pH very close to 7.

Primary pH standard values are determined using a concentration cell with transference, by measuring the potential difference between a hydrogen electrode and a standard electrode such as the silver chloride electrode. The pH scale is traceable to a set of standard solutions whose pH is established by international agreement.

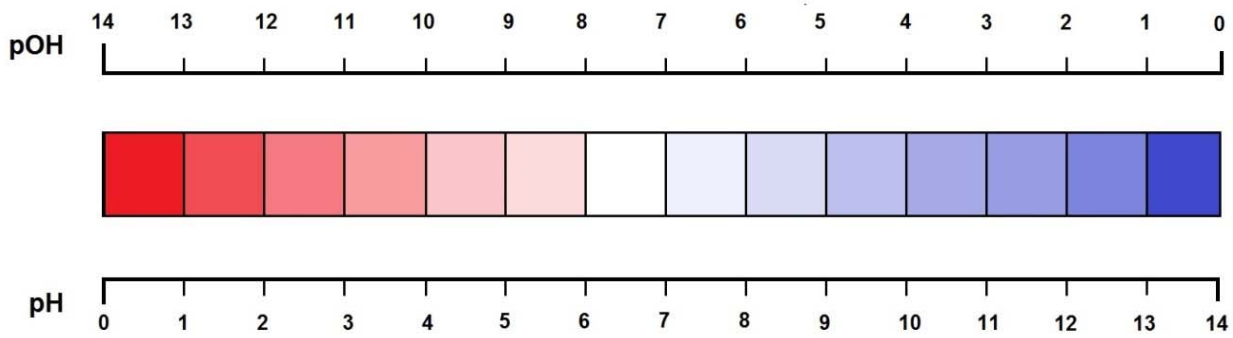
Measurement of pH for aqueous solutions can be done with a glass electrode and a pH meter, or using indicators like strip test paper.

pH measurements are important in water and wastewater processes (sampling) but also in medicine, biology, chemistry, agriculture, forestry, food science, environmental science, oceanography, civil engineering, chemical engineering, nutrition, water treatment & water purification, and many other applications.



pH - VALUE

Mathematically, pH is the measurement of hydroxyl ion activity and expressed as the negative logarithm of the activity of the (solvated) hydronium ion, more often expressed as the measure of the hydronium ion concentration.



IN RELATION BETWEEN p(OH) AND p(H) (red= ACIDIC / blue= BASIC)

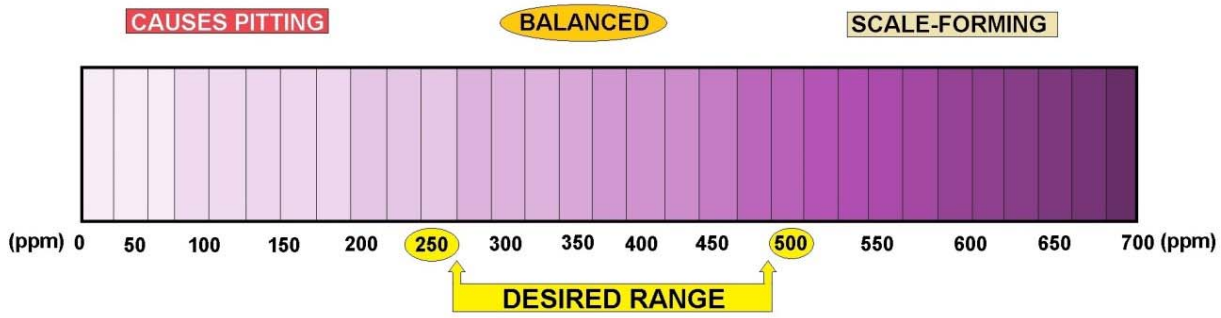
Contents

History

The scientific discovery of the p[H] concept of was first introduced by Danish chemist Søren Peder Lauritz Sørensen at the Carlsberg Laboratory back in 1909 and revised to the modern pH in 1924 to accommodate definitions and measurements in terms of electrochemical cells. In the first papers, the notation had the "H" as a subscript to the lowercase "p", as so: pH.

Alkalinity

Alkalinity is the quantitative capacity of an aqueous solution to neutralize an acid. Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater. It is one of the best measures of the sensitivity of the stream to acid inputs. There can be long-term changes in the alkalinity of rivers and streams in response to human disturbances.



CALCIUM HARDNESS MEASUREMENT

Reference. Bates, Roger G. Determination of pH: theory and practice. Wiley, 1973.

pH Definition and Measurement

CONCENTRATION OF HYDROGEN IONS COMPARED TO DISTILLED H2O				EXAMPLES OF SOLUTIONS AND THEIR RESPECTIVE pH
	1/10,000,000	14	LIQUID DRAIN CLEANER CAUSTIC SODA	
	1/1,000,000	13	BLEACHES OVEN CLEANERS	
	1/100,000	12	SOAPY WATER	
	1/10,000	11	HOUSEHOLD AMMONIA (11.9)	
	1/1,000	10	MILK OF MAGNESIUM (10.5)	
	1/100	9	TOOTHPASTE (9.9)	
	1/10	8	BAKING SODA (8.4) / SEA WATER EGGS	
	0	7	"PURE" WATER (7)	
	10	6	URINE (6) / MILK (6.6)	
	100	5	ACID RAIN (5.6) BLACK COFFEE (5)	
	1000	4	TOMATO JUICE (4.1)	
	10,000	3	GRAPEFRUIT & ORANGE JUICE SOFT DRINK	
	100,000	2	LEMON JUICE (2.3) VINEGAR (2.9)	
	1,000,000	1	HYDROCHLORIC ACID SECRETED FROM STOMACH LINING (1)	
	10,000,000	0	BATTERY ACID	

pH Scale

Technical Definition of pH

In technical terms, pH is defined as the decimal logarithm of the reciprocal of the hydrogen ion activity, *a*H+, in a solution.

$$pH = -\log_{10}(a_{H^+}) = \log_{10}\left(\frac{1}{aH+}\right)$$

Ion-selective electrodes are often used to measure pH, respond to activity.

In this calculation of electrode potential, *E*, follows the Nernst equation, which, for the hydrogen ion can be written as

$$E = E^0 + \frac{RT}{F} In\,(a_H+) = E^0 - \frac{2.303RT}{F} pH$$

where *E* is a measured potential, E^0 is the standard electrode potential, *R* is the gas constant, *T* is the temperature in kelvin, *F* is the Faraday constant.

For H^+ number of electrons transferred is one. It follows that electrode potential is proportional to pH when pH is defined in terms of activity.

International Standard ISO 31-8 is the standard for the precise measurement of pH as follows: A galvanic cell is set up to measure the electromotive force (EMF) between a reference electrode and an electrode sensitive to the hydrogen ion activity when they are both immersed in the same aqueous solution.

The reference electrode may be a silver chloride electrode or a calomel electrode. The hydrogen-ion selective electrode is a standard hydrogen electrode.

Reference electrode | concentrated solution of KCl || test solution | H_2 | Pt

Firstly, the cell is filled with a solution of known hydrogen ion activity and the emf, E_S, is measured. Then the emf, E_X, of the same cell containing the solution of unknown pH is measured.

$$pH(X) = pH(S) + \frac{E_S - E_x}{Z}$$

The difference between the two measured emf values is proportional to pH. This method of calibration avoids the need to know the standard electrode potential. The proportionality constant, *1/z* is ideally equal to $\frac{1}{2.303RT/F}$ the "Nernstian slope".

If you were to apply this practice the above calculation, a glass electrode is used rather than the cumbersome hydrogen electrode. A combined glass electrode has an in-built reference electrode. It is calibrated against buffer solutions of known hydrogen ion activity. IUPAC has proposed the use of a set of buffer solutions of known H^+ activity.

Two or more buffer solutions should be used in order to accommodate the fact that the "slope" may differ slightly from ideal.

The electrode is first immersed in a standard solution and the reading on a pH meter is adjusted to be equal to the standard buffer's value, to implement the proper calibration. The reading from a second standard buffer solution is then adjusted, using the "slope" control, to be equal to the pH for that solution. Further details, are given in the IUPAC recommendations.

When more than two buffer solutions are used the electrode is calibrated by fitting observed pH values to a straight line with respect to standard buffer values. Commercial standard buffer solutions usually come with information on the value at 25 °C and a correction factor to be applied for other temperatures.

The pH scale is logarithmic and pH is a dimensionless quantity.

pH Indicators
Visual comparison of the color of a test solution with a standard color chart provides a means to measure pH accurate to the nearest whole number. Indicators may be used to measure pH, by making use of the fact that their color changes with pH. More precise measurements are possible if the color is measured spectrophotometrically, using a colorimeter of spectrophotometer. Universal indicator consists of a mixture of indicators such that there is a continuous color change from about pH 2 to pH 10. Universal indicator paper is made from absorbent paper that has been impregnated with universal indicator.

pOH
pOH is sometimes used as a measure of the concentration of hydroxide ions, OH^-, or alkalinity. pOH values are derived from pH measurements. The concentration of hydroxide ions in water is related to the concentration of hydrogen ions by

$$[\mathrm{OH^-}] = \frac{K_W}{[\mathrm{H^+}]}$$

where K_W is the self-ionization constant of water. Taking logarithms

$$\mathrm{pOH} = \mathrm{pK_W} - \mathrm{pH}$$

So, at room temperature pOH ≈ 14 − pH. However this relationship is not strictly valid in other circumstances, such as in measurements of soil alkalinity.

Extremes of pH
Measurement of pH below about 2.5 (ca. 0.003 mol dm^{-3} acid) and above about 10.5 (ca. 0.0003 mol dm^{-3} alkali) requires special procedures because, when using the glass electrode, the Nernst law breaks down under those conditions.

Extreme pH measurements imply that the solution may be concentrated, so electrode potentials are affected by ionic strength variation. At high pH the glass electrode may be affected by "alkaline error", because the electrode becomes sensitive to the concentration of cations such as Na^+ and K^+ in the solution. Specially constructed electrodes are available which partly overcome these problems. Runoff from industrial outfalls, restaurant grease, mines or mine tailings can produce some very low pH values.

Non-Aqueous Solutions
Hydrogen ion concentrations (activities) can be measured in non-aqueous solvents. pH values based on these measurements belong to a different scale from aqueous pH values, because activities relate to different standard states. Hydrogen ion activity, a_{H^+}, can be defined as:

$$a_{H^+} = \exp\left(\frac{\mu_{H^+} - \mu^{\ominus}_{H^+}}{RT}\right)$$

where μ_{H^+} is the chemical potential of the hydrogen ion, $\mu^{\ominus}_{H^+}$ is its chemical potential in the chosen standard state, R is the gas constant and T is the thermodynamic temperature. Therefore pH values on the different scales cannot be compared directly, requiring an intersolvent scale which involves the transfer activity coefficient of hydrolyonium ion.

pH is an example of an acidity function. Other acidity functions can be defined. For example, the Hammett acidity function, H_0, has been developed in connection with superacids.

The concept of "Unified pH scale" has been developed on the basis of the absolute chemical potential of the proton. This scale applies to liquids, gases and even solids.

Applications
Water has a pH of $pK_w/2$, so the pH of pure water is about 7 at 25 °C; this value varies with temperature. When an acid is dissolved in water, the pH will be less than that of pure water. When a base, or alkali, is dissolved in water, the pH will be greater than that of pure water.

A solution of a strong acid, such as hydrochloric acid, at concentration 1 mol dm^{-3} has a pH of 0.

A solution of a strong alkali, such as sodium hydroxide, at concentration 1 mol dm^{-3}, has a pH of 14. Thus, measured pH values will lie mostly in the range 0 to 14, though negative pH values and values above 14 are entirely possible.

Since pH is a logarithmic scale, a difference of one pH unit is equivalent to a tenfold difference in hydrogen ion concentration.

The pH of an aqueous solution of pure water is slightly different from that of, a salt such as sodium chloride even though the salt is neither acidic nor basic. In this case, the hydrogen and hydroxide ions' activity is dependent on ionic strength, so K_w varies with ionic strength.

The pH of pure water decreases with increasing temperatures. One example is the pH of pure water at 50 °C is 6.55.

Seawater
The pH of seawater plays an important role in the ocean's carbon cycle, and there is evidence of ongoing ocean acidification caused by carbon dioxide emissions. pH measurement can be complicated by the chemical properties of seawater, and several distinct pH scales exist in chemical oceanography.

As part of its operational definition of the pH scale, the IUPAC defines a series of buffer solutions across a range of pH values (often denoted with NBS or NIST designation).

These solutions have a relatively low ionic strength (~0.1) compared to that of seawater (~0.7), and, as a consequence, are not recommended for use in characterizing the pH of seawater, since the ionic strength differences cause changes in electrode potential.

To resolve this problem, an alternative series of buffers based on artificial seawater was developed. This new series resolves the problem of ionic strength differences between samples and the buffers.

The newest pH scale is referred to as the **total scale**, often denoted as $\mathbf{pH_T}$.

pH Calculations

The calculation of the pH of a solution containing acids and/or bases is an example of a chemical speciation calculation, that is, a mathematical procedure for calculating the concentrations of all chemical species that are present in the solution.

The complexity of the procedure depends on the nature of the solution.

If the pH of a solution contains a weak acid requires the solution of a quadratic equation.

If the pH of a solution contains a weak base may require the solution of a cubic equation.

For strong acids and bases no calculations are necessary except in extreme situations.

The general case requires the solution of a set of non-linear simultaneous equations.

A complicating factor is that water itself is a weak acid and a weak base. It dissociates according to the equilibrium

$$2H_2O \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$

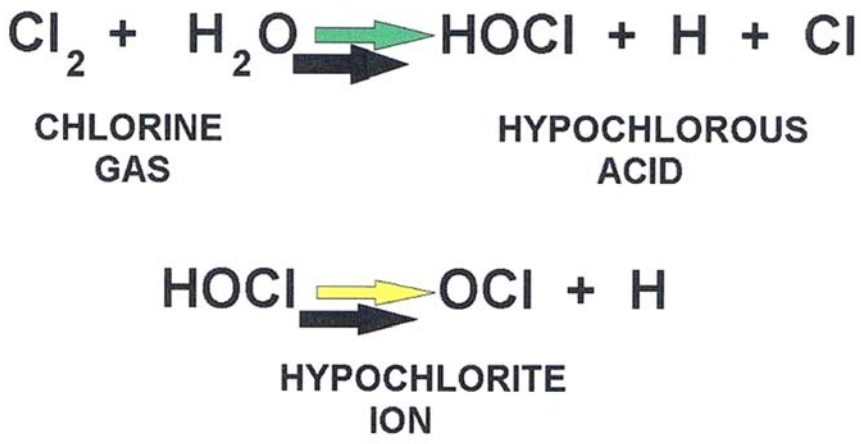
with a dissociation constant, K_w defined as

$$K_w = [H^+][OH^-]$$

where $[H^+]$ represents for the concentration of the aquated hydronium ion and $[OH^-]$ stands for the concentration of the hydroxide ion. K_w has a value of about 10^{-14} at 25 °C, so pure water has a pH of approximately 7.

This equilibrium needs to be considered at high pH and when the solute concentration is extremely low.

Strong Acids and Bases



Strong Acids and Bases
Strong acids and bases are compounds that, for practical purposes, are completely dissociated in water. Under normal circumstances this means that the concentration of hydrogen ions in acidic solution can be taken to be equal to the concentration of the acid. The pH is then equal to minus the logarithm of the concentration value.

Hydrochloric acid (HCl) is an example of a strong acid. The pH of a 0.01M solution of HCl is equal to $-\log_{10}(0.01)$, that is, pH = 2.

Sodium hydroxide, NaOH, is an example of a strong base. The p[OH] value of a 0.01M solution of NaOH is equal to $-\log_{10}(0.01)$, that is, p[OH] = 2.

From the definition of p[OH] above, this means that the pH is equal to about 12. For solutions of sodium hydroxide at higher concentrations the self-ionization equilibrium must be taken into account.

Weak Acids and Bases
A weak acid or the conjugate acid of a weak base can be treated using the same formalism.

Acid: $HA \rightleftharpoons H^+ + A^-$
Base: $HA^+ \rightleftharpoons H^+ + A$

First, an acid dissociation constant is defined as follows. Electrical charges are omitted from subsequent equations for the sake of generality

$$K_a = \frac{[H][A]}{[HA]}$$

and its value is assumed to have been determined by experiment. This being so, there are three unknown concentrations, [HA], $[H^+]$ and $[A^-]$ to determine by calculation. Two additional equations are needed.

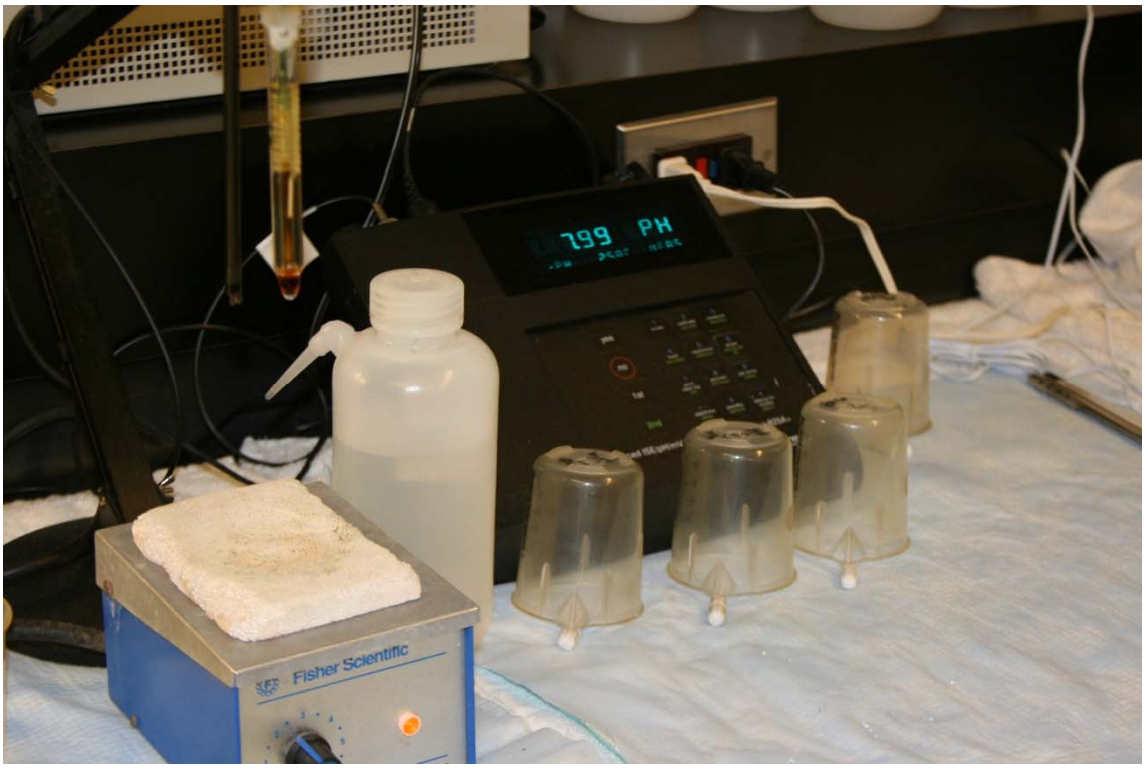
One way to provide them is to apply the law of mass conservation in terms of the two "reagents" H and A.

$$C_A = [A] + [HA]$$
$$C_H = [H] + [HA]$$

C stands for analytical concentration. In some texts one mass balance equation is replaced by an equation of charge balance. This is satisfactory for simple cases like this one, but is more difficult to apply to more complicated cases as those below.

Together with the equation defining K_a, there are now three equations in three unknowns. When an acid is dissolved in water $C_A = C_H = C_a$, the concentration of the acid, so [A] = [H]. After some further algebraic manipulation an equation in the hydrogen ion concentration may be obtained.

$$[H]^2 + K_a[H] - K_aC_a = 0$$



Electronic pH probe

Alkalinity Section

Introduction
Alkalinity of water is its acid-neutralizing capacity. It is the sum of all the titratable bases. The measured value may vary significantly with the end-point pH used. Alkalinity is a measure of an aggregate property of water and can be interpreted in terms of specific substances only when the chemical composition of the sample is known.

Alkalinity is significant in many uses and treatments of natural waters and wastewaters. Because the alkalinity of many surface waters is primarily a function of carbonate, bicarbonate, and hydroxide content, it is taken as an indication of the concentration of these constituents. The measured values also may include contributions from borates, phosphates, silicates or other bases if these are present. Alkalinity in excess of alkaline earth metal concentrations is significant in determining the suitability of water for irrigation. Alkalinity measurements are used in the interpretation and control of water and wastewater treatment processes.

Titration Method
a. Principle
Hydroxyl ions present in a sample, because of dissociation or hydrolysis of solutes react with additions of standard acid. Alkalinity thus depends on the end-point pH used.

b. Reagents
i) Standard Hydrochloric Acid – 0.02 N.
ii) Methyl Orange Indicator – Dissolve 0.1 g of methyl orange in distilled water and dilute to 1 liter.
iii) Sodium carbonate solution, 0.02 N : Dry 3 to 5 g primary standard Na_2CO_3 at 250^oC for 4 h and cool in a desiccator. Weigh 1.03 gm.
(to the nearest mg), transfer to a 1-L volumetric flask, fill flask to the mark with distilled water, dissolve and mix reagent. Do no keep longer than 1 week.

c. Procedure
Titrate over a white surface 100 ml of the sample contained in a 250-ml conical flask with standard hydrochloric acid using two or three drops of methyl orange Indicator.
(**NOTE** – If more than 30 ml of acid is required for the titration, a smaller suitable aliquot of the sample shall be taken.)

d. Calculation
Total alkalinity (as $CaCO_3$), mg/l = 10 V or NxVx50x1000

$$\text{T.A. (as } CaCO_3\text{)} = \frac{\text{NxVx50x1000}}{\text{Sample Amount}}$$

Where N = Normality of HCl used
V = volume in ml of standard hydrochloric acid used in the titration.

Alkalinity to Phenolphthalein
The sample is titrated against standard acid using phenolphthalein indicator.

a. Reagents
i) Phenolphthalein Indicator Solution :
Dissolve 0.1 g of phenolphthalein in 60 ml of ETHANOL and dilute with Distilled water to 100 ml.
ii) Standard hydrochloric Acid – 0.02 N.

b. Procedure
Add 2 drops of phenolphthalein indicator solution to a sample of suitable size, 50 or 100 ml, in a conical flask and titrate over a while surface with standard hydrochloric acid.

c. Calculation

$$\textbf{Alkalinity to phenolphthalein (as } CaCO_3\textbf{)}, \text{ mg/l} = \frac{1000\ V_1}{V_2}$$

Where
V_1 = volume in ml of standard hydrochloric acid used in the titration, and
V_2 = Volume in ml of the sample taken for the test.

Caustic Alkalinity

a. General
Caustic alkalinity is the alkalinity corresponding to the hydroxides present in water and is calculated from total alkalinity (T) and alkalinity to phenolphthalein (P).

b. Procedure Determine total alkalinity and alkalinity to phenolphthalein and calculate caustic alkalinity as shown in Table below. Result of Titration Caustic Alkalinity or Hydroxide Alkalinity as $CaCO_3$ Carbonate Alkalinity as $CaCO_3$ Bicarbonate Concentration as $CaCO_3$ **Result of Titration**	**Caustic Alkalinity or Hydroxide Alkalinity as $CaCO_3$**	**Carbonate Alkalinity as $CaCO_3$**	**Bicarbonate Concentration as $CaCO_3$**
P=0	0	0	0
P<1/2T	0	2P	T-2P
P=1/2T	0	2P	0
P>1/2T	2P-T	2(T-P)	0
P=T	T	0	0

The alkalinity of water is a measure of its capacity to neutralize acids. The alkalinity of natural water is due to the salts of carbonate, bicarbonate, borates, silicates and phosphates along with the hydroxyl ions in free state.

However, the major portion of the alkalinity in natural waters is caused by hydroxide, carbonate, and bicarbonates which may be ranked in order of their association with high pH values.

Alkalinity values provide guidance in applying proper doses of chemicals in water and waste water treatment processes, particularly in coagulation and softening.

Alkalinity (Total)

References: ASTM D 1067-92, Acidity or Alkalinity of Water.
APHA Standard Methods, 19th ed., p. 2-26, method 2320B (1995).
EPA Methods for Chemical Analysis of Water and Wastes, method 310.1 (1983).

The alkalinity of water is a measurement of its buffering capacity or ability to react with strong acids to a designated pH. Alkalinity of natural waters is typically a combination of bicarbonate, carbonate, and hydroxide ions. Sewage and wastewaters usually exhibit higher alkalinities either due to the presence of silicates and phosphates or to a concentration of the ions from natural waters.

Alkalinity inhibits corrosion in boiler and cooling waters and is therefore a desired quality that must be maintained. Alkalinity is also measured as a means of controlling water and wastewater treatment processes or the quality of various process waters. In natural waters, excessive alkalinity can render water unsuitable for irrigation purposes and may indicate the presence of industrial effluents.

The Titrimetric Method

CHEMetrics' tests determine total or "M" alkalinity using an acid titrant and a pH indicator. The end point of the titration occurs at pH 4.5. Results are expressed as ppm (mg/L) $CaCO_3$.

Hardness (calcium)

Reference: West, T. S., DSC, Ph.D., Complexometry with EDTA and Related Reagents, 3rd ed., p. 46, 164 (1969).

Originally described as water's capacity to precipitate soap, hardness is one of the most frequently determined qualities of water. It is a composite of the calcium, magnesium, strontium, and barium concentrations in a sample. The current practice is to assume total hardness refers to the calcium and magnesium concentrations only.

Completely de-hardened water, resulting from sodium zeolite or other suitable ion exchange treatment, is required for various processes-including power generation, printing and photo finishing, pulp and paper manufacturing, and food and beverage processing.

Hard water can cause scale formation on heat exchange surfaces, resulting in decreased heat transfer and equipment damage.

The Titrimetric Method. This method is specific for calcium hardness. The EGTA titrant in alkaline solution is employed with zincon indicator. Results are expressed as ppm (mg/L) $CaCO_3$.

Shelf-life. 8 months. Although the reagent itself is stable, the endpoint indicator has a limited shelf-life. We recommend stocking quantities that will be used within 7 months.

Dissolved Oxygen Detailed Section

Dissolved oxygen (**DO**) in water is not considered a contaminant. However, the (DO) level is important because too much or not enough dissolved oxygen can create unfavorable conditions. Generally, a lack of (DO) in natural waters creates anaerobic conditions. Anaerobic means without air. Certain bacteria thrive under these conditions and utilize the nutrients and chemicals available to exist. *Under anaerobic conditions the reaction is:*

Anaerobic:

Organics → intermediates + CO_2 + H_2O + energy

Where the intermediates are butyric acid, mercaptans and hydrogen sulfide gas. At least two general forms of bacteria act in balance in a wastewater digester: Saprophytic organisms and Methane Fermenters. The saprophytes exist on dead or decaying materials. The methane fermenters live on the volatile acids produced by these saprophytes. The methane fermenting bacteria require a pH range of 6.6 to 7.6 to be able to live and reproduce. Aerobic conditions indicate that dissolved oxygen is present. Aerobic bacteria require oxygen to live and thrive. When aerobes decompose organics in the water, the result is carbon dioxide and water.

Aerobic:

Organics + Oxygen → CO_2 + H_2O + energy

Dissolved Oxygen in a water sample can be detrimental to metal pipes in high concentrations because oxygen helps accelerate corrosion. Oxygen is an important component in water plant operations. Its primary value is to oxidize iron and manganese into forms that will precipitate out of the water. It also removes excess carbon dioxide. The amount of dissolved oxygen in a water sample will affect the taste of drinking water also.

Methods of Determination

There are two methods that we will be using in the lab. The membrane electrode method procedure is based on the rate of diffusion of molecular oxygen across a membrane. The other is a titrimetric procedure (Winkler Method) based on the oxidizing property of the (DO). Many factors determine the solubility of oxygen in a water sample. Temperature, atmospheric pressure, salinity, biological activity and pH all have an effect on the (DO) content.

Iodometric Test

The Iodometric (titration) test is very precise and reliable for (DO) analysis of samples free from particulate matter, color and chemical interferences. Reactions take place with the addition of certain chemicals that liberate iodine equivalent to the original (DO) content. The iodine is then measured to the starch iodine endpoint. We then calculate the dissolved oxygen from how much titrate we use. Certain oxidizing agents can liberate iodine from iodides (positive interference), and some reducing agents reduce iodine to iodide (negative interferences). The alkaline Iodide-Azide reagent effectively removes interference caused by nitrates in the water sample, so a more accurate determination of (DO) can be made.

Methods of analysis are highly dependent on the source and characteristics of the sample. The membrane electrode method involves an oxygen permeable plastic membrane that serves as a diffusion barrier against impurities. Only molecular oxygen passes through the membrane and is

measured by the meter. This method is excellent for field testing and continuous monitoring. Membrane electrodes provide an excellent method for (DO) analysis in polluted, highly colored turbid waters and strong waste effluents.

These interferences could cause serious errors in other procedures. Prolonged usage in waters containing such gases as H_2S tends to lower cell sensitivity. Frequent changing and calibrating of the electrode will eliminate this interference.

Samples are taken in BOD bottles where agitation or contact with air is at a minimum. Either condition can cause a change in the gaseous content. Samples must be determined immediately for accurate results.

The dissolved oxygen test is the one of the most important analyses in determining the quality of natural waters. The effect of oxidation wastes on streams, the suitability of water for fish and other organisms and the progress of self-purification can all be measured or estimated from the dissolved oxygen content. In aerobic sewage treatment units, the minimum objectionable odor potential, maximum treatment efficiency and stabilization of wastewater are dependent on maintenance of adequate dissolved oxygen. Frequent dissolved oxygen measurement is essential for adequate process control.

Term Review

Aerobic (AIR-O-bick) - a condition in which free or dissolved oxygen is present in the aquatic environment.

Aerobic Bacteria (aerobes) – bacteria which will live and reproduce only in an environment containing oxygen. Oxygen combined chemically, such as in water molecules (H_2O), cannot be used for respiration by aerobes.

Anaerobic (AN-air O-bick) - a condition in which ***"free"*** or dissolved oxygen is not present in the aquatic environment.

Anaerobic Bacteria (anaerobes) – bacteria that thrive without the presence of oxygen.

Saprophytic Bacteria – bacteria that break down complex solids to volatile acids.

Methane Fermenters – bacteria that break down the volatile acids to methane (CH_4) carbon dioxide (CO_2) and water (H_2O).

Oxidation – the addition of oxygen to an element or compound, or removal of hydrogen or an electron from an element or compound in a chemical reaction. The opposite of reduction.

Reduction – the addition of hydrogen, removal of oxygen or addition of electrons to an element or compound. Under anaerobic conditions in wastewater, sulfur or compounds elemental sulfur are reduced to H_2S or sulfide ions.

Procedure for Dissolved Oxygen Determination

METER-PROBE METHOD

Collect a water sample in the clean 300-ml glass stoppered BOD bottle for two or three minutes to make sure there are no air bubbles trapped in the bottle. Do one Tap water sample and one DI water sample. Mark the BOD bottles.

Insert the DO probe from the meter into your BOD bottles. Record the DO for Tap and DI water. Now continue with the Winkler Burette method.

PROCEDURES FOR WINKLER BURET METHOD

1. Add the contents of one MANGANESE SULFATE powder pillow and one ALKALINE IODIDE-AZIDE reagent powder pillow to each of your BOD bottles (TAP and DI)
2. Immediately insert the stoppers so that no air is trapped in the bottles and invert several times to mix. A flocculent precipitate will form. It will be brownish-orange if dissolved oxygen is present or white if oxygen is absent.
3. Allow the samples to stand until the floc has settled and leaves the solution clear (about 10 minutes). Again invert the bottles several times to mix and let stand until the solution is clear.
4. Remove the stoppers and add the contents of one SULFAMIC ACID powder pillow to each bottle. Replace the stoppers, being careful not to trap any air bubbles in the bottles, and invert several times to mix. The floc will dissolve and leave a yellow color if dissolved oxygen is present.
5. Measure 200 ml of the prepared solution by filling a clean 250-ml graduated cylinder to the 200-ml mark. Pour the solutions into clean 250-ml Erlenmeyer flasks. Save the last 100 mls for a duplicate.
6. Titrate the prepared solutions with PAO Titrant, 0.025N, to a pale yellow color. Use a white paper under the flask.
7. Add two droppers full of Starch Indicator Solution and swirl to mix. A dark blue color will develop.
8. Continue the titration until the solution changes from dark blue to colorless (end point). Go Slow- drop by drop. Record the burette reading to the nearest 0.01mls.
9. The total number of ml of PAO Titrant used is equal to the mg/L dissolved oxygen.

Dissolved Oxygen Results

Meter Results

1. De-ionized water _____mg/L

2. Tap water _____mg/L

3. What is the meter procedure measuring?

4. What factors would determine which the best method to use is?

5. What are two forms of bacteria present in a wastewater digester?

Wrinkler Method Results

1. **De-ionized Water**

200ml final Burette reading-
Sample initial Burette reading- -_____ = _____mg/L

100ml final Burette reading-
duplicate initial Burette reading- -_____dup=_____mg/L
mls x 2

2. **Tap water**

200ml final Burette reading-
Sample initial Burette reading- -_____=_____mg/L
mls

100ml final Burette reading
Sample initial Burette reading- -_____=_____mg/L
mls x 2

3. What are some factors that can alter the (DO) content prior to testing?

4. Were your samples anaerobic or aerobic?

5. Why is it important to monitor the (DO) content of water and wastewater?

Be specific and give a detailed explanation.

Total Dissolved Solids (TDS) Section

Water is a good solvent and picks up impurities easily. Pure water is tasteless, colorless, and odorless and is often called the universal solvent. Dissolved solids refer to any minerals, salts, metals, cations or anions dissolved in water. Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and some small amounts of organic matter that are dissolved in water.

TDS in drinking-water originate from natural sources, sewage, urban run-off, industrial wastewater, and chemicals used in the water treatment process, and the nature of the piping or hardware used to convey the water, i.e., the plumbing. In the United States, elevated TDS has been due to natural environmental features such as: mineral springs, carbonate deposits, salt deposits, and sea water intrusion, but other sources may include: salts used for road de-icing, anti-skid materials, drinking water treatment chemicals, stormwater and agricultural runoff, and point/non-point wastewater discharges.

In general, the total dissolved solids concentration is the sum of the cations (positively charged) and anions (negatively charged) ions in the water. Therefore, the total dissolved solids test provides a qualitative measure of the amount of dissolved ions, but does not tell us the nature or ion relationships.

In addition, the test does not provide us insight into the specific water quality issues, such as: Elevated Hardness, Salty Taste, or Corrosiveness. Therefore, the total dissolved solids test is used as an indicator test to determine the general quality of the water.

Total Solids

The term "total solids" refers to matter suspended or dissolved in water or wastewater, and is related to both specific conductance and turbidity.

Total solids (also referred to as total residue) are the term used for material left in a container after evaporation and drying of a water sample.

Total Solids includes both total suspended solids, the portion of total solids retained by a filter and total dissolved solids, the portion that passes through a filter (American Public Health Association, 1998).

Total solids can be measured by evaporating a water sample in a weighed dish, and then drying the residue in an oven at 103 to 105° C.

The increase in weight of the dish represents the total solids. Instead of total solids, laboratories often measure total suspended solids and/or total dissolved solids.

Lab tech removing filter for TSS analysis.

Total Suspended Solids (TSS)

Total Suspended Solids (TSS) are solids in water that can be trapped by a filter. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of suspended solids can cause many problems for stream health and aquatic life.

High TSS can block light from reaching submerged vegetation. As the amount of light passing through the water is reduced, photosynthesis slows down. Reduced rates of photosynthesis causes less dissolved oxygen to be released into the water by plants. If light is completely blocked from bottom dwelling plants, the plants will stop producing oxygen and will die. As the plants are decomposed, bacteria will use up even more oxygen from the water. Low dissolved oxygen can lead to fish kills.

Sampling downstream from a wastewater plant's discharge point.

High TSS can also cause an increase in surface water temperature, because the suspended particles absorb heat from sunlight. This can cause dissolved oxygen levels to fall even further (because warmer waters can hold less DO), and can harm aquatic life in many other ways, as discussed in the temperature section. (The decrease in water clarity caused by TSS can affect the ability of fish to see and catch food.

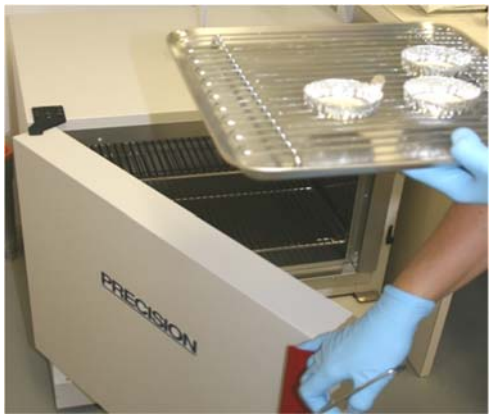
Suspended sediment can also clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development. When suspended solids settle to the bottom of a water body, they can smother the eggs of fish and aquatic insects, as well as suffocate newly hatched insect larvae. Settling sediments can fill in spaces between rocks which could have been used by aquatic organisms for homes.

Dead fish in lake using reclaimed water.

High TSS in a water body can often mean higher concentrations of bacteria, nutrients, pesticides, and metals in the water. These pollutants may attach to sediment particles on the land and be carried into water bodies with storm water. In the water, the pollutants may be released from the sediment or travel farther downstream. High TSS can cause problems for industrial use, because the solids may clog or scour pipes and machinery.

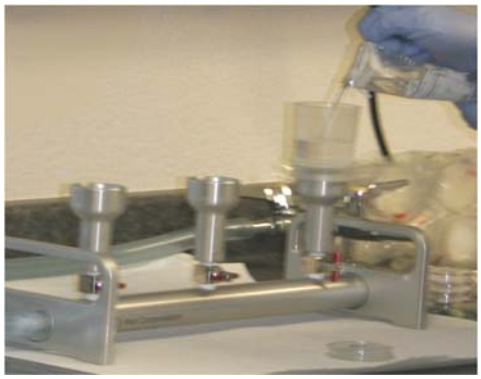
Measurement of Total Suspended Solids

To measure TSS, the water sample is filtered through a pre-weighed filter. The residue retained on the filter is dried in an oven at 103 to 105° C until the weight of the filter no longer changes. The increase in weight of the filter represents the total suspended solids. TSS can also be measured by analyzing for total solids and subtracting total dissolved solids.



Total Dissolved Solids (TDS) are solids in water that can pass through a filter (usually with a pore size of 0.45 micrometers). TDS is a measure of the amount of material dissolved in water.

This material can include carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. A certain level of these ions in water is necessary for aquatic life.



Changes in TDS concentrations can be harmful because the density of the water determines the flow of water into and out of an organism's cells (Mitchell and Stapp, 1992). However, if TDS concentrations are too high or too low, the growth of many aquatic lives can be limited, and death may occur.

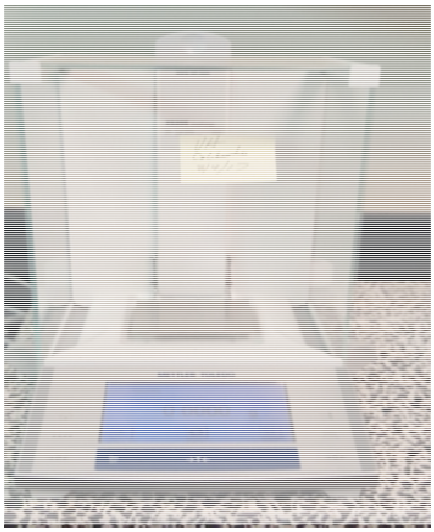
Similar to TSS, high concentrations of TDS may also reduce water clarity, contribute to a decrease in photosynthesis, combine with toxic compounds and heavy metals, and lead to an increase in water temperature.

TDS is used to estimate the quality of drinking water, because it represents the amount of ions in the water. Water with high TDS often has a bad taste and/or high water hardness, and could result in a laxative effect.

The TDS concentration of a water sample can be estimated from specific conductance if a linear correlation between the two parameters is first established. Depending on the chemistry of the water, TDS (mg/l) can be estimated by multiplying specific conductance (micromhos/cm) by a factor between 0.55 and 0.75. TDS can also be determined by measuring individual ions and adding them up.

Suspended Matter for Mixed Liquor and Return Sludge (MLSS)

Suspended matter in mixed liquor and return sludge can be used to determine process status, estimate the quantity of biomass, and evaluate the results of process adjustments.



Apparatus

- Buchner funnel and adaptor
- Filter flask
- Filter paper 110 mm diam., Whatman 1-4
- 103^0 drying oven
- Desiccator
- Balance
- Graduated Cylinder

Procedure

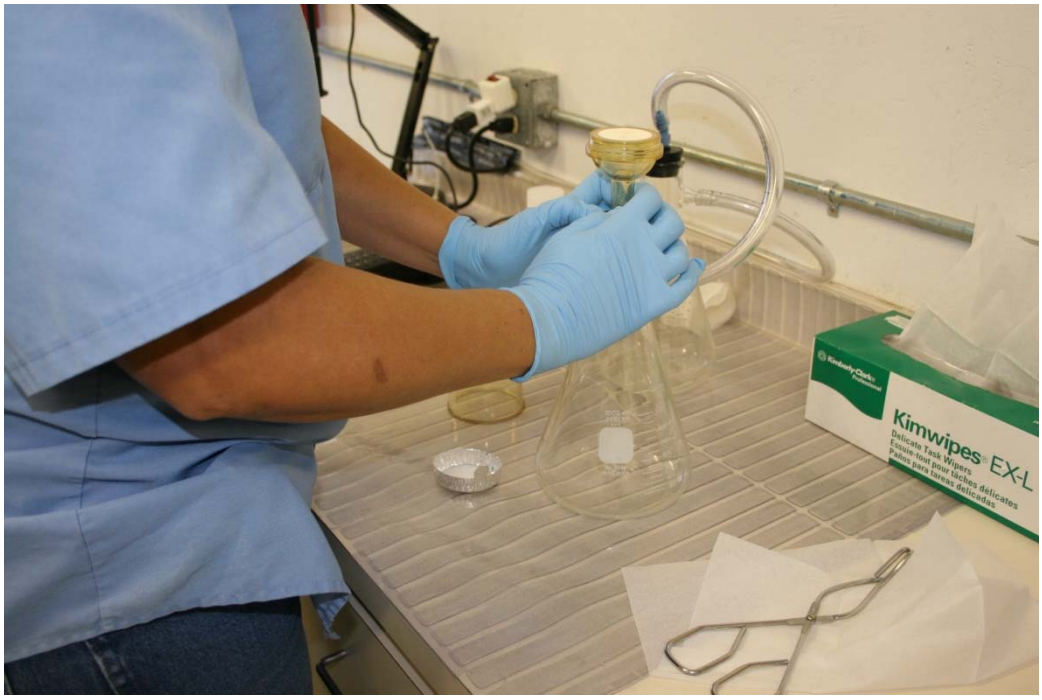
1. Dry the filter papers in oven at 103^0 c to remove all traces of moisture.
2. Remove papers from oven and desiccate to cool for approximately 5 minutes.
3. Weigh to the nearest 0.01g and record the mass (W_1)
4. Place the paper in the bottom of the Buchner funnel and carefully arrange so that the outer edges lay snugly along the side. Careful not to touch it with your finger. Use a glass rod. Wet the paper, turn on the vacuum and make a good seal, make a pocket covering the bottom of the funnel.
5. Add 20 to 100 mls of sample at a sufficient rate to keep the bottom of the funnel covered, but not fast enough to overflow the pocket made by the filter paper. Record the Volume used.
6. Remove the filter paper with tweezers. Dry in a 103^0 c oven for 30 minutes. Remove and desiccate. Reweigh the filter paper (W_2) to the nearest 0.01g.

Calculation:

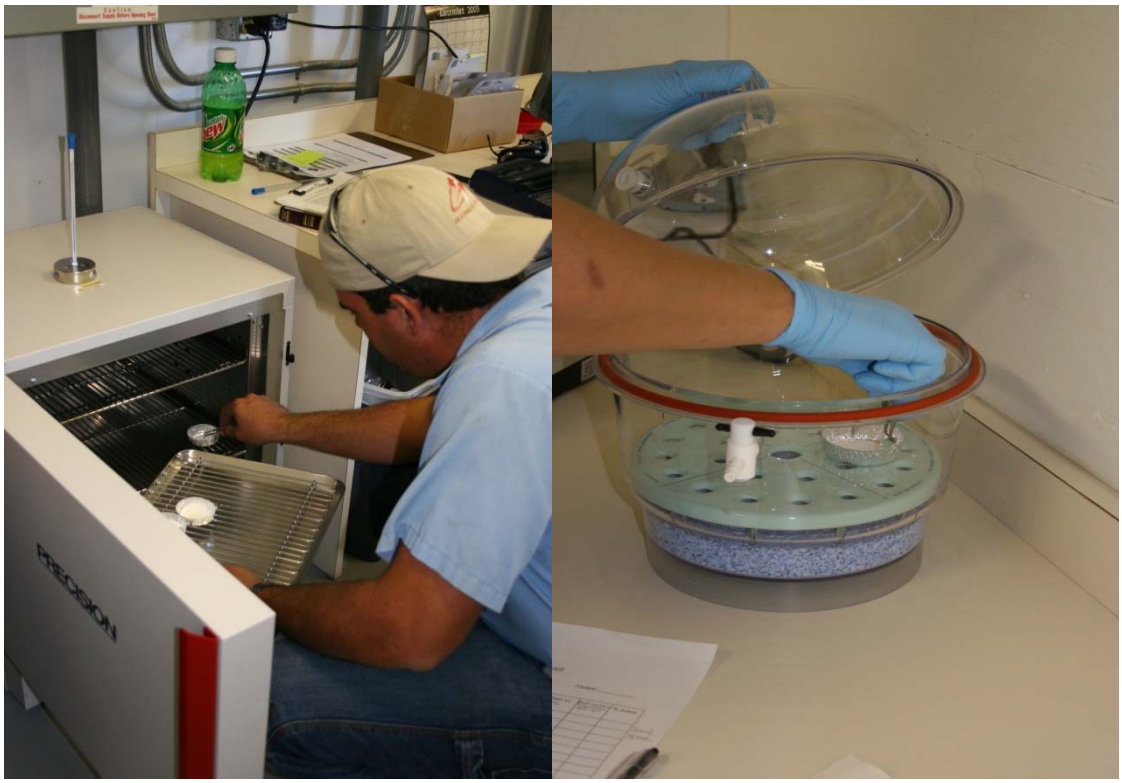
mg/L Suspended Matter

$$\frac{(W_2) - (W_1) \times 1000 \text{ ML/L}}{\text{ML Sample}}$$

Where:
(W_1) and (W_2) are expressed in mg.
(W_1) = mass of the prepared filter
(W_2) = mass of the filter and sample after the filtration step.

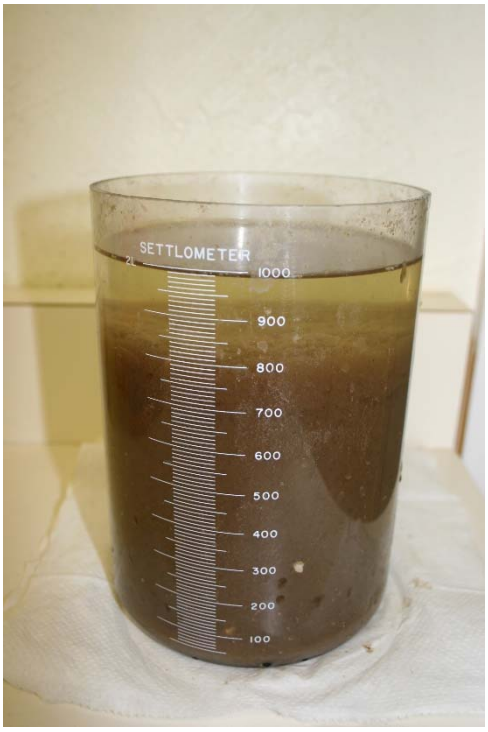


Total dissolved solids - The weight per unit volume of all volatile and non-volatile solids dissolved in a water or wastewater after a sample has been filtered to remove colloidal and suspended solids.



Top left, filters being baked at 105ºC. Right photograph, filters in desiccant.

Sludge Volume Index (SVI)



1. Pour sample of mixed liquor from the process into a 2 liter settlometer.

2. Allow it to settle for 30 minutes

3. After the time period, read the marking to determine the volume occupied by the settled sludge and the reading is expressed in terms of mL/L and this is figure is known as the sludge volume SV value.

4. Next, for MLSS, there are actually two approaches to get the value. A conventional standard approach is by filtering the sludge, drying it and then weigh the second portion of the mixed liquid. However, this can be time consuming and a faster way is by using MLSS meter.

.

Calculation:
The results obtained from the suspended matter test and settleability test on aerated mixed liquor are used to obtain the SVI.

Calculation:

SVI = $\frac{\text{sludge volume SV}}{\text{MLSS}} \times 1000$

SETTLEABILITY TEST

The settleability test is an analysis of the settling characteristics of the activated sludge mixed liquor suspended solids (MLSS). This analysis is often referred to as "running a settleometer." The analysis is normally done within the treatment plant rather than a certified laboratory.

This analysis includes five basic items:

1. A clear container to hold the MLSS
2. A timing device or clock to track elapsed time
3. A paddle or other mixing device
4. A clip board, or place to record the readings
5. Operator patience, attentiveness and diligence

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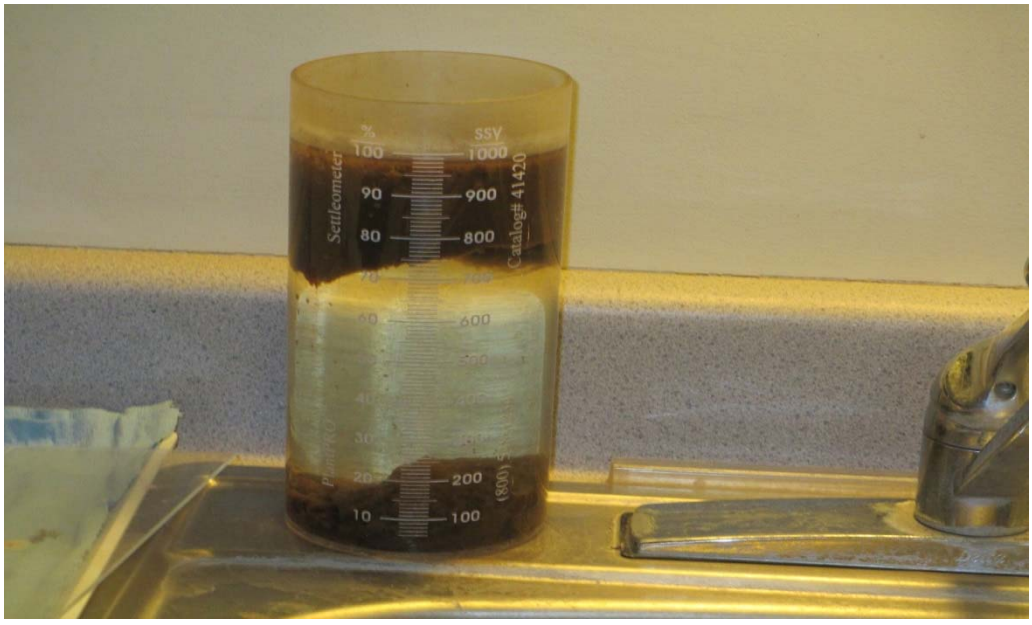
The settleometer is a great tool for operators. It indicates how the solids will settle in the clarifier and the density of the sludge.



During the settleometer test, operators not only check how the solids settle out they can also determine the rate of denitrification in the clarifier.

Sludge Volume Index Lab Report Worksheet

Suspended Mater Calculations:

(W_1) = _____mg Duplicate (W_1) = _____mg

(W_2) = _____mg (W_2) = _____mg

mls Sample = _____ mls Sample = _____ .

mg/L suspended matter = _____ dup. _____ .

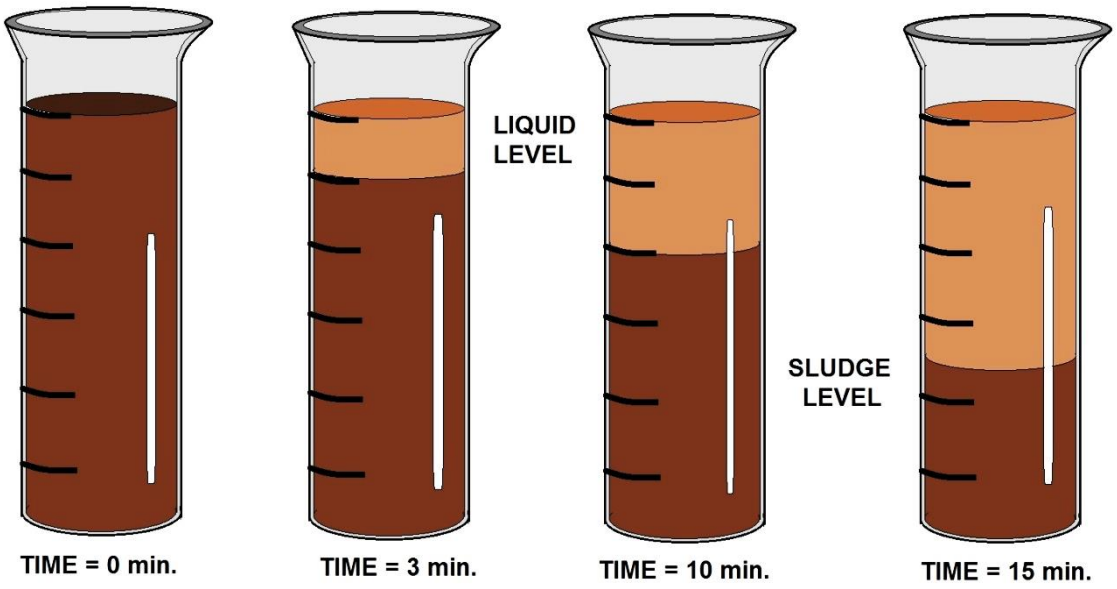
Settleability Calculations:

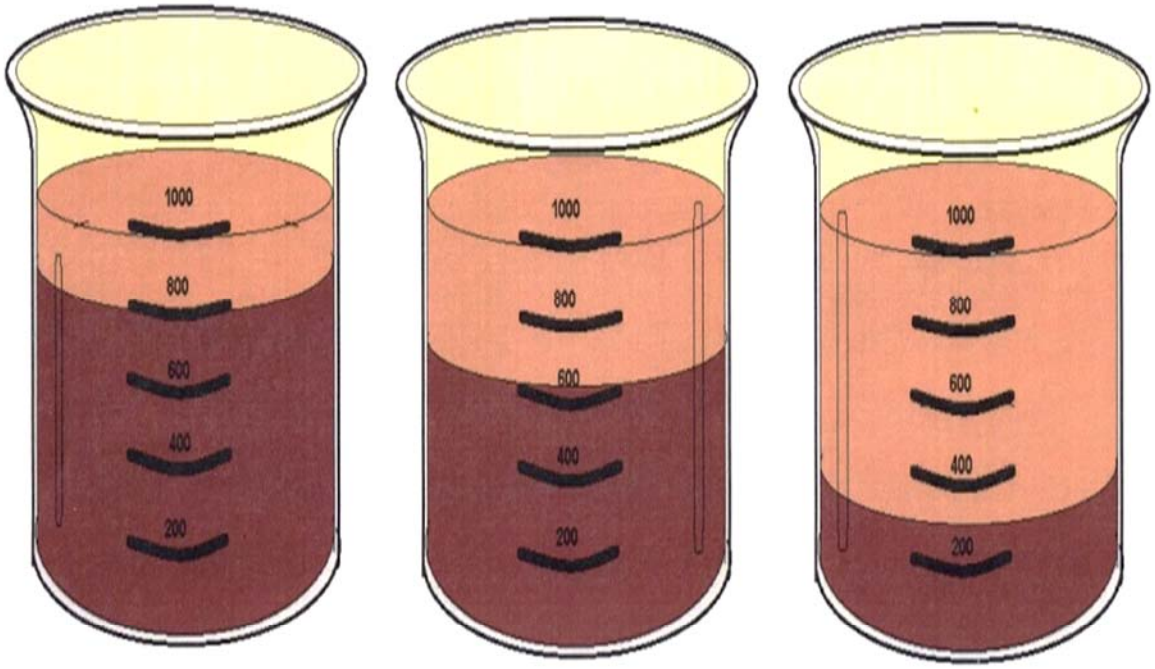
% settled sludge = _____

$$\frac{\text{(ml of sludge in settled mixed liquor or returned sludge x 100)}}{1000}$$

Sludge Volume Index Calculations:

$$\frac{\text{(ml of sludge in settled mixed liquor in 30 minutes x 1000 mg/g)}}{\text{mg/L of suspended matter in mixed liquor}}$$





SSV30 and SSV60

Activated sludge process control calculations may include determination of the thirty and sixty minute settled sludge volume (SSV30 and SSV60), sludge volume index (SVI) and pounds of waste activated sludge removed from the process. The sample jars used are 1,000 milliliters or 2,000 milliliters.

Nitrification is a microbial process by which ammonia is sequentially oxidized to nitrite and then to nitrate. The nitrification process is accomplished primarily by two groups of autotrophic nitrifying bacteria that can build organic molecules by using energy obtained from inorganic sources—in this case, ammonia or nitrite.

Denitrification is the process by which nitrates are reduced to gaseous nitrogen by facultative anaerobes. Facultative anaerobes, such as fungi, can flourish in anoxic conditions because they break down oxygen containing compounds to obtain oxygen.

MIXED LIQUOR DEFINITION

Mixed liquor suspended solids (MLSS) is the concentration of suspended solids, in an aeration tank during the activated sludge process, which occurs during the treatment of wastewater. The units MLSS is primarily measured in are milligrams per liter (mg/L). Mixed liquor is a combination of raw or unsettled wastewater and activated sludge within an aeration tank.

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MLSS

Mixed Liquor Suspended Solids (**MLSS**) is a test for the total suspended solids in a sample of mixed liquor. This test is essentially the same as the test you performed for **TSS** in the last lab, except for the use of mixed liquor as the water sample. In addition, the concentration of suspended solids found in the mixed liquor is typically much greater than that found in the raw or treated water. **MLSS** concentrations are often greater than 1,000 mg/L, but should not exceed 4,000 mg/L.

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MLVSS

Mixed Liquor Volatile Suspended Solids is generally defined as the microbiological suspension in the aeration tank of an activated-sludge biological wastewater treatment plant.

The biomass solids in a biological waste water reactor are usually indicated as **total suspended solids (TSS)** and **volatile suspended solids (VSS).** The mixture of solids resulting from combining recycled sludge with influent wastewater in the bioreactor is termed **mixed liquor suspended solids (MLSS)** and **mixed liquor volatile suspended solids (MLVSS).** The solids are comprised of biomass, **nonbiodegradable volatile suspended solids (nbVSS),** and inert **inorganic total suspended solids (iTSS).**

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MIXED LIQUOR CALCULATION

MLSS (g/L) = SV [mL/L]/SVI [mL/g]

Where:

SVI = sludge volume index (mL/g)
SV = Volume of settled solids per 1 litre after 30 minutes
SVI is a calculation from two analyses: SV30 and MLSS.
$0=(Q+Q_r)(X')-(Q_rX'_r+Q_wX'_r)$

Where:

Q = wastewater flow rate (m^3/d)
Q_r = return sludge flow rate (m^3/d)
X' = MLSS (kg/m^3)
X'_r = return sludge concentration (kg/m^3)
Q_w = sludge wasting flow rate (m^3/d)

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MIXED LIQUOR ADJUSTMENT

If content is too high

1. The process is prone to bulking of solids and the treatment system can become overloaded.
2. This can cause the dissolved oxygen content to drop; this may reduce the efficiency of nitrification and the settleability of the sludge.
3. Excessive aeration will be required, which wastes electricity.
4. It will create thick foam on upper layer.

If content is too low

1. The process may not remove sufficient organic matter from the wastewater.
2. The sludge age may be too low to enable nitrification.

The typical control band for the concentration of MLSS is 2 to 4 g/L for conventional activated sludge, or up to 15 g/l for membrane bioreactors.

Technical Learning College

Fecal Coliform Analysis Section

FECAL TESTING CONCEPT

A sample is collected and analyzed using aseptic (sterile) technique. A measured volume of sample is filtered through a sterile 0.45µ membrane filter, transferred to an absorbent pad containing m-FC broth, then incubated at 44.5°C for 24 hours. Blue/blue gray colonies are counted and reported as colony forming units (cfu) per 100 ml of sample. The method is limited by turbidity in the sample. Excessive turbidity will reduce fecal coliform recovery, requiring the MPN method to be used instead of the membrane filter method.

Technical Learning College

Sample Collection
Fecal coliform must be collected in a clean, sterile borosilicate glass or plastic bottle containing sodium thiosulfate. Pre-sterilized bags or bottles containing sodium thiosulfate can also be used. Sodium thiosulfate is added to remove residual chlorine which will kill fecal coliforms during transit. 0.1 ml of 10% sodium thiosulfate is added to a 120 ml sample bottle prior to sterilization. The minimum bottle size should be 120 ml to allow enough head space (1") for proper sample mixing.

Collection Procedure
Select a site that will provide a representative sample. Fecal coliform samples are always grab samples and should be drawn directly from the flow stream without using collection other devices. We do not want to cross contaminate the sample.

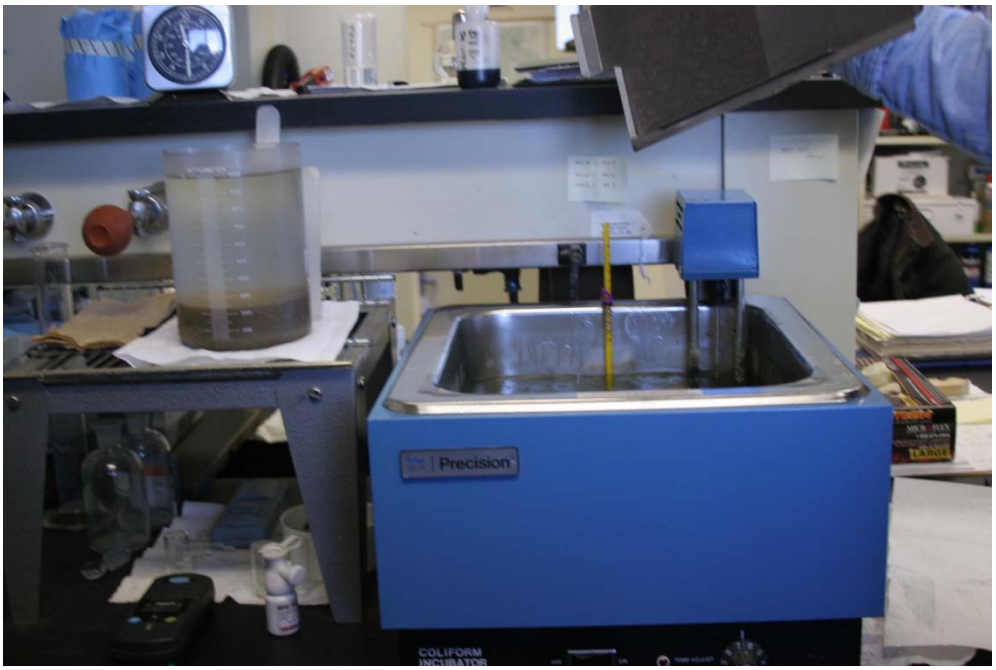
Keep the sample bottle lid closed tightly until it is to be filled.

Remove the cap and do not contaminate the inner surface of the bottle, neck, threads or cap. Fill the container without rinsing, being sure to leave ample air space to allow mixing. Rinsing will remove the dechlorinating agent.

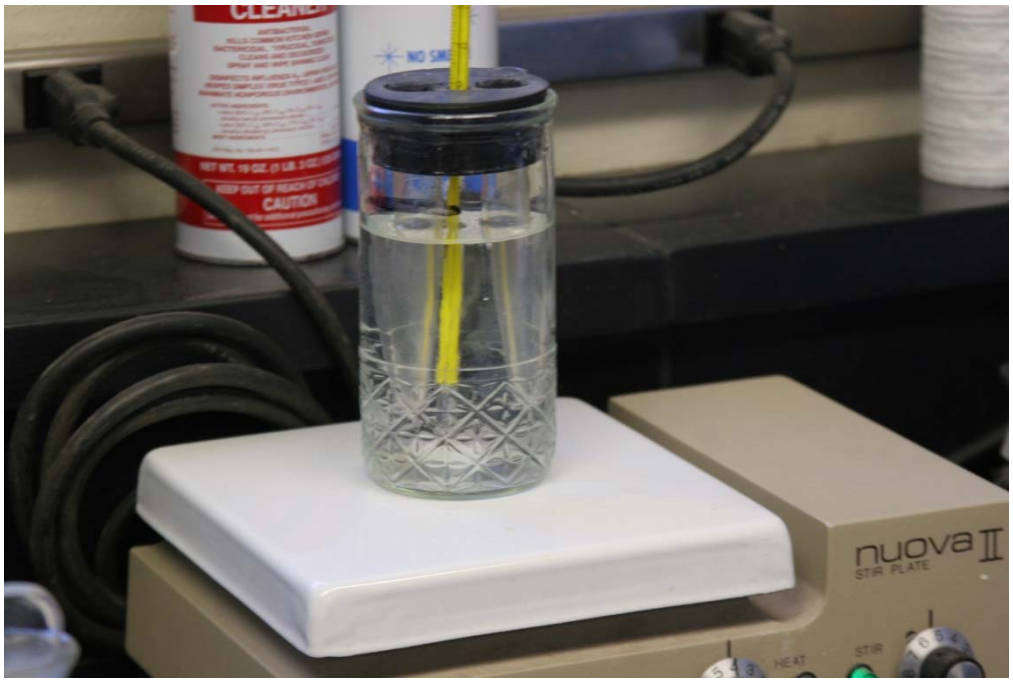
All samples should be labeled properly with date and time of collection, sampler's name, and sample collection location. Leaking sample bottles allow for contamination of the sample and should be discarded and the sampling repeated.

Preservation
Fecal coliform samples should be analyzed as soon as possible after collection to prevent changes to the microorganism population. Fecal coliforms must be transported on ice, if they cannot be analyzed within 1 hour of collection. Fecal coliforms transported at ambient temperature may reproduce and higher bias to the numbers than desired or they may be killed off resulting in lower numbers, if handled poorly such as transport in sunlight. Fecal coliform samples should be stored by the laboratory in a refrigerator until time of analysis. The maximum holding time for state or federal permit reporting purposes is 6 hours.

Photo Journal #7



An incubator for the coliform test. The operator will place the sample in this device for 24 to 48 hours depending on the desired results. There are several different methods to calculate coliform bacteria. This is an older true and tested method.



This glass bottle is used for quality control (QA/QC) for bacteria samples tubes.

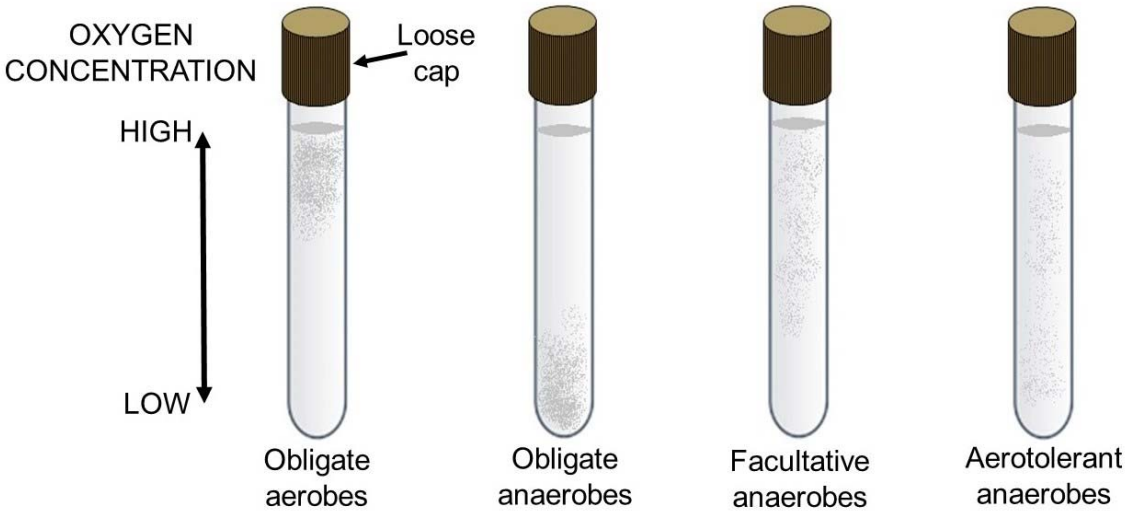
Lab technician should be wearing safety glasses/goggles for preparation of the fecal test.

This operator is splitting the sample for bacteriological analysis. Always wear gloves for your and others' safety. We have all seen the operator holds a sandwich in one hand while working in the lab, or the operator who does not wear gloves at all.

Phase microscopes are used to see indicator bugs and other MO's microorganisms. This examination is used so that the operator knows how well the process is working.

This is a filter used for the coliform test.

Operators analyze sludge samples to improve wasting.



AEROBIC & ANAEROBIC BACTERIA CULTIVATION

Pass-Through /Emerging Wastewater Contaminants Section

This section provides a brief background on emerging contaminants and key findings from studies on the co-removal of emerging contaminants by nutrient removal technologies.

The term “emerging contaminants” refers broadly to those synthetic or naturally occurring chemicals, or to any microbiological organisms, that have not been commonly monitored in the environment but which are of increasing concern because of their known or suspected adverse ecological or human health effects.

Some chemicals that we use in our everyday lives including medicines (such as prescription and non-prescription drugs), personal hygiene products (for example, soaps, disinfectants, …) and their chemical additives (such as preservatives) are present in the environment and associated with various sources such as municipal wastewater treatment plants, runoff from agricultural and urban land surfaces, and septic systems. These contaminants are referred to collectively as “contaminants of emerging concern” and represent a shift in traditional thinking as many are produced industrially yet are dispersed to the environment from domestic uses.

This investigation identifies and quantifies the environmental sources, presence, and magnitude of environmental contaminants with the underlying theme of understanding the contaminants from their source to a “receptor organism.” The goal of the investigation is to understand the actual versus the perceived health risks to humans or wildlife due to low-level exposures from understudied chemical contaminants in the environment.

Background on Emerging Contaminants
Emerging contaminants can fall into a wide range of groups defined by their effects, uses, or by their key chemical or microbiological characteristics. Two groups of emerging contaminants that are of particular interest and concern at present are endocrine disrupting chemicals (EDCs) and pharmaceutical and personal care products (PPCPs). These compounds are found in the environment, often as a result of human activities.

EDCs may interfere with the endocrine systems by damaging hormone-producing tissues, changing the processes by which hormones are made or metabolized, or mimicking hormones.

In addition to natural and synthetic forms of human hormones that are released into the environment, there are a multitude of synthetic organic compounds that are able to disrupt the endocrine system. Public concern about EDCs in the environment has been rapidly increasing since the 1990s when researchers reported unusual sexual characteristics in wildlife. A report by the USGS, found that fish in many streams had atypical ratios of male and female sex hormones (Goodbred et al., 1997).

In England, researchers found that male trout kept in cages near WWTP outfalls were developing eggs on their testes and had increased levels of the protein that is responsible for egg production (vitellogenin) (Sumpter, 1995; Kaiser, 1996). Follow-up laboratory studies showed that synthetic forms of estrogen (17α-ethynylestradiol (EE2)) could increase vitellogenin production in fish at levels as low as 1-10 ng/L, with positive responses seen down to the 0.1-0.5 ng/L level (Purdom et al., 1994).

Human estrogens have the ability to alter sexual characteristics of aquatic species at trace concentrations as low as 1 ng/L (Purdom et al., 1994). WWTP effluents have been identified as a primary source for EDCs in the environment, with the bulk of their endocrine disrupting activity resulting from human estrogen compounds (Desbrow et al., 1998, Snyder et al., 2001).

The synthetic estrogen, EE2, and the natural estrogens, estrone (E1) and 17β-estradiol (E2), are the greatest contributors to endocrine disrupting activity in WWTP effluent (Johnson et al., 2001) with EE2 showing the greatest recalcitrance in WWTPs (Joss et al., 2004). Influent concentrations range from below detection to 70 ng/L for EE2, 670 ng/L for E1 and 150 ng/L for E2 (Vethaak et al., 2005, Clara et al., 2005b). Other EDCs include tributyl tin, which was previously used in paints to prevent marine organisms from sticking to ships, nonylphenol (a surfactant), and bisphenol A (platicizer and preservative).

PPCPs encompass a wide variety of products that are used by individuals for personal health or cosmetic reasons, and also include certain agricultural and veterinary medicine products.

PPCPs comprise a diverse collection of thousands of chemical substances, including prescription and over-the counter therapeutic drugs, veterinary drugs, fragrances, sun-screen products, vitamins, and cosmetics. Many of these products, notably the pharmaceuticals for human or animal use, are specifically designed to be biologically active, and some PPCPs may also fall into the category of EDCs described previously.

Estrogens of Concern

Name	***Chemical Structure***	***Name***	***Chemical Structure***
E1	Estrone		C18H22O2
E2	17β-estradiol		C18H24O2
E3	Estriol		C18H24O3
EE2	17α-ethynylestradiol		C20H24O2

Currently, municipal sewage treatment plants are engineered to remove conventional pollutants such as solids and biodegradable organic material but are not specifically designed for PPCP removal or for other unregulated contaminants. Wastewater treatment commonly consists of primary settling followed by biological treatment, secondary settling, and disinfection. This treatment can remove more than 90 percent of many of the most commonly known or suspected EDCs found in wastewater influent; however, low concentrations of some suspected EDCs may remain in the wastewater treatment sludge or effluent (WERF, 2005). As discussed in the next section, studies have shown enhanced nutrient removal technologies to be effective in removing low concentrations of some emerging contaminants.

Removal of Emerging Contaminants by Nutrient Removal Technologies

Several studies have examined the effectiveness of current wastewater treatment technologies in the removal of emerging contaminants. Some of these studies are discussed below and their major findings are organized under three subsections: role of activated sludge SRT in removal efficiency, role of nitrifying bacteria in biodegradation, and use of RO to improve removal efficiencies. Details regarding the study design, such as evaluated treatments and contaminants, and a summary of major study findings are provided at the end of this section.

The significant findings are also presented as follows:

- Removal efficiencies were enhanced for several investigated contaminants at longer SRTs, with critical SRTs for some beyond which removal rates did not improve.
- Longer SRTs allow for the establishment of slower growing bacteria (e.g., nitrifying bacteria in activated sludge), which in turn provide a more diverse community of microorganisms with broader physiological capabilities.
- Nitrifying bacteria may play a key role in biodegradation but the role of heterotrophic bacteria may also play a significant role.
- Reverse osmosis has been found to effectively remove PPCPs below detection limits including those that that were not consistently removed at longer SRTs.

One caveat regarding studies on emerging contaminants is that their concentrations in wastewater influent are often quite low (e.g., concentrations of ng/L to µg/L range) and may be close to method detection limits. Therefore, small variations between measured influent and effluent concentrations may show large variations in apparent removal efficiencies, possibly even producing negative calculated removals.

Role of Solids Retention Time in Removal Efficiency

The focus of several studies has been the relationship of the SRT to the removal of emerging contaminants. In particular, many investigated whether longer SRTs would result in increased removal efficiencies for estrogens and other categories of PPCPs. Longer activated sludge SRTs allow for the establishment of slower growing bacteria (e.g., nitrifying bacteria in activated sludge), which in turn provide a more diverse community of microorganisms with broader physiological capabilities.

Clara et al. (2005a), Kreuzinger et al. (2004), and Oppenheimer et al. (2007) observed enhanced removal with increasing SRTs for most of the EDCs and pharmaceuticals tested and found no significant differences in removal performances between conventional activated sludge systems and MBR when operated at similar SRT10 °C. This is likely due to the molecular weight of the study compounds, which was smaller than the molecular weight cut-off of the ultrafiltration membranes in the MBR.

Researchers have observed similar findings for natural estrogens with higher removal percentages at longer SRTs. Effluent concentrations for three natural estrogens were measured near their detection limits at SRTs10° C higher than 10 days, with their critical SRTs10° C estimated between 5 and 10 days (Clara et al., 2005a).

High removal rates of > 90 percent were also observed by Joss et al. (2004) in a study in which they evaluated the removal of E1, E2, and EE2 under aerobic and anaerobic conditions in WWTPs designed for nutrient removal. Joss et al. (2004) also reported that the maximum efficiency is dependent on redox conditions, with the highest removal rate occurring during the reduction of E1 to E2 under aerobic conditions. Clara et al. (2005a) cited examples where conflicting results were obtained for EE2.

Ternes et al. (1999) found no significant elimination of this compound during batch experiments; however, Baronti et al. (2000) and Joss et al. (2004) report greater than 85 percent removal in full-scale WWTPs.

For the pharmaceuticals ibuprofen and bezafibrate, Clara et al. (2005a) reported more than 95 percent removal during treatment and calculated the critical value for SRT10° C at 5 days for ibuprofen and about 10 days for bezafibrate.

Analogous removal results were obtained in several other studies (Stumpf et al., 1998; Buser et al., 1999; Zwiener et al., 2001, as cited in Clara et al., 2005a; Oppenheimer et al., 2007). Clara et al. (2005b) noted no or slight removal of these two pharmaceuticals and two musk fragrances (tonalide and galaxolide) at a WWTP with a low SRT of 1 to 2 days.

Clara et al. (2005a, 2005b) also found that the pharmaceutical carbamazepine was not removed during wastewater treatment. In addition, these studies found contradictory results for diclofenac (e.g., removal rates ranged from no removal to > 70 percent at SRTs of > 10 days (Clara et al., 2005b)). Clara et al. (2005a) also cited several examples where conflicting results were obtained for diclofenac. No significant removal was reported by Buser et al. (1999) and Heberer (2002a); whereas, Ternes et al. (1998) observed elimination rates of up to 70 percent.

The Classes of EDCs included:
Steroids/sterols (naturally occurring, synthetic, and phytoestrogens), organohalides, metals/ organometals, alkyl phenols, polycyclic aromatic hydrocarbons (PAHs)/crude oil, and plasticizers.

Although the WERF 2005 technical brief states that in general, EDC treatment effectiveness is improved with increased SRT, it does not provide the specific SRTs that are associated with the cited removal rates.

Oppenheimer et al. (2007) examined the relationship of SRT to treatment removal efficiencies for 20 PPCPs that are commonly found in the influent of U.S. treatment facilities. Many of the studies already discussed here have been conducted primarily in Europe, were conducted at small-scale WWTPs and bench/pilot plants under controlled conditions, and focused on estrogens and prescription pharmaceuticals rather than PPCPs. The Oppenheimer et al. (2007) study also noted trends regarding the effect of HRT and pure oxygen systems compared to conventional aeration systems on PPCP removal.

Oppenheimer et al. (2007) defined a minimum critical SRT as the minimum time needed to consistently demonstrate greater than 80 percent removal. The results of the study showed that this critical SRT was compound dependent but that the majority of the 20 PPCPs were consistently removed in those treatment plants operating at SRTs of 5 to 15 days. Specifically, 9 of 12 frequently occurring PPCPs were effectively removed through secondary treatment (e.g., ibuprofen).

Conversely, six compounds that are routinely detected in influent (i.e., detected in at least 20 percent of the influent samples) were not well removed by secondary treatment (BHA, DEET, musk ketone, triclosan, benzophenone, galaxolide).

The results for galaxolide conflicted with those reported by Clara et al. (2005b) who generally found high removal rates with SRTs > 10 days and Kreuzinger et al. (2004) who reported removal at SRT between 25 to 40 days. Oppenheimer et al. (2007) found that some compounds such as octylphenol, tri-(chloroethyl) phosphate, and triphenylphosphate were not well removed by secondary treatment; however, these were seldom detected in the influent samples. Based on these results, Oppenheimer et al. (2007) concluded that secondary treatment provides an “effective first barrier” for the 20 PPCPs in the study.

Oppenheimer et al. (2007) also noted trends regarding the effect of HRT and pure oxygen systems compared to conventional aeration systems on PPCP removal but determined that insufficient data existed to make any definitive conclusions.

When the PPCP removal performance of a high-purity oxygenated activated sludge plant was compared to a conventional aeration system, the pure oxygen system showed higher removal rates although its SRT was shorter than the conventional aeration plant (i.e., 1 day versus 3 days). In addition, different HRTs operating at similar SRTs had similar removal rates, and therefore suggested that HRT does not significantly affect removal effectiveness in the investigated PPCPs.

Role of Nitrifying Bacteria in Biodegradation
As discussed above, longer SRTs allow for the establishment of slow-growing nitrifying bacteria (i.e., ammonia oxidizing bacteria and nitrite-oxidizing bacteria). Several studies evaluated whether nitrifying bacteria improve the biodegradation of certain emerging contaminants. Major findings from some of these studies are discussed in this section.

The WERF (2005) technical brief indicated that secondary biological treatment that includes nitrification, nutrient removal, and disinfection may remove more than 90 percent of certain steroids, and >95 percent of alkyl phenols; whereas, secondary biological treatment without nitrification and disinfection may decrease removal of these by more than 15 percent. Batt et al. (2006) investigated the role of nitrifying bacteria in activated sludge in the biodegradation of two pharmaceuticals, iopromide and trimethoprim.

The biodegradation of these compounds was conducted in two lab-scale bioreactors using biomass from a stage-2 activated sludge WWTP (operated at an SRT of 49 days). In one of the bioreactors, nitrification was not inhibited (Batch-1 reactor); in the other, nitrification was inhibited with allylthiourea (Batch-2 reactor).

Monitoring was also conducted in the WWTP and compared to results obtained from the batch reactors. Both reactors exhibited high removal rates for iopromide; however, for trimethoprim, Batch-1 showed a high removal rate of 70 percent, contrasted to the Batch-2 reactor removal rate of approximately 25 percent with nitrification inhibited.

Removal rates within the treatment plant, however, were consistent for both pharmaceuticals, showing significantly higher removal rate after nitrification (approx. 60 percent for iopromide and 50 percent for trimethoprim) compared to activated sludge treatment only (<1 percent for both).

Based on these results, Batt et al. (2006) concluded that nitrifying bacteria have a key role in the biodegradation of pharmaceuticals in WWTP that are operated at higher SRTs. This conclusion is supported by Marttinen et al. (2003), who investigated the fate of phthalates in a WWTP with nitrogen removal and observed that about one third of the removal occurred in the nitrification/denitrification treatment phase.

Studies by Yi and Harper (2007), Khunjar et al. (2007), and others have focused on the mechanisms of estrogen removal during nitrification. Possible mechanisms include sorption of estrogens to solids and biotransformation within the treatment facility, especially in the presence of nitrifying activated sludges (Khunjar et al., 2007).

Ammonia oxidizing bacteria have monoxygenase enzymes for ammonia oxidation and these enzymes have been shown previously to be nonspecific and able to accomplish cometabolic degradation of recalcitrant organics.

Cometabolic degradation is a reasonable hypothesis for estrogen degradation because this compound is present at low ng/L concentrations that are below those expected to support microbial growth on that compound alone.

One goal of the Yi and Harper (2007) study was to establish whether biotransformation of EE2 is due to cometabolic activity. They conducted batch experiments using enriched cultures of autotrophic ammonia oxiders. Their study and others (Vader et al., 2000, Shi et al., 2004, as reported in Yi and Harper, 2007) showed a strong relationship between nitrification and EE2 removal in enriched nitrifying cultures.

Topic 9- Laboratory Analysis/ Process Control
Section Post Quiz

1. What is the proper term used that are determined using a concentration cell with transference, by measuring the potential difference between a hydrogen electrode and a standard electrode such as the silver chloride electrode?

2. In chemistry, *pH* is a measure of the acidity or basicity of an aqueous solution. Solutions with a pH less than 7 are said to be acidic and solutions with a pH greater than 7 are basic or alkaline. Pure water has a pH very close to?

3. Mathematically, pH is the negative logarithm of the activity of the (solvated) hydronium ion, more often expressed as the measure of the?

4. Which terms is used for aqueous solutions can be done with a glass electrode and a pH meter, or using indicators?

5. The pH scale is logarithmic and therefore pH is?

6. Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater. It is one of the best measures of the sensitivity of the stream to acid inputs. There can be long-term changes in the _____ of rivers and streams in response to human disturbances.

7. pH is defined as the decimal logarithm of the reciprocal of the _____, $a_{H}+$, in a solution.

8. Alkalinity is the name given to the quantitative capacity of an aqueous solution to neutralize an?

9. What is the term used for the color of a test solution with a standard color chart provides a means to measure pH accurate to the nearest whole number?

10. The calculation of the pH of a solution containing acids and/or bases is an example of a chemical speciation calculation, that is, a mathematical procedure for calculating the concentrations of all chemical species that are present in the solution. The complexity of the procedure depends on the?

11. Under normal circumstances this means that the concentration of hydrogen ions in acidic solution can be taken to be equal to the concentration of the acid. The pH is then equal to minus the logarithm of?

12. Alkalinity of water is its acid-neutralizing capacity. It is the sum of all the titratable bases. The measured value may vary significantly with the?

13. The pH of a solution containing a weak base may require the?

14. Alkalinity is a measure of this missing term and can be interpreted in terms of specific substances only when the chemical composition of the sample is known.

15. More precise measurements are possible if the color is measured spectro-photometrically, using a?

16. For strong acids and bases no calculations are necessary except in extreme situations. The pH of a solution containing a weak acid requires?

17. The calculation of the pH of a solution containing acids and/or bases is an example of a _____ calculation, that is, a mathematical procedure for calculating the concentrations of all chemical species that are present in the solution

18. What is the term used for measurements in the interpretation and control of water and wastewater treatment processes?

19. What is the term used for compounds that, for practical purposes, are completely dissociated in water?

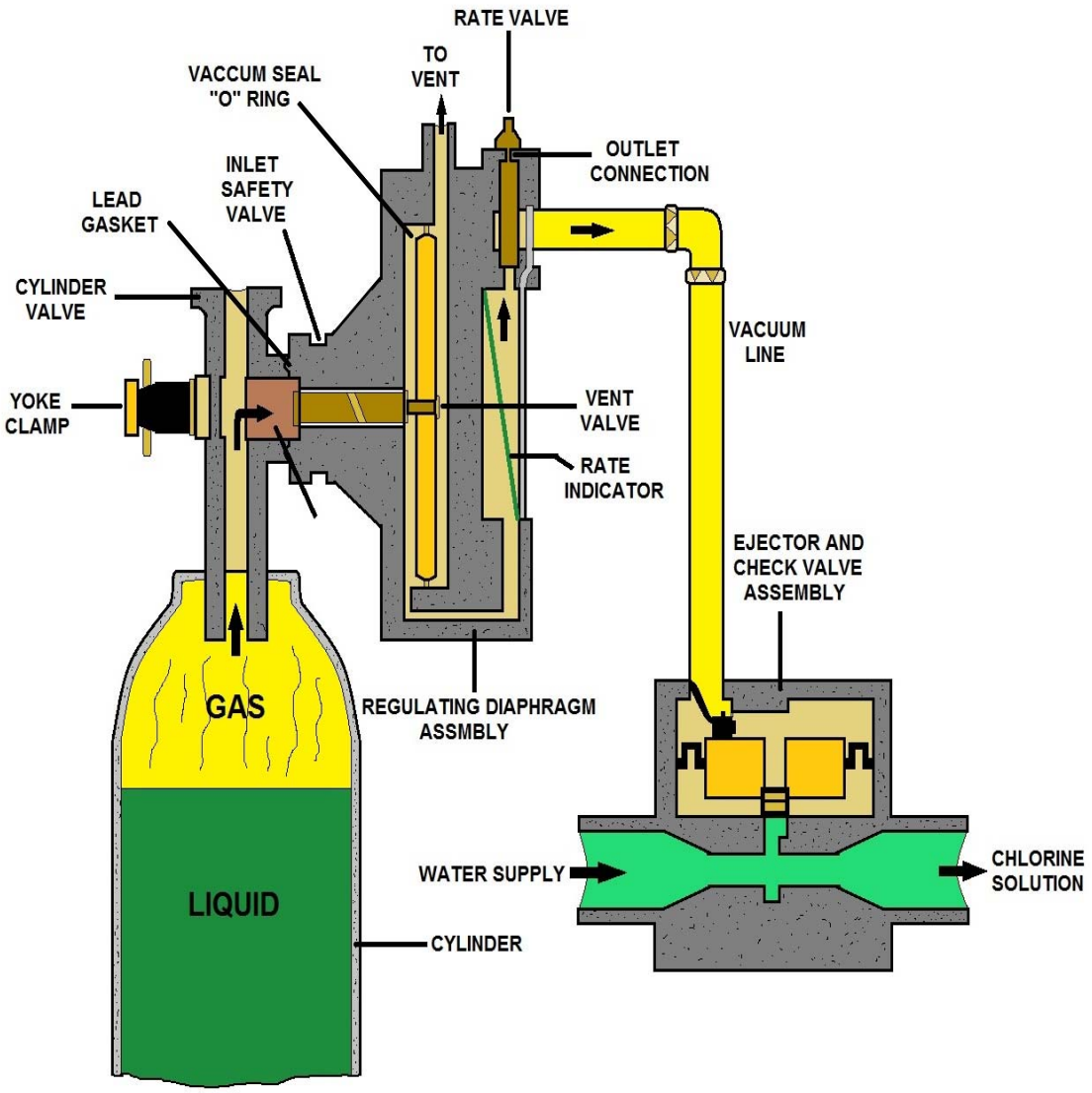
Topic 10- Disinfection Section

Topic 10 - Section Focus: You will learn the basics of disinfection with an emphasis on Chlorine. At the end of this section, you the student will be able to understand and describe wastewater disinfection. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Topic 10 – Scope/Background: Traditionally, the use of chlorine gas was the most common method of wastewater disinfection. Chlorine gas itself is relatively inexpensive but is a highly toxic chemical that must be transported and handled with extreme caution. It is stored under pressure in large tanks and is released into the wastewater as a gas. Sodium hypochlorite is a diluted liquid form of chlorine that is also commonly used.

Chlorine Introduction

Chlorine gas is the most widely used wastewater disinfectant in the U.S., and it kills most bacteria, viruses, and other microorganisms that cause disease. Chlorine is introduced to wastewater in the form of gas, hypochlorites (tablets, solutions, or powder), and other compounds. The different forms of chlorine used at wastewater treatment plants are gaseous chlorine, sodium hypochlorite solution, calcium hypochlorite, and bromium chloride. Wastewater and chlorine are first mixed completely in less than 1 second and then enter a baffled contact chamber to allow time for disinfection to occur. The effluent is then discharged to the receiving water. Chlorine residuals can persist in treated wastewater for many hours. To minimize the effect on aquatic life and the environment, EPA or States require that chlorinated wastewater be dechlorinated. Dechlorination is the process of removing the chlorine residual prior to discharge.



150 Lb. SINGLE CYLINDER CHLORINATOR

The weight refers to the weight of chlorine that is being supplied, not the weight of the full cylinder. Full 150 pound cylinders will weigh from 235 pounds to 290 pounds. Full ton containers will weigh from 3,300 pounds to 3,650 pounds.

To equal the chlorine available from one 150 lb. chlorine cylinder, you would need to use:

- 180 gal. of sodium hypochlorite or
- 228 lb. of calcium hypochlorite.

To equal the chlorine available from a one-ton chlorine container, you would need to use:

- 2,400 gal. of sodium hypochlorite or
- 3,040 lb. of calcium hypochlorite.

Chlorine Breakdown

Name: Chlorine
Symbol: Cl
Atomic Number: 17
Atomic Mass: 35.4527 amu
Melting Point: -100.98 °C (172.17 K, -149.764 °F)
Boiling Point: -34.6 °C (238.55 K, -30.279997 °F)
Number of Protons/Electrons: 17
Number of Neutrons: 18
Classification: Halogen
Crystal Structure: Orthorhombic
Density @ 293 K: 3.214 g/cm^3
Color: Green
Uses: Water purification, bleaches
Obtained From: Salt
Date of Discovery: 1774
Discoverer: Carl Wilhelm Scheele
Name Origin: From the Greek word *khlôros* (green)

Chlorine Gas Information
Identifiers
1. CAS No.: 7782-50-5
2. RTECS No.: FO2100000
3. DOT UN: 1017 20
4. DOT label: Poison gas

Chlorinators

Safety Data
NIOSH IDHL: 25 ppm
NIOSH Ceiling: **0.5ppm/15 minutes**
PEL/TWA: **1 ppm**
TLV/TWA: **1 ppm**
TLV/STEL: **3 ppm**
TLV/IDLH: **25 ppm**

Physical Data
1. **Molecular weight:** 70.9
2. **Boiling point (at 760 mm Hg):** -34.6 degrees C (-30.28 degrees F)
3. **Specific gravity (liquid):** 1.41 at 20 degrees C (68 degrees F) and a pressure of 6.86 atm
4. **Vapor density**: 2.5
5. **Melting point:** -101 degrees C (-149.8 degrees F)
6. **Vapor pressure at 20 degrees C (68 degrees F):** 4,800 mm Hg
7. **Solubility**: Slightly soluble in water; soluble in alkalis, alcohols, and chlorides.
8. **Evaporation rate:** Data not available.

Chlorine's Appearance and Odor
Chlorine is a greenish-yellow gas with a characteristic pungent odor. It condenses to an amber liquid at approximately -34 degrees C (-29.2 degrees F) or at high pressures. Odor thresholds ranging from 0.08 to part per million (ppm) parts of air have been reported. Prolonged exposures may result in olfactory fatigue.

Reactivity
1. **Conditions Contributing to Instability**: Cylinders of chlorine may burst when exposed to elevated temperatures. Chlorine in solution forms a corrosive material.
2**. Incompatibilities**: Flammable gases and vapors form explosive mixtures with chlorine. Contact between chlorine and many combustible substances (such as gasoline and petroleum products, hydrocarbons, turpentine, alcohols, acetylene, hydrogen, ammonia, and sulfur), reducing agents, and finely divided metals may cause fires and explosions. Contact between chlorine and arsenic, bismuth, boron, calcium, activated carbon, carbon disulfide, glycerol, hydrazine, iodine, methane, oxomonosilane, potassium, propylene, and silicon should be avoided. Chlorine reacts with hydrogen sulfide and water to form hydrochloric acid, and it reacts with carbon monoxide and sulfur dioxide to form phosgene and sulfuryl chloride. Chlorine is also incompatible with moisture, steam, and water.
3. **Hazardous Decomposition Products:** None reported.
4**. Special Precautions:** Chlorine will attack some forms of plastics, rubber, and coatings.

Flammability
Chlorine is a non-combustible gas.
The National Fire Protection Association has assigned a flammability rating of 0 (no fire hazard) to chlorine; however, most combustible materials will burn in chlorine.
1. **Flash point:** Not applicable.
2. **Autoignition temperature**: Not applicable.
3. **Flammable limits in air:** Not applicable.
4. **Extinguishant:** For small fires use water only; do not use dry chemical or carbon dioxide. Contain and let large fires involving chlorine burn. If fire must be fought, use water spray or fog.

Fires involving chlorine should be fought upwind from the maximum distance possible.

Keep unnecessary people away; isolate the hazard area and deny entry. For a massive fire in a cargo area, use unmanned hose holders or monitor nozzles; if this is impossible, withdraw from the area and let the fire burn. Emergency personnel should stay out of low areas and ventilate closed spaces before entering.

Containers of chlorine may explode in the heat of the fire and should be moved from the fire area if it is possible to do so safely. If this is not possible, cool fire exposed containers from the sides with water until well after the fire is out.

Stay away from the ends of containers. Firefighters should wear a full set of protective clothing and self- contained breathing apparatus when fighting fires involving chlorine.

Elemental Chlorine Essentials

Chlorine is one of 90 natural elements, the basic building blocks of our planet. To be useful, an element must be relatively abundant or have extremely desirable properties. Chlorine has both characteristics. As a result -- over the course of many decades of careful research and development -- scientists have learned to use chlorine and the products of chlorine chemistry to make drinking water safe, destroy life-threatening germs, produce life-saving drugs and medical equipment, shield police and fire fighters in the line of duty, and ensure a plentiful food supply.

In 1774, in his small experimental laboratory, Swedish pharmacist Carl Wilhem Scheele released a few drops of hydrochloric acid onto a piece of manganese dioxide. Within seconds, a greenish-yellow gas arose. Although he had no idea at the time, he had just discovered chlorine.

The fact that the greenish-yellow gas was actually an element was only recognized several decades later by English chemist Sir Humphrey Davy. Until that time, people were convinced that the gas was a compound of oxygen. Davy gave the element its name on the basis of the Greek word khloros, for greenish-yellow. In 1810 he suggested the name "*chloric gas*" or "*chlorine*."

One of the most effective and economical germ-killers, chlorine also destroys and deactivates a wide range of dangerous germs in homes, hospitals, swimming pools, hotels, restaurants, and other public places. Chlorine's powerful disinfectant qualities come from its ability to bond with and destroy the outer surfaces of bacteria and viruses.

First used as a germicide to prevent the spread of "child bed fever" in the maternity wards of Vienna General Hospital in Austria in 1846, chlorine has been one of society's most potent weapons against a wide array of life-threatening infections, viruses, and bacteria for 150 years.

When the first men to set foot on the moon returned to earth (Apollo 11 mission: 24.7.69) a hypochlorite solution was chosen as one of the disinfectants for destroying any possible moon germs.

What Happens to Chlorine When It Enters the Environment?

- When released to air, chlorine will react with water to form hypochlorous acid and hydrochloric acid, which are removed from the atmosphere by rainfall.

- Chlorine is slightly soluble in water. It reacts with water to form hypochlorous acid and hydrochloric acid. The hypochlorous acid breaks down rapidly. The hydrochloric acid also breaks down; its breakdown products will lower the pH of the water (makes it more acidic).

- Since chlorine is a gas it is rarely found in soil. If released to soil, chlorine will react with moisture forming hypochlorous acid and hydrochloric acid. These compounds can react with other substances found in soil.

- Chlorine does not accumulate in the food chain.

Disinfectant Qualities

Restaurants and meat and poultry processing plants rely on chlorine bleach and other chlorine-based products to kill harmful levels of bacteria such as *Salmonella* and *E. coli* on food preparation surfaces and during food processing. Chlorine is so important in poultry processing that the US Department of Agriculture requires an almost constant chlorine rinse for much of the cutting equipment. In fact, no proven economical alternative to chlorine disinfection exists for use in meat and poultry processing facilities.

Properties

Because it is highly reactive, chlorine is usually found in nature bound with other elements like sodium, potassium, and magnesium. When chlorine is isolated as a free element, chlorine is a greenish yellow gas, which is 2.5 times heavier than air. It turns to a liquid state at -34°C (-29°F), and it becomes a yellowish crystalline solid at -103°C (-153°F). Chemists began experimenting with chlorine and chlorine compounds in the 18th century. They learned that chlorine has an extraordinary ability to extend a chemical bridge between various elements and compounds that would not otherwise react with each other. Chlorine has been especially useful in studying and synthesizing organic compounds -- compounds that have at least one atom of the element carbon in their molecular structure. All living organisms, including humans, are composed of organic compounds.

Chlorine is one of the most abundant chemical elements on Earth. It is ubiquitous in soils, minerals, plants and animals. Seawater is a huge reservoir of dissolved chlorine weathered from the continents and transported to the oceans by Earth's rivers.

Chlorine is also one of the most useful chemical elements. Each chemical element has its own set of unique properties and chlorine is known as a very reactive element--so reactive, in fact, that it is usually found combined with other elements in the form of compounds. More than 3,500 naturally occurring chlorinated organic (associated with living organisms) compounds alone have been identified.

Chlorine's chemical properties have been harnessed innovatively for good use. For example, this element plays a huge role in public health. Chlorine-based disinfectants are capable of removing a wide variety of disease-causing germs from drinking water and wastewater as well as from hospital and food production surfaces. Additionally, chlorine plays an important role in the manufacture of thousands of products we depend upon every day, including such diverse items as cars, computers, pharmaceuticals and military flak jackets. As the ninth largest chemical produced in the U.S. by volume, chlorine is truly a "workhorse chemical."

Released from the Salt of the Earth

Chlorine is produced industrially from the compound sodium chloride, one of the many salts found in geologic deposits formed from the slow evaporation of ancient seawater. When electricity is applied to a brine solution of sodium chloride, chlorine gas (Cl2), caustic soda (NaOH) and hydrogen gas (H_2) are generated according to the following reaction:

Salt	+	Water	→	Chlorine gas	+	Caustic soda	+	Hydrogen gas
$2\ NaCl$	+	$2\ H_2O$	→	Cl_2	+	$2\ NaOH$	+	H_2

Co-Products
As the reaction demonstrates, chlorine gas cannot be produced without producing caustic soda, so chlorine and caustic soda are known as "co-products," and their economics are inextricably linked. Caustic soda, also called "alkali," is used to produce a wide range of organic and inorganic chemicals and soaps. In addition, the pulp and paper, alumina and textiles industries use caustic soda in their manufacturing processes. Thus, the "chlor-alkali" industry obtains two very useful chemicals by applying electrical energy to sea salt.

Chlorine Gas Feed Room

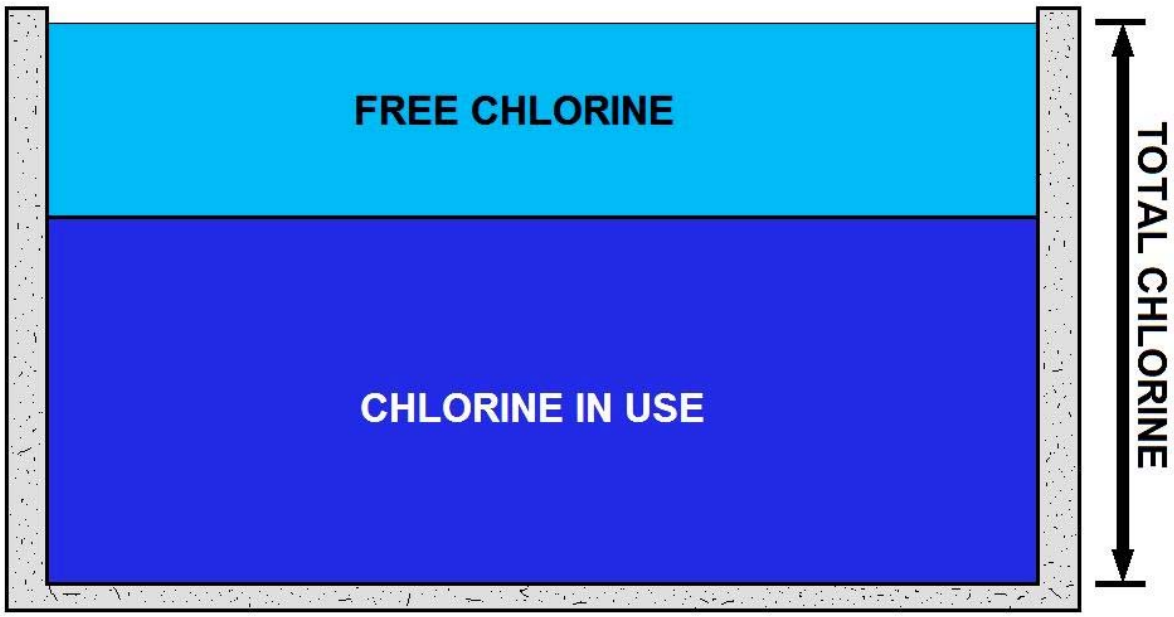
Common Definitions

Chlorine Gas Feed Room
A chlorine gas feed room, for the purposes of this document, is a room that contains the chlorinator(s) and active cylinder(s) used to apply chlorine gas at a water or wastewater facility.

Chlorine Gas Storage Room
A chlorine gas storage room, for the purposes of this document, is a room other than a chlorine gas feed room, in which full, partial, or empty chlorine gas cylinders or ton containers are stored at a water or wastewater facility.

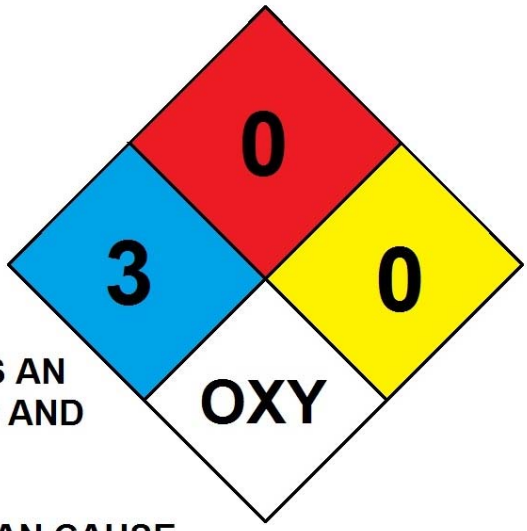
Gas Chlorinator
A gas chlorinator is a device used to meter and control the application rate of chlorine gas into a liquid. There is the danger of the gas escaping at a water or wastewater treatment facility. The gas chlorinator should be isolated from a water or wastewater treatment plant.

Chlorine Cabinet
A chlorine cabinet is a pre-assembled or factory built unit that contains the equipment used to apply chlorine gas at a water or wastewater treatment facility. It is isolated from a water or wastewater treatment plant.



CHLORINE IN USE + FREE CHLORINE = TOTAL CHLORINE

- **CHLORINE IS EXTREMELY IRRITATING AND CAN BURN THE EYES AND SKIN**
- **IF INHALED, CHLORINE CAUSES RESPIRATORY DISTRESS, AND POSSIBLY BE FATAL**



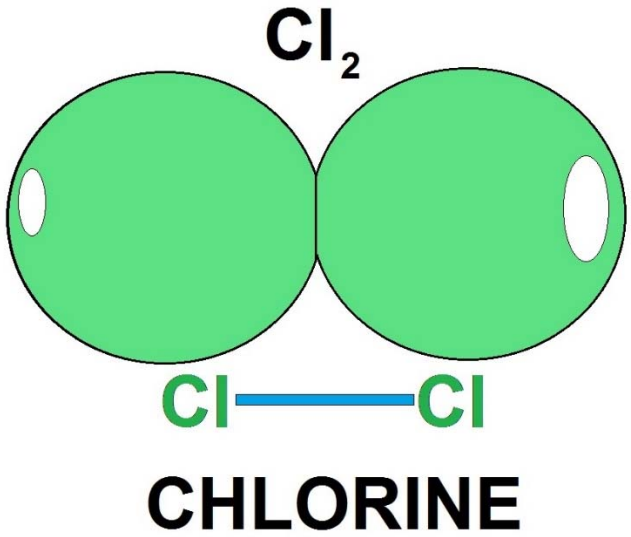
- **LIQUID CHLORINE RELEASE FORMS AN IMMEDIATE CLOUD (FLASH VAPOR) AND COOLS TO -29^{0}F**
- **EXPOSURE TO CHLORINE LIQUID CAN CAUSE SEVERE FROSTBITE, AS WELL AS CHEMICAL BURNS.**

THE HEALTH EFFECTS OF CHLORINE EXPOSURE

Chlorine Gas Section

Chlorine Gas

Background: Chlorine gas is a pulmonary irritant with intermediate water solubility that causes acute damage in the upper and lower respiratory tract. Chlorine gas was first used as a chemical weapon at Ypres, France in 1915. Of the 70,552 American soldiers poisoned with various gasses in World War I, 1843 were exposed to chlorine gas. Approximately 10.5 million tons and over 1 million containers of chlorine are shipped in the U.S. each year.



Chlorine is a yellowish-green gas at standard temperature and pressure. It is extremely reactive with most elements. Because its density is greater than that of air, the gas settles low to the ground. It is a respiratory irritant, and it burns the skin. Just a few breaths of it are fatal. Cl2 gas does not occur naturally, although Chlorine can be found in a number of compounds.

Chlorine gas is likely the most widely used oxidizing microbiocide. It has traditionally been the biocide of choice in many cooling water treatment systems. It is a strong oxidizer that is relatively easy to feed and is quite inexpensive. Upon introduction into the water stream, chlorine hydrolyzes into hypochlorous acid (HOCl) and hydrochloric acid (HCl).

This hydrolyzation provides the active toxicant, HOCl, which is pH-dependent. In alkaline cooling systems, it readily dissociates to form the hypochlorite ion (OCl-). This dissociation phenomenon is important to remember when working with systems that will operate at a higher pH. In alkaline conditions, OCl- becomes the predominant species and lacks the biocidal efficacy of the non-dissociated form. Considerably more HOCl is present at a pH of 7.0 than at pH 8.5.

It is also widely known that chlorine is non-selective, making it very sensitive to contamination from either cooling water makeup or from in-plant process leaks. Ammonia, organic acids and organic compounds, sulfides, iron and manganese all easily react with HOCl. The amount of chlorine needed to react with these contamination species is referred to as chlorine demand and it must be satisfied before active HOCl is available to provide a free chlorine residual.

The combination of high chlorine demand in process-contaminated systems and the dissociation process in alkaline systems creates the need for greater chlorine feed to obtain the same microbial efficacy. This results in a higher concentration of HCl in the cooling system. Since HCl removes alkalinity, pH depression and system corrosion could occur. In low pH water the passive metal oxide layers protecting the metal may resolubulize, exposing the surface to corrosion. At free mineral acidity (pH <4.3), many passivating inhibitors become ineffective, and corrosion will proceed rapidly. Increased chloride may also have a negative impact on system corrosion. The chloride ion (Cl^-) can damage or penetrate the passive oxide layer, leading to localized damage of the metal surface.

High chlorine concentrations have also been shown to directly attack traditional organic-based corrosion inhibitors. When these inhibitors are "deactivated," the metal surface would then be susceptible to corrosion. Process Safety Management (PSM) guidelines dictated by the U.S. Occupational Safety and Health Administration (OSHA), discharge problems related to chlorinated organic compounds such as trihalomethane (THM), dezincification of admiralty brass and delignification of cooling tower wood are other significant concerns associated with the use of chlorine.

Pathophysiology
Chlorine is a greenish-yellow, noncombustible gas at room temperature and atmospheric pressure. The intermediate water solubility of chlorine accounts for its effect on the upper airway and the lower respiratory tract.

Exposure to chlorine gas may be prolonged because its moderate water solubility may not cause upper airway symptoms for several minutes. In addition, the density of the gas is greater than that of air, causing it to remain near ground level and increasing exposure time.

The odor threshold for chlorine is approximately 0.3-0.5 parts per million (ppm); however, distinguishing toxic air levels from permissible air levels may be difficult until irritative symptoms are present.

Mechanism of Activity
The mechanisms of the above biological activity are poorly understood and the predominant anatomic site of injury may vary, depending on the chemical species produced. Cellular injury is believed to result from the oxidation of functional groups in cell components, from reactions with tissue water to form hypochlorous and hydrochloric acid, and from the generation of free oxygen radicals.

Although the idea that chlorine causes direct tissue damage by generating free oxygen radicals was once accepted, this idea is now controversial. The cylinders on the right contain chlorine gas. The gas comes out of the cylinder through a gas regulator. The cylinders are on a scale that operators use to measure the amount used each day. The chains are used to prevent the tanks from falling over. Chlorine gas is stored in vented rooms that have panic bar equipped doors. Operators have the equipment necessary to reduce the impact of a gas leak, but rely on trained emergency response teams to contain leaks.

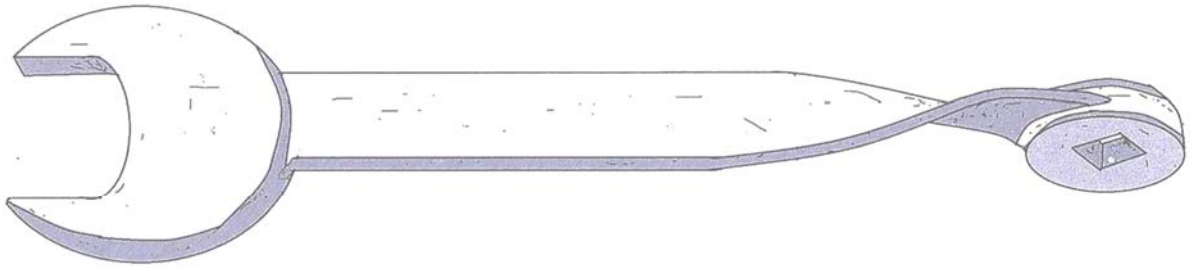
Solubility Effects
Hydrochloric acid is highly soluble in water. The predominant targets of the acid are the epithelia of the ocular conjunctivae and upper respiratory mucus membranes. Hypochlorous acid is also highly water soluble with an injury pattern similar to hydrochloric acid. Hypochlorous acid may account for the toxicity of elemental chlorine and hydrochloric acid to the human body.

Early Response to Chlorine Gas
Chlorine gas, when mixed with ammonia, reacts to form chloramine gas. In the presence of water, chloramines decompose to ammonia and hypochlorous acid or hydrochloric acid. The early response to chlorine exposure depends on the
(1) concentration of chlorine gas,
(2) duration of exposure,
3) water content of the tissues exposed, and (4) individual susceptibility.

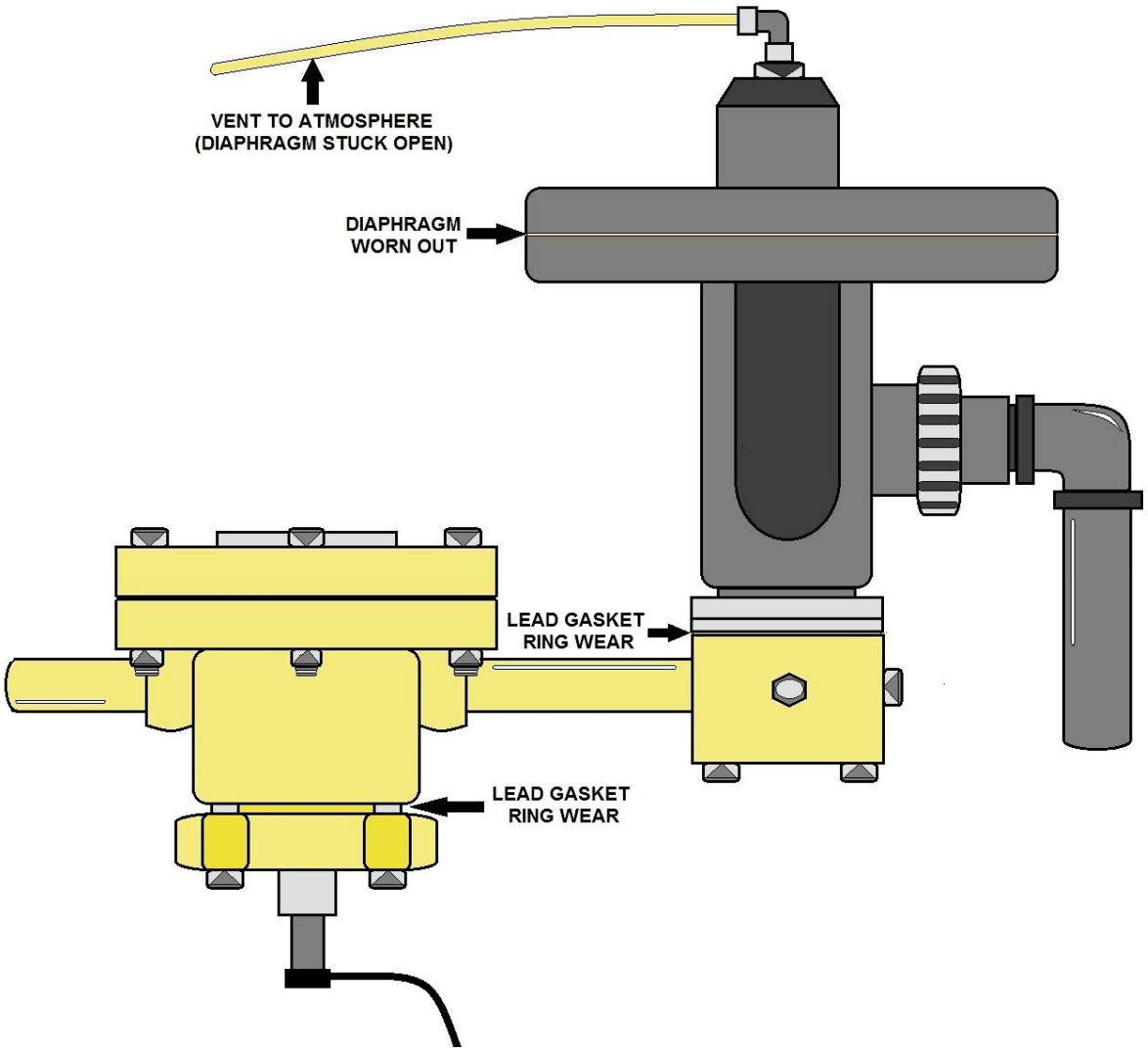
Immediate Effects
The immediate effects of chlorine gas toxicity include acute inflammation of the conjunctivae, nose, pharynx, larynx, trachea, and bronchi. Irritation of the airway mucosa leads to local edema secondary to active arterial and capillary hyperemia. Plasma exudation results in filling the alveoli with edema fluid, resulting in pulmonary congestion.

Pathological Findings
Pathologic findings are nonspecific. They include severe pulmonary edema, pneumonia, hyaline membrane formation, multiple pulmonary thromboses, and ulcerative tracheobronchitis.

The hallmark of pulmonary injury associated with chlorine toxicity is pulmonary edema, manifested as hypoxia. Noncardiogenic pulmonary edema is thought to occur when there is a loss of pulmonary capillary integrity.



TWISTED CHLORINE WRENCH



CHLORINE VACUUM REGULATOR
(SOURCES OF LEAK IN SYSTEM)

Using DPD Method for Chlorine Residuals

N, N – diethyl-p-phenylenediame

Small portable chlorine measuring kit. The redder the mixture the “hotter” or stronger the chlorine in solution.

Measuring Chlorine Residual

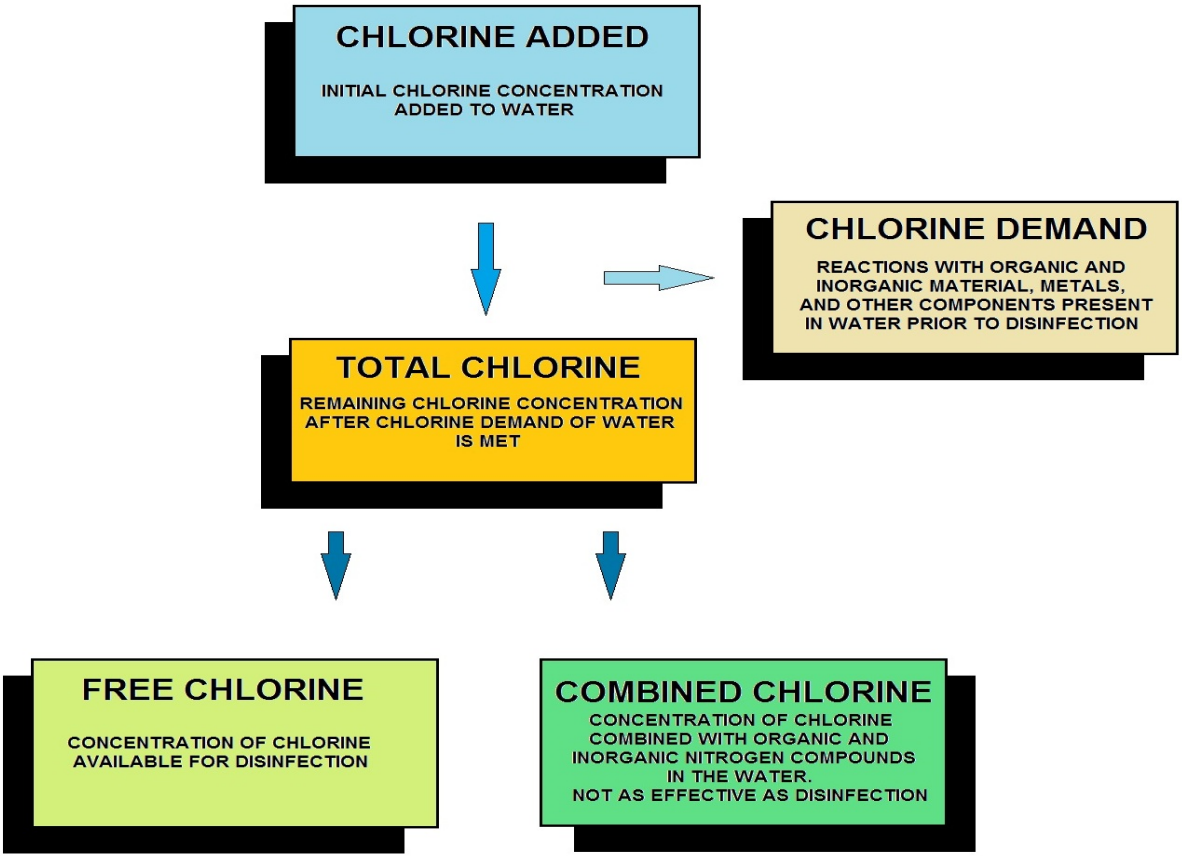
Chlorine residual is the amount of chlorine remaining in water that can be used for disinfection. A convenient, simple and inexpensive way to measure chlorine residual is to use a small portable kit with pre-measured packets of chemicals that are added to water.

(Make sure you buy a test kit using the ***DPD method***, and not the outdated orthotolodine method.)

Chlorine test kits are very useful in adjusting the chlorine dose you apply. You can measure what chlorine levels are being found in your system (especially at the far ends).

Free chlorine residuals need to be checked and recorded daily. These results should be kept on file for a health or regulatory agency inspection during a regular field visit.

The most accurate method for determining chlorine residuals to use the laboratory amperometric titration method.



CHLORINE DISINFECTION

Chlorine Demand

Chlorine combines with a wide variety of materials. These side reactions complicate the use of chlorine for disinfecting purposes. Their demand for chlorine must be satisfied before chlorine becomes available to accomplish disinfection. Amount of chlorine required to react on various water impurities before a residual is obtained. Also, means the amount of chlorine required to produce a free chlorine residual of 0.1 mg/l after a contact time of fifteen minutes as measured by Iodometric method of a sample at a temperature of twenty degrees in conformance with Standard methods.

Chlorine Questions and Answer Review

True or False. Even brief exposure to 1,000 ppm of Cl_2 can be fatal. True

How does one determine the ambient temperature in a chlorine room? Use a regular thermometer because ambient temperature is simply the air temperature of the room.

How is the effectiveness of disinfection determined? From the results of coliform testing.

How often should chlorine storage ventilation equipment be checked? Daily.

Amperometric Titration

The chlorination of water supplies and polluted waters serves primarily to destroy or deactivate disease-producing microorganisms. A secondary benefit, particularly in treating drinking water, is the overall improvement in water quality resulting from the reaction of chlorine with ammonia, iron, manganese, sulfide, and some organic substances.

Chlorination may produce adverse effects. Taste and odor characteristics of phenols and other organic compounds present in a water supply may be intensified. Potentially carcinogenic chloro-organic compounds such as chloroform may be formed.

Combined chlorine formed on chlorination of ammonia- or amine-bearing waters adversely affects some aquatic life. To fulfill the primary purpose of chlorination and to minimize any adverse effects, it is essential that proper testing procedures be used with a foreknowledge of the limitations of the analytical determination.

Chlorine applied to water in its molecular or hypochlorite form initially undergoes hydrolysis to form free chlorine consisting of aqueous molecular chlorine, hypochlorous acid, and hypochlorite ion. The relative proportion of these free chlorine forms is pH- and temperature-dependent. At the pH of most waters, hypochlorous acid and hypochlorite ion will predominate.

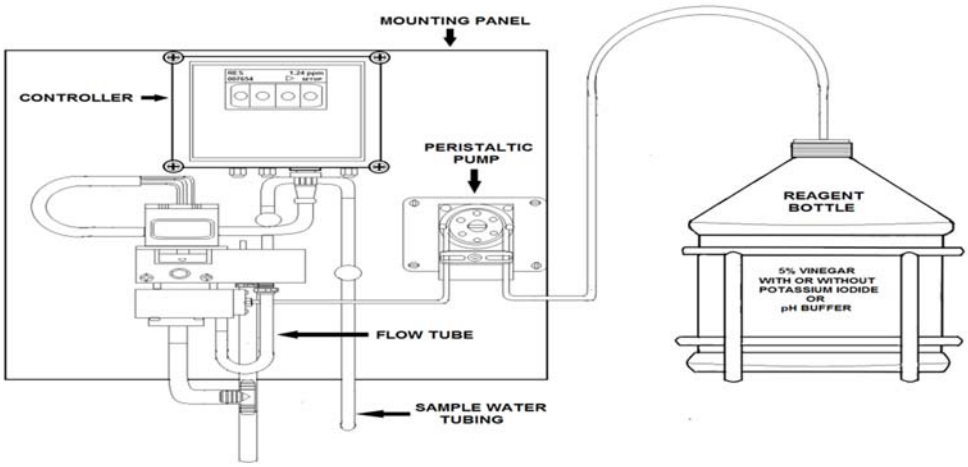
Free chlorine reacts readily with ammonia and certain nitrogenous compounds to form combined chlorine. With ammonia, chlorine reacts to form the chloramines: monochloramine, dichloramine, and nitrogen trichloride.

The presence and concentrations of these combined forms depend chiefly on pH, temperature, initial chlorine-to-nitrogen ratio, absolute chlorine demand, and reaction time. Both free and combined chlorine may be present simultaneously. Combined chlorine in water supplies may be formed in the treatment of raw waters containing ammonia or by the addition of ammonia or ammonium salts.

Chlorinated wastewater effluents, as well as certain chlorinated industrial effluents, normally contain only combined chlorine. Historically the principal analytical problem has been to distinguish between free and combined forms of chlorine.

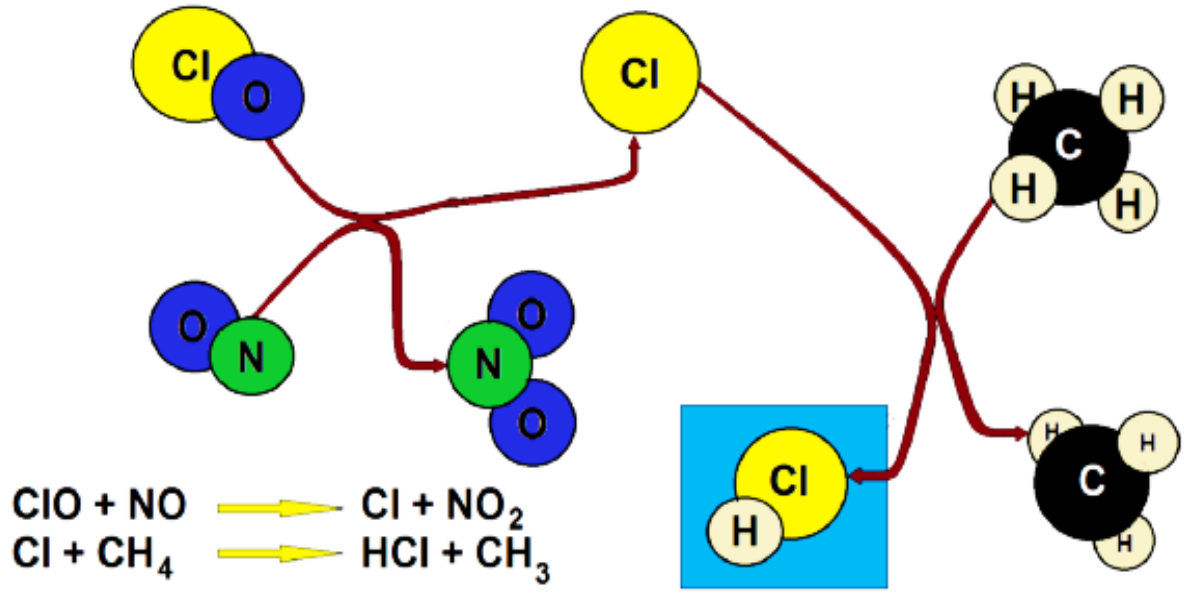
Hach's AutoCAT 9000™ Automatic Titrator is the newest solution to hit the disinfection industry – a comprehensive, benchtop chlorine-measurement system that does it all: calibration, titration, calculation, real-time graphs, graphic print output, even electrode cleaning. More a laboratory assistant than an instrument, the AutoCAT 9000 gives you:

- High throughput, performs the titration and calculates concentration, all automatically.
- Forward titration, USEPA-accepted methods for free and total chlorine and chlorine dioxide with chlorite.
- Back titration, USEPA-accepted method for total chlorine in wastewater.
- Accurate, yet convenient: the easiest way to complete ppb-level amperometric titration.



CHLORINE RESIDUAL ANALYZER

A true on-line, amperometric, chlorine residual analyzer requires a pH buffer to bring the sample pH down to a range where optimum free chlorine residuals can be accurately measured, ideally 4.0 to 4.5 pH. Any amperometric chlorine residual analyzer that claims buffers are not required uses either a pH buffered electrolyte in the probe, or makes an electronically simulated pH compensation (which is not a true chlorine residual reading). The vinegar reduces the pH in the sampling cell, which provides the current potential needed to measure chlorine residuals accurately.



CHLORINE IN THE ATMOSPHERE

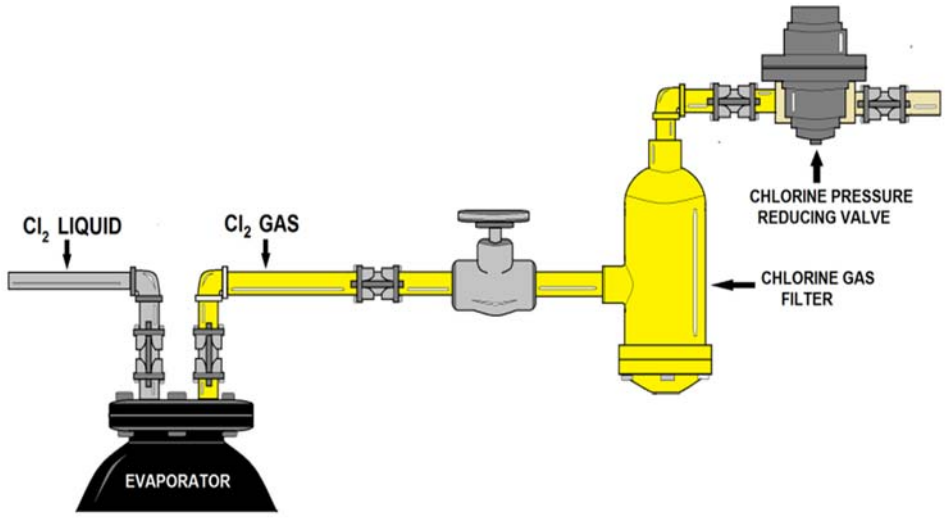
According to the journal Nature, chlorine atoms can affect nitrogen oxides and ozone production, reducing the life cycle of methane gas. When exposed to the atmosphere, chlorine atoms can deplete the ozone. This reduces the ozone's ability to block ultraviolet rays, which can contribute to skin cancer in humans. It can also contribute to the greenhouse effect.

Risks and Benefits of Chlorine

Current evidence indicates that the benefits of chlorinating our wastewater include reduced incidence of water-borne diseases. Although other disinfectants are available, chlorine continues to be the choice of wastewater treatment experts. When used with primary and secondary treatment practices, chlorine is effective against bacteria, viruses and protozoa. It is easy to apply, and, most importantly, small amounts of chlorine remain in the water and continue to disinfect. This ensures that the water remains free of microbial contamination on its journey from the wastewater treatment plant to the final outfall.

The risk of using chlorine is due to storage and application. Chlorine is considered hazardous material and proper training is very crucial. The photographs on this page show how not to store, secure, and operate chlorine containers.

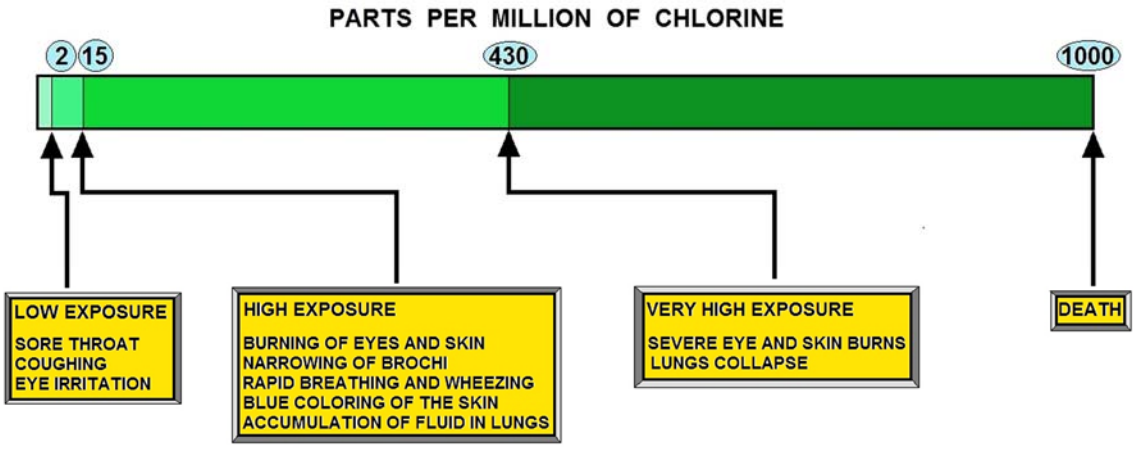
Notice the containers and see that these are not secured from rolling.



The length of the chlorine gas and liquid chlorine pipelines should be as short as possible.

All the safety equipment should be readily available and handy. The Plant should have provisions for exhausting chlorine gas, if a leak develops.

Ideally a chlorine gas leak absorption system can be provided for gas leak evacuation and neutralization. An automatic or manual Shut - Off Valve and Pressure Relief Valve is also included for safe operation.



EFFECTS OF CHLORINE GAS ON HEALTH

Chlorination Chemistry Section

Chlorine can be added as sodium hypochlorite, calcium hypochlorite or chlorine gas. When any of these is added to water, chemical reactions occur as these equations show:

Cl 2 + H 2 O → HOCl + HCl
(chlorine gas) (water) (hypochlorous acid) (hydrochloric acid)

CaOCl + H 2 O → 2HOCl + Ca(OH)
(calcium hypochlorite) (water) (hypochlorous acid) (calcium hydroxide)

NaOCl + H 2 O → HOCl + Na(OH)
(sodium hypochlorite) (water) (hypochlorous acid) (sodium hydroxide)

All three forms of chlorine produce hypochlorous acid (HOCl) when added to water. Hypochlorous acid is a weak acid but a strong disinfecting agent. The amount of hypochlorous acid depends on the pH and temperature of the water. Under normal water conditions, hypochlorous acid will also chemically react and break down into a hypochlorite. ion

(OCl -): HOCl H + + OCl – Also expressed HOCl → H + + OCl –
(hypochlorous acid) (hydrogen) (hypochlorite ion)

The hypochlorite ion is a much weaker disinfecting agent than hypochlorous acid, about 100 times less effective.

Let's now look at how pH and temperature affect the ratio of hypochlorous acid to hypochlorite ions. As the temperature is decreased, the ratio of hypochlorous acid increases. Temperature plays a small part in the acid ratio. Although the ratio of hypochlorous acid is greater at lower temperatures, pathogenic organisms are actually harder to kill. All other things being equal, higher water temperatures and a lower pH are more conducive to chlorine disinfection.

Types of Residual

If water were pure, the measured amount of chlorine in the water should be the same as the amount added. But water is not 100% pure. There are always other substances (interfering agents) such as iron, manganese, turbidity, etc., which will combine chemically with the chlorine.

This is called the ***chlorine demand***. Naturally, once chlorine molecules are combined with these interfering agents, they are not capable of disinfection. It is free chlorine that is much more effective as a disinfecting agent.

So let's look now at how free, total and combined chlorine are related. When a chlorine residual test is taken, either a total or a free chlorine residual can be read.

Total residual is all chlorine that is available for disinfection.

Total chlorine residual = free + combined chlorine residual.

Free chlorine residual is a much stronger disinfecting agent. Therefore, most water regulating agencies will require that your daily chlorine residual readings be of free chlorine residual.

Break-point chlorination is where the chlorine demand has been satisfied, and any additional chlorine will be considered ***free chlorine.***

Residual Concentration/Contact Time (CT) Requirements

Disinfection to eliminate fecal and coliform bacteria may not be sufficient to adequately reduce pathogens such as Giardia or viruses to desired levels. Use of the ***"CT"*** disinfection concept is recommended to demonstrate satisfactory treatment, since monitoring for very low levels of pathogens in treated water is analytically very difficult.

The CT concept, as developed by the United States Environmental Protection Agency (Federal Register, 40 CFR, Parts 141 and 142, June 29, 1989), uses the combination of disinfectant residual concentration (mg/L) and the effective disinfection contact time (in minutes) to measure effective pathogen reduction. The residual is measured at the end of the process, and the contact time used is the T10 of the process unit (time for 10% of the water to pass).

CT = Concentration (mg/L) x Time (minutes)

The effective reduction in pathogens can be calculated by reference to standard tables of required CTs.

Required Giardia/Virus Reduction

All surface water treatment systems shall ensure a minimum reduction in pathogen levels:
3-log reduction in Giardia; and 4-log reduction in viruses.

These requirements are based on unpolluted raw water sources with Giardia levels of = 1 cyst/100 L, and a finished water goal of 1 cyst/100,000 L (equivalent to 1 in 10,000 risk of infection per person per year). Higher raw water contamination levels may require greater removals as shown on Table 4.1.

TABLE 4.1
Level of Giardia Reduction
Raw Water Giardia Levels*
Recommended Giardia Log Reduction
< 1 cyst/100 L 3-log
1 cyst/100 L - 10 cysts/100 L 3-log - 4-log
10 cysts/100 L - 100 cysts/100 L 4-log - 5-log
> 100 cysts/100 L > 5-log
*Use geometric means of data to determine raw water Giardia levels for compliance.

Required CT Value

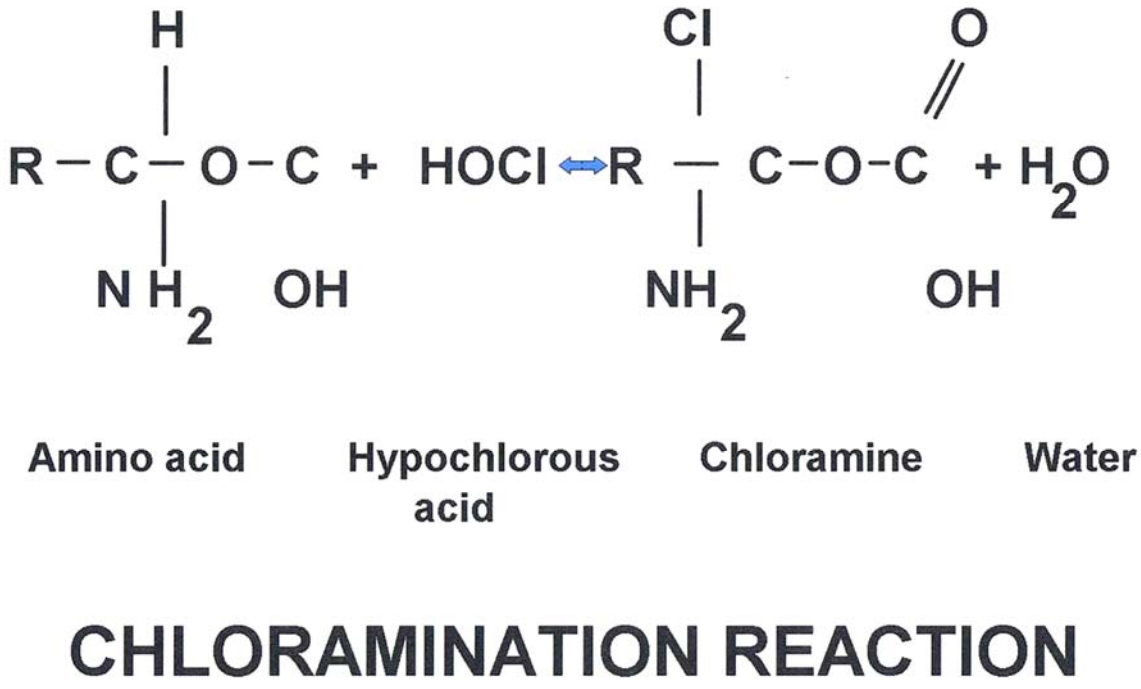
Required CT values are dependent on pH, residual concentration, temperature, and the disinfectant used. The tables attached to Appendices A and B shall be used to determine the required CT.

Calculation and Reporting of CT Data
Disinfection CT values shall be calculated daily, using either the maximum hourly flow and the disinfectant residual at the same time, or by using the lowest CT value if it is calculated more frequently. Actual CT values are then compared to required CT values.

Results shall be reported as a reduction Ratio, along with the appropriate pH, temperature, and disinfectant residual. The reduction Ratio must be greater than 1.0 to be acceptable.

Users may also calculate and record actual log reductions.

Reduction Ratio = CT actual divide by CT required.



CHLORAMINATION REACTION

Hard to tell, but these are one-ton chlorine gas containers. Notice the five-gallon bucket of motor oil in the bottom photograph. Also notice that this photograph is the only eye wash station that we found during our inspection of 10 different facilities. Do you have an eye wash and emergency shower?

Chlorine Exposure Limits and Health Sub-Section

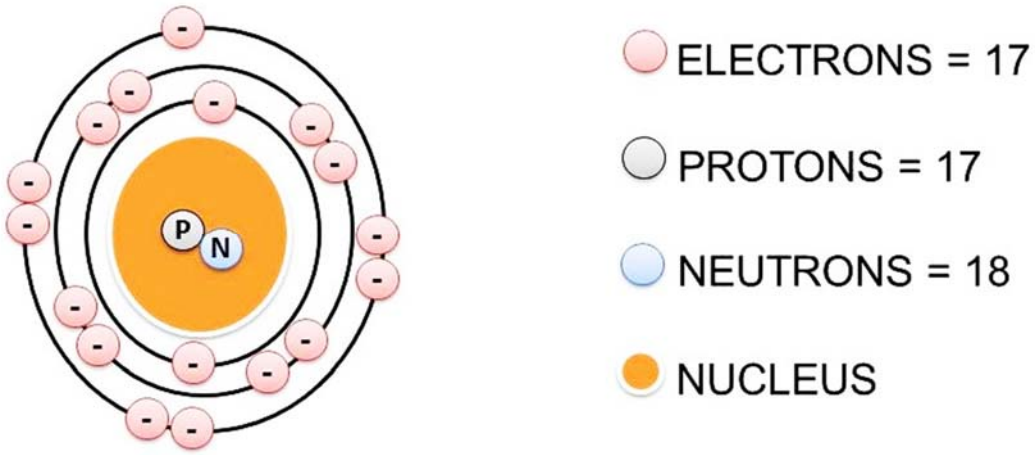
*** OSHA PEL**
The current **OSHA** permissible exposure limit (**PEL**) for chlorine is 1 ppm (3 milligrams per cubic meter ($mg/m^{(3)}$)) as a ceiling limit. A worker's exposure to chlorine shall at no time exceed this ceiling level [29 CFR 1910.1000, Table Z-1].

*** NIOSH REL**
The National Institute for Occupational Safety and Health (**NIOSH**) has established a recommended exposure limit (**REL**) for chlorine of 0.5 ppm $mg/m^{(3)}$) as a TWA for up to a 10-hour workday and a 40-hour workweek and a short-term exposure limit (**STEL**) of 1 ppm (3 $mg/m^{(3)}$)[NIOSH 1992].

*** ACGIH TLV**
The American Conference of Governmental Industrial Hygienists (**ACGIH**) has assigned chlorine a threshold limit value (**TLV**) of 0.5 ppm (1.5 $mg/m^{(3)}$) as a TWA for a normal 8-hour workday and a 40-hour workweek and a **STEL** of 1 ppm (2.9 $mg/m^{(3)}$) for periods not to exceed 15 minutes. Exposures at the STEL concentration should not be repeated more than four times a day and should be separated by intervals of at least 60 minutes [ACGIH 1994, p. 15].

*** Rationale for Limits**
The NIOSH limits are based on the risk of severe eye, mucous membrane and skin irritation [NIOSH 1992]. The ACGIH limits are based on the risk of eye and mucous membrane irritation [ACGIH 1991, p. 254].

Chlorine's Atomic Structure



Isotopes

Isotope	Half Life
Cl-35	Stable
Cl-36	301000.0 years
Cl-37	Stable
Cl-38	37.2 minutes

Top photograph, this blue device prevents the liquid from being pulled and freezing the lines. Bottom photograph, the application of an ammonia mist to detect a chlorine gas leak. Employee is not wearing any required PPE.

Health Hazard Information

Routes of Exposure
Exposure to chlorine can occur through inhalation, ingestion, and eye or skin contact [Genium 1992].

Summary of toxicology
1. Effects on Animals: Chlorine is a severe irritant of the eyes, mucous membranes, skin, and lungs in experimental animals. The 1 hour LC(50) is 239 ppm in rats and 137 ppm in mice ()[Sax and Lewis 1989]. Animals surviving sub-lethal inhalation exposures for 15 to 193 days showed marked emphysema, which was associated with bronchiolitis and pneumonia [Clayton and Clayton 1982]. Chlorine injected into the anterior chamber of rabbits' eyes resulted in severe damage with inflammation, opacification of the cornea, atrophy of the iris, and injury to the lens [Grant 1986].
2. Effects on Humans: Severe acute effects of chlorine exposure in humans have been well documented since World War I when chlorine gas was used as a chemical warfare agent. Other severe exposures have resulted from the accidental rupture of chlorine tanks. These exposures have caused death, lung congestion, and pulmonary edema, pneumonia, pleurisy, and bronchitis [Hathaway et al. 1991]. The lowest lethal concentration reported is 430 ppm for 30 minutes [Clayton and Clayton 1982].

Exposure to 15 ppm causes throat irritation, exposures to 50 ppm are dangerous, and exposures to 1000 ppm can be fatal, even if exposure is brief [Sax and Lewis 1989; Clayton and Clayton 1982]. Earlier literature reported that exposure to a concentration of about 5 ppm caused respiratory complaints, corrosion of the teeth, inflammation of the mucous membranes of the nose and susceptibility to tuberculosis among chronically-exposed workers.

However, many of these effects are not confirmed in recent studies and are of very dubious significance [ACGIH 1991]. A study of workers exposed to chlorine for an average of 10.9 years was published in 1970. All but six workers had exposures below 1 ppm; 21 had TWAs above 0.52 ppm. No evidence of permanent lung damage was found, but 9.4 percent had abnormal EKGs compared to 8.2 percent in the control group.

The incidence of fatigue was greater among those exposed above 0.5 ppm [ACGIH 1991]. In 1981, a study was published involving 29 subjects exposed to chlorine concentrations up to 2.0 ppm for 4- and 8-hour periods. Exposures of 1.0 ppm for 8 hours produced statistically significant changes in pulmonary function that were not observed at a 0.5 ppm exposure concentration. Six of 14 subjects exposed to 1.0 ppm for 8 hours showed increased mucous secretions from the nose and in the hypopharynx.

Responses for sensations of itching or burning of the nose and eyes, and general discomfort were not severe, but were perceptible, especially at the 1.0 ppm exposure level [ACGIH 1991]. A 1983 study of pulmonary function at low concentrations of chlorine exposure also found transient decreases in pulmonary function at the 1.0 ppm exposure level, but not at the 0.5 ppm level [ACGIH 1991].

Acne (chloracne) is not unusual among persons exposed to low concentrations of chlorine for long periods of time. Tooth enamel damage may also occur [Parmeggiani 1983]. There has been one confirmed case of myasthenia gravis associated with chlorine exposure [NLM 1995].

Special Requirements

The U.S. Environmental Protection Agency (**EPA**) requirements for emergency planning, reportable quantities of hazardous releases, community right-to-know, and hazardous waste management may change over time. Users are therefore advised to determine periodically whether new information is available.

Emergency Planning Requirements
Employers owning or operating a facility at which there are 100 pounds or more of chlorine must comply with the EPA's emergency planning requirements [40 CFR Part 355.30].

Reportable Quantity Requirements for Hazardous Releases
A hazardous substance release is defined by the EPA as any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment including the abandonment or discarding of contaminated containers) of hazardous substances. In the event of a release that is above the reportable quantity for that chemical, employers are required to notify the proper Federal, State, and local authorities [40 CFR

The Reportable Quantity of Chlorine is 10 Pounds.
If an amount equal to or greater than this quantity is released within a 24-hour period in a manner that will expose persons outside the facility, employers are required to do the following: Notify the National Response Center immediately at (800) or at (202) 426-2675 in Washington, D.C. [40 CFR 302.6]. Notify the emergency response commission of the State likely to be affected by the release [40 CFR 355.40]. Notify the community emergency coordinator of the local emergency planning committee (or relevant local emergency response personnel) of any area likely to be affected by the release [40 CFR 355.40].

Community Right-to-Know Requirements
Employers who own or operate facilities in SIC codes 20 to 39 that employ 10 or more workers and that manufacture 25,000 pounds or more of chlorine per calendar year or otherwise use 10,000 pounds or more of chlorine per calendar year are required by EPA [40 CFR Part 372.30] to submit a Toxic Chemical Release Inventory form (Form R) to the EPA reporting the amount of chlorine emitted or released from their facility annually.

Hazardous Waste Management Requirements
EPA considers a waste to be hazardous if it exhibits any of the following characteristics: ignitability, corrosivity, reactivity, or toxicity as defined in 40 CFR 261.21-261.24. Under the Resource Conservation and Recovery Act (**RCRA**) [40 USC 6901 et seq.], the EPA has specifically listed many chemical wastes as hazardous. Although chlorine is not specifically listed as a hazardous waste under RCRA, the EPA requires employers to treat waste as hazardous if it exhibits any of the characteristics discussed above.

Providing detailed information about the removal and disposal of specific chemicals is beyond the scope of this guideline. The U.S. Department of Transportation, the EPA, and State and local regulations should be followed to ensure that removal, transport, and disposal of this substance are conducted in accordance with existing regulations.

Signs and Symptoms of Exposure

1. Acute exposure: Acute exposure to low levels of chlorine results in eye, nose, and throat irritation, sneezing, excessive salivation, general excitement, and restlessness. Higher concentrations causes difficulty in breathing, violent coughing, nausea, vomiting, cyanosis, dizziness, headache, choking, laryngeal edema, acute tracheobronchitis, chemical pneumonia. Contact with the liquid can result in frostbite burns of the skin and eyes [Genium 1992].
2. Chronic exposure: Chronic exposure to low levels of chlorine gas can result in a dermatitis known as chloracne, tooth enamel corrosion, coughing, severe chest pain, sore throat, hemoptysis and increased susceptibility to tuberculosis [Genium 1992].

Emergency Medical Procedures: [NIOSH to supply]

1. Rescue: Remove an incapacitated worker from further exposure and implement appropriate emergency procedures (e.g., those listed on the Material Safety Data Sheet required by OSHA's Hazard Communication Standard [29 CFR 1910.1200]).
2. All workers should be familiar with emergency procedures, the location and proper use of emergency equipment, and methods of protecting themselves during rescue operations.

Exposure Sources and Control Methods
The following operations may involve chlorine and lead to worker exposures to this substance:

The Manufacture and Transportation of Chlorine

- Use as a chlorinating and oxidizing agent in organic and inorganic synthesis; in the manufacture of chlorinated solvents, automotive antifreeze and antiknock compounds, polymers (synthetic rubber and plastics), resins, elastomers, pesticides, refrigerants, and in the manufacture of rocket fuel.
- Use as a fluxing, purification, and extraction agent in metallurgy.
- Use as a bacteriostat, disinfectant, odor control, and demulsifier in treatment of drinking water, swimming pools, and in sewage.
- Use in the paper and pulp, and textile industries for bleaching cellulose for artificial fibers; use in the manufacture of chlorinated lime; use in de-tinning and de-zincing iron; use to shrink-proof wool.
- Use in the manufacture of pharmaceuticals, cosmetics, lubricants, flame-proofing, adhesives, in special batteries containing lithium or zinc, and in hydraulic fluids; use in the processing of meat, fish, vegetables, and fruit.
- Use as bleaching and cleaning agents, and as a disinfectant in laundries, dishwashers, cleaning powders, cleaning dairy equipment, and bleaching cellulose.

Methods that are effective in controlling worker exposures to chlorine, depending on the feasibility of implementation, are as follows: Process enclosure Local exhaust ventilation General dilution ventilation Personal protective equipment.

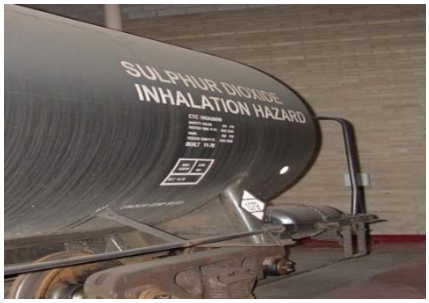
Workers responding to a release or potential release of a hazardous substance must be protected as required by paragraph (q) of OSHA's Hazardous Waste Operations and Emergency Response Standard 29 CFR.

Good Sources of Information about Control Methods are as Follows:

1. ACGIH [1992]. Industrial ventilation--a manual of recommended practice. 21st ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.
2. Burton DJ [1986]. Industrial ventilation--a self-study companion. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.
3. Alden JL, Kane JM [1982]. Design of industrial ventilation systems. New York, NY: Industrial Press, Inc.
4. Wadden RA, Scheff PA [1987]. Engineering design for control of workplace hazards. New York, NY: McGraw-Hill.
5. Plog BA [1988]. Fundamentals of industrial hygiene. Chicago, IL: National Safety Council.

Chlorine Storage

Chlorine should be stored in a cool, dry, well-ventilated area in tightly sealed containers that are labeled in accordance with OSHA's Hazard Communication Standard [29 CFR 1910.1200]. Containers of chlorine should be protected from exposure to weather, extreme temperatures changes, and physical damage, and they should be stored separately from flammable gases and vapors, combustible substances (such as gasoline and petroleum products, hydrocarbons, turpentine, alcohols, acetylene, hydrogen, ammonia, and sulfur), reducing agents, finely divided metals, arsenic, bismuth, boron, calcium, activated carbon, carbon disulfide, glycerol, hydrazine, iodine, methane, oxomonosilane, potassium, propylene, silicon, hydrogen sulfide and water, carbon monoxide and sulfur dioxide, moisture, steam, and water. (Sulfur dioxide is used for de-chlorination).



Workers handling and operating chlorine containers, cylinders, and tank wagons should receive special training in standard safety procedures for handling compressed corrosive gases. All pipes and containment used for chlorine service should be regularly inspected and tested. Empty containers of chlorine should have secured protective covers on their valves and should be handled appropriately.

Spills and Leaks

In the event of a spill or leak involving chlorine, persons not wearing protective equipment and fully-encapsulating, vapor-protective clothing should be restricted from contaminated areas until cleanup has been completed. The following steps should be undertaken following a spill or leak:

1. Notify safety personnel.
2. Remove all sources of heat and ignition.
3. Keep all combustibles (wood, paper, oil, etc.) away from the leak.
4. Ventilate potentially explosive atmospheres.
5. Evacuate the spill area for at least 50 feet in all directions.
6. Find and stop the leak if this can be done without risk; if not, move the leaking container to an isolated area until gas has dispersed. The cylinder may be allowed to empty through a reducing agent such as sodium bisulfide and sodium bicarbonate.
7. Use water spray to reduce vapors; do not put water directly on the leak or spill area.

Top photograph, a view of the top of a 150 gas cylinder. Bottom, always work in pairs when working around Chlorine. Here the hoist is being used to move the container. Employees are required to wear PPE.

Chlorinator Components

A. Ejector
B. Check Valve Assembly
C. Rate Valve
D. Diaphragm Assembly
E. Interconnection Manifold
F. Rotometer Tube and Float
G. Pressure Gauge
H. Gas Supply

Chlorine measurement devices or Rotometers.

Chlorine Safety Information

There is a fusible plug on every chlorine tank. This metal plug will melt at 158 to 165º F. This is to prevent a build-up of excessive pressure and the possibility of cylinder rupture due to fire or high temperatures.

Chlorine Gas Cylinder System Safety Procedures Example

There is a need to emphasize major precautions to be observed while working with chlorine, which is a very dangerous gas. The following outlines a program governing the moving, storage, and maintenance procedures to be used for handling chlorine gas. Consult the Safety Engineer for procedures to be followed in an emergency, and the type of first aid treatment to be rendered to persons exposed to chlorine fumes.

This list does not cover everything, but covers general Chlorine Gas cylinder safety principles.

You are required to wear PPE at all times. Chlorine gas is fatal and very dangerous to skin and clothing.

1. MOVING GAS CYLINDERS

a. Never move a chlorine gas cylinder unless the cylinder valve cap is in place.
b. Do not drop a cylinder or allow an object to strike the container with extreme force.
c. Never apply heat to chlorine cylinders or valves.
d. Any hand-truck used for moving cylinders shall have a clamp support at least two-thirds of the way up the cylinder.
e. When lifting a cylinder using a crane or hoist, a special cradle or carrier should be used. Never use a rope sling, chain, or magnetic device.
f. Never lift a cylinder by the valve cap or neck.

2. STORING CYLINDERS

a. One extra, full or empty, container may be racked and stored in the chlorine room. (Depends upon safety pan) All other containers should be stored outside of attended power or pumping plants. The storage area should be cool and dry, and protected from all heat sources including the sun.
b. Never store containers near the following: turpentine, ether, anhydrous ammonia, finely divided metals, hydrocarbons, oxygen cylinders, acetylene cylinders, or any flammable materials.
c. The storage area shall be clean, well vented to atmosphere, and remote from elevators, gangways, ventilating systems, or any other type
of area that would allow leaking gas to disperse rapidly throughout the building.
d. Cylinder valve caps should always be screwed securely in place during storage.
e. Cylinders should always be stored vertically and never stacked or laid horizontally. The storage room should never contain other stored material.

3. GENERAL PRECAUTIONS

a. Never tamper with the fusible plug safety device on containers.
b. Never alter or repair a container or valve. Tell the chlorine supplier if any damage is found.
c. Never place a container in hot water, or apply direct heat to increase the flow rate, or for any other reason.
d. A flexible copper tube connection should be used between the container and the piping system. Copper tubing shall be type K or L and sized for a minimum of 3500-kPa (500-lb/In2) working pressure. A type L9.5 mm (3/8-1n) o.d. flexible copper tube is recommended.
e. Never perform maintenance work on a system unless the tank valves are closed.

f. When a container is empty the valve should be closed, lines disconnected, and the valve tested for leakage. An outlet pipe cap should be promptly attached and the cylinder valve cap secured. If the valve does not seat immediately, open and close it lightly until it seats. Never impact the valve or cylinder with anything, with the mistaken idea it would help make a tight valve closure.
g. To detect a chlorine gas leak, attach a cloth to the end of a stick, soak it with ammonia, and hold it close to the suspected area. A white cloud of ammonia chloride will result if there is a chlorine leak. Commercial ammonia must be used; household ammonia is not strong enough.
DO NOT GET ANY AMMONIA ON THE BRASS.
h. Do not enter a chlorine contaminated area without wearing a self-contained breathing apparatus, which shall be available outside the chlorine room. Canister-type chlorine masks do not protect against chlorine concentration over 1 percent when the oxygen concentration is below 16 percent.
i. If a leak develops in a chlorine system, shut off the cylinder valves and ventilate the area to the outdoors prior to repairing the leak. Should a major leak develop which cannot be controlled, clear the area of personnel, and exhaust the fumes to the outdoors.
j. If a cylinder valve leaks, tighten the packing nut with the special wrench. Should it continue to leak, replace the outlet pipe cap and remove the cylinder to the outdoors.
k. If a cylinder leaks, tilt the cylinder to permit gas instead of liquid to escape. Less equivalent leakage can flow through a crack as gas than as liquid.
l. Do not use water on a chlorine leak.
m. In case of fire all cylinders should be removed from the fire zone Immediately.

Chlorination Equipment and Room Requirements

For all wastewater treatment facilities, chlorine gas under pressure shall not be permitted outside the chlorine room. A chlorine room is where chlorine gas cylinders and/or ton containers are stored. Vacuum regulators shall also be located inside the chlorine room. The chlorinator, which is the mechanical gas proportioning equipment, may or may not be located inside the chlorine room.

For new and upgraded facilities, from the chlorine room, chlorine gas vacuum lines should be run as close to the point of solution application as possible. Injectors should be located to minimize the length of pressurized chlorine solution lines.

A gas pressure relief system shall be included in the gas vacuum line between the vacuum regulator(s) and the chlorinator(s) to ensure that pressurized chlorine gas does not enter the gas vacuum lines leaving the chlorine room.

The gas pressure relief system shall vent pressurized gas to the atmosphere at a location that is not hazardous to plant personnel; vent line should be run in such a manner that moisture collecting traps are avoided. The vacuum regulating valve(s) shall have positive shutdown in the event of a break in the downstream vacuum lines.

As an alternative to chlorine gas, it is permissible to use hypochlorite with positive displacement pumping. Anti-siphon valves shall be incorporated in the pump heads or in the discharge piping.

Capacity
The chlorinator shall have the capacity to dose enough chlorine to overcome the demand and maintain the required concentration of the "***free***" or "***combined***" chlorine.

Methods of Control
Chlorine feed system shall be automatic proportional controlled, automatic residual controlled, or compound loop controlled. In the automatic proportional controlled system, the equipment adjusts the chlorine feed rate automatically in accordance with the flow changes to provide a constant pre-established dosage for all rates of flow.

In the automatic residual controlled system, the chlorine feeder is used in conjunction with a chlorine residual analyzer which controls the feed rate of the chlorine feeders to maintain a particular residual in the treated water.

In the compound loop control system, the feed rate of the chlorinator is controlled by a flow proportional signal and a residual analyzer signal to maintain particular chlorine residual in the water.

A manual chlorine feed system may be installed for groundwater systems with constant flow rates.

Standby Provision

As a safeguard against malfunction and/or shut-down, standby chlorination equipment having the capacity to replace the largest unit shall be provided. For uninterrupted chlorination, gas chlorinators shall be equipped with an automatic changeover system. In addition, spare parts shall be available for all chlorinators.

Weigh Scales

Scales for weighing cylinders shall be provided at all plants using chlorine gas to permit an accurate reading of total daily weight of chlorine used. At large plants, scales of the recording and indicating type are recommended. As a minimum, a platform scale shall be provided. Scales shall be of corrosion-resistant material.

Securing Cylinders

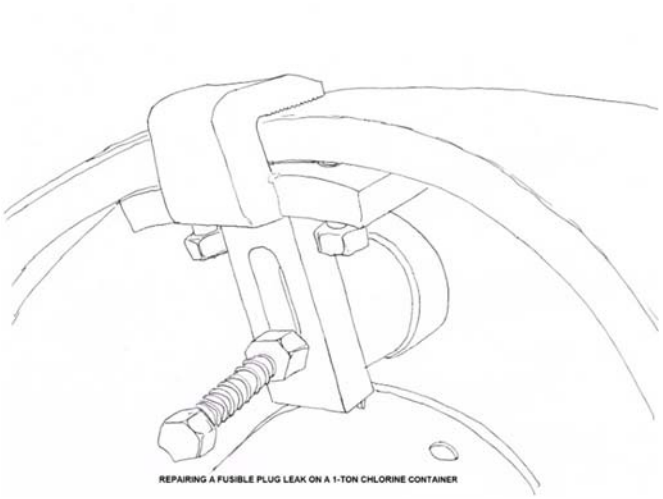
All chlorine cylinders shall be securely positioned to safeguard against movement. Tag the cylinder *"**empty**"* and store upright and chained.

Ton containers may not be stacked.

Chlorine Leak Detection

Automatic chlorine leak detection and related alarm equipment shall be installed at all water treatment plants using chlorine gas. Leak detection shall be provided for the chlorine rooms. Chlorine leak detection equipment should be connected to a remote audible and visual alarm system and checked on a regular basis to verify proper operation.

Leak detection equipment shall not automatically activate the chlorine room ventilation system in such a manner as to discharge chlorine gas.



REPAIRING A FUSIBLE PLUG LEAK ON A 1-TON CHLORINE CONTAINER

During an emergency, if the chlorine room is unoccupied, the chlorine gas leakage shall be contained within the chlorine room itself in order to facilitate a proper method of clean-up.

Consideration should also be given to the provision of caustic soda solution reaction tanks for absorbing the contents of leaking one-ton cylinders where such cylinders are in use.

Chlorine leak detection equipment may not be required for very small chlorine rooms with an exterior door (e.g., floor area less than $3m^2$).

You can use a spray solution of Ammonia or a rag soaked with Ammonia to detect a small Cl_2 leak. If there is a leak, the ammonia will create a white colored smoke, Ammonium Chloride.

Safety Equipment
The facility shall be provided with personnel safety equipment including the following: Respiratory equipment; safety shower, eyewash; gloves; eye protection; protective clothing; cylinder and/or ton repair kits.

Respiratory equipment shall be provided which has been approved under the Occupational Health and Safety Act, General Safety Regulation - Selection of Respiratory Protective Equipment. Equipment shall be in close proximity to the access door(s) of the chlorine room.

Chlorine Room Design Requirements
Where gas chlorination is practiced, the gas cylinders and/or the ton containers up to the vacuum regulators shall be housed in a gas-tight, well illuminated, corrosion resistant and mechanically ventilated enclosure. The chlorinator may or may not be located inside the chlorine room. The chlorine room shall be located at the ground floor level.

Ventilation
Gas chlorine rooms shall have entirely separate exhaust ventilation systems capable of delivering one (1) complete air change per minute during periods of chlorine room occupancy only. The air outlet from the room shall be at least 6 inches above the floor and the point of discharge located to preclude contamination of air inlets to buildings or areas used by people. The vents to the outside shall have insect screens.

Air inlets should be louvered near the ceiling, the air being of such temperature as to not adversely affect the chlorination equipment. Separate switches for fans and lights shall be outside the room at all entrance or viewing points, and a clear wire-reinforced glass window shall be installed in such a manner as to allow the operator to inspect from the outside of the room.

Heating
Chlorine rooms shall have separate heating systems, if a forced air system is used to heat the building. The hot water heating system for the building will negate the need for a separate heating system for the chlorine room. The heat should be controlled at approximately 60^{o}F or 15^{o}C.

Cylinders or containers shall be protected to ensure that the chlorine maintains its gaseous state when entering the chlorinator.

Access
All access to the chlorine room shall only be from the exterior of the building. Visual inspection of the chlorination equipment from inside may be provided by the installation of glass window(s) in the walls of the chlorine room. Windows should be at least 2 sq. ft. in area, and be made of clear wire reinforced glass. There should also be a ***'panic bar'*** on the inside of the chlorine room door for emergency exit.

Storage of Chlorine Cylinders
If necessary, a separate storage room may be provided to simply store the chlorine gas cylinders, with no connection to the line. The chlorine cylinder storage room shall have access either to the chlorine room or from the plant exterior, and arranged to prevent the uncontrolled release of spilled gas.

The chlorine gas storage room shall have provision for ventilation at thirty air changes per hour.

Viewing glass windows and panic button on the inside of door should also be provided. In very large facilities, entry into the chlorine rooms may be through a vestibule from outside.

Scrubbers
For facilities located within residential or densely populated areas, consideration shall be given to provide scrubbers for the chlorine room.

Some WWT plants transfer and store chlorine from tankers to holding tanks as shown in the above photograph.

Chlorine Exposure Limits Review

This information is necessary to pass your post-quiz.

*** OSHA PEL 1 PPM - IDLH 10 PPM and Fatal Exposure Limit 1,000 PPM**

The current Occupational Safety and Health Administration (**OSHA**) permissible exposure limit (**PEL**) for chlorine is 1 ppm (3 milligrams per cubic meter ($mg/m^{(3)}$)) as a ceiling limit. A worker's exposure to chlorine shall at no time exceed this ceiling level. *** IDLH 10 PPM**

Physical and chemical properties of chlorine: A yellowish green, nonflammable and liquefied gas with an unpleasant and irritating smell. Can be readily compressed into a clear, amber-colored liquid, a noncombustible gas, and a strong oxidizer.

Solid chlorine is about 1.5 times heavier than water and gaseous chlorine is about 2.5 times heavier than air. Atomic number of chlorine is 17. Cl is the elemental symbol and Cl2 is the chemical formula.

Monochloramine, dichloramine, and trichloramine are also known as Combined Available Chlorine. $Cl_2 + NH_4$.

HOCl and OCl-; The **OCL-** is the hypochlorite ion and both of these species are known as free available chlorine. These are the two main chemical species formed by chlorine in water and they are known collectively as hypochlorous acid and the hypochlorite ion.

When chlorine gas is added to water, it rapidly hydrolyzes. The chemical equation that best describes this reaction is **$Cl2 + H_2O$ --> H+ + Cl- + HOCl.** Hypochlorous acid is the most germicidal of the chlorine compounds with the possible exception of chlorine dioxide.

Yoke-type connectors should be used on a chlorine cylinder's valve, assuming that the threads on the valve may be worn.

The connection from a chlorine cylinder to a chlorinator should be replaced by using a new, approved gasket on the connector. Always follow your manufacturer’s instructions.

On 1-ton Chlorine gas containers, the chlorine pressure reducing valve should be located downstream of the evaporator when using an evaporator. This is the liquid chlorine supply line and it is going to be made into Chlorine gas.

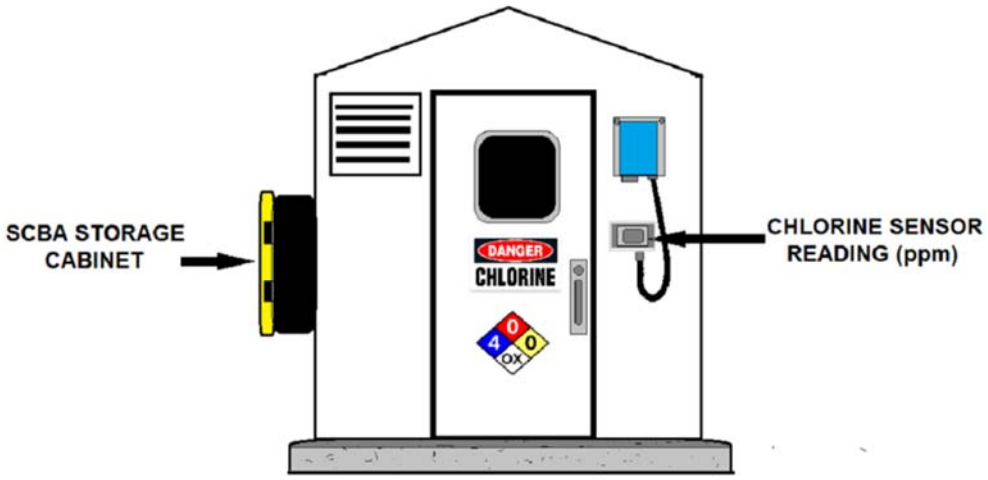
In water treatment, chlorine is added to the effluent before the contact chamber (before the clear well) for complete mixing. One reason for not adding it directly to the chamber is that the chamber has very little mixing due to low velocities.

Here are several safety precautions when using chlorine gas. In addition to protective clothing and goggles, chlorine gas should be used only in a well-ventilated area so that any leaking gas cannot concentrate.

Emergency procedures in the case of a large uncontrolled chlorine leak are as follows: Notify local emergency response team, warn and evacuate people in adjacent areas, and be sure that no one enters the leak area without adequate self-contained breathing equipment.

Here are several symptoms of chlorine exposure. Burning of eyes, nose, and mouth, coughing, sneezing, choking, nausea and vomiting, headaches and dizziness, fatal pulmonary edema, pneumonia, and skin blisters. A little Cl_2 will corrode the teeth and then progress to throat cancer.

Approved method for storing a 150 - 200-pound chlorine cylinder: Secure each cylinder in an upright position, attach the protective bonnet over the valve and firmly secure each cylinder. Never store near heat. Always store the empty in an upright, secure position with proper signage.



FIBERGLASS CHLORINE STORAGE SHELTER

The design of gas chlorine facilities should consider operator and public safety as well as maintaining long-term plant reliability and operation.

Chlorination facilities are designed such that chlorine gas can be contained in the chlorine storage room. Doors and windows should be gas-tight to minimize escape of gaseous chlorine to the exterior atmosphere or building interior.

Leak detectors should be located 1 foot above the floor of the chlorine storage room and should activate an alarm when a chlorine leak occurs. It is preferable that the detector be capable of differentiating between two or more chlorine concentrations to alert personnel of the severity of the release. This would help determine the appropriate procedure for entrance to the room, ventilation, or other solutions.

Self-contained breathing apparatus (SCBA) should not be located within the chlorine storage room. It is preferable that this equipment be located in a convenient location where personnel can easily access it in the event of an emergency.

Alternative Disinfectants Sub-Section

Chloramine
Chloramine is a very weak disinfectant for Giardia and virus reduction; it is recommended that it be used in conjunction with a stronger disinfectant. It is best utilized as a stable distribution system disinfectant.

In the production of chloramines, the ammonia residuals in the finished water, when fed in excess of stoichiometric amount needed, should be limited to inhibit growth of nitrifying bacteria.

Chlorine Dioxide
Chlorine dioxide may be used for taste and odor control, or as a pre-disinfectant. Total residual oxidants (including chlorine dioxide and chlorite, but excluding chlorate) shall not exceed 0.30 mg/L during normal operation or 0.50 mg/L (including chlorine dioxide, chlorite and chlorate) during periods of extreme variations in the raw water supply.

Chlorine dioxide provides good Giardia and virus protection but its use is limited by the restriction on the maximum residual of 0.5 mg/L ClO_2/chlorite/chlorate allowed in finished water. This limits usable residuals of chlorine dioxide at the end of a process unit to less than 0.5 mg/L.

Where chlorine dioxide is approved for use as an oxidant, the preferred method of generation is to entrain chlorine gas into a packed reaction chamber with a 25% aqueous solution of sodium chlorite ($NaClO_2$).

Warning: Dry sodium chlorite is explosive and can cause fires in feed equipment if leaking solutions or spills are allowed to dry out.

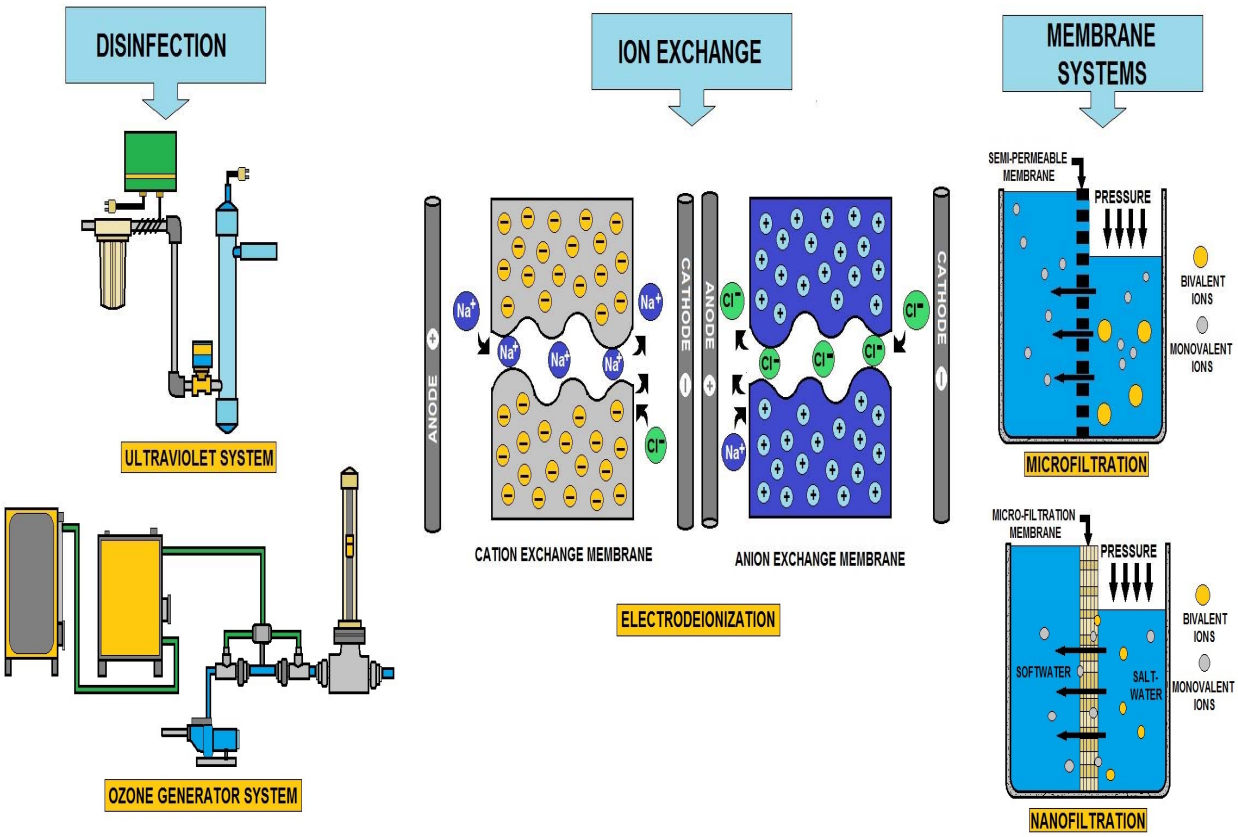
Ozone
Ozone is a very effective disinfectant for both Giardia and viruses. Ozone CT (Contact Time) values must be determined for the ozone basin alone; an accurate T10 value must be obtained for the contact chamber, residual levels measured through the chamber and an average ozone residual calculated.

Ozone does not provide a system residual and should be used as a primary disinfectant only in conjunction with free and/or combined chlorine.

Ozone does not produce chlorinated byproducts (such as trihalomethanes) but it may cause an increase in such byproduct formation if it is fed ahead of free chlorine; ozone may also produce its own oxygenated byproducts such as aldehydes, ketones, or carboxylic acids.

Any installed ozonation system must include adequate ozone leak detection alarm systems, and an ozone off-gas destruction system.

Ozone may also be used as an oxidant for removal of taste and odor, or may be applied as a pre-disinfectant.



WATER QUALITY EQUIPMENT

	CHLORINE AS A DISINFECTANT	ULTRAVIOLET GERMICIDAL IRRADIATION (UV) AS A DISINFECTANT
DISINFECTION BYPRODUCTS (DBPs)	X	No
CHEMICAL RESIDUE	X	No
NON-CORROSIVE	X	No
COMMUNITY SAFETY RISKS	X	No
EFFECTIVE AGAINST CRYPTOSPORIDIUM AND GIARDIA	X	Yes
WELL-SUITED FOR CHANGING REGULATIONS	X	Yes

CHLORINE vs. UV FOR DISINFECTION

Ozone

Ozone (O_3) is probably the strongest oxidizing agent available for water/wastewater treatment.. Ozone is obtained by passing a flow of air or oxygen between two electrodes that are subjected to an alternating current in the order of 10,000 to 20,000 volts.

$$3O_2 + \text{electrical discharge} \rightarrow 2O_3$$

Liquid ozone is very unstable and can readily explode. As a result, it is not shipped and must be manufactured on-site. Ozone is a light blue gas at room temperature. It has a self-policing pungent odor similar to that sometimes noticed during and after heavy electrical storms. In use, ozone breaks down into oxygen and nascent oxygen.

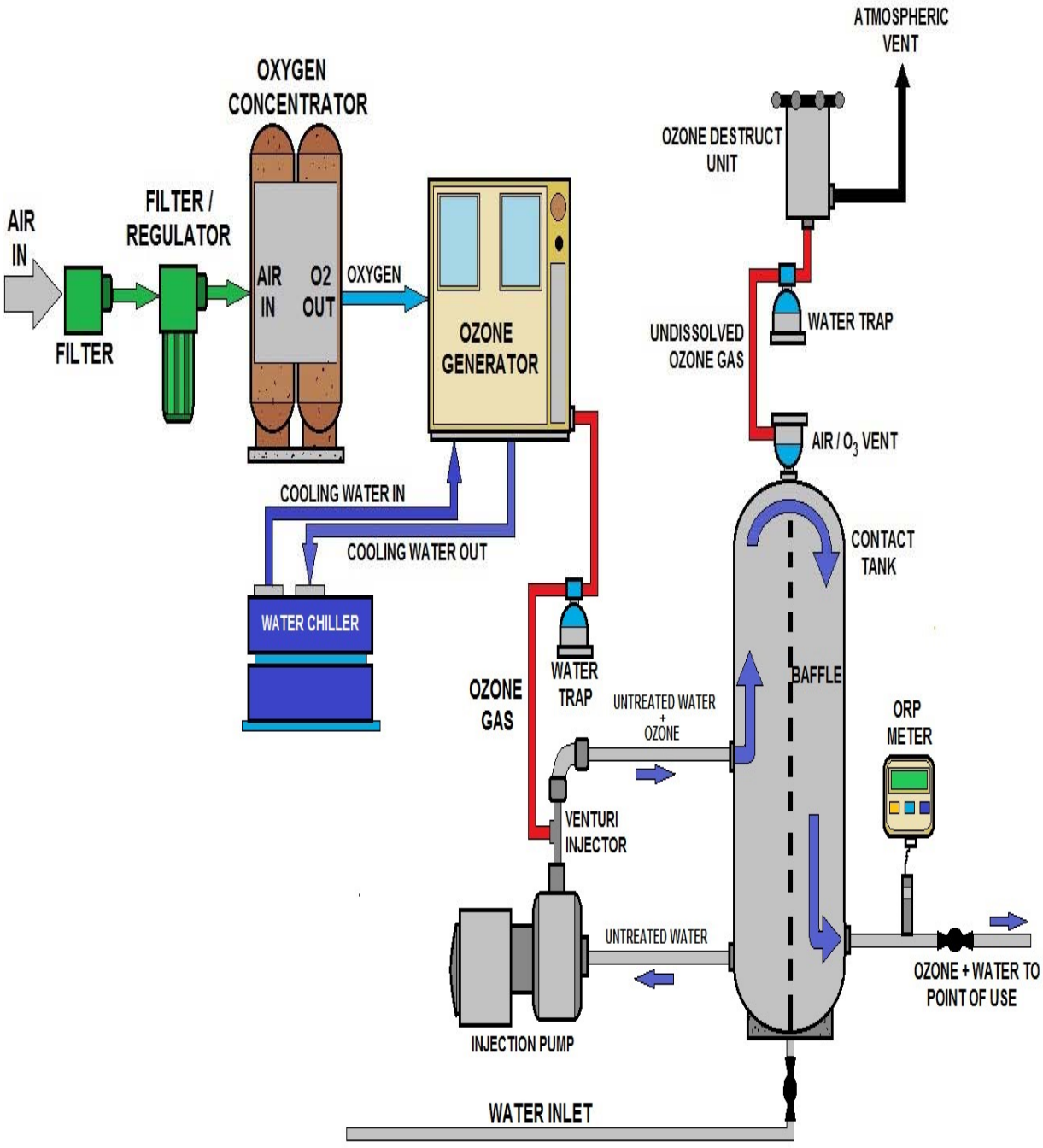
$$O_3 \rightarrow O_2 + O$$

It is the nascent oxygen that produces the high oxidation and disinfections, and even sterilization. Each water has its own ozone demand, in the order of 0.5 ppm to 5.0 ppm. Contact time, temperature, and pH of the water are factors to be determined.

Ozone acts as a complete disinfectant. It is an excellent aid to the flocculation and coagulation process, and will remove practically all color, taste, odor, iron, and manganese. It does not form chloramines or THMs, and while it may destroy some THMs, it may produce others when followed by chlorination.

Ozone is not practical for complete removal of chlorine or chloramines, or of THM and other inorganics. Further, because of the possibility of formation of other carcinogens (such as aldehydes or phthalates) it falls into the same category as other disinfectants in that it can produce DBPs.

Ozone generator



OZONE GENERATION SYSTEM

Ultraviolet Radiation

The enormous temperatures on the sun create ultraviolet (**UV**) rays in great amounts, and this radiation is so powerful that all life on earth would be destroyed if these ray were not scattered by the atmosphere and filtered out by the layers of ozone gas that float some 20 miles above the earth.

This radiation can be artificially produced by sending strong electric currents through various substances. A sun lamp, for example, sends out UV rays that, when properly controlled, result in a suntan. Of course, too much UV will cause sunburn.

Open Channel UV Lamp

The UV lamp that can be used for the disinfection of water depends upon the low-pressure mercury vapor lamp to produce the ultraviolet energy. A mercury vapor lamp is one in which an electric arc is passed through an inert gas. This in turn will vaporize the mercury contained in the lamp; and it is a result of this vaporization that UV rays are produced.

Enclosed UV lamp assembly. Assemblies will often need frequent cleaning and bulb replacements, there are facilities with 1,000's of bulbs.

The lamp itself does not come into with contact water, the lamp is placed inside a quartz tube, and the water is in contact with the outside of the quartz tube. Quartz is used in this case since practically none of the UV rays are absorbed by the quartz, allowing all of the rays to reach the water. Ordinary glass cannot be used since it will absorb the UV rays, leaving little for disinfection.

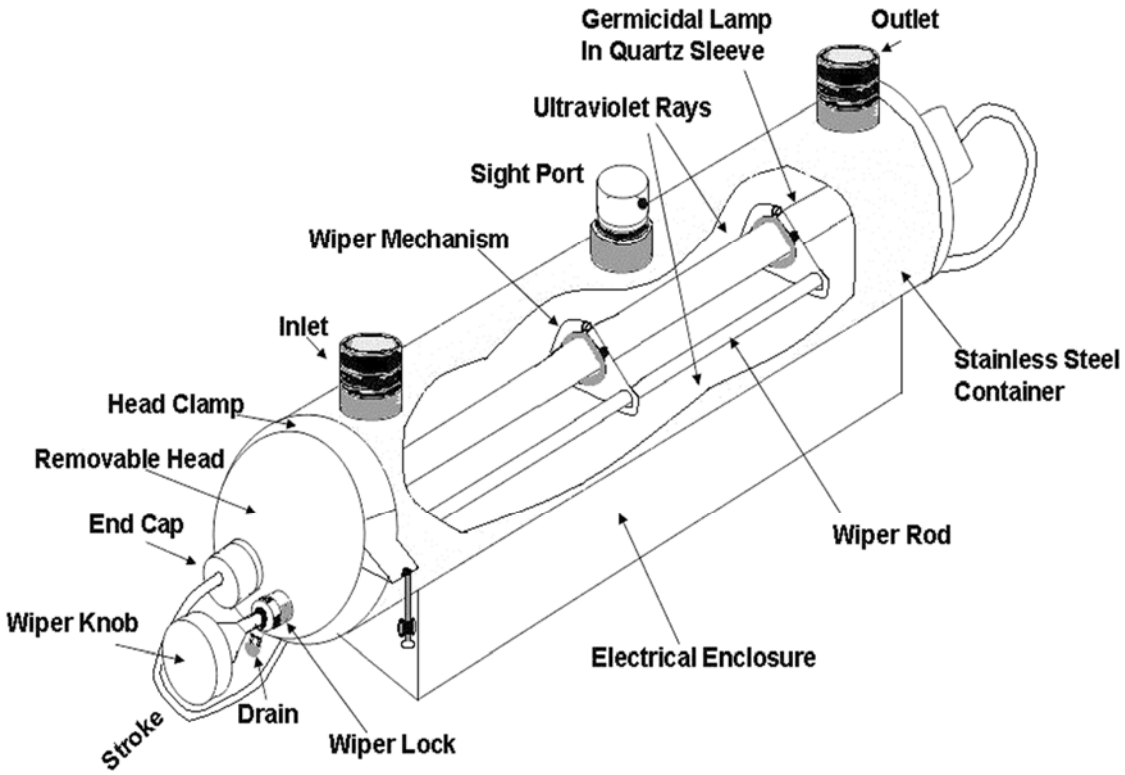
The water flows around the quartz tube. The UV sterilizer will consist of a various number of lamps and tubes, depending upon the quantity of water to be treated. As water enters the sterilizer, it is given a tangential flow pattern so that the water spins over and around the quartz sleeves. In this way the microorganisms spend maximum time and contact with the outside of the quartz tube and the source of the UV rays.

The basic design flow of water of certain UV units is in the order of 2.0 gpm for each inch of the lamp. Further, the units are designed so that the contact or retention time of the water in the unit is not less than 15 seconds. Most manufacturers claim that the UV lamps have a life of about 7,500 hours, which is about 1 years' time.

The lamp must be replaced when it loses about 40% to 50% of its UV output; in any installation this is determined by means of a photoelectric cell and a meter that shows the output of the lamp. Each lamp is outfitted with its own photoelectric cell, and with its own alarm that will be activated when the penetration drops to a present level.

Ultraviolet radiation is an excellent disinfectant that is highly effective against viruses, molds, and yeasts; and it is safe to use. It adds no chemicals to the water, it leaves no residual, and it does not form THMs. It is used to remove traces of ozone and chloramines from the finished water. Alone, UV radiation will not remove precursors, but in combination with ozone, it is said to be effective in the removal of THM precursors and THMs.

The germicidal effect of UV is thought to be associated with its absorption by various organic components essential to the cell's functioning. For effective use of ultraviolet, the water to be disinfected must be clean, and free of any suspended solids. The water must also be colorless and must be free of any colloids, iron, manganese, taste, and odor.



These are conditions that must be met. Also, although a water may appear to be clear, such substances as excesses of chlorides, bicarbonates, and sulfates affect absorption of the ultraviolet ray.

These parameters will probably require at least filtration of one type or another. The UV manufacturer will of course stipulate which pretreatment may be necessary.

Removal of Disinfection By-products		
Disinfectant	***Disinfectant By-product***	***Disinfectant By-product Removal***
Chlorine (HOCl)	Trihalomethane (THM) Chloramines Chloroprene	Granular Activated Carbon (GAC), resins, controlled coagulation, aeration. GAC-UV GAC
Chloramines (Ch_icl_y)	Probably no THM Others?	GAC UV?
Chlorine dioxide (ClO_2)	Chlorites Chlorates	Use of Fe2+ in coagulation, RO, ion-exchange
Permanganate ($KMnO_4$)	No THMs	
Ozone (O_3)	Aldehydes, Carboxylics, Phthalates	GAC
Ultraviolet (UV)	None known	GAC

The table indicates that most of the disinfectants will leave a by-product that is or would possibly be inimical to health. This may aid with a decision as to whether or not precursors should be removed before these disinfectants are added to water.

If it is decided that removal of precursors is needed, research to date indicates that this removal can be attained through the application of controlled chlorination plus coagulation and filtration, aeration, reverse osmosis, nanofiltration, GAC (Granular Activated Charcoal) or combinations of others processes.

Alternative Disinfectants Section Review

Chloramines
Chloramine is a very weak disinfectant for Giardia and virus reduction. It is recommended that it be used in conjunction with a stronger disinfectant.

It is best utilized as a stable disinfectant. In the production of chloramines, the ammonia residuals in the finished water, when fed in excess of stoichiometric amount needed, should be limited to inhibit growth of nitrifying bacteria.

Chlorine Dioxide
Chlorine dioxide may be used for either taste and odor control or as a pre-disinfectant.

Total residual oxidants (including chlorine dioxide and chlorite, but excluding chlorate) shall not exceed 0.30 mg/L during normal operation or 0.50 mg/L (including chlorine dioxide, chlorite and chlorate) during periods of extreme variations in the raw water supply.

Chlorine dioxide provides good Giardia and virus protection but its use is limited by the restriction on the maximum residual of 0.5 mg/L ClO_2/chlorite/chlorate allowed in finished water. This limits usable residuals of chlorine dioxide at the end of a process unit to less than 0.5 mg/L. Where chlorine dioxide is approved for use as an oxidant, the preferred method of generation is to entrain chlorine gas into a packed reaction chamber with a 25% aqueous solution of sodium chlorite ($NaClO^2$).

Warning: Dry sodium chlorite is explosive and can cause fires in feed equipment if leaking solutions or spills are allowed to dry out.

Ozone
Ozone is a very effective disinfectant for both Giardia and viruses. Ozone CT (Contact time) values must be determined for the ozone basin alone; an accurate T10 value must be obtained for the contact chamber, residual levels measured through the chamber and an average ozone residual calculated. Ozone does not provide a system residual and should be used as a primary disinfectant only in conjunction with free and/or combined chlorine.

Ozone does not produce chlorinated byproducts (such as trihalomethanes) but it may cause an increase in such byproduct formation if it is fed ahead of free chlorine; ozone may also produce its own oxygenated byproducts such as aldehydes, ketones, or carboxylic acids. Any installed ozonation system must include adequate ozone leak detection alarm systems, and an ozone off-gas destruction system. Ozone may also be used as an oxidant for removal of taste and odor, or may be applied as a pre-disinfectant.

UV
The germicidal effect of UV is thought to be associated with its absorption by various organic components essential to the cell's functioning. For effective use of ultraviolet, the water to be disinfected must be clean and free of any suspended solids. The water must also be colorless and must be free of any colloids, iron, manganese, taste, and odor. These are conditions that must be met.

Chlorine and Disinfection Summary

Chlorine Demand: The minimum amount of chlorine needed to react in a water purification system; used as a monitoring measurement by system operators.

Chlorine Residual: The concentration of chlorine in the water after the chlorine demand has been satisfied. The concentration is normally expressed in terms of total chlorine residual, which includes both the free and combined or chemically bound chlorine residuals.

Combined Chlorine Residual: The amount of chlorine used up in a water purification system; used as a monitoring measurement by system operators. Combined chlorine is defined as the residual chlorine existing in water in chemical combination with ammonia or organic amines which can be found in natural or polluted waters. Ammonia is sometimes deliberately added to chlorinated public water supplies to provide inorganic chloramines.

Free Chlorine: Free chlorine is defined as the concentration of residual chlorine in water present as dissolved gas (Cl_2), hypochlorous acid (HOCl), and/or hypochlorite ion (OCl-). The three forms of free chlorine exist together in equilibrium.

$$Cl_2 + H_2O \quad HOCl + H^+ + Cl^-$$
$$HOCl \quad H^+ + OCl^-$$

Their relative proportions are determined by the pH value and temperature. Regardless of whether pre-chloration is practiced or not, a free chlorine residual of at least 1.0 mg/L should be maintained in the clear well or distribution reservoir immediately downstream from the point of post-chlorination and .2 mg/L in the distribution system to guard against backflow.

Total Chlorine Residual: The total of free residual and combined residual chlorine in a water purification system; used as a monitoring measurement by system operators. Total chlorine is the sum of free and combined chlorine. When chlorinating most potable water supplies, total chlorine is essentially equal to free chlorine since the concentration of ammonia or organic nitrogen compounds (needed to form combined chlorine) will be very low. When chloramines are present in the municipal water supply, then total chlorine will be higher than free chlorine.

Pre-chlorination: The addition of chlorine at the plant headworks or prior to other water treatment or groundwater production processes and mainly used for disinfection and control of tastes, odors, and aquatic growths.

Post-chlorination: The addition of chlorine after a process or adding chlorine downstream to meet a demand in the system.

Breakpoint chlorination: Breakpoint chlorination means adding Cl_2 to the water until the Cl_2 demand is satisfied. Until all the microorganisms are killed.

What is the process of chlorination called as a treatment process and how does it differ from sterilization?
Chlorination: A method of water disinfection where gaseous, liquid, or dissolved chlorine is added to a water supply system. Water which has been treated with chlorine is effective in preventing the spread of disease. The chlorination of public drinking supplies was originally met with resistance, as people were concerned about the health effects of the practice. The use of chlorine has greatly reduced the prevalence of waterborne disease as it is effective against almost all bacteria and viruses, as well as amoeba. Sterilization kills everything.

What are the physical properties of chlorine, what hazards does it present, what advantages does it have over most other disinfectants, and how does it react with bacteria?
Physical and chemical properties of chlorine: A yellowish green, nonflammable and liquefied gas with an unpleasant and irritating smell. Can be readily compressed into a clear, amber-colored liquid, a noncombustible gas, and a strong oxidizer. Solid chlorine is about 1.5 times heavier than water and gaseous chlorine is about 2.5 times heavier than air. Atomic number of chlorine is 17. Cl is the elemental symbol and Cl2 is the chemical formula.

Chlorine reacts with bacteria as if it was very corrosive and burns the skin or covering killing the bacteria.

What is the purpose of a fusible plug, at what temperature does it melt, and where is it located on 150-lb. and 1-ton cylinders?
Fusible plug is a safety device that melts. If the temperature of a full Cl2 cylinder is increased by 50^{o} F or 30^{o} C, a rupture may occur. It will melt at 158 to 165 degrees F. It is found on the side of a 1-ton container and on top of the 150-pound cylinder and is located in the valve below the valve seat.

What is the correct procedure to follow in changing a chlorine cylinder and what item should always be replaced with a new one in doing so?
Hook up the chlorinator to the container or cylinder with the chlorine valve turned off. Use the gas side not the liquid if using a 1-ton container. Remove the cylinder valve outlet cap and check the valve face or damage. Clean with wire brush if necessary. If the valve face is smooth, clean proceed with hooking up the cylinder. Check the inlet face of the chlorinator and clean if necessary. Place a new lead gasket on the chlorinator inlet, place the chlorinator on the cylinder valve, install the yoke clamp and slowly tighten the yoke clamp until the two faces are against the lead gasket. Tighten the yoke, compressing the gasket one half to three quarters turn, do not over tighten. Replace the lead gasket with every change out.

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Topic 10- Chlorine Section Post Quiz

1. How should the connection from a chlorine cylinder to a chlorinator be replaced?

2. How many turns should a chlorine gas cylinder be initially opened?

3. If the temperature of a full chlorine cylinder is increased by 50°F or 30°C, what is the most likely result?

4. What is meant by the specific gravity of a liquid?

5. Which metals are the only metals that are ***TOTALLY*** inert to moist chlorine gas?

6. What will be discharged when opening the top valve on a one-ton chlorine cylinder?

7. What are the approved methods for storing a chlorine cylinder?

8. What are normal conditions for a gas chlorination start-up?

9. Name a safety precaution when using chlorine gas?

10. What compounds are formed in water when chlorine gas is introduced?

11. Why should roller bearings not be used to rotate a one-ton chlorine cylinder?

12. What are the physical and chemical properties of chlorine?

13. What are the necessary emergency procedures in the case of a large uncontrolled chlorine leak?

4. Name several symptoms of chlorine exposure.

15. 5 lbs. of a 70% concentration sodium hypochlorite solution is added to a tank containing 650 gallons of water. What is the chlorine dosage?

16. As soon as Cl_2 gas enters the throat area, a victim will sense a sudden stricture in this area - nature's way of signaling to prevent passage of the gas to the lungs. At this point, the victim must attempt to do two things. Name them.

17. Positive pressure SCBAs and full face piece SARs can be used in oxygen deficient atmospheres containing less than what percentage of oxygen in the atmosphere?

18. Death is possible from asphyxia, shock, reflex spasm in the larynx, or massive pulmonary edema. Populations at special risk from chlorine exposure are individuals with pulmonary disease, breathing problems, bronchitis, or chronic lung conditions.
A. TRUE B. FALSE

19. Chlorine gas reacts with water producing a strongly oxidizing solution causing damage to the moist tissue lining the respiratory tract when the tissue is exposed to chlorine. The respiratory tract is rapidly irritated by exposure to 10-20 ppm of chlorine gas in air, causing acute discomfort that warns of the presence of the toxicant.
A. TRUE B. FALSE

20. Even brief exposure to 1,000 ppm of Cl_2 can be fatal.
A. TRUE B. FALSE

21. What are the two main chemical species formed by chlorine in water and what name are they are known collectively as?

22. When chlorine gas is added to water, it rapidly hydrolyzes according to the reaction:

Topic 11 - Pretreatment Section

Topic 11 - Section Focus: You will learn the basics of the pretreatment program, POTW rules, industrial/commercial classifications and inspection procedures. At the end of this section, you the student will be able to understand and describe Clean Water Act's rule concerning pretreatment and the rational for pretreatment. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Topic 11 – Scope/Background: The Industrial Pretreatment program is a federally mandated program under the Clean Water Act, which controls the discharges of commercial and industrial facilities. The purpose of the pretreatment program is to block the introduction of pollutants, which can cause damage to equipment and interference with the wastewater treatment process, into the wastewater collection and transmission system. The program is important in preventing harm to workers, the public and the environment.

Pretreatment Introduction

Pollutants in industrial wastewater may compromise municipal treatment plant processes or contaminate waters of the state. To protect municipal treatment plants and the environment, the Pretreatment Program requires industrial dischargers to use treatment techniques and management practices to reduce or eliminate the discharge of harmful pollutants to sanitary sewers. The Pretreatment Program is a core part of the Clean Water Act's National Pollutant Discharge Elimination System (NPDES).

The National Pretreatment Program's primary goal is to protect Publicly Owned Treatment Works (POTWs) and the environment from adverse impacts that might occur when pollutants are discharged into a sewage system.

The Specific Pretreatment Program Goals are as Follows:

- Prevent the introduction of pollutants into the POTW that will pass through the treatment works or are otherwise incompatible with treatment
- Prevent the introduction of pollutants that could interfere with POTW operations, including interference with the POTW's chosen sewage sludge use and disposal practices, as well as pollutants that could threaten worker health and safety
- Improve opportunities to recycle and reclaim municipal and industrial wastewaters and sludges

Discharges to a POTW have the potential to cause the POTW to violate its National Pollutant Discharge Elimination System (NPDES) permit if the treatment system is not able to adequately remove the pollutant contained in the discharge or the pollutant otherwise damages or disrupts operations of the POTW. Industrial discharges to POTWs have historically been a significant source of pollutants in our nation's waters. Certain industrial discharges can interfere with the operation of POTWs, leading to the discharge of untreated or inadequately treated wastewater into rivers, lakes, and such.

Some pollutants are not compatible with biological wastewater treatment at POTWs and may pass through the treatment plant untreated. This pass through of pollutants affects the surrounding environment, occasionally causing fish kills or other detrimental alterations of the receiving waters. Even when POTWs have the capability to remove toxic pollutants from wastewater, the toxics can end up in the POTW's sewage sludge, which in many places is land applied to food crops, parks, or golf courses as fertilizer or soil conditioner.

The Clean Water Act (CWA or the Act) addresses this problem by requiring the U.S. Environmental Protection Agency (EPA) to promulgate federal standards for the pretreatment of wastewater discharged to a POTW [33 U.S.C. § 1317(b)(3)]. Section 307(d) of the Act prohibits discharge in violation of any pretreatment standard [33 U.S.C. § 1317(d)]. The CWA prohibits the introduction of pollutants into a POTW that might pass through or interfere with the POTW and its operations.

Discharge of a pollutant is a term specifically defined in the CWA to mean the discharge of a pollutant to navigable waters, and such discharges are generally prohibited except in compliance with the Act and a permit under section 402 of the Act. While this document uses the word discharge in its commonly understood meaning when referring to the introduction of pollutants into a POTW, such a discharge is not a CWA discharge of pollutants to navigable waters.

To address indirect discharges from industries to POTWs, EPA has established the National Pretreatment Program as a component of the NPDES Permitting Program. The National Pretreatment Program requires industrial and commercial dischargers to treat or control pollutants in their wastewater before discharge to POTWs. EPA has chosen to promulgate pretreatment standards at the same time it promulgates effluent limitations guidelines for industry categories of direct dischargers under sections 301(b) and 304(b) of the Act [33 U.S.C. § 1311(b) and 1314(b)].

These pretreatment regulations are applicable to industrial indirect dischargers—those discharging to POTWs—and are known as categorical pretreatment standards.

EPA has also developed other nationally applicable pretreatment standards (national pretreatment standards) under section 307(b) in its General Pretreatment Regulations for Existing and New Sources of Pollution (Pretreatment Regulations) at 40 CFR Part 403. Such pretreatment standards are applicable to any user of a POTW, defined as a source of an indirect discharge [40 CFR 403.3(i)].

These national pretreatment standards include (1) a general prohibition and (2) specific prohibitions.

The general prohibition prohibits any user of a POTW from introducing a pollutant into the POTW that will cause pass through or interference. EPA's regulations define both pass through and interference. Pass through is defined as a discharge that exits the POTW into waters of the United States in quantities or concentrations that, alone or in conjunction with a discharge or discharges from other sources, is a cause of a violation of any requirement of the POTW's NPDES permit.

Interference includes a discharge that, alone or in conjunction with a discharge from other sources will, among other things, prevent sewage sludge use in compliance with described regulatory provisions including section 405 of the Act [40 CFR 403.3(k)(2)]. In addition, under the Pretreatment Regulations, certain POTWs must develop and enforce local limits to implement the general and specific prohibitions of section 403.5(a)(1) and (b). Local limits that are developed by a POTW in accordance with the regulations are pretreatment standards for purposes of section 307(d) of the CWA [40 CFR 403.5(d)]. See also 40 CFR 403.3(l) ("The term National Pretreatment Standard, Pretreatment Standard, or Standard ... includes any prohibitive discharge limits established pursuant to § 403.5.").

Finally, states and POTWs always have the option of establishing more stringent requirements if such requirements are authorized and necessary, pursuant to their state or local law. Generally, this document describes only the National Pretreatment Program requirements established pursuant to the CWA and implementing regulations.

Where state or local requirements are implemented in the same control mechanism, the control mechanism should clearly identify the applicable local or state regulation or enabling legislation. (For a discussion of other conditions in IU permits based on state or local requirements, see Section 3.1.2.7.) Therefore, each the pretreatment program can be a mixture of federal, state, and local standards and requirements.

National Pretreatment Program's Purpose

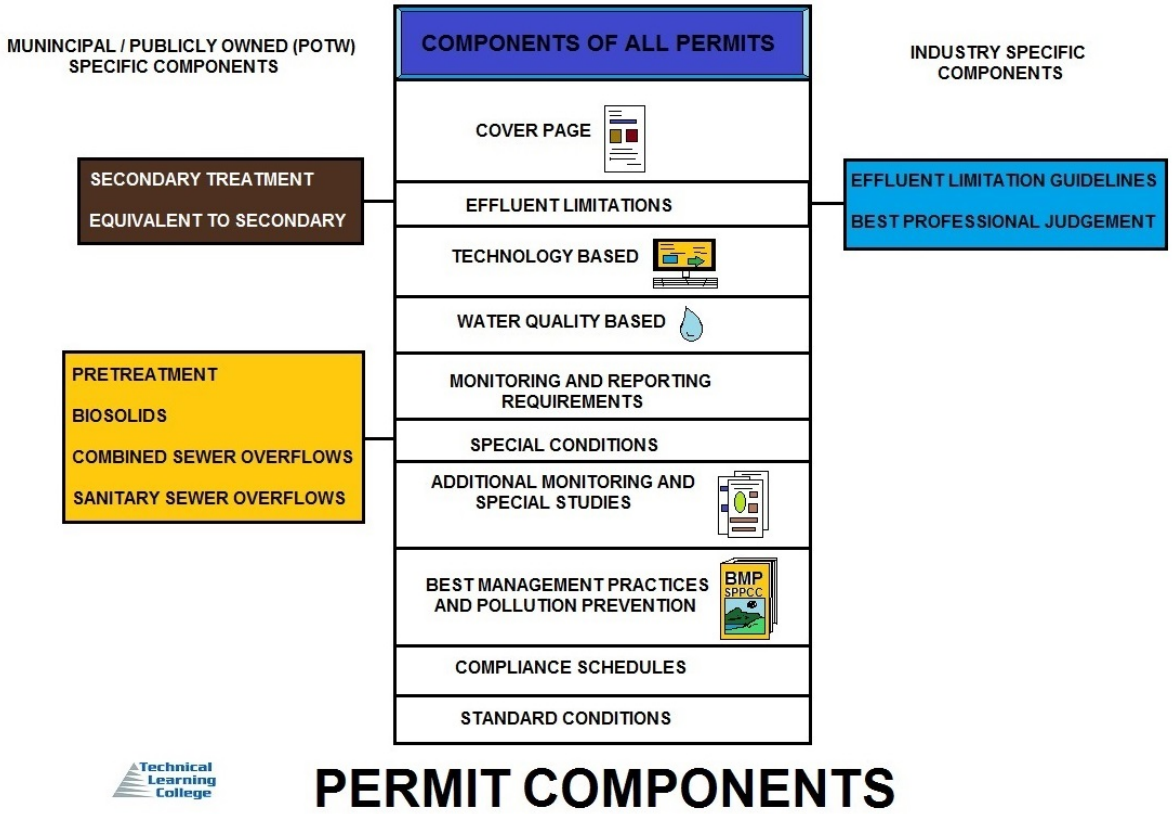
It is a cooperative effort of federal, state, and local environmental regulatory agencies established to protect water quality. The EPA authorizes the NPDES permit program to state, tribal, and territorial governments to perform permitting, administrative, and enforcement tasks for discharges to surface waters (NPDES program), EPA and authorized NPDES state pretreatment programs approve local municipalities to perform permitting, administrative, and enforcement tasks for discharges into the municipalities' publicly owned treatment works (POTWs). The national pretreatment program is a component of the NPDES program.

National Pretreatment Program's Objectives

The national pretreatment program requires nondomestic dischargers to comply with pretreatment standards to ensure the goals of the Clean Water Act (CWA) are attained.

The objectives of the program are to:

- prevent the introduction of pollutants into a POTW that will interfere with its operation, including interference. A discharge that, alone or in conjunction with a discharge or discharges from other sources, both (1) inhibits or disrupts the POTW, its treatment processes or operations, or its sludge processes, use, or disposal; and (2) therefore is a cause of a violation of any requirement of the POTW's NPDES permit (including an increase in the magnitude or duration of a violation) or of the prevention of sewage sludge use or disposal in compliance with ... [applicable] statutory provisions and regulations or permits issued thereunder (or more stringent state or local regulations). [paraphrased from 40 CFR 403.3(k)] with its use or disposal of municipal sludge,
- prevent the introduction of pollutants into a POTW that will pass through the treatment works or otherwise be incompatible with it, and
- improve opportunities to recycle and reclaim municipal and industrial wastewaters and sludges.



National Pretreatment Program Overview

The Clean Water Act

On October 18, 1972, the 92nd Congress of the United States passed the Federal Water Pollution Control Act Amendments of 1972, declaring the restoration and maintenance of the chemical, physical, and biological integrity of the Nation's water as a National Objective. While procedures for implementing this act (more commonly referred to as the Clean Water Act (CWA)) have been re-evaluated and modified over time, the 1972 objective has remained unchanged in its 49-year history.

The 1972 Amendments to the CWA established a water quality regulatory approach along with the EPA-promulgated industry-specific technology-based effluent limitations. The National Pollutant Discharge Elimination System (NPDES) permit program was established under the CWA to control the discharge of pollutants from point sources and served as a vehicle to implement the industrial technology-based standards. To implement pretreatment requirements, the EPA promulgated 40 CFR Part 128 in late 1973, establishing general prohibitions against treatment plant interference and pass through and pretreatment standards for the discharge of incompatible pollutants from specific industrial categories.

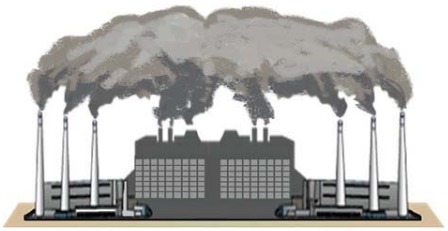
In 1975, several environmental groups filed suit against the EPA, challenging it's criteria for identifying toxic pollutants, the EPA's failure to promulgate effluent standards, and the EPA's failure to promulgate pretreatment standards for numerous industrial categories.

As a result of this litigation, the EPA promulgated the General Pretreatment Regulations at 40 CFR Part 403 on June 26, 1978, replacing the 40 CFR Part 128 requirements. Additionally, as a result of the suit, the EPA agreed to regulate the discharge of 65 categories of pollutants (making up the 126 priority pollutants presented in Figure 4) from 21 industrial categories. The list of priority pollutants is still in effect today (the original list actually had 129 pollutants, three of which have since been removed from that list) while the list of regulated industrial categories has grown to more than 51 distinct industries.

Modern wastewater treatment plant

Domestic Wastewater

- Discharge from residential homes.
- Contains Organic and Inorganic waste.
- The strength of decomposition depends on the distance to a wastewater facility.



Industrial Wastewater

- Discharge from medium to large industries.
- Contains high levels of Inorganic waste.
- Industries containing Organic waste include meat, dairy and vegetable packing plants.

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TYPES OF WASTEWATER

ALL PERMIT COMPONENTS	INDUSTRY COMPONENTS	MUNICIPAL COMPONENTS
Cover Page		
Effluent Limitations • Technology Based • Water Quality Based	• Effluent Guidelines • Best Professional Judgement	• Secondary • Equivalent to Secondary
Monitoring Reporting Requirements		
Special Conditions • Compliance Schedules • Storm Water • Special Studies, Evaluations, and Other Requirements	• Best Management Practice	• Pretreatment • Combined Sewer Overflows • Sewage Sludge
Standard Conditions		

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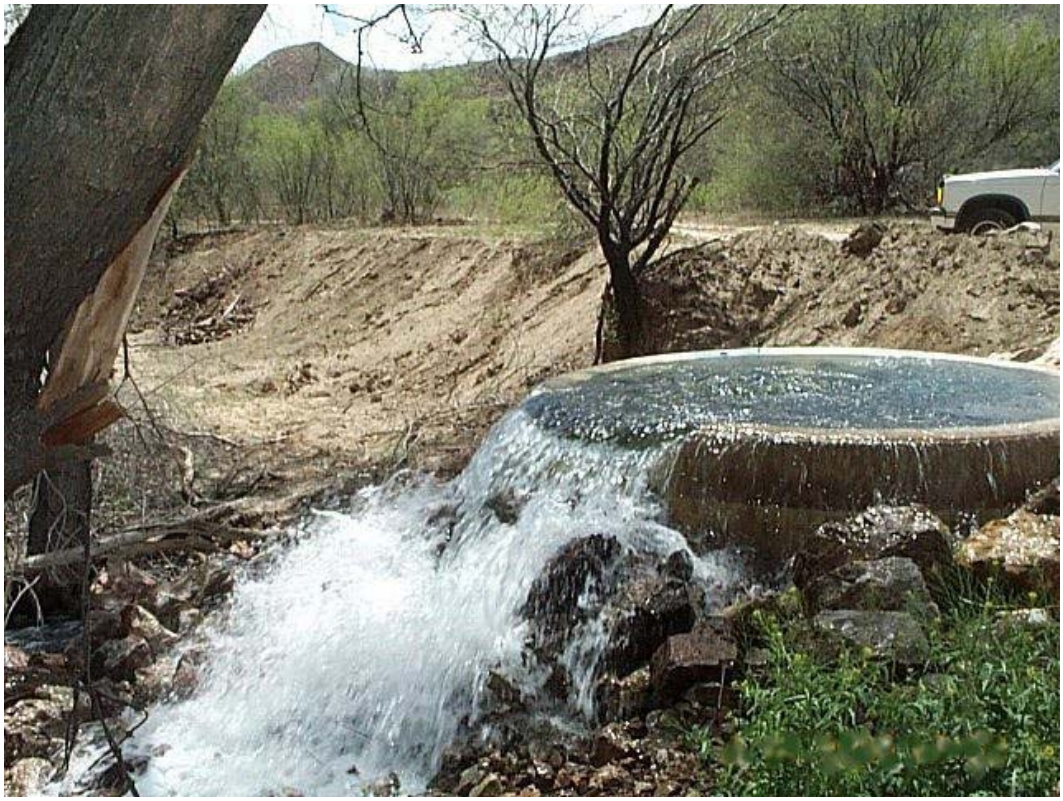
PRETREATMENT PERMIT

Section 101 of the Clean Water Act (CWA)

To restore and maintain the chemical, physical, and biological integrity of the Nation's waters:
(1) it is the national goal that the discharge of pollutants into the navigable waters be eliminated by 1985;
(2) it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983;
(3) it is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited;
(4) it is the national policy that Federal financial assistance be provided to construct publicly owned waste treatment works;
(5) it is the national policy that Area wide waste treatment management planning processes be developed and implemented to assure adequate control of sources of pollutants in each State;
(6) it is the national policy that a major research and demonstration effort be made to develop technology necessary to eliminate the discharge of pollutants into the navigable waters, waters of the contiguous zone, and the oceans; and
(7) it is the national policy that programs for the control of nonpoint sources of pollution be developed and implemented in an expeditious manner so as to enable the goals of this Chapter to be met through the control of both point and nonpoint sources of pollution.



Treated wastewater outfall.

GENERAL PROHIBITIONS

The federal pretreatment regulations at 40 CFR Part 403.5(a)(1) includes **"general prohibitions"** for industrial users stating that no user shall introduce into a POTW any pollutant(s) which causes pass through or interference. The federal regulations also established specific prohibitions for users.

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DENTAL CATEGORY

EPA's Effluent Limitations Guidelines and Standards for the **Dental Category**, also known as the Dental Amalgam Rule, went into effect for new sources on July 14, 2017. New dental offices that place or remove amalgam fillings must now install and maintain dental amalgam separators, follow best **management practices (BMPs),** and submit a one-time compliance report to their POTW or other pretreatment control authority. New dental offices must submit their compliance report no later than 90 days after beginning discharge of wastewater to a POTW.

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CATEGORICAL INDUSTRIAL USER

A **categorical industrial user** is an industry or entity which is subject to categorical standards. The wastewater from an entity or industry discharging into a sewer system tributary to a POTW (industrial user - IU) may be as simple and uncomplicated as that of a coin-operated car wash or as complex as an automobile manufacturing plant or a synthetic organic chemical producer. The IUs discharging complex wastewater would likely be subject to categorical standards, which is one of the defining criteria for significant industrial users.

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As a wastewater operator or pretreatment inspector, you should be memorizing these terms (see above boxes). These USEPA terms are essential for any successful pretreatment inspector to communicate with the public. Most wastewater treatment operators know these terms.

Pretreatment Program Defined

The term "pretreatment" refers to the requirement that non-domestic sources discharging wastewater to POTWs control their discharges, and meet limits established by the EPA, and/or your state or the local municipality (Control Authority) on the amount of pollutants allowed to be discharged. The control of the pollutants may necessitate treatment prior to discharge to the POTW (therefore the term "pretreatment").

Limits may often be met by the non-domestic source through pollution prevention techniques (product substitution, recycle and reuse of materials, more efficient production practices, improved environmental management systems, etc.), pretreatment of wastewater, or implementation of best management practices.

The National Pretreatment Program is a cooperative effort of federal, state, and local regulatory environmental agencies established to protect water quality. The program is designed to reduce the level of pollutants discharged by industry and other non-domestic wastewater sources into municipal sewer systems, and thereby, reduce the amount of pollutants released into the environment from these sources.

The national pretreatment program was established by Congress under authority of the Federal Water Pollution Control Act of 1972 (Pub. L. 92-500) as amended by the Clean Water Act of 1977 (Pub. L. 95-217). Implementation requirements of the pretreatment portions of these laws were first codified into 40 Code of Federal Regulations (CFR) Part 403 in 1978.

Objectives of the pretreatment program:

1. Protect publicly owned treatment works (POTW) from pollutants that may cause interference with sewage treatment plant operations.
2. Prevent introducing pollutants into a POTW that could cause pass through of untreated pollutants to receiving waters.
3. Manage pollutant discharges into a POTW to improve opportunities for reuse of POTW wastewater and residuals (sewage sludge).
4. Prevent introducing pollutants into a POTW that could cause worker health or safety concerns, or that could pose a potential endangerment to the public or to the environment.

POTWs

Publicly owned treatment works (POTWs) collect wastewater from homes, commercial buildings, and industrial facilities and transport it via a series of pipes, known as a collection system, to the treatment plant. Here, the POTW removes harmful organisms and other contaminants from the sewage so it can be discharged safely into the receiving stream. Generally, POTWs are designed to treat domestic sewage only.

However, POTWs also receive wastewater from industrial (non-domestic) users. The General Pretreatment Regulations establish responsibilities of Federal, State, and local government, industry and the public to implement Pretreatment Standards to control pollutants from the industrial users which may pass through or interfere with POTW treatment processes or which may contaminate sewage sludge.

National Pretreatment Program

The National Pretreatment Program identifies specific requirements that apply to all IUs, additional requirements that apply to all SIUs, and certain requirements that only apply to CIUs.

The objectives of the National Pretreatment Program are achieved by applying and enforcing three types of discharge standards:

- **prohibited discharge standards**
- **categorical Pretreatment standards**
- **local limits**

Prohibited Discharge Standards *(Credit USEPA)*

Prohibited discharge standards are somewhat general, national standards are applicable to all industrial users to a POTW, regardless of whether or not the POTW has an approved pretreatment program or the industrial user has been issued a permit.

These standards are designed to protect against pass through and interference, protect the POTW collection system, and to promote worker safety and beneficial biosolids use. These standards are listed in 40 CFR 403.5

For Final Regulations pertaining to the Pretreatment Program, refer to 40 CFR Part 403 general pretreatment regulations (Located in the rear of this course).

Categorical Pretreatment Standards

Categorical Pretreatment Standards are limitations on pollutant discharges to publicly owned treatment works (POTWs), promulgated by the EPA in accordance with Section 307 of the Clean Water Act that apply to specific process wastewaters of particular industrial categories.

These are national, technology-based standards that apply regardless of whether or not the POTW has an approved pretreatment program or the industrial user has been issued a permit. Such industries are called Categorical Industrial Users. The standards applicable to industrial discharges to a POTW collection system are designated in the Effluent Guidelines & Limitations [Parts 405-471] by the terms "Pretreatment Standards for Existing Sources" (or "PSES") and "Pretreatment Standards for New Sources" (or "PSNS").

Note: The Effluent Guidelines & Limitations designated by the terms "Best Practicable Control Technology Currently Available (BPT)", "Best Available Technology Economically Achievable (BAT)", "Best Conventional Pollutant Control Technology (BCT)", and "New Source Performance Standards (NSPS)" apply to industries that discharge process wastewater to waters of the U.S. and should have a National Pollutant Discharge Elimination System (NPDES) Permit.

Regulations for all Effluent Guidelines and Standards are located at: http://www.epa.gov/

Additional information on ongoing Categorical Standards Projects and recently published rules is located at: http://www.epa.gov/

Conventional Pollutants *(Credit USEPA)*

BOD, TSS, fecal coliform, oil and grease, and pH

In the above photo, sampling equipment after being washed and being allowed to air dry. You as a Sampler will spend up to 1-2 hours a day preparing your sample bottles. This may include washing your sample tools, bottles and other equipment.

Some bottles will need to be washed in a three or four step process. Hydrochloric and other acids are used for the cleaning of glass bottles. The Pickle jar or large jar is often re-used and washed on a daily basis.

Pretreatment Inspectors and Stormwater Inspectors will often work in pairs. Usually one Inspector will spend a lot of time setting up automatic samplers and programming flow meters, while the other Inspector will calibrate pH meters and related laboratory equipment, pre-preserve sample bottles, gather ice and calibrate the safety equipment and gas meters.

Some POTWs will hire both Samplers and Inspectors and split these duties up. Other POTWs will utilize Inspectors as Samplers.

Local Limits *(Credit USEPA)*

Local limits are developed to reflect specific needs and capabilities at individual POTWs and designed to protect the POTW receiving waters. Regulations at 40 CFR 403.8(f)(4) state that POTW Pretreatment Programs must develop local limits or demonstrate that they are unnecessary; 40 CFR 403.5(c) states that local limits are needed when pollutants are received that could result in pass through or interference at the POTW. Essentially, local limits translate the general prohibited discharge standards of 40 CFR 403.5 to site-specific needs.

Assistance on how to develop local limits may be found in the Guidance Manual for the Development and Implementation of Local Discharge Limitations under the Pretreatment Program.). Information related to ordering this publication from the Office of Wastewater Management is located at: http://www.epa.gov/.

The EPA Supplemental Manual on the Development and Implementation of Local Discharge Limitations Under the Pretreatment Program: Residential and Commercial Toxic Pollutant Loadings and POTW Removal published May 1, 1991 provides information related to residential and commercial sources of toxic pollutants and estimated removal efficiencies of municipal treatment processes.

Two automatic wastewater samplers, one for Local Limits or compliance and the other for the wastewater plant operator to determine plant efficiency.

LOCAL LIMITS

Delegated POTWs must control SIUs individually and not impose limits on them that may allow violations of the general or specific prohibitions. The POTW generally should impose required local limits (limits imposed by POTW to prevent interference or pass-through) for all SIUs, and is required to when interference or pass-through has occurred and may reoccur. A POTW also must evaluate **local limits** if an SIU causes interference or pass-through without violating a **local limit**. In addition to required local limits, a POTW may set other local limits not required by pretreatment rules. The State can enforce required local limits, but cannot enforce the non-required limits.

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LOADING LIMITS

In the context of an NPDES permit, a loading limit determines the amount of a pollutant (in pounds per day) which can be discharged in wastewater effluent. The loading limit is generally based upon the allowable concentration of the pollutant and a design flow rate for the discharge.

The loading limit would be calculated as follows:
loading limit = Flow million gallons/day x 8.34 lbs/gallon x Concentration mg/L

Loading limits are normally not included in indirect discharge permits, with an exception being permits for food processors.

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As a wastewater operator or pretreatment inspector, you should be memorizing these terms (see above boxes). These USEPA terms are essential for any successful pretreatment inspector to communicate with the public.

The Need for the Pretreatment Program

The average American uses roughly 100 to 200+ gallons of water a day, with less than one percent of that water actually being consumed. The rest is used for activities such as washing, preparing food, watering lawns, heating and cooling, transporting wastes, and fire protection.

The public is very conscious about the quality of water that comes out of their tap each day, quickly notifying authorities of changes in appearance, odor, and taste.

These same Americans, on average, discharge about the same amount of wastewater to local sewage treatment plants daily. This wastewater (commonly referred to as "*domestic sewage*") receives much less attention than drinking water, likely the result of an "out of sight, out of mind" attitude.

Most people take it for granted that once down the drain, wastes will be handled appropriately. In fact, this attitude has carried over to industry as well, as can be seen by reading the labels of many household products.

These labels often recommend that waste or excess product be disposed of down the drain. Other toxic or hazardous products are actually designed to be disposed of down the drain (e.g., drain clog remover).

Recall the phosphate detergent problems of the late 1960s and early 70s; large doses of phosphate, found in most detergents at the time, were passing through municipal treatment plants and overloading lakes, causing large algal blooms to form and subsequently reducing available light, food and oxygen for fish and other aquatic organisms.

While great strides have been taken to address the phosphate problem, it is possible that other problematic pollutants are being dumped down the drain at the expense of human health and the environment.

INTERFERENCE

Interference: a discharge from an industrial user that, alone or in conjunction with other sources a) inhibits or disrupts a POTW plant, its treatment processes or operations, or its sludge processes, use, or disposal, and b) therefore causes a violation including increasing a violation's magnitude or duration of any permit or rule that controls release of pollutants from the POTW.

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FOG Introduction

Keeping Fats, Oils, and Grease out of the Sewer System
Fats, oils, and grease (FOG) comes from meat fats in food scraps, cooking oil, shortening, lard, butter and margarine, gravy, and food products such as mayonnaise, salad dressings, and sour cream.

FOG poured down kitchen drains accumulates inside sewer pipes and cause damage to the collection system. As the FOG builds up, it restricts the flow in the pipe and can cause untreated wastewater to back up into homes and businesses, resulting in high costs for cleanup and restoration.

Manholes can overflow into parks, yards, streets, and storm drains, allowing FOG to contaminate local waters, including drinking water. Exposure to untreated wastewater is a public-health hazard and is an EPA violation. FOG discharged into septic systems and drain fields can cause malfunctions, resulting in more frequent tank pump-outs and other expenses.

Restaurants, cafeterias, and fast-food establishments spend tens of thousands of dollars on plumbing emergencies each year to deal with grease blockages and pump out grease traps and interceptors. Some cities also charge businesses for the repair of sewer pipes and spill cleanup if they can attribute the blockage to a particular business.

Some cities also add a surcharge to wastewater bills if a business exceeds a specified discharge limit. These expenses can be a significant.

Communities spend billions of dollars every year unplugging or replacing grease-blocked pipes, repairing pump stations, and cleaning up costly and illegal wastewater spills. Excessive FOG in the sewer system can affect local wastewater rates. So, keeping FOG out of the sewer system helps everyone in the community.

Controlling Fats, Oils, and Grease Discharges from Food Service Establishments
FOG gets into our sewer collection system mainly from residential customers pouring the substances down their drains and from commercial food preparation establishments with inadequate grease controls. Fats, oils and grease are a byproduct of cooking and are mostly found in the following:

- ✓ Meats
- ✓ Cooking oil
- ✓ Lard or shortening
- ✓ Butter or margarine

Our sewer system is not designed to handle or treat these substances in excess. Over time, without proper disposal of fats, oils and grease, they build up in the sewer system and eventually block collection pipes and sewer lines, resulting in sewer backups and overflows on streets, properties and even in customers' homes and/or businesses. Overflows may also impact the environment negatively and can result in contamination of ponds, streams or rivers.

Food Service Establishments (FSEs)
Food Service Establishments (FSEs) are a significant source of fats, oil and grease (FOG) because of the amount of grease used in cooking. POTW Commercial FOG Programs are generally developed to assist restaurants and other FSEs with proper handling and disposal of their FOG. Through implementation of Best Management Practices (BMPs), these establishments should be able to significantly reduce the amount of FOG that goes down their drains. This will minimize back-ups and help business owners comply with the POTW's requirements.

To work effectively, sewer systems need to be properly maintained, from the drain to the treatment plant. If wastes are disposed of correctly, the POTW's sewer system can handle them without any problem. Grease is an example of a waste that the sewer system cannot handle, and therefore should not be put down the drain.

The POTW needs businesses and individuals to do their part to maintain the system because repeated repairs are disruptive to residences and businesses alike. Furthermore, proper disposal by commercial establishments is required by law.

Environmental Problem with FOG sewers
FOG that enters the sewer system eventually solidifies and forms grease balls. These grease balls can range in size from marbles to the size of cantaloupes and must be removed periodically. Since the sewer system is unable to handle or treat these substances effectively, this incurs greater expenditures on the maintenance of the collection systems and/or treatment plants which in turn can lead to higher customer rates.

Sewer backups can also cost customers thousands of dollars for the repair or replacement of their damaged property.

Key Pretreatment Review Notes

CONVENTIONAL POLLUTANTS

POTWs are designed to treat typical household wastes and biodegradable commercial and biodegradable industrial wastes. The Clean Water Act defines the contaminants from these sources as **conventional pollutants**. **Conventional pollutants** are biological oxygen demand (BOD), total suspended solids (TSS), fecal coliform, oil and grease, and pH**.**

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GENERAL PROHIBITIONS

The federal pretreatment regulations at 40 CFR Part 403.5(a)(1) includes **"general prohibitions"** for industrial users stating that no user shall introduce into a POTW any pollutant(s) which causes pass through or interference. The federal regulations also established specific prohibitions for users.

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INDIRECT DISCHARGE

An **indirect discharge** is represented by an industry or business which sends wastewater to a sewer system tributary to a POTW in contrast to discharging directly into state surface waters. While **direct discharges** to surface waters are regulated under the NPDES permit program, indirect discharges are regulated as a component of the NPDES Permitting Program through the National Pretreatment Program. The National Pretreatment Program requires industrial and commercial dischargers to treat or control pollutants in their wastewater prior to discharge to POTWs.

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CATEGORICAL STANDARDS

Categorical standards are technology-based limitations on pollutant discharges to POTWs, which have been promulgated by U.S. EPA in accordance with Section 307 of the Clean Water Act, and apply to specific process wastewater discharges for thirty-two (32) different industrial categories. (Categorical standards can be found in 40 CFR Parts 405-471.) Categorical standards are similar to federal effluent guidelines (FEGs), with two important distinctions:

- **categorical standards** apply to indirect discharges while FEGs apply only to direct discharges to surface waters; and
- **categorical standards** are developed with the assumption that the POTW will remove at least small amounts of a pollutant, therefore the categorical standard for the pollutant will be less stringent than the corresponding best available technology (BAT) limits for the FEG applied to a direct discharger

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In this photo, the Lab Tech is waiting for the Sampler to return with samples. You can see the small refrigerator with a lock on it. Samplers will normally release the samples to the Chemist, but if the Chemist is out of the office, or after work hours, you will place the samples in the refrigerator and lock it. Write on your chain-of-custody report that you placed the samples in the locked refrigerator.

Chain-of-Custody (COC)
A record of each person involved in the possession of a sample from the person who collects the sample to the person who analyzes the sample in the laboratory.

Discharge to POTW (Credit to USEPA)

As noted above, POTWs are not designed to treat toxics in industrial waste. As such, these discharges, from both industrial and commercial sources, can cause serious problems. The undesirable outcome of these discharges can be prevented using treatment techniques or management practices to reduce or eliminate the discharge of these contaminants. The act of treating wastewater prior to discharge to a POTW is commonly referred to as "**pretreatment**." The National Pretreatment Program, published in **Title 40 Code of Federal Regulations (CFR) Part 403**, provides the regulatory basis to require non-domestic dischargers to comply with pretreatment standards (effluent limitations) to ensure that the goals of the CWA are attained.

As noted in 40CFR §403.2, the objectives of the National Pretreatment Program are to:
a. Prevent the introduction of pollutants into POTWs which will interfere with the operation of a POTW, including interference with its use or disposal of municipal sludge;
b. Prevent the introduction of pollutants into POTWs which will pass through the treatment works or otherwise be incompatible with such works; and
c. Improve opportunities to recycle and reclaim municipal and industrial wastewaters and sludges.

The two key terms used in the EPA's objectives for the National Pretreatment Program, "***interference***" and "***pass through***," are defined below.

Definitions

Interference - a discharge which, alone or in conjunction with a discharge or discharges from other sources, both inhibits or disrupts the POTW, its treatment processes or operations, or its sludge processes, use or disposal, and- therefore is a cause of a violation of any NPDES permit requirement or of the prevention of sewage sludge use or disposal in compliance with any applicable requirements.

Pass Through - a discharge which exits the POTW into waters of the U.S. in quantities or concentrations which, alone or in conjunction with a discharge or discharges from other sources, is a cause of a violation of any NPDES permit requirement.

As outlined in the EPA's objectives, toxic pollutants may pass through the treatment plant into the receiving stream, posing serious threats to aquatic life, to human recreation, and to consumption of fish and shellfish from these waters. Pass through can make waters unswimmable or unfishable in direct contrast to the goals of the CWA. Or, these discharges can interfere with the biological activity of the treatment plant causing sewage to pass through the treatment plant untreated or inadequately treated.

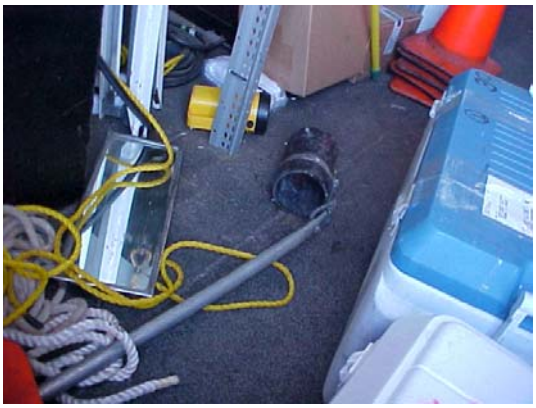
Problems Associated with Toxic Discharges *Figure 3*

Air pollution can occur from volatilization of toxic chemicals in the POTW collection system or treatment plant, or through incineration of sewage sludge.
Corrosion of collection system and treatment plant from acidic discharges or discharges containing elevated levels of sulfate (forming toxic and corrosive hydrogen sulfide).
Groundwater pollution can occur from leaks in the collection system or pollutants from contaminated sewage sludge.

Toxic Emissions (*Credit to USEPA)*

Even where the POTW has the capability to remove these toxics, the pollutants may end up in the sewage sludge, thereby limiting sludge disposal options or escalating the cost of disposal. Incinerated contaminated sludge may release toxic emissions into the atmosphere. Toxic metals removed in primary treatment, while itself not an inhibitory process, can impact sludge digestion, a process that utilizes bacteria to stabilize sludge solids.

For example, chromium can inhibit reproduction of aerobic digestion microorganisms, thereby disrupting sludge treatment and producing sludges that must be disposed of with special treatment. Uncontaminated sludge, on the other hand, can be used as fertilizer or soil conditioner, thereby improving the productivity of our land. Many municipalities apply sewage sludge to pastureland or parkland that they could not do if the sludge were contaminated.



Tools of the Trade… Above photos**,** the Refrigerated Automatic Sampler will have a Data programmer which will allow you to set the time to collect the sample or samples. This machine can also measure the amount of the sample.

These can also be used for the collection of composite samples. Sometimes you will see a pH probe with real-time reads sent to the Operator's Command Center. A common site on most wastewater plants and SIUs.

Volatile Organic Compounds (VOCs)

One more important issues we need to address before we cover the essential of a pretreatment program is volatile organics. Volatile organics discharged to sewers can accumulate in the headspace of sewers, increasing the likelihood of explosions that can cause significant damage. Probably the most well-known impact from industrial discharges to POTWs in the U.S. is the explosion in Louisville, KY that occurred in 1981 as the result of excessive discharges of hexane into the collection system, eventually igniting and destroying more than 3 miles of sewers and causing $20 million in damage. Discharge limitations and management practices to control slug discharges have significantly reduced the likelihood of future catastrophes such as the explosion in Louisville.

Discharges of toxic organics can also result in the release of poisonous gas. This occurs most often when acidic wastes react with other wastes in the discharge. For example, cyanide and acid, both present in many electroplating operations, react to form highly toxic hydrogen cyanide gas. Similarly, sulfides from leather tanning can combine with acid to form hydrogen sulfide, another toxic gas. These can be highly dangerous to POTW collection system operators exposed to such conditions in the performance of their duties.

Other problems associated with toxic discharges were summarized in Figure 3 and further document the urgency of keeping toxics out of collection systems and POTWs.

The National Pretreatment Program is charged with controlling the 129 Priority Pollutants from industries that discharge into sewer systems as described in the CWA (see Figure 4).

These pollutants fall into two categories; metals and organics:

- Metals, including lead, mercury, chromium, and cadmium that cannot be destroyed or broken down through treatment or environmental degradation. Toxic metals can cause different human health problems such as lead poisoning and cancer. Additionally, consumption of contaminated seafood and agricultural food crops has resulted in exposures exceeding recommended safe levels.

- Toxic organics, including solvents, pesticides, dioxins, and polychlorinated biphenyls (**PCBs**) can be cancer-causing and lead to other serious ailments, such as kidney and liver damage, anemia, and heart failure. In 1996, the EPA's Office of Science and Technology (**OST**) identified 2,193 water bodies with fish and wildlife advisories, up more than 25 percent from 1995.

Reductions in pollutants can ensure that industrial development vital to the economic well-being of a community is compatible with a healthy environment.

Many POTWs are responsible for ensuring that industrial and commercial facilities do not cause problems resulting from their discharges. In 1991, the EPA estimated that 190 to 204 million pounds of metals and 30 to 108 million pounds of organics were removed each year as a result of pretreatment program requirements.

This is substantiated by many POTWs that report significant reductions in the loadings of toxics to their treatment plants that is directly attributable to implementation of the National Pretreatment Program.

The National Pretreatment Program is unique in that the General Pretreatment Regulations require all large POTWs (i.e., those designed to treat flows of more than 5 million gallons per day) and smaller POTWs with significant industrial discharges to establish local pretreatment programs. These local programs must enforce all national pretreatment standards and requirements in addition to any more stringent local requirements necessary to protect site-specific conditions at the POTW.

General Pretreatment Regulations at 40 CFR Part 403§ 403.1 Purpose and Applicability *(Credit USEPA)*

Figure 6. The General Pretreatment Regulations

§ 403.2 Objectives of general pretreatment regulations
§ 403.3 Definitions
§ 403.4 State or local law
§ 403.5 National pretreatment standards: Prohibited discharges
§ 403.6 National pretreatment standards: Categorical pretreatment standards
§ 403.7 Removal credits
§ 403.8 Pretreatment program requirements: Development and implementation by POTW
§ 403.9 POTW pretreatment programs and/or authorization to revise pretreatment standards: Submission for approval
§ 403.10 Development and submission of NPDES State pretreatment programs
§ 403.11 Approval procedures for POTW pretreatment programs and POTW granting of removal credits
§ 403.12 Reporting requirements for POTW's and industrial users
§ 403.13 Variances from categorical pretreatment standards for fundamentally different factors
§ 403.14 Confidentiality
§ 403.15 Net/Gross calculation
§ 403.16 Upset provision
§ 403.17 Bypass
§ 403.18 Modification of POTW pretreatment programs
Appendix A: Program Guidance Memorandum
Appendix B: [Reserved]
Appendix C: [Reserved]
Appendix D: Selected Industrial Subcategories Considered Dilute for Purposes of the Combined Wastestream Formula
Appendix E: Sampling Procedures
Appendix F: [Reserved]
Appendix G: Pollutants Eligible for a Removal Credit

The General Pretreatment Regulations

1. The General Pretreatment Regulations establish responsibilities of Federal, State, and local government, industry and the public to implement Pretreatment Standards to control pollutants which pass through or interfere with POTW treatment processes or which may contaminate sewage sludge. The regulations, which have been revised numerous times since originally published in 1978, consist of 18 sections and several appendices.

2. The General Pretreatment Regulations apply to all non-domestic sources which introduce pollutants into a POTW. These sources of "***indirect discharge***" are more commonly referred to as industrial users (**IUs**).

3. Since IUs can be as simple as an unmanned coin operated car wash to as complex as an automobile manufacturing plant or a synthetic organic chemical producer, EPA developed four criteria that define a Significant Industrial User (**SIU**). Many of the General Pretreatment Regulations apply to SIUs as opposed to IUs, based on the fact that control of SIUs should provide adequate protection of the POTW.

These four criteria are as follows:

- An IU that discharges an average of 25,000 gallons per day or more of process wastewater to the POTW;
- An IU that contributes a process wastestream making up 5 percent or more of the average dry weather hydraulic or organic capacity of the POTW treatment plant;
- An IU designated by the Control Authority as such because of its reasonable potential to adversely affect the POTW's operation or violate any pretreatment standard or requirement; or
- An IU subject to Federal categorical pretreatment standards.

Unlike other environmental programs that rely on Federal or State governments to implement and enforce specific requirements, the Pretreatment Program places the majority of the responsibility on local municipalities. Specifically, section 403.8(a) of the General Pretreatment Regulations states that any POTW (or combination of treatment plants operated by the same authority) with a total design flow greater than 5 million gallons per day (MGD) and smaller POTWs with SIUs must establish a local pretreatment program.

As of early 1998, 1,578 POTWs are required to have local programs. While this represents only about 15 percent of the total treatment plants nationwide, these POTWs account for more than 80 percent (i.e., approximately 30 billion gallons a day) of the national wastewater flow.

Control Authority

The General Pretreatment Regulations define the term “Control Authority” as a POTW that administers an approved pretreatment program since it is the entity authorized to control discharges to its system.

Section 403.10(e) provides States authority to implement POTW pretreatment programs in lieu of POTWs. Five States have elected to assume this responsibility (Vermont, Connecticut, Alabama, Mississippi, and Nebraska). In these instances, the State is defined as the Control Authority. As described above, all Control Authorities must establish a local pretreatment program to control discharges from non-domestic sources.

Approval Authority

These programs must be approved by the “Approval Authority” who is also responsible for overseeing implementation and enforcement of these programs.

As of 6/2020, a total of 47 States /Territories are authorized to implement State NPDES Permit Programs, but only 37 are authorized to be the Pretreatment Program Approval Authority. In all other States and Territories (including the 403.10(e) States), the EPA is considered to be the Approval Authority.

POTW Pretreatment Program Requirements

The actual requirement for a POTW to develop and implement a local pretreatment program is a condition of its NPDES permit. Once the Approval Authority determines that a POTW needs a pretreatment program, the POTW's NPDES permit is modified to require development of a local program and submission of the program to the Approval Authority for review and approval. Consistent with §403.8(f), POTW pretreatment programs must contain the six minimum elements.

In addition to the six specific elements, pretreatment program submissions must include:

- a statement from the City Solicitor (or the like) declaring the POTW has adequate authority to carry out program requirements;
- copies of statutes, ordinances, regulations, agreements, or other authorities the POTW relies upon to administer the pretreatment program including a statement reflecting the endorsement or approval of the bodies responsible for supervising and/or funding the program;
- a brief description and organizational chart of the organization administering the program; and
- a description of funding levels and manpower available to implement the program.

Pretreatment program submissions found to be complete proceed to the public notice process, Public Participation and POTW Reporting. Upon program approval, the Approval Authority is responsible for modifying the POTW's NPDES permit to require implementation of the approved pretreatment program. Once approved, the Approval Authority oversees POTW pretreatment program implementation via receiving annual reports and conducting periodic audits and inspections.

As of early 1998, of the 1,578 POTWs required to develop pretreatment programs, 97 percent (1,535) have been approved. The National Pretreatment Program regulates IUs through three types of regulatory entities: the EPA, Approval Authorities, and Control Authorities. As noted above, Approval Authorities oversee Control Authorities while Control Authorities regulate IUs.

Using an extension pole with a sample attachment to grab a sample.

How to Enforce?

- **Identify Users**
  - Significant Industrial User (SIU)
  - Categorical Industrial User (CIU)
  - Industrial Users of Concern (IU)
- **Permit**
- **Monitoring and Sampling**
- **Compliance**
- **Inspection**

Technical Learning College

PRETREATMENT ENFORCEMENT

Six Minimum Pretreatment Program Elements

1. Legal Authority
The POTW must operate pursuant to legal authority enforceable in Federal, State or local courts, which authorizes or enables the POTW to apply and enforce any pretreatment regulations developed pursuant to the CWA. At a minimum, the legal authority must enable the POTW to:

I. deny or condition discharges to the POTW;
ii. require compliance with pretreatment standards and requirements;
iii. control IU discharges through permits, orders, or similar means;
iv. require IU compliance schedules when necessary to meet applicable pretreatment standards and/or requirements and the submission of reports to demonstrate compliance;
v. inspect and monitor IUs;
vi. obtain remedies for IU noncompliance; and
vii. comply with confidentiality requirements.

2. Procedures
The POTW must develop and implement procedures to ensure compliance with pretreatment requirements, including:

I. identify and locate all IUs subject to the pretreatment program;
ii. identify the character and volume of pollutants contributed by such users;
iii. notify users of applicable pretreatment standards and requirements;
iv. receive and analyze reports from IUs;
v. sample and analyze IU discharges and evaluate the need for IU slug control plans;
vi. investigate instances of noncompliance; and
vii. comply with public participation requirements.

3. Funding
The POTW must have sufficient resources and qualified personnel to carry out the authorities and procedures specified in its approved pretreatment program.

4. Local limits
The POTW must develop local limits or demonstrate why these limits are not necessary.

5. Enforcement Response Plan (ERP)
The POTW must develop and implement an ERP that contains detailed procedures indicating how the POTW will investigate and respond to instances of IU noncompliance.

6. List of SIUs
The POTW must prepare, update, and submit to the Approval Authority a list of all Significant Industrial Users (**SIUs**).

Pretreatment Roles and Responsibilities

EPA Headquarters

< Oversees program implementation at all levels
< Develops and modifies regulations for the program
< Develops policies to clarify and further define the program
< Develops technical guidance for program implementation
< Initiates enforcement actions as appropriate

Regions

< Fulfill Approval Authority responsibilities for States without a State pretreatment program
< Oversee State program implementation
< Initiate enforcement actions as appropriate.

Approval Authorities (EPA Regions and delegated States)

< Notify POTWs of their responsibilities
< Review and approve requests for POTW pretreatment program approval or modification
< Review requests for site-specific modifications to categorical pretreatment standards
< Oversee POTW program implementation
< Provide technical guidance to POTWs
< Initiate enforcement actions, against noncompliant POTWs or industries.

Control Authorities (POTWs, States, or EPA Regions)

< Develop, implement, and maintain approved pretreatment program
< Evaluate compliance of regulated IUs
< Initiate enforcement action against industries as appropriate
< Submit reports to Approval Authorities
< Develop local limits (or demonstrate why they are not needed)
< Develop and implement enforcement response plan.

Industrial Users

< Comply with applicable pretreatment standards and reporting requirements.

(Credit USEPA)

What Types of Businesses are Subject to Pretreatment Regulations?

Pretreatment regulations apply to a variety of businesses discharging wastewater from industrial and commercial processes.

Certain types of industries with the potential to discharge pollutants are regulated through an industrial discharge permit system. Industries are considered

Significant Industrial Users and therefore require a discharge permit if the user:

- Is subject to the Environmental Protection Agency's Categorical Pretreatment Standards. Categorical users receive increased scrutiny due to their potential to pollute. Examples of categorical users are metal finishers and pharmaceutical manufacturers.
- Is discharging an average of 25,000 gallons per day or more of process wastewater.
- Has the potential to adversely affect the wastewater utility.

Industry-Specific Guides

Aluminum, Copper, And Nonferrous Metals Forming and Metal Powders

- Pretreatment Standards: A Guidance Manual
- Guidance Manual For Battery Manufacturing Pretreatment Standards
- Guidance Manual for Electroplating and Metal Finishing Pretreatment Standard
- Guidance Manual for Iron and Steel Manufacturing Pretreatment Standards
- Guidance Manual for Leather Tanning and Finishing Pretreatment Standards
- Guidance Manual for Pulp, Paper, Paperboard, Builders' Paper, and
- Board Mills Pretreatment Standards

Pretreatment Standards

The National Pretreatment Program identifies specific requirements that apply to all IUs, additional requirements that apply to all SIUs, and certain requirements that only apply to CIUs. The objectives of the National Pretreatment Program are achieved by applying and enforcing three types of discharge standards:

< *prohibited discharge standards*
< *categorical standards*
< *local limits*.

Non-SIUs

Many POTWs also control contributions from non-SIUs using various means, such as through general permits issued to an entire industrial sector. These types of control mechanisms may not necessarily require compliance with specific pollutant limitations

POTW Pretreatment Program Responsibilities

This section provides an overview of these POTW programs, highlighting each of the specific program areas that are to be addressed.

Legal Authority (Credit USEPA)

POTWs seeking pretreatment program approval must develop policy and procedures for program implementation and establish the legal authority to implement and enforce program requirements. The General Pretreatment Regulations do not provide Control Authorities with the legal authority to carry out their pretreatment programs; rather, the regulations set forth the minimum requirements for POTWs with pretreatment programs.

A Control Authority's legal authority actually derives from State law. Therefore, State law must confer the minimum Federal legal authority requirements on a Control Authority. Where deficient, State law must be modified to grant the minimum requirements. In order to apply regulatory authority provided by State law, it is generally necessary for the Control Authority to establish local regulations to legally implement and enforce pretreatment requirements. Where the Control Authority is a municipality, legal authority is detailed in a Sewer Use Ordinance (SUO), which is usually part of city or county code.

Regional Control Authorities frequently adopt similar provisions in the form of "**rules and regulations**." Likewise, State agencies implementing a Statewide program under 40 CFR §403.10(e) set out pretreatment requirements as State regulations, rather than as an SUO. [Local regulations cannot give the Control Authority greater authority than that provided by State law.]

The EPA's 1992 guidance, *EPA Model Pretreatment Ordinance* provides a model for POTWs that are required to develop pretreatment programs. As POTW service areas expand, new contributions may arise from "**extra jurisdictional**" IUs located outside of the Control Authority's legal jurisdiction (see Figure 22). Multijurisdictional arrangements require special legal/contractual mechanisms to ensure adequate authority to implement and enforce program requirements in these other jurisdictions. Some state statutes may provide for general extraterritorial powers (i.e., a Control Authority is automatically allowed to regulate extra jurisdictional IUs contributing to their system).

However, the extent to which authorities (i.e., to permit, inspect, enforce, monitor, etc.) are granted may be somewhat limited, thereby, restricting a Control Authority's ability to implement and enforce a program. Where obtaining authority from the State to regulate extra jurisdictional IUs is not feasible, other options may be pursued:

Districts The creation of an independent organization (by affected municipalities or the State) which is authorized to administer and enforce an approved pretreatment program for the entire area in which it provides services is common in areas where multiple POTWs each serve various jurisdictions.

Agreements Affected Control Authorities may opt to enter into agreements requiring each municipality to implement and enforce the approved pretreatment program covering all IUs within their jurisdiction. The Control Authority must retain the means to regulate extra jurisdictional IUs where the contributing jurisdiction's efforts are inadequate. It is essential that agreements clearly define the roles of each party.

Annexation Where extra jurisdictional IUs lie in unincorporated areas, a Control Authority may annex or utility annex the service area.

Contracts
A Control Authority may enter into a contract with an extra jurisdictional IU, although contracts generally limit the enforcement capabilities of the Control Authority. As such, contracts should only be pursued when all other means fail. Since procedures for obtaining jurisdiction, creating sanitary districts, annexing service areas, etc. vary among states, Control Authority personnel should consult with their legal staff to thoroughly examine options allowed. This may include requesting State legislative changes if necessary. The EPA's 1994 *Multijurisdictional Pretreatment Programs - Guidance Manual* provides more information on these jurisdictional issues, including sample language for agreements and contracts.

Industrial Waste Surveys
As part of program development and maintenance, the Federal regulations [40 CFR §403.8(f)(2)(I)] require Control Authorities to identify and locate all IUs that might be subject to the pretreatment program. While the General Pretreatment Regulations do not specify how a Control Authority is to accomplish this, it is beneficial to conduct an initial in-depth survey, and then institute measures to update the list continuously.

Control Authorities must ensure that the entire service area is reviewed. This may include IUs located outside the jurisdictional boundaries of the POTW. In these instances, it may be appropriate to solicit assistance from other jurisdictions in developing the list of potential dischargers. The types of resources that may be consulted in compiling and updating the master list include:

- Water and sewer billing records
- Applications for sewer service
- Local telephone directories
- Chamber of Commerce and local business directories
- Business license records
- POTW and wastewater collection personnel and field observations
- Business associations
- Internet

Once IUs are identified, the Control Authority must classify these users to determine if pretreatment standards and requirements should apply to these facilities. Typically, the Control Authority develops and distributes an Industrial Waste Survey (IWS) questionnaire to the identified IUs. The IWS questionnaire requests information regarding IU activities and the nature of wastes discharged.

The Control Authority may opt to send a detailed IWS questionnaire initially or conduct the survey in two phases (i.e., send a screener requesting basic information to eliminate obvious facilities and then send a detailed IWS to those facilities with greater potential to be SIUs). Key to the IWS is to identify facilities that are subject to categorical standards (i.e., CIUs) or otherwise have the potential to impact the POTW (i.e., SIUs). A POTW's IU inventory should include the name, location, classification, applicable standards, basis for limits imposed, and volume of discharge, control mechanism status, compliance dates and other special requirements for each IU.

The IWS should provide most of the information required to develop the inventory, although some supplementary information might be required from other sources, such as the permit application or monitoring data. The IU inventory must be updated as needed [40 CFR §403.8(f)(2)(I)] and provided to the Approval Authority as part of the annual report requirement (see POTW Reports section in this Chapter). The ongoing task of maintaining a complete list of IUs requires the Control Authority to implement a system to track existing IU information and/or classification changes and new user information. Some Control Authorities may proactively opt to institute a "utility connect questionnaire" program. These types of forms are completed when a customer applies for new utility service (e.g., water, sewerage, or electricity).

Permitting (Credit USEPA)

The General Pretreatment Regulations require all IUs be controlled through permit, order, or similar means to ensure compliance with applicable pretreatment standards and requirements. Section 403.8(f)(1)(iii)(A-E) clarifies this requirement to specify that all SIUs be issued a permit or equivalent individual control mechanism which contains, at a minimum:

- Statement of duration (not to exceed five years);
- Statement of nontransferabililty (unless outlined provisions are met);
- Effluent limitations based on applicable standards;
- Self-monitoring, sampling, reporting, notification, and record-keeping requirements;
- Statement of applicable civil and criminal penalties; and a schedule of compliance (where appropriate).

The EPA's 1989 *Industrial User Permitting Guidance Manual* details procedures for drafting IU discharge permits. SIU permits issued are site specific and tailored to the unique circumstances of the IU. Permit conditions must establish clear and explicit requirements for the permittee, to include using such terms such as "shall" and "must" in lieu of vague terms such as "recommend" or "may". The Control Authority must document its decision-making process when developing permits to ensure defensibility and enforceability. Adherence to sound, documented procedures will prevent any arbitrary and capricious claims by the permittee.

Whether developing or reissuing a permit, the permitting process consists of three phases:

Phase I - Collection and verification of information
Phase II - Data interpretation and fact sheet development
Phase III - Permit development and issuance.

Phase I

As part of Phase I, Control Authorities may review and verify information contained in the permit application, perform an inspection of the IU for confirmation of facts, tally data, and potentially sample and analyze the IU's wastestream. Knowledgeable Control Authority personnel, effective communication, and SIU cooperation are essential to collection of complete and accurate information.

Phase II requires that the Control Authority interpret data and other information and document the permit decision-making rationale, preferably in a permit fact sheet. Although the contents of a fact sheet will vary by permittee, fact sheets should provide a justification of all permitting decisions. Typical components of a fact sheet are provided. Completed fact sheets should be included as part of the permit and provided to the Permittee to document the soundness of permitting decisions. For CIUs:

Components of Permit Fact Sheet

- the basis for the categorical determination(s)
- the identity and flow volume of all wastestreams generated and discharged to the POTW, and classified accordingly (i.e., regulated, unregulated, or dilution)
- data used and/or justification for estimates used to determine categorical limitations
- basis for limits imposed for categorical parameters.

For SIUs/CIUs:

- basis for limits imposed for non-categorical parameters
- rationale for compliance schedules, special plans required, special conditions, etc.
- basis for monitoring and reporting frequencies.

Inspection Considerations *(Credit USEPA)*

- Provide current data on IUs
- Confirm or determine IUs' compliance status
- Determine completeness and accuracy of the IU's performance/compliance records
- Assess the adequacy of the IU's self-monitoring and reporting requirements
- Assess the adequacy of monitoring locations and IU's sampling techniques
- Assess the adequacy of imposed limitations and pollutants of concern
- Develop rapport with IUs
- Evaluate operation and maintenance and overall performance of an IU's pretreatment system
- Assess the potential for spills and slug loadings
- Evaluate the effectiveness of slug control plan
- Reveal issues requiring action
- Identify noncompliance needing resolution
- Suggest pollution prevention opportunities
- Collect samples
- Obtain data to support enforcement actions

After all permitting decisions are made; the Control Authority must incorporate those decisions into a permit. The permit, signed by the specified Control Authority official, is provided to the Permittee for comment and after comments are addressed, a final permit is issued to the IU. While many comments may be easily addressed/resolved by the Control Authority, occasionally resolution must be obtained through a formal adjudicatory hearing process where both the Permittee and Control Authority present their case to a third party.

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Permit Application *(Credit USEPA)*

All industrial users that require a permit must be sampled to determine the characteristics of the wastes to be discharged into the POTW's sewer system. Prior to the issuance of a permit for existing industrial users, the POTW's Inspector or Water Quality Department/Pollution Control Division samples the user's effluent, and performs the analyses required by the applicable discharge standards (i.e., Categorical standards or local limits).

For new industrial users, estimates of the wastes to be discharged into the POTW's sewer system must be submitted along with the permit application. No sampling would be performed at these new facilities, since they do not presently discharge wastes into the sewer system.

A four-day sampling program is usually conducted at each site to collect both composite and grab (for pollutants not amenable to composite sampling) samples as needed.

Industrial Sector

Industrial sector general permitting programs are common where a real or potential POTW problem is linked to a particular pollutant discharged (e.g., collection system blockages caused by the discharge of excess oils and grease from food establishments). POTWs have authority to enforce their SUO or rules or regulations against non-SIUs without the need for any type of individual control mechanism. Control Authorities have the authority to require non-SIUs to comply with pretreatment standards and requirements contained in their local regulations and then take appropriate actions against IUs as noncompliance is identified.

Inspections

Control Authorities are required to inspect and sample all SIUs a minimum of once per year pursuant to 40 CFR §403.8(f)(2(v). The frequency with which a Control Authority actually inspects an SIU may vary depending on issues such as the variability of an SIU's effluent, the impact of their discharge on the POTW, and their compliance history. Inspection considerations will hinge upon the type of inspection performed (i.e., scheduled, unscheduled or demand).

The EPA's 2017 *Industrial User Inspection and Sampling Manual for POTWs* provides a detailed reference for inspection procedures and protocols. Scheduled inspections are useful when the Control Authority wants to gather specific information from the facility that necessitates meeting with specific SIU contacts. However, since scheduled inspections may interrupt normal operations (e.g., altered production schedule as a result of preparative work undertaken by the IU), unscheduled inspections may more accurately reflect IU compliance status when the inspection is performed for that reason.

POTWs must evaluate, at least once every two years, whether each SIU needs a plan to control slug discharges (i.e., a discharge of a non-routine, episodic nature, including but not limited to an accidental spill or non-customary batch discharge). To accurately evaluate the slug potential, Control Authorities likely will have to examine the SIU during normal operating conditions. If undetected, slug discharges can have serious impacts on the POTW.

The EPA's 1991 *Control of Slug Loadings to POTWs Guidance Manual* provides a description of procedures for development, implementation, and review of slug control plans. Demand inspections are non-routine in nature and occur in response to a concern (e.g., POTW

collection problems downstream from an IU, elevated enforcement actions against an IU, suspicious IU behavior, or an informer complaint).

Routine Control Authority inspections of SIUs typically consist of three activities; preparation, on-site assessment, and follow-up.

Preparation *(Credit USEPA)*

Control Authority personnel should review POTW records for SIUs to be inspected to familiarize themselves with the facility. Information reviewed may include compliance status, compliance schedule activities, reports and plans, upcoming report and plan due dates, enforcement activities, permit applications, waste surveys, previous inspection summaries, categorical regulations, water use/billing records, and POTW collection system maps.

Control Authority personnel should also be familiar with any specific issues and concerns regarding the POTW treatment plant or collection system problems receiving the SIU's discharge.

On-site Assessment
Control Authority personnel typically discuss IU operations with IU contacts and perform a walkthrough of the facility to: update IU information regarding contacts, processes, production rates, pretreatment, and other waste management activities; review records required to be kept by the IU; visually verify the need for a slug control plan; and review pretreatment system maintenance, categorical standards applicable to processes employed, metering and sampling equipment, sampling procedures, chemicals used, processes employed, management practices, containment structures, locations of floor drains, etc. Many POTWs have developed a standard inspection questionnaire to facilitate the interview process and promote consistency during the inspection.

Follow-up
An inspection report should be prepared as soon as possible after the inspector returns to the office. Unanswered questions, required permit modifications, and/or necessary enforcement actions should be processed in a timely manner. Non-routine inspections (e.g., demand) may not encompass all the activities and steps specified above, but, like routine inspections, these activities may provide the Control Authority an opportunity to collect samples of the IU’s discharge.

Sewer System Evaluation *(Credit USEPA)*

On a regular basis, selected locations in the sewer system are sampled to develop background data for purposes of updating the local limits, and to screen areas for higher than "background" pollutant levels. In addition, problem areas are sampled on an as needed basis to determine potential sources of Code violations that either occur on a frequent basis, or are the result of a slug load to the sewer system.

To monitor sewers for background information, the sampling program would typically be conducted over a four-day period. In instances where the intent is to determine sources of pollutants and/or slug loads, the length of the program would vary.

Multi-City Users (Metering Stations) Example
All wastewater, which is transported to the POTW Treatment Plant from the Multi-City users, must be analyzed for pollutants of concern to the Industrial Pretreatment Program.

This type of sampling program is usually conducted over a seven-day period to obtain four-seven days of sampling data at each sewer location (i.e., a metering station) on a quarterly basis.

Once the sampling dates have been determined, the Inspector will notify, in writing, the Sub-regional Organizational Group (SROG) or equivalent representative for that City of the dates when the sampling will be conducted.

Upon arrival at the site, safety is the priority. A visual inspection must be completed prior to any entry. The site must be free of any obstructions or hazards which may cause injury when entering the sampling area. If there are any problems detected, the SROG representative and the Inspector should be notified, and no entry should be attempted until the problem has been corrected.

Metering stations qualify as confined spaces (Example Policy)
If all safety criteria have been met, prepare equipment for the site. Check the assignment sheet to determine what parameters are required to be sampled, which in turn determines the type of tubing to be used (i.e. Tygon or Teflon).

The sampler must be completely assembled before performing QA/QC procedures. After QA/QC is complete, a sufficient amount of weight must be attached to the tubing to keep the strainer submerged in the effluent for proper siphoning of the sample, without allowing the strainer to hit the bottom of the flume. Make sure the intake tubing does not kink.

If the metering station has a flow meter, you may connect either their cable or a POTW cable to the sampler from the flow meter. Occasionally, you will set up a flow meter to have a comparison reading. Determine the pulse rate and proper setting from the flow, and program the sampler. After entering the data into the sampler, wait to make sure the equipment is pulling samples.

After the initial set-up of the sampling equipment, samples will be collected during the remainder of the sampling period. Split samples may be requested by the SROG representative.

If the volume of the sample is adequate, these may be given, provided the representative supplies the containers and allows the City Inspector to pour off the samples.

No grab samples will be collected by POTW Inspectors for any SROG representatives. (Example Policy)
Upon exiting the confined space, continue to follow the confined space entry procedures as outlined by OSHA Standards. When you return to the sampling vehicle, you must immediately perform field tests and preserve the samples according to the techniques set forth in by Standard Methods or the State/Federal Rule.

All paper work must be filled out completely before the sampling crew's departure. This paperwork includes the chain of custody which is turned in to the laboratory with the samples, "Metering Station Field Observation Form" that remains with the sampling site file, and the Multi-City Metering Station Sample Record, of which the original is given to the Inspector and the copy is given to the SROG representative.

If there is not an SROG representative at the site, these copies will be turned over to the Inspector with the originals at the end of the week. Remember, all paperwork must be completed prior to leaving the site.

Compliance Monitoring

There are two types of sampling activities that are performed as part of compliance monitoring for permitted industries: unscheduled and demand.

Unscheduled sampling is used to determine the compliance status of the user. Instances of noncompliance are often identified during unannounced monitoring visits. No notice is given for this type of sampling. This type of sampling is performed two to four times a year, at each industrial user site, over a two to five-day period to obtain sampling data

Demand sampling is usually initiated in response to a known or suspected violation, discovered as a result of a self-monitoring report, routine sampling visit, public complaint, unusual influent condition at the wastewater treatment plant, or emergency situations (e.g., plant upsets, sewer line blockages, fires, explosions, etc.). Most often, this type of sampling is conducted to support enforcement actions against an industrial user. This type of sampling activity is performed on an as needed basis. The length of the sampling program depends on the flow, nature of the wastes, and type of samples (i.e., grab or composite) to be collected. Typically, composite and grab samples are collected at each user site.

Nonpermitted Industrial Users (User Rate Charge Program) (Example Policy)
On a periodic basis (i.e., once every two to three years), commercial and minor industrial users are sampled to determine discharge concentrations of various pollutants. Typical types of users which may be sampled include: restaurants, photo processing laboratories, laundries, car washes, and printing shops. A three- to four-day sampling program is usually conducted at each assigned site. Commercial establishments are sampled to establish BOD and SS levels for various groups of users for the Finance/ Utilities department.

This activity is also helpful in identifying industrial or commercial users which may discharge pollutants of concern.

Prohibited Discharge Standards (Credit USEPA)

All IUs, whether or not subject to any other National, State, or local pretreatment requirements, are subject to the general and specific prohibitions identified in 40 CFR §§403.5(a) and (b), respectively. General prohibitions forbid the discharge of any pollutant(s) to a POTW that cause pass through or interference (Figure 10). Specific prohibitions forbid eight categories of pollutant discharges as follows:

(1) discharges containing pollutants which create a fire or explosion hazard in the POTW, including but not limited to, wastestreams with a closed cup flashpoint of less than 140°F (60°C) using the test methods specified in 40 CFR §261.21;

(2) discharges containing pollutants causing corrosive structural damage to the POTW, but in no case discharges with a pH lower than 5.0, unless the POTW is specifically designed to accommodate such discharges;

(3) discharges containing pollutants in amounts causing obstruction to the flow in the POTW resulting in interference;

(4) discharges of any pollutants released at a flow rate and/or concentration which will cause interference with the POTW;

(5) discharges of heat in amounts which will inhibit biological activity in the POTW resulting in interference, but in no case heat in such quantities that the temperature at the POTW treatment plant exceeds 40°C (104°F) unless the Approval Authority, upon request of the POTW, approves alternative temperature limits;

(6) discharges of petroleum oil, nonbiodegradable cutting oil, or products of mineral oil origin in amounts that will cause interference or pass through;

(7) discharges which result in the presence of toxic gases, vapors, or fumes within the POTW in a quantity that may cause acute worker health and safety problems; and

(8) discharges of trucked or hauled pollutants, except at discharge points designated by the POTW.

Compliance with the general and specific prohibitions is mandatory for all IUs, although a facility may have an affirmative defense in any action brought against it alleging a violation of the general prohibitions or of certain specific prohibitions [(3), (4), (5), (6) and (7) above] where the IU can demonstrate it did not have reason to know that its discharge, alone or in conjunction with a discharge or discharges from other sources, would cause pass through or interference, and the IU was in compliance with a technically-based local limit developed to prevent pass through or interference.

These prohibited discharge standards are intended to provide general protection for POTWs. However, their lack of specific pollutant limitations creates the need for additional controls, namely categorical pretreatment standards and local limits.

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Categorical Pretreatment Standards *(Credit USEPA)*

Categorical pretreatment standards (i.e., categorical standards) are national, uniform, technology-based standards that apply to discharges to POTWs from specific industrial categories (i.e., indirect dischargers) and limit the discharge of specific pollutants. Categorical pretreatment standards for both existing and new sources (PSES and PSNS, respectively) are promulgated by the EPA pursuant to Section 307(b) and (c) of the CWA. Limitations developed for indirect discharges are designed to prevent the discharge of pollutants that could pass through, interfere with, or otherwise be incompatible with POTW operations. Effluent limitations guidelines (ELGs), developed in conjunction with categorical standards, limit the discharge from facilities directly to waters of the U.S. (i.e., direct dischargers) and do not apply to indirect dischargers.

ELGs include Best Practicable Control Technology Currently Available (BPT), Best Conventional Pollutant Control Technology (BCT), and Best Available Technology Economically Achievable (BAT) limitations and New Source Performance Standards (NSPS). ELGs (i.e., BPT, BCT, BAT, and NSPS) do not apply to indirect dischargers. The significant difference between categorical standards and effluent limitations guidelines is that categorical standards account for any pollutant removal that may be afforded through treatment at the POTW, while effluent limitations guidelines do not. Industries identified as major sources of toxic pollutants are typically targeted for effluent guideline and categorical standard development.

If limits are deemed necessary, the EPA investigates affected IUs and gathers information regarding process operations as well as treatment and management practices accounting for differences in facility size and age, equipment age, and wastewater characteristics.

Sub categorization within an industrial category is evaluated based on variability in processes employed, raw materials used, types of items produced, and characteristics of wastes generated. Availability and cost of control technologies, non-water quality environmental impacts, available pollution prevention measures, and economic impacts are then identified prior to the EPA's presentation of findings in proposed development documents and publishing a notice of the proposed regulations in the *Federal Registe*r. Based on public comments on the proposed rule, the EPA promulgates (i.e., publishes) the standards.

Definition of New Source (40 CFR 403.3(k)) *(Credit USEPA)*

New Source is defined at 40 CFR §403.3 (k)(1) to mean any building, structure, facility or installation from which there is or may be a discharge of pollutants, the construction of which commenced after publication of proposed Pretreatment Standards under Section 307(c) of the Act which will be applicable to such source if Standards are thereafter promulgated in accordance with that section, *provided that:*
(i) the building, structure, facility, or installation is constructed at a site at which no other source is located; or
(ii) the building, structure, facility, or installation totally replaces the process or production equipment that causes the discharge of pollutants at an existing source; or
(iii) the production or wastewater generating processes of the building, structure, facility or installation are substantially independent of an existing source at the same site. In determining whether these are substantially independent, factors such as the extent to which the new facility is integrated with the existing plant, and the extent to which the new facility is engaged in the same general type of activity as the existing source should be considered.
(2) Construction on a site at which an existing source is located results in a modification rather than a new source if the construction does not create a new building, structure, facility, or installation meeting the criteria of paragraphs (k)(1)(ii), or (k)(1)(iii) of this section but otherwise alters, replaces, or adds to existing process or production equipment.
(3) Construction of a new source as defined under this paragraph has commenced if the owner or operator has:
(i) begun, or caused to begin as part of a continuous onsite construction program:
(ii) any placement, assembly or installation of facilities or equipment, or
(B) significant site preparation work, including clearing, excavation, or removal of existing buildings, structures, or facilities which is necessary for the placement, assembly, or installation of new source facilities or equipment; or
(ii) entered into a binding contractual obligation for the purchase of facilities or equipment which are intended to be used in its operation within a reasonable time.
Options to purchase or contracts which can be terminated or modified without substantial loss, and contracts for feasibility, engineering, and design studies do not constitute a contractual obligation under this paragraph.

New Source
As noted above, categorical pretreatment standards are developed both for existing (PSES) and new sources (PSNS). Facilities are classified as either PSES or PSNS based on the definition of “new source" set out in 40 CFR§403.3(k) of the General Pretreatment Regulations. Dischargers subject to PSES are required to comply with those standards by a specified date, typically no more than three years after the effective date of the categorical standard. Users subject to PSNS, however, are required to achieve compliance within the shortest feasible time, not to exceed 90 days from commencement of discharge. PSNS are often more stringent than PSES based on the opportunity for new sources to install the best available demonstrated technology and operate the most efficient production processes.

Congress established an initial list of 21 categorical industries under Section 306 of the CWA of 1972. As a result of various court decrees and settlement agreements resulting from litigation, and from the EPA's internal work plan development process, the EPA has developed effluent guidelines (for direct dischargers) and/or categorical pretreatment standards (for indirect dischargers) for 51 industrial categories.

Of these industrial categories, the EPA implements pretreatment standards for 32 categories, and either requires compliance solely with 40 CFR Part 403 General Pretreatment Regulations or does not address pretreatment standards for the remaining categories.

Plans for the EPA's expansion and modification of the list is detailed in the *Effluent Guidelines Plan,* published in the *Federal Register* biennially as required in section 304(m) of the CWA. A list of the industrial categories that have categorical standards is provided as Figure 13. Categorical pretreatment standards developed can be concentration-based or mass-based.

Concentration-based standards are expressed as milligrams of pollutant allowed per liter (mg/l) of wastewater discharged and are issued where production rates for the particular industrial category do not necessarily correlate with pollutant discharges. Mass-based standards are generally expressed on a mass per unit of production (e.g., milligrams of pollutant per kilogram of product produced, pounds of pollutant per million cubic feet of air scrubbed, etc.) and are issued where water conservation is an important component in the limitation development process.

For a few categories where reducing a facility's flow volume does not provide a significant difference in the pollutant load discharged, the EPA has established both mass and concentration-based standards. Generally, both a daily maximum limitation and a long-term average limitation (e.g., average daily values in a calendar month) are established for every regulated pollutant.

Primary Wastewater Treatment Clarifier

Applicability of Pretreatment Standards and Requirements

The national pretreatment program objectives are achieved by applying and enforcing three types of pretreatment standards:

- General and specific prohibitions
- Categorical pretreatment standards
- Local limits

All three types of standards can be enforced by EPA, the state, and local government, even though they are developed at different levels of government (i.e., federal, state, and local). Pretreatment standards and requirements can be expressed as numeric limits, narrative prohibitions, and best management practices.

The most effective and practical ways to control pollutants and meet environmental quality goals. BMPs exist for forestry, agriculture, stormwater and many other sectors. (BMPs The most effective and practical ways to control pollutants and meet environmental quality goals. BMPs exist for forestry, agriculture, stormwater and many other sectors.).

IUs should be aware of the standards that apply to them. The control authority, in the case of a POTW with an approved pretreatment program, or the Approval Authority, in the case of a POTW without an approved pretreatment program. [paraphrased from 40 CFR 403.3(f)] is responsible for identifying standard(s) applicable to each IU and applying the most stringent requirements where multiple provisions exist.

The different pretreatment standards are applied to IUs, significant industrial users (SIU (1) All users subject to categorical pretreatment standards under 40 CFR 403.6 and 40 CFR chapter I, subchapter N, except those designated as NSCIUs; and (2) Any other IU that discharges an average of 25,000 gallons per day or more of process wastewater to the POTW (excluding sanitary, noncontact cooling, and boiler blowdown wastewater); contributes a process wastestream that makes up 5 percent or more of the average dry-weather hydraulic or organic capacity of the POTW treatment plant; or is designated as such by the POTW on the basis that the IU has a reasonable potential for adversely affecting the POTW's operation or for violating any pretreatment standard or requirement [in accordance with 40 CFR 403.8(f)(6)]. [40 CFR 403.3(v)]s), and categorical industrial users (CIUs) as follows:

	General and Specific Prohibitions	Categorical Pretreatment Standards	Local Limits
All IUs	**X**		May apply; depends on publicly owned treatment works (POTW) ordinance and permit provisions
SIUs	**X**		Generally apply; may depend on allocation method
CIUs	**X**	**X**	Generally apply; may depend on allocation method

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Topic 11 - Pretreatment Overview Post Quiz

This is not your final assignment, but is a short comprehension quiz. The answers are located in the rear near the references.

Objectives of the pretreatment program:

1. Protect publicly owned treatment works (POTW) from pollutants that may cause interference with sewage treatment plant operations. True or False

2. Prevent introducing pollutants into a POTW that could cause pass through of untreated pollutants to receiving waters.

3. Manage pollutant discharges into a POTW to improve opportunities for reuse of POTW wastewater and residuals (sewage sludge).

4. Prevent introducing pollutants into a POTW that could cause worker health or safety concerns, or that could pose a potential endangerment to the public or to the environment.

5. _____ establish responsibilities of Federal, State, and local government, industry and the public to implement Pretreatment Standards to control pollutants from the industrial users which may pass through or interfere with POTW treatment processes or which may contaminate sewage sludge.

6. The National Pretreatment Program identifies specific requirements that apply to all IUs, additional requirements that apply to _____, and certain requirements that only apply to CIUs.

7. The objectives of the National Pretreatment Program are achieved by applying and enforcing three types of discharge standards which are?

8. _____ are limitations on pollutant discharges to publicly owned treatment works (POTWs), promulgated by the EPA in accordance with Section 307 of the Clean Water Act that apply to specific process wastewaters of particular industrial categories.

9. What term represents a discharge which exits the POTW into waters of the U.S. in quantities or concentrations which, alone or in conjunction with a discharge or discharges from other sources?

10. What term represents a discharge which, alone or in conjunction with a discharge or discharges from other sources, both inhibits or disrupts the POTW, its treatment processes or operations?

11. As outlined in the EPA's objectives_____ may pass through the treatment plant into the receiving stream, posing serious threats to aquatic life, to human recreation, and to consumption of fish and shellfish from these waters.

12. Categorical pretreatment standards (i.e., categorical standards) are national, uniform, technology-based standards that apply to discharges to POTWs from specific industrial categories (i.e., indirect dischargers) and_____.

13. Categorical pretreatment standards for _____(PSES and PSNS, respectively) are promulgated by the EPA pursuant to Section 307(b) and (c) of the CWA.

14. Limitations developed for _____are designed to prevent the discharge of pollutants that could pass through, interfere with, or otherwise be incompatible with POTW operations.

15. Which term was developed in conjunction with categorical standards, limit the discharge from facilities directly to waters of the U.S. (i.e., direct dischargers) and do not apply to indirect dischargers?

Glossary

2,4-D: A chlorinated phenoxy compound, functions as a systemic herbicide and is used to control many types of broadleaf weeds. There are many forms or derivatives (esters, amines, salts) of 2,4-D and these vary in solubility and volatility. Unless otherwise specified, this document will refer to the acid form of 2,4-D. This compound is used in cultivated agriculture and in pasture and rangeland applications, forest management, home and garden situations and for the control of aquatic vegetation. 2,4-D was a major component (about 50%) of the product Agent Orange used extensively throughout Vietnam. However most of the problems associated with the use of Agent Orange were associated with a contaminant (dioxin) in the 2,4,5-T component of the defoliant. The association of 2,4-D with Agent Orange has prompted a vast amount of study on the herbicide.

ABIOGENESIS: The concept of spontaneous generation (that life can come from non-life). This idea was refuted by Pasteur.

ABIOTIC: The non-living components of an organism's environment. The term abiotic is also used to denote a process which is not facilitated by living organisms.

ABORAL: Pertaining to the region of the body opposite that of the mouth. Normally used to describe radially symmetrical animals.

ABSCISIC ACID (ABA): A plant hormone that generally acts to inhibit growth, promote dormancy, and help the plant withstand stressful conditions.

ABSENCE OF OXYGEN: The complete absence of oxygen in water described as Anaerobic.

ABSORPTION SPECTRUM: The range of a material's ability to absorb various wavelengths of light. The absorption spectrum is studied to evaluate the function of photosynthetic pigments.

ACCURACY: How closely an instrument measures the true or actual value.

ACID ADDITION: Slowly add the acid to water while stirring. An operator should not mix acid and water or acid to a strong base.

ACID AND BASE ARE MIXED: When an acid and a base are mixed, an explosive reaction occurs and decomposition products are created under certain conditions.

ACID RAIN: Rain that is excessively acidic due to the presence of acid: causing pollutants in the atmosphere. Pollutants include nitrogen and sulfur oxides due to burning of coal and oil.

ACID: n **acid** is a molecule or ion capable of donating a hydron (proton or hydrogen ion H^+), or, alternatively, capable of forming a covalent bond with an electron pair (a Lewis acid). The first category of acids is the proton donors or Brønsted acids. In the special case of aqueous solutions, proton donors form the hydronium ion H_3O^+ and are known as Arrhenius acids. Brønsted and Lowry generalized the Arrhenius theory to include non-aqueous solvents. A Brønsted or Arrhenius acid usually contains a hydrogen atom bonded to a chemical structure that is still energetically favorable after loss of H^+.

ACIDOSIS: A condition whereby the hydrogen ion concentration of the tissues is increased (and pH decreased). Respiratory acidosis is due to the retention of CO_2; metabolic acidosis by retention of acids due either to kidney failure or diarrhea.

ACTIVATED SLUDGE PROCESS: A biological wastewater treatment process in which a mixture of wastewater and biologically enriched sludge is mixed and aerated to facilitate aerobic decomposition by microbes.

ACTIVATED SLUDGE: The biologically active solids in an activated sludge process wastewater treatment plant.

ACTIVATING ENZYME: An enzyme that couples a low-energy compound with ATP to yield a high-energy derivative.

ACTIVATION ENERGY: In a chemical reaction, the initial investment required to energize the bonds of the reactants to an unstable transition state that precedes the formation of the products.

ACTIVE SITE: That specific portion of an enzyme that attaches to the substrate by means of weak chemical bonds.

ACTIVE TRANSPORT: The movement of a substance across a biological membrane against its concentration or electrochemical gradient with the help of energy input and specific transport proteins.

ADAPTATION: Any genetically controlled characteristic that increases an organism's fitness, usually by helping the organism to survive and reproduce in the environment it inhabits.

ADAPTIVE RADIATION: This refers to the rapid evolution of one or a few forms into many different species that occupy different habitats within a new geographical area.

ADHESION: In chemistry, the phenomenon whereby one substance tends to cling to another substance. Water molecules exhibit adhesion, especially toward charged surfaces.

ADP (Adenosine diphosphate): A doubly phosphorylated organic compound that can be further phosphorylated to form ATP.

ADRENAL GLAND: An endocrine gland located adjacent to the kidney in mammals. It is composed of an outer cortex, and a central medulla, each involved in different hormone: mediated phenomena.

ADRENALIN: A hormone produced by the pituitary that stimulates the adrenal cortex.
ADSORB: Hold on a surface.
ADSORPTION: *Not to be confused with absorption.* Adsorption is a process that occurs when a gas or liquid solute accumulates on the surface of a solid or a liquid (adsorbent), forming a film of molecules or atoms (the adsorbate). It is different from absorption, in which a substance diffuses into a liquid or solid to form a solution. The term sorption encompasses both processes, while desorption is the reverse process. Adsorption is present in many natural physical, biological, and chemical systems, and is widely used in industrial applications such as activated charcoal, synthetic resins, and water purification. Adsorption, ion exchange, and chromatography are sorption processes in which certain adsorbates are selectively transferred from the fluid phase to the surface of insoluble, rigid particles suspended in a vessel or packed in a column. Similar to surface tension, adsorption is a consequence of surface energy. In a bulk material, all the bonding requirements (be they ionic, covalent, or metallic) of the constituent atoms of the material are filled by other atoms in the material. However, atoms on the surface of the adsorbent are not wholly surrounded by other adsorbent atoms, and therefore can attract adsorbates. The exact nature of the bonding depends on the details of the species involved, but the adsorption process is generally classified as physisorption (characteristic of weak van der Waals forces) or chemisorption (characteristic of covalent bonding).
AERATION: The addition of air or oxygen to water or wastewater, usually by mechanical means, to increase dissolved oxygen levels and maintains aerobic conditions.
AEROBIC DIGESTION: Sludge stabilization process involving direct oxidation of biodegradable matter and oxidation of microbial cellular material.
AEROBIC: The condition of requiring oxygen; an aerobe is an organism which can live and grow only in the presence of oxygen.
AIR ENTRAINMENT: The dissolution or inclusion of air bubbles into water.
AIR GAP SEPARATION: A physical separation space that is present between the discharge vessel and the receiving vessel; for an example, a kitchen faucet.
ALCOHOL: Any of a class of organic compounds in which one or more - OH groups are attached to a carbon compound.
ALDEHYDE: An organic molecule with a carbonyl group located at the end of the carbon skeleton.
ALGAE: Microscopic plants that are free-living and usually live in water. They occur as single cells floating in water, or as multicellular plants like seaweed or strands of algae that attach to rocks.
ALKALINE: Having a pH of more than 7. Alkaline solutions are also said to be basic.
ALKALINITY: Alkalinity or AT is a measure of the ability of a solution to neutralize acids to the equivalence point of carbonate or bicarbonate. Alkalinity is closely related to the acid neutralizing capacity (ANC) of a solution and ANC is often incorrectly used to refer to alkalinity. However, the acid neutralizing capacity refers to the combination of the solution and solids present (e.g., suspended matter, or aquifer solids), and the contribution of solids can dominate the ANC (see carbonate minerals below). The alkalinity is equal to the stoichiometric sum of the bases in solution. In the natural environment carbonate alkalinity tends to make up most of the total alkalinity due to the common occurrence and dissolution of carbonate rocks and presence of carbon dioxide in the atmosphere. Other common natural components that can contribute to alkalinity include borate, hydroxide, phosphate, silicate, nitrate, dissolved ammonia, the conjugate bases of some organic acids and sulfide. Solutions produced in a laboratory may contain a virtually limitless number of bases that contribute to alkalinity. Alkalinity is usually given in the unit mEq/L (milliequivalent per liter). Commercially, as in the pool industry, alkalinity might also be given in the unit ppm or parts per million. Alkalinity is sometimes incorrectly used interchangeably with basicity. For example, the pH of a solution can be lowered by the addition of CO_2. This will reduce the basicity; however, the alkalinity will remain unchanged.
ALLANTOIS: One of the four extraembryonic membranes found associated with developing vertebrates; it serves in gas exchange and as a repository for the embryo's nitrogenous waste. In humans, the allantois is involved in early blood formation and development of the urinary bladder.
ALLELE: Alternate forms of a gene which may be found at a given location (locus) on members of a homologous set of chromosomes. Structural variations between alleles may lead to different phenotypes for a given trait.
ALLOMETRIC: The variation in the relative rates of growth of various parts of the body, which helps shape the organism.
ALLOSTERIC ENZYME: An enzyme that can exist in two or more conformations.
ALPHA AND BETA RADIOACTIVITY: Represent two common forms of radioactive decay. Radioactive elements have atomic nuclei so heavy that the nucleus will break apart, or disintegrate spontaneously. When decay occurs, high-energy particles are released. These high-energy particles are called radioactivity. Although radioactivity from refined radioactive elements can be dangerous, it is rare to find dangerous levels of radioactivity in natural waters. An alpha particle is a doubly-charged helium nucleus comprised of two protons, two neutrons, and no electrons. A beta particle is a high-speed electron. Alpha particles do not penetrate matter easily, and are stopped by a piece of paper. Beta particles are much more penetrating and can pass through a millimeter of lead.

ALPHA EMITTERS: Certain minerals are radioactive and may emit a form of radiation known as alpha radiation. Some people who drink water containing alpha emitters in excess of the EPA standard over many years may have an increased risk of getting cancer.
ALPHA HELIX: A spiral shape constituting one form of the secondary structure of proteins, arising from a specific hydrogen: bonding structure.
ALTERNATION OF GENERATIONS: Occurrences of a multicellular diploid form, the sporophyte, with a multicellular haploid form, the gametophyte.
ALTERNATIVE DISINFECTANTS: Disinfectants - other than chlorination (halogens) - used to treat water, e.g. ozone, ultraviolet radiation, chlorine dioxide, and chloramine. There is limited experience and scientific knowledge about the by-products and risks associated with the use of alternatives.
ALTRUISM: The willingness of an individual to sacrifice its fitness for the benefit of another.
ALUMINUM SULFATE: The chemical name for Alum. The molecular formula of Alum is $Al_2(SO_4)3{\sim}14H_2O$. It is a cationic polymer.
ALVEOLUS: One of the dead-end, multilobed air sacs that constitute the gas exchange surface of the lungs.
AMINO ACID: An organic molecule possessing a carboxyl (COOH) and amino group. Amino acids serve as the monomers of polypeptides and proteins.
AMINO GROUP: A functional group consisting of a nitrogen atom bonded to two hydrogens; can act as a base in solution, accepting a hydrogen ion and acquiring a charge of +1.
AMINOACYL: tRNA synthetases- A family of enzymes, at least one for each amino acid, that catalyze the attachment of an amino acid to its specific tRNA molecule.
AMMONIA: A chemical made with Nitrogen and Hydrogen and used with chlorine to disinfect water. Most ammonia in water is present as the ammonium ion rather than as ammonia.
AMOEBA: Amoeba (sometimes amœba or ameba, plural amoebae) is a genus of protozoa that moves by means of pseudopods, and is well-known as a representative unicellular organism. The word amoeba or ameba is variously used to refer to it and its close relatives, now grouped as the Amoebozoa, or to all protozoa that move using pseudopods, otherwise termed amoeboids.
AMOEBOID: (cell) A cell which has the tendency to change shape by protoplasmic flow. (movement) A streaming locomotion characteristic of Amoeba and other protists, as well as some individual cells, such as white blood cells, in animals.
AMP (Adenosine monophosphate): A singly phosphorylated organic compound that can be further phosphorylated to form ADP.
AMYLASE: A starch-digesting enzyme.
ANABOLISM: A metabolic pathway of biosynthesis that consumes energy to build a large molecule from simpler ones.
ANAEROBIC CONDITIONS: When anaerobic conditions exist in either the metalimnion or hypolimnion of a stratified lake or reservoir, water quality problems may make the water unappealing for domestic use without costly water treatment procedures. Most of these problems are associated with Reduction in the stratified waters.
ANAEROBIC DIGESTION: Sludge stabilization process where the organic material in biological sludges are converted to methane and carbon dioxide in an airtight reactor.
ANAEROBIC: Without oxygen. An organism that lives in the absence of oxygen is called an anaerobe. An abnormal condition in which color and odor problems are most likely to occur.
ANAGENESIS: A pattern of evolutionary change involving the transformation of an entire population, sometimes to a state different enough from the ancestral population to justify renaming it as a separate species; also called phyletic.
ANALOGOUS: Characteristics of organisms that are similar in function (and often in structure) but different in embryological and/or evolutionary origins.
ANALYST: The analyst must have at least 2 years of college lecture and laboratory course work in microbiology or a closely related field. The analyst also must have at least 6 months of continuous bench experience with environmental protozoa detection techniques and IFA microscopy, and must have successfully analyzed at least 50 water and/or wastewater samples for *Cryptosporidium* and *Giardia*. Six months of additional experience in the above areas may be substituted for two years of college.
ANCESTRAL TRAIT: Trait shared by a group of organisms as a result of descent from a common ancestor.
ANEUPLOIDY: A chromosomal aberration in which certain chromosomes are present in extra copies or are deficient in number.
ANION: A negatively charged ion.
ANISOGAMOUS: Reproducing by the fusion of gametes that differ only in size, as opposed to gametes that are produced by oogamous species. Gametes of oogamous species, such as egg cells and sperm, are highly differentiated.
ANOXIC: A biological environment that is deficient in molecular oxygen, but may contain chemically bound oxygen, such as nitrates and nitrites.
ANTERIOR: Referring to the head end of a bilaterally symmetrical animal.

ANTHROPOMORPHISM: Attributing a human characteristic to an inanimate object or a species other than a human.
ANTIBIOTIC: A chemical that kills or inhibits the growth of bacteria, often via transcriptional or translational regulation.
ANTIDIURETIC HORMONE: A hormone important in osmoregulation (it acts to reduce the elimination of water from the body.
ANTIGEN: A foreign macromolecule that does not belong to the host organism and that elicits an immune response.
ANTIMONY: A chemical element with the symbol Sb (Latin: stibium, meaning "mark") and atomic number 51. A metalloid, antimony has four allotropic forms. The stable form of antimony is a blue-white metalloid. Yellow and black antimony are unstable non-metals. Antimony is used in flame-proofing, paints, ceramics, enamels, a wide variety of alloys, electronics, and rubber.
APOMORPHIC CHARACTER: A derived phenotypic character, or homology, that evolved after a branch diverged from a phylogenetic tree.
APOSEMATIC COLORATION: Serving as a warning, with reference particularly to colors and structures that signal possession of defensive device.
AQUEOUS SOLUTION: A solution in which water is the solvent.
ARCHAEBACTERIA: A lineage of prokaryotes, represented today by a few groups of bacteria inhabiting extreme environments. Some taxonomists place archaebacteria in their own kingdom, separate from the other bacteria.
ARCHENTERON: The endoderm-lined cavity formed during the gastrulation process that develops into the digestive tract of the animal.
ARISTOTLE: A Greek philosopher often credited as the first to use empirical and deductive methods in logic.
ARTIFICIAL SELECTION: The selective breeding of domesticated plants and animals to encourage the occurrence of desirable traits.
AS NITROGEN: An expression that tells how the concentration of a chemical is expressed mathematically. The chemical formula for the nitrate ion is NO3 , with a mass of 62. The concentration of nitrate can be expressed either in terms of the nitrate ion or in terms of the principal element, nitrogen. The mass of the nitrogen atom is 14. The ratio of the nitrate ion mass to the nitrogen atom mass is 4.43. Thus a concentration of 10 mg/L nitrate expressed as nitrogen would be equivalent to a concentration of 44.3 mg/L nitrate expressed as nitrate ion. When dealing with nitrate numbers it is very important to know how numeric values are expressed.
AS: The chemical symbol of Arsenic.
ASCUS: The elongate spore sac of a fungus of the Ascomycota group.
ASEXUAL: A type of reproduction involving only one parent that produces genetically identical offspring by budding or division of a single cell or the entire organism into two or more parts.
ASSORTATIVE MATING: A type of nonrandom mating in which mating partners resemble each other in certain phenotypic characters.
ASYMMETRIC CARBON: A carbon atom covalently bonded to four different atoms or groups of atoms.
ATOM: The general definition of an ion is an atom with a positive or negative charge. Electron is the name of a negatively charged atomic particle.
ATOMIC NUMBER: The number of protons in the nucleus of an atom, unique for each element.
ATOMIC THEORY: The physical theory of the structure, properties and behavior of the atom.
ATOMIC WEIGHT: The total atomic mass, which is the mass in grams of one mole of the atom (relative to that of 12C, which is designated as 12).
ATP (Adenosine triphosphate): A triply phosphorylated organic compound that functions as "energy currency" for organisms, thus allowing life forms to do work; it can be hydrolyzed in two steps (first to ADP and then to AMP) to liberate 7.3 Kcal of energy per mole during each hydrolysis.
ATPASE: An enzyme that functions in producing or using ATP.
AUTOGENOUS MODEL: A hypothesis which suggests that the first eukaryotic cells evolved by the specialization of internal membranes originally derived from prokaryotic plasma membranes.
AUTOIMMUNE DISEASE: An immunological disorder in which the immune system goes awry and turns against itself.
AUTOPOLYPLOID: A type of polyploid species resulting from one species doubling its chromosome number to become tetraploids, which may self-fertilize or mate with other tetraploids.
AUTOSOME: Chromosomes that are not directly involved in determining sex.
AUTOTROPH: An organism which is able to make organic molecules from inorganic ones either by using energy from the sun or by oxidizing inorganic substances.
AUXIN: One of several hormone compounds in plants that have a variety of effects, such as phototropic response through stimulation of cell elongation, stimulation of secondary growth, and development of leaf traces and fruit.

AUXOTROPH: A nutritional mutant that is unable to synthesize and that cannot grow on media lacking certain essential molecules normally synthesized by wild-type strains of the same species.
AXON: A typically long outgrowth, or process, from a neuron that carries nerve impulses away from the cell body toward target cells.
AXONEME: An internal flagellar structure that occurs in some protozoa, such as *Giardia*, *Spironucleous*, and *Trichonmonas*.

B

BACKFLOW PREVENTION: To stop or prevent the occurrence of, the unnatural act of reversing the normal direction of the flow of liquid, gases, or solid substances back in to the public potable (drinking) water supply. See Cross-connection control.
BACKFLOW: To reverse the natural and normal directional flow of a liquid, gases, or solid substances back in to the public potable (drinking) water supply. This is normally an undesirable effect.
BACKSIPHONAGE: A liquid substance that is carried over a higher point. It is the method by which the liquid substance may be forced by excess pressure over or into a higher point.
BACTERIA: Small, one-celled animals too small to be seen by the naked eye. Bacteria are found everywhere, including on and in the human body. Humans would be unable to live without the bacteria that inhabit the intestines and assist in digesting food. Only a small percentage of bacteria cause disease in normal, healthy humans. Other bacteria can cause infections if they get into a cut or wound. Bacteria are the principal concern in evaluating the microbiological quality of drinking water, because some of the bacteria-caused diseases that can be transmitted by drinking water are potentially life-threatening.
BACTERIOPHAGE: A bacteriophage (from 'bacteria' and Greek phagein, 'to eat') is any one of a number of viruses that infect bacteria. The term is commonly used in its shortened form, phage. Typically, bacteriophages consist of an outer protein hull enclosing genetic material. The genetic material can be ssRNA (single stranded RNA), dsRNA, ssDNA, or dsDNA between 5 and 500 kilo base pairs long with either circular or linear arrangement. Bacteriophages are much smaller than the bacteria they destroy - usually between 20 and 200 nm in size.
BACTERIUM: A unicellular microorganism of the Kingdom Monera. Bacteria are prokaryotes; their cells have no true nucleus. Bacteria are classified into two groups based on a difference in cell walls, as determined by Gram staining.
BALANCED POLYMORPHISM: A type of polymorphism in which the frequencies of the coexisting forms do not change noticeably over many generations.
BARIUM: A chemical element. It has the symbol Ba, and atomic number 56. Barium is a soft silvery metallic alkaline earth metal. It is never found in nature in its pure form due to its reactivity with air. Its oxide is historically known as baryta but it reacts with water and carbon dioxide and is not found as a mineral. The most common naturally occurring minerals are the very insoluble barium sulfate, $BaSO_4$ (barite), and barium carbonate, $BaCO_3$ (witherite). Benitoite is a rare gem containing barium.
BARR BODY: The dense object that lies along the inside of the nuclear envelope in cells of female mammals, representing the one inactivated X chromosome.
BASAL BODY: A cell structure identical to a centriole that organizes and anchors the microtubule assembly of a cilium or flagellum.
BASE PAIRING: Complementary base pairing refers to the chemical affinities between specific base pairs in a nucleic acid: adenine always pairs with thymine, and guanine always pairs with cytosine. In pairing between DNA and RNA, the uracil of RNA always pairs with adenine. Complementary base pairing is not only responsible for the DNA double helix, but it is also essential for various in vitro techniques such as PCR (polymerase chain reaction). Complementary base pairing is also known as Watson-Crick pairing.
BASE: A substance that reduces the hydrogen ion concentration in a solution.
BASEMENT MEMBRANE: The floor of an epithelial membrane on which the basal cells rest.
B-CELL LYMPHOCYTE: A type of lymphocyte that develops in the bone marrow and later produces antibodies, which mediate humoral immunity.
BELT PRESS: A dewatering device utilizing two opposing synthetic fabric belts, revolving over a series of rollers to “squeeze” water from the sludge.
BENCH TEST: A small-scale test or study used to determine whether a technology is suitable for a particular application.
BENIGN TUMOR: A noncancerous abnormal growth composed of cells that multiply excessively but remain at their place of origin in the body.
BENTHIC: Pertaining to the bottom region of an aquatic environment.
BERYLLIUM: A chemical element with the symbol Be and atomic number 4. A bivalent element, beryllium is a steel grey, strong, light-weight yet brittle alkaline earth metal. It is primarily used as a hardening agent in alloys, most notably beryllium copper. Commercial use of beryllium metal presents technical challenges due to the toxicity (especially by inhalation) of beryllium-containing dusts.

BEST AVAILABLE TECHNOLOGY ECONOMICALLY ACHIEVABLE (BAT): A level of technology based on the best existing control and treatment measures that are economically achievable within the given industrial category or subcategory.
BEST MANAGEMENT PRACTICES (BMPs): Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the U.S. BMPs also include treatment requirements, operating procedures and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.
BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE (BPT): A level of technology represented by the average of the best existing wastewater treatment performance levels within an industrial category or subcategory.
BEST PROFESSIONAL JUDGMENT (BPJ): The method used by a permit writer to develop technology-based limitations on a case-by-case basis using all reasonably available and relevant data.
BETA PLEATED SHEET: A zigzag shape, constituting one form of the secondary structure of proteins formed of hydrogen bonds between polypeptide segments running in opposite directions.
BETA/PHOTON EMITTER: Certain minerals are radioactive and may emit forms of radiation known as photons and beta radiation. Some people who drink water containing beta and photon emitters in excess of the EPA standard over many years may have an increased risk of getting cancer.
BILATERAL SYMMETRY: The property of having two similar sides, with definite upper and lower surfaces and anterior and posterior ends. The Bilateria are members of the branch of Eumetazoa (Kingdom Animalia) which possess bilateral symmetry.
BILE: A mixture of substances containing bile salts, which emulsify fats and aid in their digestion and absorption.
BINARY FISSION: The kind of cell division found in prokaryotes, in which dividing daughter cells each receive a copy of the single parental chromosome.
BINOMIAL NOMENCLATURE: Consisting of two names. In biology, each organism is given a *genus* name and a species name (i.e., the human is Homo sapiens.
BIOCHEMICAL OXYGEN DEMAND (BOD): The BOD test is used to measure the strength of wastewater. The BOD of wastewater determines the milligrams per liter of oxygen required during stabilization of decomposable organic matter by aerobic bacteria action. Also, the total milligrams of oxygen required over a five-day test period to biologically assimilate the organic contaminants in one liter of wastewater maintained at 20 degrees Centigrade.
BIOGENESIS: A central concept of biology, that living organisms are derived from other living organisms (contrasts to the concept of abiogenesis, or spontaneous generation, which held that life could be derived from inanimate material).
BIOLOGICAL MAGNIFICATION: Increasing concentration of relatively stable chemicals as they are passed up a food chain from initial consumers to top predators.
BIOMASS: The total weight of all the organisms, or of a designated group of organisms, in a given area
BIOME: A large climatic region with characteristic sorts of plants and animals.
BIOSOLIDS: Solid organic matter recovered from municipal wastewater treatment that can be beneficially used, especially as a fertilizer. “Biosolids” are solids that have been stabilized within the treatment process, whereas “sludge” has not.
BIOSPHERE: The region on and surrounding the earth which is capable of supporting life. Theoretically, the concept may be ultimately expanded to include other regions of the universe.
BMR: The basal metabolic rate is the minimal energy (in kcal) required by a homeotherm to fuel itself for a given time. Measured within the thermoneutral zone for a postabsorptive animal at rest.
BODY FEED: Coating or bulking material added to the influent of material to be treated. This adds “body” to the material during filtration cycle.
Both measurements (mg/L or KH) are usually expressed "as $CaCO_3$" – meaning the amount of hardness expressed as if calcium carbonate was the sole source of hardness. Every bicarbonate ion only counts for half as much carbonate hardness as a carbonate ion does. If a solution contained 1 liter of water and 50 mg $NaHCO_3$ (baking soda), it would have a carbonate hardness of about 18 mg/L as $CaCO_3$. If you had a liter of water containing 50 mg of Na_2CO_3, it would have a carbonate hardness of about 29 mg/L as $CaCO_3$. Carbonate hardness supplements non-carbonate (a.k.a. "permanent") hardness where hard ions are associated with anions such as Chloride that do not precipitate out of solution when heated. Carbonate hardness is removed from water through the process of softening. Softening can be achieved by adding lime in the form of $Ca(OH)_2$, which reacts first with CO_2 to form calcium carbonate precipitate, reacts next with multi-valent cations to remove carbonate hardness, then reacts with anions to replace the non-carbonate hardness due to multi-valent cations with non-carbonate hardness due to calcium. The process requires recarbonation through the addition of carbon-dioxide to lower the pH which is raised during the initial softening process.
BREAK POINT CHLORINATION: The process of chlorinating the water with significant quantities of chlorine to oxidize all contaminants and organic wastes and leave all remaining chlorine as free chlorine.

BROMATE: An inorganic anion, bromate is tasteless and colorless, with a low volatility. As a moderately strong oxidant, bromate is reactive. BrO3- is a bromine-based oxoanion. A bromate is a chemical compound that contains this ion. Examples of bromates include sodium bromate, (NaBrO3), and potassium bromate, (KBrO3).
BROMINE: Chemical disinfectant (HALOGEN) that kills bacteria and algae. This chemical disinfectant has been used only on a very limited scale for water treatment because of its handling difficulties. This chemical causes skin burns on contact, and a residual is difficult to obtain.
BUFFER: Chemical that resists pH change, e.g. sodium bicarbonate
BULKING SLUDGE: A poor or slow settling activated sludge that results from the prevalence of filamentous organisms. A phenomenon that occurs in activated sludge plants whereby the sludge occupies excessive volumes and will not concentrate readily. This condition refers to a decrease in the ability of the sludge to settle and consequent loss over the settling tank weir. Bulking in activated sludge aeration tanks is caused mainly by excess suspended solids (SS) content. Sludge bulking in the final settling tank of an activated sludge plant may be caused by improper balance of the BOD load, SS concentration in the mixed liquor, or the amount of air used in aeration.

C

Ca: The chemical symbol for calcium.
CADMIUM: A chemical element with the symbol Cd and atomic number 48. A relatively abundant, soft, bluish-white, transition metal, cadmium is known to cause cancer and occurs with zinc ores. Cadmium is used largely in batteries and pigments, for example in plastic products.
CAKE: Dewatered sludge material with a satisfactory solids concentration to allow handling as a solid material.
CALCIUM HARDNESS: A measure of the calcium salts dissolved in water.
CALCIUM ION: Is divalent because it has a valence of +2.
CALCIUM, MAGNESIUM AND IRON: The three elements that cause hardness in water.
$CaOCl_2.4H_2O$: The molecular formula of Calcium hypochlorite.
CARBON DIOXIDE GAS: The pH will decrease and alkalinity will change as measured by the Langelier index after pumping carbon dioxide gas into water.
CARBONATE HARDNESS: Carbonate hardness is the measure of Calcium and Magnesium and other hard ions associated with carbonate ($CO_3$2-) and bicarbonate (HCO_3-) ions contained in a solution, usually water. It is usually expressed either as parts per million (ppm or mg/L), or in degrees (KH - from the German "Karbonathärte"). One German degree of carbonate hardness is equivalent to about 17.8575 mg/L.
CARBONATE, BICARBONATE AND HYDROXIDE: Chemicals that are responsible for the alkalinity of water.
CATHODIC PROTECTION: An operator should protect against corrosion of the anode and/or the cathode by painting the copper cathode. Cathodic protection interrupts corrosion by supplying an electrical current to overcome the corrosion-producing mechanism. Guards against stray current corrosion.
CAUSTIC SODA: Also known as sodium hydroxide and is used to raise pH.
CAUSTIC: NaOH (also called Sodium Hydroxide) is a strong chemical used in the treatment process to neutralize acidity, increase alkalinity or raise the pH value.
CENTRATE: The liquid remaining after solids have been removed in a centrifuge.
CENTRIFUGAL FORCE: That force when a ball is whirled on a string that pulls the ball outward. On a centrifugal pump, that force throws water from a spinning impeller.
CENTRIFUGAL PUMP: A pump consisting of an impeller fixed on a rotating shaft and enclosed in a casing, having an inlet and a discharge connection. The rotating impeller creates pressure in the liquid by the velocity derived from centrifugal force.
CENTRIFUGE: A dewatering device relying on centrifugal force to separate particles of varying density such as water and solids.
CHAIN OF CUSTODY (COC): A record of each person involved in the possession of a sample from the person who collects the sample to the person who analyzes the sample in the laboratory.
CHECK VALVE: Allows water to flow in only one direction.
CHELATION: A chemical process used to control scale formation in which a chelating agent "captures" scale-causing ions and holds them in solution.
CHEMICAL FEED RATE: Chemicals are added to the water in order to improve the subsequent treatment processes. These may include pH adjusters and coagulants. Coagulants are chemicals, such as alum, that neutralize positive or negative charges on small particles, allowing them to stick together and form larger particles that are more easily removed by sedimentation (settling) or filtration. A variety of devices, such as baffles, static mixers, impellers and in-line sprays, can be used to mix the water and distribute the chemicals evenly.
CHEMICAL OXIDIZER: KMnO4 is used for taste and odor control because it is a strong oxidizer that eliminates many organic compounds.

CHEMICAL OXYGEN DEMAND (COD): The milligrams of oxygen required to chemically oxidize the organic contaminants in one liter of wastewater.
CHEMICAL REACTION RATE: In general, when the temperature decreases, the chemical reaction rate also decreases. The opposite is true for when the temperature increases.
CHEMICAL SLUDGE: Sludge resulting from chemical treatment processes of inorganic wastes that are not biologically active.
CHLORAMINATION: Treating drinking water by applying chlorine before or after ammonia. This creates a persistent disinfectant residual called chloramines.
CHLORAMINES: A group of chlorine ammonia compounds formed when chlorine combines with organic wastes in the water. Chloramines are not effective as disinfectants and are responsible for eye and skin irritation as well as strong chlorine odors (also known as Combined Chlorine).
CHLORINATION: The process in water treatment of adding chlorine (gas or solid hypochlorite) for purposes of disinfection.
CHLORINE DEMAND: Amount of chlorine required to react on various water impurities before a residual is obtained. Also, means the amount of chlorine required to produce a free chlorine residual of 0.1 mg/l after a contact time of fifteen minutes as measured by Iodometric method of a sample at a temperature of twenty degrees in conformance with Standard methods.
CHLORINE FEED: Chlorine may be delivered by vacuum-controlled solution feed chlorinators. The chlorine gas is controlled, metered, introduced into a stream of injector water and then conducted as a solution to the point of application.
CHLORINE, FREE: Chlorine available to kill bacteria or algae. The amount of chlorine available for sanitization after the chlorine demand has been met. Also known as chlorine residual.
CHLORINE: A chemical used to disinfect water. Chlorine is extremely reactive, and when it comes in contact with microorganisms in water it kills them. Chlorine is added to swimming pools to keep the water safe for swimming. Chlorine is available as solid tablets for swimming pools. Some public water system's drinking water treatment plants use chlorine in a gas form because of the large volumes required. Chlorine is very effective against algae, bacteria and viruses. Protozoa are resistant to chlorine because they have thick coats; protozoa are removed from drinking water by filtration.
CHLORITE: The chlorite ion is ClO2−. A chlorite (compound) is a compound that contains this group, with chlorine in oxidation state +3. Chlorites are also known as salts of chlorous acid.
CHROMIUM: A chemical element which has the symbol Cr and atomic number 24. It is a steel-gray, lustrous, hard metal that takes a high polish and has a high melting point. It is also odorless, tasteless, and malleable.
CHRONIC: A stimulus that lingers or continues for a relatively long period of time, often one-tenth of the life span or more. Chronic should be considered a relative term depending on the life span of an organism. The measurement of chronic effect can be reduced growth, reduced reproduction, etc., in addition to lethality.
CIRCULATION: The continual flow of drilling fluid from injection to recovery and recirculation at the surface.
CLARIFIER: A settling tank used to remove suspended solids by gravity settling. Commonly referred to as sedimentation or settling basins, they are usually equipped with a motor driven chain and flight or rake mechanism to collect settled sludge and move it to a final removal point.
ClO_2: The molecular formula of Chlorine dioxide.
COAGULATION: The best pH range for coagulation is between 5 and 7. Mixing is an important part of the coagulation process you want to complete the coagulation process as quickly as possible. A chemical added to initially destabilize, aggregate, and bind together colloids and emulsions to improve settleability, filterability, or drainability.
COLIFORM TESTING: The effectiveness of disinfection is usually determined by Coliform bacteria testing. A positive sample is a bad thing and indicates that you have bacteria contamination.
COLIFORM: Bacteria normally found in the intestines of warm-blooded animals. Coliform bacteria are present in high numbers in animal feces. They are an indicator of potential contamination of water. Adequate and appropriate disinfection effectively destroys coliform bacteria. Public water systems are required to deliver safe and reliable drinking water to their customers 24 hours a day, 365 days a year. If the water supply becomes contaminated, consumers can become seriously ill. Fortunately, public water systems take many steps to ensure that the public has safe, reliable drinking water. One of the most important steps is to regularly test the water for coliform bacteria. Coliform bacteria are organisms that are present in the environment and in the feces of all warm-blooded animals and humans. Coliform bacteria will not likely cause illness. However, their presence in drinking water indicates that disease-causing organisms (pathogens) could be in the water system. Most pathogens that can contaminate water supplies come from the feces of humans or animals. Testing drinking water for all possible pathogens is complex, time-consuming, and expensive. It is relatively easy and inexpensive to test for coliform bacteria. If coliform bacteria are found in a water sample, water system operators work to find the source of contamination and restore safe drinking water. There are three different groups of coliform bacteria; each has a different level of risk.

COLLOIDAL SUSPENSIONS: Because both iron and manganese react with dissolved oxygen to form insoluble compounds, they are not found in high concentrations in waters containing dissolved oxygen except as colloidal suspensions of the oxide.
COLORIMETRIC MEASUREMENT: A means of measuring an unknown chemical concentration in water by measuring a sample's color intensity.
COMBINED CHLORINE: The reaction product of chlorine with ammonia or other pollutants, also known as chloramines.
COMBINED RADIUM 226/228: Some people who drink water containing radium 226 or 228 in excess of EPA standard over many years may have an increased risk of getting cancer.
COMPOSITE SAMPLE: A water sample that is a combination of a group of samples collected at various intervals during the day. A combination of individual samples of water or wastewater taken at predetermined intervals to minimize the effect of variability of individual samples. To have significant meaning, samples for laboratory tests on wastewater should be representative of the wastewater. The best method of sampling is proportional composite sampling over several hours during the day. Composite samples are collected because the flow and characteristics of the wastewater are continually changing. A composite sample will give a representative analysis of the wastewater conditions.
COMPOSTING: Stabilization process relying on the aerobic decomposition of organic matter in sludge by bacteria and fungi.
CONDENSATION: The process that changes water vapor to tiny droplets or ice crystals.
CONTACT STABILIZATION PROCESS: Modification of the activated sludge process where raw wastewater is aerated with activated sludge for a short time prior to solids removal and continued aeration in a stabilization tank.
CONTACT TIME (CT): To inactivate viruses and bacteria, the minimum disinfection contact time measured before the first customer should be six milligrams per minute per liter (6 mg-min/L). This value is called “Chlorine Contact Time” or CT. To calculate CT, multiply the free chlorine residual concentration (C) times the contact time (T). To get the required CT value of 6, adjust the free chlorine residual concentration or the contact time.
CONTACT TIME: If the water temperature decreases from 70°F (21°C) to 40°F (4°C). The operator needs to increase the detention time to maintain good disinfection of the water.
CONTAMINANT: Any natural or man-made physical, chemical, biological, or radiological substance or matter in water, which is at a level that may have an adverse effect on public health, and which is known or anticipated to occur in public water systems.
CONTAMINATION: A degradation in the quality of groundwater in result of the it’s becoming polluted with unnatural or previously non-existent constituents.
COPPER: The chemical name for the symbol Cu.
CORROSION: The removal of metal from copper, other metal surfaces and concrete surfaces in a destructive manner. Corrosion is caused by improperly balanced water or excessive water velocity through piping or heat exchangers.
CORROSIVITY: The Langelier Index measures corrosivity.
CROSS-CONNECTION: A physical connection between a public water system and any source of water or other substance that may lead to contamination of the water provided by the public water system through backflow. Might be the source of an organic substance causing taste and odor problems in a water distribution system.
CROSS-CONTAMINATION: The mixing of two unlike qualities of water. For example, the mixing of good water with a polluting substance like a chemical.
CRYPTOSPORIDIUM: A disease-causing parasite, resistant to chlorine disinfection. It may be found in fecal matter or contaminated drinking water. Cryptosporidium is a protozoan pathogen of the Phylum Apicomplexa and causes a diarrheal illness called cryptosporidiosis. Other apicomplexan pathogens include the malaria parasite Plasmodium, and Toxoplasma, the causative agent of toxoplasmosis. Unlike Plasmodium, which transmits via a mosquito vector, Cryptosporidium does not utilize an insect vector and is capable of completing its life cycle within a single host, resulting in cyst stages that are excreted in feces and are capable of transmission to a new host.
CRYPTOSPORIDIUM: A parasite that enters lakes and rivers through sewage and animal waste. It causes cryptosporidiosis, a mild gastrointestinal disease. However, the disease can be severe or fatal for people with severely weakened immune systems. The EPA and the CDC have prepared advice for those with severely compromised immune systems who are concerned about Cryptosporidium.
CYANOBACTERIA: Cyanobacteria, also known as blue-green algae, blue-green bacteria or Cyanophyta, is a phylum of bacteria that obtain their energy through photosynthesis. The name "cyanobacteria" comes from the color of the bacteria (Greek: kyanós = blue). They are a significant component of the marine nitrogen cycle and an important primary producer in many areas of the ocean, but are also found on land.
CYANURIC ACID: Chemical used to prevent the decomposition of chlorine by ultraviolet (UV) light.

CYST: A phase or a form of an organism produced either in response to environmental conditions or as a normal part of the life cycle of the organism. It is characterized by a thick and environmentally resistant cell wall.

D

DAILY MAXIMUM LIMITATIONS: The maximum allowable discharge of pollutants during a 24 hour period. Where daily maximum limitations are expressed in units of mass, the daily discharge is the total mass discharged over the course of the day. Where daily maximum limitations are expressed in terms of a concentration, the daily discharge is the arithmetic average measurement of the pollutant concentration derived from all measurements taken that day.

DANGEROUS CHEMICALS: The most suitable protection when working with a chemical that produces dangerous fumes is to work under an air hood.

DECANT: Separation of a liquid from settled solids by removing the upper layer of liquid after the solids have settled.

DECOMPOSE: To decay or rot.

DECOMPOSITION OF ORGANIC MATERIAL: The decomposition of organic material in water produces taste and odors.

DEMINERALIZATION PROCESS: Mineral concentration of the feed water is the most important consideration in the selection of a demineralization process. Acid feed is the most common method of scale control in a membrane demineralization treatment system.

DENITRIFICATION: A biological process by which nitrate is converted to nitrogen gas.

DEPOLARIZATION: The removal of hydrogen from a cathode.

DESICCANT: When shutting down equipment that may be damaged by moisture, the unit may be protected by sealing it in a tight container. This container should contain a desiccant.

DESORPTION: Desorption is a phenomenon whereby a substance is released from or through a surface. The process is the opposite of sorption (that is, adsorption and absorption). This occurs in a system being in the state of sorption equilibrium between bulk phase (fluid, i.e. gas or liquid solution) and an adsorbing surface (solid or boundary separating two fluids). When the concentration (or pressure) of substance in the bulk phase is lowered, some of the sorbed substance changes to the bulk state. In chemistry, especially chromatography, desorption is the ability for a chemical to move with the mobile phase. The more a chemical desorbs, the less likely it will adsorb, thus instead of sticking to the stationary phase, the chemical moves up with the solvent front. In chemical separation processes, stripping is also referred to as desorption as one component of a liquid stream moves by mass transfer into a vapor phase through the liquid-vapor interface.

DIATOMACEOUS EARTH: A fine silica material containing the skeletal remains of algae.

DIGESTER: A tank or vessel used for sludge digestion.

DIGESTION: The biological decomposition of organic matter in sludge resulting in partial gasification, liquefaction, and mineralization of putrescible and offensive solids.

DIRECT CURRENT: A source of direct current (**DC**) may be used for standby lighting in a water treatment facility. The electrical current used in a DC system may come from a battery.

DISINFECT: The application of a chemical to kill most, but not all, microorganisms that may be present. Chlorine is added to public water drinking systems drinking water for disinfection. Depending on your state rule, drinking water must contain a minimum of 0.2 mg/L free chlorine. Disinfection makes drinking water safe to consume from the standpoint of killing pathogenic microorganisms including bacteria and viruses. Disinfection does not remove all bacteria from drinking water, but the bacteria that can survive disinfection with chlorine are not pathogenic bacteria that can cause disease in normal healthy humans.

DISINFECTION BYPRODUCTS: Disinfection byproducts are chemical, organic and inorganic substances that can form during a reaction of a disinfectant with naturally present organic matter in the water.

DISINFECTION: The treatment of water to inactivate, destroy, and/or remove pathogenic bacteria, viruses, protozoa, and other parasites.

DISSOLVED OXYGEN: Can be added to zones within a lake or reservoir that would normally become anaerobic during periods of thermal stratification.

DISSOLVED SOLIDS: Solids in solution that cannot be removed by filtration with a 0.45 micron filter.

DISTILLATION, REVERSE OSMOSIS AND FREEZING: Processes that can be used to remove minerals from the water.

DPD METHOD: Presence of free chlorine in the distribution network is indication of correct disinfection. Chlorine in water is determined according to ISO 7393-2 by colorimetric HACH method on the basis of DPD (N, N-diethyl - p – phenylendiamine). The photometric detection uses the wave lengths of 490 – 555 nm. Hach elected, for most of his DPD colorimetric systems, the wavelength of 530 nm.

DRY ACID: A granular chemical used to lower pH and or total alkalinity.

E

E. COLI, Escherichia coli: A bacterium commonly found in the human intestine. For water quality analyses purposes, it is considered an indicator organism. These are considered evidence of water contamination. Indicator organisms may be accompanied by pathogens, but do not necessarily cause disease themselves.
ECOLOGY: The study of how organisms interact with their environments.
ECOSYSTEM: The sum of physical features and organisms occurring in a given area.
ECTODERM: The outermost tissue layer of an animal embryo. Also, tissue derived from an embryonic ectoderm.
EFFECTIVENESS OF CHLORINE: The factors which influence the effectiveness of chlorination the most are pH, turbidity and temperature. Effectiveness of Chlorine decreases occurs during disinfection in source water with excessive turbidity.
EFFECTOR: The part of an organism that produces a response to a stimulus.
EFFLUENT: Partially or completely treated water or wastewater flowing out of a basin or treatment plant.
ELECTRON MICROSCOPE: A microscope that focuses an electron beam through a specimen, resulting in resolving power a thousandfold greater than that of a light microscope. A transmission EM is used to study the internal structure of thin sections of cells; a scanning EM is used to study the ultrastructure of surfaces.
ELECTRON TRANSPORT CHAIN: A series of enzymes found in the inner membranes of mitochondria and chloroplasts. These are involved in transport of protons and electrons either across the membrane during ATP synthesis.
ELECTRON: The name of a negatively charged atomic particle. A negatively charged subatomic particle of an atom or ion. In atoms, the number of electrons present is equal to the number of positively charged protons present. Hence, atoms are electrically neutral.
ELECTRONEGATIVITY: A property exhibited by some atoms whereby the nucleus has a tendency to pull electrons toward itself.
ELECTRONIC CHARGE UNIT: The charge of one electron (1.6021 x 10e - 19 coulomb).
ELECTROSTATIC FORCE: The attraction between particles with opposite charges.
ELECTROSTATIC GRADIENT: The free-energy gradient created by a difference in charge between two points, generally the two sides of a membrane.
ELEMENT: Any substance that cannot be broken down into another substance by ordinary chemical means.
ELIMINATION: The release of unabsorbed wastes from the digestive tract.
EMULSION: A suspension, usually as fine droplets of one liquid in another. A mixture made up of dissimilar elements, usually of two or more mutually insoluble liquids that would normally separate into layers based on the specific gravity of each liquid.
ENDERGONIC: A phenomenon that involves uptake of energy.
ENDOCRINE: A phenomenon that relates to the presence of ductless glands of the type typically found in vertebrates. The endocrine system involves hormones, the glands that secrete them, the molecular hormone receptors of target cells, and interactions between hormones and the nervous system.
ENDONUCLEASE: An enzyme that breaks bonds within nucleic acids. A restriction endonuclease is an enzyme that breaks bonds only within a specific sequence of bases.
ENDOPLASMIC RETICULUM: A system of membrane-bounded tubes and flattened sacs, often continuous with the nuclear envelope, found in the cytoplasm of eukaryotes. Exists as rough ER, studded with ribosomes, and smooth ER, lacking ribosomes.
ENDORPHIN: A hormone produced in the brain and anterior pituitary that inhibits pain perception.
ENDOSKELETON: An internal skeleton.
ENDOSPERM: A nutritive material in plant seeds which is triploid (3n) and results from the fusion of three nuclei during double fertilization.
ENDOSYMBIOTIC: 1) An association in which the symbiont lives within the host 2) A widely accepted hypothesis concerning the evolution of the eukaryotic cell: the idea that eukaryotes evolved as a result of symbiotic associations between prokaryote cells. Aerobic symbionts ultimately evolved into mitochondria; photosynthetic symbionts became chloroplasts.
ENERGY: The capacity to do work by moving matter against an opposing force.
ENTAMOEBA HISTOLYTICA: Entamoeba histolytica, another water-borne pathogen, can cause diarrhea or a more serious invasive liver abscess. When in contact with human cells, these amoebae are cytotoxic. There is a rapid influx of calcium into the contacted cell, it quickly stops all membrane movement save for some surface blebbing. Internal organization is disrupted, organelles lyse, and the cell dies. The ameba may eat the dead cell or just absorb nutrients released from the cell.
ENTERIC: Rod-shaped, gram-negative, aerobic but can live in certain anaerobic conditions; produce nitrite from nitrate, acids from glucose; include Escherichia coli, Salmonella (over 1000 types), and Shigella.
ENTEROVIRUS: A virus whose presence may indicate contaminated water; a virus that may infect the gastrointestinal tract of humans.
ENTROPY: A type of energy that is not biologically useful to do work (in contrast to free energy).

ENVELOPE: 1) (nuclear) The surface, consisting of two layers of membrane, that encloses the nucleus of eukaryotic cells. 2) (virus) A structure which is present on the outside of some viruses (exterior to the capsid).
ENVIRONMENT: Water, air, and land, and the interrelationship that exists among and between water, air and land and all living things. The total living and nonliving aspects of an organism's internal and external surroundings.
ENZYME: A protein, on the surface of which are chemical groups so arranged as to make the enzyme a catalyst for a chemical reaction.
EPIDERMIS: The outermost portion of the skin or body wall of an animal.
EPISOME: Genetic element at times free in the cytoplasm, at other times integrated into a chromosome.
EPISTASIS: A phenomenon in which one gene alters the expression of another gene that is independently inherited.
EPITHELIUM: An animal tissue that forms the covering or lining of all free body surfaces, both external and internal.
EQUATION: A precise representation of the outcome of a chemical reaction, showing the reactants and products, as well as the proportions of each.
EQUILIBRIUM: In a reversible reaction, the point at which the rate of the forward reaction equals that of the reverse reaction. (constant) At equilibrium, the ratio of products to reactants. (potential) The membrane potential for a given ion at which the voltage exactly balances the chemical diffusion gradient for that ion.
ESSENTIAL: 1) An amino or fatty acid which is required in the diet of an animal because it cannot be synthesized. 2) A chemical element required for a plant to grow from a seed and complete the life cycle.
ESTIVATION: A physiological state characterized by slow metabolism and inactivity, which permits survival during long periods of elevated temperature and diminished water supplies.
EUBACTERIA: The lineage of prokaryotes that includes the cyanobacteria and all other contemporary bacteria except archaebacteria.
EUCHROMATIN: The more open, unraveled form of eukaryotic chromatin, which is available for transcription.
EUCOELOMATE: An animal whose body cavity is completely lined by mesoderm, the layers of which connect dorsally and ventrally to form mesenteries.
EUGLENA: Euglena are common protists, of the class Euglenoidea of the phylum Euglenophyta. Currently, over 1000 species of Euglena have been described. Marin et al. (2003) revised the genus so and including several species without chloroplasts, formerly classified as Astasia and Khawkinea. Euglena sometimes can be considered to have both plant and animal features. Euglena gracilis has a long hair-like thing that stretches from its body. You need a very powerful microscope to see it. This is called a flagellum, and the euglena uses it to swim. It also has a red eyespot. Euglena gracilis uses its eyespot to locate light. Without light, it cannot use its chloroplasts to make itself food.
EUKARYOTE: A life form comprised of one or more cells containing a nucleus and membrane - bound organelles. Included are members of the Kingdoms Protista, Fungi, Plantae and Animalia.
EUMETAZOA: Members of the subkingdom that includes all animals except sponges.
EUTROPHIC: A highly productive condition in aquatic environments which owes to excessive concentrations of nutrients which support the growth of primary producers.
EVAGINATED: Folded or protruding outward.
EVAPORATIVE COOLING: The property of a liquid whereby the surface becomes cooler during evaporation, owing to the loss of highly kinetic molecules to the gaseous state.
EVERSIBLE: Capable of being turned inside out.
EXCITABLE CELLS: A cell, such as a neuron or a muscle cell that can use changes in its membrane potential to conduct signals.
EXCRETION: Release of materials which arise in the body due to metabolism (e.g., CO_2, NH_3, H_20).
EXERGONIC: A phenomenon which involves the release of energy.
EXOCYTOSIS: A process by which a vesicle within a cell fuses with the plasma membrane and releases its contents to the outside.
EXON: A part of a primary transcript (and the corresponding part of a gene) that is ultimately either translated (in the case of mRNA) or utilized in a final product, such as tRNA.
EXOSKELETON: An external skeleton, characteristic of members of the phylum, Arthropoda.
EXOTHERMIC: A process or reaction that is accompanied by the creation of heat.
EXOTOXIN: A toxic protein secreted by a bacterial cell that produces specific symptoms even in the absence of the bacterium.
EXTRINSIC: External to, not a basic part of; as in extrinsic isolating mechanism.

F

F PLASMID: The fertility factor in bacteria, a plasmid that confers the ability to form pili for conjugation and associated functions required for transfer of DNA from donor to recipient.

F: The chemical symbol of Fluorine.

FACILITATED DIFFUSION: Passive movement through a membrane involving a specific carrier protein; does not proceed against a concentration gradient.

FACULTATIVE: An organism which exhibits the capability of changing from one habit or metabolic pathway to another, when conditions warrant. (anaerobe) An organism that makes ATP by aerobic respiration if oxygen is present but that switches to fermentation under anaerobic conditions.

FAT: A biological compound consisting of three fatty acids linked to one glycerol molecule.

FATTY ACID: A long carbon chain carboxylic acid. Fatty acids vary in length and in the number and location of double bonds; three fatty acids linked to a glycerol molecule form fat.

FAUNA: The animals of a given area or period.

FECAL COLIFORM: A group of bacteria that may indicate the presence of human or animal fecal matter in water. Total coliform, fecal coliform, and E. coli are all indicators of drinking water quality. The total coliform group is a large collection of different kinds of bacteria. Fecal coliforms are types of total coliform that mostly exist in feces. E. coli is a sub-group of fecal coliform. When a water sample is sent to a lab, it is tested for total coliform. If total coliform is present, the sample will also be tested for either fecal coliform or E. coli, depending on the lab testing method.

FECES: Indigestible wastes discharged from the digestive tract.

FEEDBACK: The process by which a control mechanism is regulated through the very effects it brings about. Positive feedback is when the effect is amplified; negative feedback is when the effect tends toward restoration of the original condition. Feedback inhibition is a method of metabolic control in which the end-product of a metabolic pathway acts as an inhibitor of an enzyme within that pathway.

FERMENTATION: Anaerobic production of alcohol, lactic acid or similar compounds from carbohydrate resulting from glycolysis.

FERRIC CHLORIDE: An iron salt commonly used as a coagulant. Chemical formula is FeCl3.

FILTER AID: A polymer or other material added to improve the effectiveness of the filtration process.

FILTER CAKE: The layer of solids that is retained on the surface of a filter.

FILTER CLOGGING: An inability to meet demand may occur when filters are clogging.

FILTER PRESS: A dewatering device where sludge is pumped onto a filtering medium and water is forced out of the sludge, resulting in a “cake”.

FILTER: A device utilizing a granular material, woven cloth or other medium to remove pollutants from water, wastewater or air.

FILTRATE: Liquid remaining after removal of solids with filtration.

FILTRATION RATE: A measurement of the volume of water applied to a filter per unit of surface area in a given period of time.

FITNESS: The extent to which an individual passes on its genes to the next generation. Relative fitness is the number of offspring of an individual compared to the mean.

FIXATION: 1) Conversion of a substance into a biologically more usable form, for example, CO_2 fixation during photosynthesis and N_2 fixation. 2) Process of treating living tissue for microscopic examination.

FIXED ACTION PATTERN (FAP): A highly: stereotyped behavior that is innate and must be carried to completion once initiated.

FLACCID: Limp; walled cells are flaccid in isotonic surroundings, where there is no tendency for water to enter.

FLAGELLIN: The protein from which prokaryotic flagella are constructed.

FLAGELLUM: A long whip-like appendage that propels cells during locomotion in liquid solutions. The prokaryote flagellum is comprised of a protein, flagellin. The eukaryote flagellum is longer than a cilium, but as a similar internal structure of microtubules in a"9 + 2" arrangement.

FLAME CELL: A flagellated cell associated with the simplest tubular excretory system, present in flatworms: it acts to directly regulate the contents of the extracellular fluid.

FLOC SHEARING: Likely to happen to large floc particles when they reach the flocculation process.

FLOCCULANTS: Flocculants, or flocculating agents, are chemicals that promote flocculation by causing colloids and other suspended particles in liquids to aggregate, forming a floc. Flocculants are used in water treatment processes to improve the sedimentation or filterability of small particles. For example, a flocculant may be used in swimming pool or drinking water filtration to aid removal of microscopic particles which would otherwise cause the water to be cloudy and which would be difficult or impossible to remove by filtration alone. Many flocculants are multivalent cations such as aluminum, iron, calcium or magnesium. These positively charged molecules interact with negatively charged particles and molecules to reduce the barriers to aggregation. In addition, many of these chemicals, under appropriate pH and other conditions such as temperature and salinity, react with water to form insoluble hydroxides which, upon precipitating, link together to form long chains or meshes, physically trapping small particles into the larger floc. Long-chain polymer

flocculants, such as modified polyacrylamides, are manufactured and sold by the flocculant producing business. These can be supplied in dry or liquid form for use in the flocculation process. The most common liquid polyacrylamide is supplied as an emulsion with 10-40 % actives and the rest is a carrier fluid, surfactants and latex. Emulsion polymers require activation to invert the emulsion and allow the electrolyte groups to be exposed.

FLOCCULATION BASIN: A compartmentalized basin with a reduction of speed in each compartment. This set-up or basin will give the best overall results.

FLOCCULATION: The process of bringing together destabilized or coagulated particles to form larger masses that can be settled and/or filtered out of the water being treated. Conventional coagulation–flocculation-sedimentation practices are essential pretreatments for many water purification systems—especially filtration treatments. These processes agglomerate suspended solids together into larger bodies so that physical filtration processes can more easily remove them. Particulate removal by these methods makes later filtering processes far more effective. The process is often followed by gravity separation (sedimentation or flotation) and is always followed by filtration. A chemical coagulant, such as iron salts, aluminum salts, or polymers, is added to source water to facilitate bonding among particulates. Coagulants work by creating a chemical reaction and eliminating the negative charges that cause particles to repel each other. The coagulant-source water mixture is then slowly stirred in a process known as flocculation. This water churning induces particles to collide and clump together into larger and more easily removable clots, or “flocs.” The process requires chemical knowledge of source water characteristics to ensure that an effective coagulant mix is employed. Improper coagulants make these treatment methods ineffective. The ultimate effectiveness of coagulation/flocculation is also determined by the efficiency of the filtering process with which it is paired.

FLOOD RIM: The point of an object where the water would run over the edge of something and begin to cause a flood.

FLORA: The plants of a given area or period.

FLOW CYTOMETER: A particle-sorting instrument capable of counting protozoa.

FLUID FEEDER: An animal that lives by sucking nutrient-rich fluids from another living organism.

FLUID MOSAIC MODEL: The currently accepted model of cell membrane structure, which envisions the membrane as a mosaic of individually inserted protein molecules drifting laterally in a fluid bilayer of phospholipids.

FLUX: The term flux describes the rate of water flow through a semipermeable membrane. When the water flux decreases through a semipermeable membrane, it means that the mineral concentration of the water is increasing.

FLY ASH: The noncombustible particles in flue gas. Often used as a body feed or solidification chemical.

FOLLICLE STIMULATING HORMONE (FSH): A gonadotropic hormone of the anterior pituitary that stimulates growth of follicles in the ovaries of females and function of the seminiferous tubules in males.

FOLLICLE: A jacket of cells around an egg cell in an ovary.

FOOD CHAIN: Sequence of organisms, including producers, consumers, and decomposers, through which energy and materials may move in a community.

FOOD WEB: The elaborate, interconnected feeding relationships in an ecosystem.

FORMAZIN TURBIDITY UNIT (FTU): A unit used to measure the clarity of water. The ISO refers to the units as FNU (Formazin Nephelometric Units). The technique is the same as that for the NTU, but the calibration uses microspheres of the polymer formazin.

FORMULA: A precise representation of the structure of a molecule or ion, showing the proportion of atoms which comprise the material.

FOUNDER EFFECT: The difference between the gene pool of a population as a whole and that of a newly isolated population of the same species.

FRACTIONATION: An experimental technique that involves separation of parts of living tissue from one another using centrifugation.

FRAGMENTATION: A mechanism of asexual reproduction in which the parent plant or animal separates into parts that reform whole organisms.

FREE CHLORINE RESIDUAL: Regardless of whether pre-chloration is practiced or not, a free chlorine residual of at least 1.0 mg/L should be maintained in the clear well or distribution reservoir immediately downstream from the point of post-chlorination. The reason for chlorinating past the breakpoint is to provide protection in case of backflow.

FREE CHLORINE: In disinfection, chlorine is used in the form of free chlorine or as hypochlorite ion.

FREE OIL: Non-emulsified oil that separates from water, in a given period of time.

FREQUENCY DEPENDENT SELECTION: A decline in the reproductive success of a morph resulting from the morph's phenotype becoming too common in a population; a cause of balanced polymorphism in populations.

FUNCTIONAL GROUP: One of several groups of atoms commonly found in organic molecules. A functional group contributes somewhat predictable properties to the molecules that possess them.

FUNDAMENTAL NICHE: The total resources an organism is theoretically capable of utilizing.

G

G: (protein) A membrane protein that serves as an intermediary between hormone receptors and the enzyme adenylate cyclase, which converts ATP to cAMP in the second messenger system in non-steroid hormone action. Depending on the system, G proteins either increase or decrease cAMP production.

G1 PHASE: The first growth phase of the cell cycle, consisting of the portion of interphase before DNA synthesis is initiated.

G2 PHASE: The second growth phase of the cell cycle, consisting of the portion of interphase after DNA synthesis but before mitosis.

GAMETANGIUM: The reproductive organ of bryophytes, consisting of the male antheridium and female archegonium; a multi-chambered jacket of sterile cells in which gametes are formed.

GAMETE: A sexual reproductive cell that must usually fuse with another such cell before development begins; an egg or sperm.

GAMETOPHYTE: A haploid plant that can produce gametes.

GANGLION: A structure containing a group of cell bodies of neurons.

GAP JUNCTION: A narrow gap between plasma membranes of two animal cells, spanned by protein channels. They allow chemical substances or electrical signals to pass from cell to cell.

GASTRULATION: The process by which a blastula develops into a gastrula, usually by an involution of cells.

GATED ION CHANNEL: A membrane channel that can open or close in response to a signal, generally a change in the electrostatic gradient or the binding of a hormone, transmitter, or other molecular signal.

GEL ELECTROPHORESIS: In general, electrophoresis is a laboratory technique used to separate macromolecules on the basis of electric charge and size; the technique involves application of an electric field to a population of macromolecules which disperse according to their electric mobilities. In gel electrophoresis, the porous medium through which the macromolecules move is a gel.

GEL: Colloid in which the suspended particles form a relatively orderly arrangement.

GENE AMPLIFICATION: Any of the strategies that give rise to multiple copies of certain genes, thus facilitating the rapid synthesis of a product (such as rRna for ribosomes) for which the demand is great.

GENE CLONING: Formation by a bacterium, carrying foreign genes in a recombinant plasmid, of a clone of identical cells containing the replicated foreign genes.

GENE DELIVERY: This is a general term for the introduction of new genetic elements into the genomes of living cells. The delivery problem is essentially conditioned by the fact that the new genetic elements are usually large, and by the presence of the outer cell membrane and the nuclear membrane acting as barriers to incorporation of the new DNA into the genome already present in the nucleus. Viruses possess various natural biochemical methods for achieving gene delivery; artificial gene delivery is one of the essential problems of "genetic engineering". The most important barrier is apparently the outer cell membrane, which is essentially a lipid barrier, and introduction of any large complex into the cell requires a fusion of one kind or another with this membrane. Liposomes, which consist of lipid membranes themselves, and which can fuse with outer cell membranes, are thus potential vehicles for delivery of many substances, including DNA.

GENE FLOW: The movement of genes from one part of a population to another, or from one population to another, via gametes.

GENE POOL: The sum total of all the genes of all the individuals in a population.

GENE REGULATION: Any of the strategies by which the rate of expression of a gene can be regulated, as by controlling the rate of transcription.

GENE: The hereditary determinant of a specified characteristic of an individual; specific sequences of nucleotides in DNA.

GENETIC DRIFT: Change in the gene pool as a result of chance and not as a result of selection, mutation, or migration.

GENETIC RECOMBINATION: The general term for the production of offspring that combine traits of the two parents.

GENETICS: The science of heredity; the study of heritable information.

GENOME: The cell's total complement of DNA.

GENOMIC EQUIVALENCE: The presence of all of an organism's genes in all of its cells.

GENOMIC IMPRINTING: The parental effect on gene expression. Identical alleles may have different effects on offspring depending on whether they arrive in the zygote via the ovum or via the sperm.

GENOMIC LIBRARY: A set of thousands of DNA segments from a genome, each carried by a plasmid or phage.

GENOTYPE: The particular combination of genes present in the cells of an individual.

GENUS: A taxonomic category above the species level, designated by the first word of a species' binomial Latin name.

GIARDIA LAMBLIA: Giardia lamblia (synonymous with Lamblia intestinalis and Giardia duodenalis) is a flagellated protozoan parasite that colonizes and reproduces in the small intestine, causing giardiasis. The giardia parasite attaches to the epithelium by a ventral adhesive disc, and reproduces via binary fission. Giardiasis does not spread via the bloodstream, nor does it spread to other parts of the gastro-intestinal tract,

but remains confined to the lumen of the small intestine. Giardia trophozoites absorb their nutrients from the lumen of the small intestine, and are anaerobes.
GIS – GRAPHIC INFORMATION SYSTEM: Detailed information about the physical locations of structures such as pipes, valves, and manholes within geographic areas with the use of satellites.
GLIAL CELL: A non-conducting cell of the nervous system that provides support, insulation, and protection for the neurons.
GLIDING: Rod-shaped, gram-negative, mostly aerobic; glide on secreted slimy substances; form colonies, frequently with complex fruiting structures.
GLOMERULUS: A capillary bed within Bowman's capsule of the nephron; the site of ultrafiltration.
GLUCOSE: A six-carbon sugar which plays a central role in cellular metabolism.
GLYCOCALYX: The layer of protein and carbohydrates just outside the plasma membrane of an animal cell; in general, the proteins are anchored in the membrane, and the carbohydrates are bound to the proteins.
GLYCOGEN: A long, branched polymer of glucose subunits that is stored in the muscles and liver of animals and is metabolized as a source of energy.
GLYCOLYSIS: A metabolic pathway which occurs in the cytoplasm of cells and during which glucose is oxidized anaerobically to form pyruvic acid.
GLYCOPROTEIN: A protein with covalently linked sugar residues. The sugars may be bound to OH side chains of the polypeptide (O: linked) or the amide nitrogen of asparagine side chains (N: linked).
GLYCOSIDIC: A type of bond which links monosaccharide subunits together in di- or polysaccharides.
GLYOXYSOME: A type of microbody found in plants, in which stored lipids are converted to carbohydrates.
GOLGI APPARATUS: A system of concentrically folded membranes found in the cytoplasm of eukaryotic cells. Plays a role in the production and release of secretory materials such as the digestive enzymes manufactured in the pancreas.
GONADOTROPIN: Refers to a member of a group of hormones capable of promoting growth and function of the gonads. Includes hormones such as follicle stimulating hormone (FSH) and luteinizing hormone (LH) which are stimulatory to the gonads.
GOOD CONTACT TIME, pH and LOW TURBIDITY: These are factors that are important in providing good disinfection when using chlorine.
GPM: Gallons per minute.
GRAB SAMPLE: A sample that is taken from a water or wastestream on a one-time basis with no regard to the flow of the water or wastestream and without consideration of time. A single grab sample should be taken over a period of time not to exceed 15 minutes. A single water or wastewater sample taken at a time and place representative of total discharge.
GRADED POTENTIAL: A local voltage change in a neuron membrane induced by stimulation of a neuron, with strength proportional to the strength of the stimulus and lasting about a millisecond.
GRANUM: A stack-like grouping of photosynthetic membranes in a chloroplast
GRAVITY BELT THICKENER: A sludge dewatering device utilizing a filter belt to promote gravity drainage of water. Usually precedes additional dewatering treatment.
GRAVITY FILTER: A filter that operates at atmospheric pressure.
GRAVITY THICKENING: A sedimentation basin designed to operate at high solids loading rates.
GROWTH FACTOR: A protein that must be present in a cell's environment for its normal growth and development.
GT: Represents (Detention time) x (mixing intensity) in flocculation.
GYMNOSPERM: A vascular plant that bears naked seeds not enclosed in any specialized chambers.

H

H2SO4: The molecular formula of Sulfuric acid.
HABIT: In biology, the characteristic form or mode of growth of an organism.
HABITAT: The kind of place where a given organism normally lives.
HABITUATION: The process that results in a long-lasting decline in the receptiveness of interneurons to the input from sensory neurons or other interneurons (sensitization, adaptation).
HALIDES: A halide is a binary compound, of which one part is a halogen atom and the other part is an element or radical that is less electronegative than the halogen, to make a fluoride, chloride, bromide, iodide, or astatide compound. Many salts are halides. All Group 1 metals form halides with the halogens and they are white solids. A halide ion is a halogen atom bearing a negative charge. The halide anions are fluoride (F), chloride (Cl), bromide (Br), iodide (I) and astatide (At). Such ions are present in all ionic halide salts.
HALOACETIC ACIDS: Haloacetic acids are carboxylic acids in which a halogen atom takes the place of a hydrogen atom in acetic acid. Thus, in a monohaloacetic acid, a single halogen would replace a hydrogen atom. For example, chloroacetic acid would have the structural formula CH_2ClCO_2H. In the same manner, in dichloroacetic acid two chlorine atoms would take the place of two hydrogen atoms ($CHCl_2CO_2H$).
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atom. For example, chloroacetic acid would have the structural formula CH_2ClCO_2H. In the same manner, in dichloroacetic acid two chlorine atoms would take the place of two hydrogen atoms ($CHCl_2CO_2H$).
HAPLOID: The condition of having only one kind of a given type of chromosome.
HARD WATER: Hard water causes a buildup of scale in household hot water heaters. Hard water is a type of water that has high mineral content (in contrast with soft water). Hard water primarily consists of calcium (Ca2+), and magnesium (Mg2+) metal cations, and sometimes other dissolved compounds such as bicarbonates and sulfates. Calcium usually enters the water as either calcium carbonate ($CaCO_3$), in the form of limestone and chalk, or calcium sulfate ($CaSO_4$), in the form of other mineral deposits. The predominant source of magnesium is dolomite ($CaMg(CO_3)2$). Hard water is generally not harmful. The simplest way to determine the hardness of water is the lather/froth test: soap or toothpaste, when agitated, lathers easily in soft water but not in hard water. More exact measurements of hardness can be obtained through a wet titration. The total water 'hardness' (including both Ca2+ and Mg2+ ions) is read as parts per million or weight/volume (mg/L) of calcium carbonate (CaCO3) in the water. Although water hardness usually only measures the total concentrations of calcium and magnesium (the two most prevalent, divalent metal ions), iron, aluminum, and manganese may also be present at elevated levels in some geographical locations.
HARDNESS: A measure of the amount of calcium and magnesium salts in water. More calcium and magnesium lead to greater hardness. The term "hardness" comes from the fact that it is hard to get soapsuds from soap or detergents in hard water. This happens because calcium and magnesium react strongly with negatively charged chemicals like soap to form insoluble compounds.
HAZARDS OF POLYMERS: Slippery and difficult to clean-up are the most common hazards associated with the use of polymers in a water treatment plant.
HEAD: The measure of the pressure of water expressed in feet of height of water. 1 PSI = 2.31 feet of water or 1 foot of head equals about a half a pound of pressure or .433 PSI. There are various types of heads of water depending upon what is being measured. Static (water at rest) and Residual (water at flow conditions).
HEADWORKS: The facility at the "**head**" of the water source where water is first treated and routed into the distribution system.
HEALTH ADVISORY: An EPA document that provides guidance and information on contaminants that can affect human health and that may occur in drinking water, but which the EPA does not currently regulate in drinking water.
HEAT OF VAPORIZATION: The amount of energy absorbed by a substance when it changes state to a gas. Water absorbs approximately 580 calories per gram when it changes from liquid water-to-water vapor.
HEAT: The total amount of kinetic energy due to molecular motion in a body of matter. Heat is energy in its most random form.
HELPER T CELL: A type of T cell that is required by some B cells to help them make antibodies or that helps other T cells respond to antigens or secrete lymphokines or interleukins.
HEMAGGLUTININ: A surface antigen on influenza viruses that controls infectivity by associating with receptors on host erythrocytes or other cells.
HEMATOPOIETIC STEM CELLS: Cells found in the bone marrow of adult mammals which give rise to erythroid stem cells, lymphoid stem cells, and myeloid stem cells. Such cells give rise to erythrocytes and a variety of types of lymphocytes and leucocytes.
HEMOGLOBIN: An iron-containing respiratory pigment found in many organisms.
HEMOLYMPH: In invertebrates with open circulatory systems, the body fluid that bathes tissues.
HEMOPHILIA: A genetic disease resulting from an abnormal sex-linked recessive gene, characterized by excessive bleeding following injury.
HEPATIC: Pertaining to the liver.
HEREDITY: A biological phenomenon whereby characteristics are transmitted from one generation to another by virtue of chemicals (i.e. DNA) transferred during sexual or asexual reproduction.
HERPESVIRUS: A double stranded DNA virus with an enveloped, icosahedral capsid.
HERTZ: The term used to describe the frequency of cycles in an alternating current (AC) circuit. A unit of frequency equal to one cycle per second.
HETEROCHROMATIN: Non-transcribed eukaryotic chromatin that is so highly compacted that it is visible with a light microscope during interphase.
HETEROCHRONY: Evolutionary changes in the timing or rate of development.
HETEROCYST: A specialized cell that engages in nitrogen fixation on some filamentous cyanobacteria.
HETEROGAMY: The condition of producing gametes of two different types (contrast with isogamy).
HETEROMORPHIC: A condition in the life cycle of all modern plants in which the sporophyte and gametophyte generations differ in morphology.
HETEROSPOROUS: Referring to plants in which the sporophyte produces two kinds of spores that develop into unisexual gametophytes, either male or female.
HETEROTROPH: An organism dependent on external sources of organic compounds as a means of obtaining energy and/or materials. Such an organism requires carbon ("food") from its environment in an organic form. (synonym-organotroph).

HETEROTROPHIC PLATE COUNT: A test performed on drinking water to determine the total number of all types of bacteria in the water.
HETEROZYGOTE ADVANTAGE: A mechanism that preserves variation in eukaryotic gene pools by conferring greater reproductive success on heterozygotes over individuals homozygous for any one of the associated alleles.
HETEROZYGOUS: The condition whereby two different alleles of the gene are present within the same cell.
HF: The molecular formula of Hydrofluoric acid.
HIGH TURBIDITY CAUSING INCREASED CHLORINE DEMAND: May occur or be caused by the inadequate disinfection of water.
HIGH-TEST HYPOCHLORITE: A composition composed mainly of calcium hypochlorite is commonly called high test hypochlorite. High-Test Hypochlorite contains not less than 60.0% of available chlorine.
HISTAMINE: A substance released by injured cells that causes blood vessels to dilate during an inflammatory response.
HISTOLOGY: The study of tissues.
HISTONE: A type of protein characteristically associated with the chromosomes of eukaryotes.
HIV-1: Acute human immunodeficiency virus type 1 is the subtype of HIV (human immune deficiency virus) that causes most cases of AIDS in the Western Hemisphere, Europe, and Central, South, and East Africa. HIV is a retrovirus (subclass lentivirus), and retroviruses are single: stranded RNA viruses that have an enzyme called reverse transcriptase. With this enzyme the viral RNA is used as a template to produce viral DNA from cellular material. This DNA is then incorporated into the host cell's genome, where it codes for the synthesis of viral components. An HIV-1 infection should be distinguished from AIDS. Acquired immunodeficiency syndrome (AIDS) is a secondary immunodeficiency syndrome resulting from HIV infection and characterized by opportunistic infections, malignancies, neurologic dysfunction, and a variety of other syndromes.
HOLOBLASTIC: A type of cleavage in which there is complete division of the egg, as in eggs having little yolk (sea urchin) or a moderate amount of yolk (frog).
HOME RANGE: An area within which an animal tends to confine all or nearly all its activities for a long period of time.
HOMEOBOX: Specific sequences of DNA that regulate patterns of differentiation during development of an organism.
HOMEOSTASIS: A phenomenon whereby a state or process (for example, within an organism) is regulated automatically despite the tendency for fluctuations to occur.
HOMEOTHEMIC: Capable of regulation of constancy with respect to temperature.
HOMEOTIC GENES: Genes that control the overall body plan of animals by controlling the developmental fate of groups of cells.
HOMEOTIC: (mutation) A mutation in genes regulated by positional information that results in the abnormal substitution of one type of body part in place of another.
HOMOLOGOUS CHROMOSOMES: Chromosomes bearing genes for the same characters.
HOMOLOGOUS STRUCTURES: Characters in different species that were inherited from a common ancestor and thus share a similar ontogenetic pattern.
HOMOLOGY: Similarity in characteristics resulting from a shared ancestry.
HOMOPLASY: The presence in several species of a trait not present in their most common ancestor. Can result from convergent evolution, reverse evolution, or parallel evolution.
HOMOSPOROUS: Referring to plants in which a single type of spore develops into a bisexual gametophyte having both male and female sex organs.
HOMOZYGOUS: Having two copies of the same allele of a given gene.
HORMONE: A control chemical secreted in one part of the body that affects other parts of the body.
HOST RANGE: The limited number of host species, tissues, or cells that a parasite (including viruses and bacteria) can infect.
HUMORAL IMMUNITY: The type of immunity that fights bacteria and viruses in body fluids with antibodies that circulate in blood plasma and lymph, fluids formerly called humors.
HYBIRD VIGOR: Increased vitality (compared to that of either parent stock) in the hybrid offspring of two different, inbred parents.
HYBIRD: In evolutionary biology, a cross between two species. In genetics, a cross between two genetic types.
HYBIRDIZATION: The process whereby a hybrid results from interbreeding two species; 2) DNA hybridization is the comparison of whole genomes of two species by estimating the extent of hydrogen bonding that occurs between single-stranded DNA obtained from the two species.
HYBRIDOMA: A hybrid cell that produces monoclonal antibodies in culture, formed by the fusion of a myeloma cell with a normal antibody-producing lymphocyte.
HYDRATED LIME: The calcium hydroxide product that results from mixing quicklime with water. Chemical formula is CaOH2.

HYDRATION SHELL: A "covering" of water molecules which surrounds polar or charged substances in aqueous solutions. The association is due to the charged regions of the polar water molecules themselves.
HYDRIDES: Hydride is the name given to the negative ion of hydrogen, H. Although this ion does not exist except in extraordinary conditions, the term hydride is widely applied to describe compounds of hydrogen with other elements, particularly those of groups 1–16. The variety of compounds formed by hydrogen is vast, arguably greater than that of any other element. Various metal hydrides are currently being studied for use as a means of hydrogen storage in fuel cell-powered electric cars and batteries. They also have important uses in organic chemistry as powerful reducing agents, and many promising uses in hydrogen economy.
HYDROCARBON: Any compound made of only carbon and hydrogen.
HYDROCHLORIC ACID: It is the aqueous solution of hydrogen chloride gas (HCl). It is a strong acid, and the major component of gastric acid, and of wide industrial use. Hydrochloric acid must be handled with appropriate safety precautions because it is a highly corrosive liquid.
HYDROCHLORIC AND HYPOCHLOROUS ACIDS: The compounds that are formed in water when chlorine gas is introduced.
HYDROFLUOSILICIC ACID: (H_2SiF_6) a clear, fuming corrosive liquid with a pH ranging from 1 to 1.5. Used in water treatment to fluoridate drinking water.
HYDROGEN BOND: A type of bond formed when the partially positive hydrogen atom of a polar covalent bond in one molecule is attracted to the partially negative atom of a polar covalent bond in another.
HYDROGEN ION: A single proton with a charge of +1. The dissociation of a water molecule (H2O) leads to the generation of a hydroxide ion (OH-) and a hydrogen ion (H+).
HYDROGEN SULFIDE: A toxic gas formed by the anaerobic decomposition of organic matter. Chemical formula is H2S.
HYDROLYSIS: The chemical reaction that breaks a covalent bond through the addition of hydrogen (from a water molecule) to the atom forming one side of the original bond, and a hydroxyl group to the atom on the other side.
HYDROPHILIC: Having an affinity for water.
HYDROPHOBIC INTERACTION: A type of weak chemical bond formed when molecules that do not mix with water coalesce to exclude the water.
HYDROPHOBIC: The physicochemical property whereby a substance or region of a molecule resists association with water molecules.
HYDROSTATIC: Pertaining to the pressure and equilibrium of fluids. A hydrostatic skeleton is a skeletal system composed of fluid held under pressure in a closed body compartment; the main skeleton of most cnidarians, flatworms, nematodes, and annelids.
HYDROXYL GROUP: A functional group consisting of a hydrogen atom joined to an oxygen atom by a polar covalent bond. Molecules possessing this group are soluble in water and are called alcohols.
HYDROXYL ION: The OH- ion.
HYPEROSMOTIC: A solution with a greater solute concentration than another, a hypoosmotic solution. If the two solutions are separated from one another by a membrane permeable to water, water would tend to move from the hypo- to the hyperosmotic side.
HYPERPOLARIZATION: An electrical state whereby the inside of the cell is made more negative relative to the outside than was the case at resting potential. A neuron membrane is hyperpolarized if the voltage is increased from the resting potential of about -70 mV, reducing the chance that a nerve impulse will be transmitted.
HYPERTROPHY: Abnormal enlargement, excessive growth.
HYPHA: A fungal filament.
HYPOCHLORITE AND ORGANIC MATERIALS: Heat and possibly fire may occur when hypochlorite is brought into contact with an organic material.
HYPOCOTYL: The portion of the axis of a plant embryo below the point of attachment of the cotyledons; forms the base of the shoot and the root.
HYPOOSMOTIC SOLUTION: A solution with a lesser solute concentration than another, a hyperosmotic solution. If the two solutions are separated from one another by a membrane permeable to water, water would tend to move from the hypo- to the hyperosmotic side.
HYPOTHESIS: A formal statement of supposition offered to explain observations. Note that a hypothesis is only useful if it can be tested. Even if correct, it is not scientifically useful if untestable.
HYPOTHETICO-DEDUCTIVE: A method used to test hypotheses. If deductions formulated from the hypothesis are tested and proven false, the hypothesis is rejected.
If the actual pH of the water is below the calculated saturation pH, the LSI is negative and the water has a very limited scaling potential. If the actual pH exceeds pHs, the LSI is positive, and being supersaturated with CaCO3, the water has a tendency to form scale. At increasing positive index values, the scaling potential increases.

I

IMAGINAL DISK: An island of undifferentiated cells in an insect larva, which are committed (determined) to form a particular organ during metamorphosis to the adult.

IMBIBITION: The soaking of water into a porous material that is hydrophilic.

IMMUNE RESPONSE: 1) A primary immune response is the initial response to an antigen, which appears after a lag of a few days. 2) A secondary immune response is the response elicited when the animal encounters the same antigen at a later time. The secondary response is normally more rapid, of greater magnitude and of longer duration than the primary response.

IMMUNOGLOBULINE: The class of proteins comprising the antibodies.

IMMUNOLOGICAL: 1) Immunological distance is the amount of difference between two proteins as measured by the strength of the antigen: antibody reaction between them. 2) Immunological tolerance is a mechanism by which an animal does not mount an immune response to the antigenic determinants of its own macromolecules.

IMMUNOMAGNETIC SEPARATION (IMS): A purification procedure that uses microscopic, magnetically responsive particles coated with an antibodies targeted to react with a specific pathogen in a fluid stream. Pathogens are selectively removed from other debris using a magnetic field.

IMPELLERS: The semi-open or closed props or blades of a turbine pump that when rotated generate the pumping force.

IMPERVIOUS: Not allowing, or allowing only with great difficulty, the movement of water.

IMPRINTING: A type of learned behavior with a significant innate component, acquired during a limited critical period.

IN SERIES: Several components being connected one to the other without a bypass, requiring each component to work dependent on the one before it.

IN SITU: Treatment or disposal methods that do not require movement of contaminated material.

INCINERATION: The process of reducing the volume of a material by burning and reducing to ash if possible.

INCLINED PLATE SEPARATOR: A series of parallel inclined plates that can be used to increase the efficiency of clarifiers and gravity thickeners.

INCOMPLETE DOMINANCE: A type of inheritance in which F1 hybrids have an appearance that is intermediate between the phenotypes of the parental varieties.

INDETERMINATE: 1) A type of cleavage exhibited during the embryonic development in deuterostomes, in which each cell produced by early cleavage divisions retains the capacity to develop into a complete embryo; 2) A type of growth exhibited by plants: they continue to grow as long as they live, because they always retain meristematic cells capable of undergoing mitosis.

INDIRECT REUSE: The beneficial use of reclaimed water into natural surface waters or groundwater.

INDUCED FIT: The change in shape of the active site of an enzyme so that it binds more snugly to the substrate, induced by entry of the substrate.

INDUCTION: 1) The ability of one group of embryonic cells to influence the development of another. 2) A method in logic that proceeds from the specific to general and develops a general statement which explains all of the observations. Commonly used to formulate scientific hypotheses.

INDUSTRIAL WASTEWATER: Liquid wastes resulting from industrial processes.

INFECTIOUS PATHOGENS/MICROBES/GERMS: Are considered disease-producing bacteria, viruses and other microorganisms.

INFECTIOUS: 1) An infectious disease is a disease caused by an infectious microbial or parasitic agent. 2) Infectious hepatitis is the former name for hepatitis A. 3) Infectious mononucleosis is an acute disease that affects many systems, caused by the Epstein: Barr virus.

INFLAMMATORY RESPONSE: A line of defense triggered by penetration of the skin or mucous membranes, in which small blood vessels in the vicinity of an injury dilate and become leakier, enhancing infiltration of leukocytes; may also be widespread in the body.

INFLUENT: Water or wastewater flowing into a basin or treatment plant.

INFORMATION COLLECTION RULE (ICR): EPA collected data required by the Information Collection Rule (May 14, 1996) to support future regulation of microbial contaminants, disinfectants, and disinfection byproducts. The rule was intended to provide EPA with information on chemical byproducts that form when disinfectants used for microbial control react with chemicals already present in source water (disinfection byproducts (DBPs)); disease-causing microorganisms (pathogens), including Cryptosporidium; and engineering data to control these contaminants.

INGESTION: A heterotrophic mode of nutrition in which other organisms or detritus are eaten whole or in pieces.

INHIBITORY POSTSYNAPTIC POTENTIAL: An electrical charge (hyperpolarization) in the membrane of a postsynaptic neuron caused by the binding of an inhibitory neurotransmitter from a presynaptic cell to a postsynaptic receptor.

INITIAL PRECISION AND RECOVERY (IPR): Four aliquots of spiking suspension analyzed to establish the ability to generate acceptable precision and accuracy. An IPR is performed prior to the first time this method is used and any time the method or instrumentation is modified.
INNER CELL MASS: A cluster of cells in a mammalian blastocyst that protrudes into one end of the cavity and subsequently develops into the embryo proper and some of the extraembryonic membranes.
INORGANIC COMPOUND: Compounds that contain no carbon or contain only carbon bound to elements other than hydrogen.
INORGANIC CONTAMINANTS: Mineral-based compounds such as metals, nitrates, and asbestos. These contaminants are naturally occurring in some water, but can also get into water through farming, chemical manufacturing, and other human activities. EPA has set legal limits on 15 inorganic contaminants.
INORGANIC IONS: Present in all waters. Inorganic ions are essential for human health in small quantities, but in larger quantities they can cause unpleasant taste and odor or even illness. Most community water systems will commonly test for the concentrations of seven inorganic ions: nitrate, nitrite, fluoride, phosphate, sulfate, chloride, and bromide. Nitrate and nitrite can cause an illness in infants called methemoglobinemia. Fluoride is actually added to the drinking water in some public water systems to promote dental health. Phosphate, sulfate, chloride, and bromide have little direct effect on health, but high concentrations of inorganic ions can give water a salty or briny taste.
INSERTION: A mutation involving the addition of one or more nucleotide pairs to a gene.
INSOLUBLE COMPOUNDS: Are types of compounds cannot be dissolved. When iron or manganese reacts with dissolved oxygen (**DO**) insoluble compound are formed.
INSULIN: The vertebrate hormone that lowers blood sugar levels by promoting the uptake of glucose by most body cells and promoting the synthesis and storage of glycogen in the liver; also stimulates protein and fat synthesis; secreted by endocrine cells of the pancreas called islets of Langerhans.
INTAKE FACILITIES: One of the more important considerations in the construction of intake facilities is the ease of operation and maintenance over the expected lifetime of the facility. Every intake structure must be constructed with consideration for operator
INTEGRAL PROTEIN: A protein of biological membranes that penetrates into or spans the membrane.
INTERBREED: To breed with another kind or species; hybridize.
INTERFERON: A chemical messenger of the immune system, produced by virus: infected cells and capable of helping other cells resist the virus.
INTERLEUKIN: 1: A chemical regulator (cytokine) secreted by macrophages that have ingested a pathogen or foreign molecule and have bound with a helper T cell; stimulates T cells to grow and divide and elevates body temperature. Interleukin: 2, secreted by activated T cells, stimulates helper T cells to proliferate more rapidly.
INTERTIDAL ZONE: The shallow zone of the ocean where land meets water.
INTRON: The noncoding, intervening sequence of coding region (exon) in eukaryotic genes.
INVAGINATION: The buckling inward of a cell layer, caused by rearrangements of microfilaments and microtubules; an important phenomenon in embryonic development.
INVERSION: 1) An aberration in chromosome structure resulting from an error in meiosis or from mutagens; reattachment in a reverse orientation of a chromosomal fragment to the chromosome from which the fragment originated. 2) A phenomenon that occurs during early development of sponges at which time the external ciliated cells become inward-directed.
INVERTEBRATE: An animal without a backbone; invertebrates make up about 95% of animal species.
ION EXCHANGE: An effective treatment process used to remove iron and manganese in a water supply. The hardness of the source water affects the amount of water an ion exchange softener may treat before the bed requires regeneration.
ION: A charged chemical formed when an atom or group of atoms has more or less electrons than protons (rather than an equal number).
IONIC BOND: A chemical bond due to attraction between oppositely charged ions.
IRON AND MANGANESE: In water, they can usually be detected by observing the color of the inside walls of filters and the filter media. If the raw water is pre-chlorinated, there will be black stains on the walls below the water level and a black coating over the top portion of the sand filter bed. When significant levels of dissolved oxygen are present, iron and manganese exist in an oxidized state and normally precipitate into the reservoir bottom sediments. The presence of iron and manganese in water promote the growth of Iron bacteria. Only when a water sample has been acidified then you can perform the analysis beyond the 48-hour holding time. Iron and Manganese in water may be detected by observing the color of the of the filter media. Maintaining a free chlorine residual and regular flushing of water mains may control the growth of iron bacteria in a water distribution system.
IRON BACTERIA: In the management of water-supply wells, iron bacteria are bacteria that derive the energy they need to live and multiply by oxidizing dissolved ferrous iron (or the less frequently available manganese and aluminum). The resulting ferric oxide is insoluble, and appears as brown gelatinous slime that will stain plumbing fixtures, and clothing or utensils washed with the water carrying it, and may contribute to internal

corrosion of the pipes and fixtures the water flows through. They are known to grow and proliferate in waters containing as low as 0.1mg/l of iron. However, at least 0.3 ppm of dissolved oxygen is needed to carry out oxidation. The proliferation of iron bacteria, in some way, increases the chance of sulfur bacteria infestation.
IRON: The elements iron and manganese are undesirable in water because they cause stains and promote the growth of iron bacteria.
ISOMER: Molecules consisting of the same numbers and kinds of atoms, but differing in the way in which the atoms are combined.
ISOSMOTIC: Solutions of equal concentration with respect to osmotic pressure.
ISOTOPE: An atomic form of an element, containing a different number of neutrons than another isotope. Isotopes vary from one another with respect to atomic mass.

K

K- SELECTION: The concept that life history of the population is centered upon producing relatively few offspring that have a good chance of survival.
KARYOGAMY: The fusion of nuclei of two cells, as part of syngamy.
KARYOTYPE: A method of classifying the chromosomes of a cell in relation to number, size and type.
KEYSTONE PREDATOR: A species that maintains species richness in a community through predation of the best competitors in the community, thereby maintaining populations of less competitive species.
KILL = C X T: Where other factors are constant, the disinfecting action may be represented by: Kill=C x T.
KILOCALORIE: A thousand calories; the amount of heat energy required to raise the temperature of 1 kilogram of water by primary C.
KINGDOM: A taxonomic category, the second broadest after domain.

L

L.O.T.O.: If a piece of equipment is locked out, the key to the lock-out device the key should be held by the person who is working on the equipment. The tag is an identification device and the lock is a physical restraint.
LABORATORY BLANK: See Method blank
LABORATORY CONTROL SAMPLE (LCS): See Ongoing precision and recovery (OPR) standard
LAND APPLICATION: The disposal of wastewater or municipal solids onto land under controlled conditions.
LAND DISPOSAL: Application of municipal wastewater solids to the soil without production of usable agricultural products.
LANDFILL: A land disposal site that employs an engineering method of solid waste disposal to minimize environmental hazards and protect the quality of surface and subsurface waters.
LANGELIER INDEX: A measurement of Corrosivity. The water is becoming corrosive in the distribution system causing rusty water if the Langelier index indicates that the pH has decreased from the equilibrium point. Mathematically derived factor obtained from the values of calcium hardness, total alkalinity, and pH at a given temperature. A Langelier index of zero indicates perfect water balance (i.e., neither corroding nor scaling). The Langelier Saturation Index (sometimes Langelier Stability Index) is a calculated number used to predict the calcium carbonate stability of water. It indicates whether the water will precipitate, dissolve, or be in equilibrium with calcium carbonate. Langelier developed a method for predicting the pH at which water is saturated in calcium carbonate (called pHs). The LSI is expressed as the difference between the actual system pH and the saturation pH.
LARVA (pl. larvae): A free-living, sexually immature form in some animal life cycles that may differ from the adult in morphology, nutrition, and habitat.
LEACHATE: Fluid that trickles through solid materials or wastes and contains suspended or dissolved materials or products of the solids.
LEACHING: A chemical reaction between water and metals that allows for removal of soluble materials.
LEADING STRAND: The new continuously complementary DNA strand synthesized along the template strand in the 5' --- > 3' direction.
LETHAL CONCENTRATION 50: Also referred to as LC50, a concentration of a pollutant or effluent at which 50 percent of the test organisms die; a common measure of acute toxicity.
LEUKOCYTE: A white blood cell; typically functions in immunity, such as phagocytosis or antibody production.
LEVELS OF ORGANIZATION: A basic concept in biology is that organization is based on a hierarchy of structural levels, with each level building on the levels below it.
LICHEN: An organism formed by the symbiotic association between a fungus and a photosynthetic alga.
LIFE: A table of data summarizing mortality in a population.
LIGAMENT: A type of fibrous connective tissue that joins bones together at joints.
LIGAND: A ligand is a molecule that binds specifically to a receptor site of another molecule. A ligase is an enzyme that catalyzes such a reaction. For example, a DNA ligase is an enzyme that catalyzes the covalent bonding of the 3' end of a new DNA fragment to the 5' end of a growing chain.
LIGASE: Ligases are enzymes that catalyze the "stitching together" of polymer fragments. DNA ligase, for example, catalyzes phosphodiester bond formation between two DNA fragments, and this enzyme is involved

in normal DNA replication, repair of damaged chromosomes, and various in vitro techniques in genetic engineering that involve linking DNA fragments.
LIGNIN: A hard material embedded in the cellulose matrix of vascular plant cell walls that functions as an important adaptation for support in terrestrial species.
LIMBIC SYSTEM: A group of nuclei (clusters of nerve cell bodies) in the lower part of the mammalian forebrain that interact with the cerebral cortex in determining emotions; includes the hippocampus and the amygdala.
LIME SOFTENING: Lime softening is primarily used to "soften" water—that is to remove calcium and magnesium mineral salts. But it also removes harmful toxins like radon and arsenic. Though there is no consensus, some studies have even suggested that lime softening is effective at removal of Giardia. Hard water is a common condition responsible for numerous problems. Users often recognize hard water because it prevents their soap from lathering properly. However, it can also cause buildup ("scale") in hot water heaters, boilers, and hot water pipes. Because of these inconveniences, many treatment facilities use lime softening to soften hard water for consumer use. Before lime softening can be used, managers must determine the softening chemistry required. This is a relatively easy task for groundwater sources, which remain more constant in their composition. Surface waters, however, fluctuate widely in quality and may require frequent changes to the softening chemical mix. In lime softening, lime and sometimes sodium carbonate are added to the water as it enters a combination solids contact clarifier. This raises the pH (i.e., increases alkalinity) and leads to the precipitation of calcium carbonate. Later, the pH of the effluent from the clarifier is reduced again, and the water is then filtered through a granular media filter. The water chemistry requirements of these systems require knowledgeable operators, which may make lime softening an economic challenge for some very small systems.
LIME STABILIZATION: The addition of lime to untreated sludge to raise the pH to 12 for a minimum of 2 hours to chemically inactivate microorganisms.
LIME: The term generally used to describe ground limestone (calcium carbonate), hydrated lime (calcium hydroxide), or burned lime (calcium oxide).
LINKED GENES: Genes that are located on the same chromosomes.
LIPID: One of a family of compounds, including fats, phospholipids, and steroids, that are insoluble in water.
LIPOSOME: Liposomes are vesicles (spherules) in which the lipid molecules are spontaneously arranged into bilayers with hydrophilic groups exposed to water molecules both outside the vesicle and in the core.
LISTED HAZARDOUS WASTE: The designation for a waste material that appears on an EPA list of specific hazardous wastes or hazardous waste categories.
LOCUS: A particular place along the length of a certain chromosome where a specified allele is located.
LOGISTIC POPULATION GROWTH: A model describing population growth that levels off as population size approaches carrying capacity.
LSI = pH - pHs
LYSOGENIC CYCLE: A type of viral replication cycle in which the viral genome becomes incorporated into the bacterial host chromosome as a prophage.
LYTIC CYCLE: A type of viral replication cycle resulting in the release of new phages by death or lysis of the host cell.
M
M PHASE: The mitotic phase of the cell cycle, which includes mitosis and cytokinesis.
M.S.D.S.: Now S.D.S. (Safety Data Sheet) .A safety document must an employer provide to an operator upon request.
MACROMOLECULE: A giant molecule of living matter formed by the joining of smaller molecules, usually by condensation synthesis. Polysaccharides, proteins, and nucleic acids are macromolecules.
MACROPHAGE: An amoeboid cell that moves through tissue fibers, engulfing bacteria and dead cells by phagocytosis.
MAGNESIUM HARDNESS: Measure of the magnesium salts dissolved in water – it is not a factor in water balance.
MAGNETIC STARTER: Is a type of motor starter should be used in an integrated circuit to control flow automatically.
MAJOR HISTOCOMPATIBILITY COMPLEX: A large set of cell surface antigens encoded by a family of genes. Foreign MHC markers trigger T-cell responses that may lead to rejection of transplanted tissues and organs.
MAKEUP WATER: Fluid introduced in a recirculating stream to maintain an equilibrium of temperature, solids concentration or other parameters. Also refers to the quantity of water required to make a solution.
MALPHIGHIAN TUBULE: A unique excretory organ of insects that empties into the digestive tract, removes nitrogenous wastes from the blood, and functions in osmoregulation.
MANGANESE (IV) OXIDE: The chemical compound MnO_2, commonly called manganese dioxide. This blackish or brown solid occurs naturally as the mineral pyrolusite, which is the main ore of manganese. It is also present in manganese nodules. The principal use for MnO_2 is for dry-cell batteries, such as the alkaline

battery and the zinc-carbon battery. In 1976 this application accounted for 500,000 tons of pyrolusite. MnO2 is also used for production of MnO4–. It is used extensively as an oxidizing agent in organic synthesis, for example, for the oxidation of allylic alcohols.
MANTLE: A heavy fold of tissue in mollusks that drapes over the visceral mass and may secrete a shell.
MARBLE AND LANGELIER TESTS: Are used to measure or determine the corrosiveness of a water source.
MASS NUMBER: The sum of the number of protons plus the number of neutrons in the nucleus of an atom; unique for each element and designated by a superscript to the left of the elemental symbol.
MATRIX SPIKE (MS): A sample prepared by adding a known quantity of organisms to a specified amount of sample matrix for which an independent estimate of target analyte concentration is available. A matrix spike is used to determine the effect of the matrix on a method's recovery efficiency.
MATRIX: The nonliving component of connective tissue, consisting of a web of fibers embedded in homogeneous ground substance that may be liquid, jellylike, or solid.
MATTER: Anything that takes up space and has mass.
MAXIMUM CONTAMINANT LEVEL (MCL): The maximum concentration of a chemical that is allowed in public drinking water systems.
MAXIMUM CONTAMINANT LEVEL GOAL (MCLG): The maximum level at which a contaminant can exist in drinking water without having an adverse effect on human health.
MECHANICAL SEAL: A mechanical device used to control leakage from the stuffing box of a pump. Usually made of two flat surfaces, one of which rotates on the shaft. The two flat surfaces are of such tolerances as to prevent the passage of water between them. Held in place with spring pressure.
MECHANORECEPTOR: A sensory receptor that detects physical deformations in the body environment associated with pressure, touch, stretch, motion, and sound.
MEDIAN BODIES: Prominent, dark-staining, paired organelles consisting of microtubules and found in the posterior half of *Giardia*. In *G. intestinalis* (from humans), these structures often have a claw-hammer shape, while in *G. muris* (from mice), the median bodies are round.
MEDIUM WATER SYSTEM: More than 3,300 persons and 50,000 or fewer persons.
MEDULLA OBLONGATA: The lowest part of the vertebrate brain; a swelling of the hindbrain dorsal to the anterior spinal cord that controls autonomic, homeostatic functions, including breathing, heart and blood vessel activity, swallowing, digestion, and vomiting.
MEDUSA: The floating, flattened, mouth-down version of the cnidarian body plan. The alternate form is the polyp.
MEGAPASCAL: A unit of pressure equivalent to 10 atmospheres of pressure.
MEGGER: Used to test the insulation resistance on a motor.
MEIOSIS: A two-stage type of cell division in sexually reproducing organisms that results in gametes with half the chromosome number of the original cell.
MEMBRANE POTENTIAL: The charge difference between the cytoplasm and extracellular fluid in all cells, due to the differential distribution of ions. Membrane potential affects the activity of excitable cells and the transmembrane movement of all charged substances.
MEMBRANE: A thin barrier that permits passage of particles of a certain size or of particular physical or chemical properties.
M-ENDO BROTH: The coliform group are used as indicators of fecal pollution in water, for assessing the effectiveness of water treatment and disinfection, and for monitoring water quality. m-Endo Broth is used for selectively isolating coliform bacteria from water and other specimens using the membrane filtration technique. m-Endo Broth is prepared according to the formula of Fifield and Schaufus.1 It is recommended by the American Public Health Association in standard total coliform membrane filtration procedure for testing water, wastewater, and foods.2,3 The US EPA specifies using m-Endo Broth in the total coliform methods for testing water using single-step, two-step, and delayed incubation membrane filtration methods.
MESENTERIES: Membranes that suspend many of the organs of vertebrates inside fluid- filled body cavities.
MESODERM: The middle primary germ layer of an early embryo that develops into the notochord, the lining of the coelom, muscles, skeleton, gonads, kidneys and most of the circulatory system.
MESOSOME: A localized infolding of the plasma membrane of a bacterium.
MESSENGER: (RNA) A type of RNA synthesized from DNA in the genetic material that attaches to ribosomes in the cytoplasm and specifies the primary structure of a protein.
METABOLISM: The sum total of the chemical and physical changes constantly taking place in living substances.
METALLOID: Metalloid is a term used in chemistry when classifying the chemical elements. On the basis of their general physical and chemical properties, nearly every element in the periodic table can be termed either a metal or a nonmetal. A few elements with intermediate properties are, however, referred to as metalloids. (In Greek metallon = metal and eidos = sort)
METAMORPHOSIS: The resurgence of development in an animal larva that transforms it into a sexually mature adult.

METANEPHRIDIUM: A type of excretory tubule in annelid worms that has internal openings called nephrostomes that collect body fluids and external openings called nephridiopores.
METASTASIS: The spread of cancer cells beyond their original site.
METAZOAN: A multicellular animal. Among important distinguishing characteristics of metazoa are cell differentiation and intercellular communication. For certain multicellular colonial entities such as sponges, some biologists prefer the term "parazoa".
METHANE: Methane is a chemical compound with the molecular formula CH4. It is the simplest alkane, and the principal component of natural gas. Methane's bond angles are 109.5 degrees. Burning methane in the presence of oxygen produces carbon dioxide and water. The relative abundance of methane and its clean burning process makes it a very attractive fuel. However, because it is a gas at normal temperature and pressure, methane is difficult to transport from its source.
METHOD BLANK: An aliquot of reagent water that is treated exactly as a sample, including exposure to all glassware, equipment, solvents, and procedures that are used with samples. The method blank is used to determine if analytes or interferences are present in the laboratory environment, the reagents, or the apparatus.
Mg/L: Stands for "**milligrams per liter**." A common unit of chemical concentration. It expresses the mass of a chemical that is present in a given volume of water. A milligram (one one-thousandth of a gram) is equivalent to about 18 grains of table salt. A liter is equivalent to about one quart.
MICROBE OR MICROBIAL: Any minute, simple, single-celled form of life, especially one that causes disease.
MICROBIAL CONTAMINANTS: Microscopic organisms present in untreated water that can cause waterborne diseases.
MICROBIOLOGICAL: Is a type of analysis in which a composite sample unacceptable.
MICROBODY: A small organelle, bounded by a single membrane and possessing a granular interior. Peroxisomes and glyoxysomes are types of microbodies.
MICROFILAMENT: Minute fibrous structure generally composed of actin found in the cytoplasm of eukaryotic cells. They play a role in motion within cells.
MICROFILTRATION: A low-pressure membrane filtration process that removes suspended solids and colloids generally larger than 0.1 micron diameter.
MICROORGANISMS: Very small animals and plants that are too small to be seen by the naked eye and must be observed using a microscope. Microorganisms in water include algae, bacteria, viruses, and protozoa. Algae growing in surface waters can cause off-taste and odor by producing the chemicals MIB and geosmin. Certain types of bacteria, viruses, and protozoa can cause disease in humans. Bacteria are the most common microorganisms found in treated drinking water. The great majority of bacteria are not harmful. In fact, humans would not be able to live without the bacteria that inhabit the intestines. However, certain types of bacteria called coliform bacteria can signal the presence of possible drinking water contamination.
MICROSCOPE: An instrument that magnifies images either by using lenses in an optical system to bend light (light microscope) or electromagnets to direct the movement of electrons (electron microscope).
MICROTUBULE: A minute tubular structure found in centrioles, spindle apparati, cilia, flagella, and other places in the cytoplasm of eukaryotic cells. Microtubules play a role in movement and maintenance of shape.
MICROVILLUS: Collectively, fine, fingerlike projections of the epithelial cells in the lumen of the small intestine that increase its surface area.
MILLIGRAMS PER LITER: (mg/L) A common unit of measurement of the concentration of a material in solution.
MILLILITER: One one-thousandth of a liter; A liter is a little more than a quart. A milliliter is about two drops from an eyedropper.
MIMICRY: A phenomenon in which one species benefits by a superficial resemblance to an unrelated species. A predator or species of prey may gain a significant advantage through mimicry.
MISCIBLE: Capable of being mixed together.
MISSENSE: (mutation) The most common type of mutation involving a base- pair substitution within a gene that changes a codon, but the new codon makes sense, in that it still codes for an amino acid.
MITOCHONDRIAL MATRIX: The compartment of the mitochondrion enclosed by the inner membrane and containing enzymes and substrates for the Krebs cycle.
MITOCHONDRION: An organelle that occurs in eukaryotic cells and contains the enzymes of the citric acid cycle, the respiratory chain, and oxidative phosphorylation. A mitochondrion is bounded by a double membrane.
MITOSIS: A process of cell division in eukaryotic cells conventionally divided into the growth period (interphase) and four stages: prophase, metaphase, anaphase, and telophase. The stages conserve chromosome number by equally allocating replicated chromosomes to each of the daughter cells.
MIXED LIQUOR SUSPENDED SOLIDS: Suspended solids in the mixture of wastewater and activated sludge undergoing aeration in the aeration basin.

MODEM SYNTHESIS: A comprehensive theory of evolution emphasizing natural selection, gradualism, and populations as the fundamental units of evolutionary change; also called Neo-Darwinism.
MOISTURE AND POTASSIUM PERMANGANATE: The combination of moisture and potassium permanganate produces heat.
MOISTURE: If a material is hygroscopic, it must it be protected from water.
MOLARITY: A common measure of solute concentration, referring to the number of moles of solute in 1 L of solution.
MOLD: A rapidly growing, asexually reproducing fungus.
MOLE: The number of grams of a substance that equals its molecular weight in daltons and contains Avogadro's number of molecules.
MOLECULAR FORMULA: A type of molecular notation indicating only the quantity of the constituent atoms.
MOLECULAR WEIGHT: The molecular mass (abbreviated Mr) of a substance, formerly also called molecular weight and abbreviated as MW, is the mass of one molecule of that substance, relative to the unified atomic mass unit u (equal to 1/12 the mass of one atom of carbon-12). This is distinct from the relative molecular mass of a molecule, which is the ratio of the mass of that molecule to 1/12 of the mass of carbon 12 and is a dimensionless number. Relative molecular mass is abbreviated to Mr.
MOLECULE: Two or more atoms of one or more elements held together by ionic or covalent chemical bonds.
MOLTING: A process in arthropods in which the exoskeleton is shed at intervals to allow growth by secretion of a larger exoskeleton.
MONERA: The kingdom of life forms that includes all of the bacteria.
MONOMER: A small molecule, two or more of which can be combined to form oligomers (consisting of a few monomers) or polymers (consisting of many monomers).
MONOPHYLETIC: A term used to describe any taxon derived from a single ancestral form that gave rise to no species in other taxa.
MONOSACCHARIDE: A simple sugar; a monomer.
MORPHOGENESIS: The development of body shape and organization during ontogeny.
MORPHOSPECIES: Species defined by their anatomical features.
MOSAIC: A pattern of development, such as that of a mollusk, in which the early blastomeres each give rise to a specific part of the embryo. In some animals, the fate of the blastomeres is established in the zygote.
MOTOR NERVOUS SYSTEM: In vertebrates, the component of the peripheral nervous system that transmits signals from the central nervous system to effector cells.
MPF: M: phase promoting factor: A protein complex required for a cell to progress from late interphase to mitosis; the active form consists of cyclin and cdc2, a protein kinase.
MUD BALLS IN FILTER MEDIA: Is a possible result of an ineffective or inadequate filter backwash.
MULLERIAN MIMICRY: A mutual mimicry by two unpalatable species.
MULTIGENE FAMILY: A collection of genes with similar or identical sequences, presumably of common origin.
MUNICIPAL WASTE: The combined solid and liquid waste from residential, commercial and industrial sources.
MUNICIPAL WASTEWATER TREATMENT PLANT (MWTP): Treatment works designed to treat municipal wastewater.
MURIATIC ACID: An acid used to reduce pH and alkalinity. Also used to remove stain and scale.
MUST: This action, activity, or procedural step is required.
MUTAGEN: A chemical or physical agent that interacts with DNA and causes a mutation.
MUTAGENESIS: The creation of mutations.
MUTATION: A spontaneous or induced change in a gene's or chromosome's structure or number. The resulting individual is termed a mutant.
MUTUALISM: A symbiotic relationship in which both the host and the symbiont benefit.
MYCELIUM: The densely branched network of hyphae in a fungus.
MYCOBACTERIUM: Pleomorphic spherical or rod-shaped, frequently branching, no gram stain, aerobic; commonly form yellow pigments; include Mycobacterium tuberculosis, cause of tuberculosis.
MYCOPLASMA: Spherical, commonly forming branching chains, no gram stain, aerobic but can live in certain anaerobic conditions; without cell walls yet structurally resistant to lysis; among smallest of bacteria; named for superficial resemblance to fungal hyphae (myco-means “fungus’).
MYELIN SHEATH: An insulating coat of cell membrane from Schwann cells that is interrupted by nodes of Ranvier where saltatory conduction occurs.
MYOFIBRILS: Fibrils arranged in longitudinal bundles in muscle cells (fibers); composed of thin filaments of actin and a regulatory protein and thick filaments of myosin.
MYOGLOBIN: An oxygen-storing, pigmented protein in muscle cells.
MYOSIN: A type of protein filament that interacts with actin filaments to cause cell movement, such as contraction in muscle cells.

N

NAD+: Nicatinamide adenine dinucleotide (oxidized); a coenzyme present in all cells that assists enzymes in transferring electrons during the redox reactions of metabolism.

NANO-FILTRATION: A specialty membrane filtration process that rejects solutes larger than approximately one nanometer (10 angstroms) in size.

NANOMETER: A unit of measure (length). 1 nm is equal to 1 x 10: 9 m, or 1/1,000,000 mm.

NaOCl: Is the molecular formula of Sodium hypochlorite.

NaOH: Is the molecular formula of Sodium hydroxide.

NATURAL ORGANIC MATTER: Organic matter present in natural waters.

NEGATIVE CONTROL: See Method blank.

NEGATIVE FEEDBACK: A primary mechanism of homeostasis, whereby a change in a physiological variable that is being monitored triggers a response that counteracts the initial fluctuation.

NEPHELOMETRIC TURBIDITY UNIT (NTU): The unit used to describe turbidity. Nephelometric refers to the way the instrument, a nephelometer, measures how much light is scattered by suspended particles in the water. The greater the scattering, the higher the turbidity. Therefore, low NTU values indicate high water clarity, while high NTU values indicate low water clarity.

NEURON: A nerve cell; the fundamental unit of the nervous system, having structure and properties that allow it to conduct signals by taking advantage of the electrical charge across its cell membrane.

NEUROSECRETORY CELLS: Cells that receive signals from other nerve cells, but instead of signaling to an adjacent nerve cell or muscle, release hormones into the blood stream.

NEUROTRANSMITTER: The chemical messenger released from the synaptic terminals of a neuron at a chemical synapse that diffuses across the synaptic cleft and binds to and stimulates the postsynaptic cell.

NEUTRAL VARIATION: Genetic diversity that confers no apparent selective advantage.

NEUTRALIZATION REACTIONS: Chemical reactions between acids and bases where water is an end product.

NEUTRALIZATION: The chemical process that produces a solution that is neither acidic nor alkaline. Usually with a pH between 6 and 8.

NEUTRON: An uncharged subatomic particle of about the same size and mass as a proton.

NH3: The molecular formula of Ammonia.

NH4+: The molecular formula of the Ammonium ion.

NITRATES: A dissolved form of nitrogen found in fertilizers and sewage by-products that may leach into groundwater and other water sources. Nitrates may also occur naturally in some waters. Over time, nitrates can accumulate in aquifers and contaminate groundwater.

NITROGEN AND PHOSPHORUS: Pairs of elements and major plant nutrients that cause algae to grow.

NITROGEN: Nitrogen is a nonmetal, with an electronegativity of 3.0. It has five electrons in its outer shell and is therefore trivalent in most compounds. The triple bond in molecular nitrogen (N2) is one of the strongest in nature. The resulting difficulty of converting (N_2) into other compounds, and the ease (and associated high-energy release) of converting nitrogen compounds into elemental N2, have dominated the role of nitrogen in both nature and human economic activities. At atmospheric pressure molecular nitrogen condenses (liquefies) at 77 K (-195.8 °C) and freezes at 63 K (-210.0 °C) into the beta hexagonal close-packed crystal allotropic form. Below 35.4 K (-237.6 °C) nitrogen assumes the alpha cubic crystal allotropic form. Liquid nitrogen, a fluid resembling water, but with 80.8% of the density, is a common cryogen. Unstable allotropes of nitrogen consisting of more than two nitrogen atoms have been produced in the laboratory, like N3 and N4.[1] Under extremely high pressures (1.1 million atm) and high temperatures (2000 K), as produced under diamond anvil conditions, nitrogen polymerizes into the single bonded diamond crystal structure, an allotrope nicknamed "nitrogen diamond."

NITROGEN-FIXING: Rod-shaped, gram-negative, aerobic; convert atmospheric nitrogen gas to ammonium in soil; include Azotobacter, a common genus.

NO3-: The molecular formula of the Nitrate ion.

NOMENCLATURE: The method of assigning names in the classification of organisms.

NON-CARBONATE HARDNESS: The portion of the total hardness in excess of the alkalinity.

NON-CARBONATE IONS: Water contains non-carbonate ions if it cannot be softened to a desired level through the use of lime only.

NONCOMPETITIVE INHIBITOR: A substance that reduces the activity of an enzyme by binding to a location remote from the active site, changing its conformation so that it no longer binds to the substrate.

NON-POINT SOURCE POLLUTION: Air pollution may leave contaminants on highway surfaces. This non-point source pollution adversely impacts reservoir water and groundwater quality.

NONPOLAR: Electrically symmetrical. For example, in many molecules with covalent bonds, the electrons are shared equally; the poles are electrically neutral.

NONSENSE MUTATION: A mutation that changes an amino acid codon to one of the three stop codons, resulting in a shorter and usually nonfunctional protein.

NORM OF REACTION: The range of phenotypic possibilities for a single genotype, as influenced by the environment.
NORMALITY: It is the number of equivalent weights of solute per liter of solution. Normality highlights the chemical nature of salts: in solution, salts dissociate into distinct reactive species (ions such as H+, Fe3+, or Cl-). Normality accounts for any discrepancy between the concentrations of the various ionic species in a solution. For example, in a salt such as MgCl2, there are two moles of Cl- for every mole of Mg2+, so the concentration of Cl- as well as of Mg2+ is said to be 2 N (read: "two normal"). Further examples are given below. A normal is one gram equivalent of a solute per liter of solution. The definition of a gram equivalent varies depending on the type of chemical reaction that is discussed - it can refer to acids, bases, redox species, and ions that will precipitate. It is critical to note that normality measures a single ion which takes part in an overall solute.
NTU: (Nephelometric turbidity unit)**:** A measure of the clarity or cloudiness of water.
NUCLEAR: 1) (envelope) The surface, consisting of two layers of membrane, that encloses the nucleus of eukaryotic cells. 2) (pore) An opening of the nuclear envelope which allows for the movement of materials between the nucleus and surrounding cytoplasm.
NUCLEIC: (acid) A polymer composed of nucleotides that are joined by covalent bonds (phosphodiester linkages) between the phosphate of one nucleotide and the sugar of the next nucleotide.
NUCLELUS: A small, generally spherical body found within the nucleus of eukaryotic cells. The site of ribosomal RNA synthesis.
NUCLEOID: The region that harbors the chromosome of a prokaryotic cell. Unlike the eukaryotic nucleus, it is not bounded by a membrane.
NUCLEOLUS (pl. nucleoli): A specialized structure in the nucleus, formed from various chromosomes and active in the synthesis of ribosomes.
NUCLEOSIDE: An organic molecule consisting of a nitrogenous base joined to a five- carbon sugar.
NUCLEOSOME: The basic, beadlike unit of DNA packaging in eukaryotes, consisting of a segment of DNA wound around a protein core composed of two copies of each of four types of histone.
NUCLEOTIDE: The basic chemical unit (monomer) of a nucleic acid. A nucleotide in RNA consists of one of four nitrogenous bases linked to ribose, which in turn is linked to phosphate. In DNA, deoxyribose is present instead of ribose.
NUCLEUS: A membrane-bound organelle containing genetic material. Nuclei are a prominent internal structure seen both in *Cryptosporidium* oocysts and *Giardia* cysts. In *Cryptosporidium* oocysts, there is one nucleus per sporozoite. One to four nuclei can be seen in *Giardia* cysts.
NUCLEUS: The membrane bound organelle of eukaryotic cells that contains the cell's genetic material. Also the central region of an atom composed of protons and neutrons.
NULL: In the scientific method, the hypothesis which one attempts to falsify.

O

O_3: The molecular formula of ozone.
OLIGOTROPHIC: A reservoir that is nutrient-poor and contains little plant or animal life. An oligotrophic ecosystem or environment is one that offers little to sustain life. The term is commonly utilized to describe bodies of water or soils with very low nutrient levels. It derives etymologically from the Greek oligo (small, little, few) and trophe (nutrients, food). Oligotrophic environments are of special interest for the alternative energy sources and survival strategies upon which life could rely.
ONGOING PRECISION AND RECOVERY (OPR) STANDARD: A method blank spiked with known quantities of analytes. The OPR is analyzed exactly like a sample. Its purpose is to assure that the results produced by the laboratory remain within the limits specified in this method for precision and recovery.
OOCYST: The encysted zygote of some sporozoa; e.g., *Cryptosporidium*. The oocyst is a phase or form of the organism produced as a normal part of the life cycle of the organism. It is characterized by a thick and environmentally resistant outer wall.
ORGANIC MATTER: Substances containing carbon compounds, usually of animal or vegetable origin.
ORGANIC PRECURSORS: Natural or man-made compounds with chemical structures based upon carbon that, upon combination with chlorine, leading to trihalomethane formation.
ORGANIC: Relating to, or derived from, a living thing. A description of a substance that contains carbon atoms linked together by carbon-carbon bonds.
OSMOSIS: Osmosis is the process by which water moves across a semi permeable membrane from a low concentration solute to a high concentration solute to satisfy the pressure differences caused by the solute.
OXIDE: An oxide is a chemical compound containing at least one oxygen atom as well as at least one other element. Most of the Earth's crust consists of oxides. Oxides result when elements are oxidized by oxygen in air. Combustion of hydrocarbons affords the two principal oxides of carbon, carbon monoxide and carbon dioxide. Even materials that are considered to be pure elements often contain a coating of oxides. For example, aluminum foil has a thin skin of Al2O3 that protects the foil from further corrosion. Virtually all elements burn in an atmosphere of oxygen. In the presence of water and oxygen (or simply air), some elements - lithium, sodium, potassium, rubidium, caesium, strontium and barium - react rapidly, even

dangerously to give the hydroxides. In part for this reason, alkali and alkaline earth metals are not found in nature in their metallic, i.e., native, form. Caesium is so reactive with oxygen that it is used as a getter in vacuum tubes, and solutions of potassium and sodium, so called NaK are used to deoxygenate and dehydrate some organic solvents. The surface of most metals consists of oxides and hydroxides in the presence of air. A well-known example is aluminum foil, which is coated with a thin film of aluminum oxide that passivates the metal, slowing further corrosion. The aluminum oxide layer can be built to greater thickness by the process of electrolytic anodizing. Although solid magnesium and aluminum react slowly with oxygen at STP, they, like most metals, will burn in air, generating very high temperatures. As a consequence, finely divided powders of most metals can be dangerously explosive in air.

OXIDIZING: The process of breaking down organic wastes into simpler elemental forms or by products. Also used to separate combined chlorine and convert it into free chlorine.

OXYGEN DEFICIENT ENVIRONMENT: One of the most dangerous threats to an operator upon entering a manhole.

OZONE: Ozone or trioxygen (O3) is a triatomic molecule, consisting of three oxygen atoms. It is an allotrope of oxygen that is much less stable than the diatomic O2. Ground-level ozone is an air pollutant with harmful effects on the respiratory systems of animals. Ozone in the upper atmosphere filters potentially damaging ultraviolet light from reaching the Earth's surface. It is present in low concentrations throughout the Earth's atmosphere. It has many industrial and consumer applications. Ozone, the first allotrope of a chemical element to be recognized by science, was proposed as a distinct chemical compound by Christian Friedrich Schönbein in 1840, who named it after the Greek word for smell (ozein), from the peculiar odor in lightning storms. The formula for ozone, O3, was not determined until 1865 by Jacques-Louis Soret and confirmed by Schönbein in 1867.

P

PACKING: Material, usually of woven fiber, placed in rings around the shaft of a pump and used to control the leakage from the stuffing box.

PARAMECIUM: Paramecia are a group of unicellular ciliate protozoa formerly known as slipper animalcules from their slipper shape. They are commonly studied as a representative of the ciliate group. Simple cilia cover the body which allows the cell to move with a synchronous motion (like a caterpilla). There is also a deep oral groove containing inconspicuous compound oral cilia (as found in other peniculids) that is used to draw food inside. They generally feed upon bacteria and other small cells. Osmoregulation is carried out by a pair of contractile vacuoles, which actively expel water absorbed by osmosis from their surroundings. Paramecia are widespread in freshwater environments, and are especially common in scums. Paramecia are attracted by acidic conditions. Certain single-celled eukaryotes, such as Paramecium, are examples for exceptions to the universality of the genetic code (translation systems where a few codons differ from the standard ones).

PARTS PER MILLION (PPM): A common unit of measure used to express the number of parts of a substance contained within a million parts of a liquid, solid, or gas.

PASTEURIZATION: A process for killing pathogenic organisms by applying heat for a specific period of time.

PATHOGENS: Disease-causing pathogens; waterborne pathogens A pathogen may contaminate water and cause waterborne disease.

Pb: The chemical symbol of Lead.

PCE: abbr. perchloroethylene. Known also as perc or tetrachloroethylene, perchloroethylene is a clear, colorless liquid with a distinctive, somewhat ether-like odor. It is non-flammable, having no measurable flashpoint or flammable limits in air. Effective over a wide range of applications, perchloroethylene is supported by closed loop transfer systems, stabilizers and employee exposure monitoring.

pCi/L: Picocuries per liter A curie is the amount of radiation released by a set amount of a certain compound. A picocurie is one quadrillionth of a curie.

PEAK DEMAND: The maximum momentary load placed on a water treatment plant, pumping station or distribution system.

PERKINESIS: The aggregation resulting from random thermal motion of fluid molecules.

PERMEATE: The term for water which has passed through the membrane of a reverse osmosis unit. The liquid that passes through a membrane.

PERMISSIBLE EXPOSURE LIMIT (PEL or OSHA PEL): A legal limit in the United States for exposure of an employee to a substance or physical agent. For substances it is usually expressed in parts per million (ppm), or sometimes in milligrams per cubic meter (mg/m^3). Units of measure for physical agents such as noise are specific to the agent. Permissible Exposure Limits are established by the Occupational Safety and Health Administration (OSHA).

pH OF SATURATION: The ideal pH for perfect water balance in relation to a particular total alkalinity level and a particular calcium hardness level, at a particular temperature. The pH where the Langelier Index equals zero.

pH: A unit of measure which describes the degree of acidity or alkalinity of a solution. The pH scale runs from 0 to 14 with 7 being the mid-point or neutral. A pH of less than 7 is on the acid side of the scale with 0 as the

point of greatest acid activity. A pH of more than 7 is on the basic (alkaline) side of the scale with 14 as the point of greatest basic activity. The term pH is derived from “p”, the mathematical symbol of the negative logarithm, and “H”, the chemical symbol of Hydrogen. The definition of pH is the negative logarithm of the Hydrogen ion activity. $pH=-\log[H^+]$.

PHENOL RED: Chemical reagent used for testing pH in the range of 6.8 - 8.4.

PHENOLPHTHALEIN/TOTAL ALKALINITY: The relationship between the alkalinity constituent’s bicarbonate, carbonate, and hydroxide can be based on the P and T alkalinity measurement.

PHOSPHATE, NITRATE AND ORGANIC NITROGEN: Nutrients in a domestic water supply reservoir may cause water quality problems if they occur in moderate or large quantities.

PHYSICAL CHEMICAL TREATMENT: Treatment processes that are non-biological in nature.

PICOCURIE: A unit of radioactivity. "Pico" is a metric prefix that means one one-millionth of one one-millionth. A picocurie is one one-millionth of one one-millionth of a Curie. A Curie is that quantity of any radioactive substance that undergoes 37 billion nuclear disintegrations per second. Thus a picocurie is that quantity of any radioactive substance that undergoes 0.037 nuclear disintegrations per second.

PIEZOMETRIC SURFACE: See potentiometric surface.

PIN FLOC: Small flocculated particle size.

PLATE AND FRAME PRESS: A batch process dewatering device in which sludge is pumped under high pressure through a series of parallel plates, in which a chamber is created between the plates. Each plate is fitted with filter cloth and the solids are collected in the chambers and the water is filtered from the sludge.

POINT SOURCE DISCHARGE: A pipe, ditch, channel or other container from which pollutants may be discharged.

POLLUTANT: A substance, organism or energy form present in amounts that impair or threaten an ecosystem to the extent that its current or future uses are prevented.

POLLUTION: To make something unclean or impure. See Contaminated.

POLYMER: A type of chemical when combined with other types of coagulants aid in binding small suspended particles to larger particles to help in the settling and filtering processes. Chemical used for flocculation in dewatering. Also known as a "polyelectrolyte" which is a substance made of giant molecules formed by the union of simple smaller molecules.

POLYPHOSPHATES: Chemicals that may be added to remove low levels of iron and manganese.

PORE SPACE: The interstitial space between sediments and fractures that is capable of storing and transmitting water.

POROSITY: A factor representing a rock, soil, or formations percentage of open space available for the percolation and storage of groundwater.

POSITIVE CONTROL: See Ongoing precision and recovery standard.

POST TREATMENT: Treatment of finished water or wastewater to further enhance its quality.

POST-CHLORINE: Where the water is chlorinated to make sure it holds a residual in the distribution system.

POTABLE: Good water which is safe for drinking or cooking purposes. Non-Potable: A liquid or water that is not approved for drinking.

POTENTIAL ENERGY: The energy that a body has by virtue of its position or state enabling it to do work.

POWDERED ACTIVATED CARDON TREATMENT (PACT): A wastewater technology in which powdered activated carbon is added to an anaerobic or aerobic treatment system. The carbon in the biological treatment process acts as a "buffer" against the effects of toxic organics in the wastewater.

PPM: Abbreviation for parts per million.

PRE-CHLORINATION: The addition of chlorine before the filtration process will help:

PRE-CHLORINE: Where the raw water is dosed with a large concentration of chlorine.

PRECIPITATE: A solid that separates from a solution.

PRECIPTATION: The phenomenon that occurs when a substance held in solution passes out of solution into a solid form.

PRELIMINARY TREATMENT: Treatment steps including comminution, screening, grit removal, pre-aeration, and/or flow equalization that prepares wastewater influent for further treatment.

PRESSURE FILTER: Filter unit enclosed in a vessel that may be operated under pressure.

PRESSURE HEAD: The height of a column of water capable of being maintained by pressure. See also Total Head, Total Dynamic Head.

PRESSURE MEASUREMENT: Bourdon tube, Bellows gauge and Diaphragm are commonly used to measure pressure in waterworks systems. A Bellows-type sensor reacts to a change in pressure.

PRESSURE: Pressure is defined as force per unit area. It is usually more convenient to use pressure rather than force to describe the influences upon fluid behavior. The standard unit for pressure is the Pascal, which is a Newton per square meter. For an object sitting on a surface, the force pressing on the surface is the weight of the object, but in different orientations it might have a different area in contact with the surface and therefore exert a different pressure.

PREVENTION: To take action. Stop something before it happens.

PRIMARY CLARIFIER: Sedimentation basin that precedes secondary wastewater treatment.

PRIMARY SLUDGE: Sludge produced in a primary waste treatment unit.
PRIMARY TREATMENT: Treatment steps including sedimentation and/or fine screening to produce an effluent suitable for biological treatment.
PROCESS WASTEWATER: Wastewater generated during manufacture or production processes.
PROCESS WATER: Water that is used for, or comes in contact with an end product or the materials used in an end product.
PROPIONIC ACID: Rod-shaped, pleomorphic, gram-positive, anaerobic; ferment lactic acid; fermentation produces holes in Swiss cheese from the production of carbon dioxide.
PROTON, NEUTRON AND ELECTRON: Are the 3 fundamental particles of an atom.
PROTOZOA: Microscopic animals that occur as single cells. Some protozoa can cause disease in humans. Protozoa form cysts, which are specialized cells like eggs that are very resistant to chlorine. Cysts can survive the disinfection process, then "hatch" into normal cells that can cause disease. Protozoa must be removed from drinking water by filtration, because they cannot be effectively killed by chlorine.
PSEUDOMONAD: Rod-shaped (straight or curved) with polar flagella, gram-negative, aerobic; can use up to 100 different compounds for carbon and energy.
PTFE: Polytetrafluoroethylene.
PUMPING LIFT: The height to which water must be pumped or lifted to, feet of head.

Q

QUANTITATIVE TRANSFER: The process of transferring a solution from one container to another using a pipette in which as much solution as possible is transferred, followed by rinsing of the walls of the source container with a small volume of rinsing solution (e.g., reagent water, buffer, etc.), followed by transfer of the rinsing solution, followed by a second rinse and transfer.
QUICKLIME: A calcium oxide material produced by calcining limestone to liberate carbon dioxide, also called “calcined lime” or “pebble lime”, commonly used for pH adjustment. Chemical formula is CaO.
QUICKLIME: A calcium oxide material produced by calcining limestone to liberate carbon dioxide, also called “calcined lime” or “pebble lime”, commonly used for pH adjustment. Chemical formula is CaO.

R

RADON: A gas that can dissolve and accumulate in underground water sources, such as wells, and in the air in your home. Breathing radon can cause lung cancer. Drinking water containing radon presents a risk of developing cancer. Radon in air is more dangerous than radon in water.
RAW SEWAGE: Untreated wastewater and its contents.
RAW SLUDGE: Undigested sludge recently removed from a sedimentation basin.
RAW TURBIDITY: The turbidity of the water coming to the treatment plant from the raw water source.
RAW WATER: Untreated surface or groundwater.
REAGENT WATER BLANK: see Method blank.
REAGENT WATER: Water demonstrated to be free from the analytes of interest and potentially interfering substances at the method detection limit for the analyte.
REAGENT: A substance used in a chemical reaction to measure, detect, examine, or produce other substances.
RECLAIMED WATER: Wastewater that has been treated to a level that allows for its reuse for a beneficial purpose.
RECLAMATION: The process of improving or restoring the condition of land or other material to a better or more useful state.
RECOMMENDED EXPOSURE LIMIT (REL): An occupational exposure limit that has been recommended by the U.S. National Institute for Occupational Safety and Health to OSHA for adoption as a Permissible Exposure Limit. The REL is a level that NIOSH believes would be protective of worker safety and health over a working lifetime if used in combination with engineering and work practice controls, exposure and medical monitoring, posting and labeling of hazards, worker training and personal protective equipment. No REL has ever been adopted by OSHA, but they have been used as guides by some industry and advocacy organizations.
RECYCLING: The process by which recovered materials are transformed into new products.
REDOX POTENTIAL: Reduction potential (also known as redox potential, oxidation / reduction potential or ORP) is the tendency of a chemical species to acquire electrons and thereby be reduced. Each species has its own intrinsic reduction potential; the more positive the potential, the greater the species' affinity for electrons and tendency to be reduced. In aqueous solutions, the reduction potential is the tendency of the solution to either gain or lose electrons when it is subject to change by introduction of a new species. A solution with a higher (more positive) reduction potential than the new species will have a tendency to gain electrons from the new species (i.e. to be reduced by oxidizing the new species) and a solution with a lower (more negative) reduction potential will have a tendency to lose electrons to the new species (i.e. to be oxidized by reducing the new species). Just as the transfer of hydrogen ions between chemical species determines the pH of an aqueous solution, the transfer of electrons between chemical species determines the reduction potential of an aqueous solution. Like pH, the reduction potential represents an intensity factor. It does not characterize the

capacity of the system for oxidation or reduction, in much the same way that pH does not characterize the buffering capacity.
RELATIVE STANDARD DEVIATION (RSD): The standard deviation divided by the mean times 100.
RELAY LOGIC: The name of a popular method of automatically controlling a pump, valve, chemical feeder, and other devices.
RESERVOIR: An impoundment used to store water.
RESIDENCE TIME: The period of time that a volume of liquid remains in a tank or system.
RESPIRATION: Intake of oxygen and discharge of carbon dioxide as a result of biological oxidation.
RETURN ACTIVATED SLUDGE: Settled activated sludge that is returned to mix with raw or primary settled wastewater.
RICKETTSIA: Spherical or rod-shaped, gram-negative, aerobic; cause Rocky Mountain spotted fever and typhus; closely related to Agrobacterium, a common gall-causing plant bacterium.
ROBERT HOOKE: Coined the term "cell" to describe the structures he saw while examining a piece of cork using a microscope.
ROTARY DRUM SCREEN: Cylindrical screen used to remove floatable and suspended solids.
ROTIFER: Rotifers get their name (derived from Greek and meaning "wheel-bearer"; they have also been called wheel animalcules) from the corona, which is composed of several ciliated tufts around the mouth that in motion resemble a wheel. These create a current that sweeps food into the mouth, where it is chewed up by a characteristic pharynx (called the mastax) containing a tiny, calcified, jaw-like structure called the trophi. The cilia also pull the animal, when unattached, through the water. Most free-living forms have pairs of posterior toes to anchor themselves while feeding. Rotifers have bilateral symmetry and a variety of different shapes. There is a well-developed cuticle which may be thick and rigid, giving the animal a box-like shape, or flexible, giving the animal a worm-like shape; such rotifers are respectively called loricate and illoricate.

S

SANITARY SURVEY: Persons trained in public health engineering and the epidemiology of waterborne diseases should conduct the sanitary survey. The importance of a detailed sanitary survey of a new water source cannot be overemphasized. An on-site review of the water sources, facilities, equipment, operation, and maintenance of a public water systems for the purpose of evaluating the adequacy of the facilities for producing and distributing safe drinking water. The purpose of a non-regulatory sanitary survey is to identify possible biological and chemical pollutants which might affect a water supply.
SANITIZER: A disinfectant or chemical which disinfects (kills bacteria), kills algae and oxidizes organic matter.
SATURATED ZONE: Where an unconfined aquifer becomes saturated beneath the capillary fringe.
SATURATION INDEX: See Langelier's Index.
SATURATOR: A device which produces a fluoride solution for the fluoride process. Crystal-grade types of sodium fluoride should be fed with a saturator. Overfeeding must be prevented to protect public health when using a fluoridation system.
SCADA: A remote method of monitoring pumps and equipment. 130 degrees F is the maximum temperature that transmitting equipment is able to with stand. If the level controller may be set with too close a tolerance 45 could be the cause of a control system that is frequently turning a pump on and off.
SCALE: Crust of calcium carbonate, the result of unbalanced water. Hard insoluble minerals deposited (usually calcium bicarbonate) which forms on pool and spa surfaces and clog filters, heaters and pumps. Scale is caused by high calcium hardness and/or high pH. The regular use of stain prevention chemicals can prevent scale.
SCREENINGS PRESS: A mechanical press used to compact and/or dewater material removed from mechanical screening equipment.
SCROLL AND BASKET: The two basic types of centrifuges used in water treatment.
SCRUBBER: A device used to removal particulates or pollutant gases from combustion or chemical process exhaust streams.
SCUM: Floatable materials found on the surface of primary and secondary settling tanks consisting of food wastes, grease, fats, paper, foam, and similar matter.
SECONDARY CLARIFIER: A clarifier following a secondary treatment process, designed for gravity removal of suspended matter.
SECONDARY SLUDGE: The sludge from the secondary clarifier in a wastewater treatment plant.
SECONDARY TREATMENT: The treatment of wastewater through biological oxidation after primary treatment.
SEDIMENT: Grains of soil, sand, gravel, or rock deposited by and generated by water movement.
SEDIMENTATION BASIN: A quiescent tank used to remove suspended solids by gravity settling. Also called clarifiers or settling tanks, they are usually equipped with a motor driven rake mechanism to collect settled sludge and move it to a central discharge point.

SEDIMENTATION BASIN: Where the thickest and greatest concentration of sludge will be found. Twice a year sedimentation tanks should be drained and cleaned if the sludge buildup interferes with the treatment process.
SEDIMENTATION: The process of suspended solid particles settling out (going to the bottom of the vessel) in water.
SEDIMENTATION: The removal of settleable suspended solids from water or wastewater by gravity in a quiescent basin or clarifier.
SENSOR: A float and cable system are commonly found instruments that may be used as a sensor to control the level of liquid in a tank or basin.
SEPTIC: Condition characterized by bacterial decomposition under anaerobic conditions.
SETTLEABILITY: The tendency of suspended solids to settle.
SETTLEABLE SOLIDS: That portion of suspended solids which are of a sufficient size and weight to settle to the bottom of an Imhoff cone in one hour.
SETTLED SLUDGE VOLUME: Volume of settled sludge measured at predetermined time increments for use in process control calculations.
SETTLED SOLIDS: Solids that have been removed from the raw water by the coagulation and settling processes.
SEWAGE: Liquid or waterborne wastes polluted or fouled from households, commercial or industrial operations, along with any surface water, storm water or groundwater infiltration.
SEWER GAS: A gas mixture produced by anaerobic decomposition of organic matter usually containing high percentages of methane and hydrogen sulfide.
SHEATHED: Filamentous, gram-negative, aerobic; “swarmer” (colonizing) cells form and break out of a sheath; sometimes coated with metals from environment.
SHOCK LOAD: A sudden hydraulic or organic load to a treatment plant, also descriptive of a change in the material being treated.
SHOCK: Also known as superchlorination or break point chlorination. Ridding a water of organic waste through oxidization by the addition of significant quantities of a halogen.
SHORT-CIRCUITING: Short Circuiting is a condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable since it may result in shorter contact, reaction or settling times in comparison with the presumed detention times.
SHOULD: This action, activity, or procedural step is suggested but not required.
SINGLE PHASE POWER: The type of power used for lighting systems, small motors, appliances, portable power tools and in homes.
SLOP OIL: Separator skimmings and tramp oil generated during refinery startup, shutdown or abnormal operation.
SLUDGE BASINS: After cleaning sludge basins and before returning the tanks into service the tanks should be inspected, repaired if necessary, and disinfected.
SLUDGE BLANKET: The accumulated sludge suspended in a clarifier or other enclosed body of water.
SLUDGE DEWATERING: The removal of a portion or majority of the water contained in sludge by means of a filter press, centrifuge or other mechanism.
SLUDGE DRYING BED: A closed area consisting of sand or other porous material upon which sludge is dewatered by gravity drainage and evaporation.
SLUDGE REDUCTION: Organic polymers are used to reduce the quantity of sludge. If a plant produces a large volume of sludge, the sludge could be dewatered, thickened, or conditioned to decrease the volume of sludge. Turbidity of source water, dosage, and type of coagulant used are the most important factors which determine the amount of sludge produced in a treatment of water.
SLUDGE: Accumulated and concentrated solids generated within a treatment process that have not undergone a stabilization process.
SLURRY: A mixture of a solid and a liquid that facilitates the transfer of the solid into a treatment solution.
SOC: A common way for a synthetic organic chemical such as dioxin to be introduced to a surface water supply is from an industrial discharge, agricultural drainage, or a spill.
SODA ASH: Chemical used to raise pH and total alkalinity (sodium carbonate)
SODIUM BICARBONATE: Commonly used to increase alkalinity of water and stabilize pH.
SODIUM BISULFATE: Chemical used to lower pH and total alkalinity (dry acid).
SODIUM HYDROXIDE: Also known as caustic soda, a by-product chlorine generation and often used to raise pH.
SOFTENING WATER: When the water has a low alkalinity, it is advantageous to use soda ash instead of caustic soda for softening water.
SOFTENING: The process that removes the ions which cause hardness in water.
SOLID WASTE: Garbage, refuse, sludge and other discarded material resulting from community activities or commercial or industrial operations.
SOLID, LIQUID AND VAPOR: 3 forms of matter.

SOLUBILITY: The amount of a substance that can dissolve in a solution under a given set of conditions.
SPADNS: The lab reagent called SPADNS solution is used in performing the Fluoride test.
SPIKING SUSPENSION: Diluted stock suspension containing the organism(s) of interest at a concentration appropriate for spiking samples.
SPIRILLUM: Spiral-shaped, gram-negative, aerobic; include Bdellovibrio, predatory on other bacteria.
SPIROCHETE: Spiral-shaped, gram-negative, mostly anaerobic; common in moist environments, from mammalian gums to coastal mudflats; complex internal structures convey rapid movement; include *Treponemapallidum,* cause of syphilis.
SPOROZOITE: A motile, infective stage of certain protozoans; e.g., *Cryptosporidium*. There are four sporozoites in each *Cryptosporidium* oocyst, and they are generally banana-shaped.
SPRAY BOTTLE OF AMMONIA: An operator should use ammonia to test for a chlorine leak around a valve or pipe. You will see white smoke if there is a leak.
SPRING PRESSURE: Is what maintains contact between the two surfaces of a mechanical seal.
STABILIZATION POND: A large shallow basin used for wastewater treatment by natural processes involving the use of algae and bacteria to accomplish biological oxidation of organic matter.
STERILIZED GLASSWARE: The only type of glassware that should be used in testing for coliform bacteria.
STOCK SUSPENSION: A concentrated suspension containing the organism(s) of interest that is obtained from a source that will attest to the host source, purity, authenticity, and viability of the organism(s).
STUFFING BOX: That portion of the pump that houses the packing or mechanical seal.
SUBNATANT: Liquid remaining beneath the surface of floating solids.
SUCCESSION: Transition in the species composition of a biological community, often following ecological disturbance of the community; the establishment of a biological community in an area virtually barren of life.
SULFATE- AND SULFUR- REDUCING: Commonly rod-shaped, mostly gram-negative, anaerobic; include *Desulfovibrio,* ecologically important in marshes.
SULFIDE: The term sulfide refers to several types of chemical compounds containing sulfur in its lowest oxidation number of -2. Formally, "sulfide" is the dianion, S2-, which exists in strongly alkaline aqueous solutions formed from H2S or alkali metal salts such as Li2S, Na2S, and K2S. Sulfide is exceptionally basic and, with a pKa > 14, it does not exist in appreciable concentrations even in highly alkaline water, being undetectable at pH < ~15 (8 M NaOH). Instead, sulfide combines with electrons in hydrogen to form HS, which is variously called hydrogen sulfide ion, hydrosulfide ion, sulfhydryl ion, or bisulfide ion. At still lower pH's (<7), HS- converts to H2S, hydrogen sulfide. Thus, the exact sulfur species obtained upon dissolving sulfide salts depends on the pH of the final solution. Aqueous solutions of transition metals cations react with sulfide sources (H2S, NaSH, Na2S) to precipitate solid sulfides. Such inorganic sulfides typically have very low solubility in water and many are related to minerals. One famous example is the bright yellow species CdS or "cadmium yellow". The black tarnish formed on sterling silver is Ag2S. Such species are sometimes referred to as salts. In fact, the bonding in transition metal sulfides is highly covalent, which gives rise to their semiconductor properties, which in turn is related to the practical applications of many sulfide materials.
SULFUR- AND IRON- OXIDIZING: Commonly rod-shaped, frequently with polar flagella, gram-negative, mostly anaerobic; most live in neutral (nonacidic) environment.
SUPERNATANT: The liquid layer which forms above the sludge in a settling basin.
SURFACE SEAL: The upper portion of a wells construction where surface contaminants are adequately prevented from entering the well, normally consisting of surface casing and neat cement grout.
SURFACTANT: Surfactants reduce the surface tension of water by adsorbing at the liquid-gas interface. They also reduce the interfacial tension between oil and water by adsorbing at the liquid-liquid interface. Many surfactants can also assemble in the bulk solution into aggregates. Examples of such aggregates are vesicles and micelles. The concentration at which surfactants begin to form micelles is known as the critical micelle concentration or CMC. When micelles form in water, their tails form a core that can encapsulate an oil droplet, and their (ionic/polar) heads form an outer shell that maintains favorable contact with water. When surfactants assemble in oil, the aggregate is referred to as a reverse micelle. In a reverse micelle, the heads are in the core and the tails maintain favorable contact with oil. Surfactants are also often classified into four primary groups; anionic, cationic, non-ionic, and zwitterionic (dual charge).
SUSPENDED SOLIDS: Solids captured by filtration through a 0.45 micron filter membrane.

T

TCE, *trichloroethylene:* A solvent and degreaser used for many purposes; for example dry cleaning, it is a common groundwater contaminant. Trichloroethylene is a colorless liquid which is used as a solvent for cleaning metal parts. Drinking or breathing high levels of trichloroethylene may cause nervous system effects, liver and lung damage, abnormal heartbeat, coma, and possibly death. Trichloroethylene has been found in at least 852 of the 1,430 National Priorities List sites identified by the Environmental Protection Agency (EPA).
TDS-TOTAL DISSOLVED SOLIDS: An expression for the combined content of all inorganic and organic substances contained in a liquid which are present in a molecular, ionized or micro-granular (colloidal sol) suspended form. Generally, the operational definition is that the solids (often abbreviated TDS) must be small

enough to survive filtration through a sieve size of two micrometers. Total dissolved solids are normally only discussed for freshwater systems, since salinity comprises some of the ions constituting the definition of TDS. The principal application of TDS is in the study of water quality for streams, rivers and lakes, although TDS is generally considered not as a primary pollutant (e.g. it is not deemed to be associated with health effects), but it is rather used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of presence of a broad array of chemical contaminants.

TELEMETERING: The use of a transmission line with remote signaling to monitor a pumping station or motors. Can be used to accomplish accurate and reliable remote monitoring and control over a long distribution system.

TEMPERATURE SAMPLE: This test should be performed immediately in the field, a grab sample.

TERTIARY TREATMENT: The use of physical, chemical, or biological means to improve secondary wastewater effluent quality.

The addition of chlorine to the water prior to any other plant treatment processes.

THE RATE DECREASES: In general, when the temperature decreases, the chemical reaction rate decreases also.

THICKENING, CONDITIONING AND DEWATERING: Common processes that are utilized to reduce the volume of sludge.

THICKENING: A procedure used to increase the solids content of sludge by removing a portion of the liquid.

TIME FOR TURBIDITY BREAKTHROUGH AND MAXIMUM HEADLOSS: Are the two factors which determine whether or not a change in filter media size should be made.

TITRATION: A method of testing by adding a reagent of known strength to a water sample until a specific color change indicates the completion of the reaction.

TOTAL ALKALINITY: A measure of the acid-neutralizing capacity of water which indicates its buffering ability, i.e. measure of its resistance to a change in pH. Generally, the higher the total alkalinity, the greater the resistance to pH change.

TOTAL COLIFORM: Total coliform, fecal coliform, and E. coli are all indicators of drinking water quality. The total coliform group is a large collection of different kinds of bacteria. Fecal coliforms are types of total coliform that mostly exist in feces. E. coli is a sub-group of fecal coliform. When a water sample is sent to a lab, it is tested for total coliform. If total coliform is present, the sample will also be tested for either fecal coliform or E. coli, depending on the lab testing method.

TOTAL DISSOLVED SOLIDS (TDS): The accumulated total of all solids that might be dissolved in water. The weight per unit volume of all volatile and non-volatile solids dissolved in a water or wastewater after a sample has been filtered to remove colloidal and suspended solids.

TOTAL DYNAMIC HEAD: The pressure (psi) or equivalent feet of water, required for a pump to lift water to its point of storage overcoming elevation head, friction loss, line pressure, drawdown and pumping lift.

TOTAL SOLIDS: The sum of dissolved and suspended solids in a water or wastewater.

TOTAL SUSPENDED SOLIDS: The measure of particulate matter suspended in a sample of water or wastewater.

TOXIC: Capable of causing an adverse effect on biological tissue following physical contact or absorption.

TRANSIENT, NON-COMMUNITY WATER SYSTEM: TNCWS A water system which provides water in a place such as a gas station or campground where people do not remain for long periods of time. These systems do not have to test or treat their water for contaminants which pose long-term health risks because fewer than 25 people drink the water over a long period. They still must test their water for microbes and several chemicals. A Transient Non-community Water System: Is not required to sample for VOC's.

TREATABILITY STUDY: A study in which a waste is subjected to a treatment process to determine treatment and/or to determine the treatment efficiency or optimal process conditions for treatment.

TRIHALOMETHANES (THM): Four separate compounds including chloroform, dichlorobromomethane, dibromochloromethane, and bromoform. The most common class of disinfection by-products created when chemical disinfectants react with organic matter in water during the disinfection process. See Disinfectant Byproducts.

TUBE SETTLERS: This modification of the conventional process contains many metal tubes that are placed in the sedimentation basin, or clarifier. These tubes are approximately 1 inch deep and 36 inches long, split-hexagonal shape and installed at an angle of 60 degrees or less. These tubes provide for a very large surface area upon which particles may settle as the water flows upward. The slope of the tubes facilitates gravity settling of the solids to the bottom of the basin, where they can be collected and removed. The large surface settling area also means that adequate clarification can be obtained with detention times of 15 minutes or less. As with conventional treatment, this sedimentation step is followed by filtration through mixed media.

TUBERCLES: The creation of this condition is of the most concern regarding corrosive water effects on a water system. Tubercles are formed due to joining dissimilar metals, causing electro-chemical reactions. Like iron to copper pipe. We have all seen these little rust mounds inside cast iron pipe.

TURBIDIMETER: Monitoring the filter effluent turbidity on a continuous basis with an in-line instrument is a recommended practice. Turbidimeter is best suited to perform this measurement.
TURBIDITY: A measure of the cloudiness of water caused by suspended particles. A qualitative measurement of water clarity which results from suspended matter that scatters or otherwise interferes with the passage of light through the water.
TURBIDITY: Turbidity can interfere with disinfection and provide a medium for microbial growth. Turbidity may indicate the presence of disease causing organisms. These organisms include bacteria, viruses, and parasites that can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.
U
U.S. ENVIRONMENTAL PROTECTION AGENCY: In the United States, this agency responsible for setting drinking water standards and for ensuring their enforcement. This agency sets federal regulations which all state and local agencies must enforce.
ULTRAFILTRATION: A low pressure membrane filtration process which separates solutes up to 0.1 micron size range.
UNDER PRESSURE IN STEEL CONTAINERS: After chlorine gas is manufactured, it is primarily transported in steel containers.
UP FLOW CLARIFIER: Clarifier where flocculated water flows upward through a sludge blanket to obtain floc removal by contact with flocculated solids in the blanket.
V
VANE: That portion of an impeller that throws the water toward the volute.
VAPOR: The gaseous phase of a material that is in the solid or liquid state at standard temperature and pressure.
VARIABLE DISPLACEMENT PUMP: A pump that will produce different volumes of water dependent on the pressure head against it.
VELOCITY HEAD: The vertical distance a liquid must fall to acquire the velocity with which it flows through the piping system. For a given quantity of flow, the velocity head will vary indirectly as the pipe diameter varies.
VENTURI: If water flows through a pipeline at a high velocity, the pressure in the pipeline is reduced. Velocities can be increased to a point that a partial vacuum is created.
VERTICAL TURBINE: A type of variable displacement pump in which the motor or drive head is mounted on the wellhead and rotates a drive shaft connected to the pump impellers.
VIBRIO: Rod- or comma-shaped, gram-negative, aerobic; commonly with a single flagellum; include *Vibrio cholerae,* cause of cholera, and luminescent forms symbiotic with deep-water fishes and squids.
VIRUSES: Very small disease-causing microorganisms that are too small to be seen even with microscopes. Viruses cannot multiply or produce disease outside of a living cell.
VIRUSES: are very small disease-causing microorganisms that are too small to be seen even with microscopes. Viruses cannot multiply or produce disease outside of a living cell.
VITRIFICATION: Vitrification is a process of converting a material into a glass-like amorphous solid that is free from any crystalline structure, either by the quick removal or addition of heat, or by mixing with an additive. Solidification of a vitreous solid occurs at the glass transition temperature (which is lower than melting temperature, Tm, due to supercooling). When the starting material is solid, vitrification usually involves heating the substances to very high temperatures. Many ceramics are produced in such a manner. Vitrification may also occur naturally when lightning strikes sand, where the extreme and immediate heat can create hollow, branching rootlike structures of glass, called fulgurite. When applied to whiteware ceramics, vitreous means the material has an extremely low permeability to liquids, often but not always water, when determined by a specified test regime. The microstructure of whiteware ceramics frequently contain both amorphous and crystalline phases.
VOID: An opening, gap, or space within rock or sedimentary formations formed at the time of origin or deposition.
VOLATILE ORGANIC COMPOUNDS (VOCs): Solvents used as degreasers or cleaning agents. Improper disposal of VOCs can lead to contamination of natural waters. VOCs tend to evaporate very easily. This characteristic gives VOCs very distinct chemical odors like gasoline, kerosene, lighter fluid, or dry cleaning fluid. Some VOCs are suspected cancer-causing agents. Volatile organic compounds (VOCs) are organic chemical compounds that have high enough vapor pressures under normal conditions to significantly vaporize and enter the atmosphere. A wide range of carbon-based molecules, such as aldehydes, ketones, and other light hydrocarbons are VOCs. The term often is used in a legal or regulatory context and in such cases the precise definition is a matter of law. These definitions can be contradictory and may contain "loopholes"; e.g. exceptions, exemptions, and exclusions. The United States Environmental Protection Agency defines a VOC as any organic compound that participates in a photoreaction; others believe this definition is very broad and vague as organics that are not volatile in the sense that they vaporize under normal conditions can be considered volatile by this EPA definition. The term may refer both to well characterized organic compounds and to mixtures of variable composition.

VOLATILE: A substance that evaporates or vaporizes at a relatively low temperature.
VOLTAGE: Voltage (sometimes also called electric or electrical tension) is the difference of electrical potential between two points of an electrical or electronic circuit, expressed in volts.[1] It measures the potential energy of an electric field to cause an electric current in an electrical conductor. Depending on the difference of electrical potential it is called extra low voltage, low voltage, high voltage or extra high voltage. Specifically Voltage is equal to energy per unit charge.
VOLUTE: The spiral-shaped casing surrounding a pump impeller that collects the liquid discharge by the impeller.
VORTEX: The helical swirling of water moving towards a pump.
VORTICELLA: Vorticella is a genus of protozoa, with over 100 known species. They are stalked inverted bell-shaped ciliates, placed among the peritrichs. Each cell has a separate stalk anchored onto the substrate, which contains a contracile fibril called a myoneme. When stimulated this shortens, causing the stalk to coil like a spring. Reproduction is by budding, where the cell undergoes longitudinal fission and only one daughter keeps the stalk. Vorticella mainly lives in freshwater ponds and streams - generally anywhere protists are plentiful. Other genera such as Carchesium resemble Vorticella but are branched or colonial.
VULNERABILITY ASSESSMENT: An evaluation of drinking water source quality and its vulnerability to contamination by pathogens and toxic chemicals.

W

WAIVERS: Monitoring waivers for nitrate and nitrite are prohibited.
WASTE ACTIVATED SLUDGE: Excess activated sludge that is discharged from an activated sludge treatment process.
WASTEWATER: Liquid or waterborne wastes polluted or fouled from households, commercial or industrial operations, along with any surface water, storm water or groundwater infiltration.
WATER HAMMER: A surge in a pipeline resulting from the rapid increase or decrease in water flow. Water hammer exerts tremendous force on a system and can be highly destructive.
WATER QUALITY CRITERIA: Comprised of both numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or States for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal.
WATER QUALITY STANDARD: A statute or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.
WATER RECLAMATION: The restoration of wastewater to a state that will allow its beneficial reuse.
WATERBORNE DISEASE: A disease, caused by a virus, bacterium, protozoan, or other microorganism, capable of being transmitted by water (e.g., typhoid fever, cholera, amoebic dysentery, gastroenteritis).
WHOLE EFFLUENT TOXICITY: The total toxic effect of an effluent measured directly with a toxicity test.
WPCF: Water Pollution Control Facility
WTP: Water Treatment Plant
WWTP: Wastewater Treatment Plant

Z

ZERO DISCHARGE: A facility that discharges no liquid effluent to the environment.

Post Quiz Answers

Topic 1 - Wastewater Treatment Introduction
1. True, 2. False, 3. True, 4. False, 5. False, 6. True, 7. False, 8. True, 9. False, 10. False, 11. False, 12. True, 13. True, 14. True, 15. False

Topic 2 – Primary Wastewater Treatment Section Post Quiz
1. BOD and COD, 2. Suspended solids, 3. Natural self-purification, 4. Primary treatment, 5. Coarse solids, 6. Two basic stages, 7. Biological processes, 8. Solid matter, 9. Second clarification process, 10. Quiescent (or calm) conditions, 11. 77 to 95, 12. Biological treatment activity, 13. Wastewater temperature, 14. Aquatic life, 15. The acidity or alkalinity, 16. Low pH

Topic 3 Secondary Treatment Section Post Quiz
1. BOD, 2. Heterotrophic, 3. Aerobic BOD, 4. Phosphorus, 5. Biodegradable organics 6. Complete mix systems, 7. Trickling filter, 8. Anaerobic methane, 9. Heterotrophic bacteria, 10. SRT leading, 11. Municipal biosolids, 12. 4 to 30 days, 13. Phosphorus, 14. Anaerobic conditions, 15. Anaerobic digestion

Topic 4 - Activated Sludge Process Section Post Quiz
1. True, 2. False, 3. False, 4. True, 5. True, 6. True, 7. True, 8. True, 9. False, 10. False, 11. False, 12. False, 13. True, 14. True, 15. True

Topic 5- Advanced Treatment Section Post Quiz
1. A filtration membrane, 2. Membrane separation processes, 3. Membrane technology, 4. Ultra/microfiltration, 5. High-molecular-weight materials, 6. Simultaneous concentration, 7. Pore dimensions, 8. Ion exchangers, 9. Nanofiltration, 10. Ultrafiltration, 11. Measurable pressure, 12. Salt water source, 13. The concentrate, 14. Required product water quality, 15. Sugars, 16. Charged particles, 17. Inorganic dead dirt minerals

Topic 6 – Nutrient Section Post Quiz
1. Soil conditions, 2. Fixed-film systems (FFSs), 3. Nitrified effluent, 4. BOD and TSS, 5. Treated water, 6. Recirculation rates, 7. Aeration, 8. SBR process, 9. Package plant SBRs, 10. Sand filters, 11. Most suspended solids, 12. Characteristics of the media, 13. Subsurface infiltration onsite, 14. Sand, gravel, or other media, 15. Wetland systems

Topic 7- Wastewater Microbiology Section Post Quiz
1. True, 2. False, 3. True, 4. False, 5. True, 6. True, 7. True, 8. False, 9. False, 10. False, 11. False, 12. True, 13. True, 14. False, 15. False, 16. True, 17. True, 18. True, 19. False, 20. False

Topic 8 -Wastewater Sampling Section
1. False, 2. True, 3. False, 4. True, 5. True, 6. False, 7. False, 8. True, 9. False, 10. True, 11. False, 12. True, 13. False, 14. True, 15. False

Topic 9- Laboratory Analysis/ Process Control Section Post Quiz
1. Primary pH standard values, 2. 7, 3. Hydronium ion concentration, 4. Measurement of pH, 5. A dimensionless quantity, 6. Alkalinity, 7. Hydrogen ion activity, 8. Acid, 9. Visual comparison, 10. Nature of the solution, 11. The concentration value, 12. End-point pH, 13. Solution of a cubic equation, 14. An aggregate property of water, 15. Colorimeter of spectrophotometer, 16. The solution of a quadratic equation, 17. Chemical speciation, 18. Alkalinity, 19. Strong acids and bases

Topic 10 - Chlorine Section Post Quiz Answers

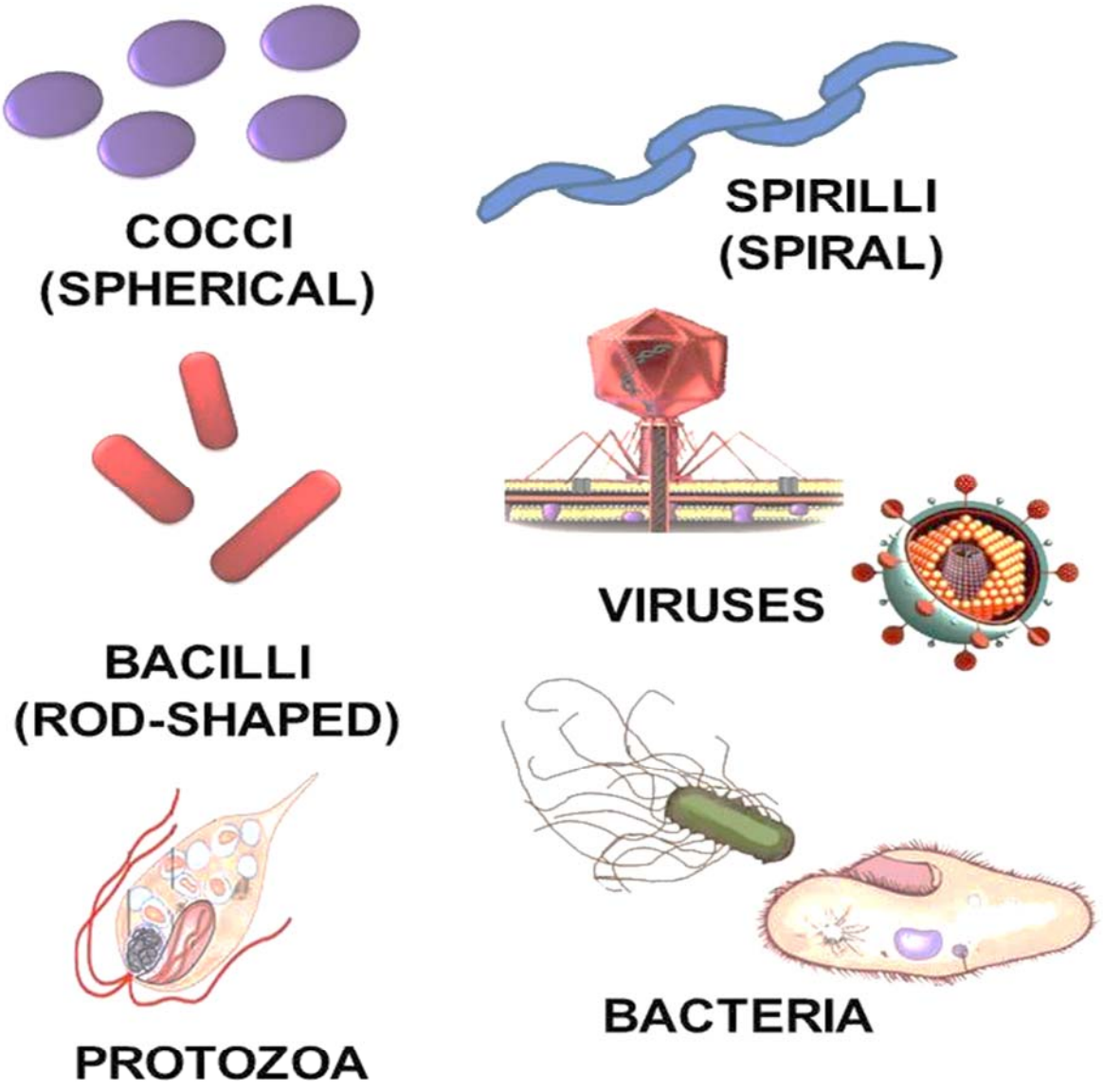
1. Use a new, approved gasket on the connector, 2. 1/4 turn to unseat the valve, then open one complete turn, 3. The cylinder may rupture, 4. The ratio of the density of the liquid to the density of water at 4 degrees C, 5. Gold, Platinum, and Tantalum, 6. Gas chlorine, 7. Secure each cylinder in an upright position. Attach the protective bonnet over the valve. Firmly secure each cylinder, 8. Open chlorine metering orifice slightly. Inspect vacuum lines. Start injector water supply,9. In addition to protective clothing and goggles, chlorine gas should be used only in a well-ventilated area so that any leaking gas cannot concentrate, 10. Chlorine gas forms a mixture of hydrochloric and hypochlorous acids, 11. Because it is too easy to roll, 12. A yellowish green, nonflammable and liquefied gas with an unpleasant and irritating smell. Can be readily compressed into a clear, amber colored liquid, a noncombustible gas, and a strong oxidizer. Chlorine is about 1.5 times heavier than water and gaseous chlorine is about 2.5 times heavier than air, 13. Notify local emergency response team. Warn and evacuate people in adjacent areas, be sure that no one enters the leak area without adequate self-contained breathing equipment,14. Burning of eyes, nose, and mouth; lacrimation and rhinorrhea; Coughing, sneezing, choking, nausea and vomiting; headaches and dizziness; Fatal pulmonary edema; pneumonia; conjunctivitis; keratitis; pharyngitis; burning chest pain; dyspnea; hemoptysis; hypoxemia; dermatitis; and skin blisters, 15. 646 mg/L, 16. Get out of the area of the leak, proceeding upwind, and 2) take only very short breaths through the mouth, 17. 0.195 or also written 19.5%, 18. True, 19. True, 20. True, 21. HOCl and OCl-; free available chlorine, 22. $Cl_2 + H_2O \rightarrow H^+ + Cl^- + HOCl$

Pretreatment Post Quiz Answers

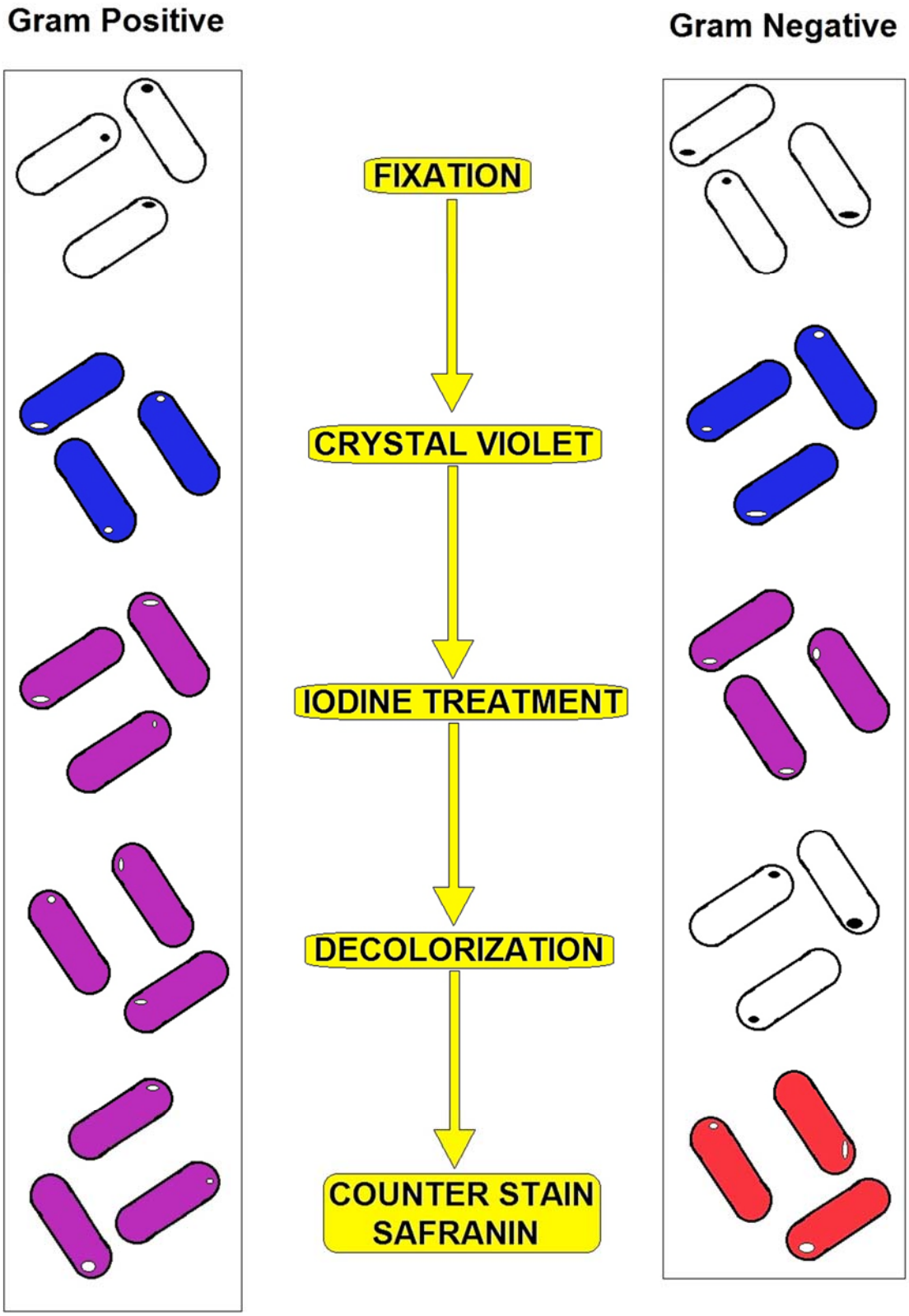
1. True, 2. True, 3. True, 4. True, 5. The General Pretreatment Regulations, 6. All SIUs, 7. Prohibited discharge standards, categorical Pretreatment standards, local limits, 8. Categorical Pretreatment Standards, 9. Pass Through, 10. Interference, 11. Toxic pollutants, 12. Limit the discharge of specific pollutants, 13. Both existing and new sources, 14. Indirect discharges, 15. Effluent limitations guidelines (ELGs)

Waterborne Microorganisms and Bacteria Appendix

This section will give a close-up and short explanation of the major microorganisms found in wastewater.



BACTERIA TYPES



GRAM STAINING DIAGRAM

Protozoa Section

CLASSIFICATION OF LIVING THINGS						
DOMAIN	BACTERIA	ARCHAEA	EUKARYA			
KINGDOM	EUBACTERIA	ARCHAEBACTERIA	PROTISTS	FUNGI	PLANTAE	ANIMALIA
CELL TYPE	PROKARYOTE	PROKARYOTE	EUKARYOTE	EUKARYOTE	EUKARYOTE	EUKARYOTE
CELL STRUCTURES	CELL WALLS WITH PEPTIDOGLYCAN	CELL WALLS WITHOUT PEPTIDOGLYCAN	CELL WALLS OF CELLULOSE IN SOME; SOME HAVE CHLOROPLASTS	CELL WALLS OF CHITIN	CELL WALLS OF CELLULOSE; CHLOROPLASTS	NO CELL WALLS OR CHLOROPLASTS
NUMBER OF CELLS	UNICELLULAR	UNICELLULAR	MOST UNICELLULAR; SOME COLONIAL; SOME MULTICELLULAR	MOST MULTICELLULAR; SOME UNICELLULAR	MULTICELLULAR	MULTICELLULAR
MODE OF NUTRITION	AUTOTROPH OR HETEROTROPH	AUTOTROPH OR HETEROTROPH	AUTOTROPH OR HETEROTROPH	HETEROTROPH	AUTOTROPH	HETEROTROPH
EXAMPLES	STREPTOCOCCUS, ESCHERICHIA COLI	METHANOGENS, HALOPHILES	AMOEBA, PARAMECIUM, SLIME MOLDS, GIANT KELP	MUSHROOMS, YEASTS	MOSSES, FERNS, FLOWERING PLANTS	SPONGES, WORMS, INSECTS, FISHES MAMMALS

The diverse assemblage of organisms that carry out all of their life functions within the confines of a single, complex eukaryotic cell are called protozoa.

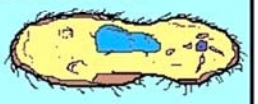
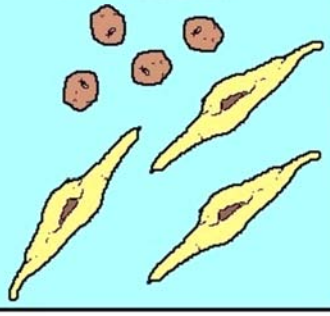
Paramecium, Euglena, and Amoeba are well-known examples of these major groups of organisms. Some protozoa are more closely related to animals, others to plants, and still others are relatively unique.

Although it is not appropriate to group them together into a single taxonomic category, the research tools used to study any unicellular organism are usually the same, and the field of protozoology has been created to carry out this research.

The unicellular photosynthetic protozoa are sometimes also called algae and are addressed elsewhere. This report considers the status of our knowledge of heterotrophic protozoa (protozoa that cannot produce their own food).

Free-living Protozoa
Protozoans are found in all moist habitats within the United States, but we know little about their specific geographic distribution. Because of their small size, production of resistant cysts, and ease of distribution from one place to another, many species appear to be cosmopolitan and may be collected in similar microhabitats worldwide (Cairns and Ruthven 1972). Other species may have relatively narrow limits to their distribution.

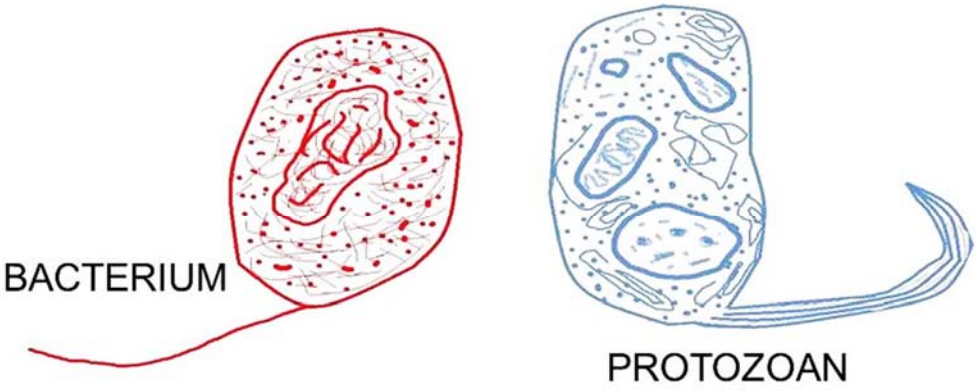
Marine ciliates inhabit interstices of sediment and beach sands, surfaces, deep sea and cold Antarctic environments, planktonic habitats, and the algal mats and detritus of estuaries and wetlands.

PHYLUM	COMMON NAME	LOCOMOTION	EXAMPLES
SARCODINA	SARCODINES	PSEUDOPODIA	AMOEBA 
CILIOPHORA	CILIATES	CILIA	PARAMECIUM 
SARCO-MASTIGOPHORA (ZOOMASTIGINA)	ZOOFLAGELLATES	FLAGELLA	TRYPANOSMA  GIARDIA
APICOMPLEXA (SPOROZOA)	SPOROZOANS	NONE IN ADULT FORM	PLASMODIUM 

PROTOZOA CLASSIFICATION

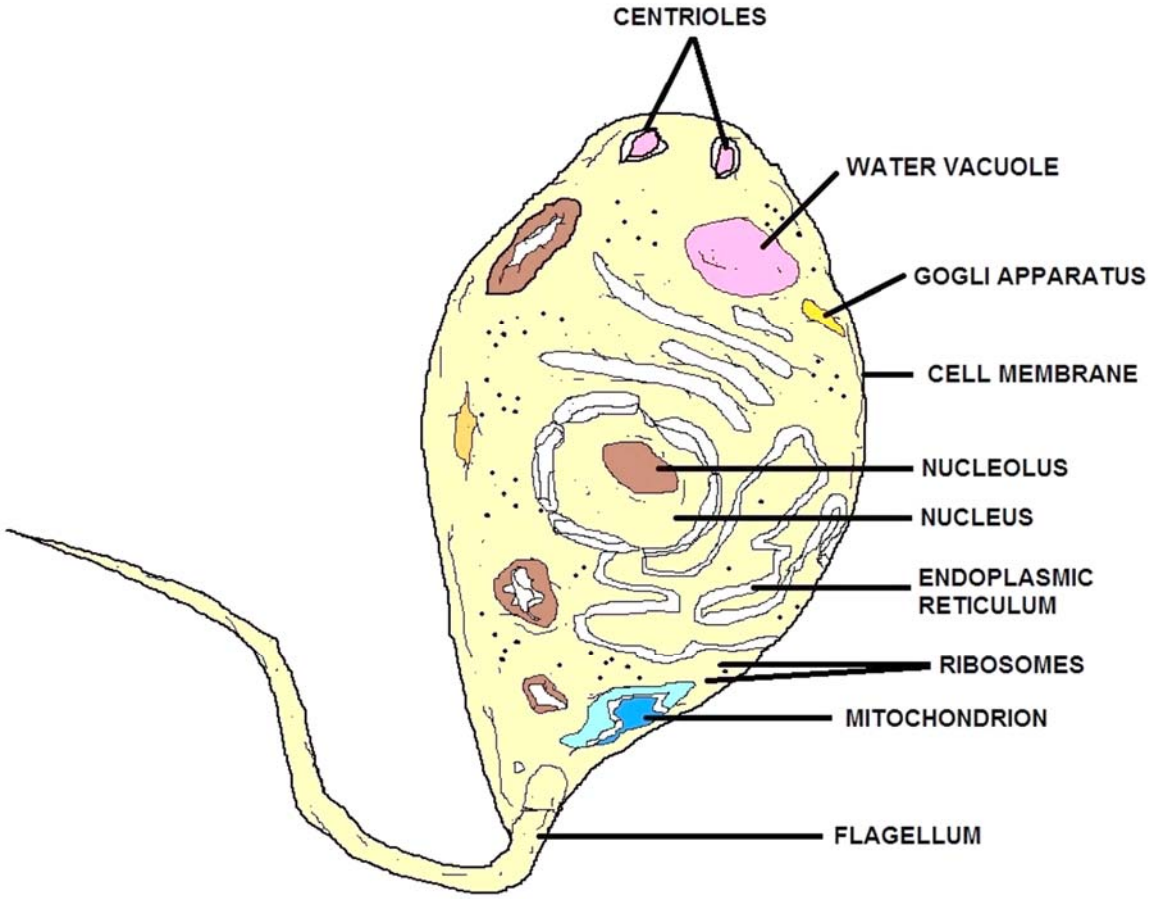
PROKARYOTE

EUKARYOTE



PROKARYOTE ARE SIMPLER THAN EUKARYOTE

Protozoa



PROTOZOAN CELL

Protozoa are around 10–50 micrometer, but can grow up to 1 mm and can easily be seen under a microscope. Protozoa exist throughout aqueous environments and soil. Protozoa occupy a range of trophic levels. As predators, they prey upon unicellular or filamentous algae, bacteria, and microfungi.

Protozoa play a role both as herbivores and as consumers in the decomposer link of the food chain. Protozoa also play a vital role in controlling bacteria populations and biomass. As components of the micro- and meiofauna, protozoa are an important food source for microinvertebrates. Thus, the ecological role of protozoa in the transfer of bacterial and algal production to successive trophic levels is important. Protozoa such as the malaria parasites (Plasmodium spp.), trypanosomes and leishmania are also important as parasites and symbionts of multicellular animals.

Most protozoa exist in 5 stages of life which are in the form of trophozoites and cysts. As cysts, protozoa can survive harsh conditions, such as exposure to extreme temperatures and harmful chemicals, or long periods without access to nutrients, water, or oxygen for a period of time. Being a cyst enables parasitic species to survive outside of the host, and allows their transmission from one host to another. When protozoa are in the form of trophozoites (Greek, tropho=to nourish), they actively feed and grow.

The process by which the protozoa takes its cyst form is called encystation, while the process of transforming back into trophozoite is called excystation.

Protozoa can reproduce by binary fission or multiple fission. Some protozoa reproduce sexually, some asexually, and some both (e.g. Coccidia). An individual protozoan is hermaphroditic.

Classification
Protozoa were commonly grouped in the kingdom of Protista together with the plant-like algae and fungus-like water molds and slime molds. In the 21st-century systematics, protozoans, along with ciliates, mastigophorans, and apicomplexans, are arranged as animal-like protists. However, protozoans are neither Animalia nor Metazoa (with the possible exception of the enigmatic, moldy Myxozoa).

Sub-groups
Protozoa have traditionally been divided on the basis of their means of locomotion, although this is no longer believed to represent genuine relationships:

* Flagellates (e.g. Giardia lambia)
* Amoeboids (e.g. Entamoeba histolytica)
* Sporozoans (e.g. Plasmodium knowlesi)
* Apicomplexa
* Myxozoa
* Microsporidia
* Ciliates (e.g. Balantidium coli)

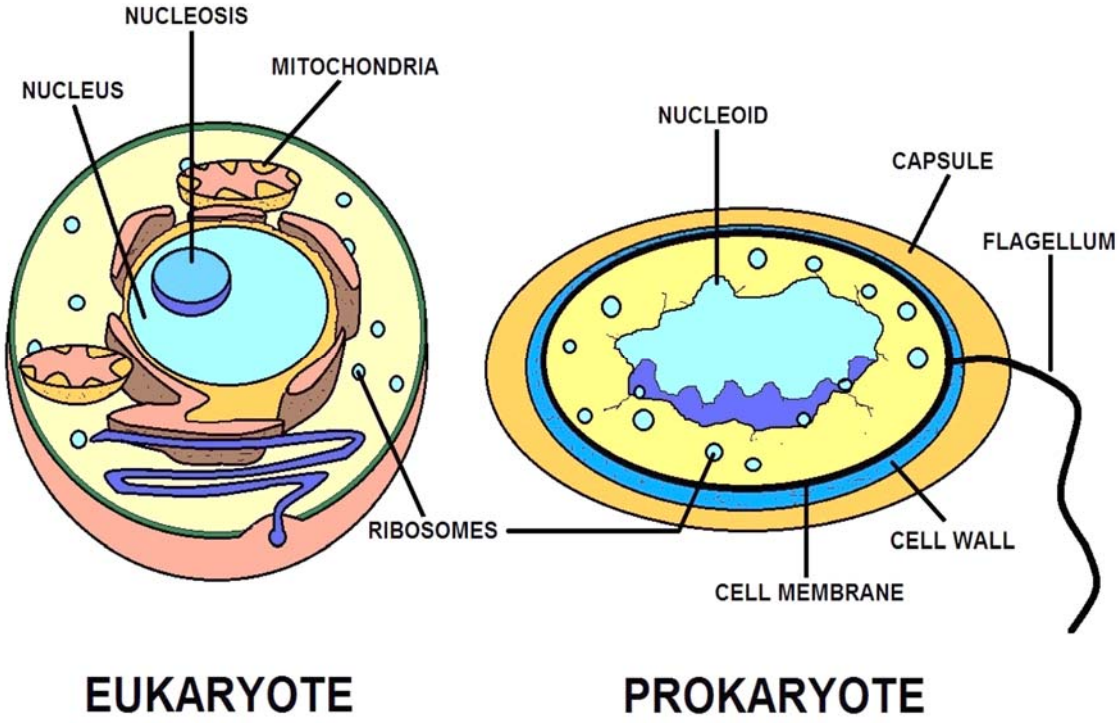
There are many ways that infectious diseases can spread. Pathogens usually have specific routes by which they are transmitted, and these routes may depend on the type of cells and tissue that a particular agent targets. For example, because cold viruses infect the respiratory tract, they are dispersed into the air via coughing and sneezing.

Once in the air, the viruses can infect another person who is unlucky enough to inhale air containing the virus particles.

Agents vary greatly in their stability in the environment. Some viruses may survive for only a few minutes outside of a host, while some spore-forming bacteria are extremely durable and may survive in a dormant state for a decade or more.

Eukaryote

Eukaryotes are organisms with complex cells, in which the genetic material is organized into membrane-bound nuclei. They include the animals, plants, and fungi, which are mostly multicellular, as well as various other groups called protists, many of which are unicellular. In contrast, other organisms such as bacteria lack nuclei and other complex cell structures, and are called prokaryotes. The eukaryotes share a common origin, and are often treated formally as a super kingdom, empire, or domain. The name comes from the Greek *eus* or true and *karyon* or nut, referring to the nucleus.



What are Protists?

- They are **eukaryotes** because they all have a **nucleus**.
- Most have **mitochondria** although some have later lost theirs. Mitochondria were derived from aerobic alpha-proteobacteria (prokaryotes) that once lived within their cells.
- Many have **chloroplasts** with which they carry on photosynthesis. Chloroplasts were derived from photosynthetic **cyanobacteria** (also prokaryotes) living within their cells.

Eukaryotic Cells

Eukaryotic cells are generally much larger than prokaryotes, typically with a thousand times their volumes. They have a variety of internal membranes and structures, called organelles, and a cytoskeleton composed of microtubules and microfilaments, which plays an important role in defining the cell's organization.

Eukaryotic DNA is divided into several bundles called chromosomes, which are separated by a microtubular spindle during nuclear division. In addition to asexual cell division, most eukaryotes have some process of sexual reproduction via cell fusion, which is not found among prokaryotes.

Eukaryotic cells include a variety of membrane-bound structures, collectively referred to as the endomembrane system. Simple compartments, called vesicles or vacuoles, can form by budding off of other membranes. Many cells ingest food and other materials through a process of endocytosis, where the outer membrane invaginates and then pinches off to form a vesicle. It is probable that most other membrane-bound organelles are ultimately derived from such vesicles.

The nucleus is surrounded by a double membrane, with pores that allow material to move in and out. Various tube- and sheet-like extensions of the nuclear membrane form what is called the endoplasmic reticulum or ER, which is involved in protein transport. It includes rough sections where ribosomes are attached, and the proteins they synthesize enter the interior space or lumen. Subsequently, they generally enter vesicles, which bud off from the smooth section. In most eukaryotes, the proteins may be further modified in stacks of flattened vesicles, called Golgi bodies or dictyosomes.

Vesicles may be specialized for various purposes. For instance, lysosomes contain enzymes that break down the contents of food vacuoles, and peroxisomes are used to break down peroxide which is toxic otherwise.

Contractile Vacuoles

Many protozoa have contractile vacuoles, which collect and expel excess water, and extrusomes, which expel material used to deflect predators or capture prey. In multicellular organisms, hormones are often produced in vesicles. In higher plants, most of a cell's volume is taken up by a central vacuole or tonoplast, which maintains its osmotic pressure.

Many eukaryotes have slender motile projections, usually called flagella when long and cilia when short. These are variously involved in movement, feeding, and sensation. These are entirely distinct from prokaryotic flagella. They are supported by a bundle of microtubules arising from a basal body, also called a kinetosome or centriole, characteristically arranged as nine doublets surrounding two singlets. Flagella also may have hairs or mastigonemes, scales, connecting membranes, and internal rods. Their interior is continuous with the cell's cytoplasm.

Centrioles

Centrioles are often present even in cells and groups that do not have flagella. They generally occur in groups of one or two, called kinetids that give rise to various microtubular roots. These form a primary component of the cytoskeletal structure, and are often assembled over the course of several cell divisions, with one flagellum retained from the parent and the other derived from it.

Centrioles may also be associated in the formation of a spindle during nuclear division. Some protists have various other microtubule-supported organelles. These include the radiolaria and heliozoa, which produce axopodia used in flotation or to capture prey, and the haptophytes, which have a peculiar flagellum-like organelle called the haptonema.

Amoebas

Amoebas (Phylum Rhizopoda) are unicellular protists that are able to change their shape constantly. Each species has its own distinct repertoire of shapes.

How does an amoeba locomote?
Amoebas locomote by way of cytoplasmic movement. (cytoplasm is the cell content around the nucleus of the cell) The amoeba forms pseudopods (false feet) with which they 'flow' over a surface. The cytoplasma not only flows, it also changes from a fluid into a solid state.

These pseudopods are also used to capture prey; they simply engulf the food. They can detect the kind of prey and use different 'engulfing tactics'.

The image from the last page shows several cell organelles. Left from the center we can see aspherical water expelling vesicle and just right of it, the single nucleus of this species can be seen. Other species may have many nuclei. The cell is full of brown food vacuoles and also contains small crystals.

Protozoa Information
Our actual knowledge of salinity, temperature, and oxygen requirements of marine protozoa is poor (although some groups, such as the foraminifera, are better studied than others), and even the broadest outlines of their biogeographic ranges are usually a mystery. In general, freshwater protozoan communities are similar to marine communities except the specialized interstitial fauna of the sand is largely missing. In freshwater habitats, the foraminifera and radiolaria common in marine environments are absent or low in numbers while testate amoebae exist in greater numbers. Relative abundance of species in the marine versus freshwater habitat is unknown.

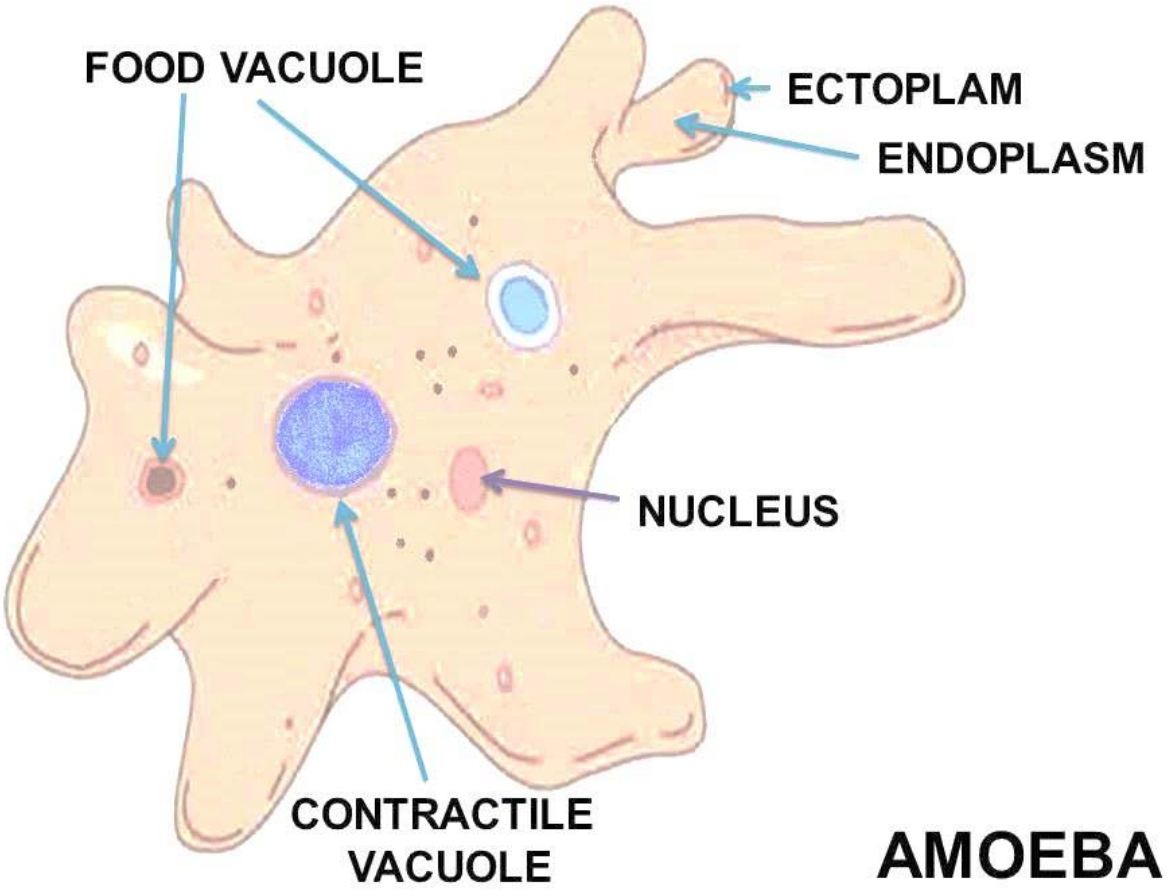
Soil-dwelling protozoa have been documented from almost every type of soil and in every kind of environment, from the peat-rich soil of bogs to the dry sands of deserts. In general, protozoa are found in greatest abundance near the soil surface, especially in the upper 15 cm (6 in), but occasional isolates can be obtained at depths of a meter (yard) or more.

Protozoa do not constitute a major part of soil biomass, but in some highly productive regions such as forest litter, the protozoa are a significant food source for the microinvertebrates, with a biomass that may reach 20 g/m2 of soil surface area there.

Environmental Quality Indicators
Polluted waters often have a rich and characteristic protozoan fauna. The relative abundance and diversity of protozoa are used as indicators of organic and toxic pollution (Cairns et al. 1972; Foissner 1987; Niederlehner et al. 1990; Curds 1992). Bick (1972), for example, provided a guide to ciliates that are useful as indicators of environmental quality of European freshwater systems, along with their ecological distribution with respect to parameters such as amount of organic material and oxygen levels.

Foissner (1988) clarified the taxonomy of European ciliates as part of a system for classifying the state of aquatic habitats according to their faunas.

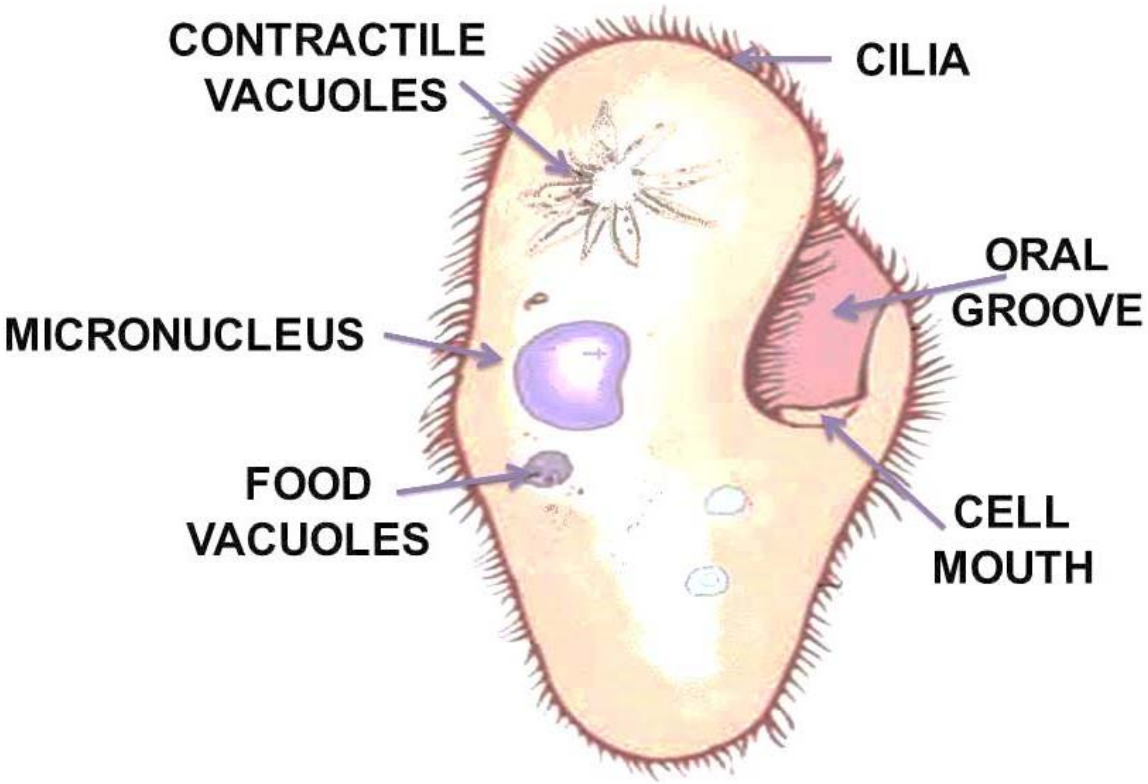
Amoeba



Amoeba (sometimes amœba or ameba, plural amoebae) is a genus of protozoa that moves by means of pseudopods, and is well-known as a representative unicellular organism.

The word amoeba or ameba is variously used to refer to it and its close relatives, now grouped as the Amoebozoa, or to all protozoa that move using pseudopods, otherwise termed amoeboids.

Paramecia



PARAMECIUM

Paramecia are a group of unicellular ciliate protozoa formerly known as slipper animalcules from their slipper shape. They are commonly studied as a representative of the ciliate group. Simple cilia cover the body which allows the cell to move with a synchronous motion (like a caterpilla).

There is also a deep oral groove containing inconspicuous compound oral cilia (as found in other peniculids) that is used to draw food inside. They generally feed upon bacteria and other small cells.

Osmoregulation is carried out by a pair of contractile vacuoles, which actively expel water absorbed by osmosis from their surroundings.

Paramecia are widespread in freshwater environments, and are especially common in scums. Paramecia are attracted by acidic conditions. Certain single-celled eukaryotes, such as Paramecium, are examples for exceptions to the universality of the genetic code (translation systems where a few codons differ from the standard ones).

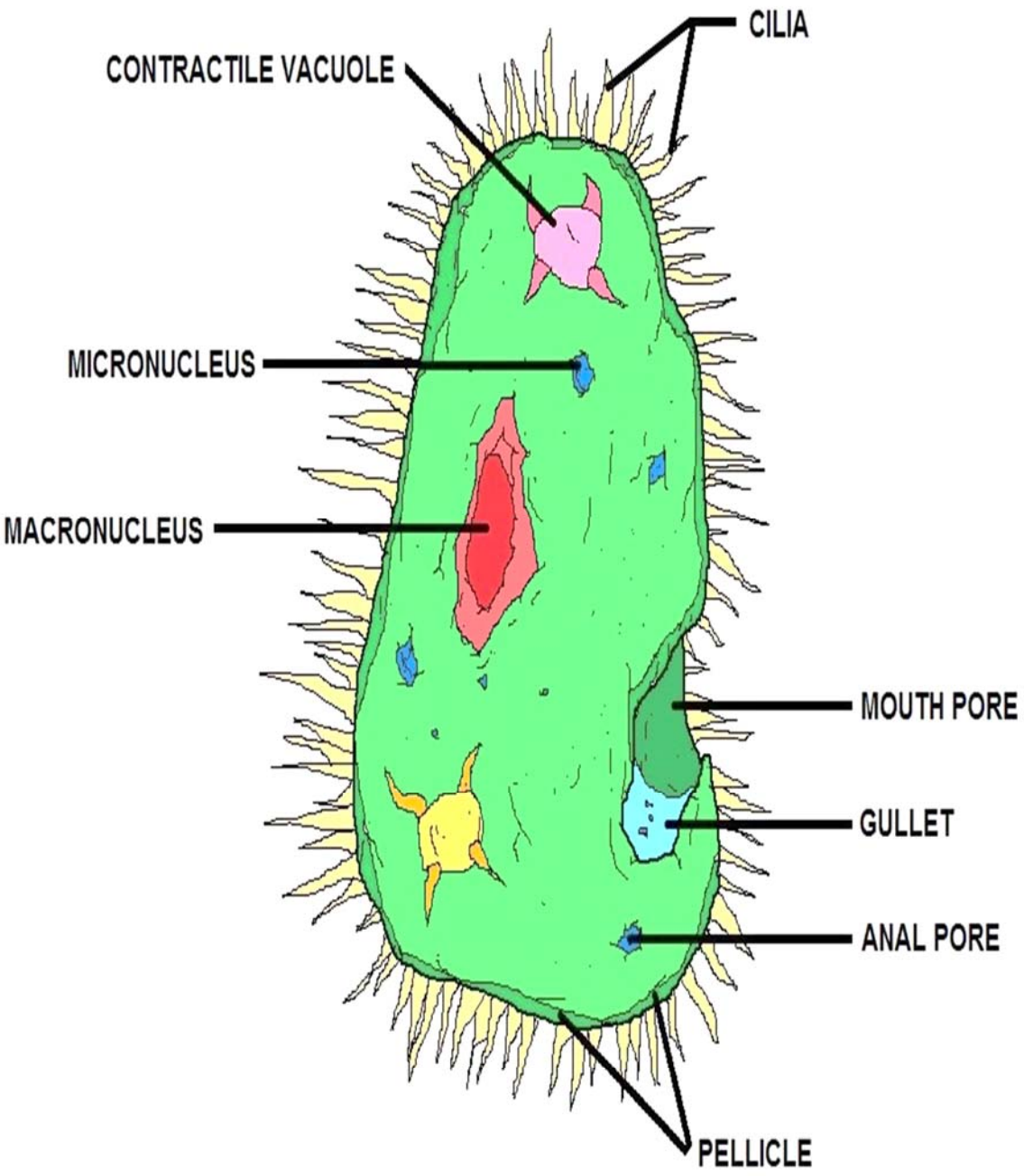
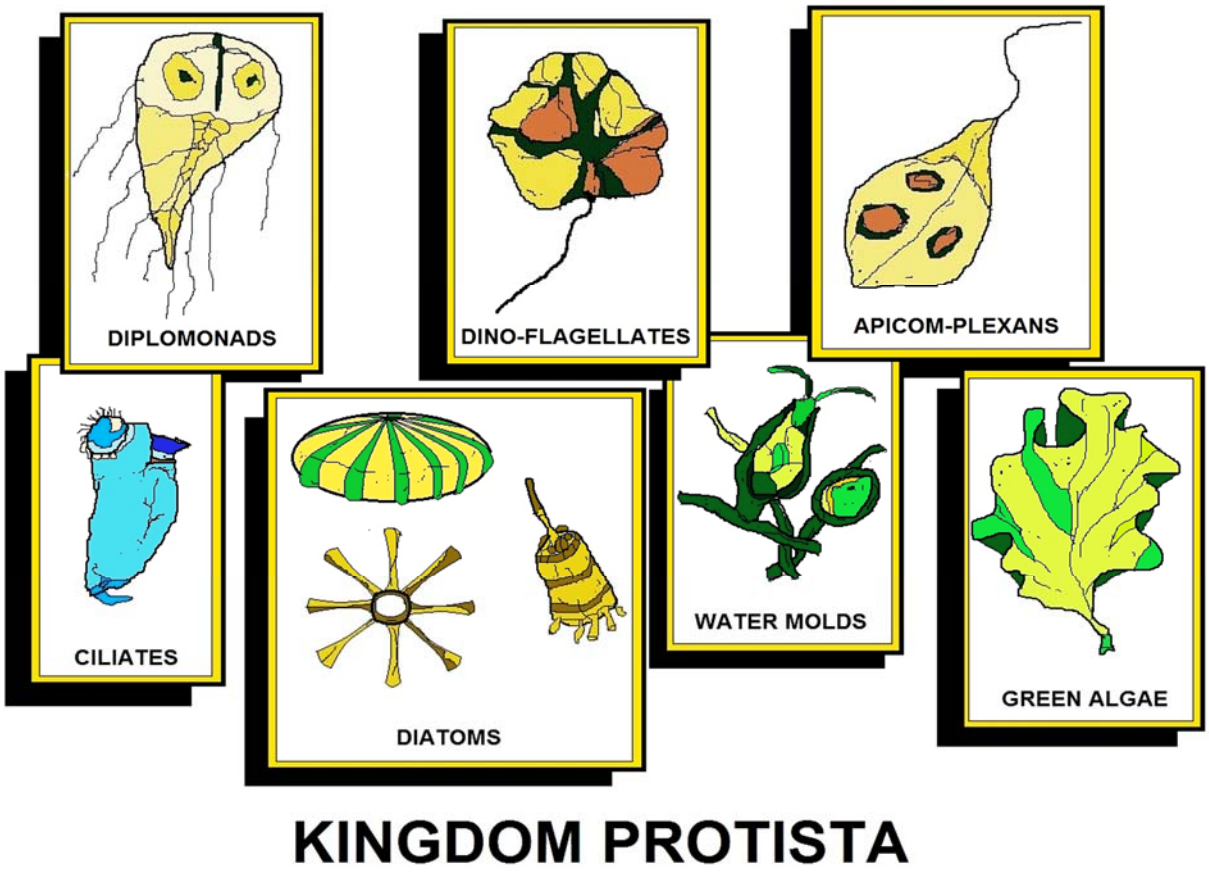


DIAGRAM OF A PARAMECIUM SP.

Symbiotic Protozoa



Parasites
Protozoa are infamous for their role in causing disease, and parasitic species are among the best-known protozoa. Nevertheless, our knowledge has large gaps, especially of normally free-living protozoa that may become pathogenic in immunocompromised individuals.

For example, microsporidia comprise a unique group of obligate, intracellular parasitic protozoa. Microsporidia are amazingly diverse organisms with more than 700 species and 80 genera that are capable of infecting a variety of plant, animal, and even other protist hosts.

They are found worldwide and have the ability to thrive in many ecological conditions. Until the past few years, their ubiquity did not cause a threat to human health, and few systematists worked to describe and classify the species. Since 1985, however, physicians have documented an unusual rise in worldwide infections in AIDS patients caused by four different genera of microsporidia (Encephalitozoon, Nosema, Pleistophora, and Enterocytozoon).

According to the Centers for Disease Control in the United States, difficulties in identifying microsporidian species are impeding diagnosis and effective treatment of AIDS patients.

Protozoan Reservoirs of Disease
The presence of bacteria in the cytoplasm of protozoa is well known, whereas that of viruses is less frequently reported. Most of these reports simply record the presence of bacteria or viruses and assume some sort of symbiotic relationship between them and the protozoa.

Recently, however, certain human pathogens were shown to not only survive but also to multiply in the cytoplasm of free-living, nonpathogenic protozoa. Indeed, it is now believed that protozoa are the natural habitat for certain pathogenic bacteria. To date, the main focus of attention has been on the bacterium Legionella pneumophila, the causative organism of Legionnaires' disease; these bacteria live and reproduce in the cytoplasm of some free-living amoebae (Curds 1992). More on this subject in the following pages.

Symbionts
Some protozoa are harmless or even beneficial symbionts. A bewildering array of ciliates, for example, inhabit the rumen and reticulum of ruminates and the cecum and colon of equids. Little is known about the relationship of the ciliates to their host, but a few may aid the animal in digesting cellulose.

Data on Protozoa
While our knowledge of recent and fossil foraminifera in the U.S. coastal waterways is systematically growing, other free-living protozoa are poorly known. There are some regional guides and, while some are excellent, many are limited in scope, vague on specifics, or difficult to use. Largely because of these problems, most ecologists who include protozoa in their studies of aquatic habitats do not identify them, even if they do count and measure them for biomass estimates (Taylor and Sanders 1991).

Parasitic protozoa of humans, domestic animals, and wildlife are better known although no attempt has been made to compile this information into a single source. Large gaps in our knowledge exist, especially for haemogregarines, microsporidians, and myxosporidians (see Kreier and Baker 1987).

Museum Specimens
For many plant and animal taxa, museums represent a massive information resource. This is not true for protozoa. In the United States, only the National Natural History Museum (Smithsonian Institution) has a reference collection preserved on microscope slides, but it does not have a protozoologist curator and cannot provide species' identification or verification services. The American Type Culture Collection has some protozoa in culture, but its collection includes relatively few kinds of protozoa.

Ecological Role of Protozoa
Although protozoa are frequently overlooked, they play an important role in many communities where they occupy a range of trophic levels. As predators upon unicellular or filamentous algae, bacteria, and microfungi, protozoa play a role both as herbivores and as consumers in the decomposer link of the food chain. As components of the micro- and meiofauna, protozoa are an important food source for microinvertebrates. Thus, the ecological role of protozoa in the transfer of bacterial and algal production to successive trophic levels is important.

Factors Affecting Growth and Distribution
Most free-living protozoa reproduce by cell division (exchange of genetic material is a separate process and is not involved in reproduction in protozoa). The relative importance for population growth of biotic versus chemical-physical components of the environment is difficult to ascertain from the existing survey data. Protozoa are found living actively in nutrient-poor to organically rich waters and in fresh water varying between 0°C (32°F) and 50°C (122°F). Nonetheless, it appears that rates of population growth increase when food is not constrained and temperature is increased (Lee and Fenchel 1972; Fenchel 1974; Montagnes et al. 1988).

Comparisons of oxygen consumption in various taxonomic groups show wide variation (Laybourn and Finlay 1976), with some aerobic forms able to function at extremely low oxygen tensions and to thereby avoid competition and predation.

Many parasitic and a few free-living species are obligatory anaerobes (grow without atmospheric oxygen). Of the free-living forms, the best known are the plagiopylid ciliates that live in the anaerobic sulfide-rich sediments of marine wetlands (Fenchel et al. 1977). The importance of plagiopylids in recycling nutrients to aerobic zones of wetlands is potentially great.

Because of the small size of protozoa, their short generation time, and (for some species) ease of maintaining them in the laboratory, ecologists have used protozoan populations and communities to investigate competition and predation.

The result has been an extensive literature on a few species studied primarily under laboratory conditions. Few studies have been extended to natural habitats with the result that we know relatively little about most protozoa and their roles in natural communities. Intraspecific competition for common resources often results in cannibalism, sometimes with dramatic changes in morphology of the cannibals (Giese 1973). Field studies of interspecific competition are few and most evidence for such species interactions is indirect (Cairns and Yongue 1977).

Contractile Vacuoles
Many protozoa have contractile vacuoles, which collect and expel excess water, and extrusomes, which expel material used to deflect predators or capture prey. In multicellular organisms, hormones are often produced in vesicles. In higher plants, most of a cell's volume is taken up by a central vacuole or tonoplast, which maintains its osmotic pressure. Many eukaryotes have slender motile projections, usually called flagella when long and cilia when short. These are variously involved in movement, feeding, and sensation. These are entirely distinct from prokaryotic flagella. They are supported by a bundle of microtubules arising from a basal body, also called a kinetosome or centriole, characteristically arranged as nine doublets surrounding two singlets. Flagella also may have hairs or mastigonemes, scales, connecting membranes, and internal rods. Their interior is continuous with the cell's cytoplasm.

Centrioles
Centrioles are often present even in cells and groups that do not have flagella. They generally occur in groups of one or two, called kinetids that give rise to various microtubular roots. These form a primary component of the cytoskeletal structure, and are often assembled over the course of several cell divisions, with one flagellum retained from the parent and the other derived from it.

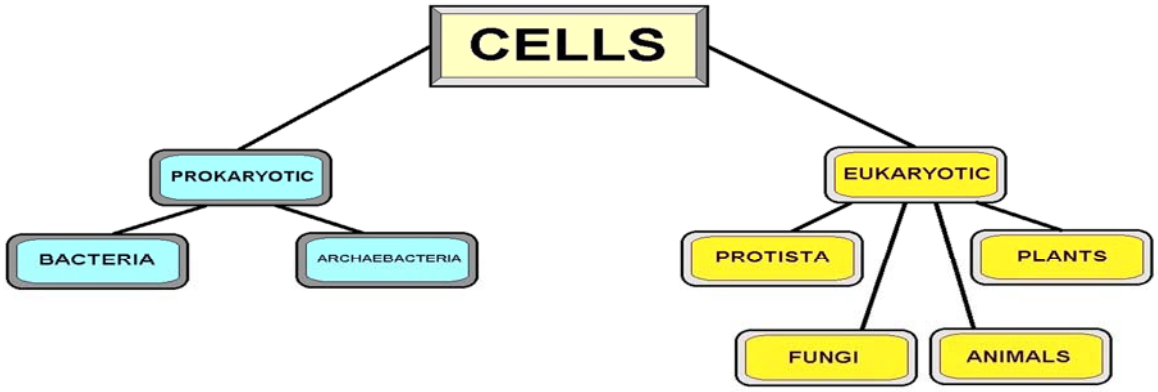
Centrioles may also be associated in the formation of a spindle during nuclear division. Some protists have various other microtubule-supported organelles.

These include the radiolaria and heliozoa, which produce axopodia used in flotation or to capture prey, and the haptophytes, which have a peculiar flagellum-like organelle called the haptonema.

Paramecium

Members of the genus *Paramecium* are single-celled, freshwater organisms in the kingdom Protista. They exist in an environment in which the osmotic concentration in their external environment is much lower than that in their cytoplasm. More specifically, the habitat in which they live is **hypotonic** to their cytoplasm. As a result of this, *Paramecium* is subjected to a continuous influx of water, as water diffuses inward to a region of higher osmotic concentration.

If *Paramecium* is to maintain homeostasis, water must be continually pumped out of the cell (against the osmotic gradient) at the same rate at which it moves in. This process, known as **osmoregulation**, is carried out by two organelles in *Paramecium* known as **contractile vacuoles**.



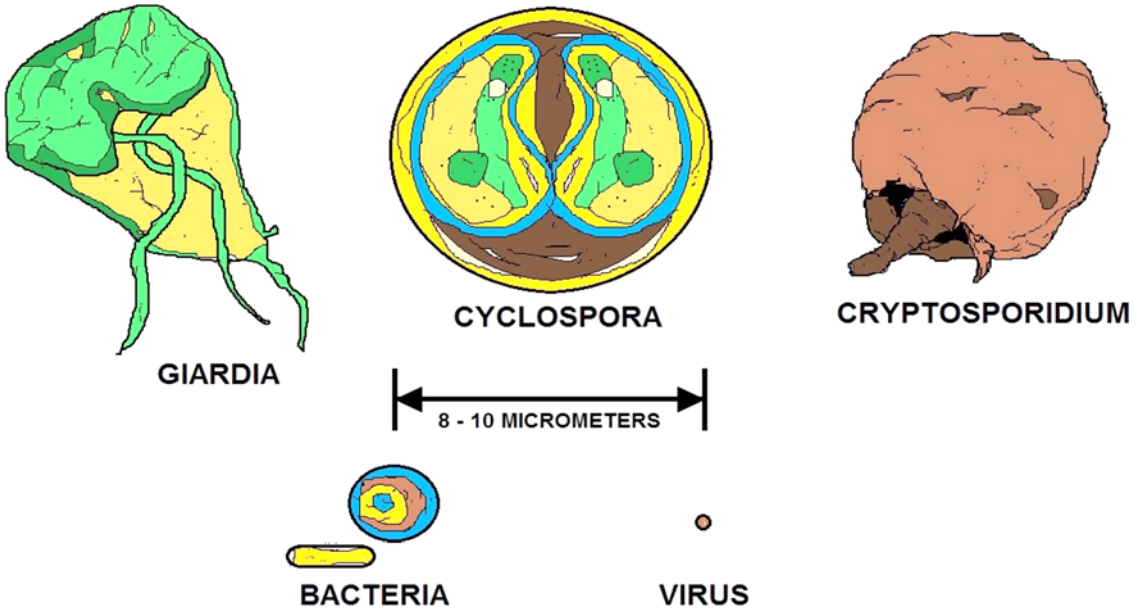
SINGLE CELL DIAGRAM

FEATURE	ANIMAL CELL	PLANT CELL
CELL WALL	NOT PRESENT	PRESENT (MADE OF CELLULOSE)
CHLOROPLASTS	NOT PRESENT	PRESENT IN PLANT CELLS THAT PHOTOSYNTHESISE
CARBOHYDRATE STORAGE	GLYCOGEN	STARCH
VACUOLE	NOT USUALLY PRESENT. IF PRESENT, THEY ARE SMALL	LARGE AND PERMANENT
PLANT AND ANIMAL CELLS HAVE MANY SIMILARITIES BECAUSE THEY ARE BOTH EUKARYOTIC		

PLANT CELLS vs. ANIMAL CELLS

Protozoan Diseases

Protozoan pathogens are larger than bacteria and viruses, but still microscopic. They invade and inhabit the gastrointestinal tract. Some parasites enter the environment in a dormant form, with a protective cell wall called a "*cyst*." The cyst can survive in the environment for long periods of time and be extremely resistant to conventional disinfectants such as chlorine. Effective filtration treatment is therefore critical to removing these organisms from water sources.



COMPARATIVE SIZES OF PROTOZOAN PARASITES

Giardiasis

Giardiasis is a commonly reported protozoan-caused disease. It has also been referred to as "*backpacker's disease*" and "*beaver fever*" because of the many cases reported among hikers and others who consume untreated surface water.

Symptoms include chronic diarrhea, abdominal cramps, bloating, frequent loose and pale greasy stools, fatigue and weight loss. The incubation period is 5-25 days or longer, with an average of 7-10 days. Many infections are asymptomatic (no symptoms).

Giardiasis occurs worldwide. Waterborne outbreaks in the United States occur most often in communities receiving their drinking water from streams or rivers without adequate disinfection or a filtration system. The organism, *Giardia lamblia,* has been responsible for more community-wide outbreaks of disease in the U.S. than any other pathogen. Drugs are available for treatment but are not 100% effective.

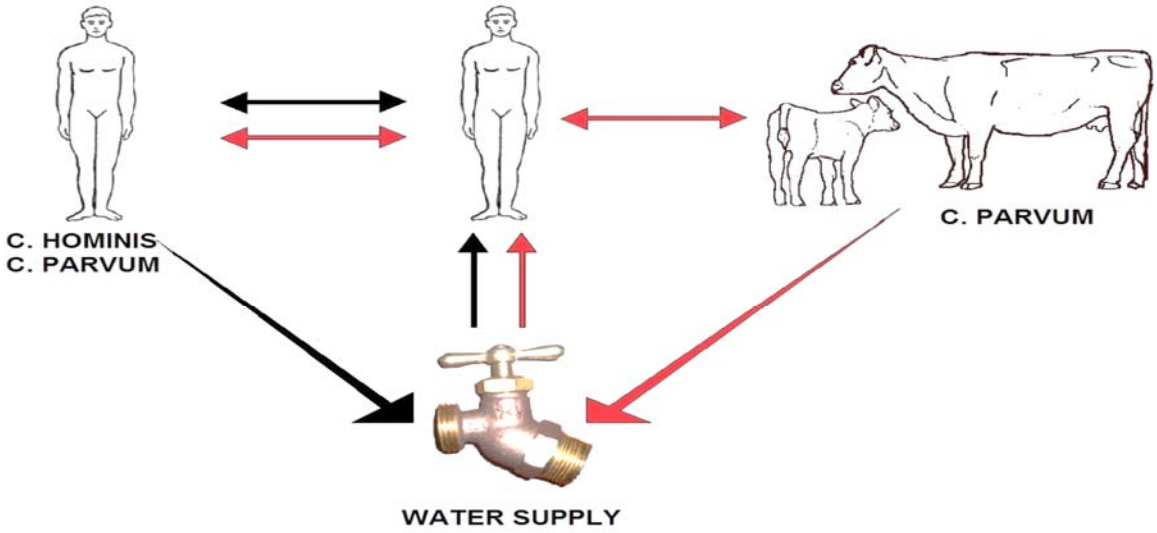
Cryptosporidiosis

Cryptosporidiosis is an example of a protozoan disease that is common worldwide, but was only recently recognized as causing human disease. The major symptom in humans is diarrhea, which may be profuse and watery. The diarrhea is associated with cramping abdominal pain. General malaise, fever, anorexia, nausea, and vomiting occur less often.

Symptoms usually come and go, and end in fewer than 30 days in most cases. The incubation period is 1-12 days, with an average of about seven days. *Cryptosporidium* organisms have been identified in human fecal specimens from more than 50 countries on six continents. The mode of transmission is fecal-oral, either by person-to-person or animal-to-person. There is no specific treatment for *Cryptosporidium* infections.

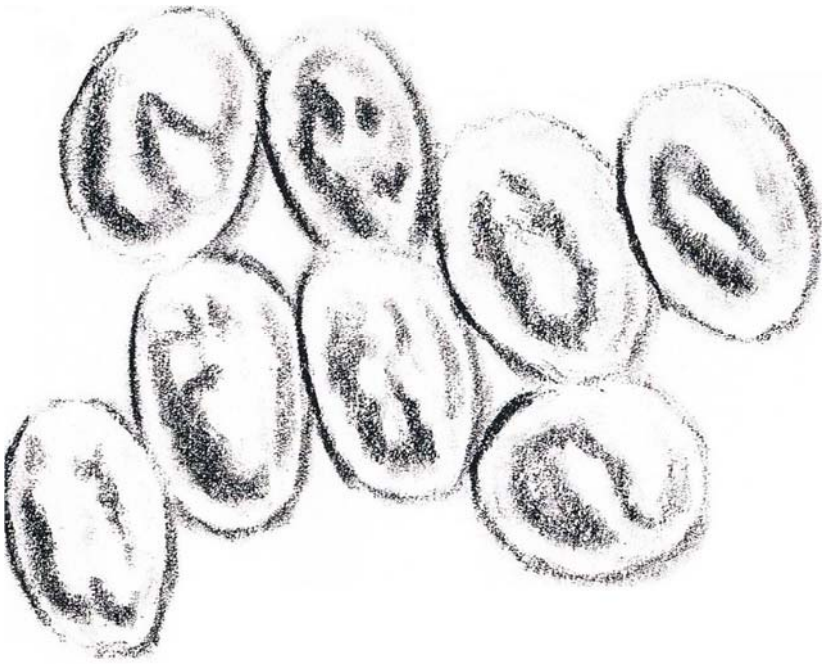
All of these diseases, with the exception of hepatitis A, have one symptom in common: diarrhea. They also have the same mode of transmission, fecal-oral, whether through person-to-person or animal-to-person contact, and the same routes of transmission, being either foodborne or waterborne. Although most pathogens cause mild, self-limiting disease, on occasion, they can cause serious, even life threatening illness. Particularly vulnerable are persons with weak immune systems such as those with HIV infections or cancer. By understanding the nature of waterborne diseases, the importance of properly constructed, operated and maintained public water systems becomes obvious.

While water treatment cannot achieve sterile water (no microorganisms), the goal of treatment must clearly be to produce drinking water that is as pathogen-free as possible at all times. For those who operate water systems with inadequate source protection or treatment facilities, the potential risk of a waterborne disease outbreak is real. For those operating systems that currently provide adequate source protection and treatment, operating and maintaining the system at a high level on a continuing basis is critical to prevent disease.



CRYPTOSPORIDIUM TRANSMISSION

Cryptosporidium



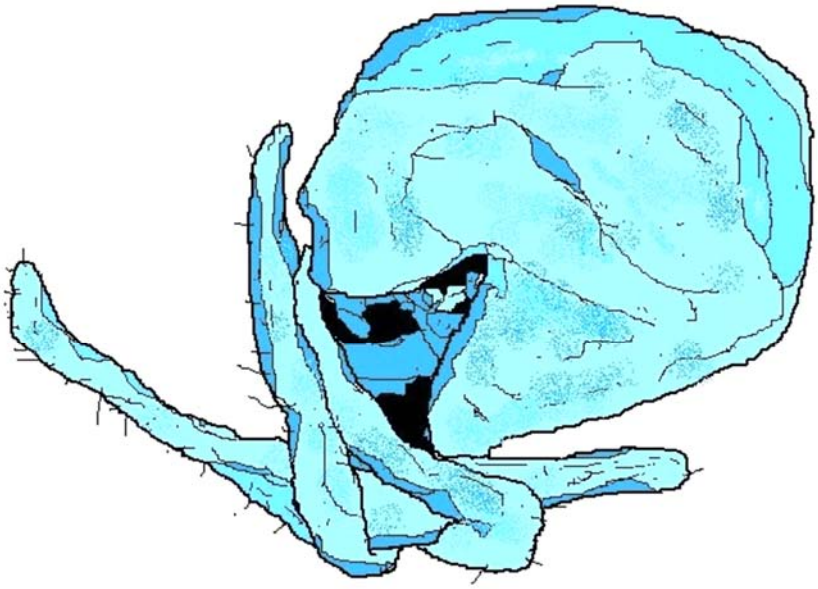
Cryptosporidium is a protozoan pathogen of the Phylum Apicomplexa and causes a diarrheal illness called cryptosporidiosis. Other apicomplexan pathogens include the malaria parasite Plasmodium, and Toxoplasma, the causative agent of toxoplasmosis. Unlike Plasmodium, which transmits via a mosquito vector, Cryptosporidium does not utilize an insect vector and is capable of completing its life cycle within a single host, resulting in cyst stages which are excreted in feces and are capable of transmission to a new host.

A number of species of Cryptosporidium infect mammals. In humans, the main causes of disease are C. parvum and C. hominis (previously C. parvum genotype 1). C. canis, C. felis, C. meleagridis, and C. muris can also cause disease in humans. In recent years, cryptosporidiosis has plagued many commercial Leopard gecko breeders. Several species of the Cryptosporidium family (C. serpentes and others) are involved, and outside of geckos it has been found in monitor lizards, iguanas, tortoises as well as several snake species.

Cryptosporidiosis is typically an acute short-term infection but can become severe and non-resolving in children and immunocompromised individuals. The parasite is transmitted by environmentally hardy cysts (oocysts) that, once ingested, excyst in the small intestine and result in an infection of intestinal epithelial tissue. The genome of Cryptosporidium parvum was sequenced in 2004 and was found to be unusual amongst Eukaryotes in that the mitochondria seem not to contain DNA. A closely-related species, C. hominis, also has its genome sequence available. CryptoDB.org is a NIH-funded database that provides access to the Cryptosporidium genomics data sets.

When *C. parvum* was first identified as a human pathogen, diagnosis was made by a biopsy of intestinal tissue (Keusch, *et al*., 1995).

However, this method of testing can give false negatives due the "patchy" nature of the intestinal parasitic infection (Flanigan and Soave, 1993). Staining methods were then developed to detect and identify the oocysts directly from stool samples. The modified acid-fast stain is traditionally used to most reliably and specifically detect the presence of cryptosporidial oocysts.



CRYPTO - PARVUM

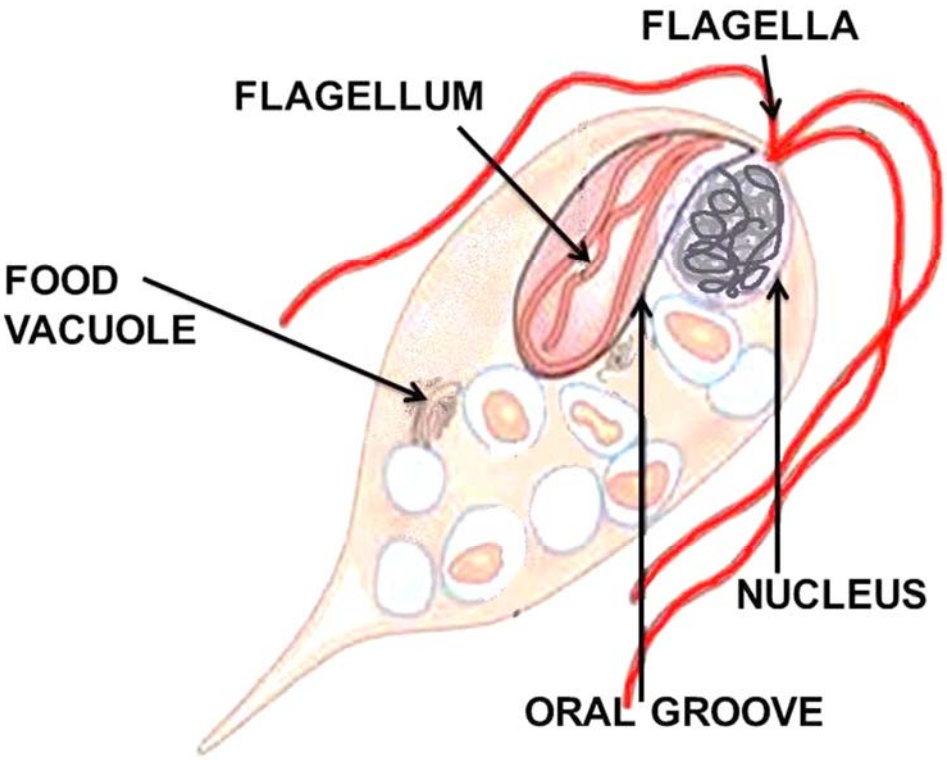
There have been six major outbreaks of cryptosporidiosis in the United States as a result of contamination of drinking water (Juranek, 1995). One major outbreak in Milwaukee in 1993 affected over 400,000 persons.

Outbreaks such as these usually result from drinking water taken from surface water sources such as lakes and rivers (Juranek, 1995).

Swimming pools and water park wave pools have also been associated with outbreaks of cryptosporidiosis. Also, untreated groundwater or well water public drinking water supplies can be sources of contamination.

The highly environmentally resistant cyst of *C. parvum* allows the pathogen to survive various drinking water filtrations and chemical treatments such as chlorination. Although municipal drinking water utilities may meet federal standards for safety and quality of drinking water, complete protection from cryptosporidial infection is not guaranteed. In fact, *all* waterborne outbreaks of cryptosporidiosis have occurred in communities where the local utilities met all state and federal drinking water standards (Juranek, 1995).

Giardia Lamblia



Giardia lamblia (synonymous with Lamblia intestinalis and Giardia duodenalis) is a flagellated protozoan parasite that colonizes and reproduces in the small intestine, causing giardiasis. The giardia parasite attaches to the epithelium by a ventral adhesive disc, and reproduces via binary fission. Giardiasis does not spread via the bloodstream, nor does it spread to other parts of the gastro-intestinal tract, but remains confined to the lumen of the small intestine. Giardia trophozoites absorb their nutrients from the lumen of the small intestine, and are anaerobes.

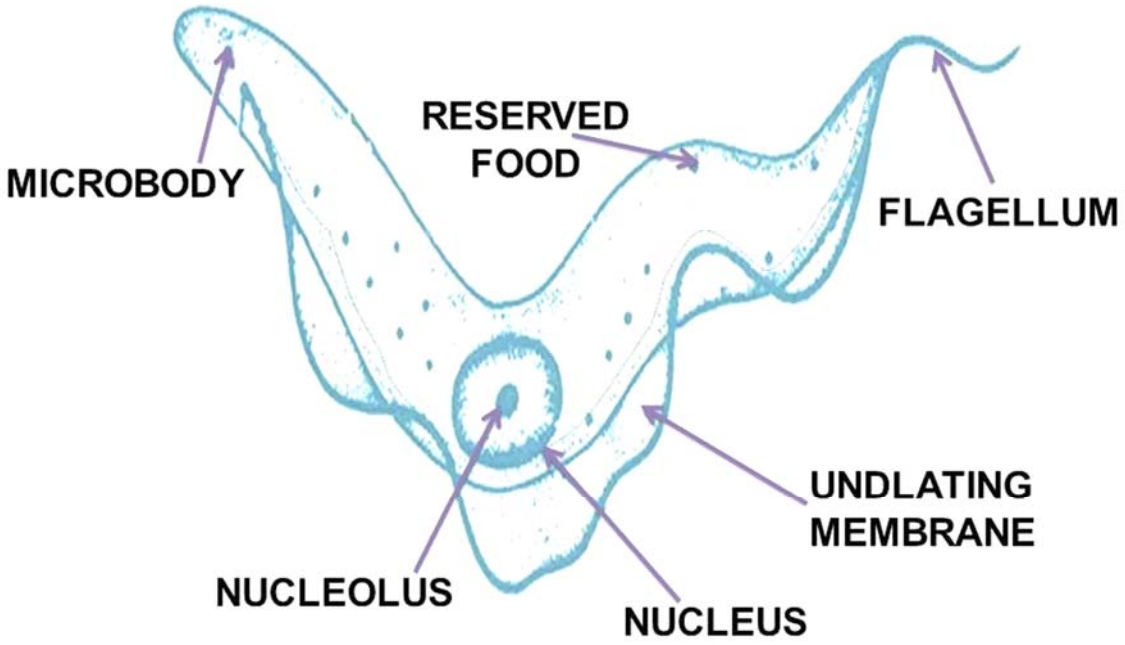
Giardia infection can occur through ingestion of dormant cysts in contaminated water, or by the fecal-oral route (through poor hygiene practices). The Giardia cyst can survive for weeks to months in cold water and therefore can be present in contaminated wells and water systems, and even clean-looking mountain streams, as well as city reservoirs, as the Giardia cysts are resistant to conventional water treatment methods, such as chlorination and ozonolysis.

Zoonotic transmission is also possible, and therefore Giardia infection is a concern for people camping in the wilderness or swimming in contaminated streams or lakes, especially the artificial lakes formed by beaver dams (hence the popular name for giardiasis, "Beaver Fever"). As well as water-borne sources, fecal-oral transmission can also occur, for example in day care centers, where children may have poorer hygiene practices.

Those who work with children are also at risk of being infected, as are family members of infected individuals. Not all Giardia infections are symptomatic, so some people can unknowingly serve as carriers of the parasite.

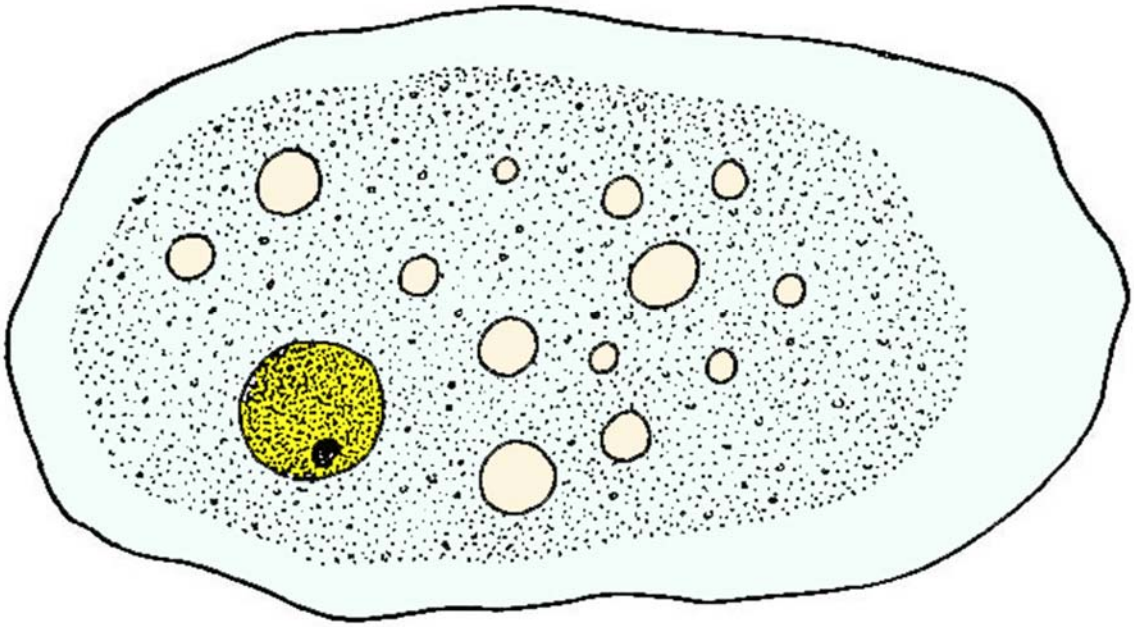
The life cycle begins with a non-infective cyst being excreted with feces of an infected individual. Once out in the environment, the cyst becomes infective. A distinguishing characteristic of the cyst is 4 nuclei and a retracted cytoplasm. Once ingested by a host, the trophozoite emerges to an active state of feeding and motility. After the feeding stage, the trophozoite undergoes asexual replication through longitudinal binary fission. The resulting trophozoites and cysts then pass through the digestive system in the feces. While the trophozoites may be found in the feces, only the cysts are capable of surviving outside of the host.

Distinguishing features of the trophozoites are large karyosomes and lack of peripheral chromatin, giving the two nuclei a halo appearance. Cysts are distinguished by a retracted cytoplasm. This protozoa lacks mitochondria, although the discovery of the presence of mitochondrial remnant organelles in one recent study "indicate that Giardia is not primitively amitochondrial and that it has retained a functional organelle derived from the original mitochondrial endosymbiont"



PROTOZOAN PARASITE

Entamoeba histolytica



Entamoeba histolytica, another water-borne pathogen, can cause diarrhea or a more serious invasive liver abscess. When in contact with human cells, these amoebae are cytotoxic. There is a rapid influx of calcium into the contacted cell, it quickly stops all membrane movement save for some surface blebbing. Internal organization is disrupted, organelles lyse, and the cell dies. The ameba may eat the dead cell or just absorb nutrients released from the cell.

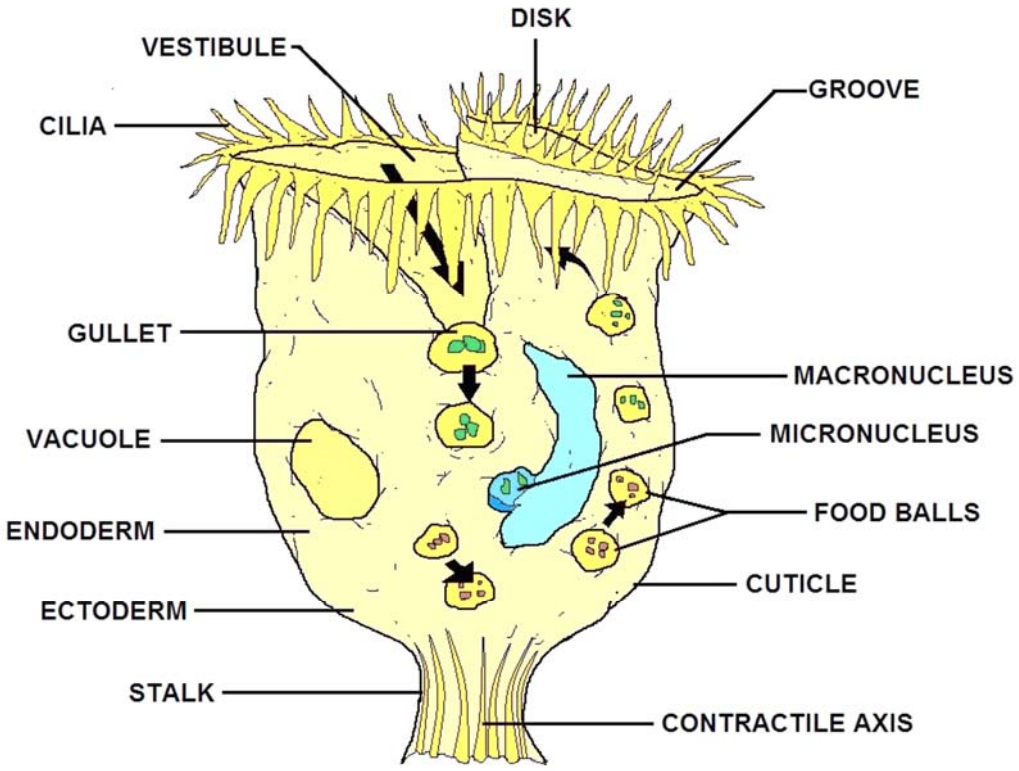
On average, about one in 10 people who are infected with *E. histolytica* becomes sick from the infection. The symptoms often are quite mild and can include loose stools, stomach pain, and stomach cramping.

Amebic dysentery is a severe form of amebiasis associated with stomach pain, bloody stools, and fever. Rarely, *E. histolytica* invades the liver and forms an abscess. Even less commonly, it spreads to other parts of the body, such as the lungs or brain.

Scientific Classification

Domain: Eukaryota
Phylum: Amoebozoa
Class: Archamoebae
Genus: Entamoeba
Species: E. histolytica

Vorticella



VORTICELLA
(TYPE OF PROTOZOAN FOUND IN STAGNANT WATER)

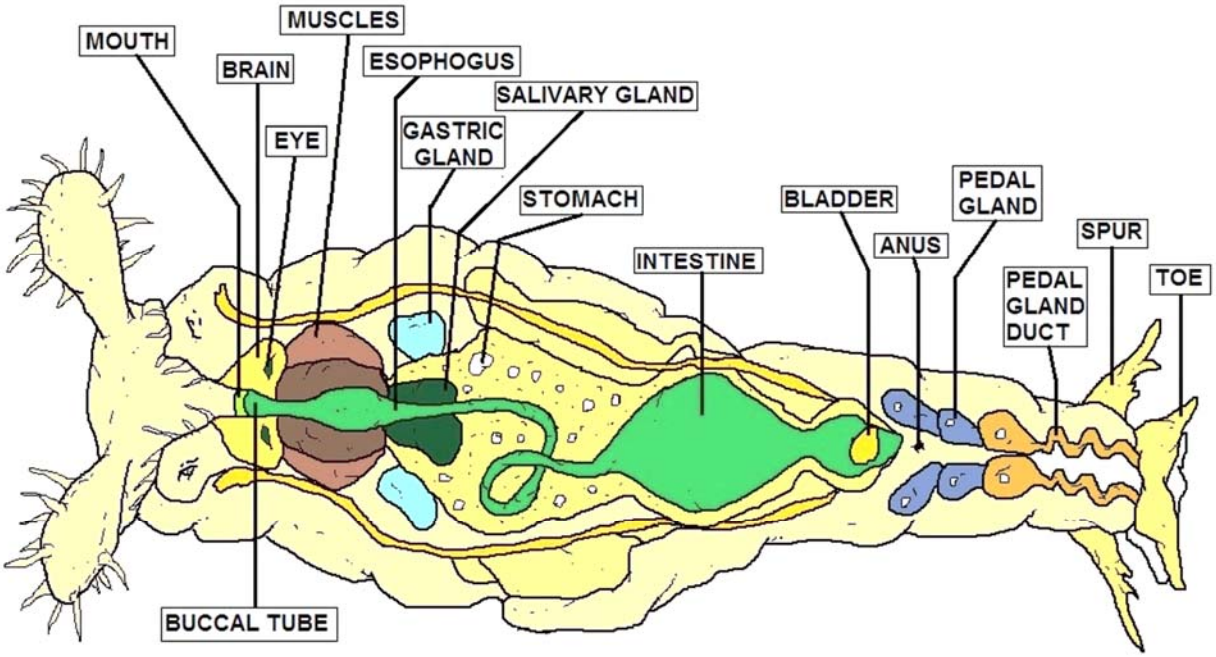
Vorticella is a genus of protozoa, with over 100 known species. They are stalked inverted bell-shaped ciliates, placed among the peritrichs. Each cell has a separate stalk anchored onto the substrate, which contains a contracile fibril called a myoneme. When stimulated this shortens, causing the stalk to coil like a spring.

Reproduction is by budding, where the cell undergoes longitudinal fission and only one daughter keeps the stalk.

Vorticella mainly lives in freshwater ponds and streams - generally anywhere protists are plentiful. Other genera such as Carchesium resemble Vorticella but are branched or colonial.

Domain: Eukaryota
Phylum: Ciliophora
Class: Oligohymenophorea
Subclass: Peritrichia
Order: Sessilida
Family: Vorticellidae
Genus: Vorticella

Rotifer



ROTIFER

The rotifers make up a phylum of microscopic and near-microscopic pseudocoelomate animals. They were first described by John Harris in 1696 (Hudson and Gosse, 1886). Leeuwenhoek is mistakenly given credit for being the first to describe rotifers but Harris had produced sketches in 1703.

Most rotifers are around 0.1-0.5 mm long, and are common in freshwater throughout the world with a few saltwater species. Rotifers may be free swimming and truly planktonic, others move by inch worming along the substrate, whilst some are sessile, living inside tubes or gelatinous holdfasts. About 25 species are colonial (e.g. Sinantherina semibullata), either sessile or planktonic.

Rotifers get their name (derived from Greek and meaning "wheel-bearer"; they have also been called wheel animalcules) from the corona, which is composed of several ciliated tufts around the mouth that in motion resemble a wheel. These create a current that sweeps food into the mouth, where it is chewed up by a characteristic pharynx (called the mastax) containing a tiny, calcified, jaw-like structure called the trophi. The cilia also pull the animal, when unattached, through the water.

Most free-living forms have pairs of posterior toes to anchor themselves while feeding. Rotifers have bilateral symmetry and a variety of different shapes. There is a well-developed cuticle which may be thick and rigid, giving the animal a box-like shape, or flexible, giving the animal a worm-like shape; such rotifers are respectively called loricate and illoricate.

Like many other microscopic animals, adult rotifers frequently exhibit eutely - they have a fixed number of cells within a species, usually on the order of one thousand.

Males in the class Monogononta may be either present or absent depending on the species and environmental conditions. In the absence of males, reproduction is by parthenogenesis and results in clonal offspring that are genetically identical to the parent.

Individuals of some species form two distinct types of parthenogenetic eggs; one type develops into a normal parthenogenetic female, while the other occurs in response to a changed environment and develops into a degenerate male that lacks a digestive system, but does have a complete male reproductive system that is used to inseminate females thereby producing fertilized 'resting eggs'.

Resting eggs develop into zygotes that are able to survive extreme environmental conditions such as may occur during winter or when the pond dries up. These eggs resume development and produce a new female generation when conditions improve again. The life span of monogonont females varies from a couple of days to about three weeks.

Bdelloid rotifers are unable to produce resting eggs, but many can survive prolonged periods of adverse conditions after desiccation. This facility is termed anhydrobiosis, and organisms with these capabilities are termed anhydrobionts.

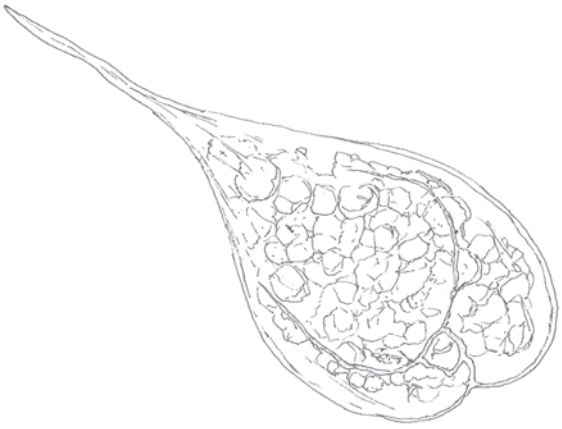
Under drought conditions, bdelloid rotifers contract into an inert form and lose almost all body water; when rehydrated, however, they resume activity within a few hours.

Bdelloids can survive the dry state for prolonged periods, with the longest well-documented dormancy being nine years.

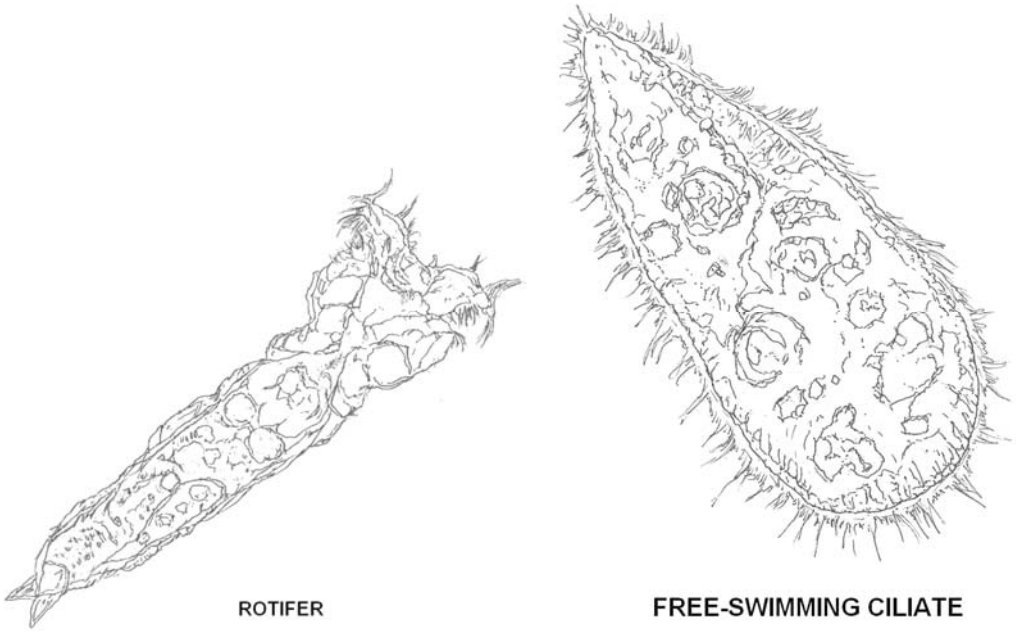
While in other anhydrobionts, such as the brine shrimp, this desiccation tolerance is thought to be linked to the production of trehalose, a non-reducing disaccharide (sugar), bdelloids apparently lack the ability to synthesize trehalose.

Bdelloid rotifer genomes contain two or more divergent copies of each gene. Four copies of hsp82 are, for example, found. Each is different and found on a different chromosome, excluding the possibility of homozygous sexual reproduction.

Various and Commonly found Wastewater Bugs

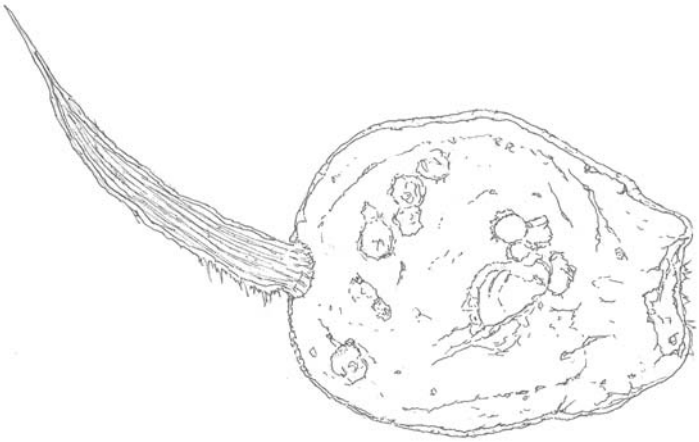


EUGLENOID

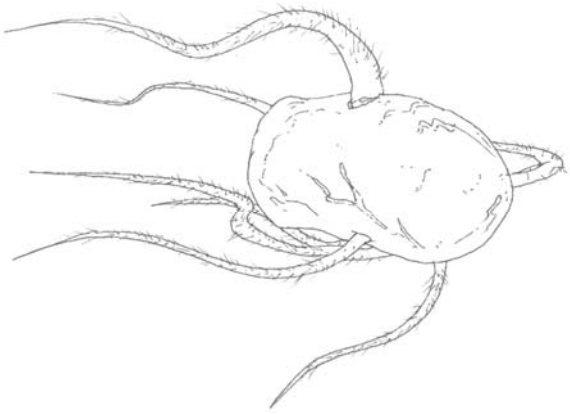


ROTIFER

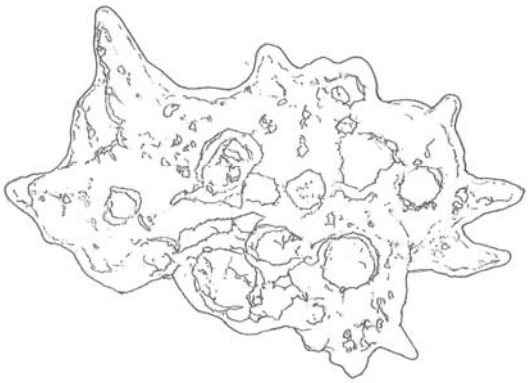
FREE-SWIMMING CILIATE



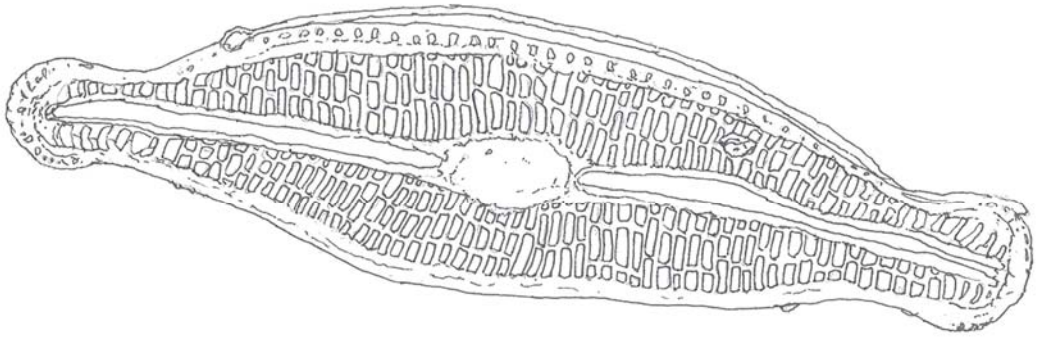
STALKED CILLIATE



FLAGELLATE



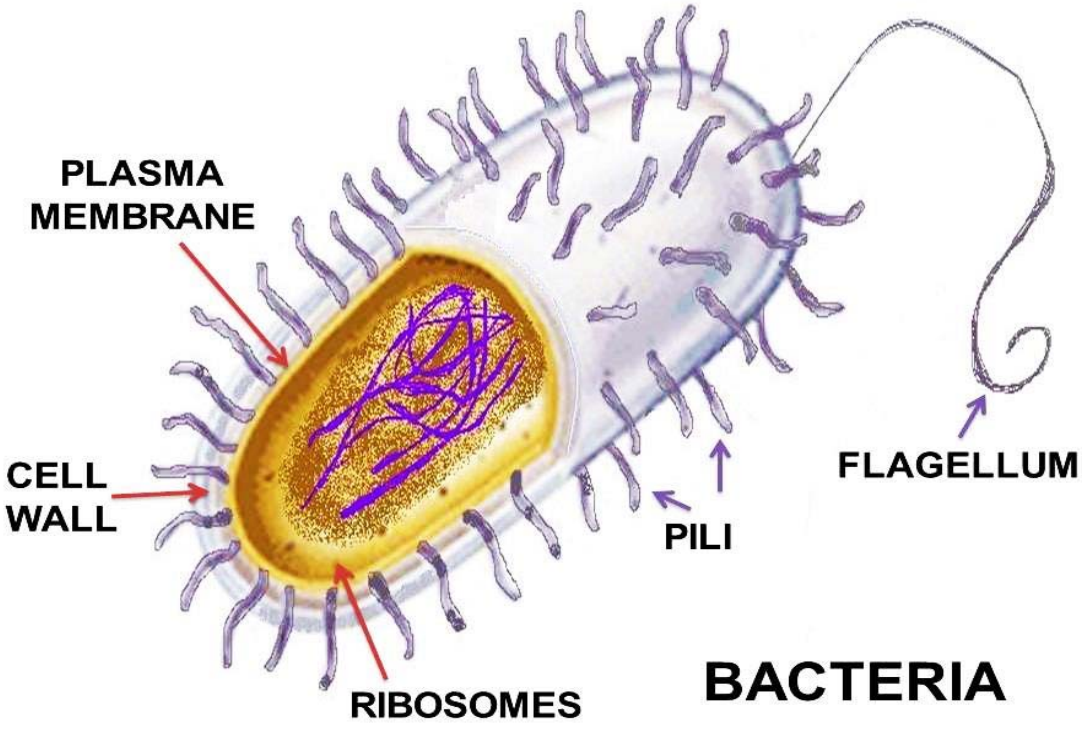
AMOEBOID

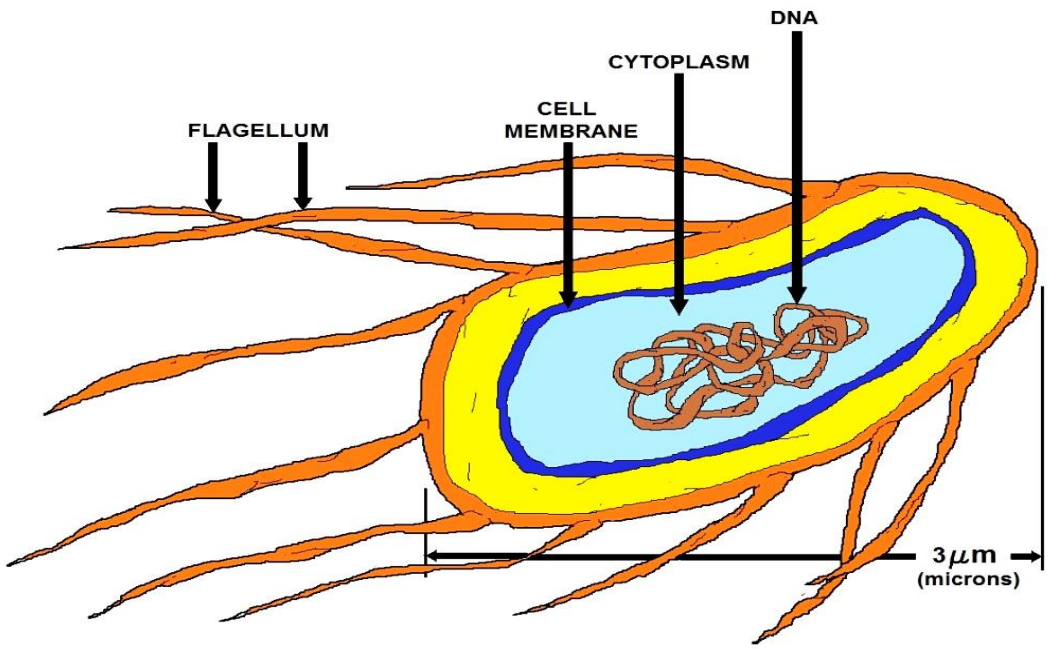


DIATOM

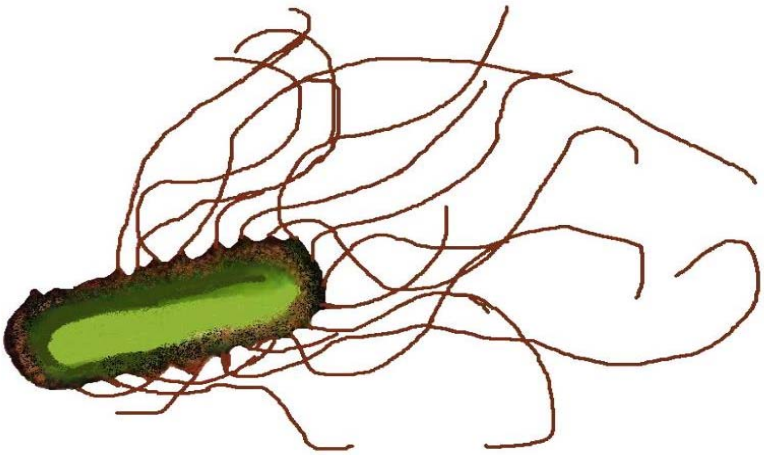
NEMATODE

Bacteria - Detailed Section





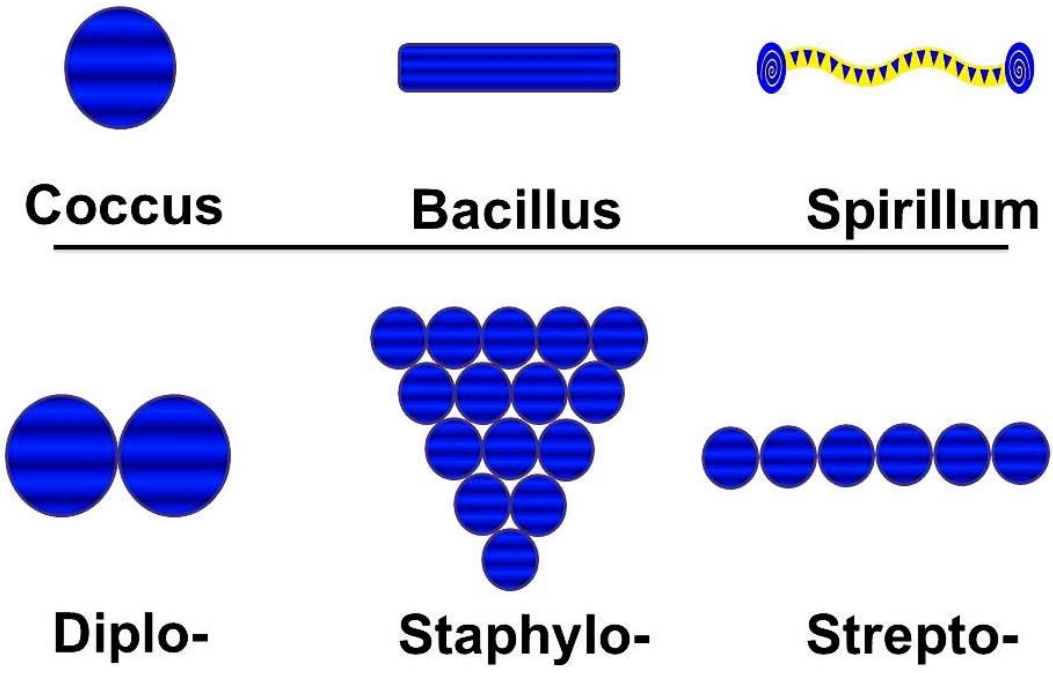
E-COLI BACTERIUM



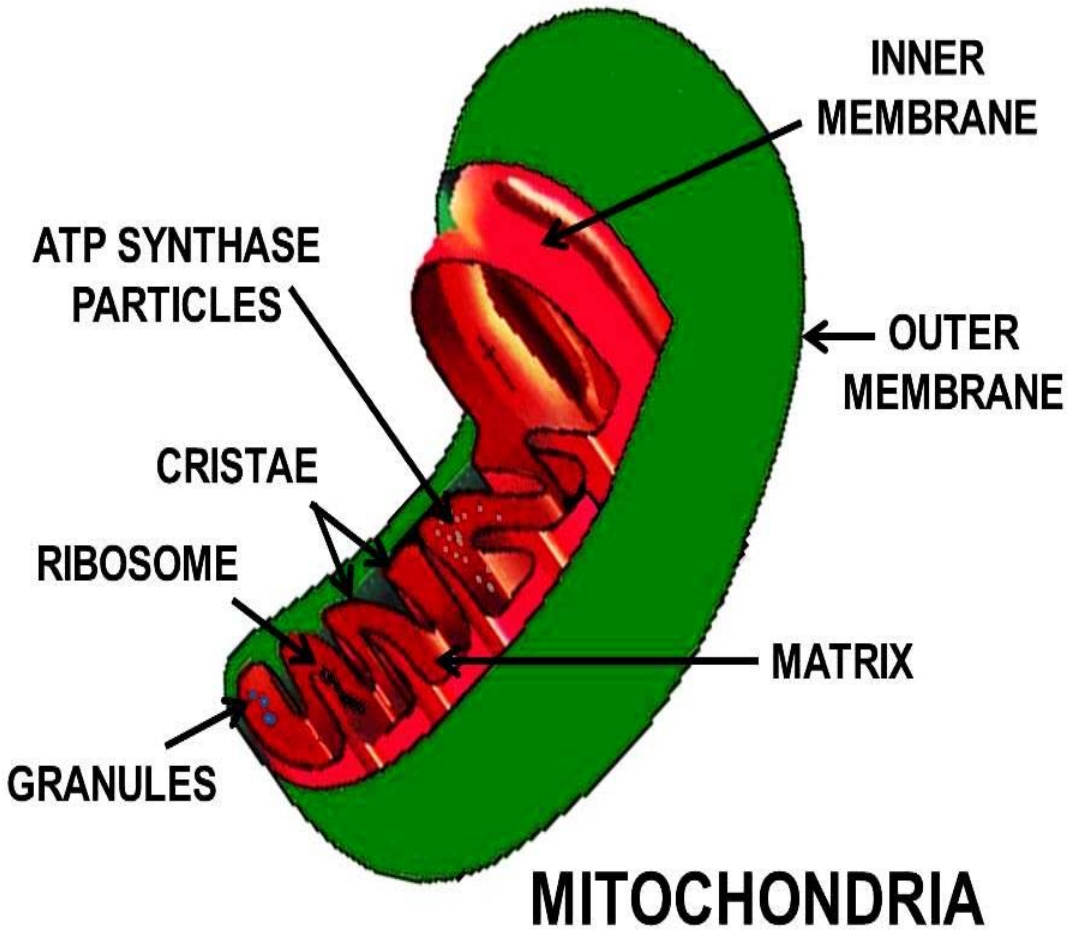
Peritrichous Bacteria

Microbiologists broadly classify bacteria according to their shape: spherical, rod-shaped, and spiral-shaped. Pleomorphic bacteria can assume a variety of shapes. Bacteria may be further classified according to whether they require oxygen (aerobic or anaerobic) and how they react to a test with Gram's stain.

Bacteria in which alcohol washes away Gram's stain are called gram-negative, while bacteria in which alcohol causes the bacteria's walls to absorb the stain are called gram-positive.



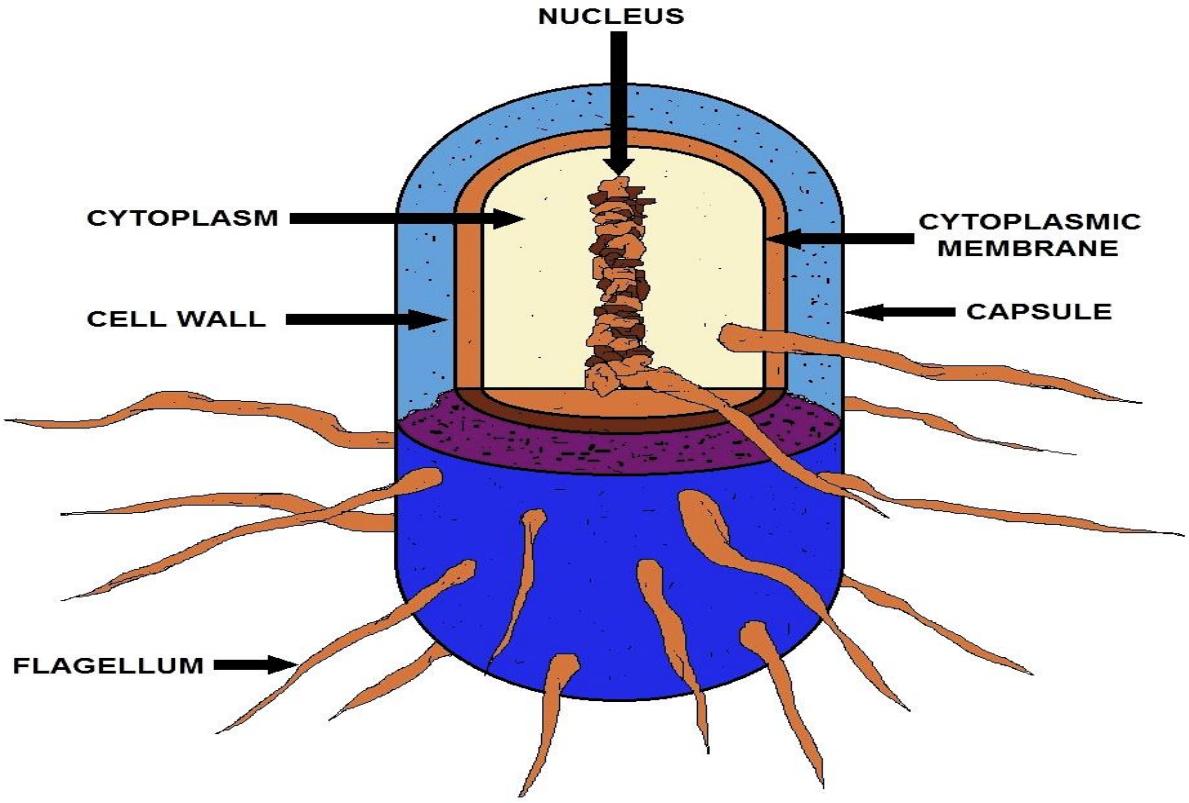
Bacterial Cell



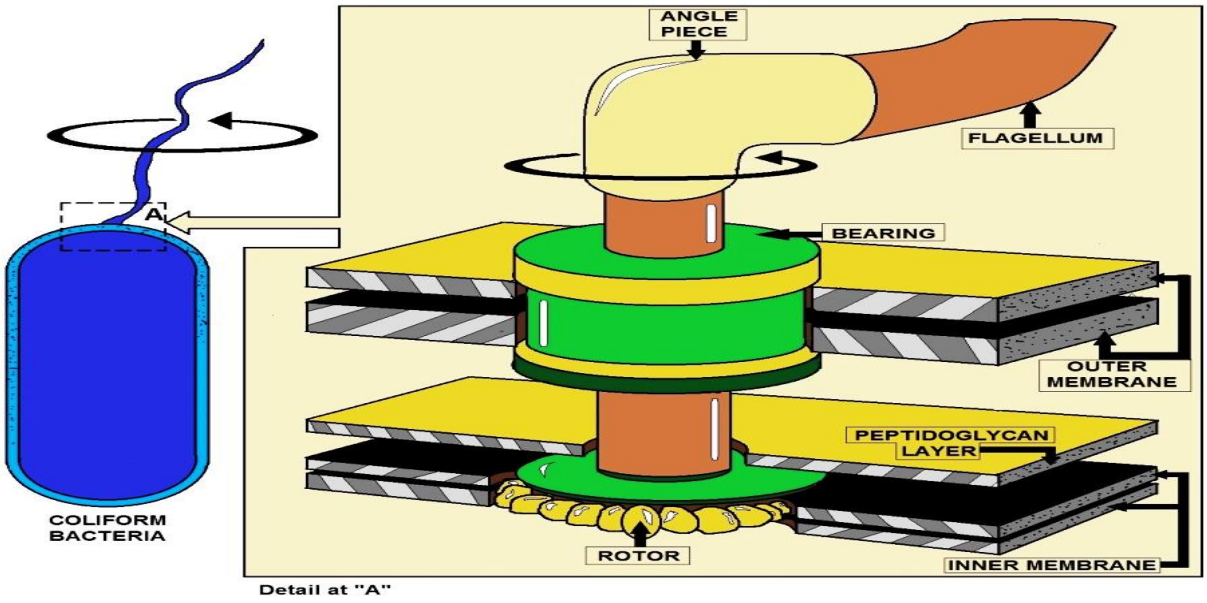
Mitochondria

The bacterial cell is surrounded by a lipid membrane, or cell membrane, which encloses the contents of the cell and acts as a barrier to hold nutrients, proteins and other essential components of the cytoplasm within the cell. As they are prokaryotes, bacteria do not tend to have membrane-bound organelles in their cytoplasm and thus contain few large intracellular structures.

They consequently lack a nucleus, mitochondria, chloroplasts and the other organelles present in eukaryotic cells, such as the Golgi apparatus and endoplasmic reticulum.



BACTERIAL STRUCTURE

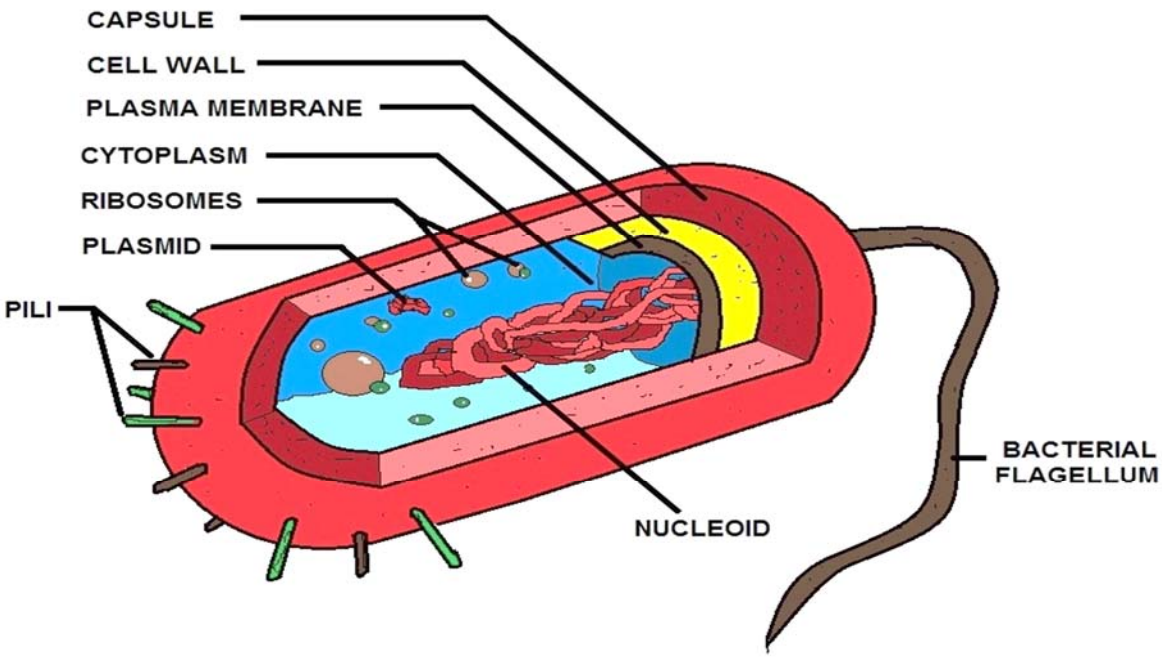


FLAGELLUM DIAGRAM

Bacterial Glossary

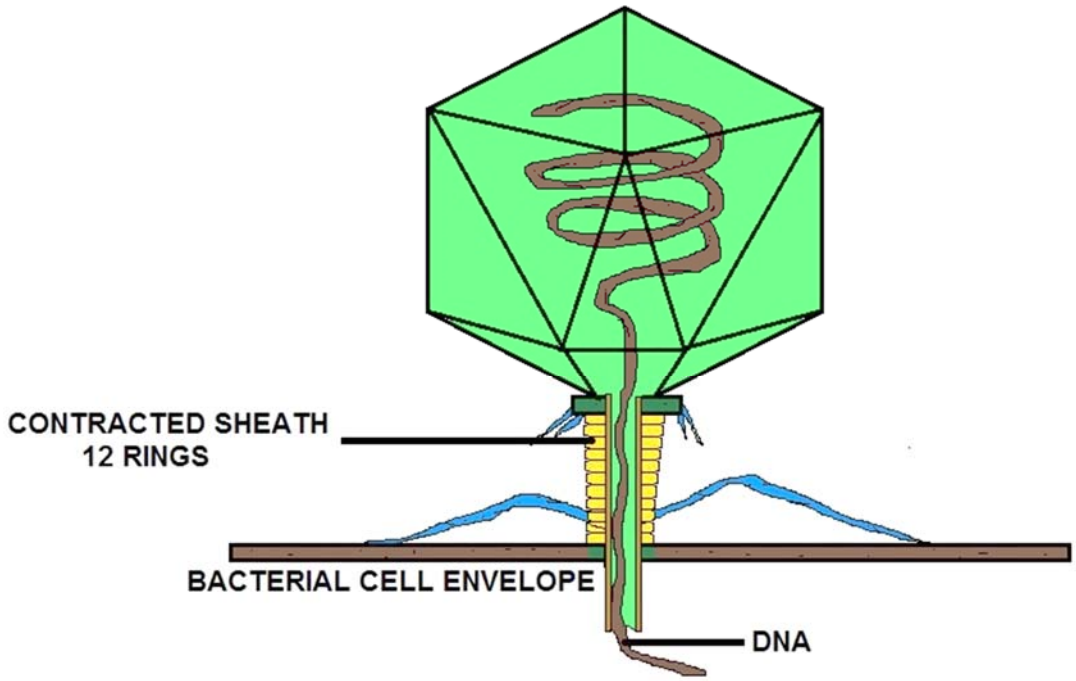
Type	Characteristics
Acetic acid	Rod-shaped, gram-negative, aerobic; highly tolerant of acidic conditions; generate organic acids
Actinomycete	Rod-shaped or filamentous, gram-positive, aerobic; common in soils; essential to growth of many plants; source of much of original antibiotic production in pharmaceutical industry
Coccoid	Spherical, sometimes in clusters or strings, gram-positive, aerobic and anaerobic; resistant to drying and high-salt conditions; *Staphylococcus* species common on human skin, certain strains associated with toxic shock syndrome
Coryneform	Rod-shaped, form club or V shapes, gram-positive, aerobic; found in wide variety of habitats, particularly soils; highly resistant to drying; include *Arthrobacter,* among most common forms of life on earth
Endospore-forming	Usually rod-shaped, can be gram-positive or gram-negative; have highly adaptable, heat-resistant spores that can go dormant for long periods, possibly thousands of years; include *Clostridium* (anaerobic) and *Bacillus* (aerobic)
Enteric	Rod-shaped, gram-negative, aerobic but can live in certain anaerobic conditions; produce nitrite from nitrate, acids from glucose; include *Escherichia coli, Salmonella* (over 1000 types), and *Shigella*
Gliding	Rod-shaped, gram-negative, mostly aerobic; glide on secreted slimy substances; form colonies, frequently with complex fruiting structures
Lactic acid	Gram-positive, anaerobic; produce lactic acid through fermentation; include *Lactobacillus*, essential in dairy product formation, and *Streptococcus*, common in humans
Mycobacterium	Pleomorphic, spherical or rod-shaped, frequently branching, no gram stain, aerobic; commonly form yellow pigments; include *Mycobacterium tuberculosis,* cause of tuberculosis
Mycoplasma	Spherical, commonly forming branching chains, no gram stain, aerobic but can live in certain anaerobic conditions; without cell walls yet structurally resistant to lysis; among smallest of bacteria; named for superficial resemblance to fungal hyphae (*myco-* means 'fungus')
Nitrogen-fixing	Rod-shaped, gram-negative, aerobic; convert atmospheric nitrogen gas to ammonium in soil; include *Azotobacter,* a common genus
Propionic acid	Rod-shaped, pleomorphic, gram-positive, anaerobic; ferment lactic acid; fermentation produces holes in Swiss cheese from the production of carbon dioxide
Pseudomonad	Rod-shaped (straight or curved) with polar flagella, gram-negative, aerobic; can use up to 100 different compounds for carbon and energy
Rickettsia	Spherical or rod-shaped, gram-negative, aerobic; cause Rocky Mountain spotted fever and typhus; closely related to *Agrobacterium,* a common gall-causing plant bacterium

Sheathed	Filamentous, gram-negative, aerobic; 'swarmer' (colonizing) cells form and break out of a sheath; sometimes coated with metals from environment
Spirillum	Spiral-shaped, gram-negative, aerobic; include *Bdellovibrio,* predatory on other bacteria
Spirochete	Spiral-shaped, gram-negative, mostly anaerobic; common in moist environments, from mammalian gums to coastal mudflats; complex internal structures convey rapid movement; include *Treponemapallidum,* cause of syphilis
Sulfate- and Sulfur-reducing	Commonly rod-shaped, mostly gram-negative, anaerobic; include *Desulfovibrio,* ecologically important in marshes
Sulfur- and iron-oxidizing	Commonly rod-shaped, frequently with polar flagella, gram-negative, mostly anaerobic; most live in neutral (nonacidic) environment
Vibrio	Rod- or comma-shaped, gram-negative, aerobic; commonly with a single flagellum; include *Vibrio cholerae,* cause of cholera, and luminescent forms symbiotic with deep-water fishes and squids



PROKARYOTIC CELL (BACTERIA)

Bacteriophage



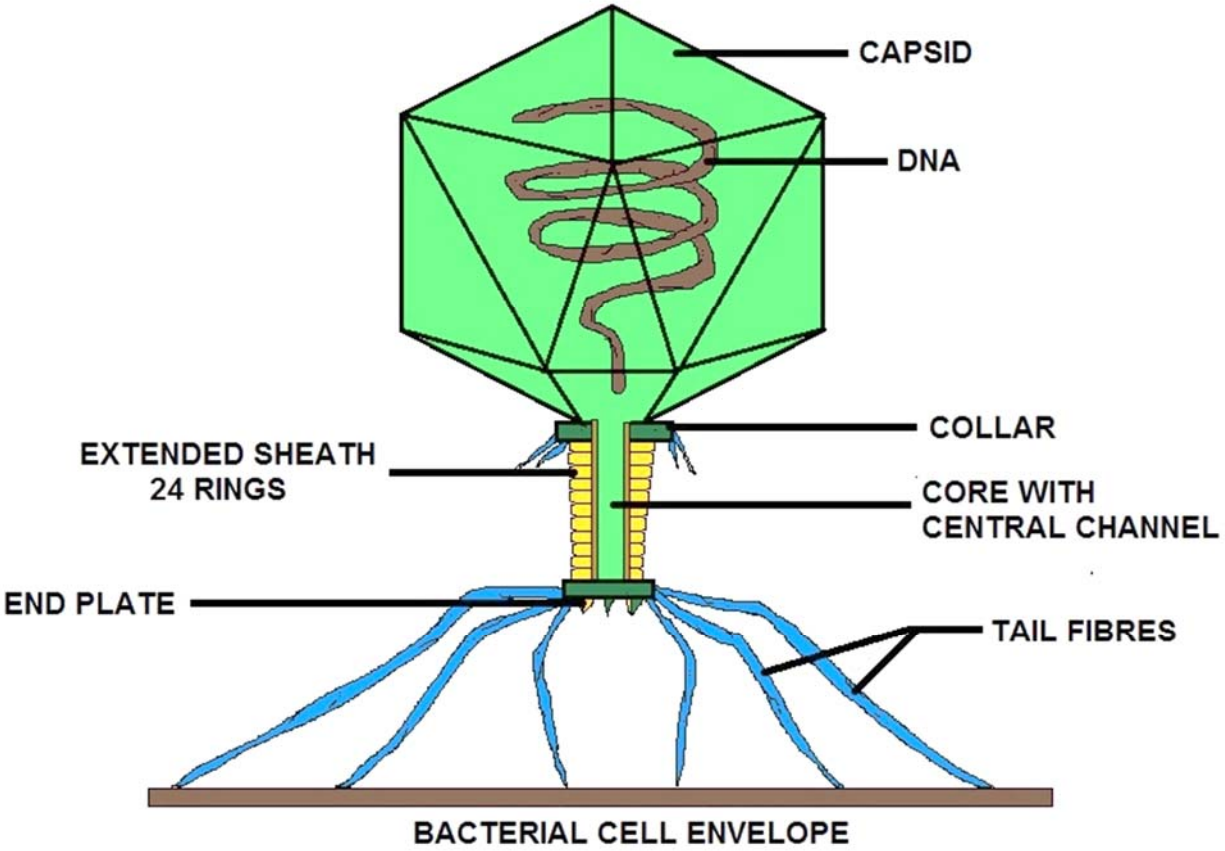
VIRUS CAPSID (BACTERIOPHAGES)

A bacteriophage (from 'bacteria' and Greek phagein, 'to eat') is any one of a number of viruses that infect bacteria. The term is commonly used in its shortened form, phage.

Typically, bacteriophages consist of an outer protein hull enclosing genetic material. The genetic material can be ssRNA (single stranded RNA), dsRNA, ssDNA, or dsDNA between 5 and 500 kilo base pairs long with either circular or linear arrangement. Bacteriophages are much smaller than the bacteria they destroy - usually between 20 and 200 nm in size.

Phages are estimated to be the most widely distributed and diverse entities in the biosphere. Phages are ubiquitous and can be found in all reservoirs populated by bacterial hosts, such as soil or the intestine of animals.

One of the densest natural sources for phages and other viruses is sea water, where up to 9×108 virions per milliliter have been found in microbial mats at the surface, and up to 70% of marine bacteria may be infected by phages.



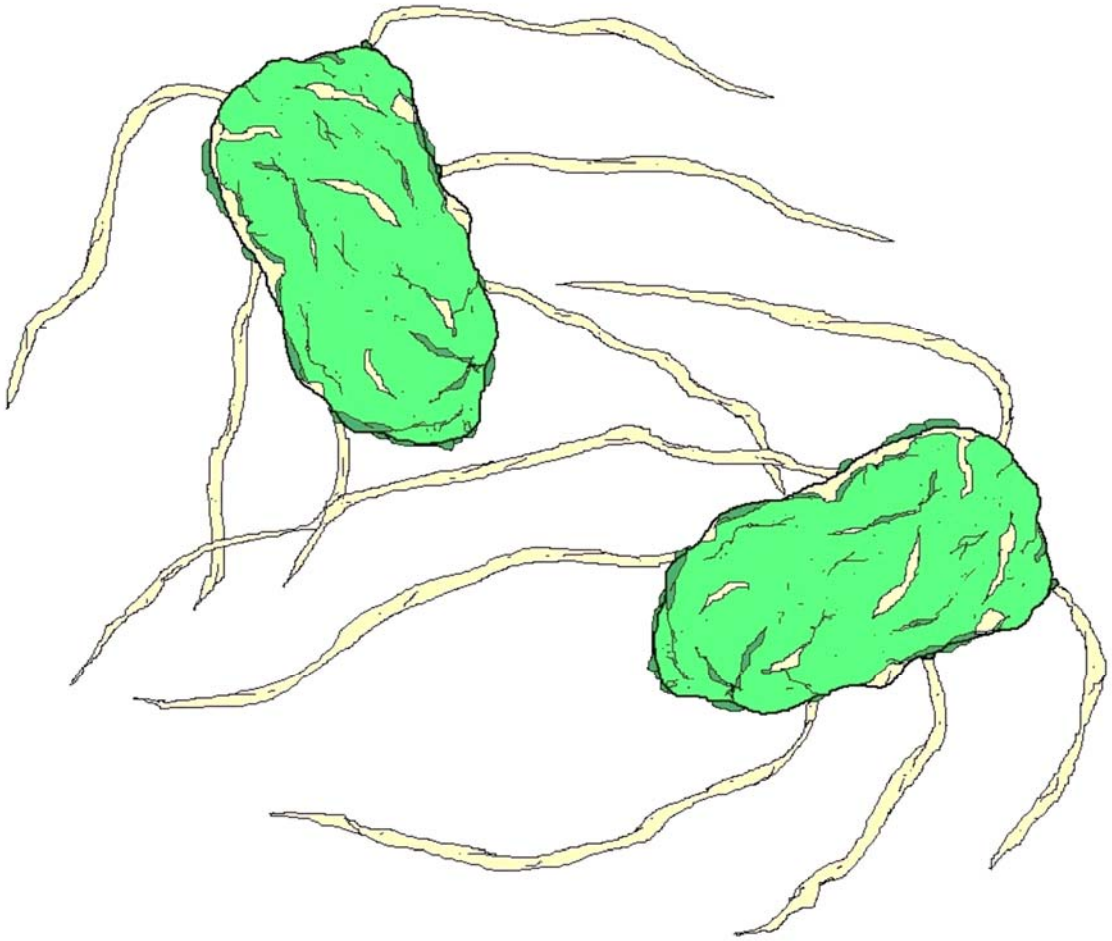
VIRUS CAPSID (BACTERIOPHAGES)

Release of Virions

Phages may be released via cell lysis or by host cell secretion. In the case of the T4 phage, in just over twenty minutes after injection upwards of three hundred phages will be released via lysis within a certain timescale. This is achieved by an enzyme called endolysin which attacks and breaks down the peptidoglycan.

In contrast, "lysogenic" phages do not kill the host but rather become long-term parasites and make the host cell continually secrete more new virus particles. The new virions bud off the plasma membrane, taking a portion of it with them to become enveloped viruses possessing a viral envelope. All released virions are capable of infecting a new bacterium.

Salmonella



SALMONELLA

Salmonella is a Gram-negative bacterium. It is found in many turtles and other reptiles. In clinical laboratories, it is usually isolated on MacConkey agar, XLD agar, XLT agar, DCA agar, or Önöz agar.

Because they cause intestinal infections and are greatly outnumbered by the bacteria normally found in the healthy bowel, primary isolation requires the use of a selective medium, so use of a relatively non-selective medium such as CLED agar is not often practiced. Numbers of salmonella may be so low in clinical samples that stools are routinely also subjected to "enrichment culture", where a small volume of stool is incubated in a selective broth medium, such as selenite broth or Rappaport Vassiliadis soya peptone broth, overnight.

These media are inhibitory to the growth of the microbes normally found in the healthy human bowel, while allowing salmonellae to become enriched in numbers. Salmonellae may then be recovered by inoculating the enrichment broth on one or more of the primary selective media. On blood agar, they form moist colonies about 2 to 3 mm in diameter.

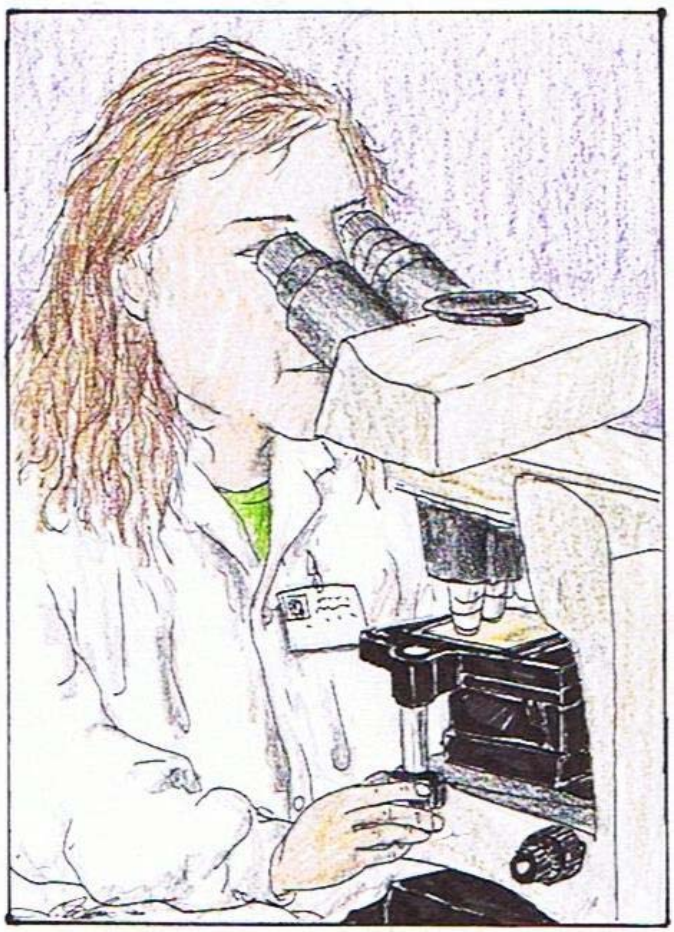
When the cells are grown for a prolonged time at a range of 25—28°C, some strains produce a biofilm, which is a matrix of complex carbohydrates, cellulose and proteins.

The ability to produce biofilm (a.k.a. "rugose", "lacy", or "wrinkled") can be an indicator of dimorphism, which is the ability of a single genome to produce multiple phenotypes in response to environmental conditions. Salmonellae usually do not ferment lactose; most of them produce hydrogen sulfide which, in media containing ferric ammonium citrate, reacts to form a black spot in the center of the creamy colonies.

Classification

Salmonella taxonomy is complicated. As of December 7, 2005, there are two species within the genus: S. bongori (previously subspecies V) and S. enterica (formerly called S. choleraesuis), which is divided into six subspecies:

* I—enterica
* II—salamae
* IIIa—arizonae
* IIIb—diarizonae
* IV—houtenae
* V—obsolete (now designated S. bongori)
* VI—indica

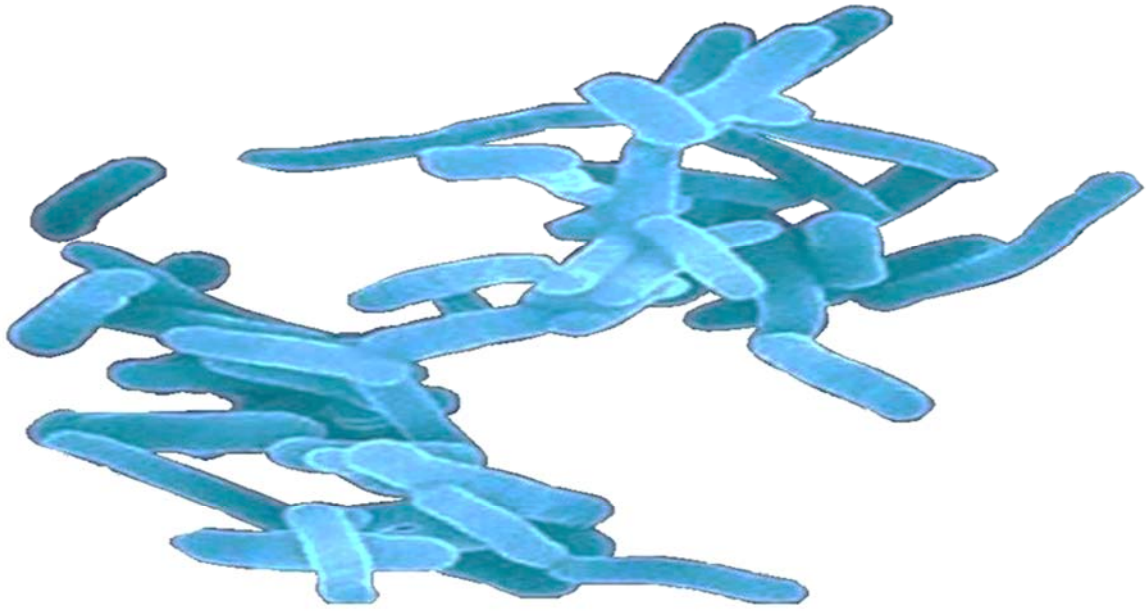


There are also numerous (over 2500) serovars within both species, which are found in a disparate variety of environments and which are associated with many different diseases.

The vast majority of human isolates (>99.5%) are subspecies S. enterica. For the sake of simplicity, the CDC recommends that Salmonella species be referred to only by their genus and serovar, e.g.

Salmonella Typhi instead of the more technically correct designation, Salmonella enterica subspecies enterica serovar Typhi.

Shigella dysenteriae



SHIGELLA DYSENTERIAE

Shigella dysenteriae is a species of the rod-shaped bacterial genus Shigella. Shigella can cause shigellosis (bacillary dysentery). Shigellae are Gram-negative, non-spore-forming, facultatively anaerobic, non-motile bacteria.

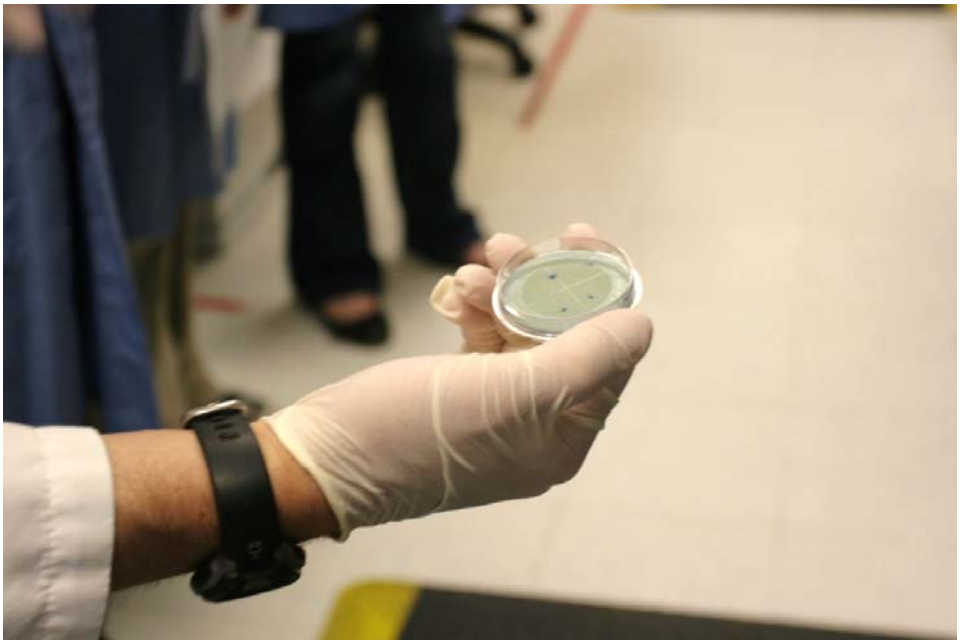
S. dysenteriae, spread by contaminated water and food, causes the most severe dysentery because of its potent and deadly Shiga toxin, but other species may also be dysentery agents. Shigella infection is typically via ingestion (fecal–oral contamination); depending on age and condition of the host as few as ten bacterial cells can be enough to cause an infection. Shigella causes dysentery that result in the destruction of the epithelial cells of the intestinal mucosa in the cecum and rectum. Some strains produce enterotoxin and Shiga toxin, similar to the verotoxin of E. coli O157:H7. Both Shiga toxin and verotoxin are associated with causing hemolytic uremic syndrome.

Shigella invades the host through epithelial cells of the large intestine. Using a Type III secretion system acting as a biological syringe, the bacterium injects IpaD protein into cell, triggering bacterial invasion and the subsequent lysis of vacuolar membranes using IpaB and IpaC proteins. It utilizes a mechanism for its motility by which its IcsA protein triggers actin polymerization in the host cell (via N-WASP recruitment of Arp2/3 complexes) in a "rocket" propulsion fashion for cell-to-cell spread.

The most common symptoms are diarrhea, fever, nausea, vomiting, stomach cramps, and straining to have a bowel movement. The stool may contain blood, mucus, or pus (e.g. dysentery). In rare cases, young children may have seizures. Symptoms can take as long as a week to show up, but most often begin two to four days after ingestion. Symptoms usually last for several days, but can last for weeks. Shigella is implicated as one of the pathogenic causes of reactive arthritis worldwide.

Top Photo: This technician is using Colilert which is a commercially available enzyme-substrate liquid-broth medium (IDEXX Laboratories, Inc.) that allows the simultaneous detection of total coliforms and *Escherichia coli* (*E. coli*). It is available in the most-probable number (MPN) or the presence/absence (PA) format. The MPN method is facilitated by use of a specially designed disposable incubation tray called the Quanti-Tray®.

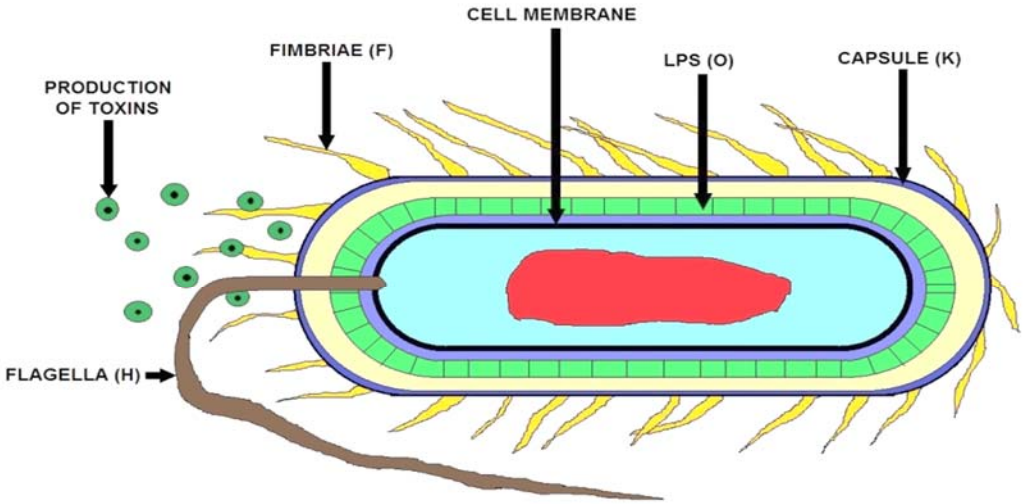
Bottom Photo: Another method is using a petri dish with a filter membrane. The broth and membrane used vary depending on the sample type for water or wastewater.



Escherichia Coli Section

Fecal Coliform Bacteria
Fecal coliform bacteria are microscopic organisms that live in the intestines of warm-blooded animals. They also live in the waste material, or feces, excreted from the intestinal tract. When fecal coliform bacteria are present in high numbers in a water sample, it means that the water has received fecal matter from one source or another. Although not necessarily agents of disease, fecal coliform bacteria may indicate the presence of disease-carrying organisms, which live in the same environment as the fecal coliform bacteria.

Reasons for Natural Variation
Unlike the other conventional water quality parameters, fecal coliform bacteria are living organisms. They do not simply mix with the water and float straight downstream. Instead they multiply quickly when conditions are favorable for growth, or die in large numbers when conditions are not. Because bacterial concentrations are dependent on specific conditions for growth, and these conditions change quickly, fecal coliform bacteria counts are not easy to predict. For example, although winter rains may wash more fecal matter from urban areas into a stream, cool water temperatures may cause a major die-off. Exposure to sunlight (with its ultraviolet disinfection properties) may have the same effect, even in the warmer water of summertime.



E. COLI

Expected Impact of Pollution
The primary sources of fecal coliform bacteria to fresh water are wastewater treatment plant discharges, failing septic systems, and animal waste. Bacteria levels do not necessarily decrease as a watershed develops from rural to urban. Instead, urbanization usually generates new sources of bacteria. Farm animal manure and septic systems are replaced by domestic pets and leaking sanitary sewers.

In fact, stormwater runoff in urbanized areas has been found to be surprisingly high in fecal coliform bacteria concentrations. General coliforms, E. Coli, and Enterococcus bacteria are the "indicator" organisms generally measured to assess microbiological quality of water. However, these aren't generally what get people sick.

Other bacteria, viruses, and parasites are what we are actually worried about because it is so much more expensive and tedious to do so; actual pathogens are virtually never tested for.

Coliform Standards (in colonies/100ml)

Drinking water..... 0 FC
Total body contact (swimming).....200 FC
Partial body contact (boating)..... 1000 FC
Threatened sewage effluent .....not to exceed 200 FC
*Total coliform (TC) includes bacteria from cold-blooded animals and various soil organisms. According to recent literature, total coliform counts are normally about 10 times higher than fecal coliform (FC) counts.

Indicator Connection Varies
Over the course of a professional lifetime pouring over indicator tests, in a context where all standards are based on indicators, water workers tend to forget that the indicators are not the things we actually care about. Infection rates are around 5% in the US, and approach 100% in areas with poor hygiene and contaminated water supplies.

Keep in the back of your mind that ***the ratio of indicators to actual pathogens is not fixed***. It will always be different, sometimes very different.

Whenever you are trying to form a mental map of reality based on water tests, you should include in the application of your water intuition an adjustment factor for your best guess of the ratio between indicators and actual pathogens.

What are these indicators? More information in the Laboratory section.

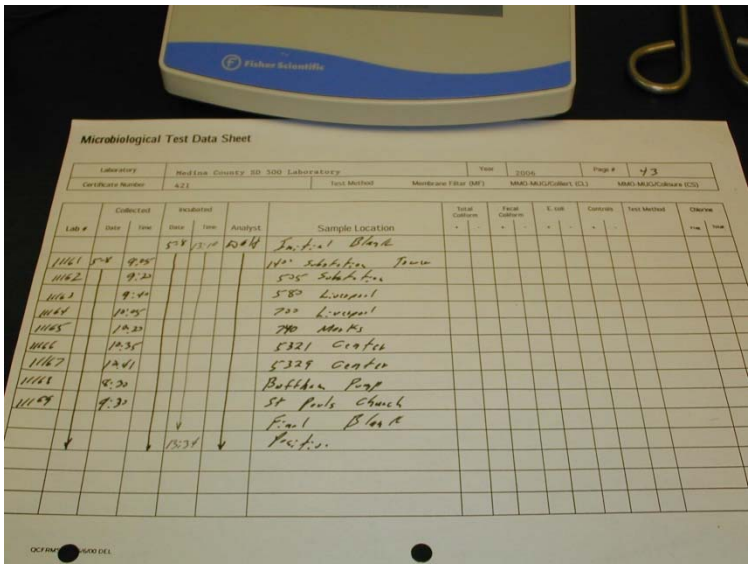
- **General coliforms** indicate that the water has come in contact with plant or animal life. General coliforms are universally present, including in pristine spring water. They are of little concern at low levels, except to indicate the effectiveness of disinfection. Chlorinated water and water from perfectly sealed tube wells is the only water I've tested which had zero general coliforms. At very high levels they indicate there is what amounts to a lot of compost in the water, which could easily include pathogens (Ten thousand general coliform bacteria will get you a beach closure, compared to two or four hundred fecal coliforms, or fifty enterococcus).
- **Fecal coliforms**, particularly E. coli, indicate that there are mammal or bird feces in the water.
- **Enterococcus bacteria** also indicate that there are feces from warm blooded animals in the water. Enterococcus are a type of fecal streptococci. They are another valuable indicator for determining the amount of fecal contamination of water.
  According to studies conducted by the EPA, enterococci have a greater correlation with swimming-associated gastrointestinal illness in both marine and fresh waters than other bacterial indicator organisms, and are less likely to "die off" in saltwater.

Membrane Filter Total Coliform Technique

The membrane filter total Coliform technique is used at Medina County for drinking water quality testing. The following is a summary of this test. A sampling procedure sheet is given to all sample takers by Medina County.

The samples are taken in sterile 100 mL containers. These containers, when used for chlorinated water samples, have a sodium thiosulfate pill or solution to dechlorinate the sample.

The sample is placed in cold storage after proper sample taking procedures are followed. (See sample procedures below)



The samples are taken to the laboratory with a chain of custody to assure no tampering of samples can occur.

These samples are logged in at the laboratory.

No longer than 30 hours can lapse between the time of sampling and time of test incubation. (8 hours for heterotrophic, non-potable 6 hours, others not longer than 24 hours)

All equipment is sterilized by oven and autoclave.
Glassware in oven at 170°C ± 10°C with foil (or other suitable wrap) loosely fitting and secured immediately after sterilization.

Filtration units in autoclave at 121°C for 30 minutes.

Use sterile petri dishes, grid, and pads bought from a reliable company – certified, quality assured - test for satisfactory known positive amounts.

Incubators – 35°C ± .5°C (60% relative humidity)

M-endo medium is prepared and heated to near boiling removed from heat cooled to 45°C pH adjusted to 7.2 ± .2 and immediately dispensed 8ml to plates. Keep refrigerated and discard after 2 weeks.

Plates can be stored in a dated box with expiration date and discarded if not used. No denatured alcohol should be used. Everclear or 95% proof alcohol or absolute methyl may be used for sterilizing forceps by flame.

Procedure:

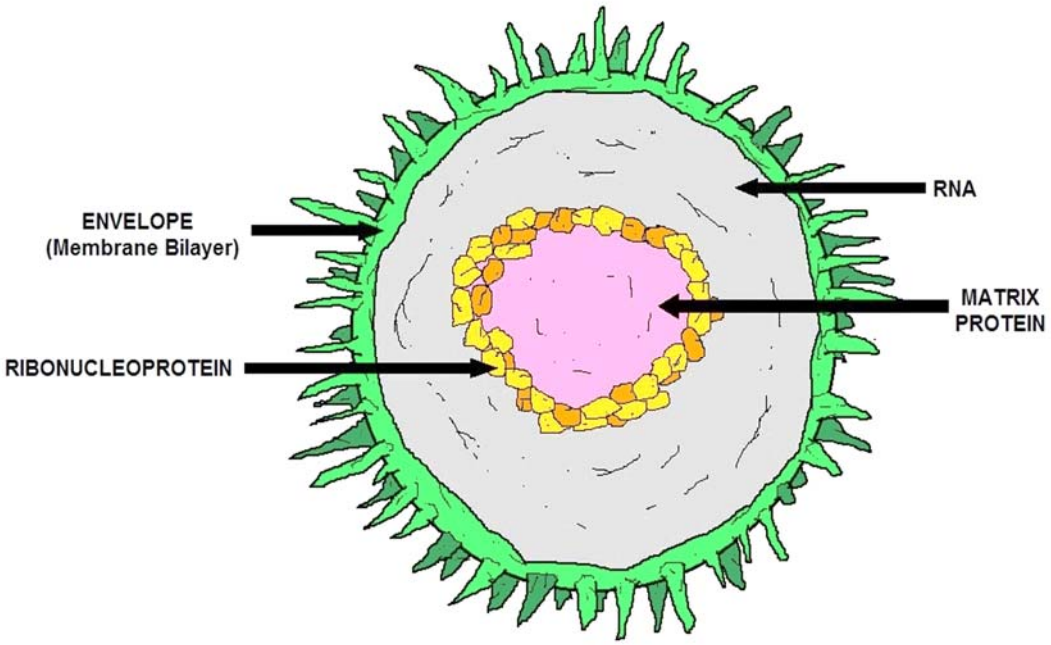
1. Counters are alcohol wiped.
2. Bench sheets are filled out.
3. Samples are removed from refrigeration.
4. Sterile wrapped utensils are placed on counters.
5. Filtration units are placed onto sterile membrane filters by aseptic technique using sterile forceps.
6. Sterile petri dishes are labeled.
7. The samples closures are clipped.
8. The sample is shaken 25 times 1 foot in length within 7 seconds.
9. 100 mL is filtered and rinsed with sterile distilled water 3 times.
10. The membrane filter is aseptically removed from filter holder.
11. A sterile padded petri dish is used and the membrane filter is rolled onto the pad making sure no air bubbles form.
12. The sterile labeled lid is placed on the petri dish.
13. 2 blanks and a known is run with each series of samples.
14. The samples are placed in the 35^{o}C $\pm$ .5^{o}C incubator stacked no higher than 3 for 22 – 24 hours (Humidity can be maintained by saturated paper towels placed under containers holding petri dishes.)
15. After 22- 24 hours view the petri dishes under a 10 –15 power magnification with cool white fluorescent light.
16. Count all colonies that appear pink to dark red with a metallic surface sheen – the sheen may vary in size from a pin head to complete coverage.
17. Report as Total Coliform per 100 mL.
18. If no colonies are present report as <1 coliform/100mL.

Anything greater than 1 is over the limit for drinking water for 2 samples taken 24 hours apart. Further investigation may be necessary – follow Standard Methods accordingly.

Photograph and Credits to Mary McPherson
Aran™ Aqua Analytical Laboratory Director.

Viruses

Viruses are acellular microorganisms. They are made up of only genetic material and a protein coat. Viruses depend on the energy and metabolic machinery of the host cell to reproduce. A virus is an infectious agent found in virtually all life forms, including humans, animals, plants, fungi, and bacteria. Viruses consist of genetic material—either deoxyribonucleic acid (DNA) or ribonucleic acid (RNA)—surrounded by a protective coating of protein, called a capsid, with or without an outer lipid envelope. Viruses are between 20 and 100 times smaller than bacteria and hence are too small to be seen by light microscopy.



CROSS SECTIONAL VIEW OF A VIRUS

Viruses vary in size from the largest poxviruses of about 450 nanometers (about 0.000014 in) in length to the smallest polioviruses of about 30 nanometers (about 0.000001 in). Viruses are not considered free-living, since they cannot reproduce outside of a living cell; they have evolved to transmit their genetic information from one cell to another for the purpose of replication. Viruses often damage or kill the cells that they infect, causing disease in infected organisms.

A few viruses stimulate cells to grow uncontrollably and produce cancers. Although many infectious diseases, such as the common cold, are caused by viruses, there are no cures for these illnesses.

The difficulty in developing antiviral therapies stems from the large number of variant viruses that can cause the same disease, as well as the inability of drugs to disable a virus without disabling healthy cells. However, the development of antiviral agents is a major focus of current research, and the study of viruses has led to many discoveries important to human health.

Virions
Individual viruses, or virus particles, also called virions, contain genetic material, or genomes, in one of several forms. Unlike cellular organisms, in which the genes always are made up of DNA, viral genes may consist of either DNA or RNA. Like cell DNA, almost all viral DNA is double-stranded, and it can have either a circular or a linear arrangement. Almost all viral RNA is single-stranded; it is usually linear, and it may be either segmented (with different genes on different RNA molecules) or non-segmented (with all genes on a single piece of RNA).

Capsids
The viral protective shell, or capsid, can be either helical (spiral-shaped) or icosahedral (having 20 triangular sides). Capsids are composed of repeating units of one or a few different proteins. These units are called protomers or capsomers. The proteins that make up the virus particle are called structural proteins. Viruses also carry genes for making proteins that are never incorporated into the virus particle and are found only in infected cells. These viral proteins are called nonstructural proteins; they include factors required for the replication of the viral genome and the production of the virus particle.

Capsids and the genetic material (DNA or RNA) they contain are together referred to as nucleocapsids. Some virus particles consist only of nucleocapsids, while others contain additional structures.

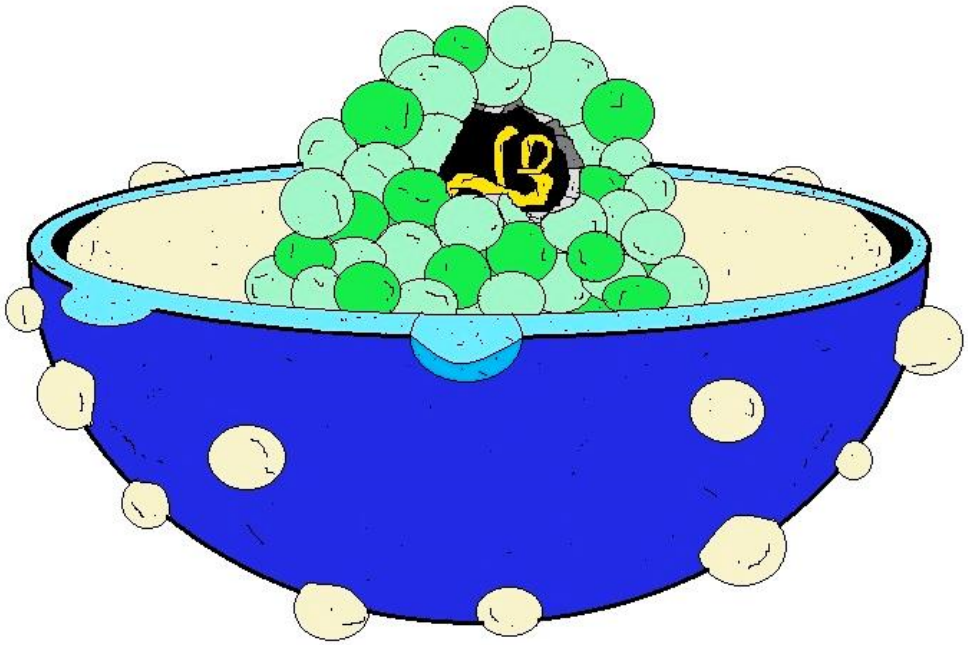
Some icosahedral and helical animal viruses are enclosed in a lipid envelope acquired when the virus buds through host-cell membranes. Inserted into this envelope are glycoproteins that the viral genome directs the cell to make; these molecules bind virus particles to susceptible host cells.

Bacteriophages
The most elaborate viruses are the bacteriophages, which use bacteria as their hosts. Some bacteriophages resemble an insect with an icosahedral head attached to a tubular sheath. From the base of the sheath extend several long tail fibers that help the virus attach to the bacterium and inject its DNA to be replicated, direct capsid production, and virus particle assembly inside the cell.

Viroids and Prions
Viroids and prions are smaller than viruses, but they are similarly associated with disease. Viroids are plant pathogens that consist only of a circular, independently replicating RNA molecule. The single-stranded RNA circle collapses on itself to form a rod-like structure. The only known mammalian pathogen that resembles plant viroids is the deltavirus (hepatitis D), which requires hepatitis B virus proteins to package its RNA into virus particles. Co-infection with hepatitis B and D can produce more severe disease than can infection with hepatitis B alone. Prions are mutated forms of a normal protein found on the surface of certain animal cells.

Virus Classification
Viruses are classified according to their type of genetic material, their strategy of replication, and their structure. The ICNV report published in 1995 assigned more than 4000 viruses into 71 virus families. Hundreds of other viruses remain unclassified because of the lack of sufficient information.

Hepatitis



HEPATITUS VIRUS

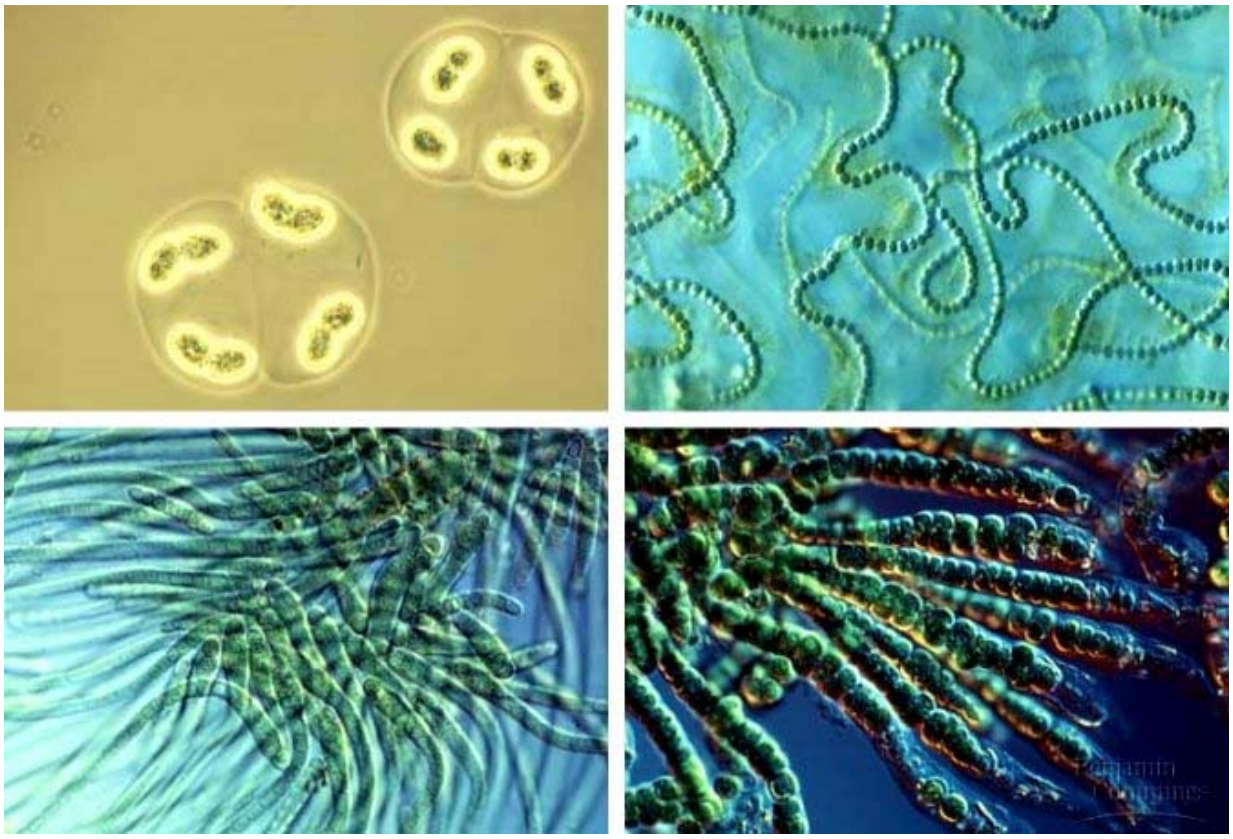
There are five types of hepatitis -- A through E -- all of which cause inflammation of the liver. Type D affects only those who also have hepatitis B, and hepatitis E is extremely rare in the United States.

- Type A hepatitis is contracted through anal-oral contact, by coming in contact with the feces of someone with hepatitis A, or by eating or drinking hepatitis A contaminated food or water.
- Type B hepatitis can be contracted from infected blood, seminal fluid, vaginal secretions, or contaminated drug needles, including tattoo or body-piercing equipment. It can also be spread from a mother to her newborn.
- Type C hepatitis is not easily spread through sex. You're more likely to get it through contact with infected blood, contaminated razors, needles, tattoo and body-piercing equipment, or manicure or pedicure tools that haven't been properly sanitized, and a mother can pass it to her baby during delivery.
- Type D hepatitis can be passed through contact with infected blood, contaminated needles, or by sexual contact with an HIV-infected person.
- Type E hepatitis is most likely to be transmitted in feces, through oral contact, or in water that's been contaminated.

Peptidoglycan

Peptidoglycan, also known as murein, is a polymer consisting of sugars and amino acids that forms a mesh-like layer outside the plasma membrane of eubacteria. The sugar component consists of alternating residues of β-(1,4) linked N-acetylglucosamine and N-acetylmuramic acid residues. Attached to the N-acetylmuramic acid is a peptide chain of three to five amino acids. The peptide chain can be cross-linked to the peptide chain of another strand forming the 3D mesh-like layer.

Cyanobacteria



Cyanobacteria

Cyanobacteria, also known as blue-green algae, blue-green bacteria or Cyanophyta, is a phylum of bacteria that obtain their energy through photosynthesis. The name "cyanobacteria" comes from the color of the bacteria (Greek: kyanós = blue). They are a significant component of the marine nitrogen cycle and an important primary producer in many areas of the ocean, but are also found on land.

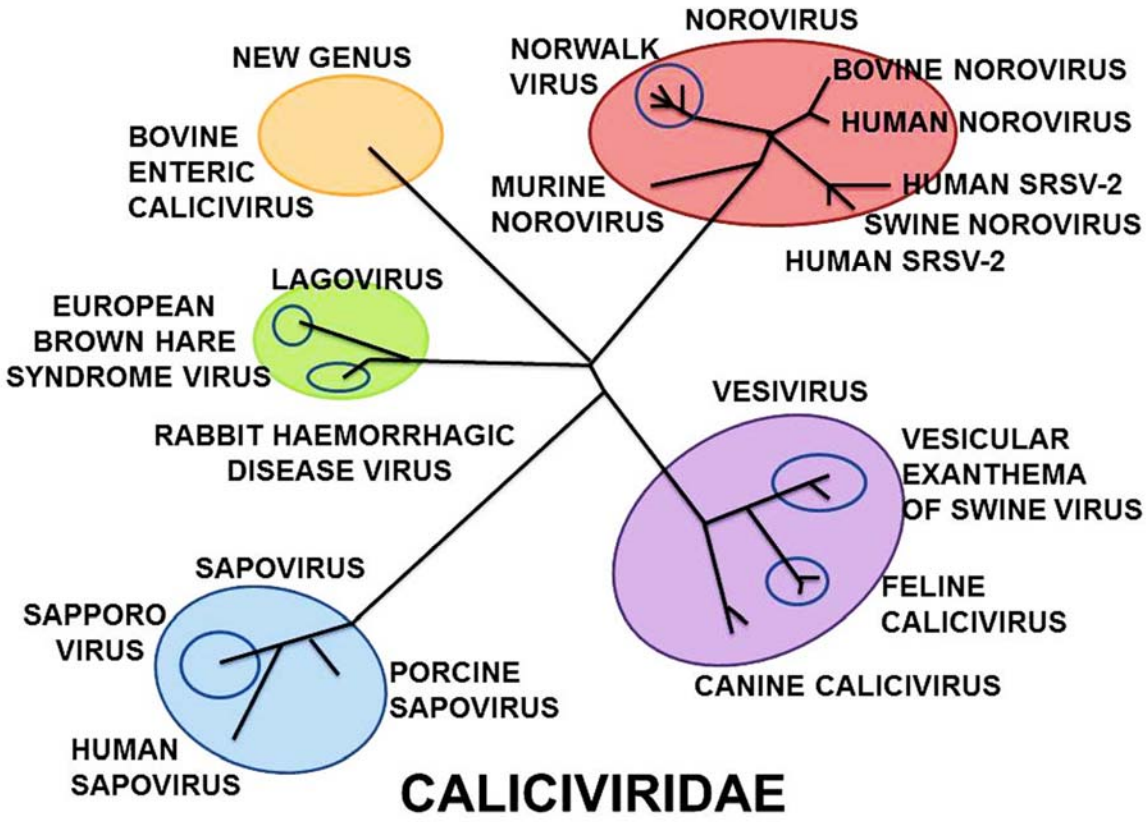
Cyanobacteria include unicellular and colonial species. Colonies may form filaments, sheets or even hollow balls. Some filamentous colonies show the ability to differentiate into several different cell types: vegetative cells, the normal, photosynthetic cells that are formed under favorable growing conditions; akinetes, the climate-resistant spores that may form when environmental conditions become harsh; and thick-walled heterocysts, which contain the enzyme nitrogenase, vital for nitrogen fixation.

Heterocysts may also form under the appropriate environmental conditions (anoxic) wherever nitrogen is necessary. Heterocyst-forming species are specialized for nitrogen fixation and are able to fix nitrogen gas, which cannot be used by plants, into ammonia (NH_3), nitrites (NO_2) or nitrates (NO_3), which can be absorbed by plants and converted to protein and nucleic acids.

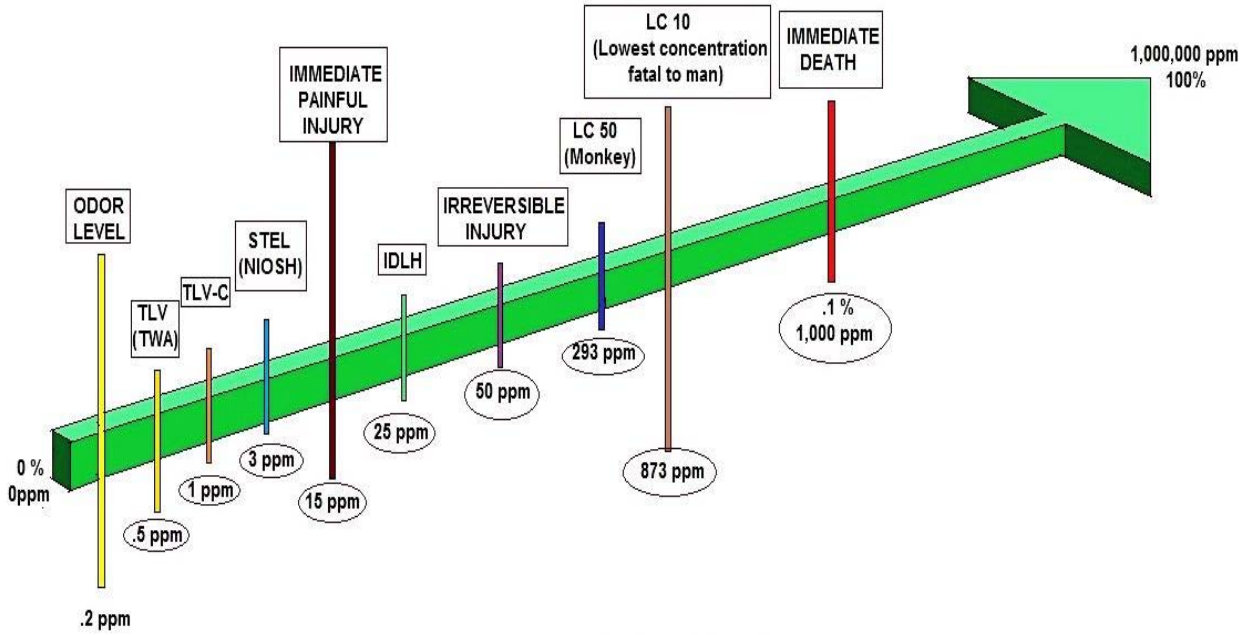
The rice paddies of Asia, which produce about 75% of the world's rice, could not do so were it not for healthy populations of nitrogen-fixing cyanobacteria in the rice paddy fertilizer too.

Many cyanobacteria also form motile filaments, called hormogonia, that travel away from the main biomass to bud and form new colonies elsewhere. The cells in a hormogonium are often thinner than in the vegetative state, and the cells on either end of the motile chain may be tapered. In order to break away from the parent colony, a hormogonium often must tear apart a weaker cell in a filament, called a necridium.

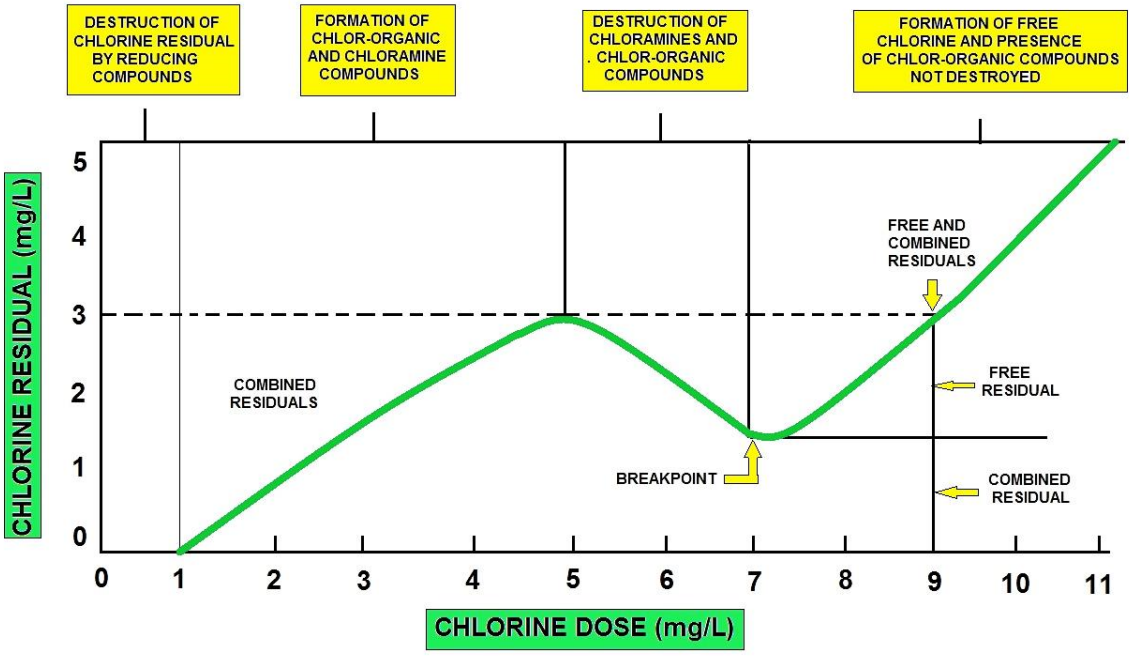
Each individual cell of a cyanobacterium typically has a thick, gelatinous cell wall. They differ from other gram-negative bacteria in that the quorum sensing molecules autoinducer-2[4] and acyl-homoserine lactones are absent. They lack flagella, but hormogonia and some unicellular species may move about by gliding along surfaces. In water columns some cyanobacteria float by forming gas vesicles, like in archaea.



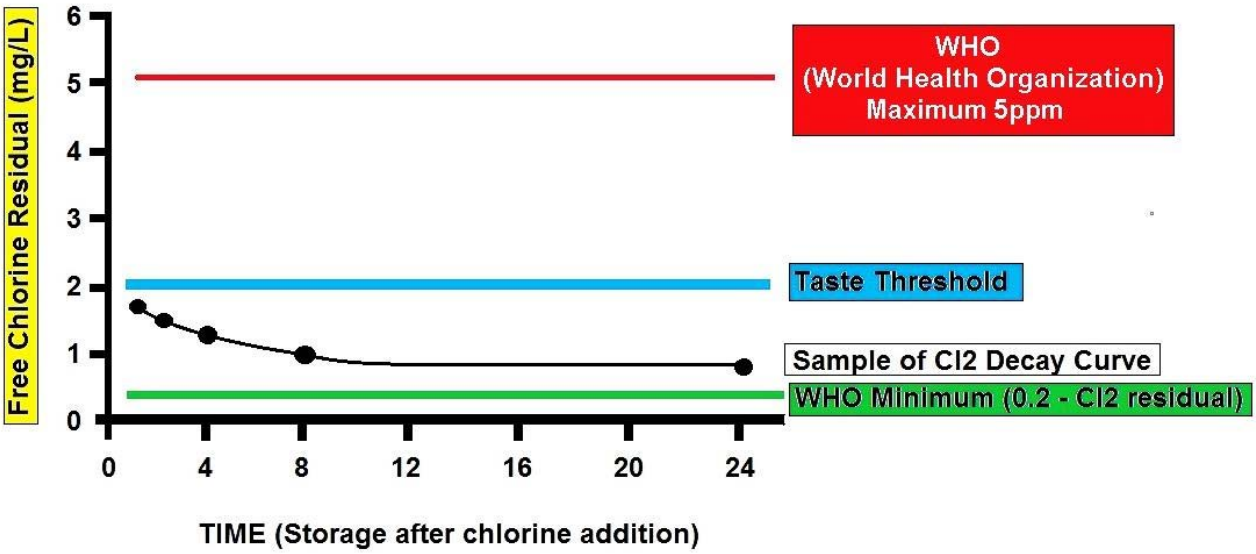
Chlorine and Disinfection Charts



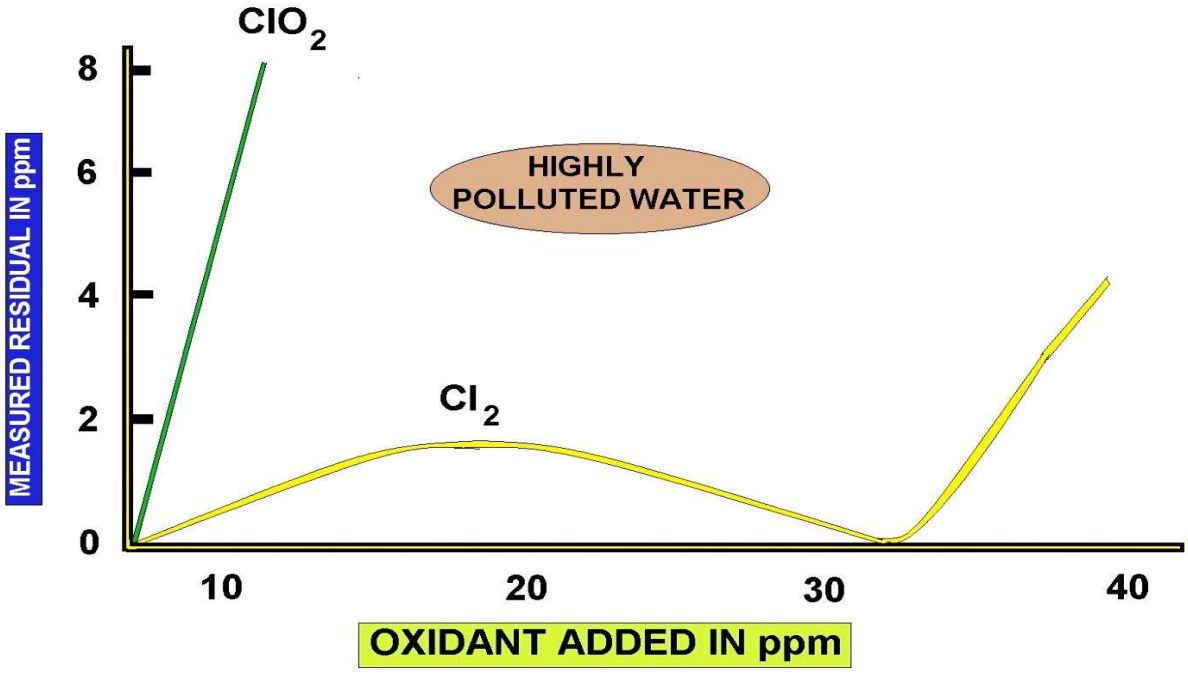
CHLORINE POISON LINES



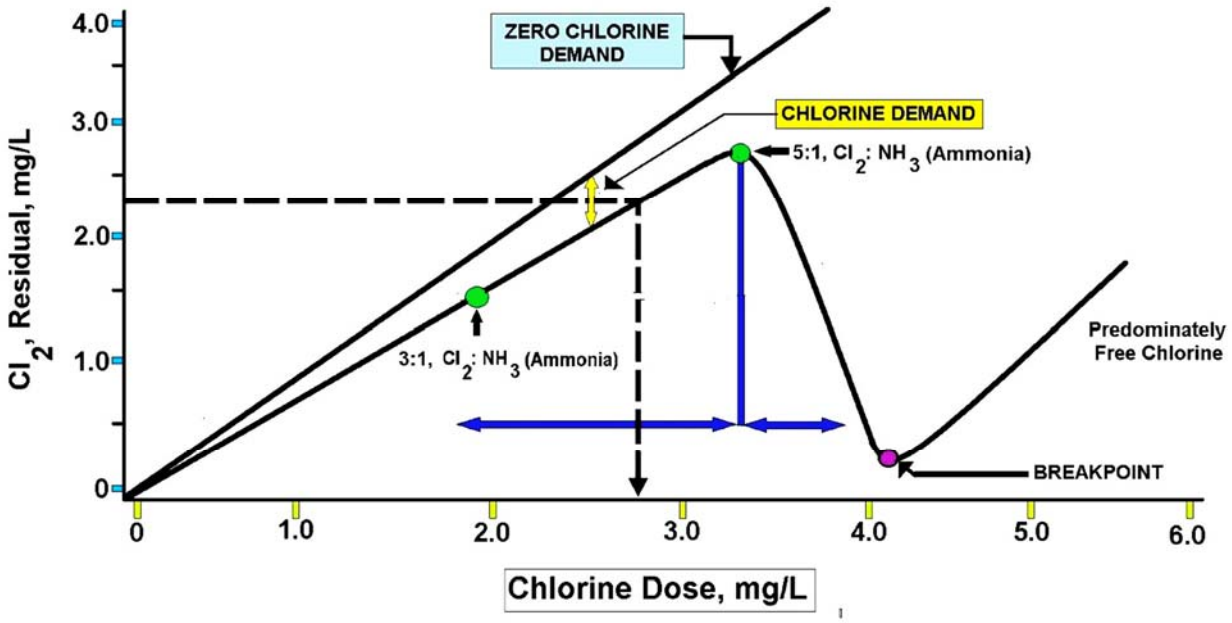
CHLORINE BREAKPOINT



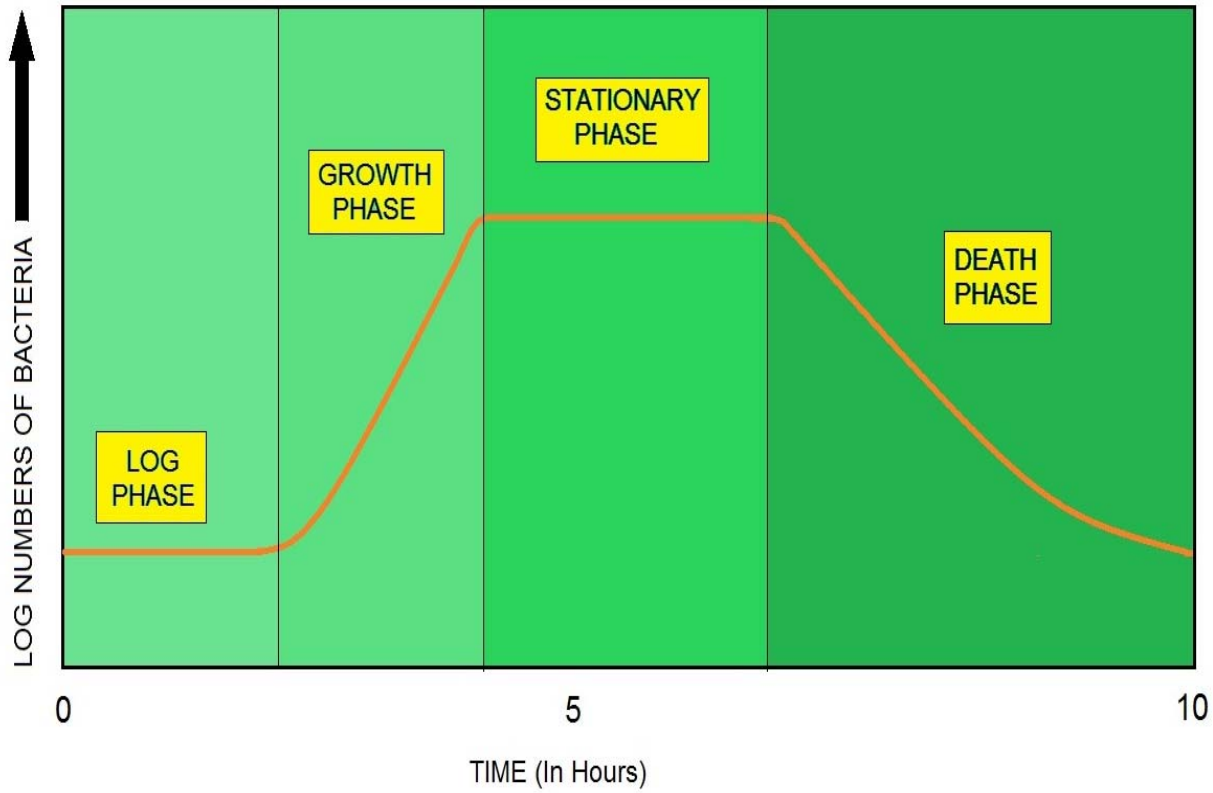
CHLORINE DECAY CURVE

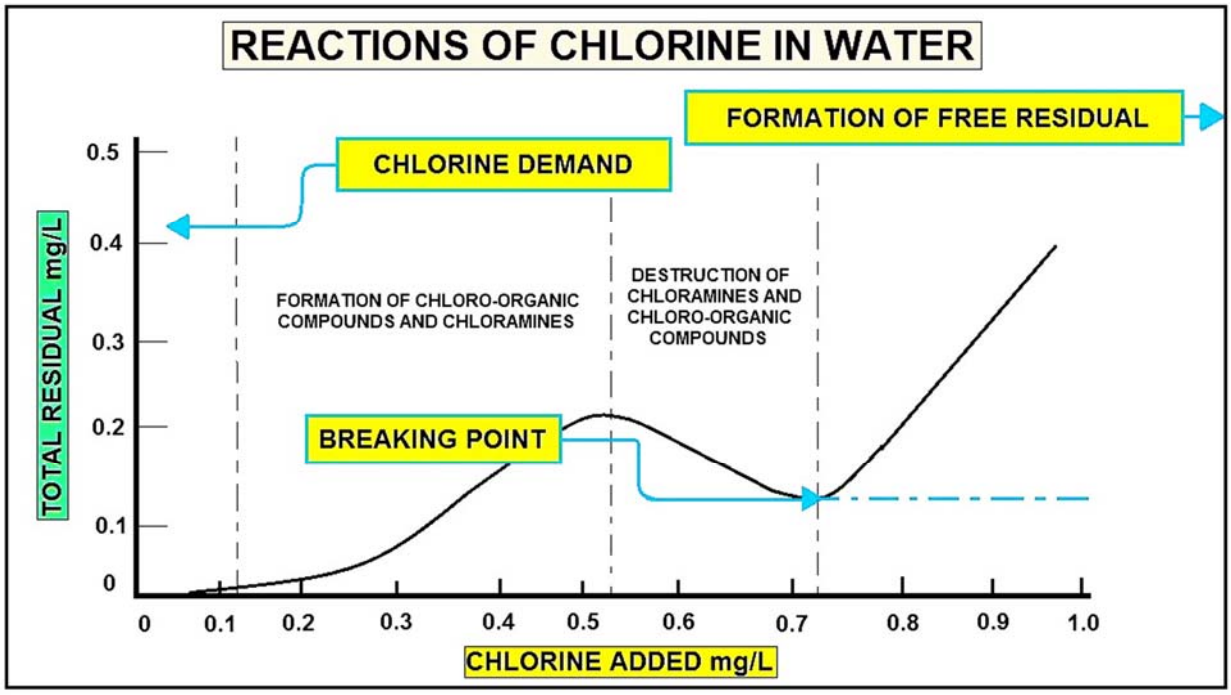


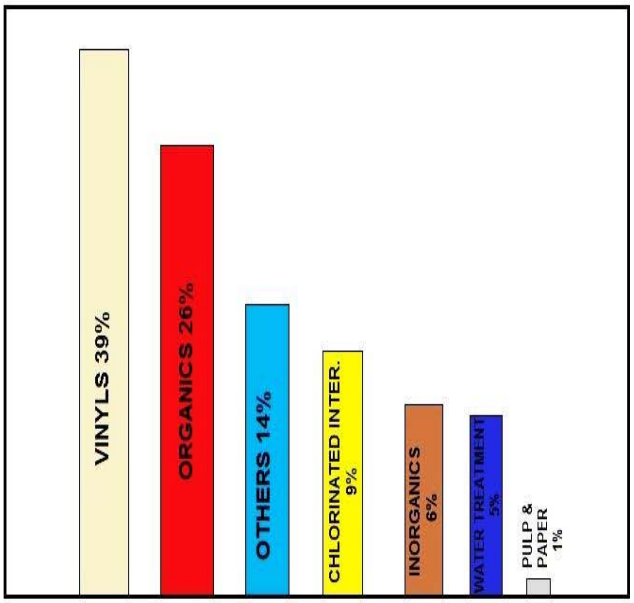
USING CHLORINE DIOXIDE vs CHLORINE

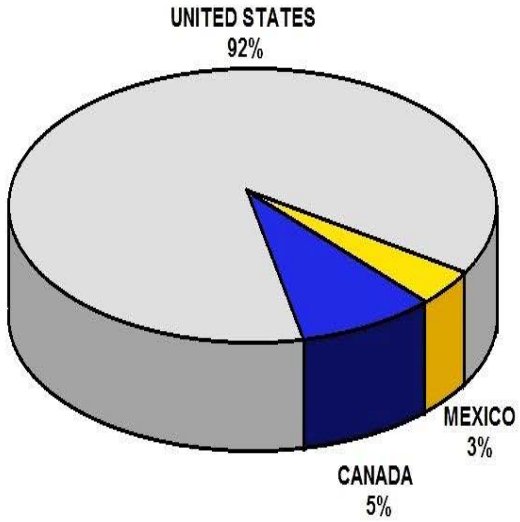


CHLORAMINATION

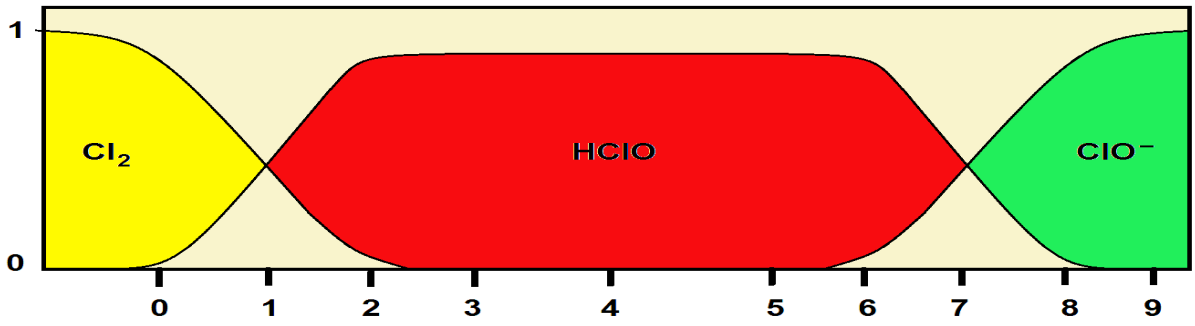




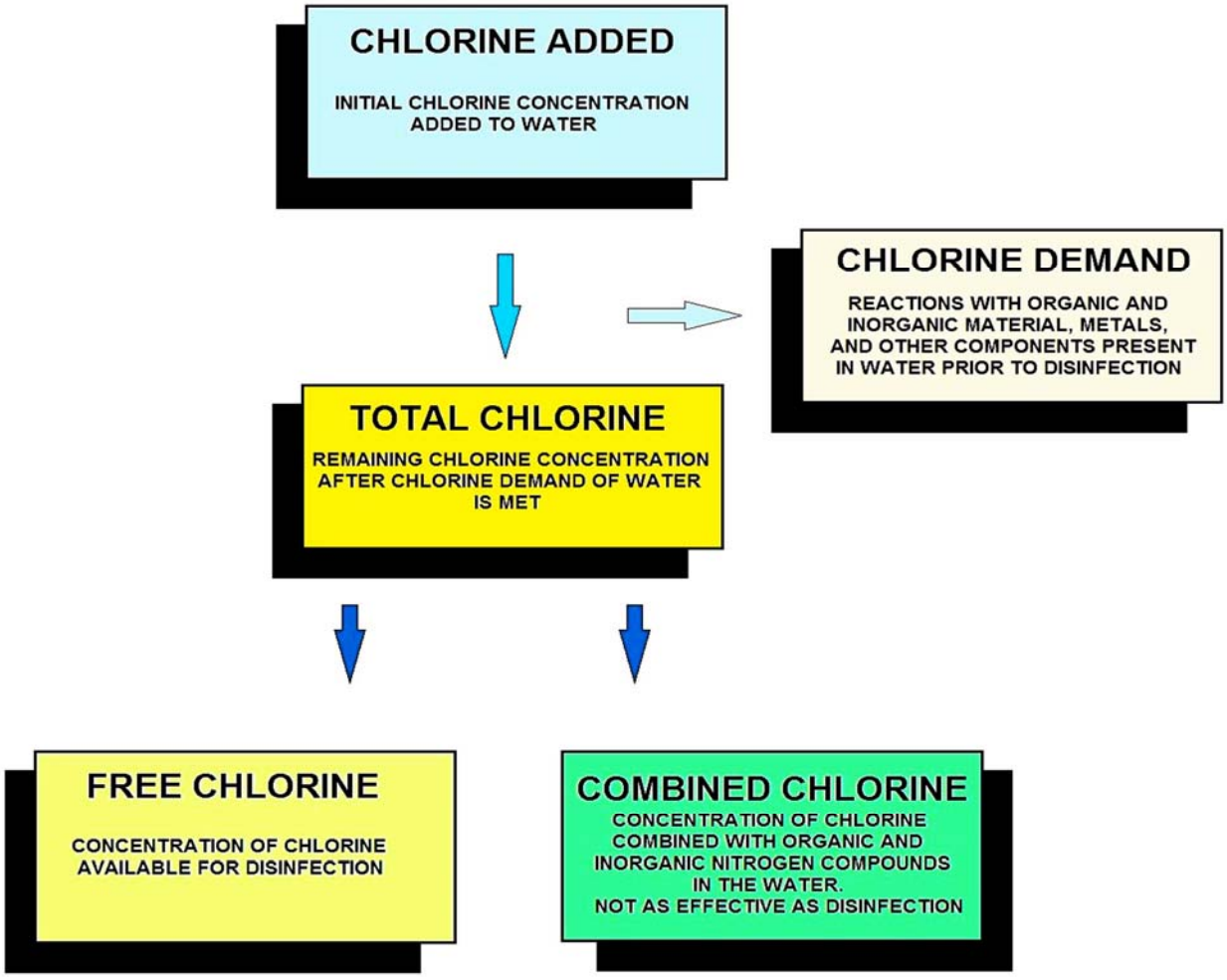




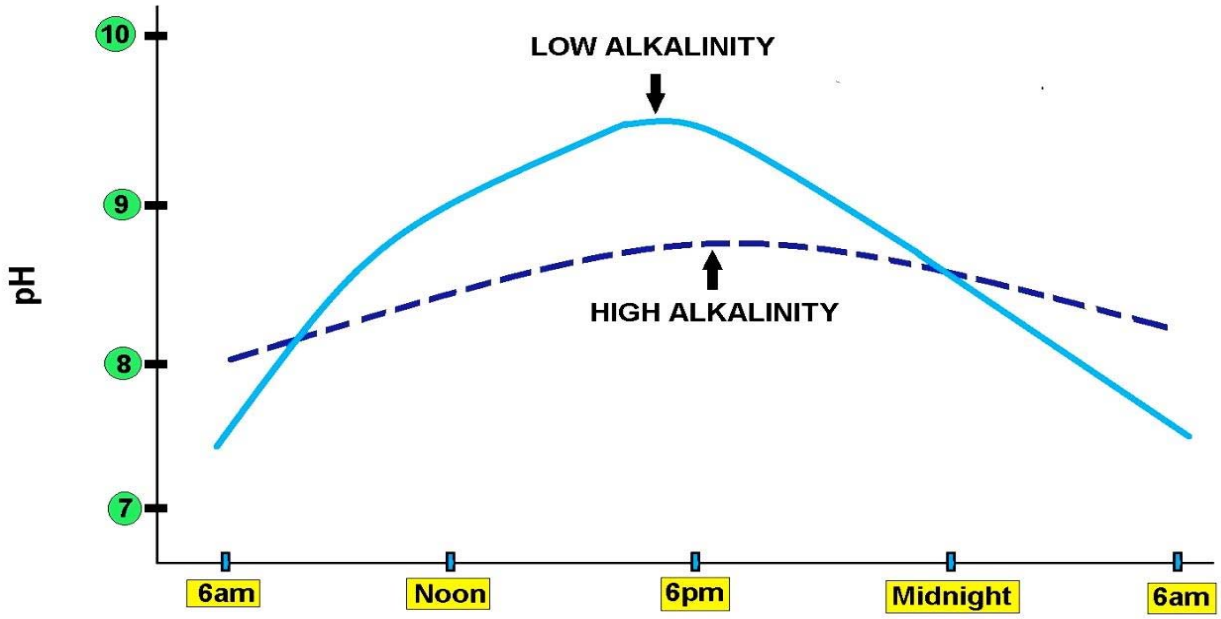
NORTH AMERICA CHLORINE DEMAND COMPARISON



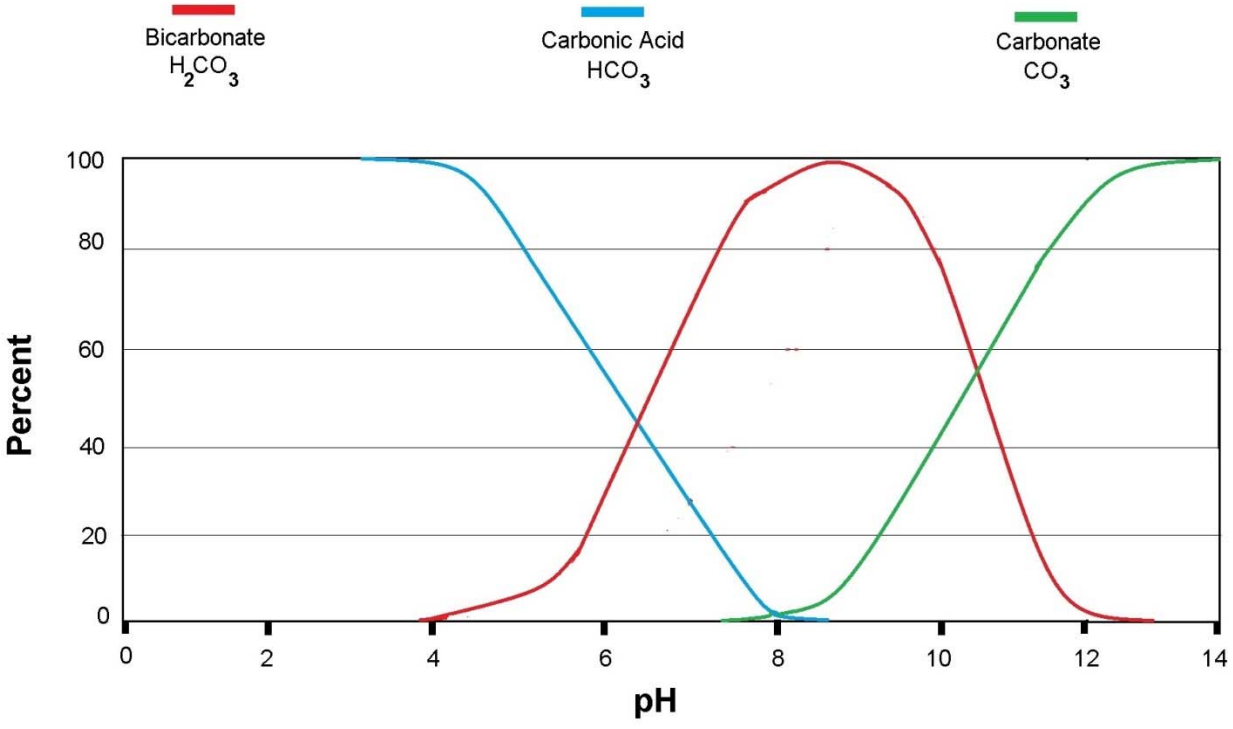
pH - VALUE



CHLORINE DISINFECTION



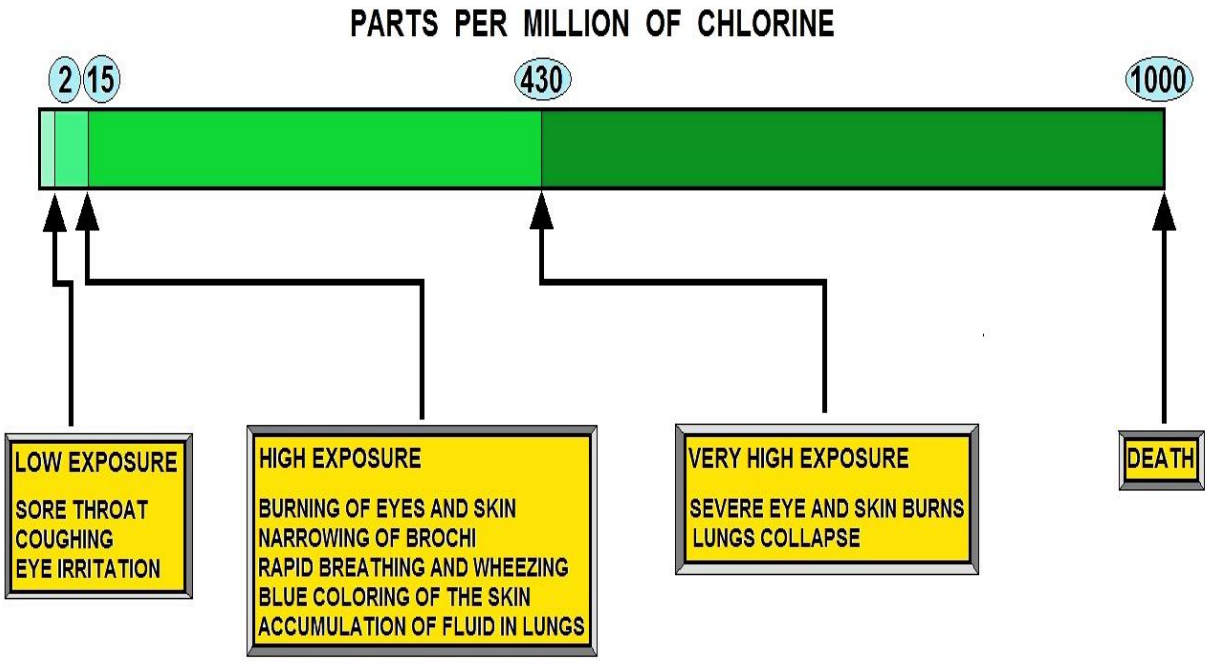
ALKALINITY



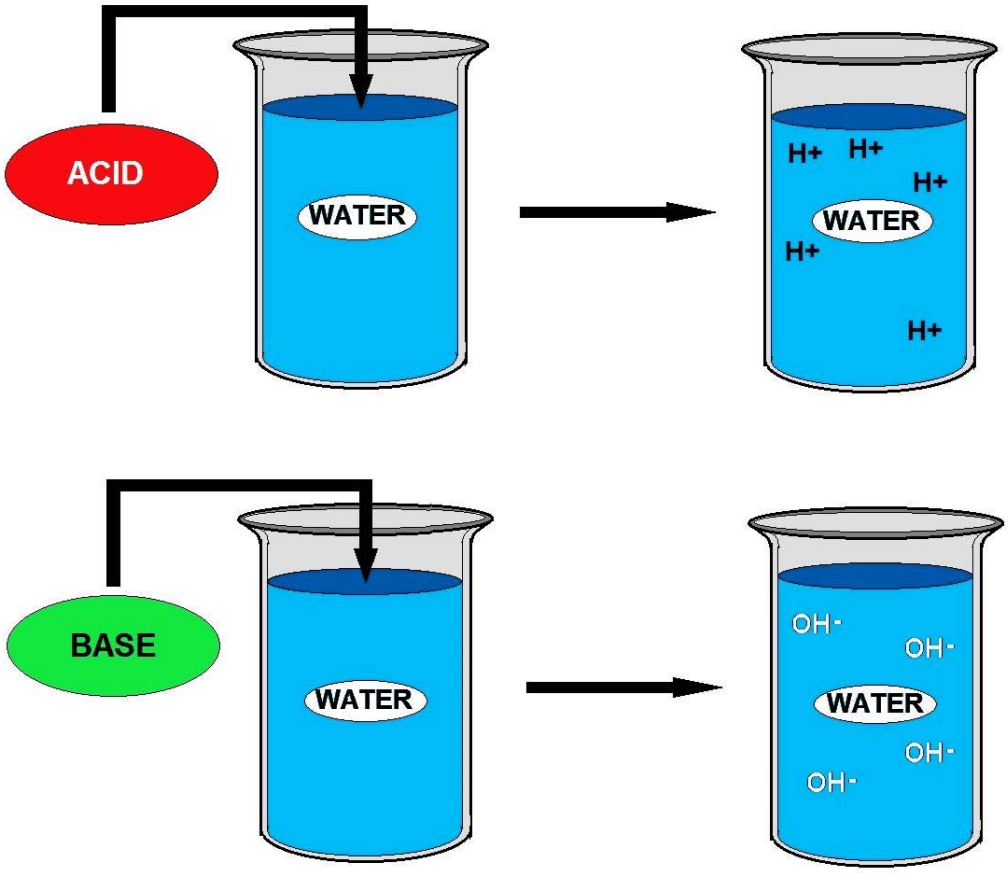
EFFECTS OF ALKALINITY FROM pH

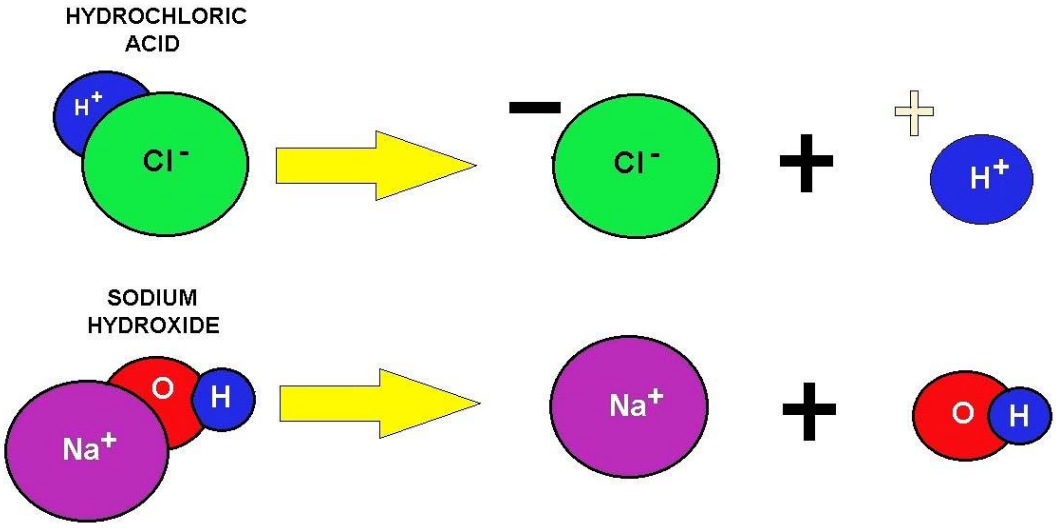
DENSITY (at 32°F & 1 atm)	0.2006 lbs. / cu.ft.
SPECIFIC GRAVITY (at 32°F & 1 atm)	2.482 (air = 1)
LIQUEFYING POINT (at 1 atm)	−30.1°F
VISCOSITY (at 68°F)	0.01325 centipose
SOLUBILITY IN WATER	60.84 lbs. / 1000 gal.

PROPERTIES OF GASEOUS CHLORINE



EFFECTS OF CHLORINE GAS ON HEALTH



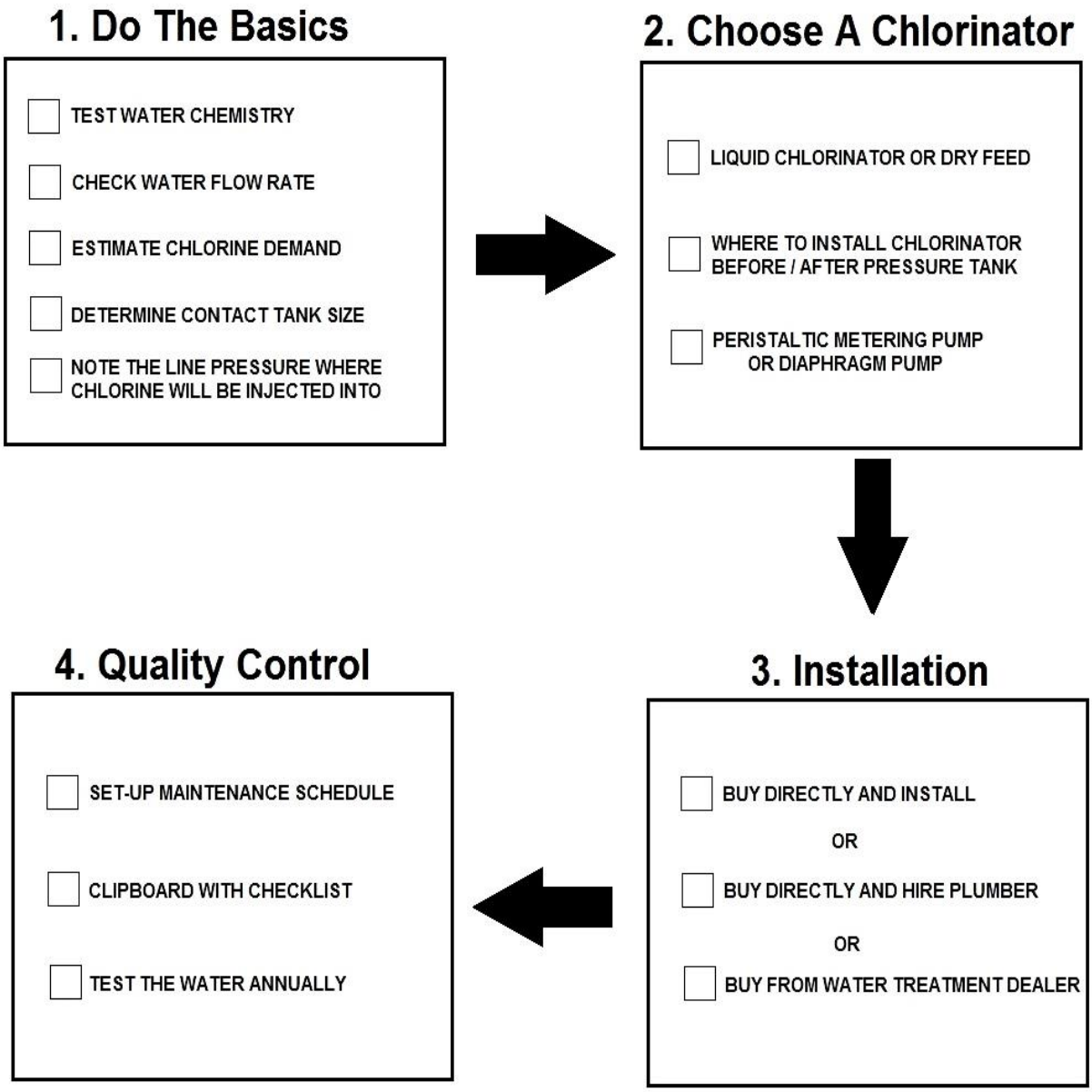


ACIDS AND BASES (comparison)

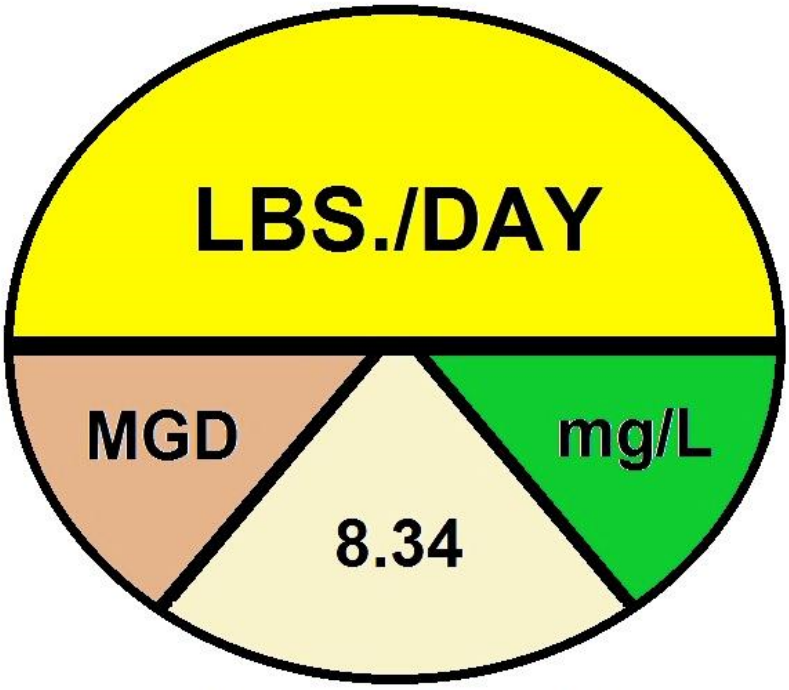
WATER	BLEACHING POWDER (25 - 35 %) (g)	HIGH STRENGTH CALCIUM HYPOCHLORITE (70 %) (g)	LIQUID BLEACH (5 % SODIUM HYPOCHLORITE) (ml)
1	2.3	1.0	14
1.2	3.0	1.2	17
1.5	3.5	1.5	21
2	5.0	2.0	28
2.5	6.0	2.5	35
3	7.0	3.0	42
4	9.0	4.0	56
5	12	5.0	70
6	14	6.0	84
7	16	7.0	98
8	19	8.0	110
10	23	10	140
12	28	12	170
15	35	15	210
20	50	20	280
30	70	30	420
40	90	40	560
50	120	50	700
60	140	60	840
70	160	70	980
80	190	80	1 100
100	230	100	1 400
120	280	120	1 700
150	350	150	2 100
200	470	200	2 800
250	580	250	3 500
300	700	300	4 200
400	940	400	5 600
500	1 170	500	7 000

(* Approximate dose = 0.7 mg of applied Chlorine per litre of water)

CHLORINE DOSES WITH DIFFERENT TYPES OF CHLORINE



HOW TO DETERMINE A CHLORINATION SYSTEM



POUNDS FORMULA WHEEL

$$\text{DOSE , mg/L} = \frac{(332)\quad \text{lbs. / day}}{(5.27)\quad \text{MGD x 8.34 lbs./mg/L/MG}}$$

DOSE , mg/L = (7.6) **mg/L**

DOSE CALCULATION EXAMPLE

MATH CONVERSION FACTORS

1 PSI = 2.31 Feet of Water
1 Foot of Water = .433 PSI
1.13 Feet of Water = 1 Inch of Mercury
454 Grams = 1 Pound
1 Gallon of Water = 8.34 pounds/gal
1 mg/L = 1 PPM
17.1 mg/L = 1 Grain/Gallon
1% = 10,000 mg/L
694 Gallons per Minute = MGD
1.55 Cubic Feet per Second = 1 MGD
60 Seconds = 1 Minute
1440 Minutes = 1 Day
.746 kW = 1 Horsepower

LENGTH
12 Inches = 1 Foot
3 Feet = 1 Yard
5280 Feet = 1 Mile

AREA
144 Square Inches = 1 Square Foot
43,560 Square Feet = 1 Acre

VOLUME
1000 Milliliters = 1 Liter
3.785 Liters = 1Gallon
231 Cubic Inches = 1 Gallon
7.48 Gallons = 1 Cubic Foot
62.38 Pounds = 1 Cubic Foot

DIMENSIONS

SQUARE: Area (sq. ft.) = Length X Width

Volume (cu. ft.) = Length (ft) X Width (ft) X Height (ft)

CIRCLE: Area (sq. ft.) = 3.14 X Radius (ft) X Radius (ft)

CYLINDER: Volume (Cu. ft) = 3.14 X Radius (ft) X Radius (ft) X Depth (ft)

SPHERE: $\frac{(3.14)\ (\text{Diameter})^3}{(6)}$ Circumference = 3.14 X Diameter

HOW TO CALCULATE CHLORINE DOSAGE TO DISINFECT A WELL USING CALCIUM HYPOCHLORITE

EQUIPMENT

- 20 litre bucket
- HSCH Chlorine granules or powder

METHOD

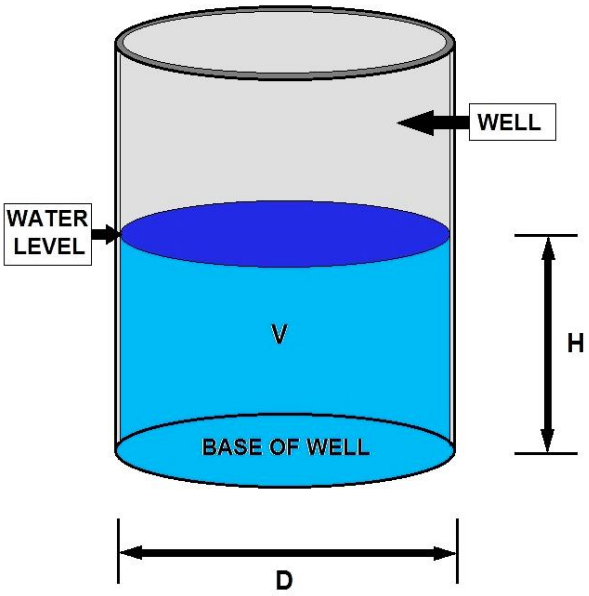
- Calculate the volume of water in the well using formula:

$$V = \frac{\pi D^2 h}{4}$$

WHERE

V = Volume of water
D = Diameter
h = Depth of water
π = 3.142

- Fill bucket with clear water from source
- Add about 300g of HSCH and stir (dissolve)
- For every cubic meter of water, add 10 litres (half bucket) of chlorine solution.
- Double the quantity of HSCH added if the solution is to be used for cleaning well lining or aprons



GENERAL

POUNDS PER DAY AKA SOLIDS APPLIED = Concentration (mg/L) X Flow (MG) X 8.34

PERCENT EFFICIENCY = $\frac{\text{In – Out}}{\text{In}}$ X 100

TEMPERATURE: $^0F = (^0C \times 9/5) + 32$
$^0C = (^0F - 32) \times 5/9$

CONCENTRATION: Conc. (A) X Volume (A) = Conc. (B) X Volume (B)

FLOW RATE (Q): Q = A X V (Quantity = Area X Velocity)

FLOW RATE (gpm): Flow Rate (gpm) = $\frac{2.83 \text{ (Diameter, in)}^2 \text{ (Distance, in)}}{\text{Height, in}}$

% SLOPE = $\frac{\text{Rise (feet)}}{\text{Run (feet)}}$ X 100

ACTUAL LEAKAGE = $\frac{\text{Leak Rate (GPD)}}{\text{Length (mi.) X Diameter (in)}}$

VELOCITY = $\frac{\text{Distance (ft)}}{\text{Time (Sec)}}$

N = Manning's Coefficient of Roughness
R = Hydraulic Radius (ft.)
S = Slope of Sewer (ft/ft.)

HYDRAULIC RADIUS (ft) = $\frac{\text{Cross Sectional Area of Flow (ft)}}{\text{Wetted pipe Perimeter (ft)}}$

WATER HORSEPOWER = $\frac{\text{Flow (gpm) X Head (ft)}}{3960}$

BRAKE HORSEPOWER = $\frac{\text{Flow (gpm) X Head (ft)}}{3960 \text{ X Pump Efficiency}}$

MOTOR HORSEPOWER = $\frac{\text{Flow (gpm) X Head (ft)}}{3960 \text{ X Pump Eff. X Motor Eff.}}$

MEAN OR AVERAGE = $\frac{\text{Sum of the Values}}{\text{Number of Values}}$

TOTAL HEAD (ft) = Suction Lift (ft) X Discharge Head (ft)

SURFACE LOADING RATE = $\frac{\text{Flow Rate (gpm)}}{\text{Surface Area (sq. ft)}}$
(gal/min/sq. ft.)

MIXTURE STRENGTH (%) = $\frac{\text{(Volume 1, gal) (Strength 1, \%) + (Volume 2, gal) (Strength 2,\%)}}{\text{(Volume 1, gal) + (Volume 2, gal)}}$

INJURY FREQUENCY RATE = $\frac{\text{(Number of Injuries) 1,000,000}}{\text{Number of hours worked per year}}$

DETENTION TIME (hrs) = $\frac{\text{Volume of Basin (gals) X 24 hrs}}{\text{Flow (GPD)}}$

Slope = $\frac{\text{Rise (ft)}}{\text{Run (ft)}}$ Slope(%) = $\frac{\text{Rise (ft) X 100}}{\text{Run (ft)}}$

POPULATION EQUIVENT (PE):

1 PE = .17 Pounds of BOD per Day
1 PE = .20 Pounds of Solids per Day
1 PE = 100 Gallons per Day

LEAKAGE (GPD/inch) = $\frac{\text{Leakage of Water per Day (GPD)}}{\text{Sewer Diameter (inch)}}$

CHLORINE DEMAND (mg/L) = Chlorine Dose (mg/L) – Chlorine Residual (mg/L)

MANNING FORMULA

τQ = Allowable time for decrease in pressure from 3.5 PSI to 2.5 PSI
τq = As below

$\tau Q = (0.022)\ (d_1^2 L_1)/Q$ $\tau q = \frac{[\ 0.085]\ [(d_1^2 L1)/(d_1 L_1)]}{q}$

Q = 2.0 cfm air loss
θ = .0030 cfm air loss per square foot of internal pipe surface
δ = Pipe diameter (inches)
L = Pipe Length (feet)

$V = \frac{1.486}{\nu} R^{2/3} S^{1/2}$

V = Velocity (ft./sec.)
ν = Pipe Roughness
R = Hydraulic Radius (ft)
S= Slope (ft/ft)

HYDRAULIC RADIUS (ft) = $\frac{\text{Flow Area (ft. 2)}}{\text{Wetted Perimeter (ft.)}}$

WIDTH OF TRENCH (ft) = Base (ft) + (2 Sides) X $\frac{\text{Depth (ft 2)}}{\text{Slope}}$

AMPERAGE = $\frac{\text{Voltage}}{\text{Ohms}}$

VOLTAGE IMBALANCE = $\frac{\text{Maximum Voltage Deviation (Volts) X 100}}{\text{Average Voltage (Volts)}}$

LABORATORY

TSS (mg/L) = Paper Wt. And Dried Solids (g) – Paper Wt. (g) X 1,000,000
Milliliters of Sample

BOD (mg/L = (Initial DO – Final DO) X 300
(unseeded) Milliliters of Sample

LANGELIER INDEX = pH - pH_s

STABILIZATION PONDS

DETENTION TIME (Days) = Volume of Ponds (gals)
Flow Rate (gals/day)

ORGANIC LOADING (Lbs. Of BOD/Acre/Day) = Pounds of BOD Applied per Day
Surface Areas (Acres)

FIXED MEDIA

HYDRAULIC LOADING (gals/1000 cu. ft./day) = Flow Rate (gals./day)
1000's Cubic Feet of Media

ORGANIC LOADING (lbs BOD/day/1000 cu. ft.) = Pounds of BOD applied per Day
1000'S OF Cubic Feet of Media

ACTIVATED SLUDGE

DETENTION TIME (hrs.) = Volume of the tank (gals)
Flow Rate (gals/hour)

SVI (mg/L) = Settled Sludge Volume (mls) X 1000
MLSS (mg/L)

SDI (g/ml) = 1 X 100
SVI

F/M = BOD (applied to aerator) X Flow (MGD) X 8.34
Pounds of Solids under Aeration

MCRT (Days) = Pounds of Solids under Aeration B Pounds of Solids in Clarifier
Pounds of Solids Wasted B Pounds of Solids over the Weirs

DIGESTER AND SOLIDS HANDLING

OXYGEN UPTAKE RATE (OUR) = $\frac{\text{mg of } O_2 \text{ used}}{\text{Minute}}$

ORGANIC LOADING (lbs./day/cu. ft.) = $\frac{\text{Pounds of Volatile Solids applied per Day}}{\text{Volume of Digester (cu. ft.)}}$

VOLATILE SOLIDS REDUCTION = $\frac{(\text{In} - \text{Out})\ (100\%)}{\text{In} - (\text{In} - \text{Out})}$

DRY POLYMER (lbs) = (Gal. Of solution) X (8.34 lbs./gal.) X (% polymer solution)

SLUDGE APPLICATION (lbs) = (Gal. Of Sludge) X (8.34 lbs./gal.) X (% Solids in sludge)

1 TON = 2,000 lbs I METER = 3.28 Feet

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