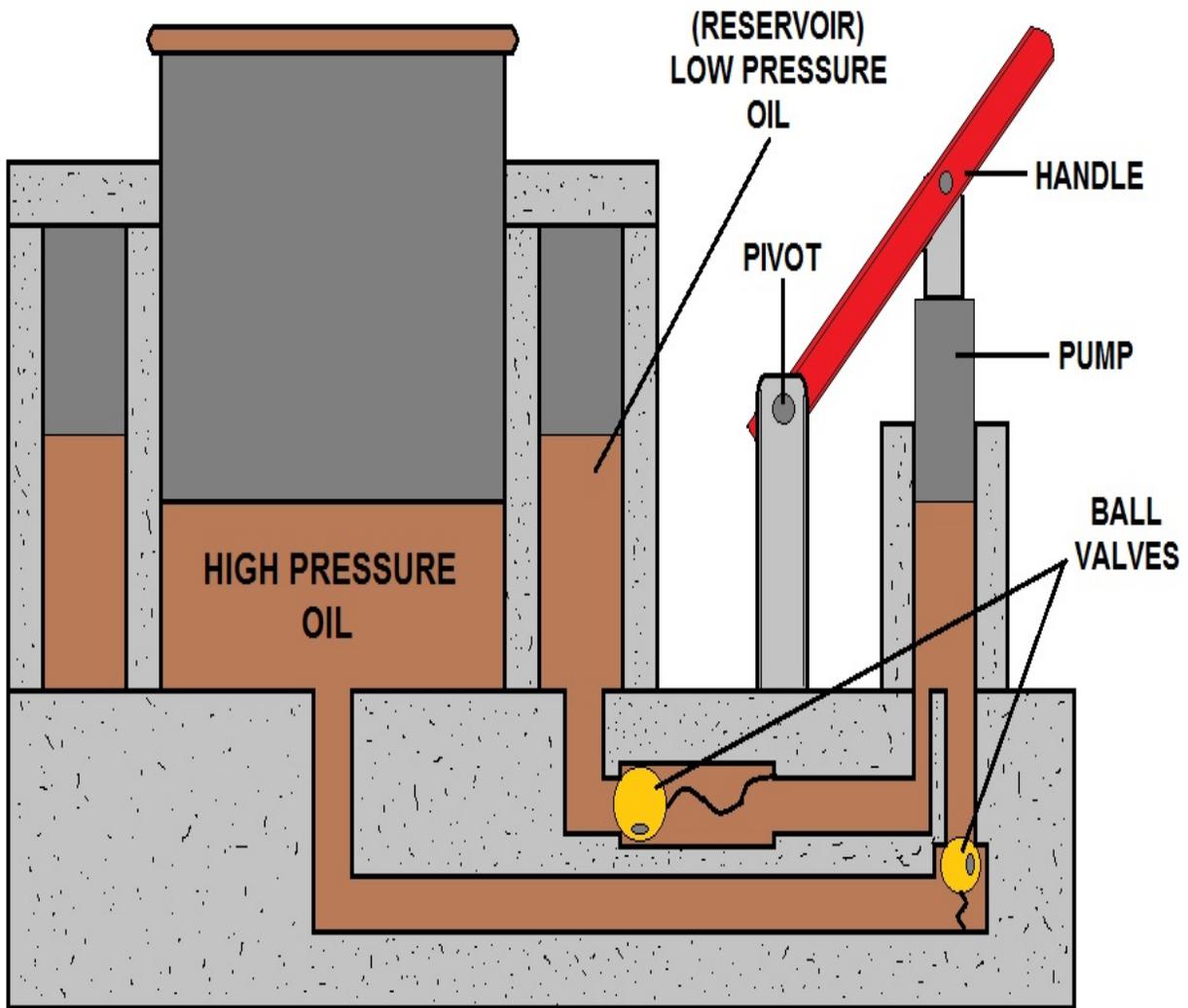


# HYDRAULIC PRINCIPLES

## CONTINUING EDUCATION PROFESSIONAL DEVELOPMENT COURSE



**BASIC HYDRAULICS/LEVER PRINCIPAL**





## Printing and Saving Instructions

TLC recommends that you download and save this pdf document and assignment to your computer desktop and open it with Adobe Acrobat DC reader.

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You can complete the course by viewing the course on your computer or you can print it out. This course booklet does not have the assignment (the test). Please visit our website and download the assignment (the test).

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### Hyperlink to Assignment...

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**State Approval Listing Link**, check to see if your State accepts or has pre-approved this course. Not all States are listed. Not all courses are listed. Do not solely trust our list for it may be outdated. It is your sole responsibility to ensure this course is accepted for credit. No refunds.

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## Important Information about this Manual

This manual has been prepared to educate operators in the general education of hydraulic principles, including basic mechanical and mathematical training and different hydraulic applications. For most students, the study of hydraulics is quite large, requiring a major effort to bring it under control and understanding.

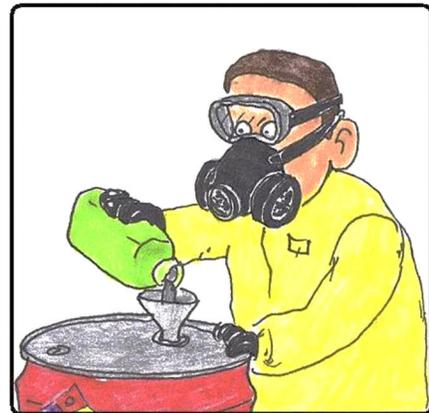
This manual should not be used as a guidance document for employees who are involved with cross-connection control. It is not designed to meet the requirements of the United States Environmental Protection Agency (EPA), the Department of Labor-Occupational Safety and Health Administration (OSHA), or your state environmental or health agency. 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.



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**WEAR PROPER PPE**



**HANDLING CHEMICALS**

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 purposes and is not considered a legal document. Individuals who are responsible for hydraulic equipment, cross-connection control, backflow prevention or water distribution should obtain and comply with the most recent federal, state, and local regulations relevant to these sites and are urged to consult with OSHA, the EPA and other appropriate federal, state and local agencies.

In this course, you will learn the various and interesting physic laws and the long exciting history related to hydraulic power as well as hydraulic terms and mathematics commonly used throughout the water related industry. This is a universal course that can be utilized by all classifications and positions.

The reason this course is universal is because we examine how water works. Here are some examples: Industrial Inspector that needs to know how to figure a water flow. A Plumbing or Customer Inspector who needs to figure flow restriction in a water line. This course will cover several unique and interesting water related facts that most of us have forgotten or haven't recognized.

# 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 to finish the material at your convenience. 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 will 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**

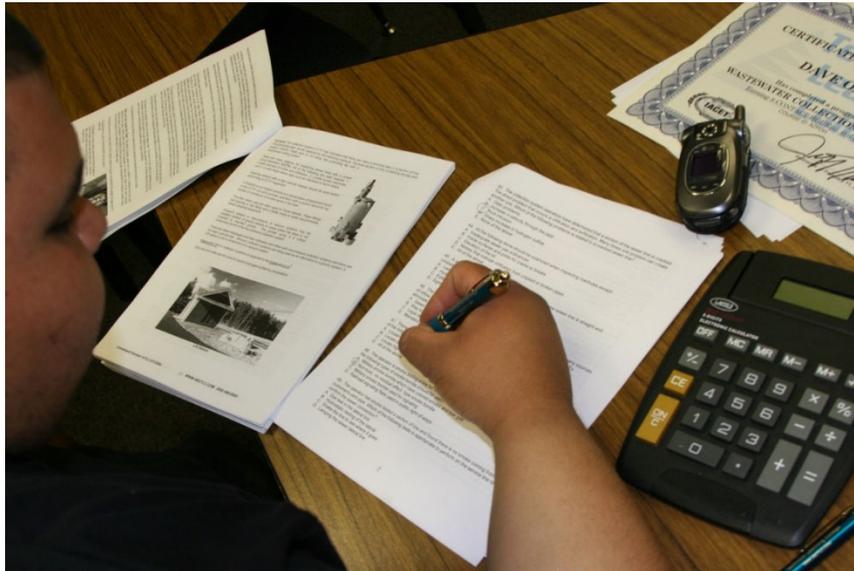
TLC's online courses combine the best of online delivery and traditional university textbooks. You can easily find the course syllabus, course content, assignments, and the post-exam (Assignment). This student-friendly course design allows you the most flexibility in choosing when and where you will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

**Contact Numbers**  
**Fax (928) 468-0675**  
**Email [Info@tlch2o.com](mailto:Info@tlch2o.com)**  
**Telephone (866) 557-1746**

# CEU Course Description

## Hydraulic Principles CEU Training Course

This short CEU course will review of hydraulic fundamentals and principles--from taking this CEU course, the student will develop an understanding of the engineering science pertaining to liquid pressure and flow. This course will cover the basics of hydraulic fundamentals commonly related to the study of the mechanical properties of water.

This course will also examine hydrostatics or fluid mechanics as well as the history and development of pumps, hydraulics and the science of fluids. This training course will present several familiar topics in hydraulics and hydrostatics which often appear in most educational expositions of introductory science, and which are also of historical interest that can enliven a student's educational experience. *You will not need any other materials for this course.*

**Water Distribution, Well Drillers, Pump Installers, Water Treatment Operators, Wastewater Treatment Operators, Wastewater Collection Operators, Industrial Wastewater Operators, Customer Service Professionals and General Backflow Assembly Testers**--the target audience for this course is the person interested in working in a water or wastewater treatment or distribution/collection 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.

### Final Examination for Credit

Opportunity to pass the final comprehensive examination is limited to three attempts per course enrollment.

**Prerequisites:** None

### Course Procedures for Registration and Support

All of Technical Learning College'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 will attempt immediate and prompt service. We are here to help educate you.

When a student registers for a distance or correspondence course, he/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/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 will be assigned to the student.

### Instructions for Assignment

The Hydraulic Principles CEU training course uses a multiple choice type answer key. You can find a copy of the answer key in the front of the course assignment or lesson in Word format on TLC's website under the Assignment Page. You can also find complete course support under the Assignment Page. You can write your answers in the separate answer key or assignment. TLC would prefer that you type out and fax or e-mail the final exam to TLC, but it is not required.

### Feedback Mechanism (Examination Procedures)

Each student will receive a feedback form as part of their study packet. You will be able to find this form in the front of the course 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 sharing of answers. Any fraud or deceit and the student will forfeit 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 *Hydraulic Principles* CEU training course will not require any other materials. This course comes complete. No other materials are needed.

### **Recordkeeping and Reporting Practices**

TLC will keep all student records for a minimum of seven years. It is your responsibility to give the completion certificate to the appropriate agencies.

### **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. Please check with your State for special instructions.

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 should need any assistance, please email all concerns and the final test to: [info@tlch2o.com](mailto: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 and environmental education,*

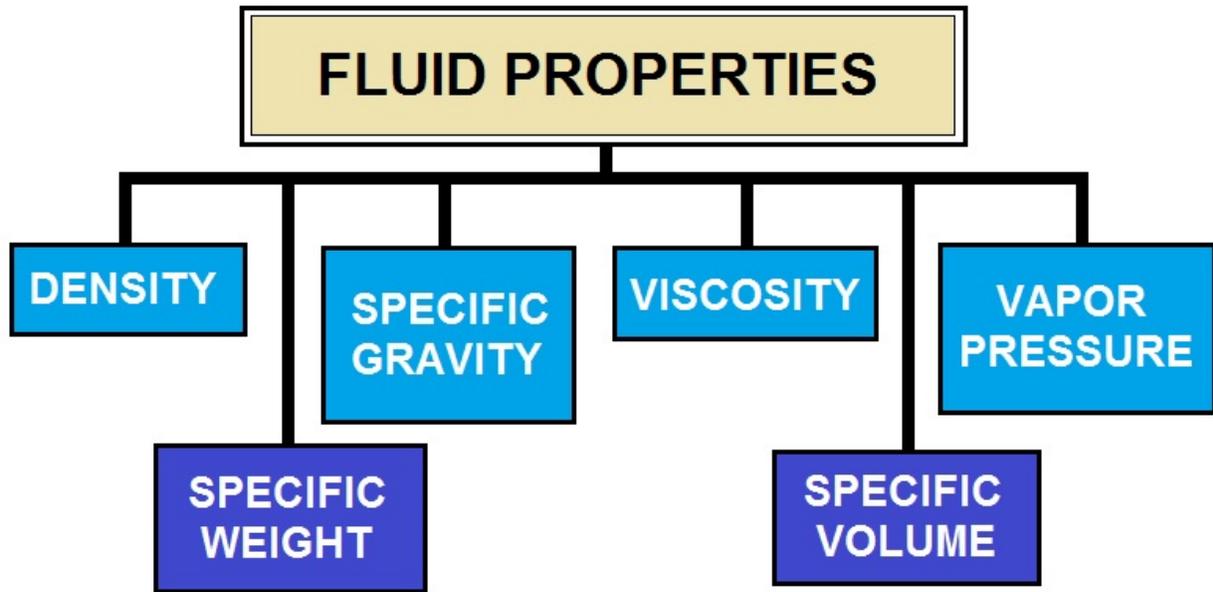
*To provide opportunities for TLC students to learn and practice environmental educational skills with members of the community for the purpose of sharing diverse perspectives and experience,*

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

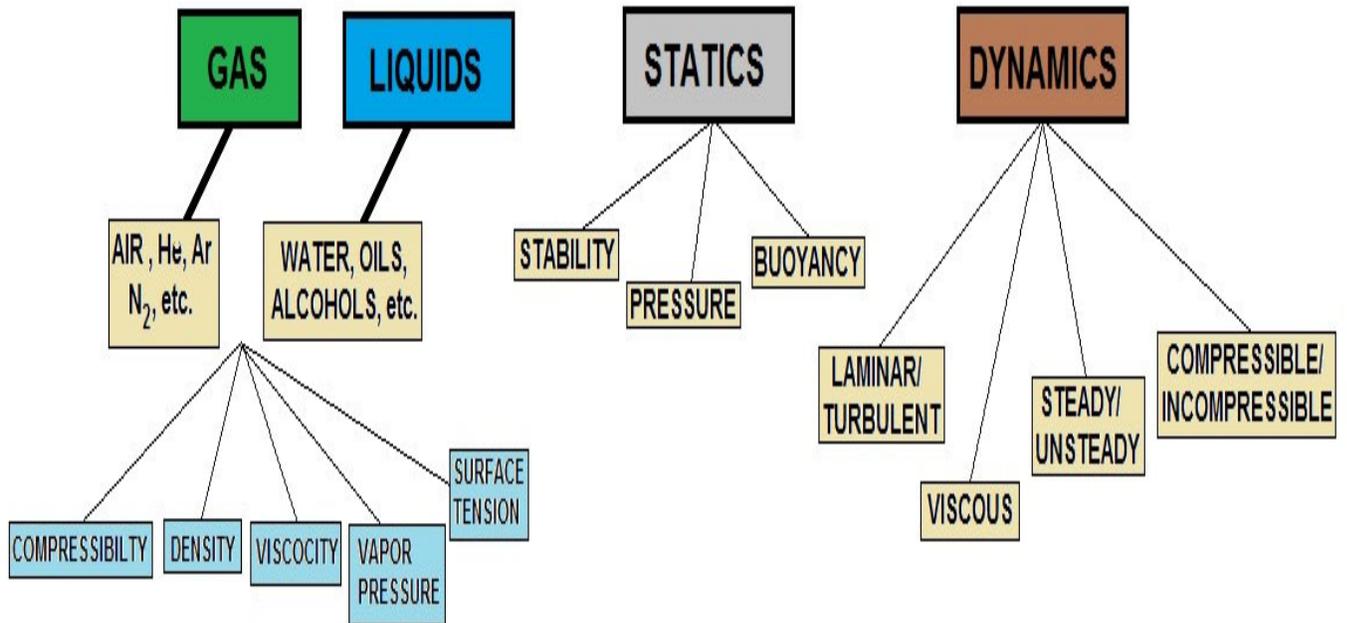
*To provide a forum for the collection and dissemination of current information related to environmental education, and to maintain an environment that nurtures academic and personal growth.*

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**BASICS USED TO DEFINE FLUIDS**



**FLUID MECHANICS OVERVIEW DIAGRAM**

## **Common Hydraulic Terms**

### **Head**

The height of a column or body of fluid above a given point expressed in linear units. Head is often used to indicate gauge pressure. Pressure is equal to the height times the density of the liquid.

### **Head, Friction**

The head required to overcome the friction at the interior surface of a conductor and between fluid particles in motion. It varies with flow, size, type, and conditions of conductors and fittings, and the fluid characteristics.

### **Head, Static**

The height of a column or body of fluid above a given point.

### **Hydraulics**

Engineering science pertaining to liquid pressure and flow.

### **Hydrokinetics**

Engineering science pertaining to the energy of liquid flow and pressure.

### **Pascal's Law**

A pressure applied to a confined fluid at rest is transmitted with equal intensity throughout the fluid.

### **Pressure**

The application of continuous force by one body upon another that it is touching; compression. Force per unit area, usually expressed in pounds per square inch (Pascal or bar).

### **Pressure, Absolute**

Is the pressure exported by the atmosphere at any specific location. The pressure above zone absolute, i.e. the sum of atmospheric and gauge pressure. In vacuum related work it is usually expressed in millimeters of mercury. (mmHg).

### **Pressure, Atmospheric**

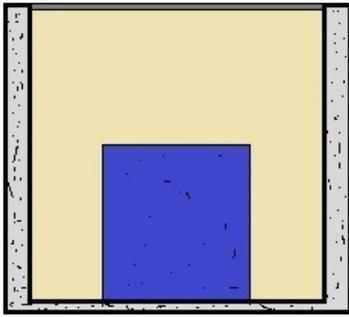
Pressure exerted by the atmosphere at any specific location. (Sea level pressure is approximately 14.7 pounds per square inch absolute, 1 bar = 14.5psi.)

### **Pressure, Gauge**

Pressure differential above or below ambient atmospheric pressure.

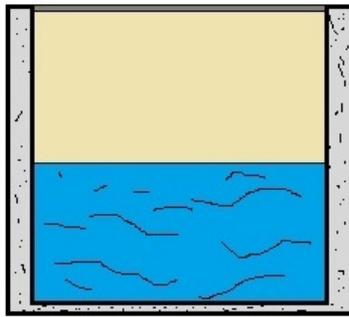
### **Pressure, Static**

The pressure in a fluid at rest.



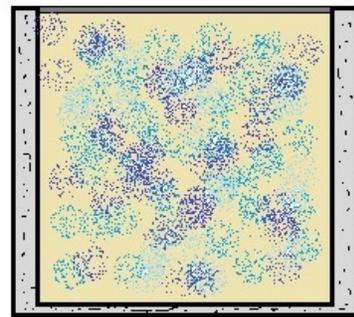
### SOLID

MATTER HOLDS SHAPE  
IS A FIXED VOLUME



### LIQUID

FORMS SHAPE OF CONTAINER  
FREE SURFACE  
IS A FIXED VOLUME

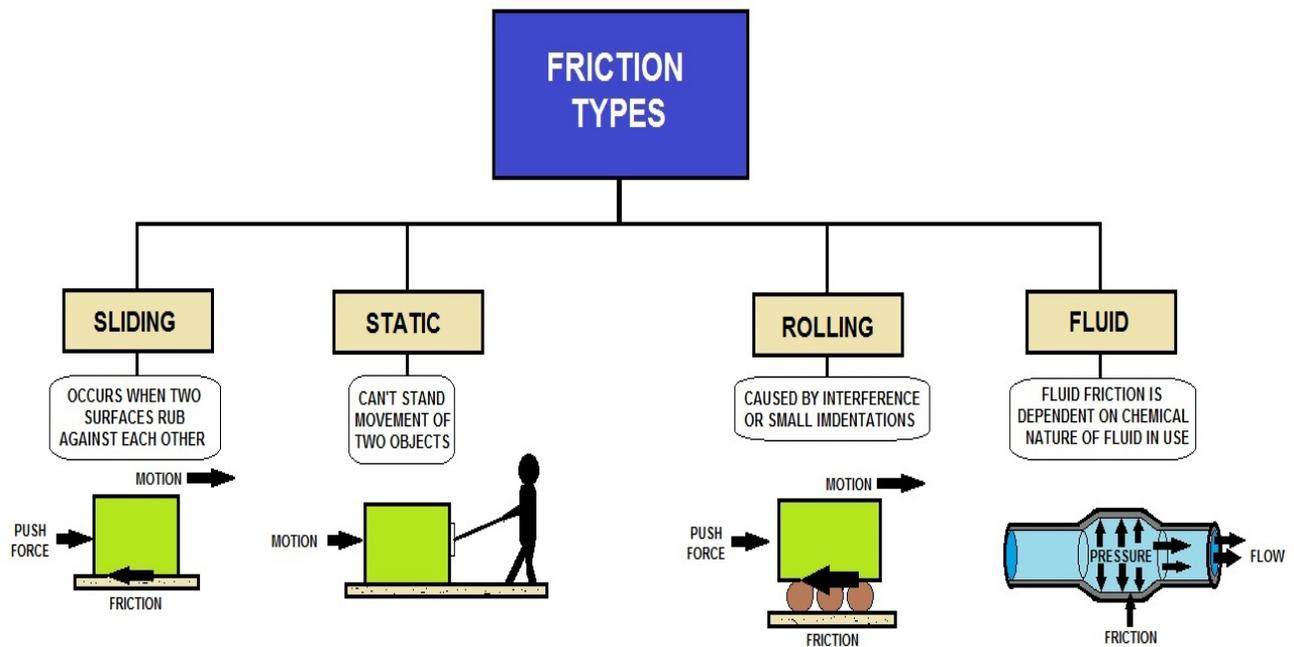


### GAS

FORMS SHAPE OF CONTAINER  
BECOMES VOLUME OF CONTAINER



## DIFFERENT PHASES OF MATTER

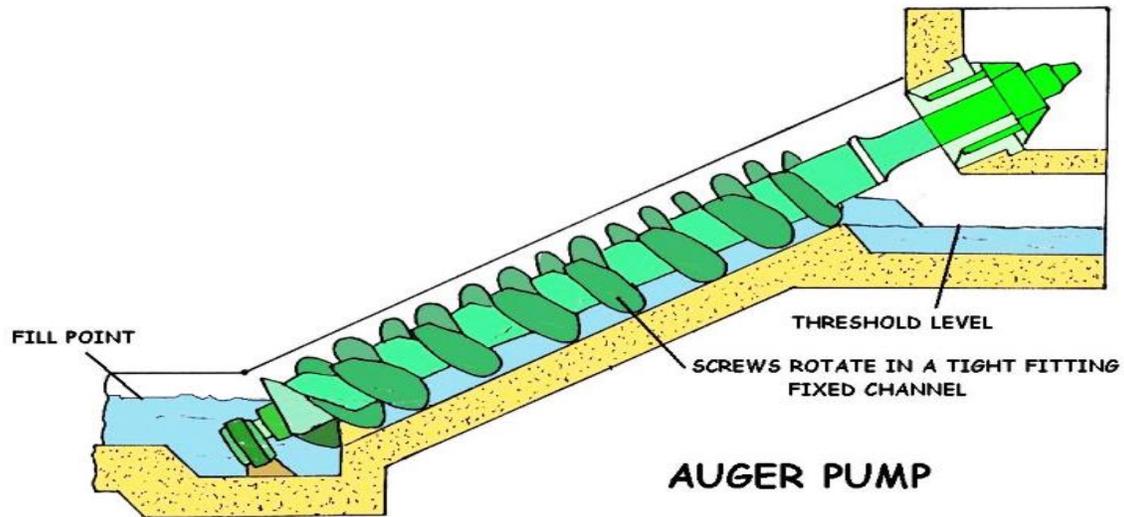


## FRICTION TYPE EXAMPLES

## **Archimedes -The King of Hydraulics**



### **ARCHIMEDES - FATHER OF HYDRAULICS**



**This type of pump is at least 2,000 years old.**

The Archimedes Screw (also called an Archimedes Snail) was used for irrigation and powered by horses, people, mules, etc. This pump is even used today, although rarely! The helix revolves inside a tube (only the bottom of the tube is shown) and the water rises accordingly. Whether or not it was actually invented by Archimedes is certainly debatable, though his overall brilliance is not.

## Archimedes

<b>Born</b>	About 287 BC in Syracuse, Sicily. At the time, Syracuse was an independent Greek city-state with a 500-year history.
<b>Died</b>	212 or 211 BC in Syracuse when it was being sacked by a Roman army. He was killed by a Roman soldier who did not know who he was.
<b>Education</b>	Probably studied in Alexandria, Egypt, under the followers of Euclid.
<b>Family</b>	His father was an astronomer named Phidias and he was probably related to Hieron II, the king of Syracuse. It is not known whether he was married nor had any children.
<b>Inventions</b>	Many war machines used in the defense of Syracuse, compound pulley systems, planetarium, water screw (possibly), water organ (possibly), burning mirrors (very unlikely).
<b>Fields of Science Initiated</b>	Hydrostatics, static mechanics, pycnometry (the measurement of the volume or density of an object). He is called the "father of integral calculus" and also the "father of mathematical physics".
<b>Major Writings</b>	On plane equilibriums, Quadrature of the parabola, On the sphere and cylinder, On spirals, On conoids and spheroids, On floating bodies, Measurement of a circle, The Sand reckoner, On the method of mechanical problems.
<b>Place in History</b>	Generally regarded as the greatest mathematician and scientist of antiquity and one of the three greatest mathematicians of all time (together with Isaac Newton (English 1643-1727) and Carl Friedrich Gauss (German 1777-1855)).

Archimedes was a great mathematician of ancient times. His greatest contributions were in geometry. He also spent some time in Egypt, where he invented the machine now called Archimedes' screw, which was a mechanical water pump. Among his most famous works is *Measurement of the Circle*, where he determined the exact value of pi between the two fractions,  $3 \frac{10}{71}$  and  $3 \frac{1}{7}$ . He got this information by inscribing and circumscribing a circle with a 96-sided regular polygon.

Archimedes made many contributions to geometry in his work in the areas of plane figures and in the areas of area and volumes of curved surfaces. His methods started the idea for calculus which was "invented" 2,000 years later by Sir Isaac Newton and Gottfried Wilhelm von Leibniz. Archimedes proved that the volume of an inscribed sphere is two-thirds the volume of a circumscribed cylinder. He requested that this formula/diagram be inscribed on his tomb.

His works (that survived) include:

- Measurement of a Circle
- On the Sphere and Cylinder
- On Spirals
- The Sand Reckoner

The Roman's highest numeral was a myriad (10,000). Archimedes was not content to use that as the biggest number, so he decided to conduct an experiment using large numbers.

The question: How many grains of sand there are in the universe? He made up a system to measure the sand. While solving this problem, Archimedes discovered something called powers. The answer to Archimedes' question was one with 62 zeros after it ( $1 \times 10^{62}$ ).

When numbers are multiplied by themselves, they are called powers.

Some powers of two are:

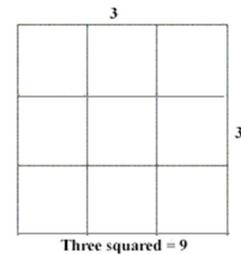
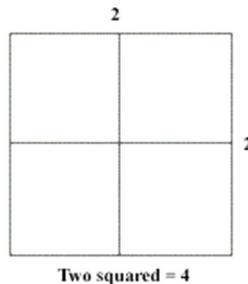
$$1 = 0 \text{ power} = 2^0$$

$$2 = 1^{\text{st}} \text{ power} = 2^1$$

$$2 \times 2 = 2^{\text{nd}} \text{ power (squared)} = 2^2$$

$$2 \times 2 \times 2 = 3^{\text{rd}} \text{ power (cubed)} = 2^3$$

$$2 \times 2 \times 2 \times 2 = 4^{\text{th}} \text{ power} = 2^4$$



There are short ways to write exponents. For example, a short way to write 81 is  $3^4$ . This is read as three to the fourth power.

- On Plane Equilibriums
- On Floating Bodies

This problem was after Archimedes had solved the problem of King Hiero's gold crown. He experimented with liquids. He discovered *density* and *specific gravity*.

## Hydraulic Principles Founders



### **DANIEL BERNOULLI (1700-1782)**

Daniel Bernoulli was born in Groningen, in the Netherlands, into a family of distinguished mathematicians. The Bernoulli family came originally from Antwerp, at that time in the Spanish Netherlands, but emigrated to escape the Spanish persecution of the Huguenots. After a brief period in Frankfurt the family moved to Basel, in Switzerland.

Daniel was the son of Johann Bernoulli (one of the "early developers" of calculus), nephew of Jakob Bernoulli (who "was the first to discover the theory of probability"), and older brother of Johann II. Daniel Bernoulli was described by W. W. Rouse Ball as "by far the ablest of the younger Bernoullis". He is said to have had a bad relationship with his father, Johann. Upon both of them entering and tying for first place in a scientific contest at the University of Paris, Johann, unable to bear the "shame" of being compared as Daniel's equal, banned Daniel from his house.

Johann Bernoulli also plagiarized some key ideas from Daniel's book *Hydrodynamica* in his own book *Hydraulica* which he backdated to before *Hydrodynamica*. Despite Daniel's attempts at reconciliation, his father carried the grudge until his death.

When Daniel was seven, his younger brother Johann II Bernoulli was born. Around schooling age, his father, Johann Bernoulli, encouraged him to study business, there being poor rewards awaiting a mathematician. However, Daniel refused, because he wanted to study mathematics. He later gave in to his father's wish and studied business.



## **BLAISE PASCAL (1623-1662)**

**Blaise Pascal** (19 June 1623 – 19 August 1662) was a French mathematician, physicist, inventor, writer and Christian philosopher. He was a child prodigy who was educated by his father, a tax collector in Rouen. Pascal's earliest work was in the natural and applied sciences where he made important contributions to the study of fluids, and clarified the concepts of pressure and vacuum by generalizing the work of Evangelista Torricelli. Pascal also wrote in defense of the scientific method.

In 1642, while still a teenager, he started some pioneering work on calculating machines. After three years of effort and fifty prototypes, he invented the mechanical calculator. He built 20 of these machines (called Pascal's calculator and later pascaline) in the following ten years. Pascal was an important mathematician, helping create two major new areas of research: he wrote a significant treatise on the subject of projective geometry at the age of 16, and later corresponded with Pierre de Fermat on probability theory, strongly influencing the development of modern economics and social science. Following Galileo and Torricelli, in 1646 he refuted Aristotle's followers who insisted that nature abhors a vacuum. Pascal's results caused many disputes before being accepted.

In 1646, he and his sister Jacqueline identified with the religious movement within Catholicism known by its detractors as Jansenism. His father died in 1651. Following a mystical experience in late 1654, he had his "second conversion", abandoned his scientific work, and devoted himself to philosophy and theology.

His two most famous works date from this period: the *Lettres provinciales* and the *Pensées*, the former set in the conflict between Jansenists and Jesuits. In this year, he also wrote an important treatise on the arithmetical triangle. Between 1658 and 1659 he wrote on the cycloid and its use in calculating the volume of solids. Pascal had poor health especially after his 18th year and his death came just two months after his 39th birthday.

## Hydraulic Principles - Introduction

**Definition** **Hydraulics** is a branch of engineering concerned mainly with moving liquids. The term is applied commonly to the study of the mechanical properties of water, other liquids, and even gases when the effects of compressibility are small. Hydraulics can be divided into two areas, hydrostatics and hydrokinetics.

### **Hydraulics** *The Engineering science pertaining to liquid pressure and flow.*

The word **hydraulics** is based on the Greek word for water, and originally covered the study of the physical behavior of water at rest and in motion. Use has broadened its meaning to include the behavior of all liquids, although it is primarily concerned with the motion of liquids.

Hydraulics includes the manner in which liquids act in tanks and pipes, deals with their properties, and explores ways to take advantage of these properties.

Hydrostatics, the consideration of liquids at rest, involves problems of buoyancy and flotation, pressure on dams and submerged devices, and hydraulic presses. The relative incompressibility of liquids is one of its basic principles. Hydrodynamics, the study of liquids in motion, is concerned with such matters as friction and turbulence generated in pipes by flowing liquids, the flow of water over weirs and through nozzles, and the use of hydraulic pressure in machinery.

### **Hydrostatics**

Hydrostatics is about the pressures exerted by a fluid at rest. Any fluid is meant, not just water. Research and careful study on water yields many useful results of its own, however, such as forces on dams, buoyancy and hydraulic actuation, and is well worth studying for such practical reasons.



The definition of a fluid deserves careful consideration. It is usually stated that a fluid is a substance that cannot resist a shearing stress, so that pressures are normal to confining surfaces.

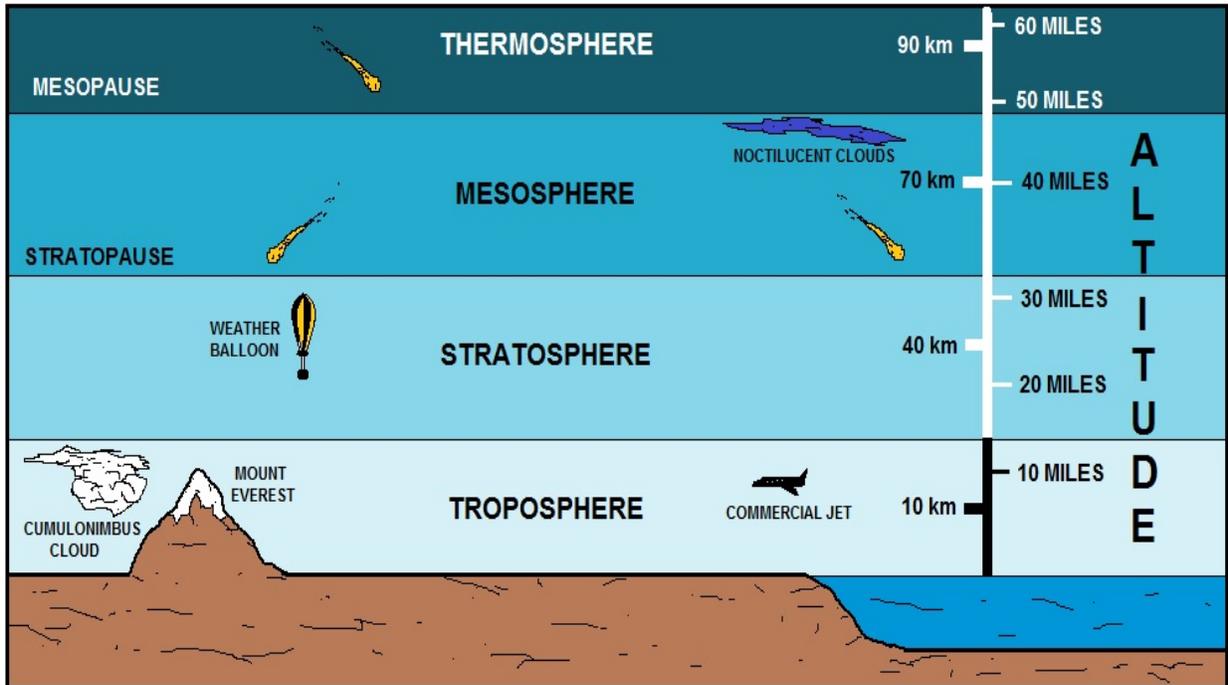
Geology has now shown us clear that there are substances which can resist shearing forces over short time intervals, and appear to be typical solids, but which flow like liquids over long time intervals. Such materials include wax and pitch, ice, and even rock.

A ball of pitch, which can be shattered by a hammer, will spread out and flow in months. Ice, a typical solid, will flow in a period of years, as shown in glaciers, and rock will flow over hundreds of years, as in convection in the mantle of the earth.

Shear earthquake waves, with periods of seconds, propagate deep in the earth, though the rock there can flow like a liquid when considered over centuries. The rate of shearing may not be strictly proportional to the stress, but exists even with low stress.

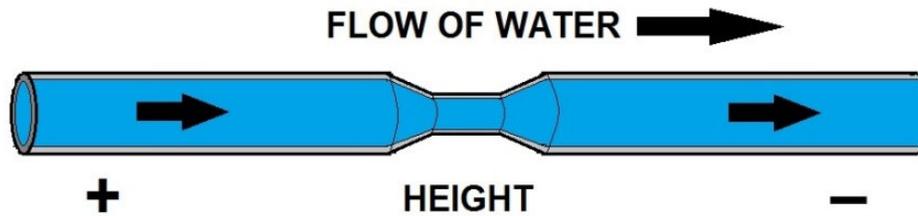
Viscosity may be the physical property that varies over the largest numerical range, competing with electrical resistivity.

There are several familiar topics in hydrostatics which often appears in expositions of introductory science, and which are also of historical interest and can enliven their presentation. Let's start our study with the principles of our atmosphere.



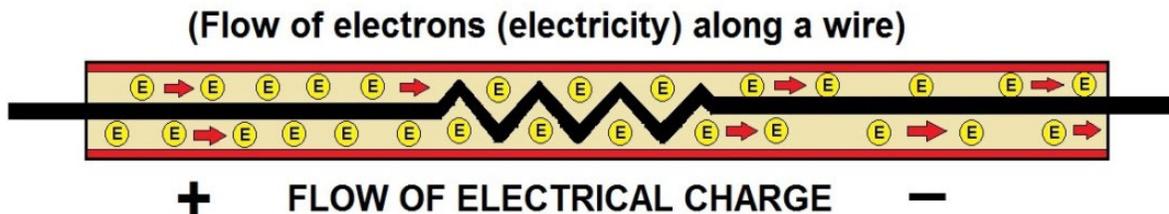
**ATMOSPHERE DIAGRAM**

## Hydraulic Analogy Principles - Introduction



### Electricity flow can be compared to flow of water:

- When pressure is applied at one end of a pipe (or wire) then, water (or electricity) will come out the other end.

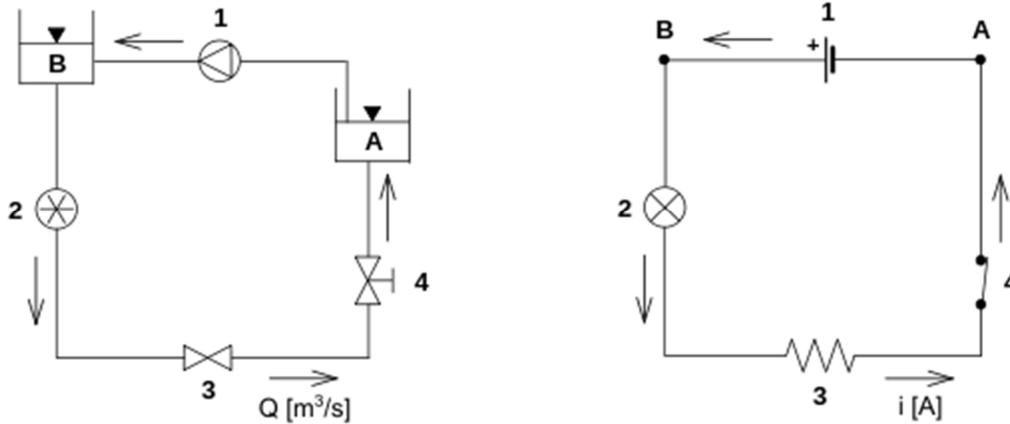


## BASIC ELECTRICAL/HYDRAULIC CONCEPT

### Water (Hydraulic) and Electrical Principles Are Very Similar

The electronic–**hydraulic analogy** (derisively referred to as the **drain-pipe theory** by Oliver Heaviside) is the most widely used analogy for "electron fluid" in a metal conductor. Since electric current is invisible and the processes at play in electronics are often difficult to demonstrate, the various electronic components are represented by hydraulic equivalents.

Electricity (as well as heat) was originally understood to be a kind of fluid, and the names of certain electric quantities (such as current) are derived from hydraulic equivalents. As all analogies, it demands an intuitive and competent understanding of the baseline paradigms (electronics and hydraulics).



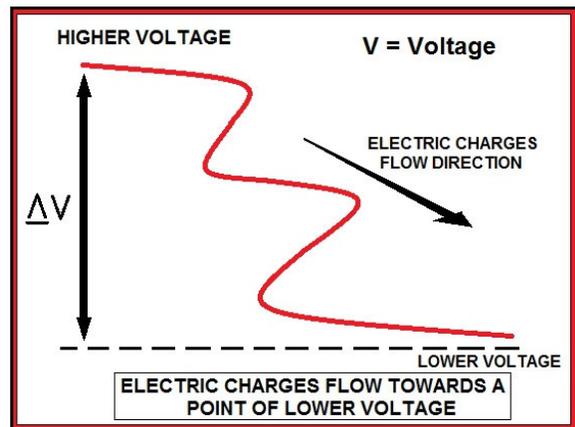
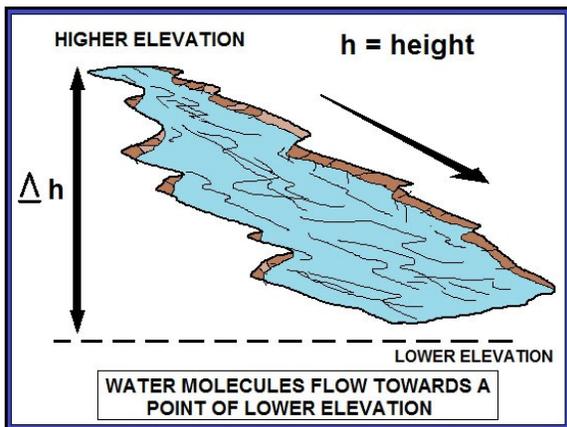
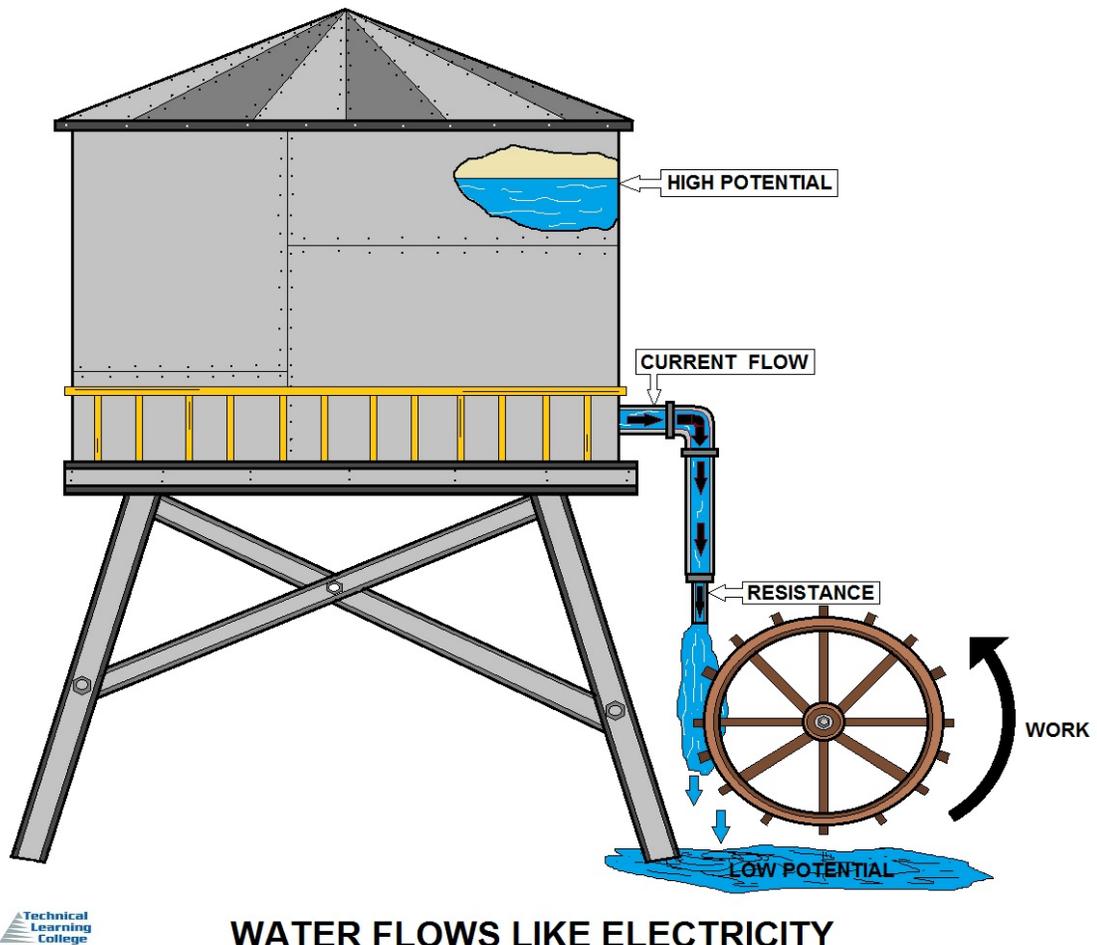
Analogy between a hydraulic circuit (left) and an electronic circuit (right).

### Basic Hydraulic Ideas

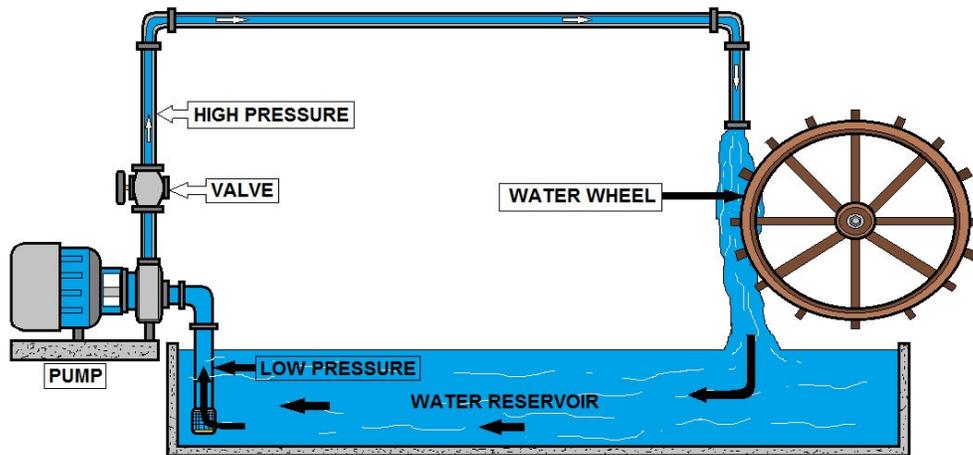
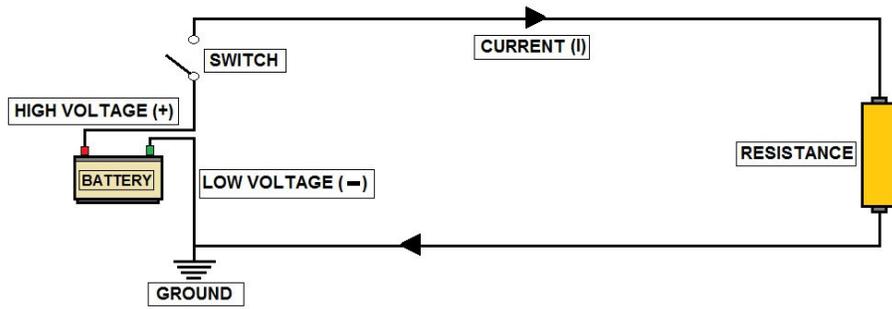
*There are two basic paradigms:*

- Version with pressure induced by gravity. Large tanks of water are held up high, or are filled to differing water levels, and the potential energy of the water head is the pressure source. This is reminiscent of electrical diagrams with an up arrow pointing to +V, grounded pins that otherwise are not shown connecting to anything, and so on.
- Completely enclosed version with pumps providing pressure only; no gravity. This is reminiscent of a circuit diagram with a voltage source shown and the wires actually completing a circuit.

**Applications:** Flow and pressure variables can be calculated in fluid flow network with the use of the hydraulic ohm analogy. The method can be applied to both steady and transient flow situations.

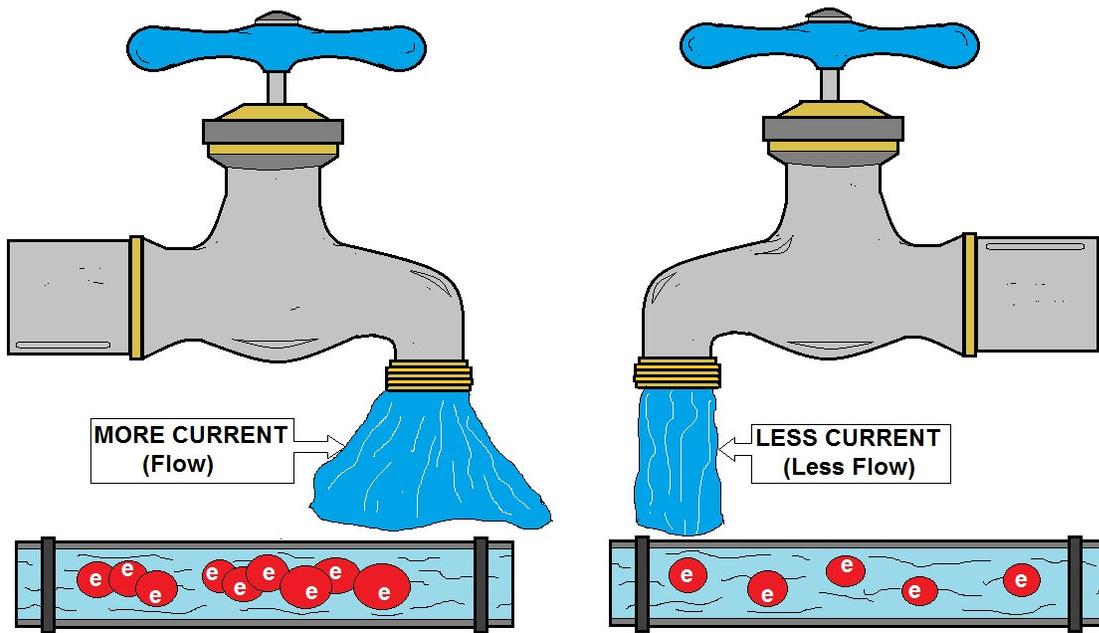


**WATER FLOWS LIKE ELECTRICITY EXAMPLE**



Technical Learning College

EXAMPLE OF HOW WATER FLOWS SIMILAR TO ELECTRICITY



Technical Learning College

ELECTRIC CURRENT - WATER ANALOGY

# Hydraulic Component Equivalents

## Wires

A relatively wide pipe completely filled with water is equivalent to a piece of wire. When comparing to a piece of wire, the pipe should be thought of as having semi-permanent caps on the ends. Connecting one end of a wire to a circuit is equivalent to forcibly un-capping one end of the pipe and attaching it to another pipe. With few exceptions (such as a high-voltage power source), a wire with only one end attached to a circuit will do nothing; the pipe remains capped on the free end, and thus adds nothing to the circuit.

## Electric potential

In general, it is equivalent to hydraulic head. In this article, it is assumed that the water is flowing horizontally, so that the force of gravity can be ignored, and then electric potential is equivalent to pressure.

## Voltage

Also called voltage drop or *potential difference*. A difference in pressure between two points. Usually measured in volts.

## Electric charge

Equivalent to a quantity of water.

## Current

Equivalent to a hydraulic volume flow rate; that is, the volumetric quantity of flowing water over time. Usually measured in amperes.

## Ideal voltage source, or ideal battery

A dynamic pump with feedback control. A pressure meter on both sides shows that regardless of the current being produced, this kind of pump produces constant pressure difference. If one terminal is kept fixed at ground, another analogy is a large body of water at a high elevation, sufficiently large that the drawn water does not affect the water level.

## Ideal current source

A positive displacement pump. A current meter (little paddle wheel) shows that when this kind of pump is driven at a constant speed, it maintains a constant speed of the little paddle wheel.

## Resistor

A constriction in the bore of the pipe which requires more pressure to pass the same amount of water. All pipes have some resistance to flow, just as all wires have some resistance to current.

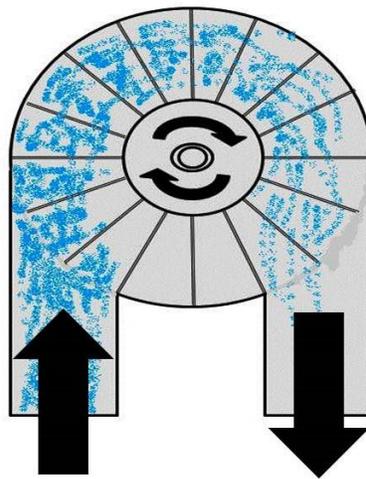
## Capacitor

A tank with one connection at each end and a rubber sheet dividing the tank in two lengthwise (a hydraulic accumulator). When water is forced into one pipe, equal water is simultaneously forced out the other pipe, yet no water can penetrate the rubber diaphragm. Energy is stored by the stretching of the rubber. As more current flows "through" the capacitor, the back-pressure (voltage) becomes greater, thus current "leads" voltage in a capacitor. As the back-pressure from the stretched rubber approaches the applied pressure, the current becomes less and less. Thus capacitors "filter out" constant pressure differences and slowly varying, low-frequency pressure differences, while allowing rapid changes in pressure to pass through.

Note that the device described will pass all changes in pressure "through" equally well, regardless of rate of change, just as an electrical capacitor will. Any device in series must obey (electrical) Kirchhoff's Current Law, or its hydraulic equivalent. Considering the "filter" action, a better and more exact analogy is the hydraulic accumulator "pressure tank", as described, but with a closed, pressurized air bladder and only one water connection. Such accumulators are commonly used in hydraulic power systems exactly for the purpose of damping out pressure surges and "hammers" due to valves opening and closing.

### **Inductor**

A heavy paddle wheel placed in the current. The mass of the wheel and the size of the blades restrict the water's ability to rapidly change its rate of flow (current) through the wheel due to the effects of inertia, but, given time, a constant flowing stream will pass mostly unimpeded through the wheel, as it turns at the same speed as the water flow. The mass and surface area of the wheel and its blades are analogous to inductance, and friction between its axle and the axle bearings corresponds to the resistance that accompanies any non-superconducting inductor.



### **TURBINE INDUCTOR PADDLE**

Inductors are analogous to a heavy paddle wheel/turbine placed in the current.

An alternative inductor model is simply a long pipe, perhaps coiled into a spiral for convenience. This fluid-inertia device is used in real life as an essential component of a hydraulic ram. The inertia of the water flowing through the pipe produces the inductance effect; inductors "filter out" rapid changes in flow, while allowing slow variations in current to be passed through. The drag imposed by the walls of the pipe is somewhat analogous to parasitic resistance.

In either model, the pressure difference (voltage) across the device must be present before the current will start moving, thus in inductors voltage "leads" current. As the current increases, approaching the limits imposed by its own internal friction and of the current that the rest of the circuit can provide, the pressure drop across the device becomes lower and lower.

**Diode**

Equivalent to a one-way check valve with a slightly leaky valve seat. As with a diode, a small pressure difference is needed before the valve opens. And like a diode, too much reverse bias can damage or destroy the valve assembly.

**Transistor**

A valve in which a diaphragm, controlled by a low-current signal (either constant current for a BJT or constant pressure for a FET), moves a plunger which affects the current through another section of pipe.

**CMOS**

A combination of two MOSFET transistors. As the input pressure changes, the pistons allow the output to connect to either zero or positive pressure.

**Memristor**

A needle valve operated by a flow meter. As water flows through in the forward direction, the needle valve restricts flow more; as water flows the other direction, the needle valve opens further providing less resistance.

**Hydraulic - Electrical Principle Equivalents****EM Wave Speed (velocity of propagation)**

Speed of sound in water. When a light switch is flipped, the electric wave travels very quickly through the wires.

**Charge Flow Speed (drift velocity)**

Particle speed of water. The moving charges themselves move rather slowly.

**DC**

Constant flow of water in a circuit of pipe.

**Low Frequency AC**

Water oscillating back and forth in a pipe.

**Higher-Frequency AC and Transmission Lines**

Sound being transmitted through the water pipes: Be aware that this does not properly mirror the cyclical reversal of alternating electric current. As described, the fluid flow conveys pressure fluctuations, but fluids "do not" reverse at high rates in hydraulic systems, which the above "low frequency" entry does accurately describe. A better concept (if sound waves are to be the phenomenon) is that of direct current with high-frequency "ripple" superimposed.

**Inductive Spark**

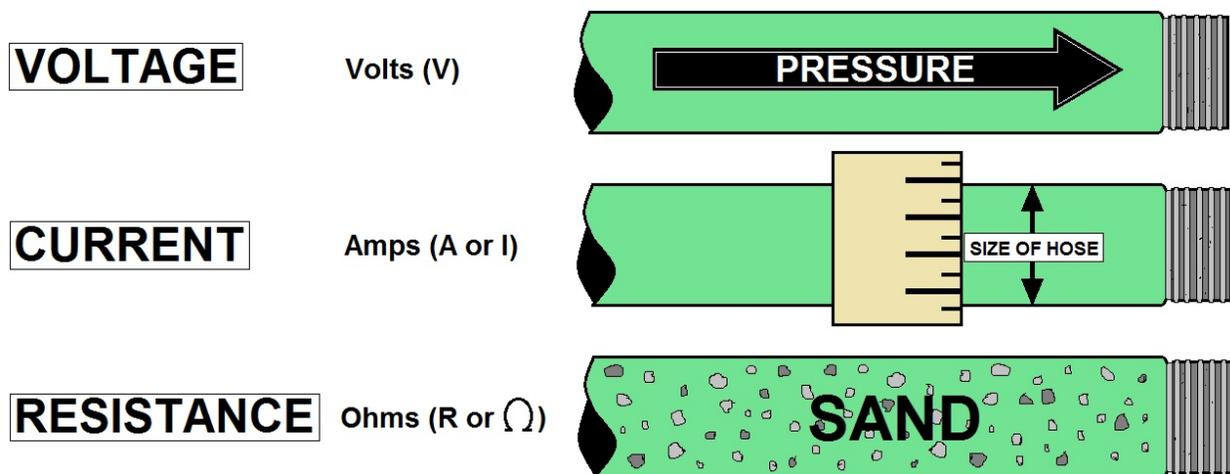
Used in induction coils, similar to water hammer, caused by the inertia of water.

## Hydraulic Equation Examples

Some examples of equivalent electrical and hydraulic equations:

type	hydraulic	electric	thermal	mechanical
quantity	volume $V$ [m <sup>3</sup> ]	charge $q$ [C]	heat $Q$ [J]	momentum $P$ [Ns]
potential	pressure $P$ [Pa=J/m <sup>3</sup> ]	potential $\phi$ [V=J/C]	temperature $T$ [K=J/ $k_B$ ]	velocity $v$ [m/s]
flux	Volumetric flow rate $\Phi_V$ [m <sup>3</sup> /s]	current $I$ [A=C/s]	heat transfer rate $\dot{Q}$ [J/s]	force $F$ [N]
flux density	velocity $v$ [m/s]	current density $j$ [C/(m <sup>2</sup> ·s) = A/m <sup>2</sup> ]	heat flux $\dot{Q}''$ [W/m <sup>2</sup> ]	stress $\sigma$ [N/m <sup>2</sup> = Pa]
linear model	Poiseuille's law $\Phi_V = \frac{\pi r^4 \Delta p^*}{8\eta \ell}$	Ohm's law $j = -\sigma \nabla \phi$	Fourier's law $\dot{Q}'' = \kappa \nabla T$	Dashpot $\sigma = c \Delta v$

If the differential equations have the same form, the response will be similar.



### HOW ELECTRICITY IS SIMILAR TO A WATER HOSE

## Limits to the Hydraulic Analogy

If taken too far, the water analogy can create misconceptions. For it to be useful, we must remain aware of the regions where electricity and water behave very differently.

### Fields (Maxwell equations, Inductance)

Electrons can push or pull other distant electrons via their fields, while water molecules experience forces only from direct contact with other molecules. For this reason, waves in water travel at the speed of sound, but waves in a sea of charge will travel much faster as the forces from one electron are applied to many distant electrons and not to only the neighbors in direct contact. In a hydraulic transmission line, the energy flows as mechanical waves through the water, but in an electric transmission line the energy flows as fields in the space surrounding the wires, and does not flow inside the metal. Also, an accelerating electron will drag its neighbors along while attracting them, both because of magnetic forces.

### Charge

Unlike water, movable charge carriers can be positive or negative, and conductors can exhibit an overall positive or negative net charge. The mobile carriers in electric currents are usually electrons, but sometimes they are charged positively, such as  $H^+$  ions in proton conductors or holes in p-type semiconductors and some (very rare) conductors.

### Leaking Pipes

The electric charge of an electrical circuit and its elements is usually almost equal to zero, hence it is (almost) constant. This is formalized in Kirchhoff's current law, which does not have an analogy to hydraulic systems, where amount of the liquid is not usually constant. Even with incompressible liquid the system may contain such elements as pistons and open pools, so the volume of liquid contained in a part of the system can change. For this reason, continuing electric currents require closed loops rather than hydraulics' open source/sink resembling spigots and buckets.

#### **James Thurber spoke of his maternal grandmother thus:**

*She came naturally by her confused and groundless fears, for her own mother lived the latter years of her life in the horrible suspicion that electricity was dripping invisibly all over the house. - My Life and Hard Times (1933).*

### Fluid Velocity and Resistance of Metals

As with water hoses, the carrier drift velocity in conductors is directly proportional to current. However, water only experiences drag via the pipes' inner surface, while charges are slowed at all points within a metal.

Also, typical velocity of charge carriers within a conductor is less than centimeters per minute, and the "electrical friction" is extremely high. If charges ever flowed as fast as water can flow in pipes, the electric current would be immense, and the conductors would become incandescently hot and perhaps vaporize.

To model the resistance and the charge-velocity of metals, perhaps a pipe packed with sponge, or a narrow straw filled with syrup, would be a better analogy than a large-diameter water pipe. Resistance in most electrical conductors is a linear function: as current increases, voltage drop increases proportionally (Ohm's Law). Liquid resistance in pipes is not linear with volume, varying as the square of volumetric flow (see Darcy–Weisbach equation).

## Quantum Mechanics

Conductors and insulators contain charges at more than one discrete level of atomic orbit energy, while the water in one region of a pipe can only have a single value of pressure. For this reason there is no hydraulic explanation for such things as a battery's charge pumping ability, a diode's voltage drop, solar cell functions, Peltier effect, etc., however equivalent devices can be designed which exhibit similar responses, although some of the mechanisms would only serve to regulate the flow curves rather than to contribute to the component's primary function.

Usefulness requires that the reader or student has a substantial understanding of the model (hydraulic) system's principles. It also requires that the principles can be transferred to the target (electrical) system. Hydraulic systems are deceptively simple: the phenomenon of pump cavitation is a known, complex problem that few people outside of the fluid power or irrigation industries would understand. For those who do, the hydraulic analogy is amusing, as no "cavitation" equivalent exists in electrical engineering. The hydraulic analogy can give a mistaken sense of understanding that will be exposed once a detailed description of electrical circuit theory is required.

One must also consider the difficulties in trying to make the analogy work. The above "electrical friction" example, where the hydraulic analog is a pipe filled with sponge material, illustrates the problem: the model must be increased in complexity beyond any realistic scenario.

## Electrical Measurements and Equipment

Molecule of liquid  $\longrightarrow$  electron of electricity

Flow rate (gpm)  $\longrightarrow$  current (ampere) I, A

Pressure (psi)  $\longrightarrow$  potential (V)

Pressure drop  $\longrightarrow$  voltage drop

Pump  $\longrightarrow$  generator

## Atmospheric Pressure

The atmosphere is the entire mass of air that surrounds the earth. While it extends upward for about 300 miles, the section of primary interest is the portion that rests on the earth's surface and extends upward for about 7 1/2 miles. This layer is called the troposphere.

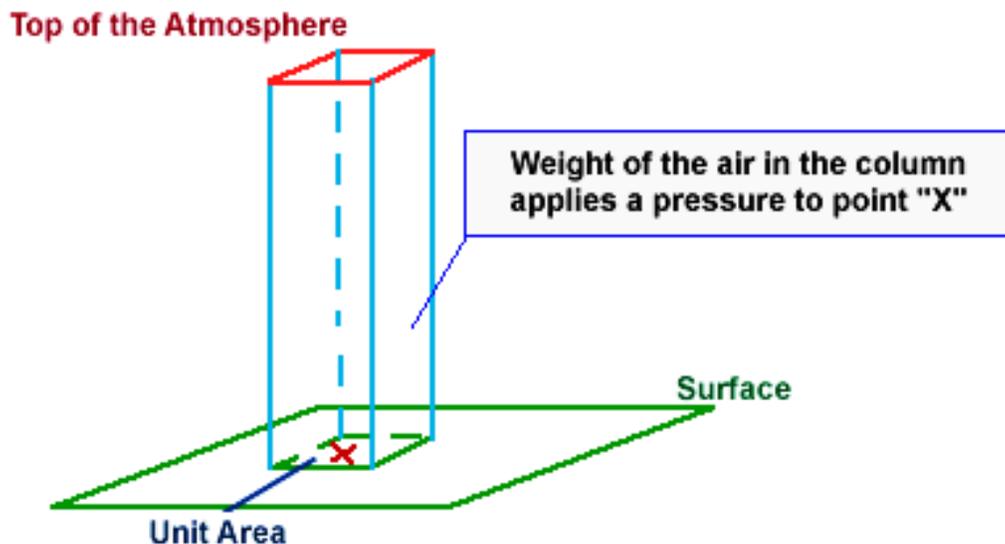
If a column of air 1-inch square extending all the way to the "top" of the atmosphere could be weighed, this column of air would weigh approximately 14.7 pounds at sea level. Thus, atmospheric pressure at sea level is approximately 14.7 psi.

As one ascends, the atmospheric pressure decreases by approximately 1.0 psi for every 2,343 feet. However, below sea level, in excavations and depressions, atmospheric pressure increases. Pressures under water differ from those under air because the weight of the water must be added to the pressure of the air.

Atmospheric pressure can be measured by any of several methods. The common laboratory method uses the mercury column barometer. The height of the mercury column serves as an indicator of atmospheric pressure. At sea level and at a temperature of 0° Celsius (C), the height of the mercury column is approximately 30 inches, or 76 centimeters. This represents a pressure of approximately 14.7 psi. The 30-inch column is used as a reference standard.

Another device used to measure atmospheric pressure is the aneroid barometer. The aneroid barometer uses the change in shape of an evacuated metal cell to measure variations in atmospheric pressure. The thin metal of the aneroid cell moves in or out with the variation of pressure on its external surface. This movement is transmitted through a system of levers to a pointer, which indicates the pressure.

The atmospheric pressure does not vary uniformly with altitude. It changes very rapidly. Atmospheric pressure is defined as the force per unit area exerted against a surface by the weight of the air above that surface. In the diagram below, the pressure at point "X" increases as the weight of the air above it increases. The same can be said about decreasing pressure, where the pressure at point "X" decreases if the weight of the air above it also decreases.

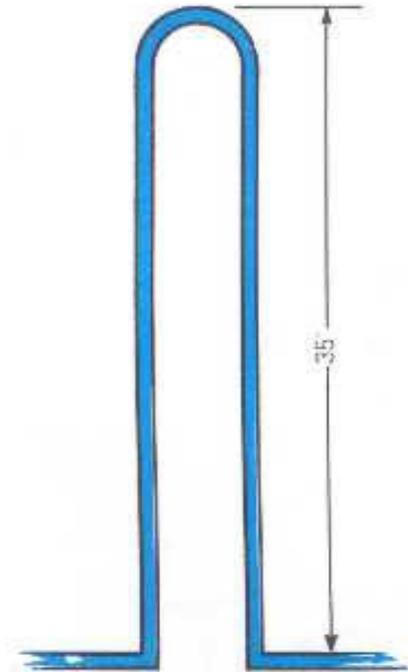


## Barometric Loop

The barometric loop consists of a continuous section of supply piping that abruptly rises to a height of approximately 35 feet and then returns back down to the originating level. It is a loop in the piping system that effectively protects against backsiphonage. It may not be used to protect against back-pressure.

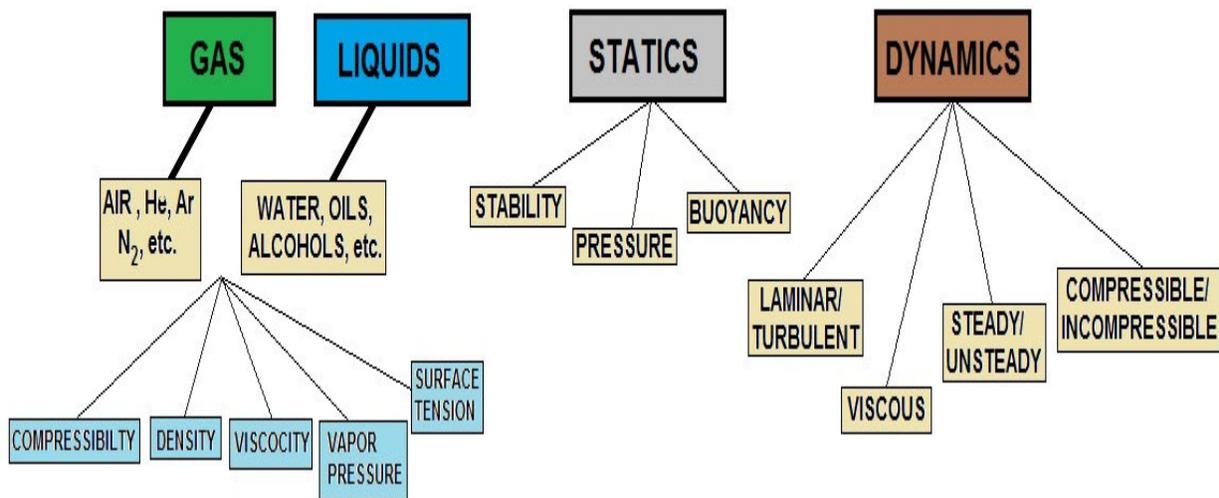
Its operation, in the protection against backsiphonage, is based upon the principle that a water column, at sea level pressure, will not rise above 33.9 feet. In general, barometric loops are locally fabricated, and are 35 feet high.

Pressure may be referred to using an absolute scale, pounds per square inch absolute (**psia**), or gauge scale, (**psig**). Absolute pressure and gauge pressure are related. Absolute pressure is equal to gauge pressure plus the atmospheric pressure. At sea level, the atmospheric pressure is 14.7 psia.



Absolute pressure is the total pressure.

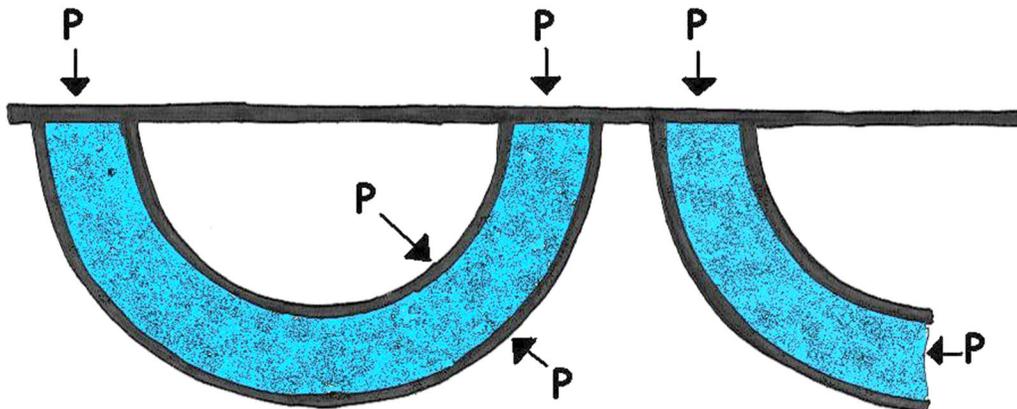
Gauge pressure is simply the pressure read on the gauge. If there is no pressure on the gauge other than atmospheric, the gauge will read zero. Then the absolute pressure would be equal to 14.7 psi, which is the atmospheric pressure.



**FLUID MECHANICS OVERVIEW DIAGRAM #1**

## Pressure

By a fluid, we have a material in mind like water or air, two very common and important fluids. Water is incompressible, while air is very compressible, but both are fluids. Water has a definite volume; air does not. Water and air have low viscosity; that is, layers of them slide very easily on one another, and they quickly their shapes when disturbed by flows. Other fluids, such as molasses, may have high viscosity and take a long time to come to equilibrium, but they are no less fluids. The coefficient of viscosity is the ratio of the shearing force to the velocity gradient. Hydrostatics deals with permanent, time-independent states of fluids, so viscosity does not appear, except as discussed in the Introduction.



**EQUALITY OF PRESSURE –CURTIAN RINGS DIAGRAM**

### Pressure Definition

A fluid, therefore, is a substance that cannot exert any permanent forces tangential to a boundary. Any force that it exerts on a boundary must be normal perpendicular to the boundary. Such a force is proportional to the area on which it is exerted, and is called a pressure.

We can imagine any surface in a fluid as dividing the fluid into parts pressing on each other, as if it were a thin material membrane, and so think of the pressure at any point in the fluid, not just at the boundaries. In order for any small element of the fluid to be in equilibrium, the pressure must be the same in all directions (or the element would move in the direction of least pressure), and if no other forces are acting on the body of the fluid, the pressure must be the same at all neighboring points.

### Pascal's Principle

Therefore, in this case the pressure will be the same throughout the fluid, and the same in any direction at a point (Pascal's Principle). Pressure is expressed in units of force per unit area such as dyne/cm<sup>2</sup>, N/cm<sup>2</sup> (pascal), pounds/in<sup>2</sup> (psi) or pounds/ft<sup>2</sup> (psf). The axiom that if a certain volume of fluid were somehow made solid, the equilibrium of forces would not be disturbed, is useful in reasoning about forces in fluids.

### Equality of Pressure

On earth, fluids are also subject to the force of gravity, which acts vertically downward, and has a magnitude  $\gamma = \rho g$  per unit volume, where  $g$  is the acceleration of gravity, approximately 981 cm/s<sup>2</sup> or 32.15 ft/s<sup>2</sup>,  $\rho$  is the density, the mass per unit volume, expressed in g/cm<sup>3</sup>, kg/m<sup>3</sup>, or slug/ft<sup>3</sup>, and  $\gamma$  is the specific weight, measured in lb/in<sup>3</sup>, or lb/ft<sup>3</sup> (pcf).

## Gravitation

Gravitation is an example of a body force that disturbs the equality of pressure in a fluid. The presence of the gravitational body force causes the pressure to increase with depth, according to the equation  $dp = \rho g dh$ , in order to support the water above. We call this relation the barometric equation, for when this equation is integrated, we find the variation of pressure with height or depth. If the fluid is incompressible, the equation can be integrated at once, and the pressure as a function of depth  $h$  is  $p = \rho gh + p_0$ .

The density of water is about  $1 \text{ g/cm}^3$ , or its specific weight is  $62.4 \text{ pcf}$ .

We may ask what depth of water gives the normal sea-level atmospheric pressure of  $14.7 \text{ psi}$ , or  $2117 \text{ psf}$ .

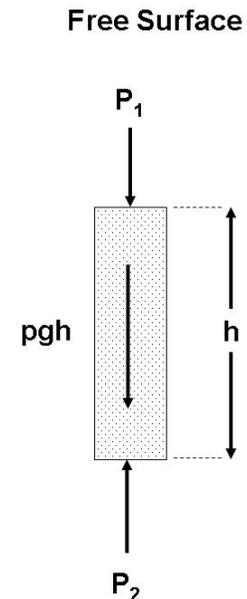
This is simply  $2117 / 62.4 = 33.9 \text{ ft}$  of water. This is the maximum height to which water can be raised by a suction pump, or, more correctly, can be supported by atmospheric pressure.

## Equality of Pressure

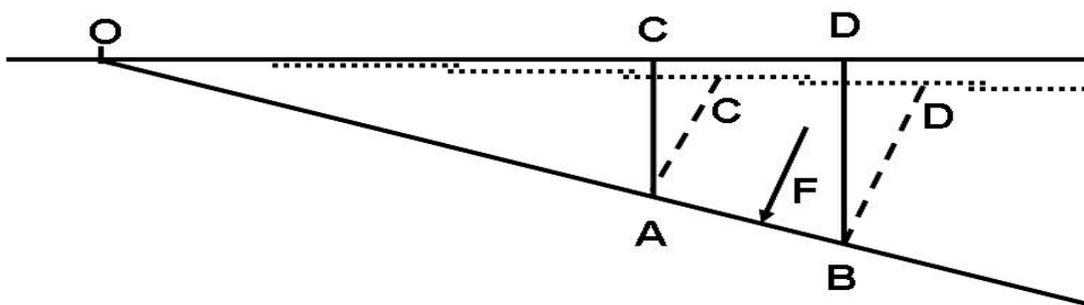
Professor James Thomson (brother of William Thomson, Lord Kelvin) illustrated the equality of pressure by a "curtain-ring" analogy shown in the diagram. A section of the toroid was identified, imagined to be solidified, and its equilibrium was analyzed.

The forces exerted on the curved surfaces have no component along the normal to a plane section, so the pressures at any two points of a plane must be equal, since the fluid represented by the curtain ring was in equilibrium.

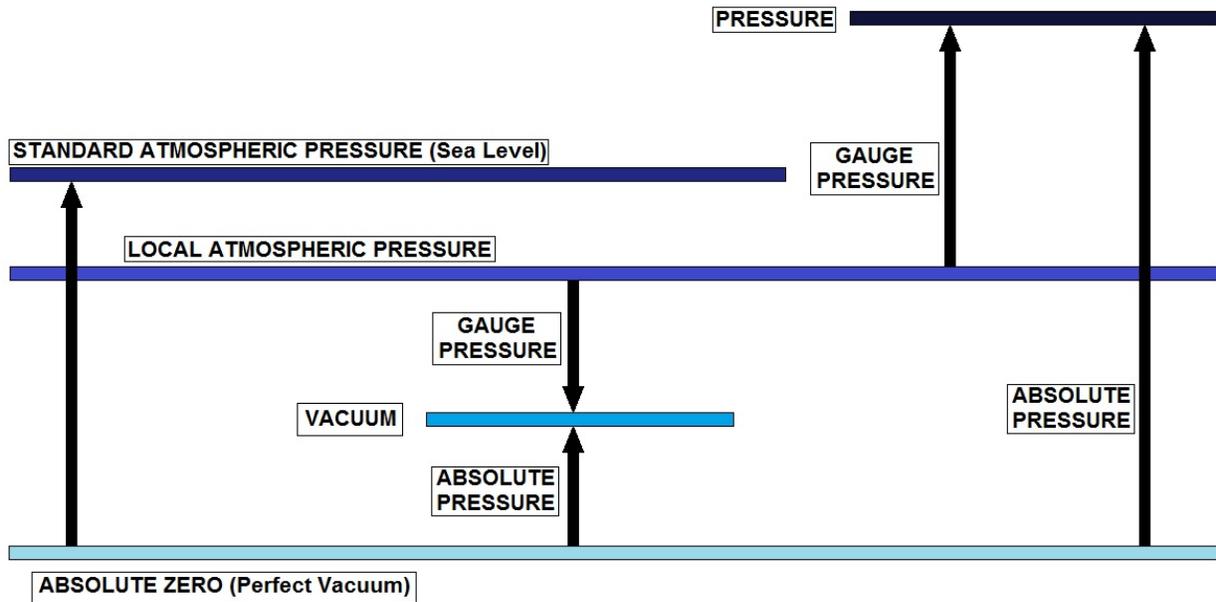
The diagram illustrates the equality of pressures in orthogonal directions. This can be extended to any direction whatever, so Pascal's Principle is established. This demonstration is similar to the usual one using a triangular prism and considering the forces on the end and lateral faces separately.



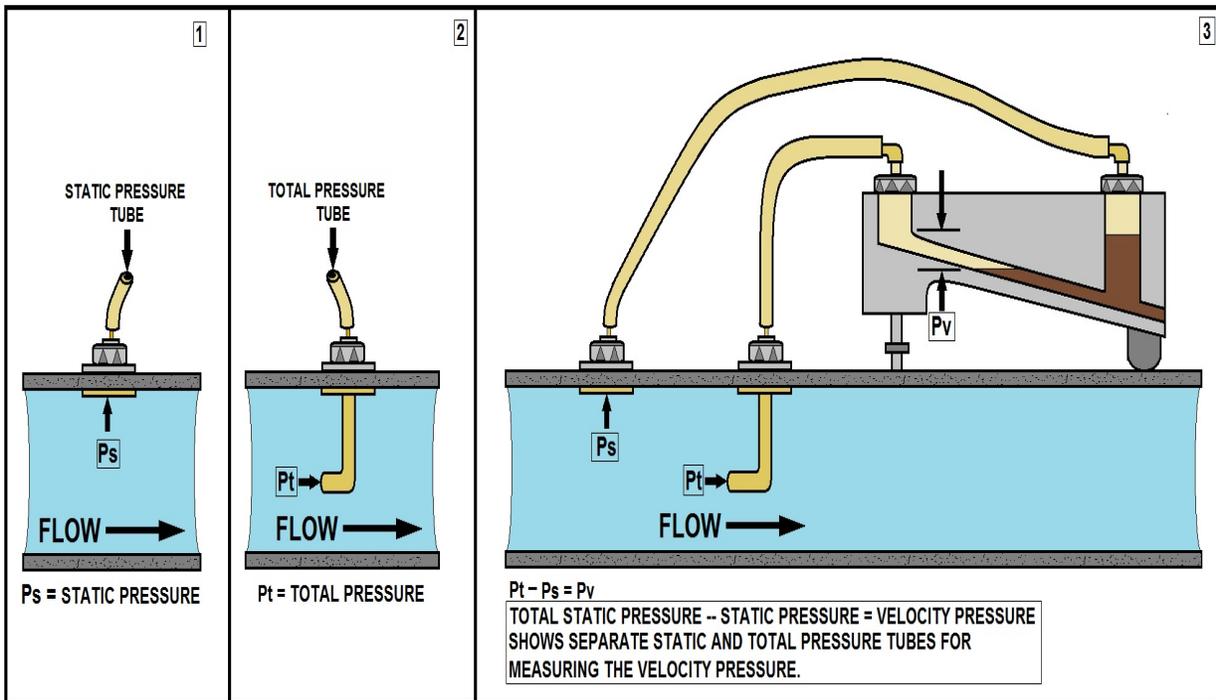
Increase of Pressure with Depth



THRUST ON A PLANE DIAGRAM

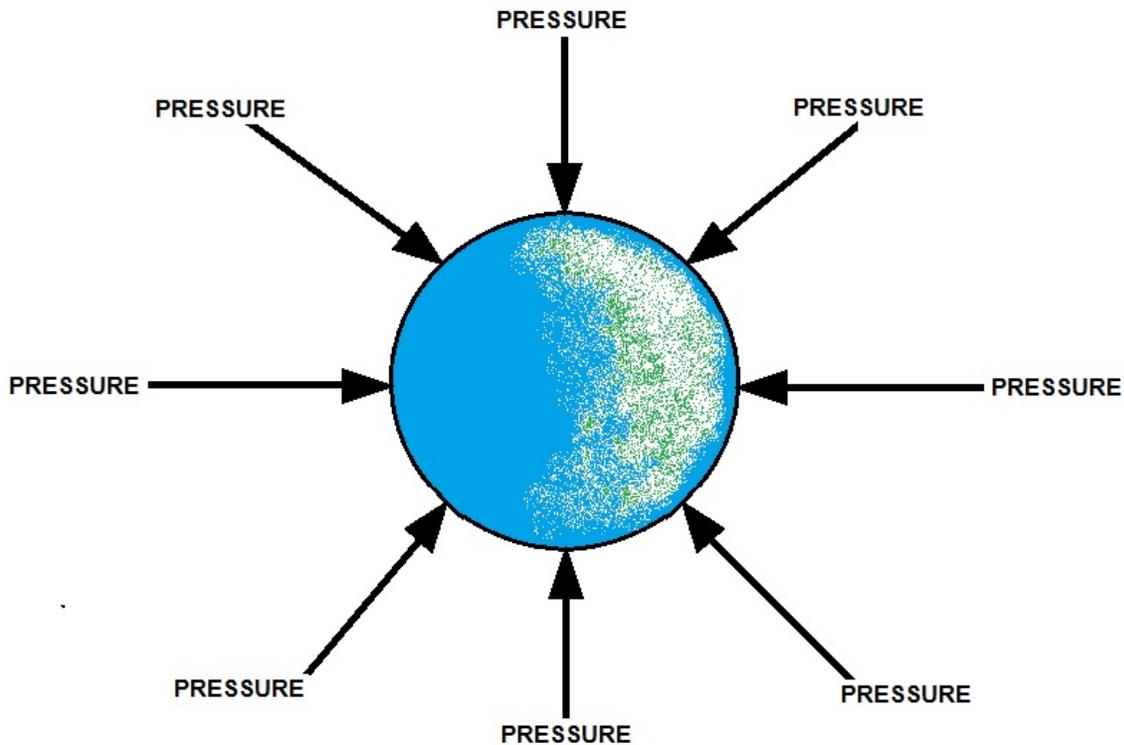


### VACUUM / ABSOLUTE PRESSURE EXAMPLE



### STATIC PRESSURE (VELOCITY HEAD)





- ISOTROPIC = SAME IN ALL DIRECTIONS
- PRESSURE AT ANY POINT OF A FLUID IS ISOTROPIC

## PROPERTIES OF FLUIDS (Isotropic)



Isotropy of pressure here means that the pressure at any point in the liquid acts with equal magnitude in all directions.

### How do we know this?

We can of course experimentally show this for any given liquid.

On a theoretical basis -- Liquids can flow so if the pressure at all points in an incompressible liquid at rest (these are important assumptions) was not isotropic, it would flow in that direction of the excess pressure. If it is in a container, it would even then tend to flow and e.g. manifest the flow via an uneven liquid surface.

One practical application of the above is using liquids to transmit force from one point of a pipe to another end. This is not true for solids.

## Water Pressure

The weight of a cubic foot of water is 62.4 pounds per square foot. The base can be subdivided into 144-square inches with each subdivision being subjected to a pressure of 0.433 psig. Suppose you placed another cubic foot of water on top of the first cubic foot. The pressure on the top surface of the first cube which was originally atmospheric, or 0 psig, would now be 0.4333 psig as a result of the additional cubic foot of water. The pressure of the base of the first cubic foot would be increased by the same amount of 0.866 psig or two times the original pressure.

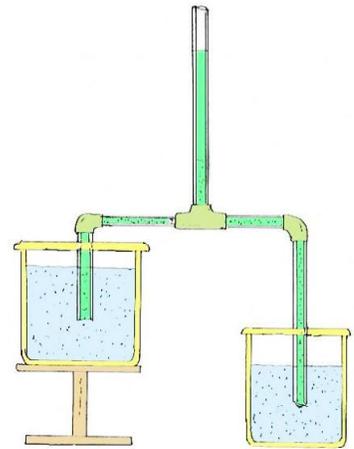
Pressures are very frequently stated in terms of the height of a fluid. If it is the same fluid whose pressure is being given, it is usually called "head," and the factor connecting the head and the pressure is the weight density  $\rho g$ .

In the English engineer's system, weight density is in pounds per cubic inch or cubic foot. A head of 10 ft is equivalent to a pressure of 624 psf, or 4.33 psi. It can also be considered an energy availability of ft-lb per lb. Water with a pressure head of 10 ft can furnish the same energy as an equal amount of water raised by 10 ft. Water flowing in a pipe is subject to head loss because of friction.

Take a jar and a basin of water. Fill the jar with water and invert it under the water in the basin. Now raise the jar as far as you can without allowing its mouth to come above the water surface. It is always a little surprising to see that the jar does not empty itself, but the water remains with no visible means of support. By blowing through a straw, one can put air into the jar, and as much water leaves as air enters. In fact, this is a famous method of collecting insoluble gases in the chemical laboratory, or for supplying hummingbird feeders. It is good to remind oneself of exactly the balance of forces involved.

Another application of pressure is the siphon. The name is Greek for the tube that was used for drawing wine from a cask. This is a tube filled with fluid connecting two containers of fluid, normally rising higher than the water levels in the two containers, at least to pass over their rims.

In the diagram, the two water levels are the same, so there will be no flow. When a siphon goes below the free water levels, it is called an inverted siphon. If the levels in the two basins are not equal, fluid flows from the basin with the higher level into the one with the lower level, until the levels are equal.



PASCAL'S SIPHON

A siphon can be made by filling the tube, closing the ends, and then putting the ends under the surface on both sides.

Alternatively, the tube can be placed in one fluid and filled by sucking on it. When it is full, the other end is put in place. The analysis of the siphon is easy, and should be obvious. The pressure rises or falls as described by the barometric equation through the siphon tube.

There is obviously a maximum height for the siphon which is the same as the limit of the suction pump, about 34 feet. Inverted siphons are sometimes used in pipelines to cross valleys.

Differences in elevation are usually too great to use regular siphons to cross hills, so the fluids must be pressurized by pumps so the pressure does not fall to zero at the crests.

## Liquids at Rest

In studying fluids at rest, we are concerned with the transmission of force and the factors which affect the forces in liquids. Additionally, pressure in and on liquids and factors affecting pressure are of great importance.

### Pressure and Force

Pressure is the force that pushes water through pipes. Water pressure determines the flow of water from the tap. If pressure is not sufficient then the flow can reduce to a trickle and it will take a long time to fill a kettle or a cistern.

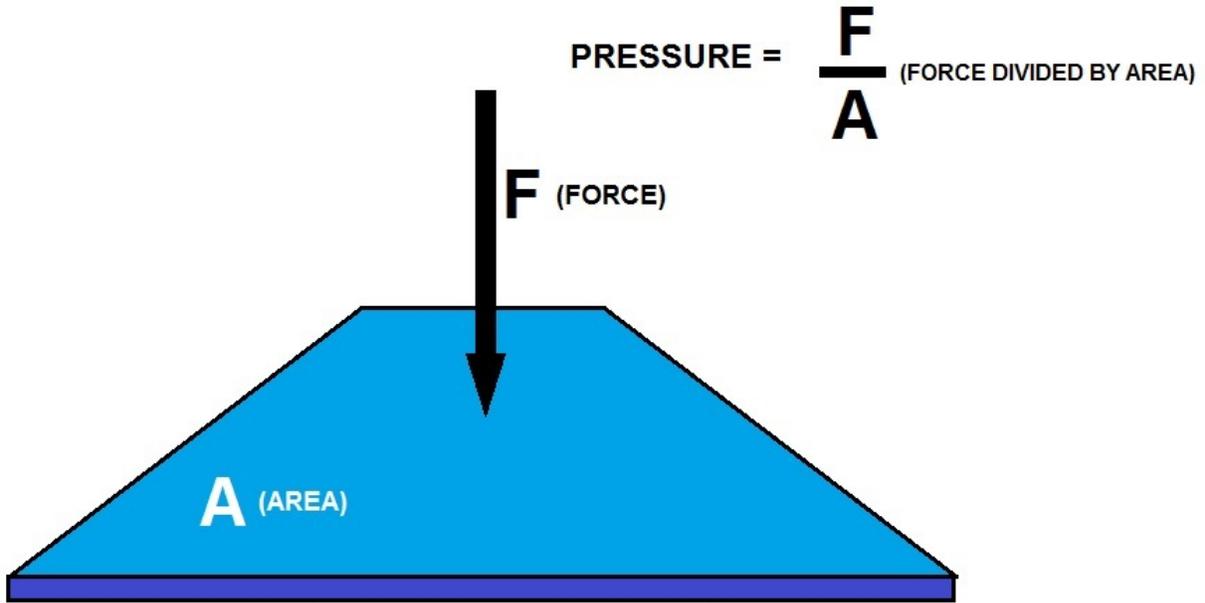
The terms **force** and **pressure** are used extensively in the study of fluid power. It is essential that we distinguish between the terms.

Force means a total push or pull. It is the push or pull exerted against the total area of a particular surface and is expressed in pounds or grams. Pressure means the amount of push or pull (force) applied to each unit area of the surface and is expressed in pounds per square inch (lb/in<sup>2</sup>) or grams per square centimeter (gm/cm<sup>2</sup>). Pressure maybe exerted in one direction, in several directions, or in all directions.

### Computing Force, Pressure, and Area

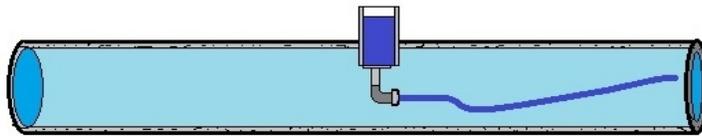
A formula is used in computing force, pressure, and area in fluid power systems. In this formula, P refers to pressure, F indicates force, and A represents area. Force equals pressure times area. Thus, the formula is written:

$$A = \frac{F}{P}$$
$$F = PA$$

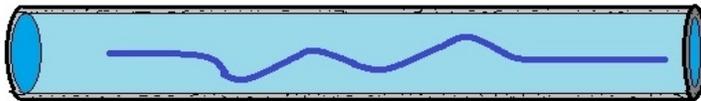


**WHAT IS PRESSURE?**

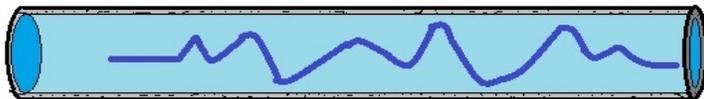
PRESSURE IS THE AMOUNT OF FORCE ACTING ON A SPECIFIC AREA AND IS EQUAL TO THE FORCE DIVIDED BY THE AREA



**LAMINAR FLOW**  
- PREDICTABLE, SLOW MIXING



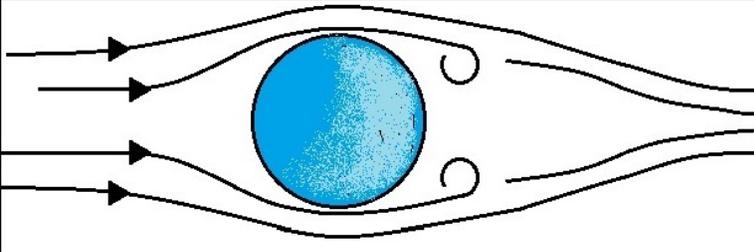
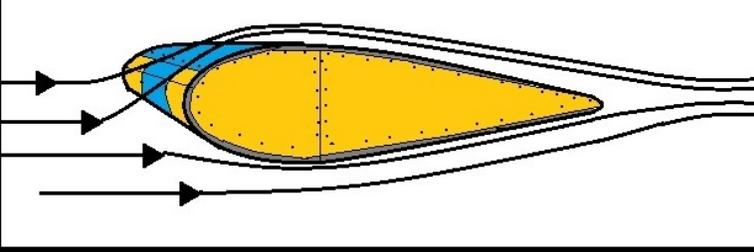
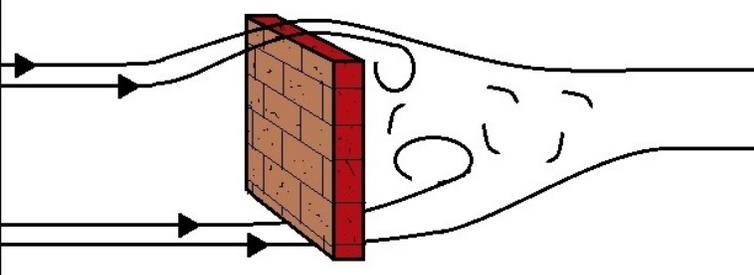
**TRANSITIONAL**  
- TURBULENT OUTBURSTS



**TURBULENT FLOW**  
- UNPREDICTABLE, RAPID MIXING

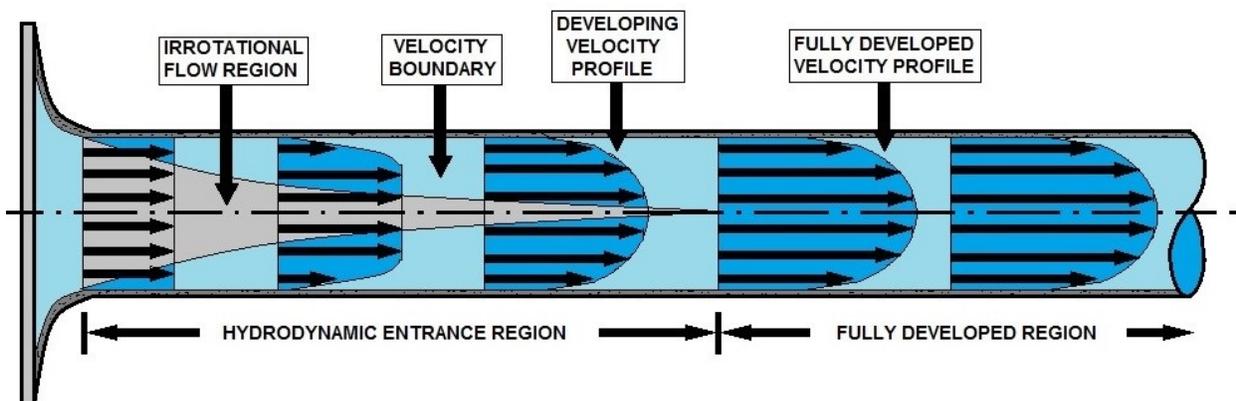
**FLOW CHARACTERISTICS IN PIPING**



	<p><b>SPHERE</b></p> <p>-ROUND OBJECTS SUCH AS BASEBALLS / SOFTBALLS EXPERIENCE A MEDIUM AMOUNT OF DRAG</p>
	<p><b>AIRFOIL</b></p> <p>-THE SHAPE OF AIRPLANE WINGS MINIMIZE DRAG</p>
	<p><b>SQUARE</b></p> <p>-FLAT OBJECTS, SUCH AS BOXES OR WALLS EXPERIENCE A VERY HIGH AMOUNT OF DRAG</p>

### DRAG FORCE (VISCOUS)

- THIS IS THE FORCE OF FRICTION CAUSED BY FLOWING FLUID
- IN THE OPPOSITE DIRECTION TO THE MOVEMENT OF FLUID



### BREAKDOWN OF WATER FLOWING INSIDE A PIPE DIAGRAM

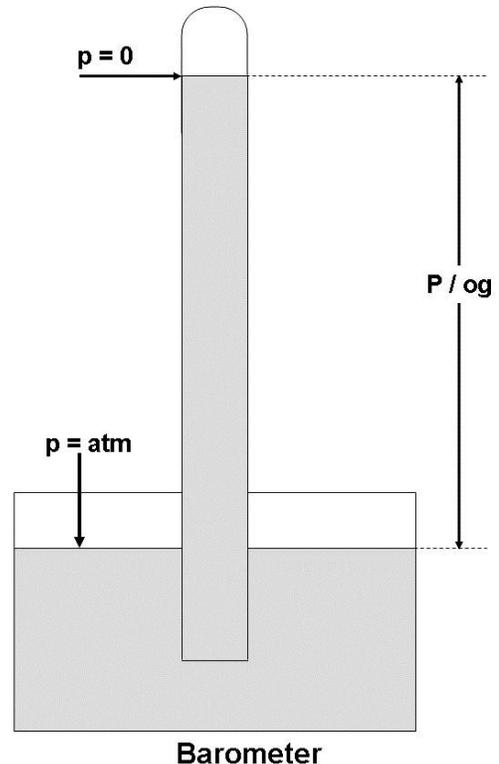
## Free Surface Perpendicular to Gravity

When gravity acts, the liquid assumes a free surface perpendicular to gravity, which can be proved by Thomson's method. A straight cylinder of unit cross-sectional area (assumed only for ease in the arithmetic) can be used to find the increase of pressure with depth. Indeed, we see that  $p_2 = p_1 + \rho gh$ . The upper surface of the cylinder can be placed at the free surface if desired. The pressure is now the same in any direction at a point, but is greater at points that lie deeper. From this same figure, it is easy to prove Archimedes' Principle that the buoyant force is equal to the weight of the displaced fluid, and passes through the center of mass of this displaced fluid.

## Geometric Arguments

Ingenious geometric arguments can be used to substitute for easier, but less transparent arguments using calculus. For example, the force acting on one side of an inclined plane surface whose projection is AB can be found as in the diagram on the previous page. O is the point at which the prolonged projection intersects the free surface.

The line AC' perpendicular to the plane is made equal to the depth AC of point A, and line BD' is similarly drawn equal to BD. The line OD' also passes through C', by proportionality of triangles OAC' and OAD'. Therefore, the thrust F on the plane is the weight of a prism of fluid of cross-section AC'D'B, passing through its centroid normal to plane AB. Note that the thrust is equal to the density times the area times the depth of the center of the area; its line of action does not pass through the center, but below it, at the center of thrust. The same result can be obtained with calculus by summing the pressures and the moments.



## Atmospheric Pressure and its Effects

Suppose a vertical pipe is stood in a pool of water, and a vacuum pump applied to the upper end. Before we start the pump, the water levels outside and inside the pipe are equal, and the pressures on the surfaces are also equal and are equal to the atmospheric pressure.

Now start the pump. When it has sucked all the air out above the water, the pressure on the surface of the water inside the pipe is zero, and the pressure at the level of the water on the outside of the pipe is still the atmospheric pressure. Of course, there is the vapor pressure of the water to worry about if you want to be precise, but we neglect this complication in making our point.

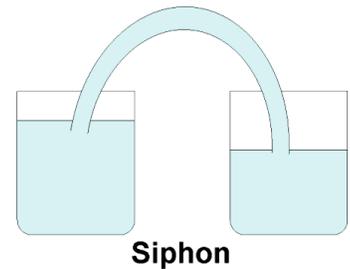
We require a column of water 33.9 ft high inside the pipe, with a vacuum above it, to balance the atmospheric pressure. Now do the same thing with liquid mercury, whose density at 0 °C is 13.5951 times that of water. The height of the column is 2.494 ft, 29.92 in, or 760.0 mm.

## Standard Atmospheric Pressure

This definition of the standard atmospheric pressure was established by Regnault in the mid-19th century. In Britain, 30 in. Hg (inches of mercury) had been used previously. As a practical matter, it is convenient to measure pressure differences by measuring the height of liquid columns, a practice known as manometry. The barometer is a familiar example of this, and atmospheric pressures are traditionally given in terms of the length of a mercury column. To make a barometer, the barometric tube, closed at one end, is filled with mercury and then inverted and placed in a mercury reservoir. Corrections must be made for temperature, because the density of mercury depends on the temperature, and the brass scale expands for capillarity if the tube is less than about 1 cm in diameter, and even slightly for altitude, since the value of  $g$  changes with altitude.

The vapor pressure of mercury is only 0.001201 mmHg at 20°C, so a correction from this source is negligible. For the usual case of a mercury column ( $\alpha = 0.000181792$  per °C) and a brass scale ( $\alpha = 0.0000184$  per °C) the temperature correction is -2.74 mm at 760 mm and 20°C. Before reading the barometer scale, the mercury reservoir is raised or lowered until the surface of the mercury just touches a reference point, which is mirrored in the surface so it is easy to determine the proper position.

An aneroid barometer uses a partially evacuated chamber of thin metal that expands and contracts according to the external pressure. This movement is communicated to a needle that revolves in a dial. The materials and construction are arranged to give a low temperature coefficient. The instrument must be calibrated before use, and is usually arranged to read directly in elevations.



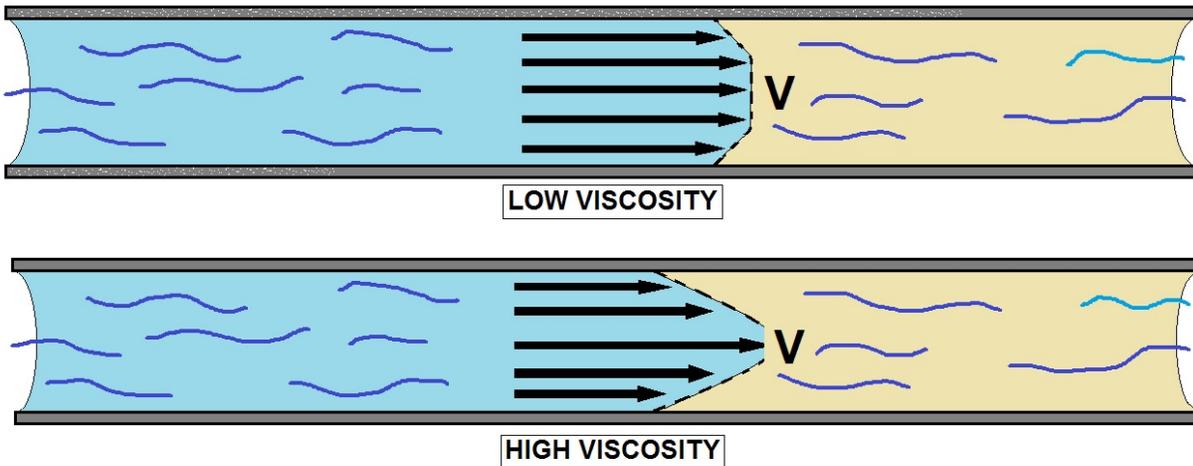
An aneroid barometer is much easier to use in field observations, such as in reconnaissance surveys. In a particular case, it would be read at the start of the day at the base camp, at various points in the vicinity, and then finally at the starting point, to determine the change in pressure with time. The height differences can be calculated from  $h = 60,360 \log (P/p) [1 + (T + t - 64)/986]$  feet, where  $P$  and  $p$  are in the same units, and  $T, t$  are in °F.

An absolute pressure is referring to a vacuum, while a gauge pressure is referring to the atmospheric pressure at the moment. A negative gauge pressure is a (partial) vacuum. When a vacuum is stated to be so many inches, this means the pressure below the atmospheric pressure of about 30 in. A vacuum of 25 inches is the same thing as an absolute pressure of 5 inches (of mercury).

## Vacuum

The term **vacuum** indicates that the absolute pressure is less than the atmospheric pressure and that the gauge pressure is negative. A complete or total vacuum would mean a pressure of 0 psia or -14.7 psig. Since it is impossible to produce a total vacuum, the term vacuum, as used in this document, will mean all degrees of partial vacuum. In a partial vacuum, the pressure would range from slightly less than 14.7 psia (0 psig) to slightly greater than 0 psia (-14.7 psig). Backsiphonage results from atmospheric pressure exerted on a liquid, forcing it toward a supply system that is under a vacuum.

VELOCITY INCREASES RAPIDLY FROM WALL INWARD FOR A LOW - VISCOSITY  
BUT MORE GRADUALLY FOR A HIGH VISCOSITY FLUID



## VISCOSITY OF LIQUID

**Viscosity of liquids** in chemistry is the resistance to flow exhibited by fluids (liquids or gases) like glycerol, ester, oils, water, alcohol, ether. The flow of some liquids is slower than the others due to this property.

For example, glycerol, ester, oil flow slowly while water, ether, alcohol flow rapidly on the solid surface due to viscosity. The former liquids are called high viscous liquids while the latter liquids are called low viscous liquids. The reciprocal of viscosity is called fluidity which measures the flowing tendency of the liquid for learning chemistry and physics.

### What is kinematic viscosity?

Kinematic viscosity in physics sometimes is used in engineering studies to compare the following property of the different liquids.

It is defined as kinematic viscosity = viscosity coefficient ( $\eta$ )/density ( $\rho$ ) and expressed or calculate in the Stoke unit for the honor of the scientist Stoke.

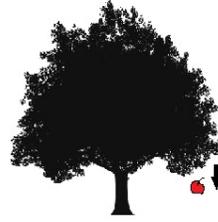
The measurement of viscosity data of fluids is important in the study of biology, chemistry, and physiology, it also uses to dealing with various problems solve in fluid mechanics, especially in paint, ink, colloids, rubber, textiles, etc. Recently it was used in the determination of the molecular weight of polymers.



FRictional FORCE



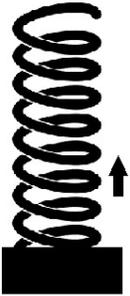
APPLIED FORCE



GRAVITATIONAL FORCE



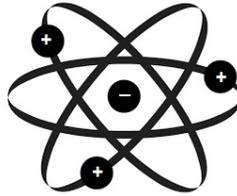
DRAG FORCE



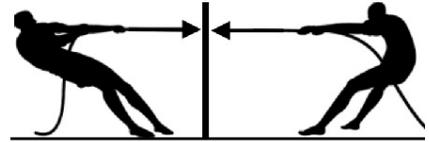
SPRING FORCE



MAGNETIC FORCE



ELECTRICAL FORCE



TENSION FORCE

### GRAVITY AND APPLIED FORCES EXAMPLES



## Development of Hydraulics

Although the modern development of hydraulics is comparatively recent, the ancients were familiar with many hydraulic principles and their applications. The Egyptians and the ancient people of Persia, India, and China conveyed water along channels for irrigation and domestic purposes, using dams and sluice gates to control the flow. The ancient Cretans had an elaborate plumbing system. Archimedes studied the laws of floating and submerged bodies. The Romans constructed aqueducts to carry water to their cities.

After the breakup of the ancient world, there were few new developments for many centuries. Then, over a comparatively short period, beginning near the end of the seventeenth century, Italian physicist, Evangelista Torricelle, French physicist, Edme Mariotte, and later, Daniel Bernoulli conducted experiments to study the elements of force in the discharge of water through small openings in the sides of tanks and through short pipes. During the same period, Blaise Pascal, a French scientist, discovered the fundamental law for the science of hydraulics. Pascal's law states that increase in pressure on the surface of a confined fluid is transmitted undiminished throughout the confining vessel or system.

For Pascal's law to be made effective for practical applications, it was necessary to have a piston that "fit exactly." It was not until the latter part of the eighteenth century that methods were found to make these snugly fitted parts required in hydraulic systems.

This was accomplished by the invention of machines that were used to cut and shape the necessary closely fitted parts and, particularly, by the development of gaskets and packings. Since that time, components such as valves, pumps, actuating cylinders, and motors have been developed and refined to make hydraulics one of the leading methods of transmitting power.

Liquids are almost incompressible. For example, if a pressure of 100 pounds per square inch (**psi**) is applied to a given volume of water that is at atmospheric pressure, the volume will decrease by only 0.03 percent. It would take a force of approximately 32 tons to reduce its volume by 10 percent; however, when this force is removed, the water immediately returns to its original volume. Other liquids behave in about the same manner as water.

Another characteristic of a liquid is the tendency to keep its free surface level. If the surface is not level, liquids will flow in the direction which will tend to *make* the surface level.

### Evangelista Torricelli

Evangelista Torricelli (1608-1647), Galileo's student and secretary and a member of the Florentine Academy of Experiments, invented the mercury barometer in 1643, and brought the weight of the atmosphere to light. The mercury column was held up by the pressure of the atmosphere, not by horror vacui as Aristotle had supposed. Torricelli's early death was a blow to science, but his ideas were furthered by Blaise Pascal (1623-1662).

Pascal had a barometer carried up the 1465 m high Puy de Dôme, an extinct volcano in the Auvergne just west of his home of Clermont-Ferrand in 1648 by Périer, his brother-in-law. Pascal's experimentum crucis is one of the triumphs of early modern science. The Puy de Dôme is not the highest peak in the Massif Central--the Puy de Sancy, at 1866 m is, but it was the closest. Clermont is now the center of the French pneumatics industry.

## Burgomeister of Magdeburg

The remarkable Otto von Guericke (1602-1686), Burgomeister of Magdeburg, Saxony, took up the cause, making the first vacuum pump, which he used in vivid demonstrations of the pressure of the atmosphere to the Imperial Diet at Regensburg in 1654. Famously, he evacuated a sphere consisting of two well-fitting hemispheres about a foot in diameter, and showed that 16 horses, 8 on each side, could not pull them apart. An original vacuum pump and hemispheres from 1663 are shown at the right (photo edited from the Deutsches Museum; see on right). He also showed that air had weight, and how much force it did require to separate evacuated hemispheres. Then, in England, Robert Hooke (1635-1703) made a vacuum pump for Robert Boyle (1627-1691). Christian Huygens (1629-1695) became interested in a visit to London in 1661 and had a vacuum pump built for him. By this time, Torricelli's doctrine had triumphed over the Church's support for horror vacui. This was one of the first victories for rational physics over the illusions of experience, and is well worth consideration.



Pascal demonstrated that the siphon worked by atmospheric pressure, not by horror vacui. The two beakers of mercury are connected by a three-way tube as shown, with the upper branch open to the atmosphere. As the large container is filled with water, pressure on the free surfaces of the mercury in the beakers pushes mercury into the tubes. When the state shown is reached, the beakers are connected by a mercury column, and the siphon starts, emptying the upper beaker and filling the lower. The mercury has been open to the atmosphere all this time, so if there were any horror vacui, it could have flowed in at will to soothe itself.

## Torr

The mm of mercury is sometimes called a torr after Torricelli, and Pascal also has been honored by a unit of pressure, a newton per square meter or  $10 \text{ dyne/cm}^2$ . A cubic centimeter of air weighs 1.293 mg under standard conditions, and a cubic meter 1.293 kg, so air is by no means even approximately weightless, though it seems so. The weight of a sphere of air as small as 10 cm in diameter is 0.68 g, easily measurable with a chemical balance. The pressure of the atmosphere is also considerable, like being 34 ft under water, but we do not notice it. A bar is  $10^6 \text{ dyne/cm}^2$ , very close to a standard atmosphere, which is 1.01325 bar. In meteorology, the millibar, mb, is used.  $1 \text{ mb} = 1.333 \text{ mmHg} = 100 \text{ Pa} = 1000 \text{ dyne/cm}^2$ .

A kilogram-force per square centimeter is  $981,000 \text{ dyne/cm}^2$ , also close to one atmosphere. In Europe, it has been considered approximately 1 atm, as in tire pressures and other engineering applications.

As we have seen, in English units the atmosphere is about 14.7 psi, and this figure can be used to find other approximate equivalents. For example,  $1 \text{ psi} = 51.7 \text{ mmHg}$ . In Britain, tons per square inch has been used for large pressures. The ton in this case is 2240 lb, not the American short ton.  $1 \text{ tsi} = 2240 \text{ psi}$ ,  $1 \text{ tsf} = 15.5 \text{ psi}$  (about an atmosphere!). The fluid in question here is air, which is by no means incompressible. As we rise in the atmosphere and the pressure decreases, the air also expands.

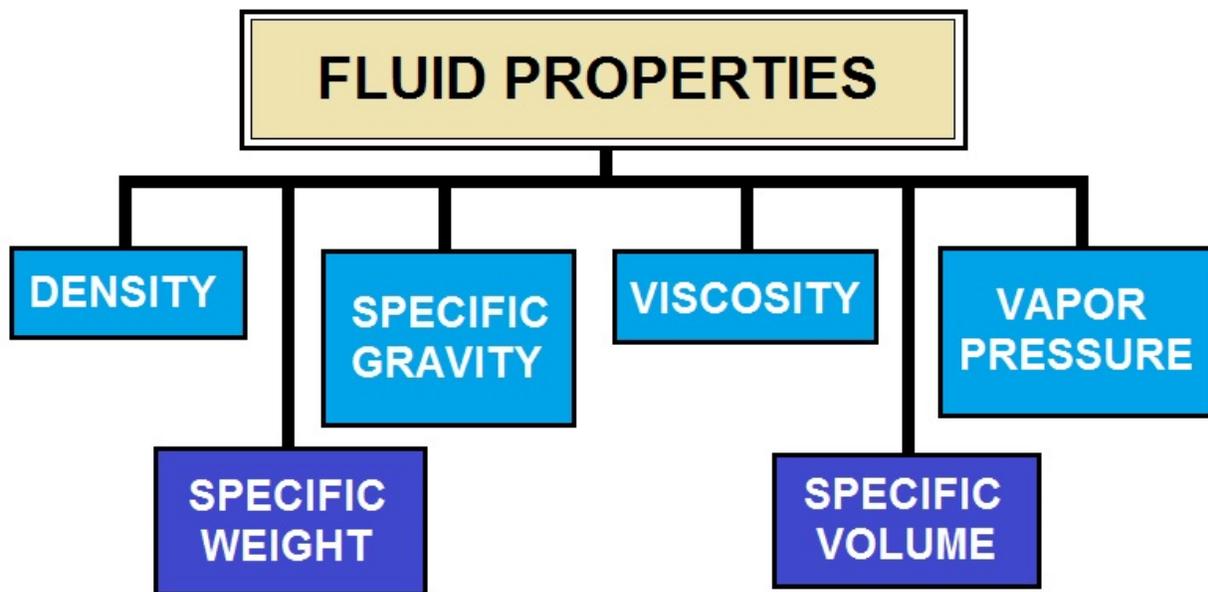
To see what happens in this case, we can make use of the ideal gas equation of state,  $p = \rho RT/M$ , and assume that the temperature  $T$  is constant. Then the change of pressure in a change of altitude  $dh$  is  $dp = -\rho g dh = -(\rho M/RT) g dh$ , or  $dp/p = -(Mg/RT) dh$ .

This is a little harder to integrate than before, but the result is  $\ln p = -Mgh/RT + C$ , or  $\ln (p/p_0) = -Mgh/RT$ , or finally  $p = p_0 \exp(-Mgh/RT)$ .

In an isothermal atmosphere, the pressure decreases exponentially. The quantity  $H = RT/Mg$  is called the "height of the homogeneous atmosphere" or the scale height, and is about 8 km at  $T = 273K$ .

This quantity gives the rough scale of the decrease of pressure with height. Of course, the real atmosphere is by no means isothermal close to the ground, but cools with height nearly linearly at about  $6.5^\circ C/km$  up to an altitude of about 11 km at middle latitudes, called the tropopause.

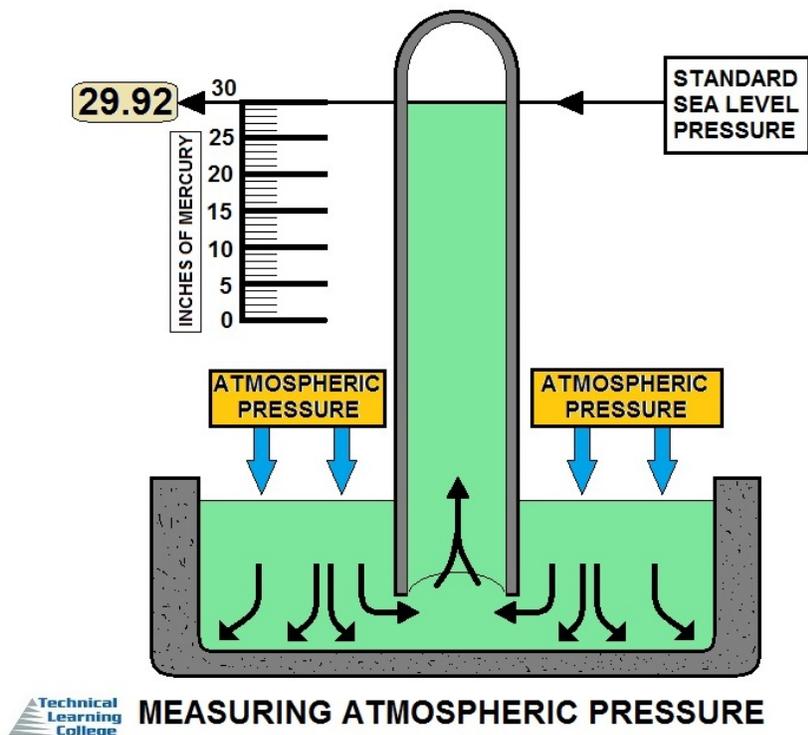
Above this is a region of nearly constant temperature, the stratosphere, and then at some higher level the atmosphere warms again to near its value at the surface. Of course, there are variations from the average values. When the temperature profile with height is known, we can find the pressure by numerical integration quite easily.



## BASICS USED TO DEFINE FLUIDS



## Meteorology



The atmospheric pressure is of great importance in meteorology, since it determines the winds, which generally move at right angles to the direction of the most rapid change of pressure, that is, along the isobars, which are contours of constant pressure.

Certain typical weather patterns are associated with relatively high and relatively low pressures, and how they vary with time. The barometric pressure may be given in popular weather forecasts, though few people know what to do with it.

If you live at a high altitude, your local weather reporter may report the pressure to be, say, 29.2 inches, but if you have a real barometer, you may well find that it is closer to 25 inches. At an elevation of 1500 m (near Denver, or the top of the Puy de Dôme), the atmospheric pressure is about 635 mm, and water boils at 95 °C.

In fact, altitude is quite a problem in meteorology, since pressures must be measured at a common level to be meaningful.

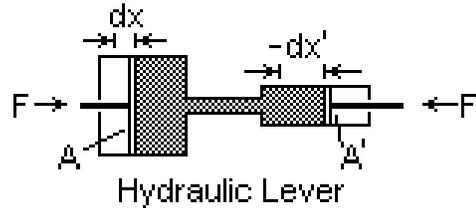
The barometric pressures quoted in the news are reduced to sea level by standard formulas that amount to assuming that there is a column of air from your feet to sea level with a certain temperature distribution, and adding the weight of this column to the actual barometric pressure.

This is only an arbitrary 'fix' and leads to some strange conclusions, such as the permanent winter highs above high plateaus that are really imaginary.

## The Hydraulic Lever

A cylinder and piston is a chamber of variable volume, a mechanism for transforming pressure to force.

If  $A$  is the area of the cylinder, and  $p$  the pressure of the fluid in it, then  $F = pA$  is the force on the piston. If the piston moves outwards a distance  $dx$ , then the change in volume is  $dV = A dx$ .



The work done by the fluid in this displacement is  $dW =$

$F dx = pA dx = p dV$ . If the movement is slow enough that inertia and viscosity forces are negligible, then hydrostatics will still be valid. A process for which this is true is called quasi-static. Now consider two cylinders, possibly of different areas  $A$  and  $A'$ , connected with each other and filled with fluid. For simplicity, suppose that there are no gravitational forces.

Then the pressure is the same,  $p$ , in both cylinders. If the fluid is incompressible, then  $dV + dV' = 0$ , so that  $dW = p dV + p dV' = F dx + F' dx' = 0$ . This says the work done on one piston is equal to the work done by the other piston: the conservation of energy. The ratio of the forces on the pistons is  $F' / F = A' / A$ , the same as the ratio of the areas, and the ratios of the displacements  $dx' / dx = F / F' = A / A'$  is in the inverse ratio of the areas. This mechanism is the hydrostatic analogue of the lever, and is the basis of hydraulic activation.

## Bramah Hydraulic Press

The most famous application of this principle is the Bramah hydraulic press, invented by Joseph Bramah (1748-1814), who also invented many other useful machines, including a lock and a toilet. Now, it was not very remarkable to see the possibility of a hydraulic press; what was remarkable was to find a way to seal the large cylinder properly.

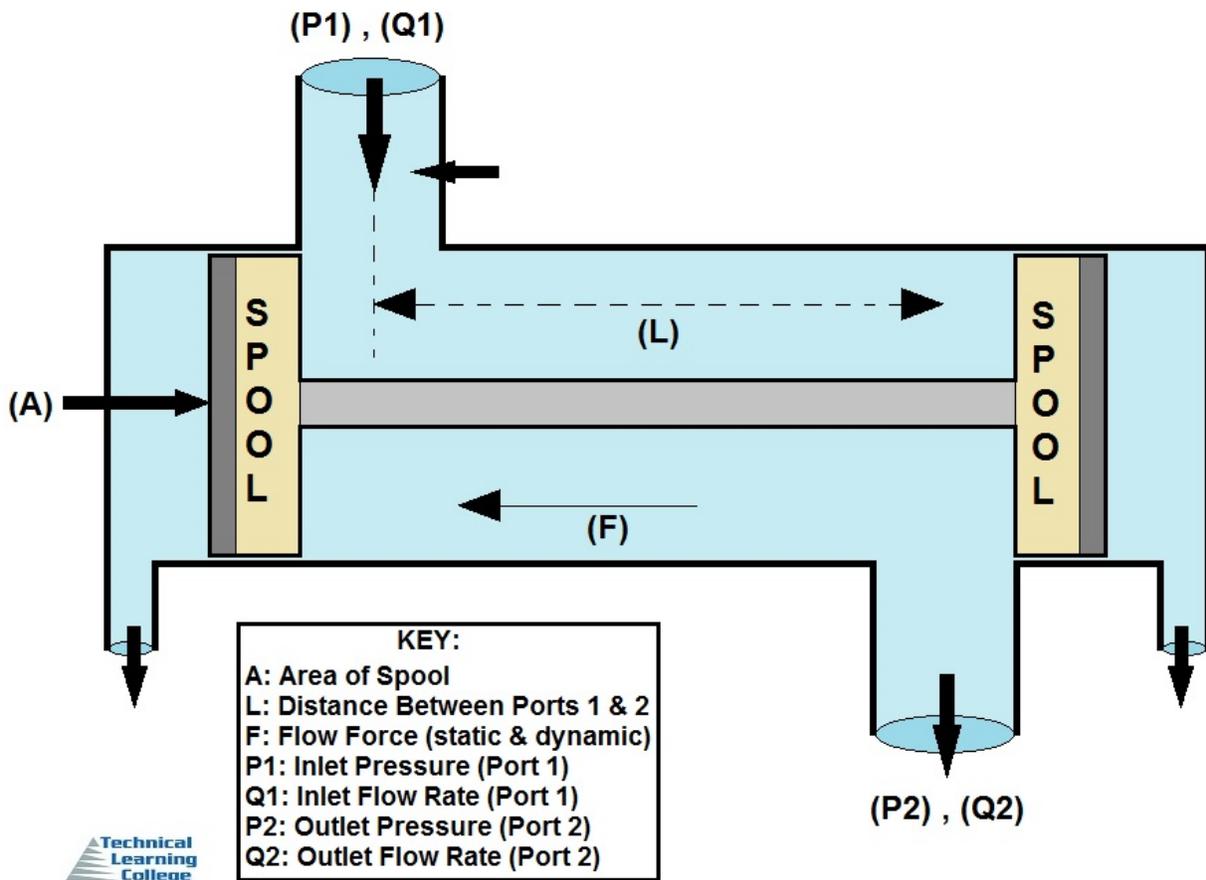
This was the crucial problem that Bramah solved by his leather seal that was held against the cylinder and the piston by the hydraulic pressure itself.

In the presence of gravity,  $p' = p + pgh$ , where  $h$  is the difference in elevation of the two cylinders.

Now,  $p' dV' = -dV (p + pgh) = -p dV - (p dV) gh$ , or the net work done in the process is  $p' dV' + p dV = -dM gh$ , where  $dM$  is the mass of fluid displaced from the lower cylinder to the upper cylinder.

Again, energy is conserved if we take into account the potential energy of the fluid.

Pumps are seen to fall within the province of hydrostatics if their operation is quasi-static, which means that dynamic or inertia forces are negligible.



### BASIC HYDRAULIC OPERATING PRINCIPLE

## Review Statements

Hydrostatics is an excellent example of deductive mathematical physics, and in which the predictions agree closely with experiment and is usually stated that a fluid is a substance that cannot resist a shearing stress, so that pressures are normal to confining surfaces.

Hydrostatics may be the physical property that varies over the largest numerical range, competing with electrical resistivity.

### Pressure

Water is incompressible, while air is very compressible. A fluid is a substance that cannot exert any permanent forces tangential to a boundary and any force that it exerts on a boundary must be normal to the boundary. Both air and water are considered to be fluids.

Water possess volume while air does not.

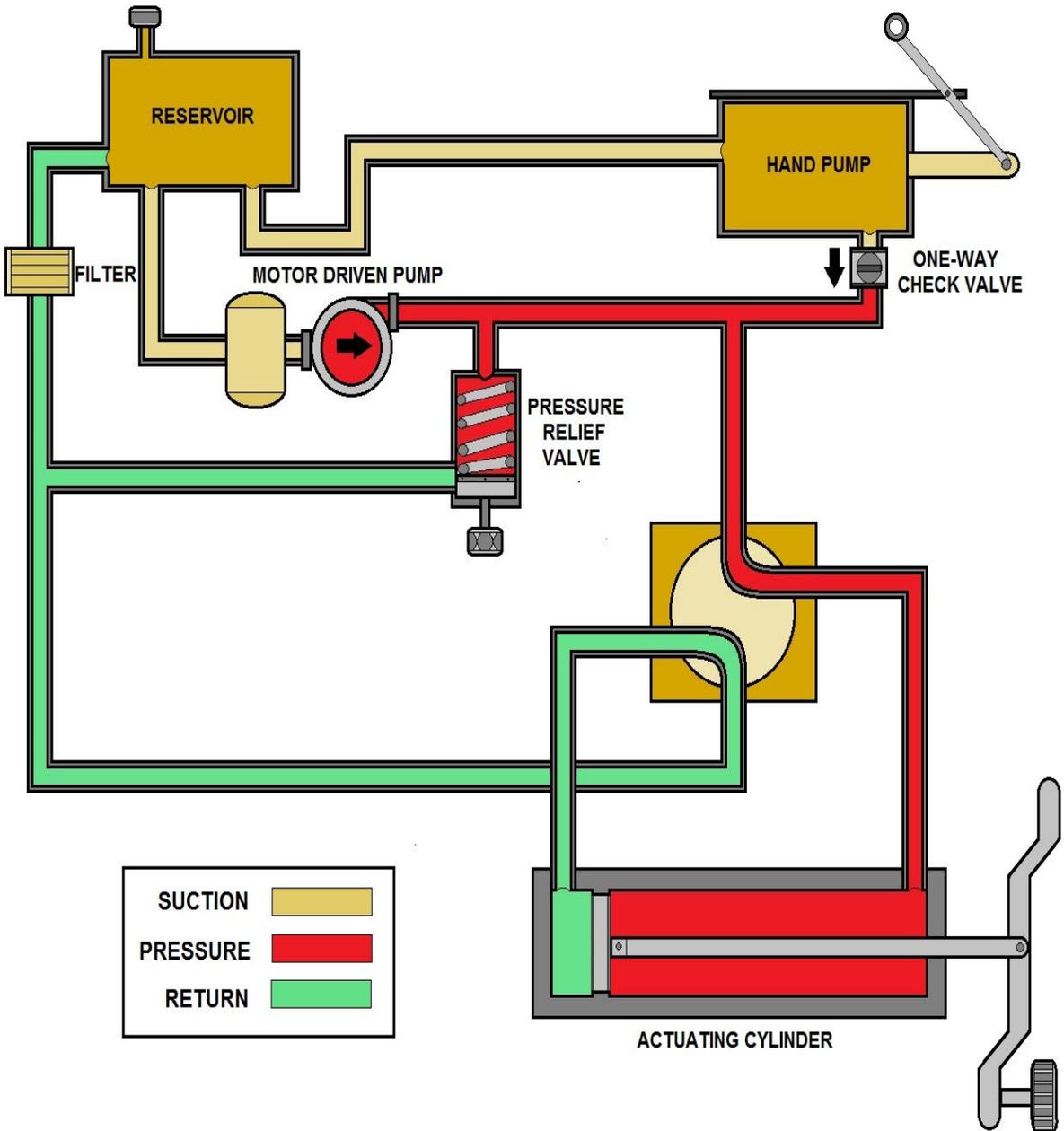
A force is proportional to the area on which it is exerted, and is called a pressure.

### Water Pressure

Pressure are very frequently stated in terms of the height of a fluid.

Water with a pressure head of 20 ft can provide the same energy as an equal amount of water raised by 20 ft.

The weight of a cubic foot of water is 62.4 pounds per square foot. The base can be subdivided into 144-square inches with each subdivision being subjected to a pressure of 0.433 psig. This is one of our key foundation for backflow prevention.



**LIQUID PRESSURE AND FLOW HYDRAULICS EXAMPLE**



## Pump Principles - Short Introduction

Pumps are used to move or raise fluids. They are not only very useful, but are excellent examples of hydrostatics. Pumps are of two general types, hydrostatic or positive displacement pumps, and pumps depending on dynamic forces, such as centrifugal pumps. Here we will only consider positive displacement pumps, which can be understood purely by hydrostatic considerations. They have a piston (or equivalent) moving in a closely-fitting cylinder and forces are exerted on the fluid by motion of the piston. We have already seen an important example of this in the hydraulic lever or hydraulic press, which we have called quasi-static.

The simplest pump is the syringe, filled by withdrawing the piston and emptied by pressing it back in, as its port is immersed in the fluid or removed from it. More complicated pumps have valves allowing them to work repetitively. These are usually check valves that open to allow passage in one direction, and close automatically to prevent reverse flow. There are many kinds of valves, and they are usually the most trouble-prone and complicated part of a pump. The force pump has two check valves in the cylinder, one for supply and the other for delivery. The supply valve opens when the cylinder volume increases, the delivery valve when the cylinder volume decreases.

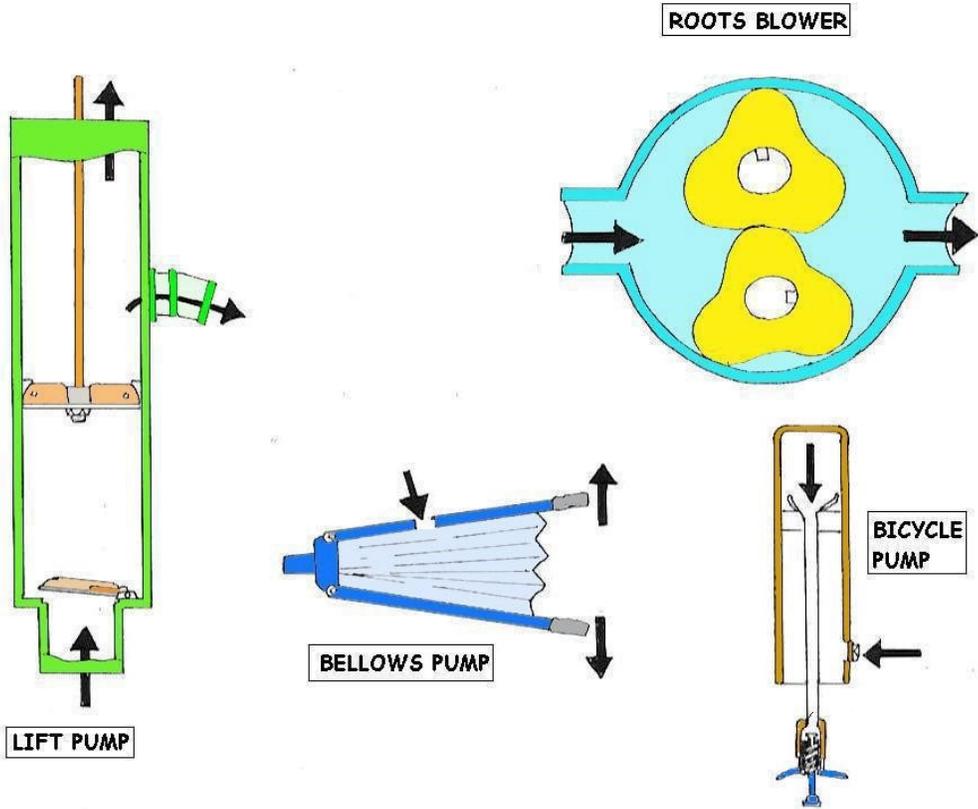
The lift pump has a supply valve and a valve in the piston that allows the liquid to pass around it when the volume of the cylinder is reduced. The delivery in this case is from the upper part of the cylinder which the piston does not enter. Diaphragm pumps are force pumps in which the oscillating diaphragm takes the place of the piston. The diaphragm may be moved mechanically, or by the pressure of the fluid on one side of the diaphragm.

Some positive displacement pumps are shown below. The force and lift pumps are typically used for water. The force pump has two valves in the cylinder, while the lift pump has a one valve in the cylinder and one in the piston. The maximum lift, or "suction," is determined by the atmospheric pressure, and either cylinder must be within this height of the free surface. The force pump, however, can give an arbitrarily large pressure to the discharged fluid, as in the case of a diesel engine injector. A nozzle can be used to convert the pressure to velocity, to produce a jet, as for firefighting. Fire fighting force pumps usually have two cylinders feeding one receiver alternately. The air space in the receiver helps to make the water pressure uniform.

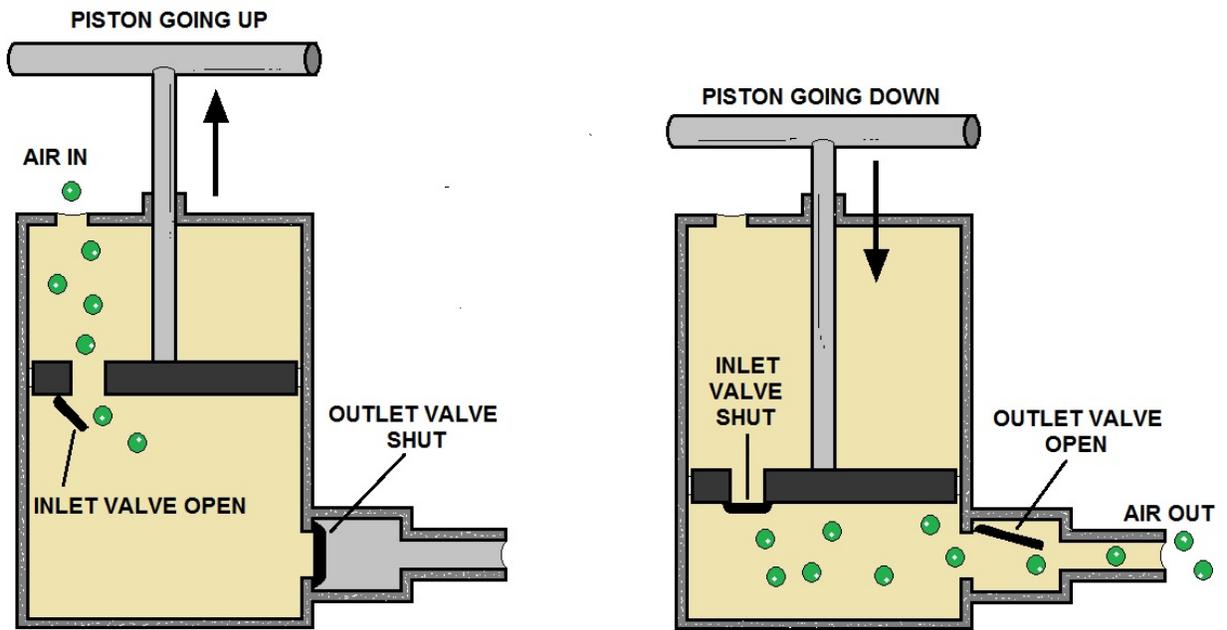
The three pumps on the right are typically used for air, but would be equally applicable to liquids. The Roots blower has no valves, their place taken by the sliding contact between the rotors and the housing. The Roots blower can either exhaust a receiver or provide air under moderate pressure, in large volumes. The bellows is a very old device, requiring no accurate machining. The single valve is in one or both sides of the expandable chamber. Another valve can be placed at the nozzle if required. The valve can be a piece of soft leather held close to holes in the chamber.

The bicycle pump uses the valve on the valve stem of the tire or inner tube to hold pressure in the tire. The piston, which is attached to the discharge tube, has a flexible seal that seals when the cylinder is moved to compress the air, but allows air to pass when the movement is reversed.

Diaphragm and vane pumps are not shown, but they act the same way by varying the volume of a chamber, and directing the flow with check valves. Pumps were applied to the dewatering of mines, a very necessary process as mines became deeper. Newcomen's atmospheric engine was invented to supply the power for pumping.



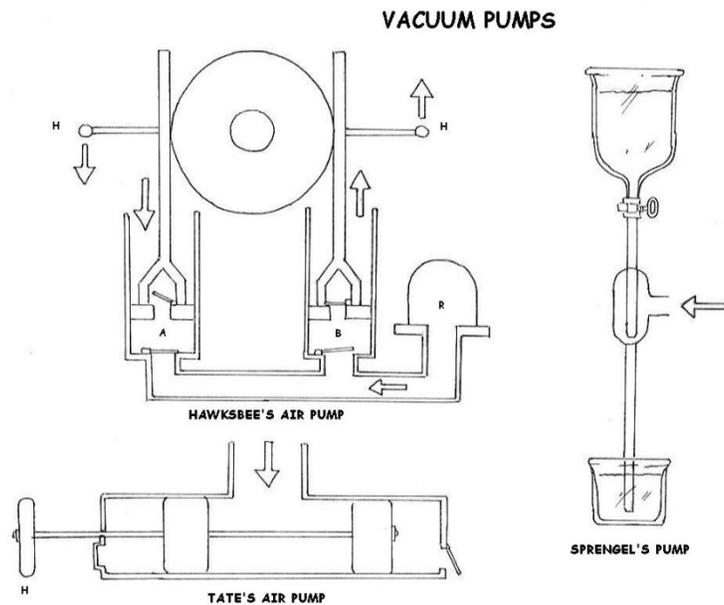
**POSITIVE DISPLACEMENT TYPES OF PUMPS**



**BICYCLE PUMP BASIC OPERATION**

## Dudley Castle Engine

The first engine may have been erected in Cornwall in 1710, but the Dudley Castle engine of 1712 is much better known and thoroughly documented. The first pumps used in Cornwall were called bucket pumps, which we recognize as lift pumps, with the pistons somewhat miscalled buckets. They pumped on the up-stroke, when a clack in the bottom of the pipe opened and allowed water to enter beneath the piston. At the same time, the piston lifted the column of water above it, which could be of any length. The piston could only "suck" water 33 ft, or 28 ft more practically, of course, but this occurred at the bottom of the shaft, so this was only a limit on the piston stroke. On the down stroke, a clack in the bucket opened, allowing it to sink through the water to the bottom, where it would be ready to make another lift. More satisfactory were the plunger pumps, also placed at the bottom of the shaft. A plunger displaced volume in a chamber, forcing the water in it through a check valve up the shaft, when it descended. When it rose, water entered the pump chamber through a clack, as in the bucket pump.



Only the top of the plunger had to be packed; it was not necessary that it fit the cylinder accurately. In this case, the engine at the surface lifted the heavy pump rods on the up-stroke. When the atmospheric engine piston returned, the heavy timber pump rods did the actual pumping, borne down by their weight. A special application for pumps is to produce a vacuum by exhausting a container, called the receiver.

## Hawksbee's Dual Cylinder Pump

Hawksbee's dual cylinder pump, designed in the 18th century, is the final form of the air pump invented by Guericke by 1654. A good pump could probably reach about 5-10 mmHg, the limit set by the valves. The cooperation of the cylinders made the pump much easier to work when the pressure was low. In the diagram, piston A is descending, helped by the partial vacuum remaining below it, while piston B is rising, filling with the low-pressure air from the receiver.

## Bell-jar Receiver

The bell-jar receiver, invented by Huygens, is shown; previously, a cumbersome globe was the usual receiver. Tate's air pump is a 19th century pump that would be used for simple vacuum demonstrations and for utility purposes in the lab. It has no valves on the low-pressure side, just exhaust valves V, V', so it could probably reach about 1 mmHg. It is operated by pushing and pulling the handle H. At the present day, motor-driven rotary-seal pumps sealed by running in oil are used for the same purpose. At the right is Sprengel's pump, with the valves replaced by drops of mercury.

Small amounts of gas are trapped at the top of the fall tube as the mercury drops, and moves slowly down the fall tube as mercury is steadily added, coming out at the bottom carrying the air with it. The length of the fall tube must be greater than the barometric height, of course.

Theoretically, a vacuum of about 1  $\mu\text{m}$  can be obtained with a Sprengel pump, but it is very slow and can only evacuate small volumes. Later, Langmuir's mercury diffusion pump, which was much faster, replaced Sprengel pumps, and led to oil diffusion pumps that can reach very high vacua. The column of water or hydrostatic engine is the inverse of the force pump, used to turn a large head (pressure) of water into rotary motion. It looks like a steam engine, with valves operated by valve gear, but of course is not a heat engine and can be of high efficiency.

However, it is not of as high efficiency as a turbine, and is much more complicated, but has the advantage that it can be operated at variable speeds, as for lifting. A few very impressive column of water engines were made in the 19th century, but they were never popular and remained rare. Richard Trevithick, famous for high pressure steam engines, also built hydrostatic engines in Cornwall. The photograph at the right shows a column-of-water engine built by Georg von Reichenbach, and placed in service in 1917. This engine was exhibited in the Deutsches Museum in München as late as 1977. It was used to pump brine for the Bavarian state salt industry.



## Solehebemaschine

This machine, a Solehebemaschine ("brine-lifting machine"), entered service in 1821. It had two pressure-operated poppet valves for each cylinder. These engines are brass to resist corrosion by the salt water. Water pressure engines must be designed taking into account the incompressibility of water, so both valves must not close at the same time, and abrupt changes of rate of flow must not be made. Air chambers can be used to eliminate shocks. Georg von Reichenbach (1771-1826) is much better known as an optical designer than as a mechanical engineer. He was associated with Joseph Fraunhofer, and they died within days of each other in 1826. He was of an aristocratic family, and was Salinenrat, or manager of the state salt works, in southeastern Bavaria, which was centered on the town of Reichenhall, now Bad Reichenhall, near Salzburg.

The name derives from "rich in salt." This famous salt region had salt springs flowing nearly saturated brine, at 24% to 26% (saturated is 27%) salt, that from ancient times had been evaporated over wood fires. A brine pipeline to Traunstein was constructed in 1617-1619, since wood fuel for evaporating the brine was exhausted in Reichenhall. The pipeline was further extended to Rosenheim, where there was turf as well as wood, in 1818-10.

Von Reichenbach is said to have built this pipeline, for which he designed a water-wheel-driven, four-barrel pump. Maximilian I, King of Bavaria, commissioned von Reichenbach to bring brine from Berchtesgaden, elevation 530 m, to Reichenhall, elevation 470 m, over a summit 943 m high. Fresh water was also allowed to flow down to the salt beds, and the brine was then pumped to the surface. This was a much easier way to mine salt than underground mining.

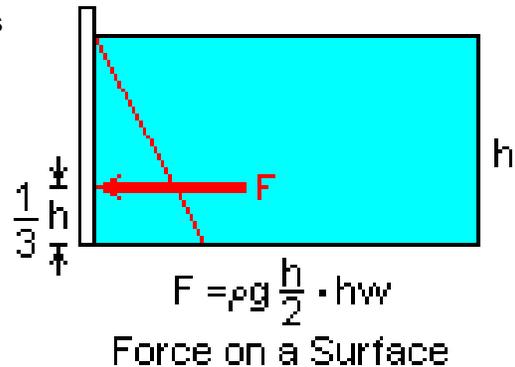
## Forces on Submerged Surfaces

Suppose we want to know the force exerted on a vertical surface of any shape with water on one side, assuming gravity to act, and the pressure on the surface of the water zero. We have already solved this problem by a geometrical argument, but now we apply calculus, which is easier but not as illuminating.

The force on a small area  $dA$  a distance  $x$  below the surface of the water is  $dF = p dA = \rho g x dA$ , and the moment of this force about a point on the surface is  $dM = p x dA = \rho g x^2 dA$ .

By integration, we can find the total force  $F$ , and the depth at which it acts,  $c = M / F$ . If the surface is not symmetrical, the position of the total force in the transverse direction can be obtained from the

integral of  $dM' = \rho g x y dA$ , the moment about some vertical line in the plane of the surface. If there happens to be a pressure on the free surface of the water, then the forces due to this pressure can be evaluated separately and added to this result. We must add a force equal to the area of the surface times the additional pressure, and a moment equal to the product of this force and the distance to the centroid of the surface.



The simplest case is a rectangular gate of width  $w$ , and height  $h$ , whose top is a distance  $H$  below the surface of the water.

In this case, the integrations are very easy, and  $F = \rho g w [(h + H)^2 - h^2]/2 = \rho g H (H + 2h)/2 = \rho g (h + H/2) Hw$ .

The total force on the gate is equal to its area times the pressure at its center.  $M = \rho g w [(h + H)^3 - h^3]/3 = \rho g (H^2/3 + Hh + h^2) Hw$ , so that  $c = (H^2/3 + Hh + h^2) / (h + H/2)$ .

In the simple case of  $h = 0$ ,  $c = 2H/3$ , or two-thirds of the way from the top to the bottom of the gate. If we take the atmospheric pressure to act not only on the surface of the water, but also the dry side of the gate, there is no change to this result. This is the reason atmospheric pressure often seems to have been neglected in solving sub  $h$  problems.

Consider a curious rectangular tank, with one side vertical but the opposite side inclined inwards or outwards.

The horizontal forces exerted by the water on the two sides must be equal and opposite, or the tank would scoot off. If the side is inclined outward, then there must be a downward vertical force equal to the weight of the water above it, and passing through the centroid of this water.

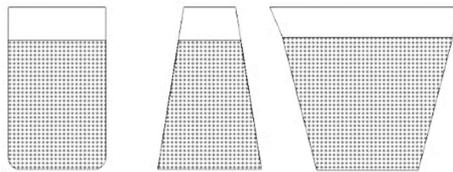
If the side is inclined inward, there must be an upward vertical force equal to the weight of the 'missing' water above it. In both cases, the result is demanded by ordinary statics.

## Hydrostatic Paradox

What we have here has been called the 'hydrostatic paradox.' It was conceived by the celebrated Flemish engineer Simon Stevin (1548-1620) of Brugge, the first modern scientist to investigate the statics of fluids and solids.

Consider three tanks with bottoms of equal sizes and equal heights, filled with water. The pressures at the bottoms are equal, so the vertical force on the bottom of each tank is the same. But suppose that one tank has vertical sides, one has sides inclined inward, and third sides inclined outwards. The tanks do not contain the same weight of water, yet the forces on their bottoms are equal! I am sure that you can spot the resolution of this paradox.

### Hydrostatic Paradox



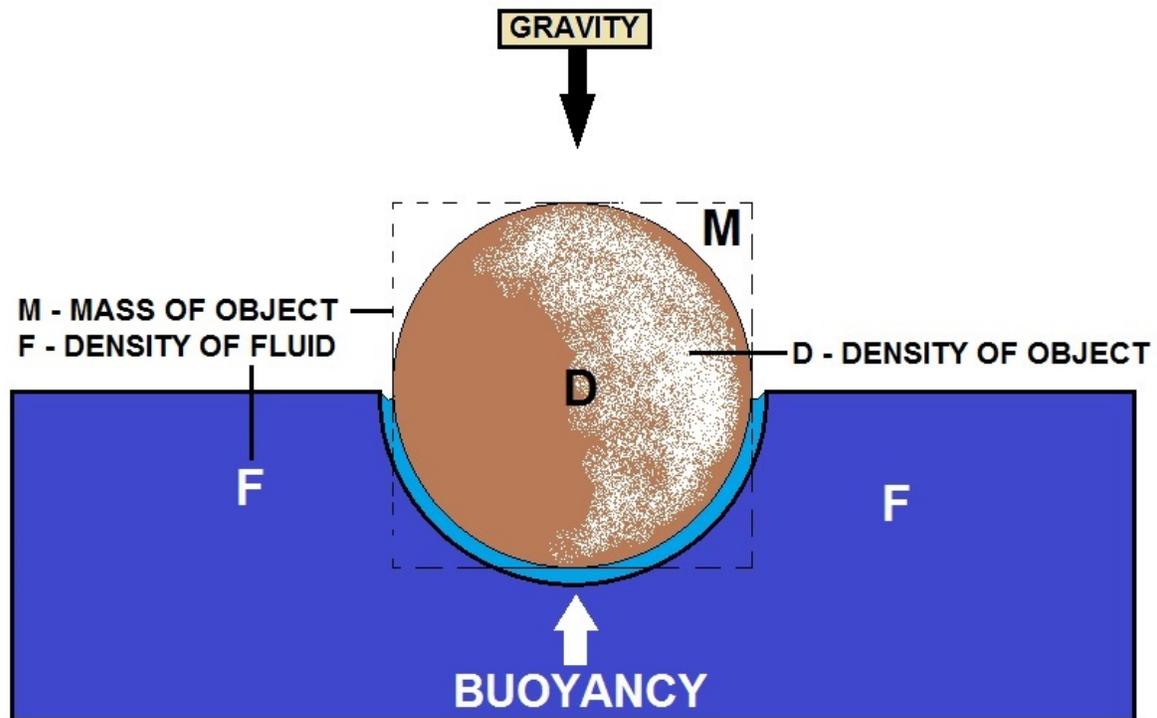
Sometimes the forces are required on curved surfaces. The vertical and horizontal components can be found by considering the equilibrium of volumes with a plane surface equal to the projected area of the curved surface in that direction.

The general result is usually a force plus a couple, since the horizontal and vertical forces are not necessarily in the same plane. Simple surfaces, such as cylinders, spheres and cones, may often be easy to solve. In general, however, it is necessary to sum the forces and moments numerically on each element of area, and only in simple cases can this be done analytically.

If a volume of fluid is accelerated uniformly, the acceleration can be added to the acceleration of gravity. A free surface now becomes perpendicular to the total acceleration, and the pressure is proportional to the distance from this surface. The same can be done for a rotating fluid, where the centrifugal acceleration is the important quantity.

The earth's atmosphere is an example. When air moves relative to the rotating system, the Coriolis force must also be taken into account. However, these are dynamic effects and are not strictly a part of hydrostatics.

## Buoyancy



### BASICS THAT IMPACT HOW BUOYANCY WORKS



Archimedes, so the legend runs, was asked to determine if the goldsmith who made a golden crown for Hieron, Tyrant of Syracuse, had substituted cheaper metals for gold. The story is told by Vitruvius. A substitution could not be detected by simply weighing the crown, since it was craftily made to the same weight as the gold supplied for its construction. Archimedes realized that finding the density of the crown, that is, the weight per unit volume, would give the answer.

The weight was known, of course, and Archimedes cunningly measured its volume by the amount of water that ran off when it was immersed in a vessel filled to the brim. By comparing the results for the crown, and for pure gold, it was found that the crown displaced more water than an equal weight of gold, and had, therefore, been adulterated.

This story, typical of the charming way science was made more interesting in classical times, may or may not actually have taken place, but whether it did or not, Archimedes taught that a body immersed in a fluid lost apparent weight equal to the weight of the fluid displaced, called Archimedes' Principle.

Specific gravity, the ratio of the density of a substance to the density of water, can be determined by weighing the body in air, and then in water. The specific gravity is the weight in air divided by the loss in weight when immersed. This avoids the difficult determination of the exact volume of the sample.

## How Buoyancy Works

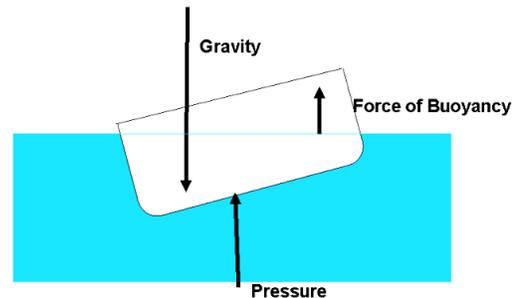
To see how buoyancy works, consider a submerged brick, of height  $h$ , width  $w$  and length  $l$ . The difference in pressure on top and bottom of the brick is  $\rho gh$ , so the difference in total force on top and bottom of the brick is simply  $(\rho gh)(wl) = \rho gV$ , where  $V$  is the volume of the brick.

The forces on the sides have no vertical components, so they do not matter. The net upward force is the weight of a volume  $V$  of the fluid of density  $\rho$ . Anybody can be considered made up of brick shapes, as small as desired, so the result applies in general. This is just the integral calculus in action, or the application of Professor Thomson's analogy.

Consider a man in a rowboat on a lake, with a large rock in the boat. He throws the rock into the water.

What is the effect on the water level of the lake? Suppose you make a drink of ice water with ice cubes floating in it. What happens to the water level in the glass when the ice has melted?

## Change of Ship Stability



The force exerted by the water on the bottom of a boat acts through the center of gravity  $B$  of the displaced volume, while the force exerted by gravity on the boat acts through its own center of gravity  $A$ . This looks bad for the boat, since the boat's c.g. will naturally be higher than the c.g. of the displaced water, so the boat will tend to capsize. Well, a boat floats, and can tell us why. Should the boat start to rotate to one side, the displaced volume immediately moves to that side, and the buoyant force tends to correct the rotation. A floating body will be stable provided the line of action of the buoyant force passes through a point  $M$  above the c.g. of the body, called the metacenter, so that there is a restoring couple when the boat heels. A ship with an improperly designed hull will not float. It is not as easy to make boats as it might appear.

## Montgolfier Brothers' Hot Air Balloon

Archimedes' Principle can also be applied to balloons. The Montgolfier brothers' hot air balloon with a paper envelope ascended first in 1783 (the brothers got Pilâtre de Rozier and Chevalier d'Arlandes to go up in it). Such "fire balloons" were then replaced with hydrogen-filled balloons, and then with balloons filled with coal gas, which was easier to obtain and did not diffuse through the envelope quite as rapidly.

Methane would be a good filler, with a density 0.55 that of air. Slack balloons, like most large ones, can be contrasted with taut balloons with an elastic envelope, such as weather balloons. Slack balloons will not be filled full on the ground, and will plump up at altitude. Balloons are naturally stable, since the center of buoyancy is above the center of gravity in all practical balloons.

Submarines are yet another application of buoyancy, with their own characteristic problems. Small neoprene or natural rubber balloons have been used for meteorological observations, with hydrogen filling. A 10g ceiling balloon was about 17" in diameter when inflated to have a free lift of 40g. It ascended 480ft the first minute, 670ft in a minute and a half, and 360ft per minute afterwards, to find cloud ceilings by timing, up to 2500ft, when it subtended about 2' of arc, easily seen in binoculars.

Large sounding balloons were used to lift a radiosonde and a parachute for its recovery. An AN/AMT-2 radiosonde of the 1950's weighed 1500g, the paper parachute 100g, and the balloon 350g. The balloon was inflated to give 800g free lift, so it would rise 700-800 ft/min to an altitude of about 50,000 ft (15 km) before it burst. This balloon was about 6 ft in diameter when inflated at the surface, 3 ft in diameter before inflation. The information was returned by radio telemetry, so the balloon did not have to be followed optically. Of intermediate size was the pilot balloon, which was followed with a theodolite to determine wind directions and speeds. At night, a pilot balloon could carry a light for ceiling determinations.

## Weather Balloons

The greatest problem with using hydrogen for lift is that it diffuses rapidly through many substances. Weather balloons had to be launched promptly after filling, or the desired free lift would not be obtained. Helium is a little better in this respect, but it also diffuses rapidly. The lift obtained with helium is almost the same as with hydrogen (density 4 compared to 2, where air is 28.97). However, helium is exceedingly rare, and only its unusual occurrence in natural gas from Kansas makes it available. Great care must be taken when filling balloons with hydrogen to avoid sparks and the accumulation of hydrogen in air, since hydrogen is exceedingly flammable and explosive over a wide range of concentrations. Helium has the great advantage that it is not inflammable.

The hydrogen for filling weather balloons came from compressed gas in cylinders, from the reaction of granulated aluminum with sodium hydroxide and water, or from the reaction of calcium hydroxide with water. The chemical reactions are  $2Al + 2NaOH + 2H_2O \rightarrow 2NaAlO_2 + 3H_2$ , or  $CaH_2 + 2H_2O \rightarrow Ca(OH)_2 + 2H_2$ . In the first, silicon or zinc could be used instead of aluminum, and in the second, any similar metal hydride. Both are rather expensive sources of hydrogen, but very convenient when only small amounts are required. Most hydrogen is made from the catalytic decomposition of hydrocarbons, or the reaction of hot coke with steam.

Electrolysis of water is an expensive source, since more energy is used than is recovered with the hydrogen. Any enthusiasm for a "hydrogen economy" should be tempered by the fact that there are no hydrogen wells, and all the hydrogen must be made with an input of energy usually greater than that available from the hydrogen, and often with the appearance of carbon.

Although about 60,000 Btu/lb is available from hydrogen, compared to 20,000 Btu/lb from gasoline, hydrogen compressed to 1000 psi requires 140 times as much volume for the same weight as gasoline. For the energy content of a 13-gallon gasoline tank, a 600-gallon hydrogen tank would be required. The critical temperature of hydrogen is 32K, so liquid storage is out of the question for general use.

## Measurement of Specific Gravity

The specific gravity of a material is the ratio of the mass (or weight) of a certain sample of it to the mass (or weight) of an equal volume of water, the conventional reference material. In the metric system, the density of water is 1 g/cc, which makes the specific gravity numerically equal to the density. Strictly speaking, density has the dimensions g/cc, while specific gravity is a dimensionless ratio. However, in casual speech the two are often confounded. In English units, however, density, perhaps in lb/cu.ft or pcf, is numerically different from the specific gravity, since the weight of water is 62.5 lb/cu.ft.

## Variations

Things are complicated by the variation of the density of water with temperature, and also by the confusion that gave us the distinction between cc and ml. The milliliter is the volume of 1.0 g of water at 4°C, by definition. The actual volume of 1.0 g of water at 4°C is 0.999973 cm<sup>3</sup> by measurement. Since most densities are not known, or needed, to more than three significant figures, it is clear that this difference is of no practical importance, and the ml can be taken equal to the cc. The density of water at 0°C is 0.99987 g/ml, at 20° 0.99823, and at 100°C 0.95838. The temperature dependence of the density may have to be taken into consideration in accurate work. Mercury, while we are at it, has a density 13.5955 at 0°C, and 13.5461 at 20°C.

The basic idea in finding specific gravity is to weigh a sample in air, and then immersed in water. Then the specific gravity is  $W / (W - W')$ , if  $W$  is the weight in air, and  $W'$  the weight immersed. The denominator is just the buoyant force, the weight of a volume of water equal to the volume of the sample. This can be carried out with an ordinary balance, but special balances, such as the Jolly balance, have been created specifically for this application. Adding an extra weight to the sample allows measurement of specific gravities less than 1.

## Pycnometer

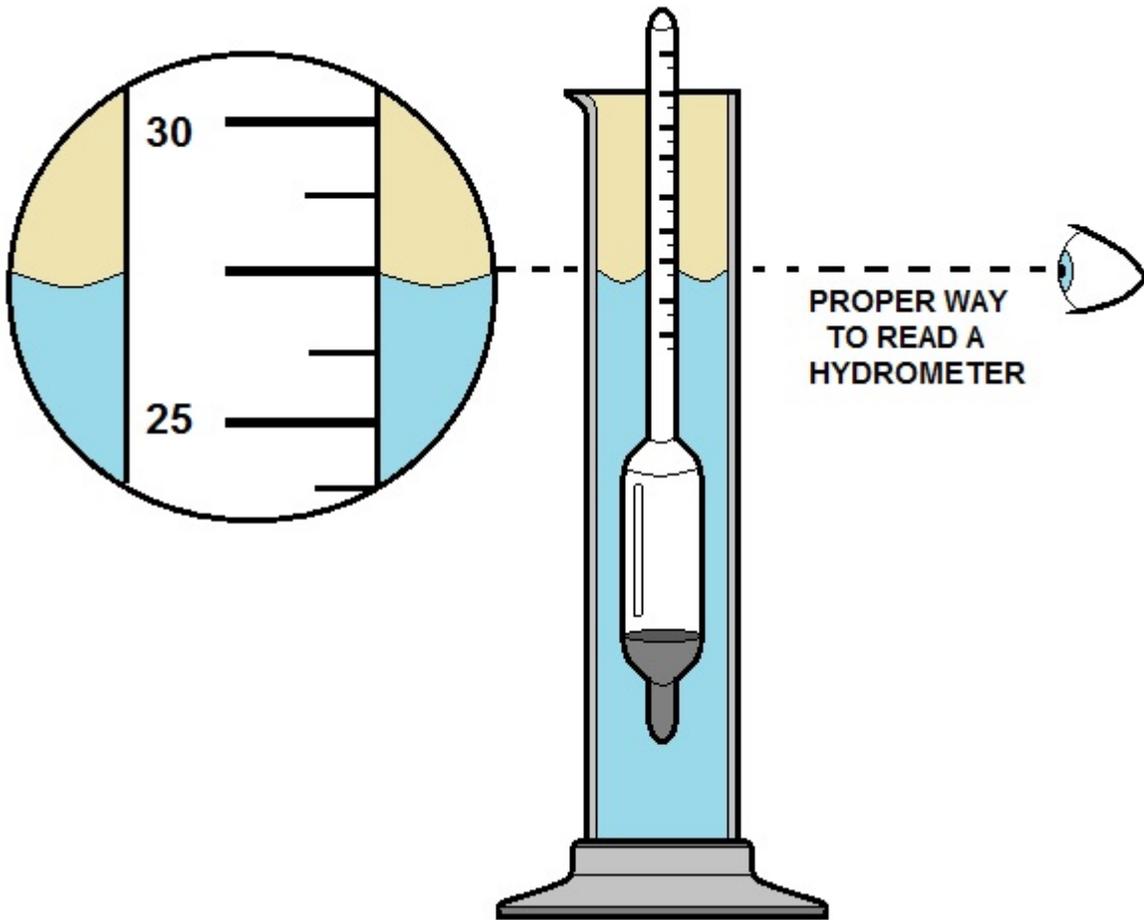
A pycnometer is a flask with a close-fitting ground glass stopper with a fine hole through it, so a given volume can be accurately obtained. The name comes from the Greek word meaning "density." If the flask is weighed empty, full of water, and full of a liquid whose specific gravity is desired, the specific gravity of the liquid can easily be calculated. A sample in the form of a powder, to which the usual method of weighing cannot be used, can be put into the pycnometer. The weight of the powder and the weight of the displaced water can be determined, and from them the specific gravity of the powder.

The specific gravity of a liquid can be found with a collection of small weighted, hollow spheres that will just float in certain specific gravities. The closest spheres that will just float and just sink put limits on the specific gravity of the liquid. This method was once used in Scotland to determine the amount of alcohol in distilled liquors. Since the density of a liquid decreases as the temperature increases, the spheres that float are an indication of the temperature of the liquid. Galileo's thermometer worked this way.

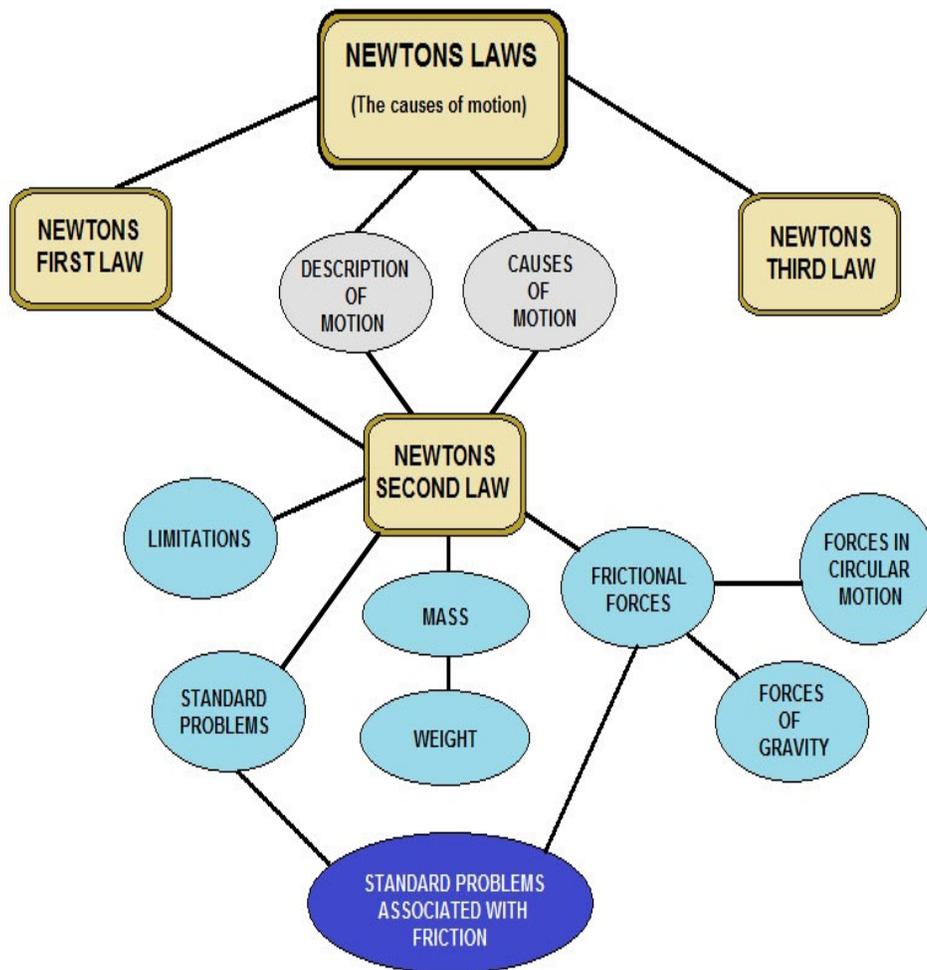
## Hydrometer

A better instrument is the hydrometer, which consists of a weighted float and a calibrated stem that protrudes from the liquid when the float is entirely immersed. A higher specific gravity will result in a greater length of the stem above the surface, while a lower specific gravity will cause the hydrometer to float lower.

The small cross-sectional area of the stem makes the instrument very sensitive. Of course, it must be calibrated against standards. In most cases, the graduations ("degrees") are arbitrary and reference is made to a table to determine the specific gravities. Hydrometers are used to determine the specific gravity of lead-acid battery electrolyte, and the concentration of antifreeze compounds in engine coolants, as well as the alcohol content of whiskey.



**HYDROMETER EXAMPLE**



<b>FIRST LAW:</b>	Objects at rest remain at rest and objects in motion in a straight line unless acted upon by an unbalanced force.
<b>SECOND LAW:</b>	Forces equal mass times acceleration ( $f = ma$ ).
<b>THIRD LAW:</b>	For every action, there is an equal and opposite reaction

## NEWTON'S THREE LAWS OF MOTION

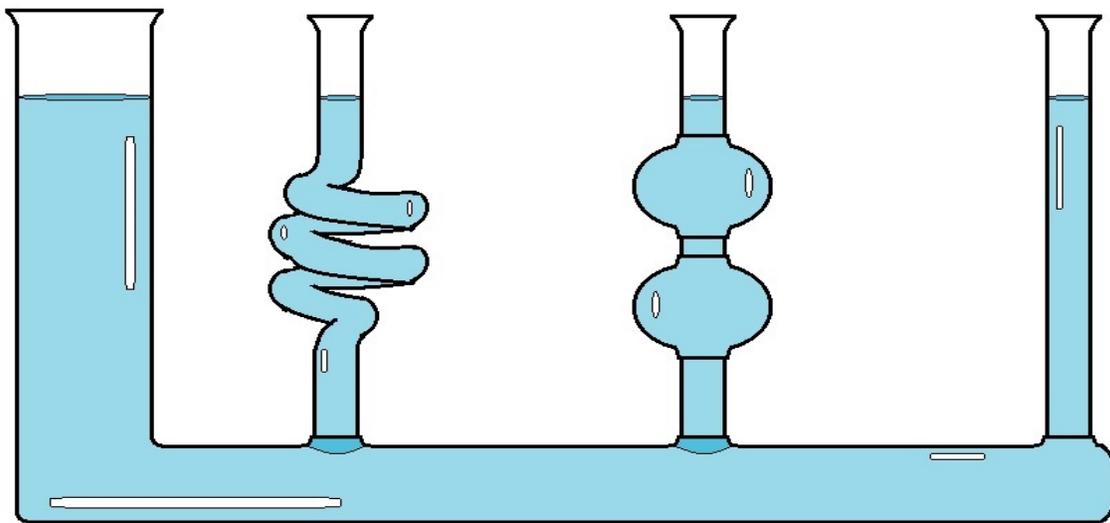
## Pascal's Law

The foundation of modern hydraulics was established when Pascal discovered that pressure in a fluid acts equally in all directions. This pressure acts at right angles to the containing surfaces. If some type of pressure gauge, with an exposed face, is placed beneath the surface of a liquid at a specific depth and pointed in different directions, the pressure will read the same. Thus, we can say that pressure in a liquid is independent of direction.

Pressure due to the weight of a liquid, at any level, depends on the depth of the fluid from the surface. If the exposed face of the pressure gauges are moved closer to the surface of the liquid, the indicated pressure will be less. When the depth is doubled, the indicated pressure is doubled. Thus the pressure in a liquid is directly proportional to the depth. Consider a container with vertical sides that is 1 foot long and 1 foot wide. Let it be filled with water 1 foot deep, providing 1 cubic foot of water. 1 cubic foot of water weighs 62.4 pounds. Using this information and equation,  $P = F/A$ , we can calculate the pressure on the bottom of the container.

Since there are 144 square inches in 1 square foot, this can be stated as follows: the weight of a column of water 1 foot high, having a cross-sectional area of 1 square inch, is 0.433 pound. If the depth of the column is tripled, the weight of the column will be  $3 \times 0.433$ , or 1.299 pounds, and the pressure at the bottom will be 1.299 lb/in<sup>2</sup> (psi), since pressure equals the force divided by the area.

Thus, the pressure at any depth in a liquid is equal to the weight of the column of liquid at that depth divided by the cross-sectional area of the column at that depth. The volume of a liquid that produces the pressure is referred to as the fluid head of the liquid. The pressure of a liquid due to its fluid head is also dependent on the density of the liquid.



### PRESSURE IN LIQUIDS

PASCAL'S VASES DEMONSTRATE THE FACT THAT THE PRESSURE OF THE LIQUID DEPENDS SOLELY ON THE DEPTH ALONE, AND NOT THE VOLUME OR THE SHAPE OF THE FLUID

## Gravity

Gravity is one of the four forces of nature. The strength of the gravitational force between two objects depends on their masses. The more massive the objects are, the stronger the gravitational attraction. When you pour water out of a container, the earth's gravity pulls the water towards the ground. The same thing happens when you put two buckets of water, with a tube between them, at two different heights. You must work to start the flow of water from one bucket to the other, but then gravity takes over and the process will continue on its own.

Gravity, applied forces, and atmospheric pressure are static factors that apply equally to fluids at rest or in motion, while inertia and friction are dynamic factors that apply only to fluids in motion. The mathematical sum of gravity, applied force, and atmospheric pressure is the static pressure obtained at any one point in a fluid at any given time.

## Static Pressure

Static pressure exists in addition to any dynamic factors that may also be present at the same time. Pascal's law states that a pressure set up in a fluid acts equally in all directions and at right angles to the containing surfaces. This covers the situation only for fluids at rest or practically at rest. It is true only for the factors making up static head.

Obviously, when velocity becomes a factor it must have a direction, and as previously explained, the force related to the velocity must also have a direction, so that Pascal's law alone does not apply to the dynamic factors of fluid power.

The dynamic factors of inertia and friction are related to the static factors. Velocity head and friction head are obtained at the expense of static head. However, a portion of the velocity head can always be reconverted to static head.

Force, which can be produced by pressure or head when dealing with fluids, is necessary to start a body moving if it is at rest, and is present in some form when the motion of the body is arrested; therefore, whenever a fluid is given velocity, some part of its original static head is used to impart this velocity, which then exists as velocity head.

## Volume and Velocity of Flow

The volume of a liquid passing a point in a given time is known as its *volume of flow* or flow rate. The volume of flow is usually expressed in gallons per minute (gpm) and is associated with relative pressures of the liquid, such as 5 gpm at 40 psi. The *velocity of flow* or velocity of the fluid is defined as the average speed at which the fluid moves past a given point. It is usually expressed in feet per second (fps) or feet per minute (fpm). Velocity of flow is an important consideration in sizing the hydraulic lines.

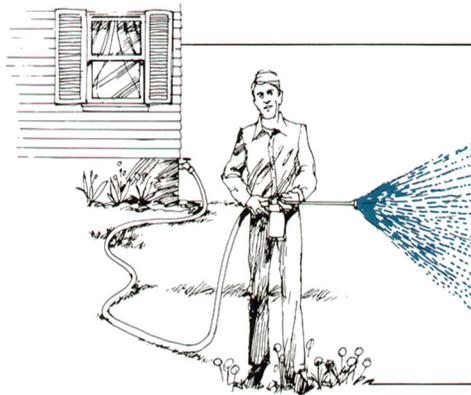
Volume and velocity of flow are often considered together. With other conditions unaltered—that is, with volume of input unchanged—the velocity of flow increases as the cross section or size of the pipe decreases, and the velocity of flow decreases as the cross section increases. For example, the velocity of flow is slow at wide parts of a stream and rapid at narrow parts, yet the volume of water passing each part of the stream is the same.

## Bernoulli's Principle

Bernoulli's principle thus says that a rise (fall) in pressure in a flowing fluid must always be accompanied by a decrease (increase) in the speed, and conversely, if an increase (decrease) in the speed of the fluid results in a decrease (increase) in the pressure.

This is at the heart of a number of everyday phenomena. As a very trivial example, Bernoulli's principle is responsible for the fact that a shower curtain gets "**sucked inwards**" when the water is first turned on. What happens is that the increased water/air velocity inside the curtain (relative to the still air on the other side) causes a pressure drop.

The pressure difference between the outside and inside causes a net force on the shower curtain which sucks it inward. A more useful example is provided by the functioning of a perfume bottle: squeezing the bulb over the fluid creates a low pressure area due to the higher speed of the air, which subsequently draws the fluid up. This is illustrated in the following figure.



Action of a spray atomizer

Bernoulli's principle also tells us why windows tend to explode, rather than implode in hurricanes: the very high speed of the air just outside the window causes the pressure just outside to be much less than the pressure inside, where the air is still. The difference in force pushes the windows outward, and hence they explode. If you know that a hurricane is coming it is therefore better to open as many windows as possible, to equalize the pressure inside and out.

Another example of Bernoulli's principle at work is in the lift of aircraft wings and the motion of "**curve balls**" in baseball.

In both cases the design is such as to create a speed differential of the flowing air past the object on the top and the bottom - for aircraft wings this comes from the movement of the flaps, and for the baseball it is the presence of ridges.

Such a speed differential leads to a pressure difference between the top and bottom of the object, resulting in a net force being exerted, either upwards or downwards.

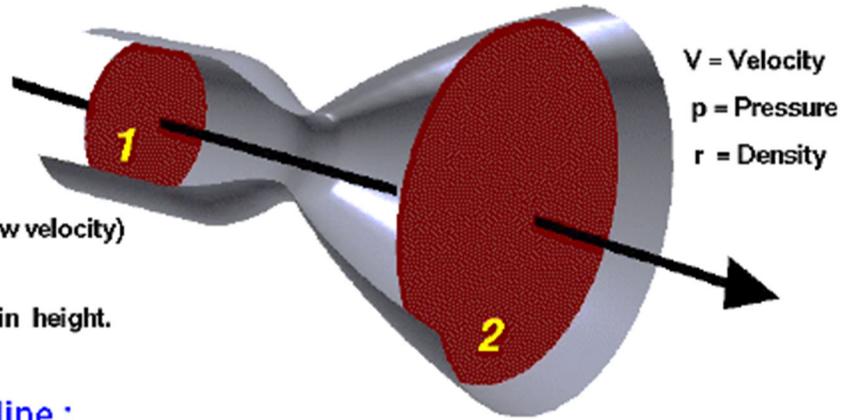


# Bernoulli's Equation

Glenn  
Research  
Center

## Restrictions :

- Inviscid
- Steady
- Incompressible (low velocity)
- No heat addition.
- Negligible change in height.



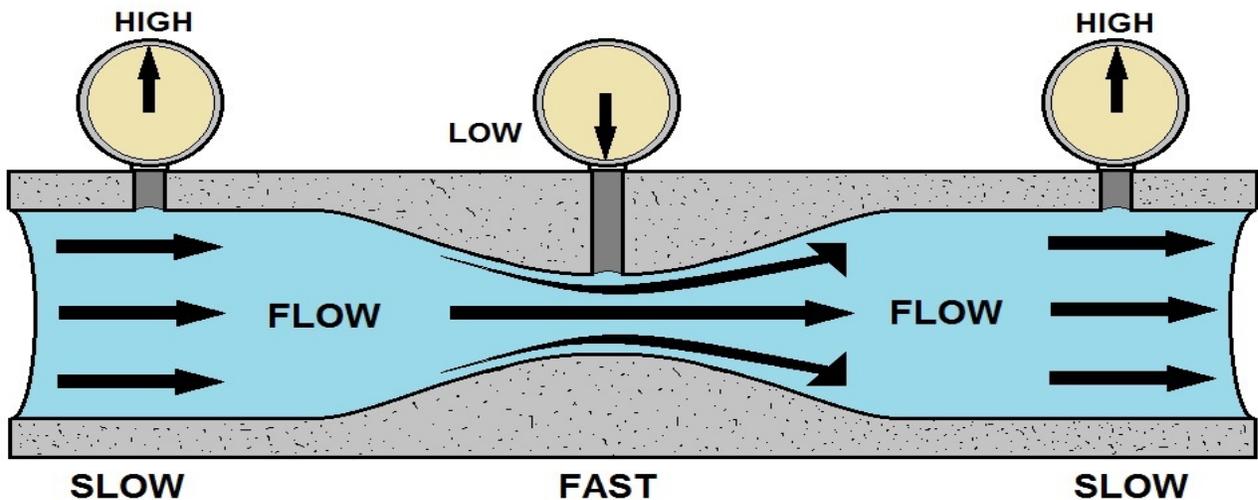
## Along a streamline :

static pressure + dynamic pressure = total pressure

$$p_s + \frac{rV^2}{2} = p_t$$

$$\left( p_s + \frac{rV^2}{2} \right)_1 = \left( p_s + \frac{rV^2}{2} \right)_2$$

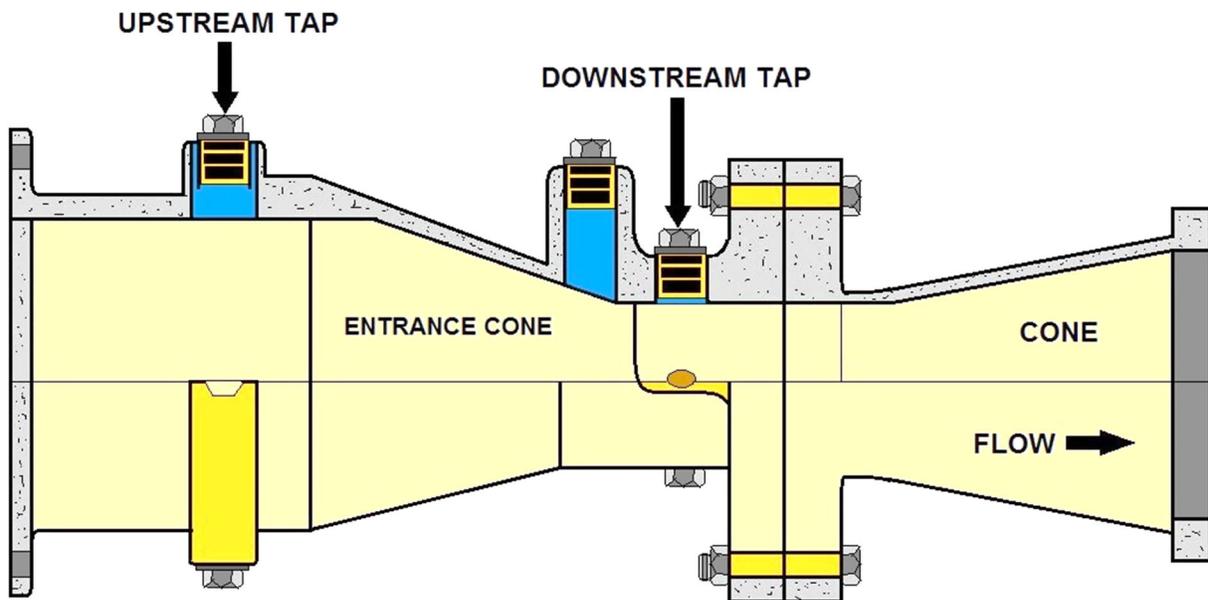
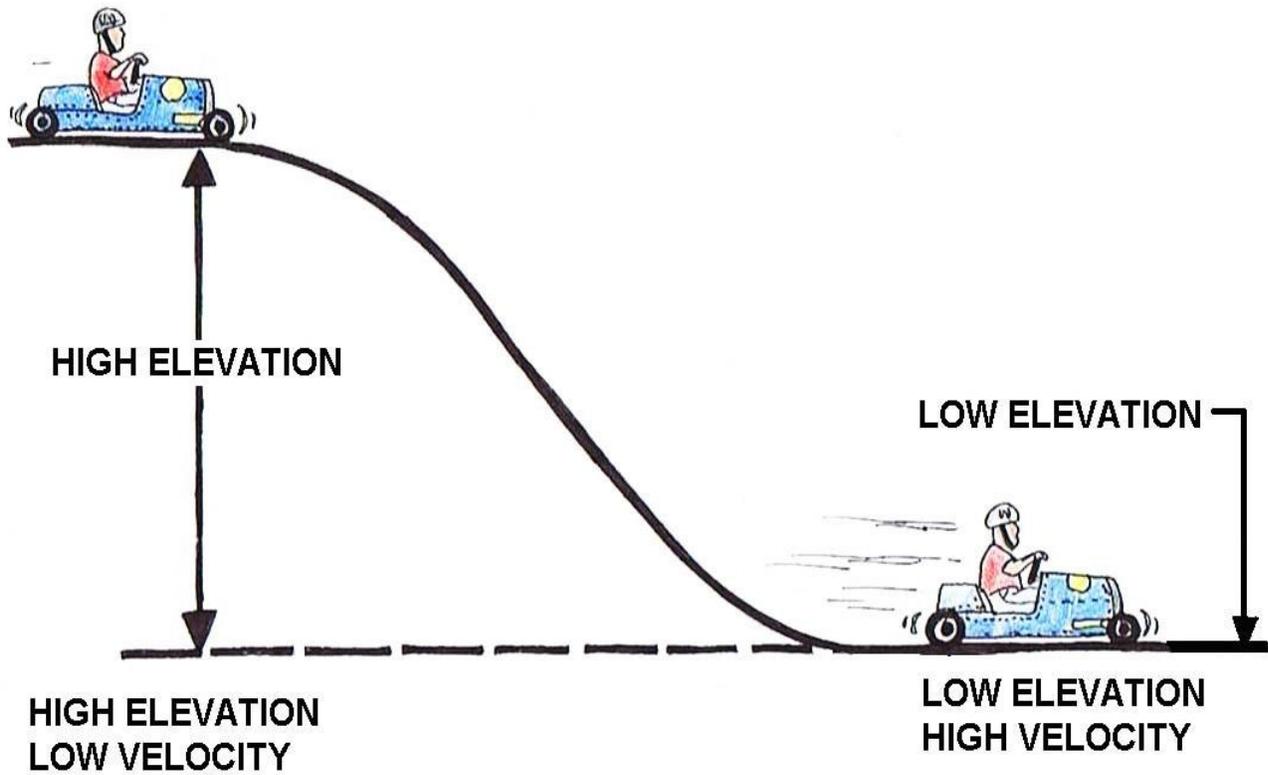
## STATIC PRESSURE



### BERNOULLI EFFECT:

THE INCREASE OF SPEED OF THE FLUID OCCURS  
SIMULTANEOUSLY WITH THE DECREASE IN PRESSURE





**VENTURI TUBE EXAMPLE**



## Understanding the Venturi

It is not easy to understand the reason low pressure occurs in the small diameter area of the venturi. This explanation may seem to help the principle.

It is clear that all the flow must pass from the larger section to the smaller section. Or in other words, the flow rate will remain the same in the large and small portions of the tube. The flow rate is the same rate, but the velocity changes.

The velocity is greater in the small portion of the tube. There is a relationship between the pressure energy and the velocity energy; if velocity increases the pressure energy must decrease.

This is known as the principle of conservation of energy at work which is also Bernoulli's law. This is similar to the soapbox derby car in the illustration at the top of a hill. At the top or point, the elevation of the soapbox derby car is high and the velocity low.

At the bottom the elevation is low and the velocity is high, elevation (potential) energy has been converted to velocity (kinetic) energy. Pressure and velocity energies behave in the same way. In the large part of the pipe the pressure is high and velocity is low, in the small part, pressure is low and velocity high.

## Backflow Section - Introduction

Backflow Prevention, also referred to as Cross-Connection Control, addresses a serious health issue. This issue was addressed on the federal level by passage of the "*Federal Safe Drinking Water Act*" as developed by the Environmental Protection Agency (E.P.A.) and passed into law on December 16, 1974.

This Act tasked each state with primary enforcement responsibility for a program to assure access to safe drinking water by all citizens. Such state program regulations as adopted are required to be at least as stringent as the federal regulations as developed and enforced by the E.P.A.

The official definition of a cross-connection is "*the link or channel connecting a source of pollution with a potable water supply.*" There are two distinct levels of concern with this issue. The first is protection of the general public and the second is protection of persons subject to such risks involving service to a single customer, be that customer an individual residence or business.

Sources of pollution which may result in a danger to health are not always obvious and such cross-connections are certainly not usually intentional. They are usually the result of oversight or a non-professional installation.

As source examples, within a business environment the pollutant source may involve the unintentional cross-connection of internal or external piping with chemical processes or a heating boiler.

In a residential environment, the pollutant source may be improper cross-connection with a landscape sprinkler system or reserve tank fire protection system. Or, a situation as simple as leaving a garden hose nozzle submerged in a bucket of liquid or attached to a chemical sprayer.

Another potential hazard source within any environment may be a cross-connection of piping involving a water well located on the property. This is a special concern with older residences or businesses, which may have been served by well water prior to connection to the developed water system. There are many other potential sources of pollutant hazards.

Control of cross-connections is possible but only through knowledge and vigilance. Public education is essential, for many that are educated in piping and plumbing installations fail to recognize cross-connection dangers.

### Possible Bad Connection



Direct connection from hydrant to pump.



Air Gap



Fitting at hydrant



Lines cut but it had been connected to a chemical barrel earlier.

## Actual Backflow Events

### Paraquat

In June 1983, "yellow gushy stuff" poured from some faucets in the Town of Woodsboro, Maryland. Town personnel notified the County Health Department and the State Water Supply Division. The State dispatched personnel to take water samples for analysis and placed a ban on drinking the Town's water.

Firefighters warned residents not to use the water for drinking, cooking, bathing, or any other purpose except flushing toilets. The Town began flushing its water system. An investigation revealed that the powerful agricultural herbicide Paraquat had backflowed into the Town's water system.

Someone left open a gate valve between an agricultural herbicide holding tank and the Town's water system and, thus, created a cross-connection. Coincidentally, water pressure in the Town temporarily decreased due to failure of a pump in the Town's water system. The herbicide Paraquat was backsiphoned into the Town's water system. Upon restoration of pressure in the Town's water system, Paraquat flowed throughout much of the Town's water system. Fortunately, this incident did not cause any serious illness or death. The incident did, however, create an expensive burden on the Town. Tanker trucks were used temporarily to provide potable water, and the Town flushed and sampled its water system extensively.

### Mortuary

The chief plumbing inspector in a large southern city received a telephone call advising that blood was coming from drinking fountains at a mortuary (i.e., a funeral home). Plumbing and health inspectors went to the scene and found evidence that blood had been circulating in the potable water system within the funeral home. They immediately ordered the funeral home cut off from the public water system at the meter.

City water and plumbing officials did not think that the water contamination problem had spread beyond the funeral home, but they sent inspectors into the neighborhood to check for possible contamination. Investigation revealed that blood had backflowed through a hydraulic aspirator into the potable water system at the funeral home.

The funeral home had been using a hydraulic aspirator to drain fluids from bodies as part of the embalming process. The aspirator was directly connected to a faucet at a sink in the embalming room. Water flow through the aspirator created suction used to draw body fluids through a needle and hose attached to the aspirator. When funeral home personnel used the aspirator during a period of low water pressure, the potable water system at the funeral home became contaminated. Instead of body fluids flowing into the wastewater system, they were drawn in the opposite direction--into the potable water system.

*U.S. Environmental Protection Agency, Cross-Connection Control Manual, 1989*

## **Recent Backflow Situations**

### **Oregon 1993**

Water from a drainage pond, used for lawn irrigation, is pumped into the potable water supply of a housing development.

### **California 1994**

A defective backflow device in the water system of the County Courthouse apparently caused sodium nitrate contamination that sent 19 people to the hospital.

### **New York 1994**

An 8-inch reduced pressure principle backflow assembly in the basement of a hospital discharged under backpressure conditions, dumping 100,000 gallons of water into the basement.

### **Nebraska 1994**

While working on a chiller unit of an air conditioning system at a nursing home, a hole in the coil apparently allowed Freon to enter the circulating water, and from there into the city water system.

### **California 1994**

The blue tinted water in a pond at an amusement park backflowed into the city water system and caused colored water to flow from homeowner's faucets.

### **California 1994**

A film company shooting a commercial for television accidentally introduced a chemical into the potable water system.

### **Iowa 1994**

A backflow of water from the Capitol Building chilled water system contaminates potable water with Freon.

### **Indiana 1994**

Water main break caused a drop in water pressure, allowing anti-freeze from an air conditioning unit to backsiphon into the potable water supply.

### **Washington 1994**

An Ethylene Glycol cooling system was illegally connected to the domestic water supply at a veterinarian hospital.

### **Ohio 1994**

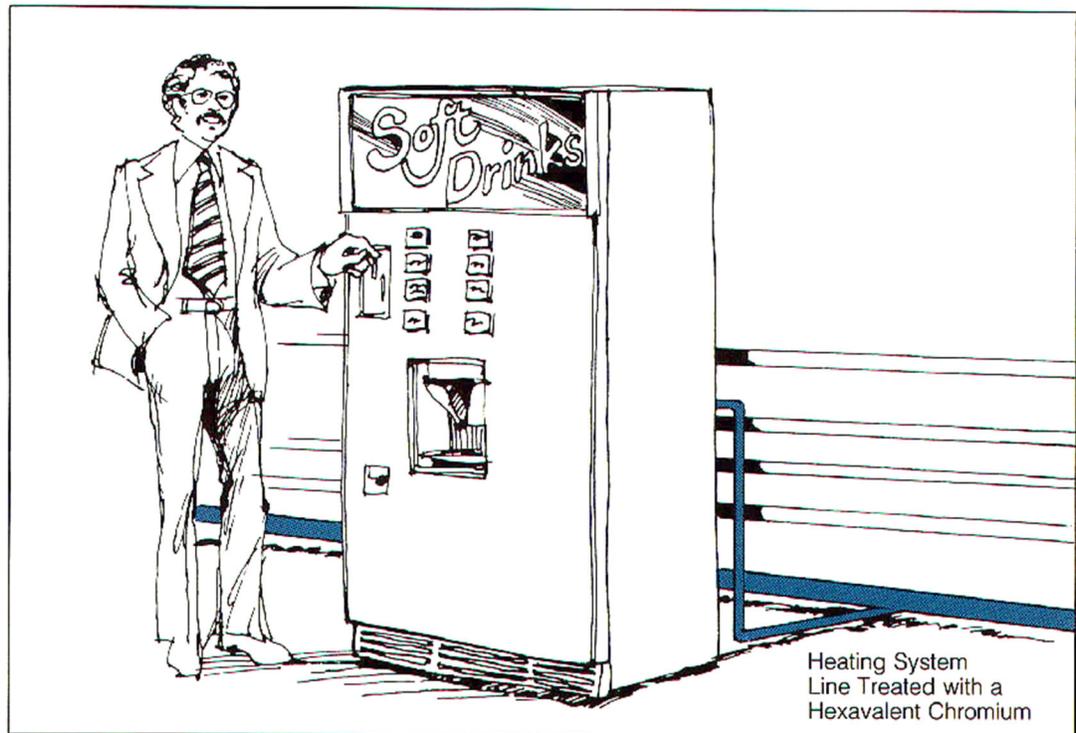
An ice machine connected to a sewer sickened dozens of people attending a convention.

## Cross-Connection Terms

### Cross-Connection

A cross-connection is any temporary or permanent connection between a public water system or consumer's potable (i.e., drinking) water system and any source or system containing nonpotable water or other substances.

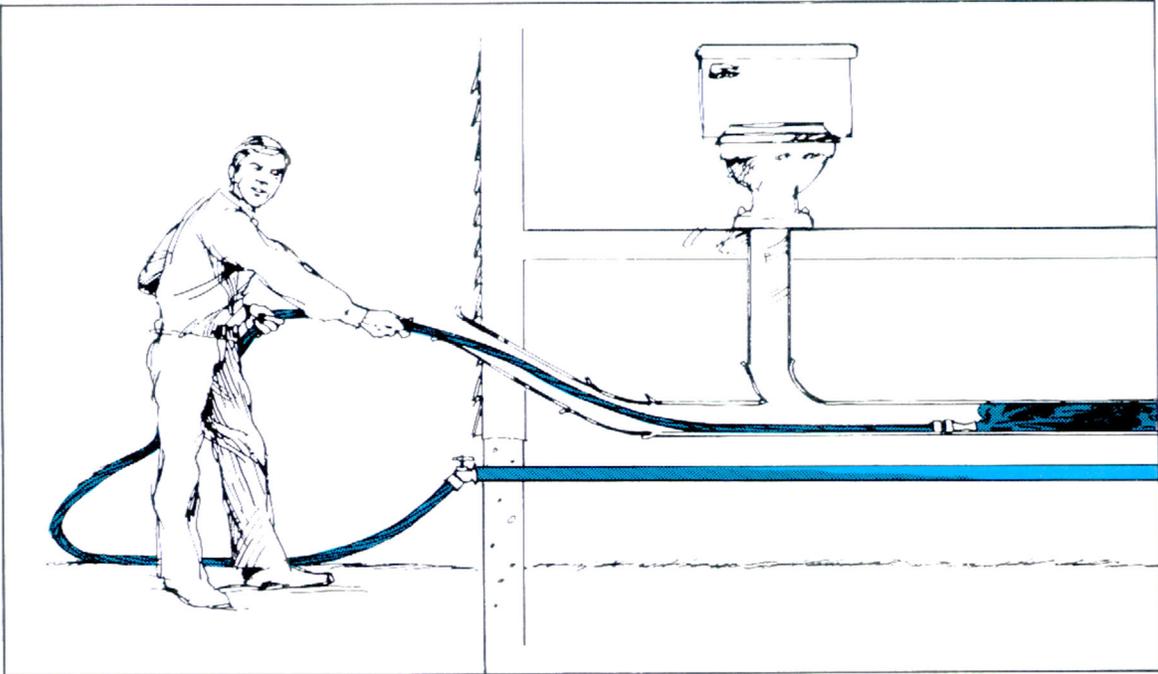
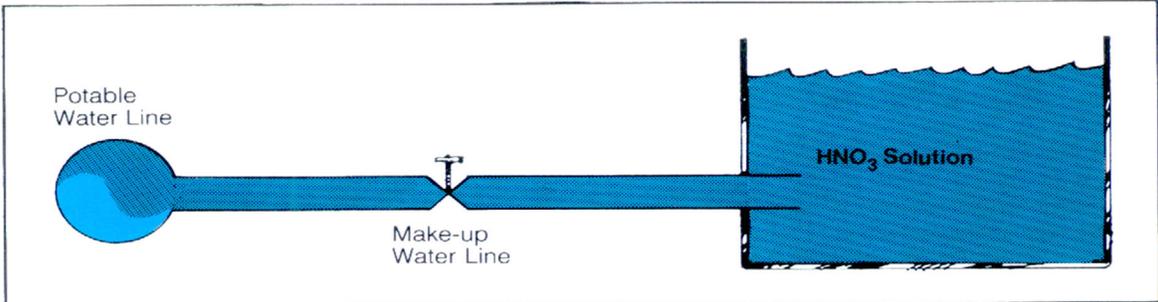
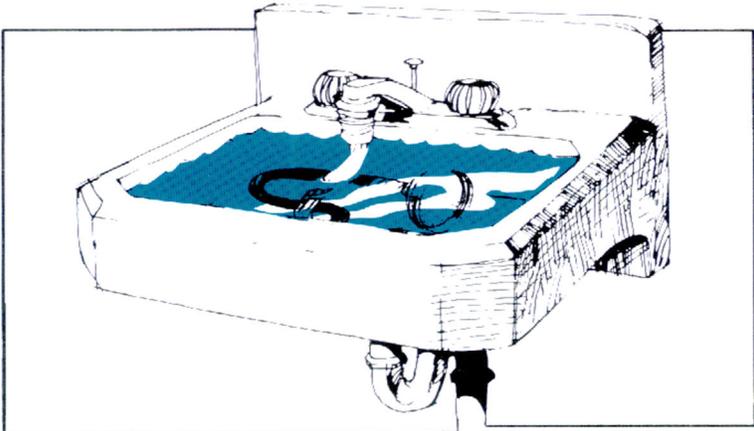
An example is the piping between a public water system or consumer's potable water system and an auxiliary water system, cooling system, or irrigation system.



Several cross-connection have been made to soda machines, the one to worry about is when you have a copper water line hooked to CO<sub>2</sub> without a backflow preventer.

The reason is that the CO<sub>2</sub> will mix in the water and create copper carbonic acid, which can be deadly. This is one reason that you will see clear plastic lines at most soda machines and no copper lines. Most codes require a stainless steel RP backflow assembly at soda machines.

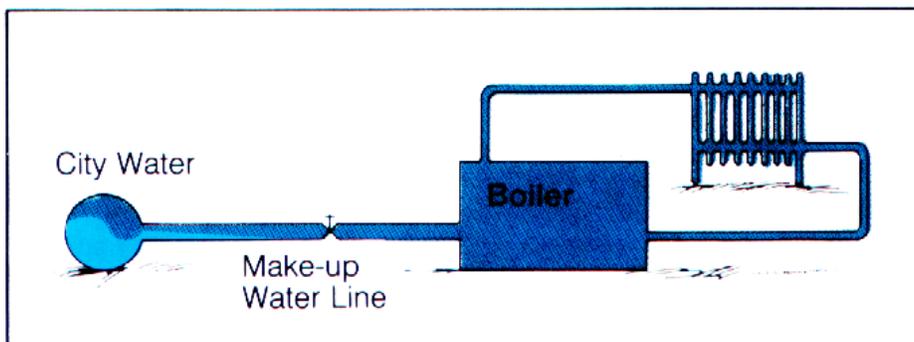
**Common Cross-Connections**



## Backflow

Backflow is the undesirable reversal of flow of nonpotable water or other substances through a cross-connection and into the piping of a public water system or consumer's potable water system. There are two types of backflow--**backpressure** and **backsiphonage**.

### *Backsiphonage*

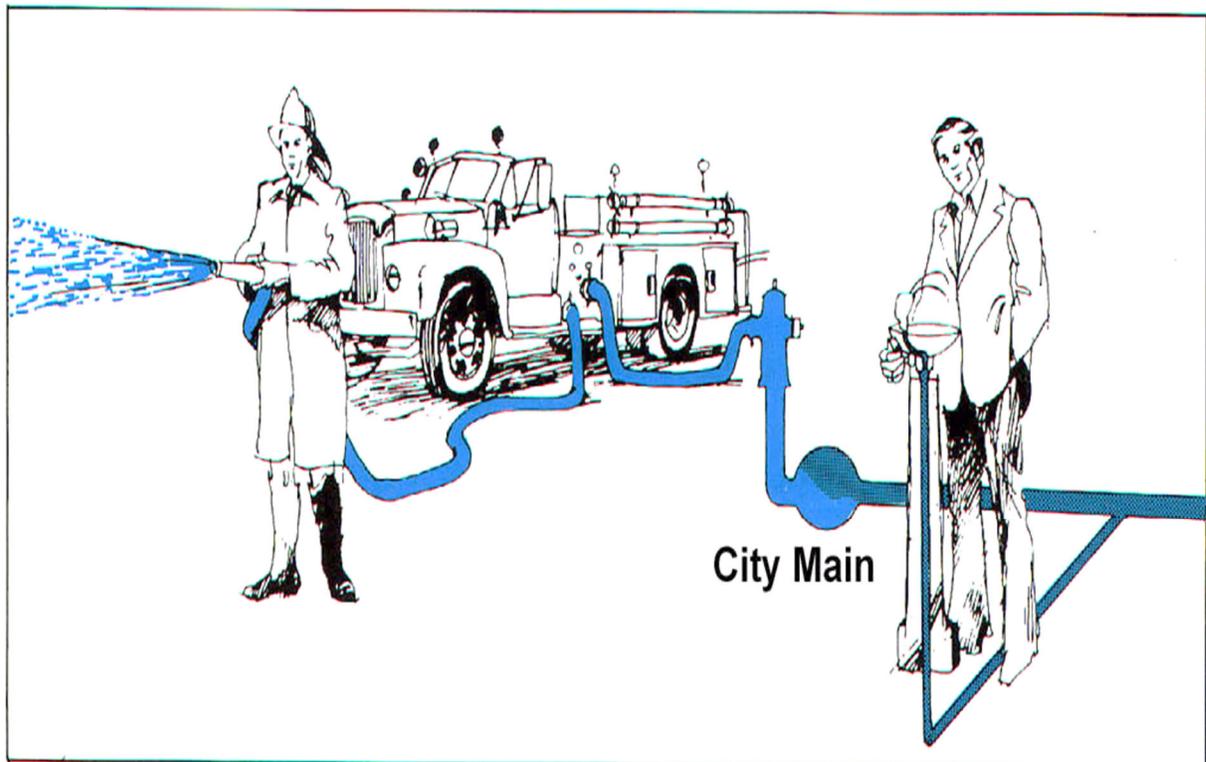


Backpressure caused by heat.

## Backsiphonage

Backsiphonage is backflow caused by a negative pressure (i.e., a vacuum or partial vacuum) in a public water system or consumer's potable water system. The effect is similar to drinking water through a straw.

Backsiphonage can occur when there is a stoppage of water supply due to nearby firefighting, a break in a water main, etc.



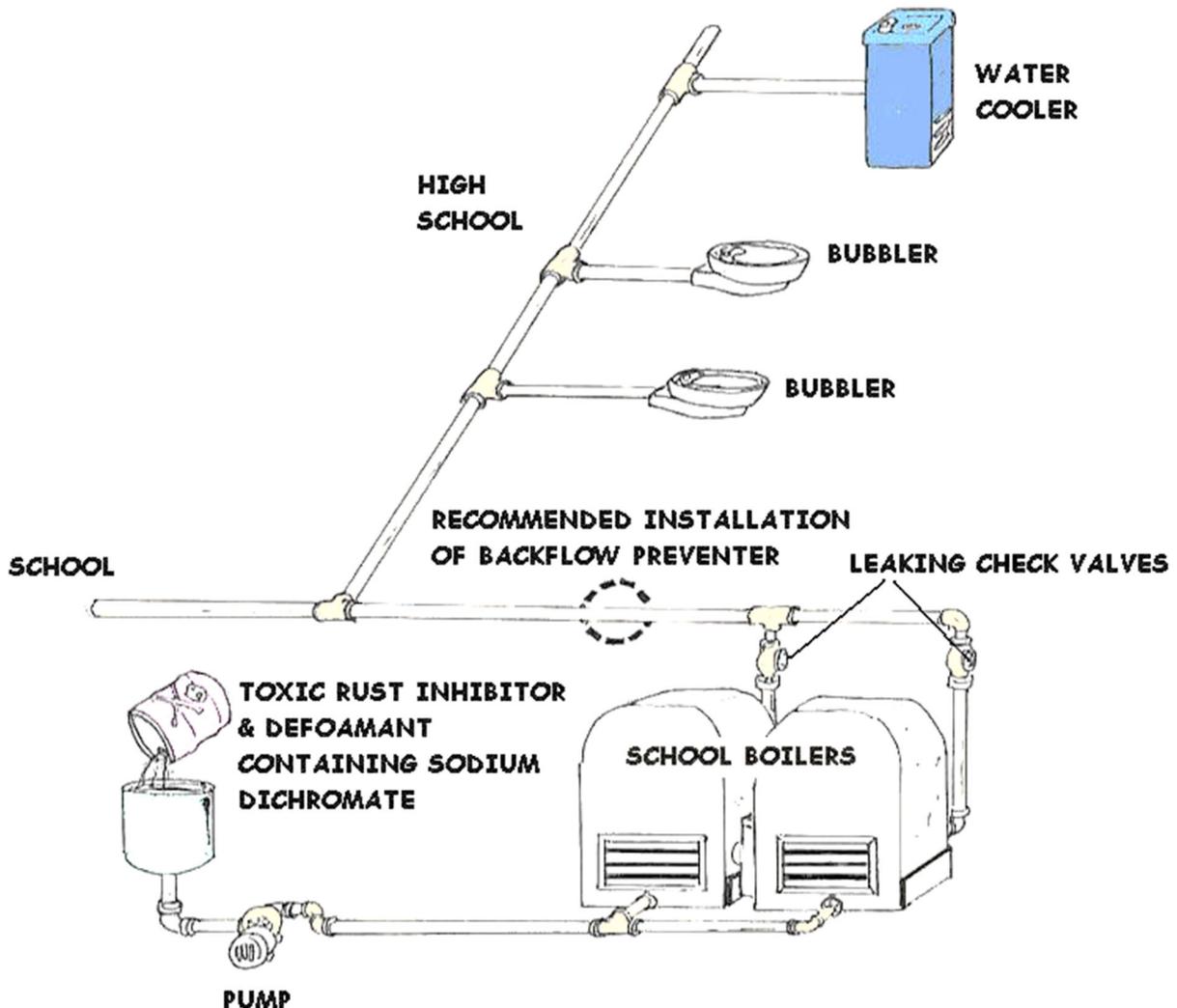
Every day, our public water system has several backsiphonage occurrences, think of people that use water driven equipment, from a device that drains water-beds to pesticide applicators.

Backpressure is rarer, but does happen in areas of high elevation, like tall buildings or buildings with pumps. A good example is the pressure exerted by a building that is 100 feet tall is about 43 PSI; the water main feeding the building is at 35 PSI. The water will flow back to the water main. Never drink water or coffee inside a funeral home, vet clinic or hospital.

## Backpressure

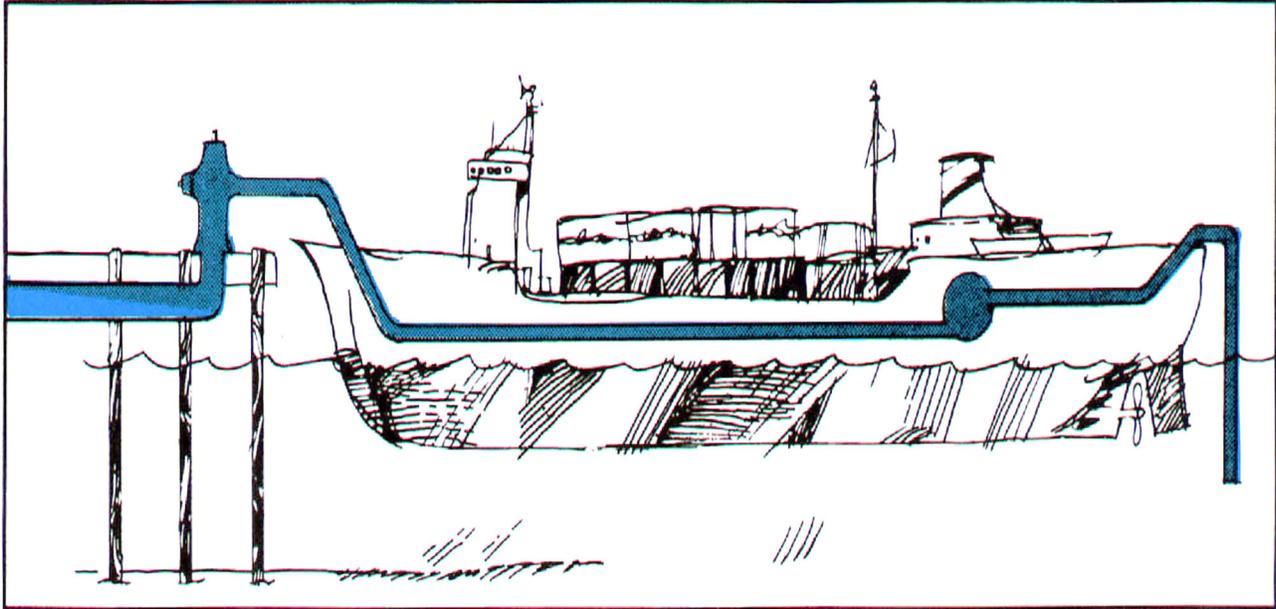
Backpressure backflow is backflow caused by a downstream pressure that is greater than the upstream or supply pressure in a public water system or consumer's potable water system. Backpressure (i.e., downstream pressure that is greater than the potable water supply pressure) can result from an increase in downstream pressure, a reduction in the potable water supply pressure, or a combination of both. Increases in downstream pressure can be created by pumps, temperature increases in boilers, etc.

Reductions in potable water supply pressure occur whenever the amount of water being used exceeds the amount of water being supplied, such as during water line flushing, firefighting, or breaks in water mains.



## Backpressure Examples

*Booster pumps, pressure vessels, elevation, heat*



A backflow preventer is a means or mechanism to prevent backflow. The basic means of preventing backflow is an air gap, which either eliminates a cross-connection or provides a barrier to backflow. The basic mechanism for preventing backflow is a mechanical backflow preventer, which provides a physical barrier to backflow. The principal types of mechanical backflow preventer are the reduced-pressure principle assembly, the pressure vacuum breaker assembly, and the double check valve assembly.

### **Residential Dual Check Valve**

A secondary type of mechanical backflow preventer is the residential dual check valve. We do not recommend the installation of dual checks because there is no testing method or schedule for these devices. Once these devices are in place, they, like all mechanical devices, are subject to failure and will probably be stuck open.

Some type of debris will keep the device from working properly.

## Types of Backflow Prevention Methods and Assemblies

### Backflow Devices

Cross connections must either be physically disconnected or have an approved backflow prevention device installed to protect the public water system. There are five types of approved devices/methods:

1. **Air gap- *Is not really a device but is a method.***
2. **Atmospheric vacuum breaker**
3. **Pressure vacuum breaker**
4. **Double check valve**
5. **Reduced pressure principle backflow preventer (RP device)**

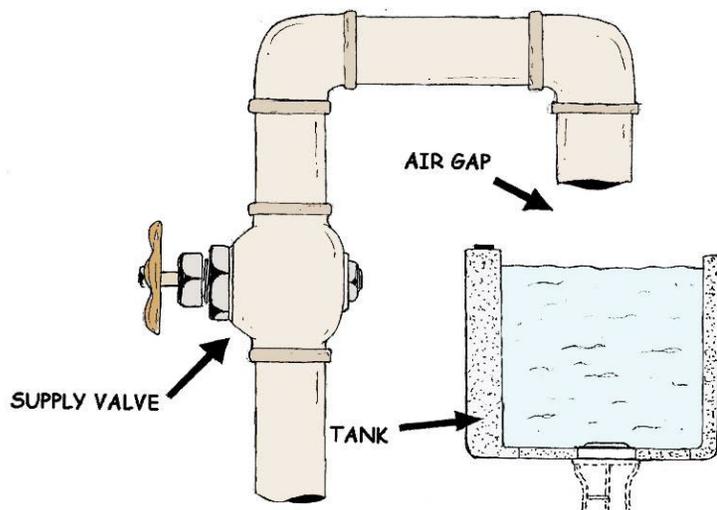
The type of device selected for a particular installation depends on several factors. First, the degree of hazard must be assessed. A high hazard facility is one in which a cross connection could be hazardous to health, such as a chrome plating shop or a sewage treatment plant. A low hazard situation is one in which a cross connection would cause only an aesthetic problem such as a foul taste or odor.

Second, the plumbing arrangement must be considered.

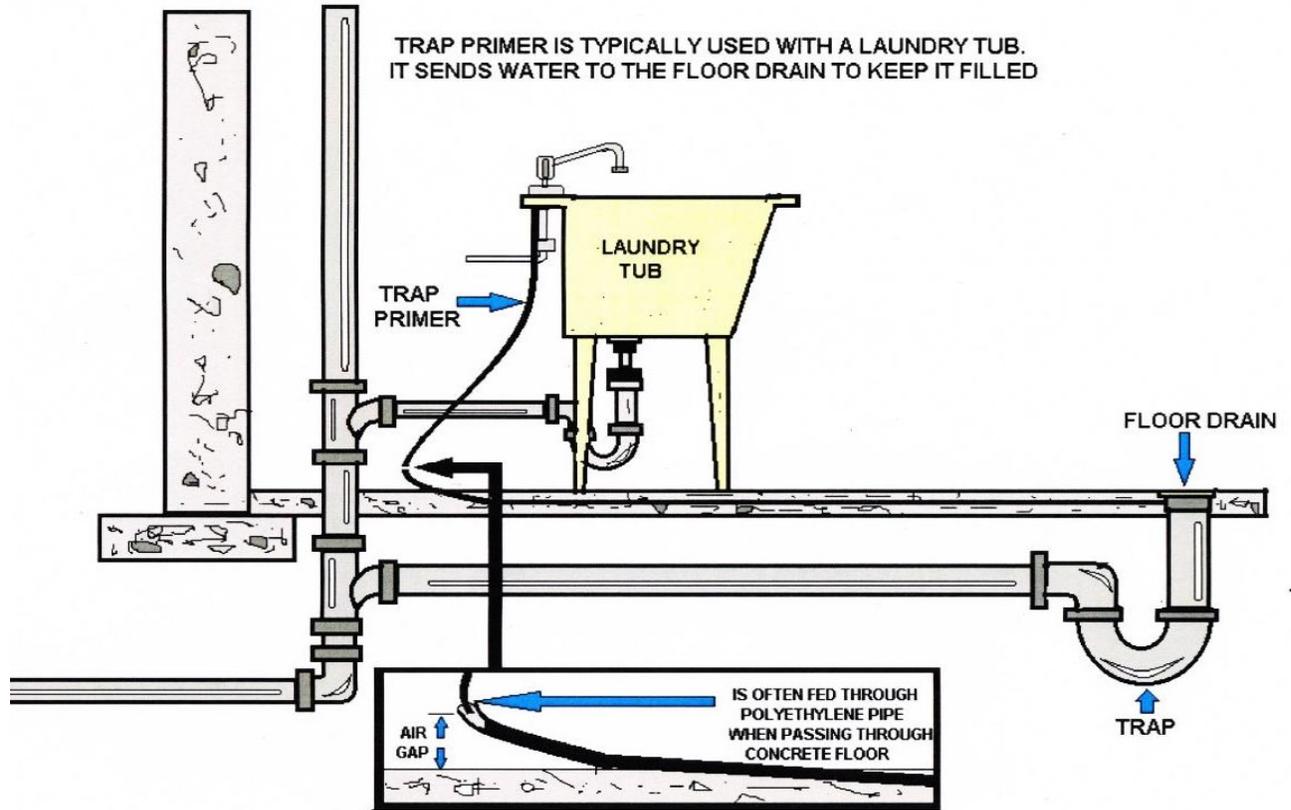
Third, it must be determined whether protection is needed at the water meter or at a location within the facility. A summary of these factors and the recommended device selection is given in Table 7-1.

### Approved Air Gap Separation (AG)

An approved air gap is a physical separation between the free flowing discharge end of a potable water supply pipeline, and the overflow rim of an open or non-pressure receiving vessel. These separations must be vertically orientated a distance of at least twice the inside diameter of the inlet pipe, but never less than one inch.



An obstruction around or near an air gap may restrict the flow of air into the outlet pipe and nullify the effectiveness of the air gap to prevent backsiphonage. When the air flow is restricted, such as the case of an air gap located near a wall, the air gap separation must be increased. Also, within a building where the air pressure is artificially increased above atmospheric, such as a sports stadium with a flexible roof kept in place by air blowers, the air gap separation must be increased.



## TRAP PRIMER



Which of these ice machine drains has an approved air gap? Here is a better question; would you use the ice from this ice machine? Here is where all those stories about cockroaches and stomach flu originate. The stories are true.

## Air Gap

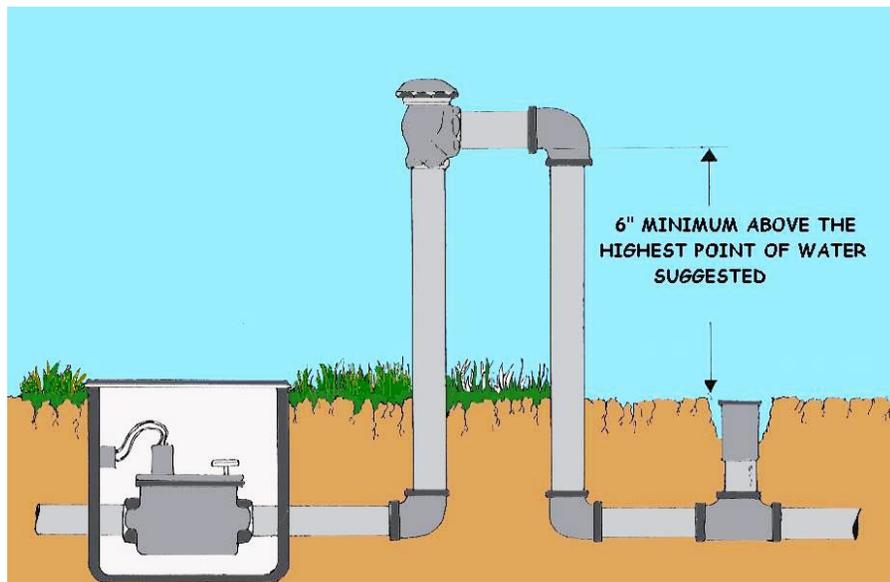
An air gap is a physical disconnection between the free flowing discharge end of a potable water pipeline and the top of an open receiving vessel. The air gap must be at least two times the diameter of the supply pipe and not less than one inch. This type of protection is acceptable for high hazard installations and is theoretically the most effective protection.

However, this method of prevention can be circumvented if the supply pipe is extended.



## Vacuum Breakers

There are two types of vacuum breakers, atmospheric and pressure. The difference between them is that the pressure vacuum breaker is spring loaded to assist the device's opening. Both devices open the pipeline to atmosphere in the event of backsiphonage only. Neither device is approved for backpressure conditions. Both devices are only suitable for low hazard applications. Their primary purpose is to protect the water system from cross connections due to submerged inlets, such as irrigation systems and tank applications. Shutoff valves may not be installed downstream of atmospheric vacuum breakers but are allowed on pressure vacuum breakers. The devices must be installed above the highest downstream piping.

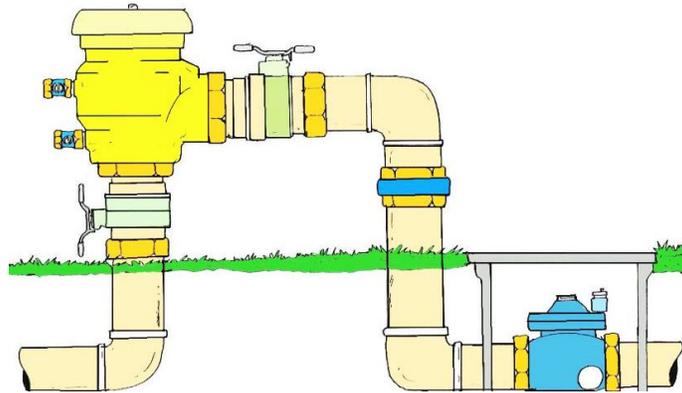


**Atmospheric Vacuum Breaker (AVB)** The Atmospheric Vacuum Breaker contains a float check (poppet), a check seat, and an air inlet port. The device allows air to enter the water line when the line pressure is reduced to a gauge pressure of zero or below. The air inlet valve is not internally loaded. To prevent the air inlet from sticking closed, the device must not be installed on the pressure side of a shutoff valve, or wherever it may be under constant pressure more than 12 hours during a 24 hour period.

Atmospheric vacuum breakers are designed to prevent backflow caused by backsiphonage only from low health hazards. Atmospheric Vacuum Breaker Uses: Irrigation systems, commercial dishwasher and laundry equipment, chemical tanks and laboratory sinks (backsiphonage only, non-pressurized connections.) (Note: hazard relates to the water purveyor's risk assessment; plumbing codes may allow AVB for high hazard fixture isolation).

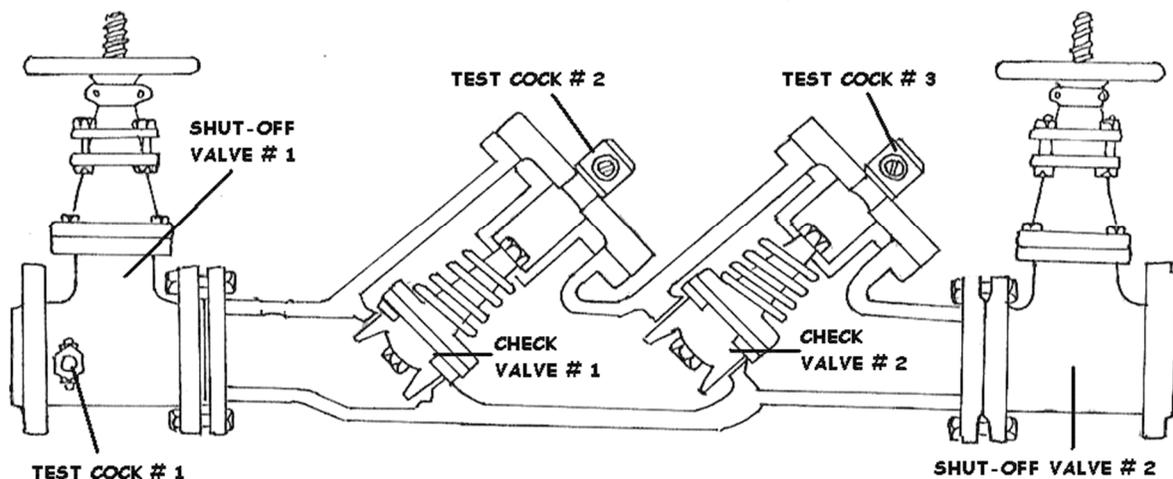
## Pressure Vacuum Breaker Assembly (PVB)

The Pressure Vacuum Breaker Assembly consists of a spring loaded check valve, an independently operating air inlet valve, two resilient seated shutoff valves, and two properly located resilient seated test cocks. It shall be installed as a unit as shipped by the manufacturer. The air inlet valve is internally loaded to the open position, normally by means of a spring, allowing installation of the assembly on the pressure side of a shutoff valve. The PVB needs to be installed 12 inches above the highest downstream outlet to work correctly.



## Double Check Valve Assembly (DC)

The Double Check Valve Assembly consists of two internally loaded check valves, either spring loaded or internally weighted, two resilient seated full ported shutoff valves, and four properly located resilient seated test cocks. This assembly shall be installed as a unit as shipped by the manufacturer. The double check valve assembly is designed to prevent backflow caused by backpressure and backsiphonage from low health hazards or pollutional concerns only. The double check valve should be installed in an accessible location and protected from freezing. The DC needs to be installed 12 inches above the ground for testing purposes only.



Double Check Assembly –Common on Firelines

## Reduced Pressure Backflow Assembly (RP)

The reduced pressure backflow assembly consists of two independently acting spring loaded check valves separated by a spring loaded differential pressure relief valve, two resilient seated full ported shutoff valves, and four properly located resilient seated test cocks. This assembly shall be installed as a unit shipped by the manufacturer.

During normal operation, the pressure between the two check valves, referred to as the zone of reduced pressure, is maintained at a lower pressure than the supply pressure. If either check valve leaks, the differential pressure relief valve maintains a differential pressure of at least two (2) psi between the supply pressure and the zone between the two check valves by discharging water to atmosphere.

The reduced pressure backflow assembly is designed to prevent backflow caused by backpressure and backsiphonage from low to high health hazards. The RP needs to be installed 12 inches above the ground for testing purposes only.



Two brand new RPs.

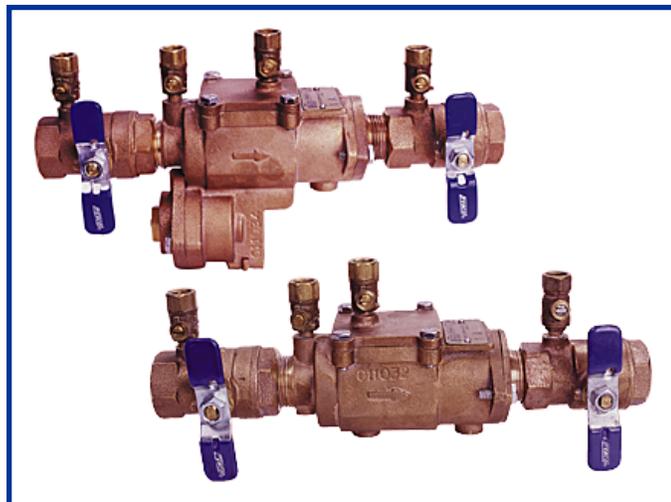
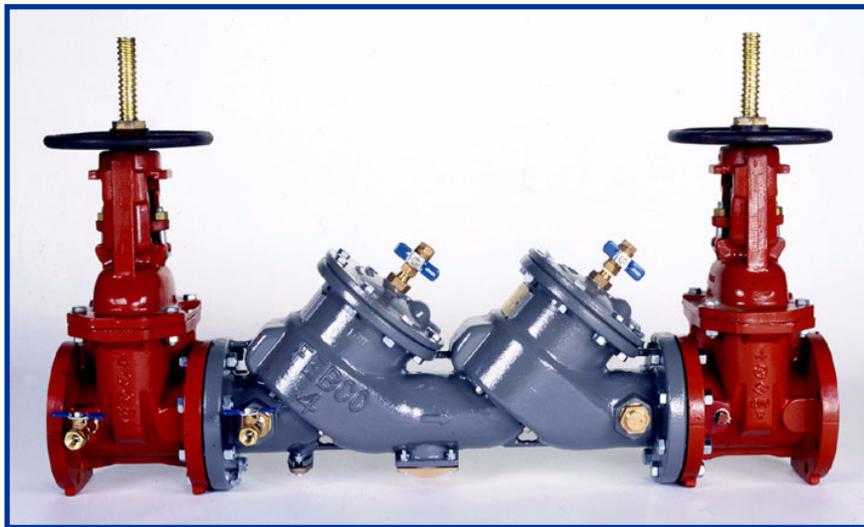
## Different Types of RPs

The RP consists of two internally loaded (weighted or spring loaded) check valves separated by a reduced pressure zone with a relief port to vent water to the atmosphere.

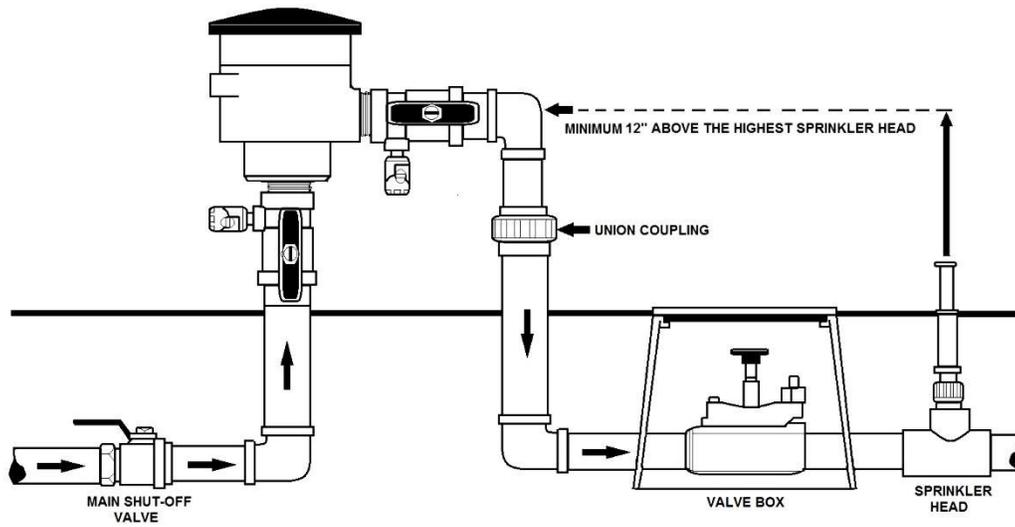
The reduced pressure device can be used for high hazard situations under both backpressure and backsiphonage conditions. Under normal conditions, the second check valve should prevent backflow.

However, if the second check valve fails or becomes fouled and backflow into the reduced pressure zone occurs, the relief port vents the backflow to atmosphere.

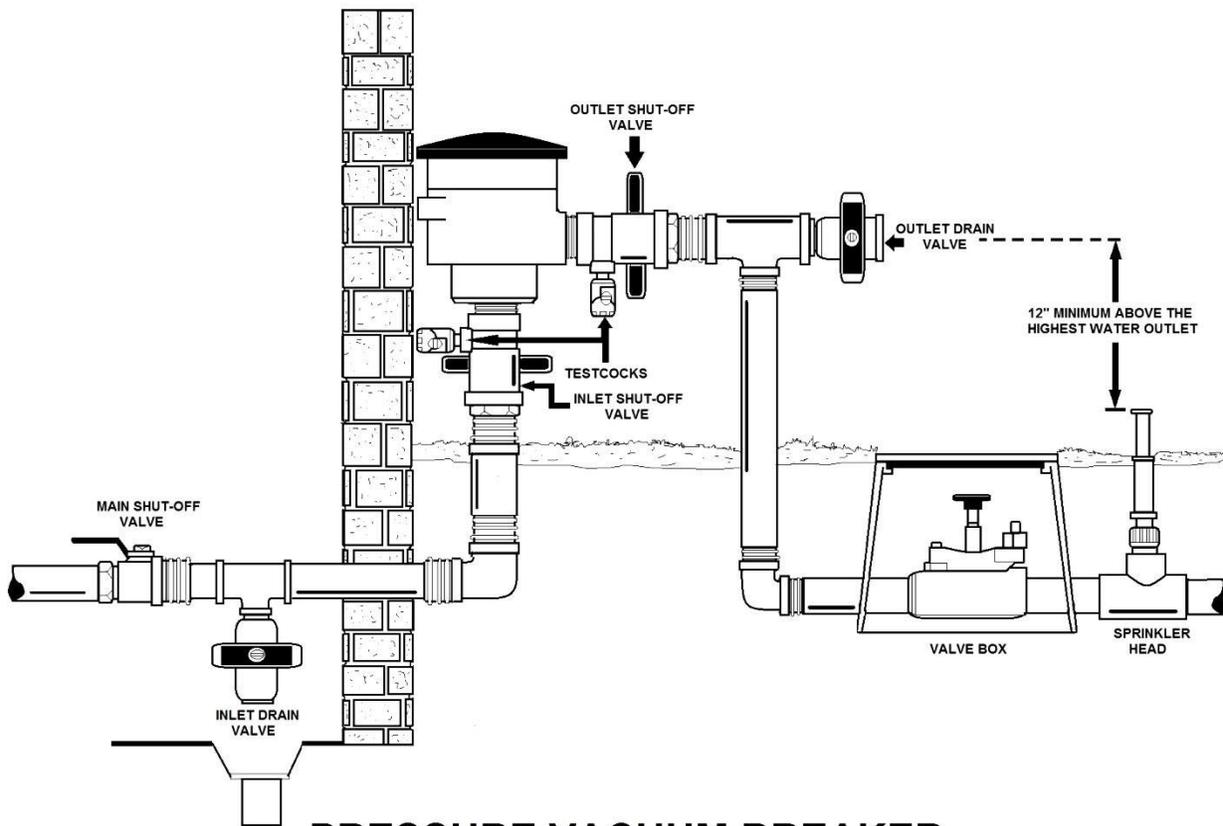
The reduced pressure zone port opens anytime pressure in the zone comes within 2 psi of the supply pressure.



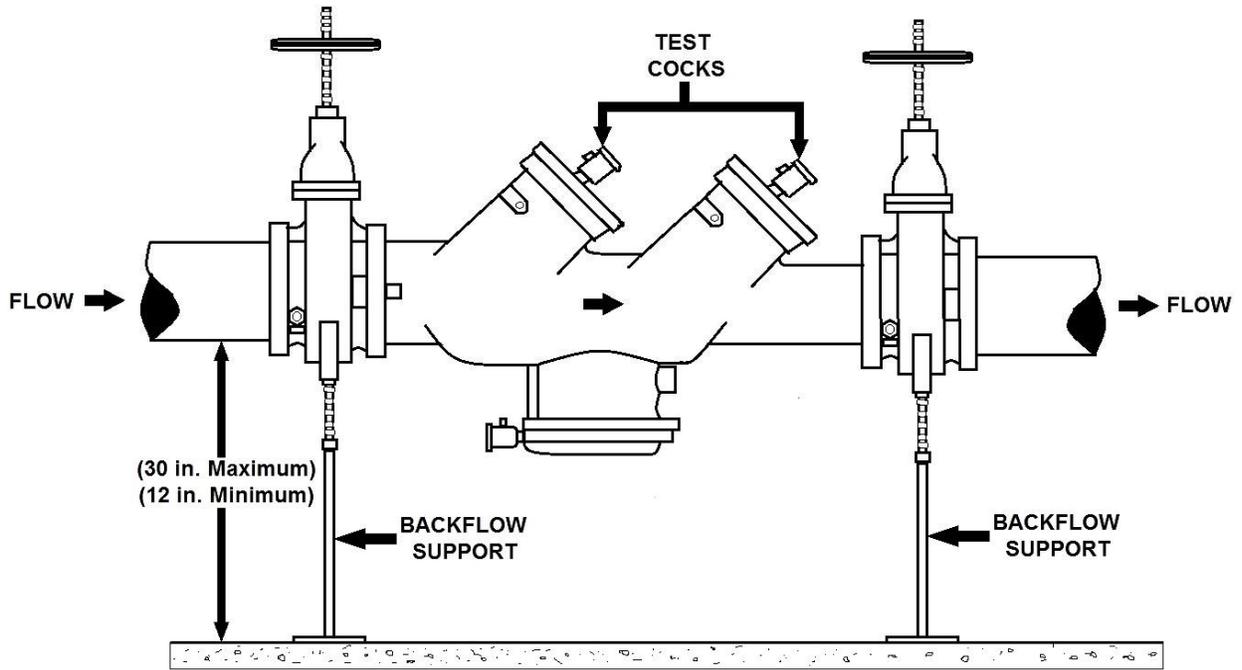
# Standard Installation Details



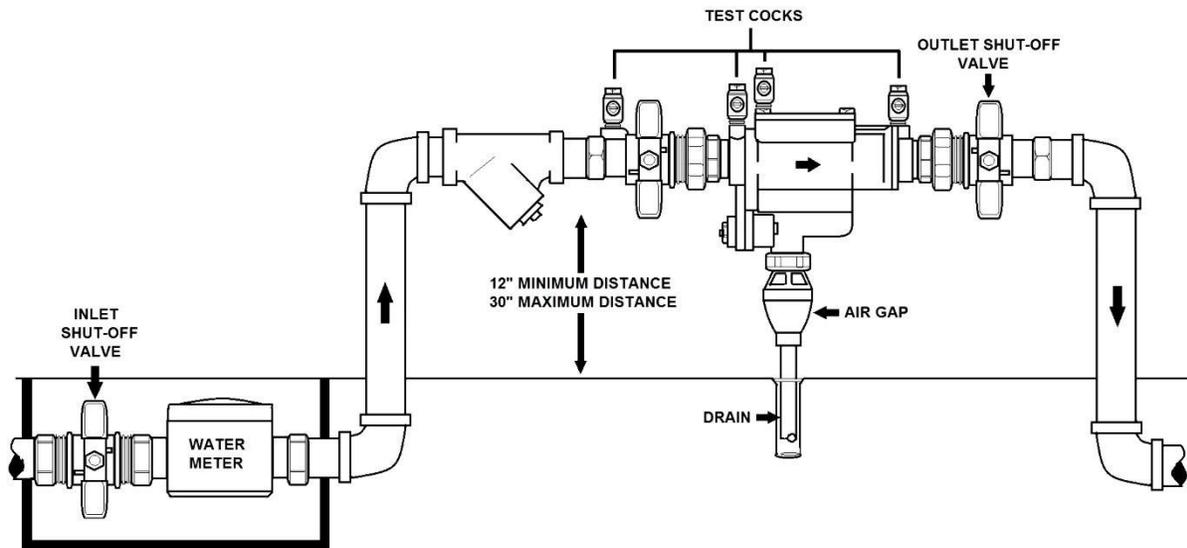
**PRESSURE VACUUM BREAKER  
BACKFLOW PREVENTER**



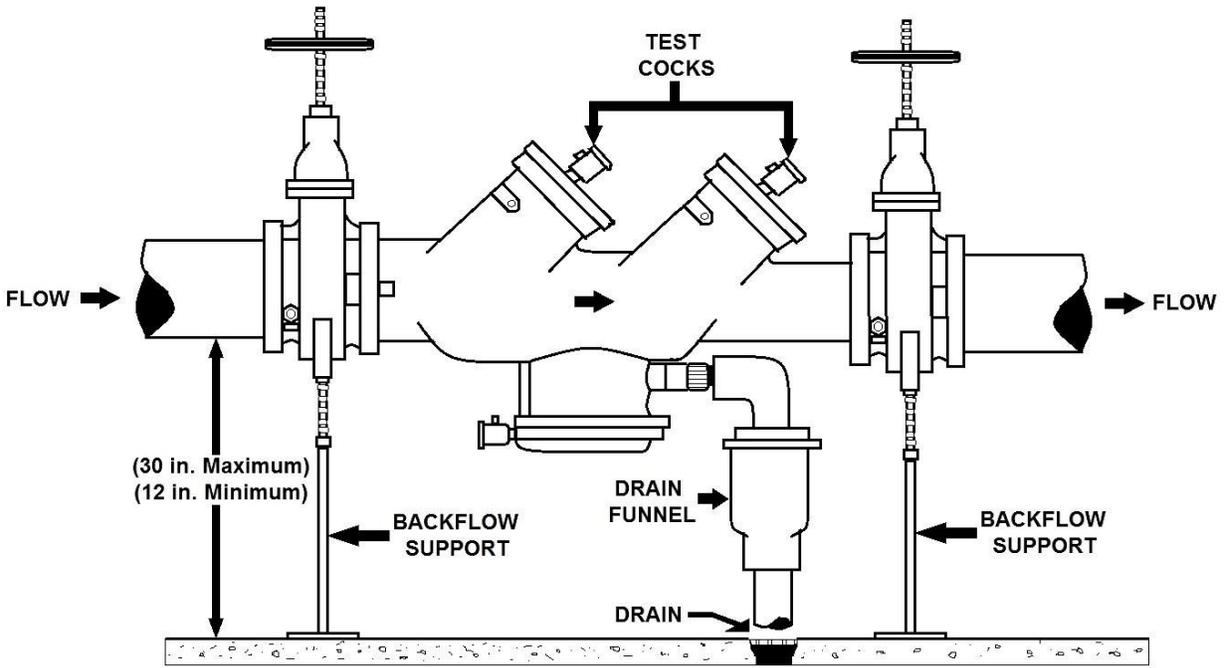
**PRESSURE VACUUM BREAKER**



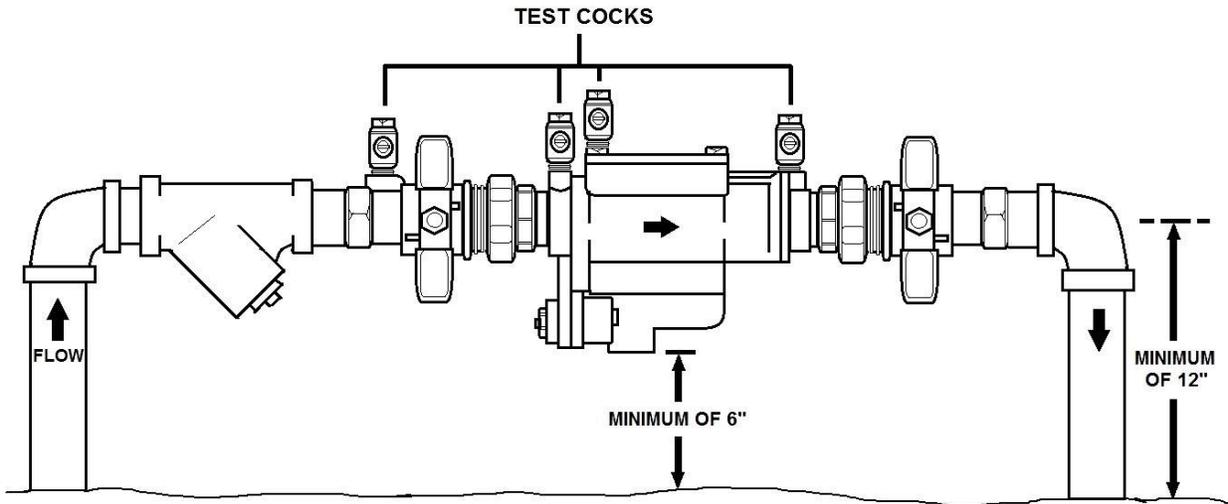
**DOUBLE CHECK VALVE**



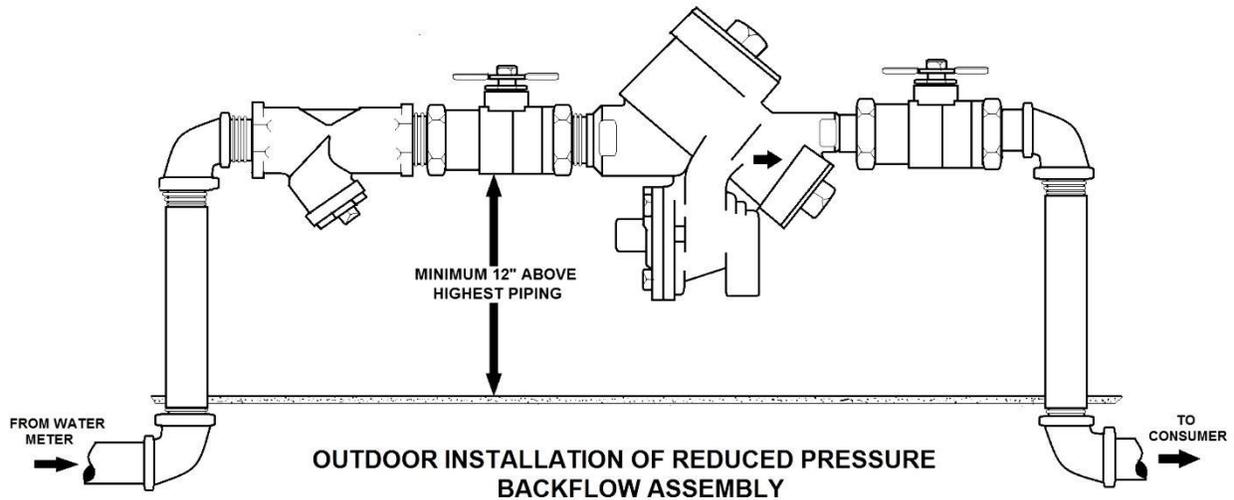
**REDUCED PRESSURE  
BACKFLOW PREVENTER**



**REDUCED PRESSURE BACKFLOW PREVENTER  
(Indoor Installation)**



**REDUCED PRESSURE PRINCIPLE BACKFLOW PREVENTER DIAGRAM**



**Texas Students Only**  
**Special Notice to all TCEQ Students**

**§ 344.51. SPECIFIC CONDITIONS AND CROSS-CONNECTION CONTROL.**

(d) If an irrigation system is designed or installed on a property that is served by an on-site sewage facility, as defined in Chapter 285 of this title (relating to On-Site Sewage Facilities), then:

(1) all irrigation piping and valves must meet the separation distances from the On-Site Sewage Facilities system as required for a private water line in §285.91(10) of this title (relating to Minimum Required Separation Distances for On-Site Sewage Facilities);

(2) any connections using a private or public potable water source must be connected to the water source through a reduced pressure principle backflow prevention assembly as defined in §344.50 of this title (relating to Backflow Prevention Methods); and

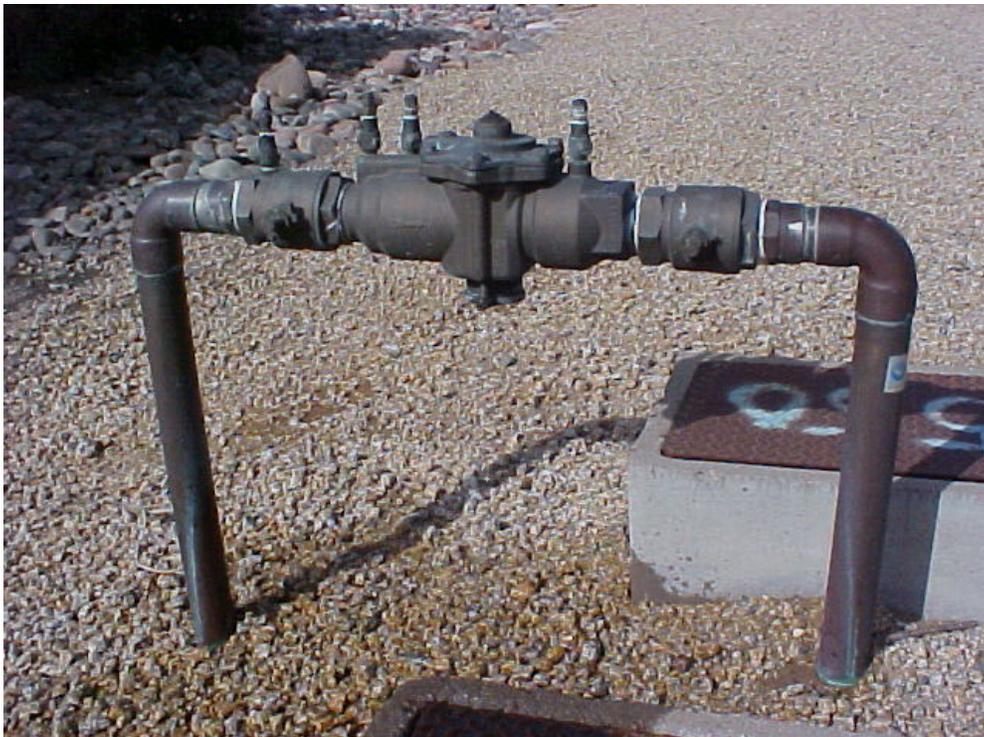
(3) any water from the irrigation system that is applied to the surface of the area utilized by the On-Site Sewage Facility system must be controlled on a separate irrigation zone or zones so as to allow complete control of any irrigation to that area so that there will not be excess water that would prevent the On-Site Sewage Facilities system from operating effectively.

## Why do Backflow Preventors have to be Tested Periodically?

Mechanical backflow preventors have internal seals, springs, and moving parts that are subject to fouling, wear, or fatigue. Also, mechanical backflow preventors and air gaps can be bypassed. Therefore, all backflow preventors have to be tested periodically to ensure that they are functioning properly. A visual check of air gaps is sufficient, but mechanical backflow preventors have to be tested with properly calibrated gauge equipment.

Backflow prevention devices must be tested annually to ensure that they work properly. It is usually the responsibility of the property owner to have this test done and to make sure that a copy of the test report is sent to the Public Works Department or Water Purveyor.

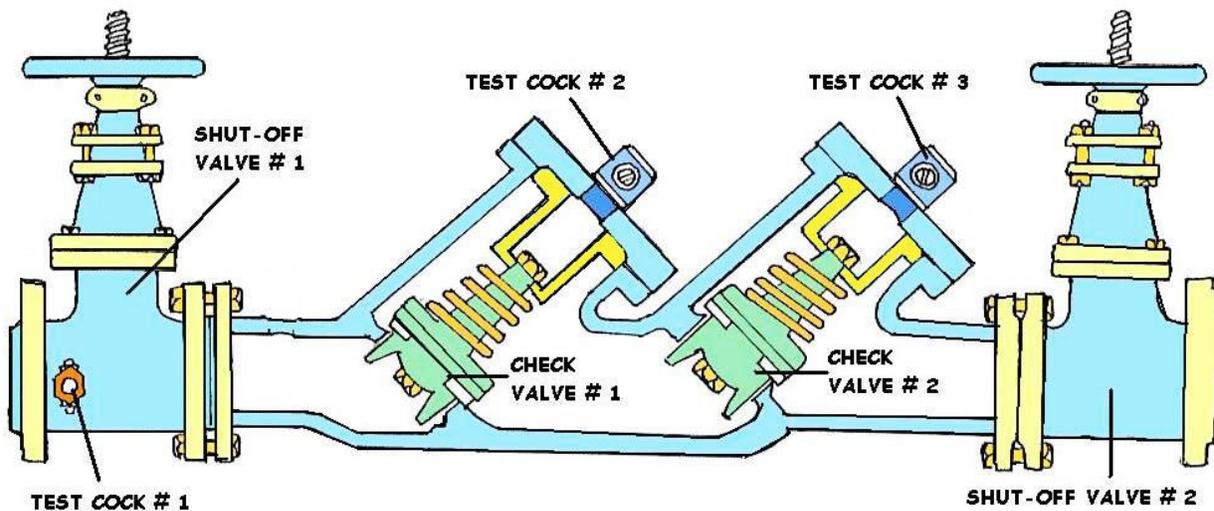
If a device is not tested annually, Public Works or the Water Purveyor will notify the property owner, asking them to comply. If the property owner does not voluntarily test their device, the City may be forced to turn off water service to that property. State law requires the City to discontinue water service until testing is complete.



**Leaky RP**--have your assemblies tested annually or more often. Re-test after repairs and problems. A RP should not leak more than 1 or 2 minute—any more than that, there is a problem; a piece of debris or stuck check is causing the RP's hydraulic relief port to dump.



Here is an RP that had never been tested and leaked every day until the grass was 3 feet high and the owner notified the Water Department of a water leak. The water meter reader should have caught this problem in the first couple months.

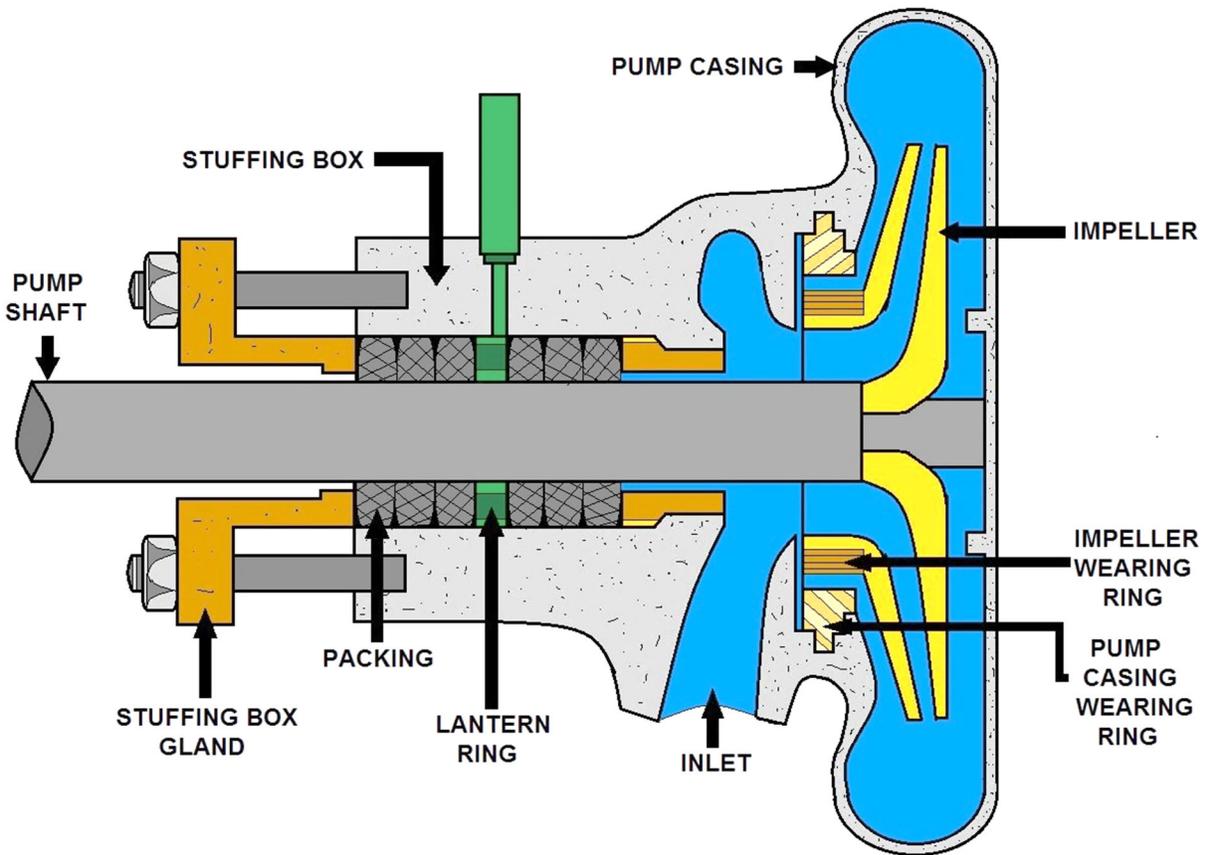


**DOUBLE-CHECK BACKFLOW ASSEMBLY #2**

# Pump Operation Section

## Pump Objectives. In this section we will examine...

- ★ What is a pump?
- ★ Identify different types of pumps and related parts.
- ★ Identify the main purpose of a motor starter.
- ★ Describe the main use of AC and DC motors.
- ★ Describe the operations of level sensor controls.
- ★ Identify and describe the most commonly used pumps.
- ★ Identify the suction and discharge valving.
- ★ Distinguish between discharge head, total head, suction head, and suction lift.
- ★ Describe information to be obtained from pump performance graphs.
- ★ Identify types of couplings, bearings, seals and other pump components.
- ★ Describe the importance of the alignment of couplings.
- ★ Indicate when packing seals need to be replaced.
- ★ Describe cavitation.
- ★ Describe water hammer.
- ★ State the basic principles of positive displacement pumps.



## CENTRIFUGAL PUMP PARTS

A centrifugal pump has two main components:

- I. A rotating component comprised of an impeller and a shaft
- II. A stationary component comprised of a casing, casing cover, and bearings.

## General Pumping Fundamentals- Introduction

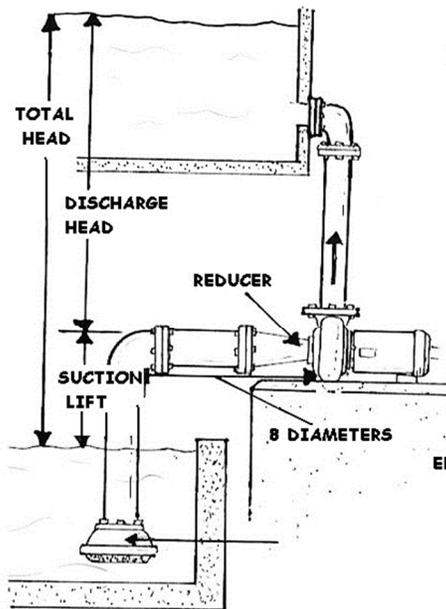


ILLUSTRATION 1

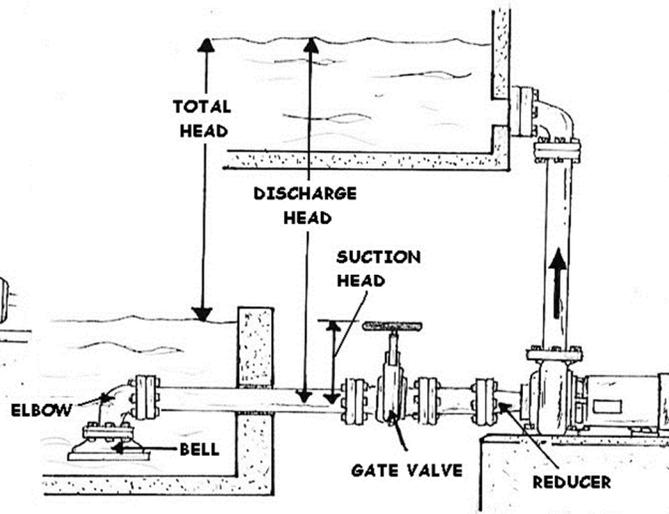


ILLUSTRATION 2

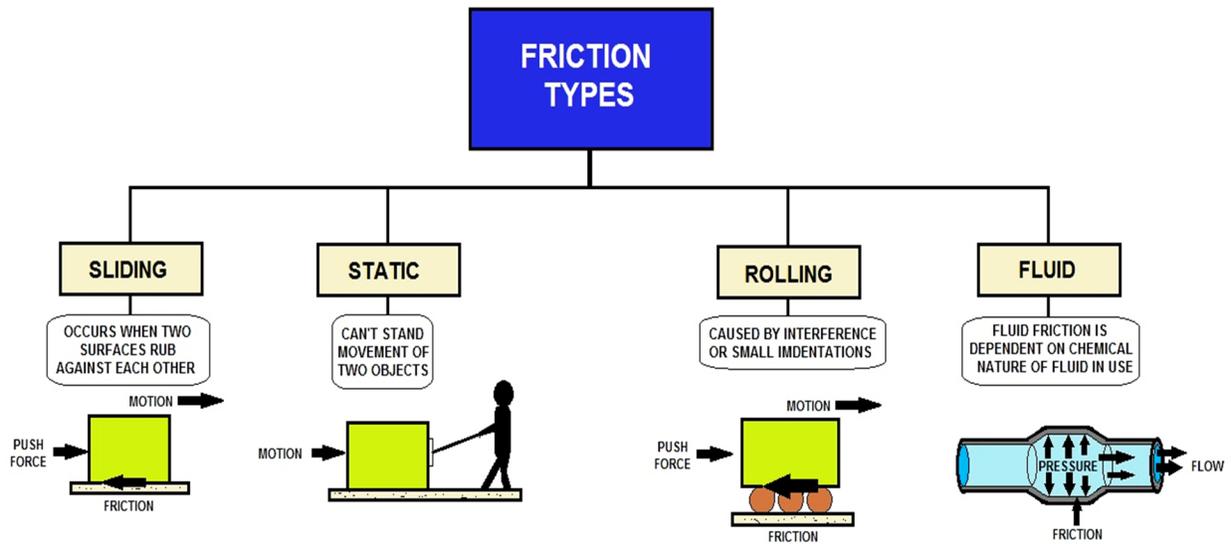
Here are the important points to consider about suction piping when the liquid being pumped is below the level of the pump:

- First, suction lift is when the level of water to be pumped is below the centerline of the pump. Sometimes suction lift is also referred to as 'negative suction head'.
- The ability of the pump to lift water is the result of a partial vacuum created at the center of the pump.
- This works similar to sucking soda from a straw. As you gently suck on a straw, you are creating a vacuum or a pressure differential. Less pressure is exerted on the liquid inside the straw, so that the greater pressure is exerted by the atmosphere on the liquid around the outside of the straw, causing the liquid in the straw to move up. By sucking on the straw, this allows atmospheric pressure to move the liquid.
- Look at the diagram illustrated as "1". The foot valve is located at the end of the suction pipe of a pump. It opens to allow water to enter the suction side, but closes to prevent water from passing back out of the bottom end.
- The suction side of pipe should be one diameter larger than the pump inlet. The required eccentric reducer should be turned so that the top is flat and the bottom tapered.

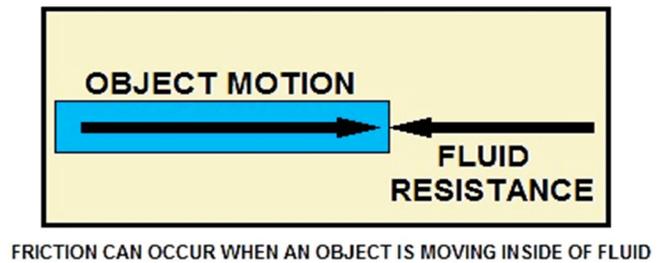
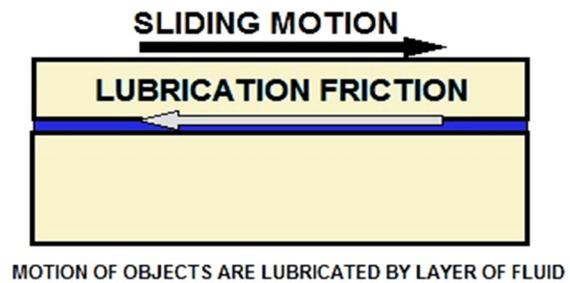
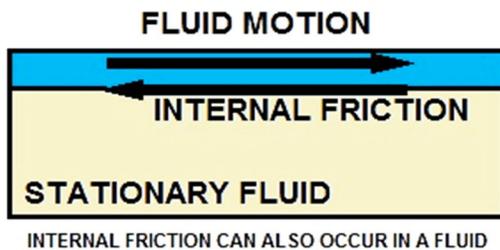
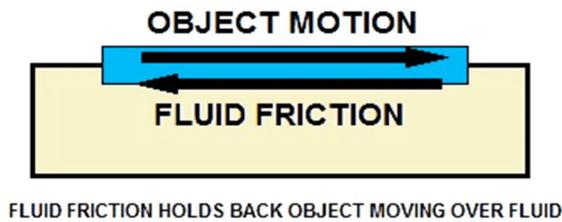
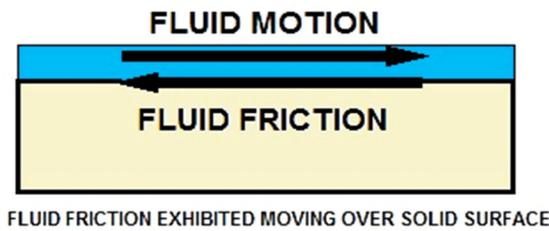
Notice in illustration "2" that the liquid is above the level of the pump. Sometimes this is referred to as 'flooded suction' or 'suction head' situations.

### Points to Note are:

If an elbow and bell are used, they should be at least one pipe diameter from the tank bottom and side. This type of suction piping must have a gate valve which can be used to prevent the reverse flow when the pump has to be removed. In the illustration, you can see in both cases the discharge head is from the centerline of the pump to the level of the discharge water. The total head is the difference between the two liquid levels.



## FRICTION TYPE EXAMPLES



## EXAMPLES OF FLUID FRICTION

## Dynamic Pump Definitions

### Hyperlink to the Glossary and Appendix

<http://www.abctlc.com/downloads/PDF/WTGlossary.pdf>

**Fluid:** Any substance that can be pumped such as oil, water, refrigerant, or even air.

**Gasket:** Flat material that is compressed between two faces to form a seal.

**Gland follower:** A bushing used to compress the packing in the stuffing box and to control leakoff.

**Gland sealing line:** A line that directs sealing fluid to the stuffing box.

**Horizontal pumps:** Pumps in which the center line of the shaft is horizontal.

**Impeller:** The part of the pump that increases the speed of the fluid being handled.

**Inboard:** The end of the pump closest to the motor.

**Inter-stage diaphragm:** A barrier that separates stages of a multi-stage pump.

**Key:** A rectangular piece of metal that prevents the impeller from rotating on the shaft.

**Keyway:** The area on the shaft that accepts the key.

**Kinetic energy:** Energy associated with motion.

**Lantern ring:** A metal ring located between rings of packing that distributes gland sealing fluid.

**Leak-off:** Fluid that leaks from the stuffing box.

**Mechanical seal:** A mechanical device that seals the pump stuffing box.

**Mixed flow pump:** A pump that uses both axial-flow and radial-flow components in one impeller.

**Multi-stage pumps:** Pumps with more than one impeller.

**Outboard:** The end of the pump farthest from the motor.

**Packing:** Soft, pliable material that seals the stuffing box.

**Positive displacement pumps:** Pumps that move fluids by physically displacing the fluid inside the pump.

**Radial bearings:** Bearings that prevent shaft movement in any direction outward from the center line of the pump.

**Radial flow:** Flow at 90° to the center line of the shaft.

**Retaining nut:** A nut that keeps the parts in place.

**Rotor:** The rotating parts, usually including the impeller, shaft, bearing housings, and all other parts included between the bearing housing and the impeller.

**Score:** To cause lines, grooves or scratches.

**Shaft:** A cylindrical bar that transmits power from the driver to the pump impeller.

**Shaft sleeve:** A replaceable tubular covering on the shaft.

**Shroud:** The metal covering over the vanes of an impeller.

**Slop drain:** The drain from the area that collects leak-off from the stuffing box.

**Slurry:** A thick, viscous fluid, usually containing small particles.

**Stages:** Impellers in a multi-stage pump.

**Stethoscope:** A metal device that can amplify and pinpoint pump sounds.

**Strainer:** A device that retains solid pieces while letting liquids through.

**Stuffing box:** The area of the pump where the shaft penetrates the casing.

**Suction:** The place where fluid enters the pump.

**Suction eye:** The place where fluid enters the pump impeller.

**Throat bushing:** A bushing at the bottom of the stuffing box that prevents packing from being pushed out of the stuffing box into the suction eye of the impeller.

**Thrust:** Force, usually along the center line of the pump.

**Thrust bearings:** Bearings that prevent shaft movement back and forth in the same direction as the center line of the shaft.

**Troubleshooting:** Locating a problem.

**Vanes:** The parts of the impeller that push and increase the speed of the fluid in the pump.

**Vertical pumps:** Pumps in which the center line of the shaft runs vertically.

**Volute:** The part of the pump that changes the speed of the fluid into pressure.

**Wearing rings:** Replaceable rings on the impeller or the casing that wear as the pump operates.

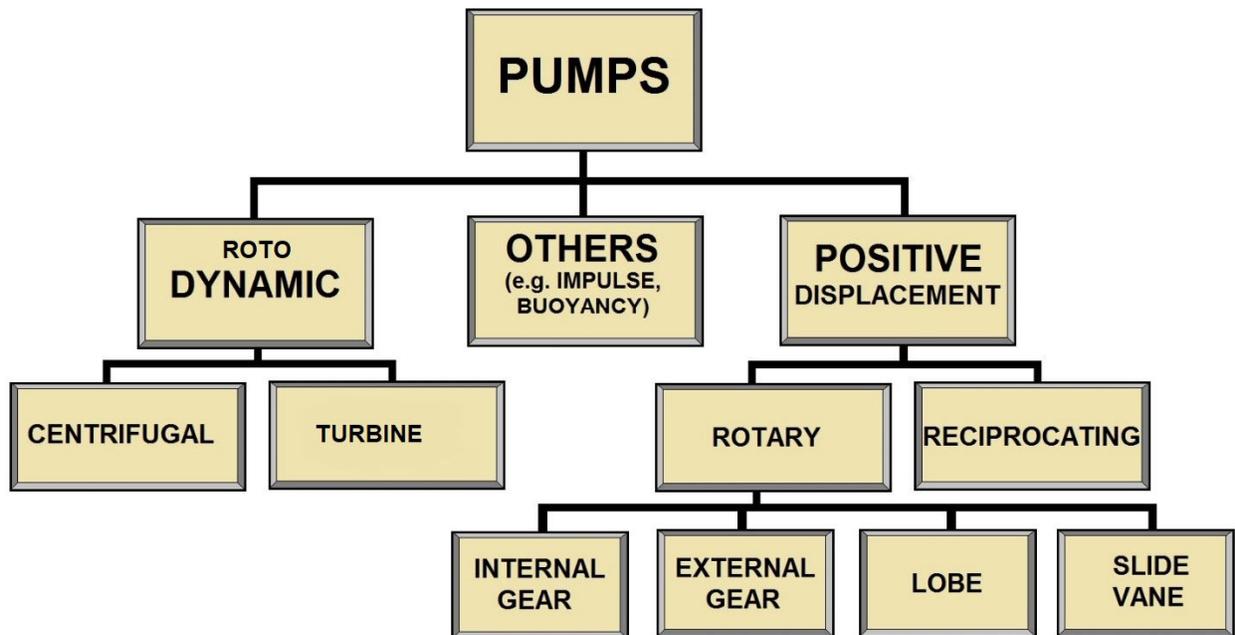
# Pump Introduction

Pumps are used to move or raise fluids. They are not only very useful, but are excellent examples of hydrostatics. Pumps are of two general types, hydrostatic or positive displacement pumps, and pumps depending on dynamic forces, such as centrifugal pumps. Here we will only consider positive displacement pumps, which can be understood purely by hydrostatic considerations. They have a piston (or equivalent) moving in a closely-fitting cylinder, and forces are exerted on the fluid by motion of the piston.

Let's cover the essentials first. The key to the whole operation is, of course, the *pump*. And regardless of what type it is (reciprocating piston, centrifugal, turbine or jet-ejector, for either shallow or deep well applications), its purpose is to move water and generate the delivery force we call pressure.

Sometimes — with centrifugal pumps in particular — pressure is not referred to in pounds per square inch but rather as the equivalent in elevation, called head. No matter; head in feet divided by 2.31 equals pressure, so it's simple enough to establish a common figure.

Pumps may be classified on the basis of the application they serve. All pumps may be divided into two major categories: (1) dynamic, in which energy is continuously added to increase the fluid velocities within the machine, and (2) displacement, in which the energy is periodically added by application of force.



## Types of Pumps

The family of pumps comprises a large number of types based on application and capabilities. The two major groups of pumps are dynamic and positive displacement.

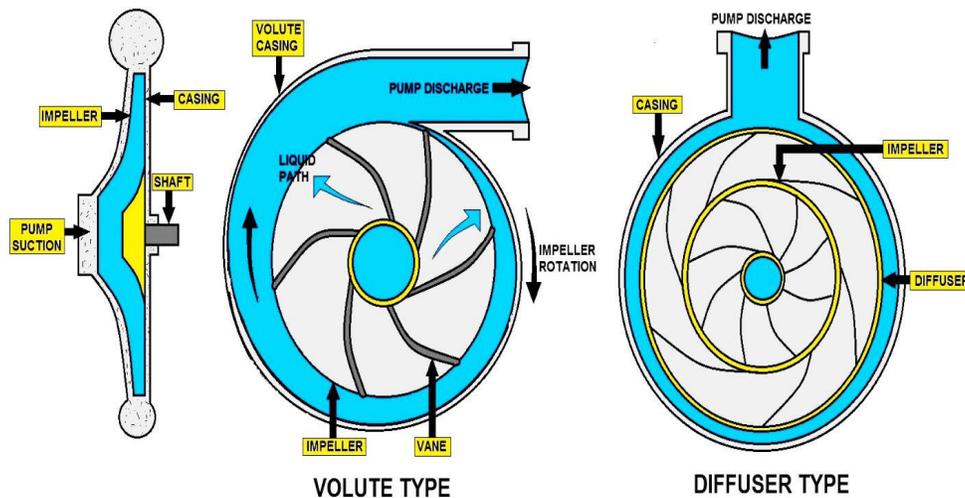
### Dynamic Pumps (Centrifugal Pump)

Centrifugal pumps are classified into three general categories:

**Radial flow**—a centrifugal pump in which the pressure is developed wholly by centrifugal force.

**Mixed flow**—a centrifugal pump in which the pressure is developed partly by centrifugal force and partly by the lift of the vanes of the impeller on the liquid.

**Axial flow**—a centrifugal pump in which the pressure is developed by the propelling or lifting action of the vanes of the impeller on the liquid.



### TYPES OF CENTRIFUGAL PUMPS

We have already seen an important example of this in the hydraulic lever or hydraulic press, which we have called quasi-static. The simplest pump is the syringe, filled by withdrawing the piston and emptied by pressing it back in, as its port is immersed in the fluid or removed from it.

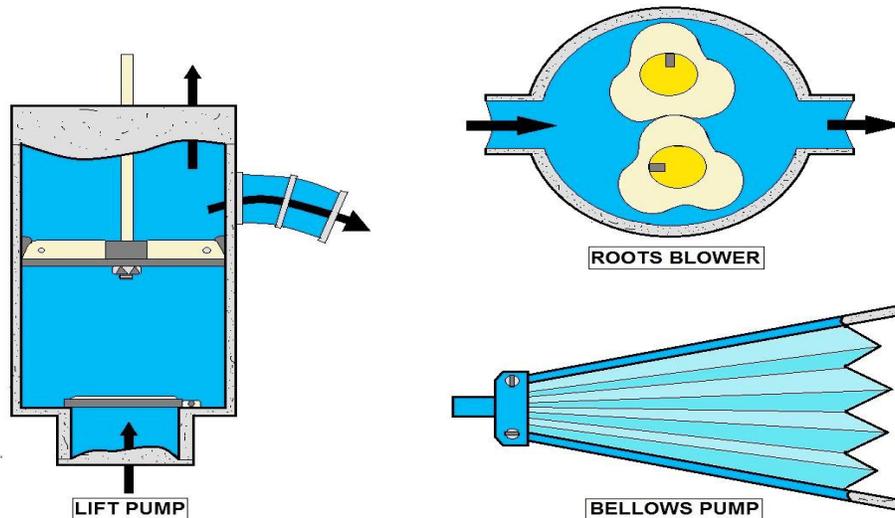
More complicated pumps have valves allowing them to work repetitively. These are usually check valves that open to allow passage in one direction, and close automatically to prevent reverse flow. There are many kinds of valves, and they are usually the most trouble-prone and complicated part of a pump.

The force pump has two check valves in the cylinder, one for supply and the other for delivery. The supply valve opens when the cylinder volume increases, the delivery valve when the cylinder volume decreases.

The lift pump has a supply valve and a valve in the piston that allows the liquid to pass around it when the volume of the cylinder is reduced. The delivery in this case is from the upper part of the cylinder, which the piston does not enter.

Diaphragm pumps are force pumps in which the oscillating diaphragm takes the place of the piston. The diaphragm may be moved mechanically, or by the pressure of the fluid on one side of the diaphragm.

Some positive displacement pumps are shown below. The force and lift pumps are typically used for water. The force pump has two valves in the cylinder, while the lift pump has one valve in the cylinder and one in the piston. The maximum lift, or "suction," is determined by the atmospheric pressure, and either cylinder must be within this height of the free surface.



### TYPES OF POSITIVE DISPLACEMENT PUMPS

The force pump, however, can give an arbitrarily large pressure to the discharged fluid, as in the case of a diesel engine injector. A nozzle can be used to convert the pressure to velocity, to produce a jet, as for firefighting. Fire fighting force pumps usually have two cylinders feeding one receiver alternately. The air space in the receiver helps to make the water pressure uniform.

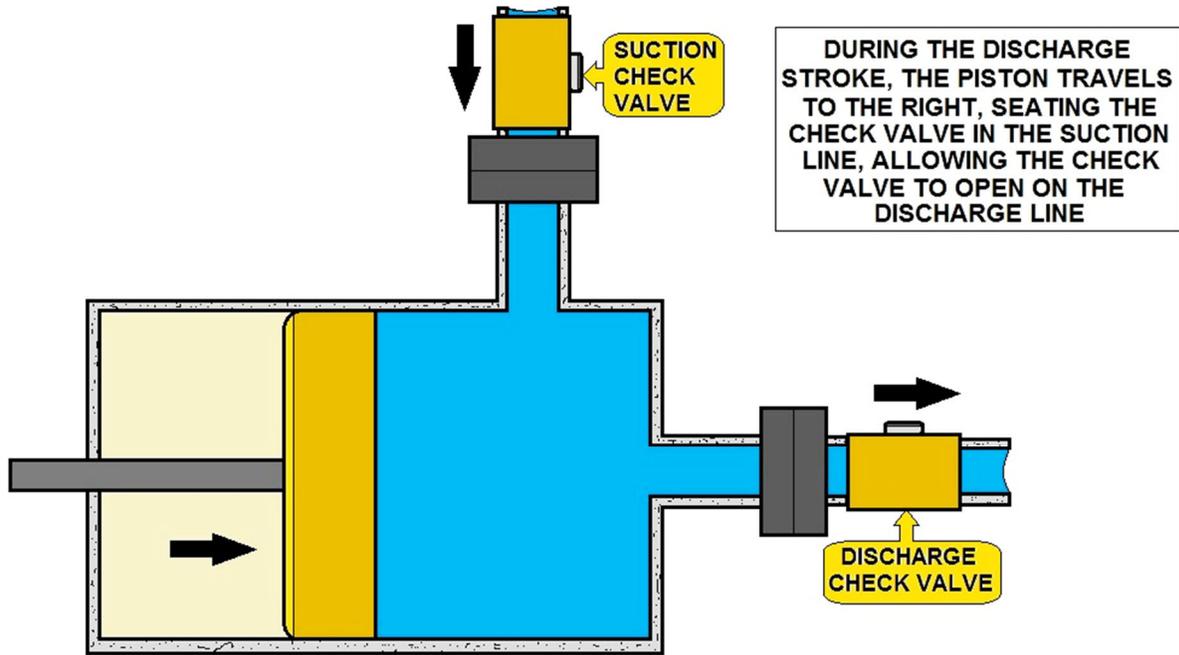
The three pumps below are typically used for air, but would be equally applicable to liquids. The Roots blower has no valves, their place taken by the sliding contact between the rotors and the housing.

The **Roots (rotating lobe) blower** can either exhaust a receiver or provide air under moderate pressure, in large volumes.

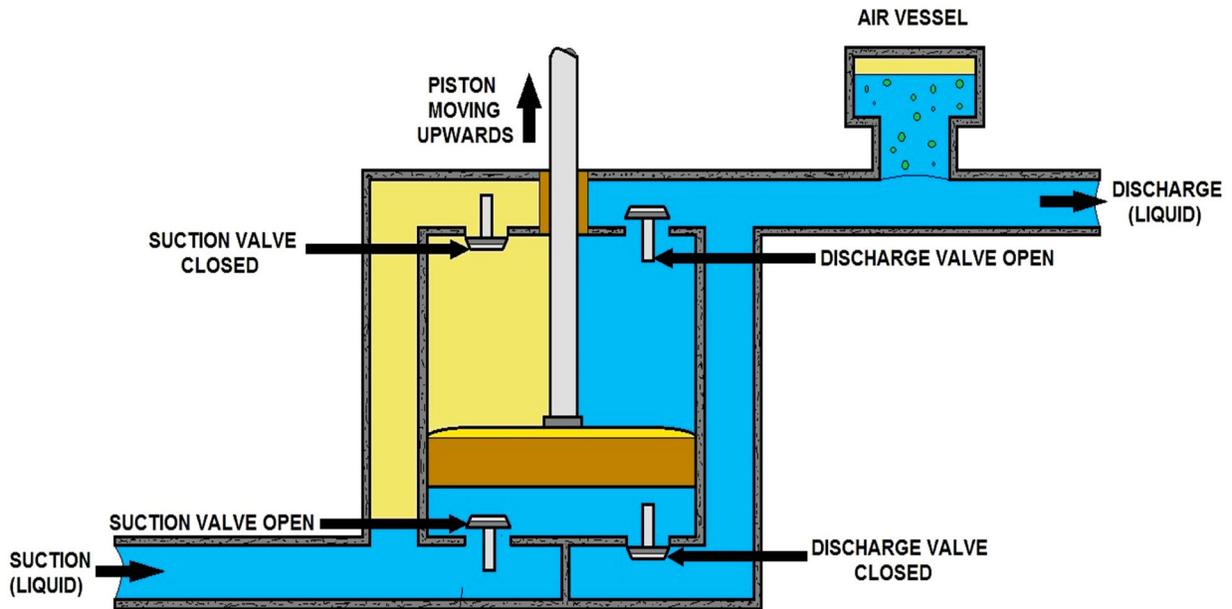
The **Bellows** is a very old device, requiring no accurate machining. The single valve is in one or both sides of the expandable chamber. Another valve can be placed at the nozzle if required. The valve can be a piece of soft leather held close to holes in the chamber.

The **bicycle pump** uses the valve on the valve stem of the tire or inner tube to hold pressure in the tire. The piston, which is attached to the discharge tube, has a flexible seal that seals when the cylinder is moved to compress the air, but allows air to pass when the movement is reversed. Diaphragm and vane pumps are not shown, but they act the same way by varying the volume of a chamber, and directing the flow with check valves.

# Positive Displacement Pump Examples



**PISTON TYPE –POSITIVE DISPLACEMENT PUMP**

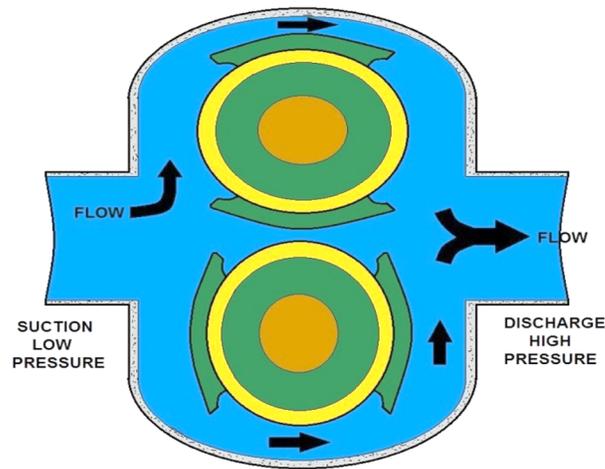


**POSITIVE DISPLACEMENT PUMP  
RECIPROCATING PISTON TYPE**

## Positive Displacement Pumps

A positive displacement pump has an expanding cavity on the suction side of the pump and a decreasing cavity on the discharge side. Liquid is allowed to flow into the pump as the cavity on the suction side expands and the liquid is forced out of the discharge as the cavity collapses. This principle applies to all types of positive displacement pumps whether the pump is a rotary lobe, gear within a gear, piston, diaphragm, screw, progressing cavity, etc.

A positive displacement pump, unlike a centrifugal pump, will produce the same flow at a given RPM no matter what the discharge pressure is. A positive displacement pump cannot be operated against a closed valve on the discharge side of the pump, i.e. it does not have a shut-off head like a centrifugal pump does. If a positive displacement pump is allowed to operate against a closed discharge valve, it will continue to produce flow that will increase the pressure in the discharge line until either the line bursts or the pump is severely damaged or both.



**POSITIVE DISPLACEMENT PUMP WITH ROTATING LOBES**

### Types of Positive Displacement Pumps

Single Rotor	Multiple Rotor
Vane	Gear
Piston	Lobe
Flexible Member	Circumferential Piston
Single Screw	Multiple Screw

**There are many other types of positive displacement pumps. We will look at:**

- Plunger pumps
- Diaphragm pumps
- Progressing cavity pumps, and
- Screw pumps

## Single Rotator Positive Displacement Pump

Component	Description
Vane	The vane(s) may be blades, buckets, rollers, or slippers that cooperate with a dam to draw fluid into and out of the pump chamber.
Piston	Fluid is drawn in and out of the pump chamber by a piston(s) reciprocating within a cylinder(s) and operating port valves.
Flexible Member	Pumping and sealing depends on the elasticity of a flexible member(s) that may be a tube, vane, or a liner.
Single Screw	Fluid is carried between rotor screw threads as they mesh with internal threads on the stator.

## Multiple Rotator

Component	Description
Gear	Fluid is carried between gear teeth and is expelled by the meshing of the gears that cooperate to provide continuous sealing between the pump inlet and outlet.
Lobe	Fluid is carried between rotor lobes that cooperate to provide continuous sealing between the pump inlet and outlet.
Circumferential piston	Fluid is carried in spaces between piston surfaces not requiring contacts between rotor surfaces.
Multiple Screw	Fluid is carried between rotor screw threads as they mesh.

## Plunger Pump

The plunger pump is a positive displacement pump that uses a plunger or piston to force liquid from the suction side to the discharge side of the pump. It is used for heavy sludge. The movement of the plunger or piston inside the pump creates pressure inside the pump, so you have to be careful that this kind of pump is never operated against any closed discharge valve. All discharge valves must be open before the pump is started, to prevent any fast build-up of pressure that could damage the pump.

## Diaphragm Pumps

In this type of pump, a diaphragm provides the mechanical action used to force liquid from the suction to the discharge side of the pump. The advantage the diaphragm has over the plunger is that the diaphragm pump does not come in contact with moving metal. This can be important when pumping abrasive or corrosive materials.

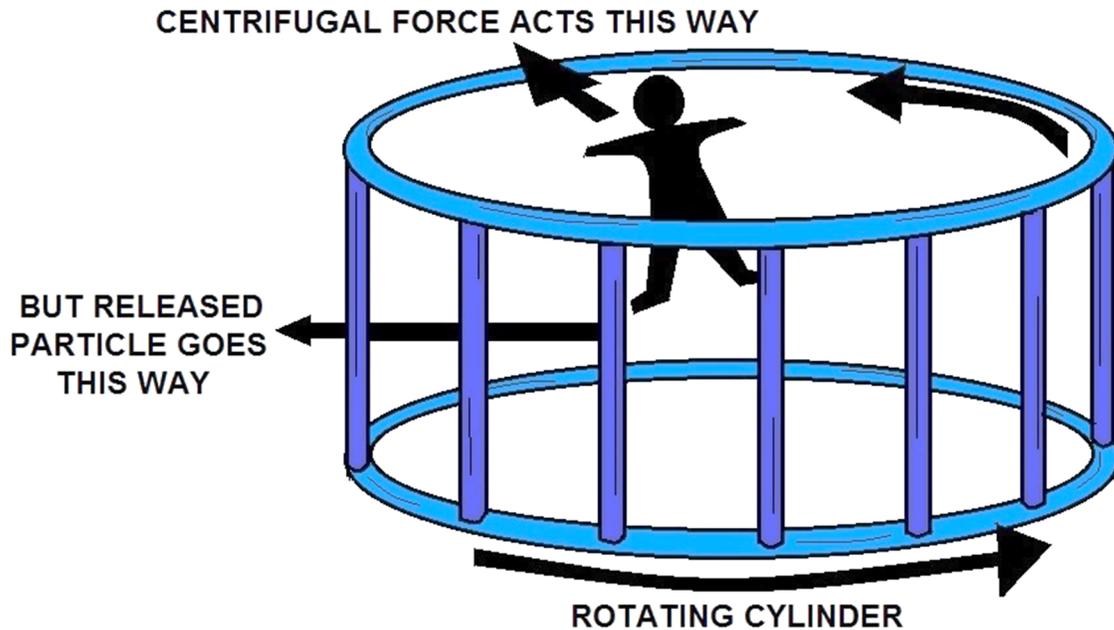
### There are three main types of diaphragm pumps available:

1. Diaphragm sludge pump
2. Chemical metering or proportional pump
3. Air-powered double-diaphragm pump

## Basic Centrifugal Pump

The water pump commonly found in our systems is centrifugal pumps. These pumps work by spinning water around in a circle inside a cylindrical pump housing. The pump makes the water spin by pushing it with an impeller. The blades of this impeller project outward from an axle like the arms of a turnstile and, as the impeller spins, the water spins with it. As the water spins, the pressure near the outer edge of the pump housing becomes much higher than near the center of the impeller.

*There are many ways to understand this rise in pressure, and here are two:*



### CENTRIFUGAL WATER EFFECT IN ACTION DIAGRAM

First, you can view the water between the impeller blades as an object traveling in a circle. Objects do not naturally travel in a circle--they need an inward force to cause them to accelerate inward as they spin. Without such an inward force, an object will travel in a straight line and will not complete the circle. In a centrifugal pump, that inward force is provided by high-pressure water near the outer edge of the pump housing.

The water at the edge of the pump pushes inward on the water between the impeller blades and makes it possible for that water to travel in a circle. The water pressure at the edge of the turning impeller rises until it is able to keep water circling with the impeller blades.

You can also view the water as an incompressible fluid, one that obeys Bernoulli's equation in the appropriate contexts. As water drifts outward between the impeller blades of the pump, it must move faster and faster because its circular path is getting larger and larger. The impeller blades cause the water to move faster and faster. By the time the water has reached the outer edge of the impeller, it is moving quite fast. However, when the water leaves the impeller and arrives at the outer edge of the cylindrical pump housing, it slows down because of the loss of energy.

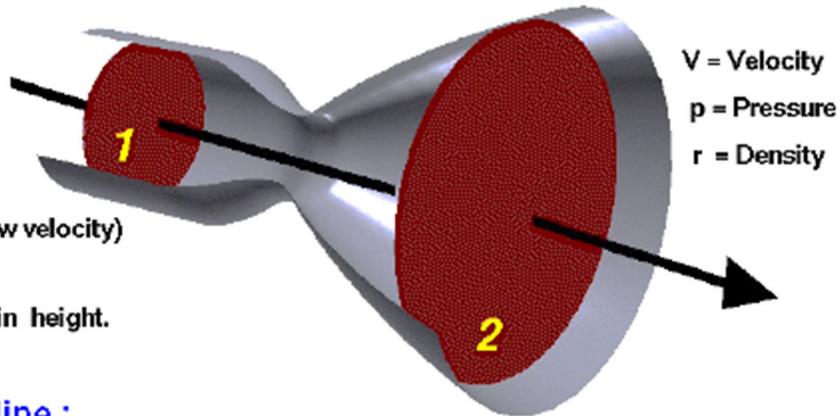


# Bernoulli's Equation

Glenn  
Research  
Center

## Restrictions :

- Inviscid
- Steady
- Incompressible (low velocity)
- No heat addition.
- Negligible change in height.



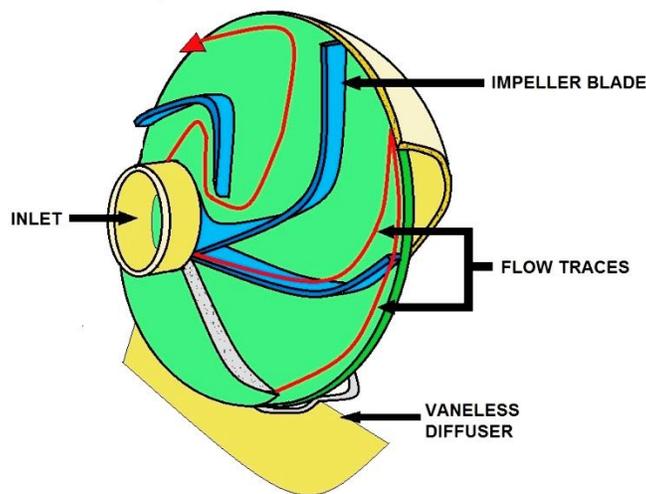
## Along a streamline :

static pressure + dynamic pressure = total pressure

$$p_s + \frac{rV^2}{2} = p_t$$

$$\left( p_s + \frac{rV^2}{2} \right)_1 = \left( p_s + \frac{rV^2}{2} \right)_2$$

Here is where Bernoulli's equation figures in. As the water slows down and its kinetic energy decreases, that water's pressure potential energy increases (*to conserve energy*). Thus, the slowing is accompanied by a pressure rise. That is why the water pressure at the outer edge of the pump housing is higher than the water pressure near the center of the impeller. When water is actively flowing through the pump, arriving through a hole near the center of the impeller and leaving through a hole near the outer edge of the pump housing, the pressure rise between center and edge of the pump is not as large.



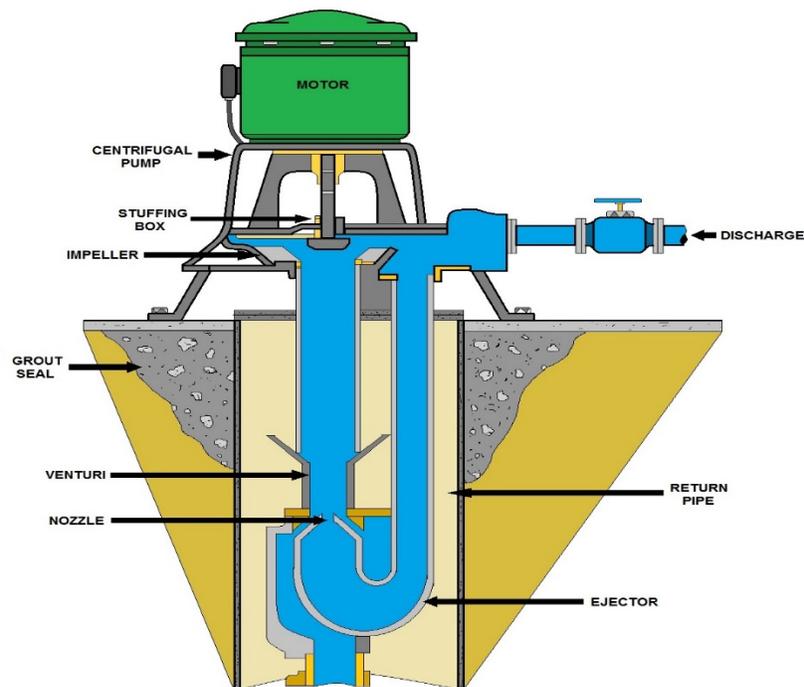
COMMON PUMP IMPELLER

## Three Types of Water Pumps

The most common type of water pumps used for municipal and domestic water supplies are *dynamic pumps* or also referred to as *variable displacement pumps*. A variable displacement pump will produce at different rates relative to the amount of pressure or lift the pump is working against. *Centrifugal* pumps are variable displacement pumps that are by far used the most. The water production well industry almost exclusively uses *Turbine* pumps, which are a type of centrifugal pump.

### Turbine Pump

The turbine pump utilizes *impellers* enclosed in single or multiple *bowls or stages* to lift water by *centrifugal force*. The impellers may be of either a *semi-open or closed type*. Impellers are rotated by the *pump motor*, which provides the horsepower needed to overcome the pumping head. A more thorough discussion of how these and other pumps work is presented later in this section. The size and number of stages, horsepower of the motor and pumping head are the key components relating to the pump's lifting capacity.



VERTICAL TURBINE INSTALLATION DIAGRAM

### Vertical Turbine Pump

*Vertical turbine pumps* are commonly used in groundwater wells but also in many other applications. These pumps are driven by a shaft rotated by a motor that is usually on the surface. The shaft turns the impellers within the pump housing while the water moves up the column.

This type of pumping system is also called a *line-shaft turbine*. The rotating shaft in a line shaft turbine is actually housed within the column pipe that delivers the water to the surface. The size of the column, impeller, and bowls are selected based on the desired pumping rate and lift requirements.

Column pipe sections can be threaded or coupled together while the drive shaft is coupled and suspended within the column by *spider bearings*. The spider bearings provide both a seal at the column pipe joints and keep the shaft aligned within the column. The water passing through the column pipe serves as the lubricant for the bearings. Some vertical turbines are lubricated by oil rather than water. These pumps are essentially the same as water lubricated units; only the drive shaft is enclosed within an *oil tube*.

Food grade oil is supplied to the tube through a gravity feed system during operation. The oil tube is suspended within the column by *spider flanges*, while the line shaft is supported within the oil tube by *brass or redwood bearings*. A continuous supply of oil lubricates the drive shaft as it proceeds downward through the oil tube.

A small hole located at the top of the pump bow unit allows excess oil to enter the well. This results in the formation of an oil film on the water surface within oil-lubricated wells. Careful operation of oil lubricated turbines is needed to ensure that the pumping levels do not drop enough to allow oil to enter the pump. Both water and oil lubricated turbine pump units can be driven by electric or fuel powered motors.

Most installations use an electric motor that is connected to the drive shaft by a keyway and nut. However, where electricity is not readily available, fuel powered engines may be connected to the drive shaft by a right angle drive gear. Also, both oil and water lubricated systems will have a strainer attached to the intake to prevent sediment from entering the pump.

When the line shaft turbine is turned off, water will flow back down the column, turning the impellers in a reverse direction. A pump and shaft can easily be broken if the motor were to turn on during this process. This is why a *time delay* or *ratchet* assembly is often installed on these motors to either prevent the motor from turning on before reverse rotation stops or simply not allow it to reverse at all.

### **Three Main Types of Diaphragm Pumps**

In the first type, the diaphragm is sealed with one side in the fluid to be pumped, and the other in air or hydraulic fluid. The diaphragm is flexed, causing the volume of the pump chamber to increase and decrease. A pair of non-return check valves prevents reverse flow of the fluid.

### **Volumetric Positive Displacement**

The second type of diaphragm pump also works with volumetric positive displacement, but differs in that the prime mover of the diaphragm is neither oil nor air; but is electro-mechanical, working through a crank or geared motor drive. This method flexes the diaphragm through simple mechanical action, and one side of the diaphragm is open to air. The third type of diaphragm pump has one or more unsealed diaphragms with the fluid to be pumped on both sides.

The diaphragm(s) again are flexed, causing the volume to change. When the volume of a chamber of either type of pump is increased (the diaphragm moving up), the pressure decreases, and fluid is drawn into the chamber.

When the chamber pressure later increases from decreased volume (the diaphragm moving down), the fluid previously drawn in is forced out. Finally, the diaphragm moving up once again draws fluid into the chamber, completing the cycle. This action is similar to that of the cylinder in an internal combustion engine.

## **Cavitation**

Cavitation is defined as the phenomenon of formation of vapor bubbles of a flowing liquid in a region where the pressure of the liquid falls below its vapor pressure. Cavitation is usually divided into two classes of behavior: inertial (or transient) cavitation and non-inertial cavitation. Inertial cavitation is the process where a void or bubble in a liquid rapidly collapses, producing a shock wave.

Such cavitation often occurs in pumps, propellers, impellers, and in the vascular tissues of plants. Non-inertial cavitation is the process in which a bubble in a fluid is forced to oscillate in size or shape due to some form of energy input, such as an acoustic field. Such cavitation is often employed in ultrasonic cleaning baths and can also be observed in pumps, propellers etc.

Cavitation is, in many cases, an undesirable occurrence. In devices such as propellers and pumps, cavitation causes a great deal of noise, damage to components, vibrations, and a loss of efficiency. When the cavitation bubbles collapse, they force liquid energy into very small volumes, thereby creating spots of high temperature and emitting shock waves, the latter of which are the source of a rattling noise.

The noise created by cavitation is a particular problem for military submarines, as it increases the chances of being detected by passive sonar. Although the collapse of a cavity is a relatively low-energy event, highly localized collapses can erode metals, such as steel, over time. The pitting caused by the collapse of cavities produces great wear on components and can dramatically shorten a propeller's or pump's lifetime. After a surface is initially affected by cavitation, it tends to erode at an accelerating pace.

The cavitation pits increase the turbulence of the fluid flow and create crevasses that act as nucleation sites for additional cavitation bubbles. The pits also increase the component's surface area and leave behind residual stresses. This makes the surface more prone to stress corrosion.

## **Impeller**

An impeller is a rotating component of a centrifugal pump, usually made of iron, steel, aluminum or plastic, which transfers energy from the motor that drives the pump to the fluid being pumped by accelerating the fluid outwards from the center of rotation.

The velocity achieved by the impeller transfers into pressure when the outward movement of the fluid is confined by the pump casing. Impellers are usually short cylinders with an open inlet (called an eye) to accept incoming fluid, vanes to push the fluid radially, and a splined center to accept a driveshaft.

<b>Factor</b>	<b>Dynamic (Centrifugal) Pump</b>	<b>Positive Displacement Pump</b>
Mechanics	Impellers pass on velocity from the motor to the liquid which helps move the fluid to the discharge port (produces flow by creating pressure).	Traps confined amounts of liquid and forces it from the suction to the discharge port (produces pressure by creating flow).
Performance	Flow rate varies with a change in pressure.	Flow rate remains constant with a change in pressure.
Viscosity	Flow rate rapidly decreases with increasing viscosity, even any moderate thickness, due to frictional losses inside the pump.	Due to the internal clearances high viscosities are handled easily and flow rate increases with increasing viscosity.
Efficiency	Efficiency peaks at a specific pressure; any variations decrease efficiency dramatically. Does not operate well when run off the middle of the curve; can cause damage and cavitation.	Efficiency is less affected by pressure, but if anything tends to increase as pressure increases. Can be run at any point on their curve without damage or efficiency loss.
Suction Lift	Standard models cannot create suction lift, although self-priming designs are available and manometric suction lift is possible through a non-return valve on the suction line.	Create a vacuum on the inlet side, making them capable of creating suction lift.
Shearing	High-speed motor leads to shearing of liquids. Not good for shear sensitive mediums.	Low internal velocity means little shear is applied to the pumped medium. Ideal for shear sensitive fluids.

## Submersible Pump Sub-Section

### Introduction

Submersible pumps are in essence very similar to turbine pumps. They both use impellers rotated by a shaft within the bowls to pump water. However, the pump portion is directly connected to the motor.

The pump shaft has a keyway in which the splined motor end shaft inserts. The water-tight motor is bolted to the pump housing. The pump's intake is located between the motor and the pump and is normally screened to prevent sediment from entering the pump and damaging the impellers.

The efficient cooling of submersible motors is very important, so these types of pumps are often installed such that flow through the well screen can occur upwards past the motor and into the intake. If the motor end is inserted below the screened interval or below all productive portions of the aquifer, it will not be cooled, resulting in premature motor failure.

Some pumps may have *pump shrouds* installed on them to force all the water to move past the motor to prevent overheating.

The shroud is a piece of pipe that attaches to the pump housing with an open end below the motor. As with turbine pumps, the size of the bowls and impellers, number of stages, and horsepower of the motor are adjusted to achieve the desired production rate within the limitations of the pumping head.



Insertion of motor spline into the pump keyway.

Left- Cut away of a small turbine pump without the motor.

## Key Pump Words

**NPSH:** Net positive suction head - related to how much suction lift a pump can achieve by creating a partial vacuum. Atmospheric pressure then pushes liquid into the pump. A method of calculating if the pump will work or not in a given application.

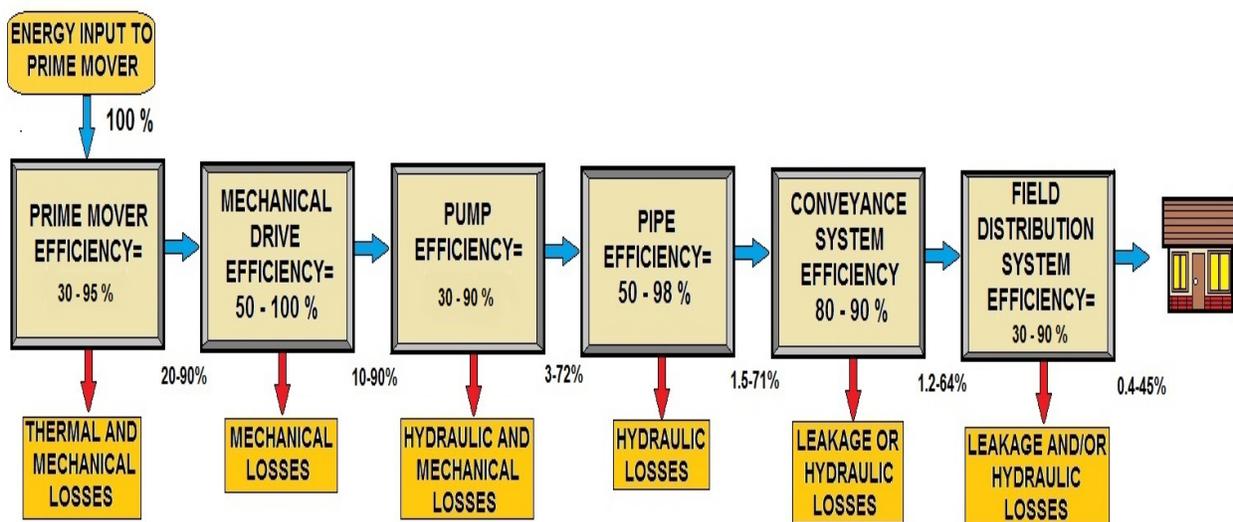
**S.G.:** Specific gravity. The weight of liquid in comparison to water at approx. 20 degrees C, when it has a SG = 1.

**Specific Speed:** A number which is the function of pump flow, head, efficiency etc. Not used in day to day pump selection, but very useful, as pumps with similar specific speed will have similar shaped curves, similar efficiency / NPSH / solids handling characteristics.

**Vapor Pressure:** If the vapor pressure of a liquid is greater than the surrounding air pressure, the liquid will boil.

**Viscosity:** A measure of a liquid's resistance to flow. i.e.: how thick it is. The viscosity determines the type of pump used, the speed it can run at, and with gear pumps, the internal clearances required.

**Friction Loss:** The amount of pressure / head required to 'force' liquid through pipe and fittings.



SYSTEM ENERGY EFFICIENCY LOSSES DIAGRAM

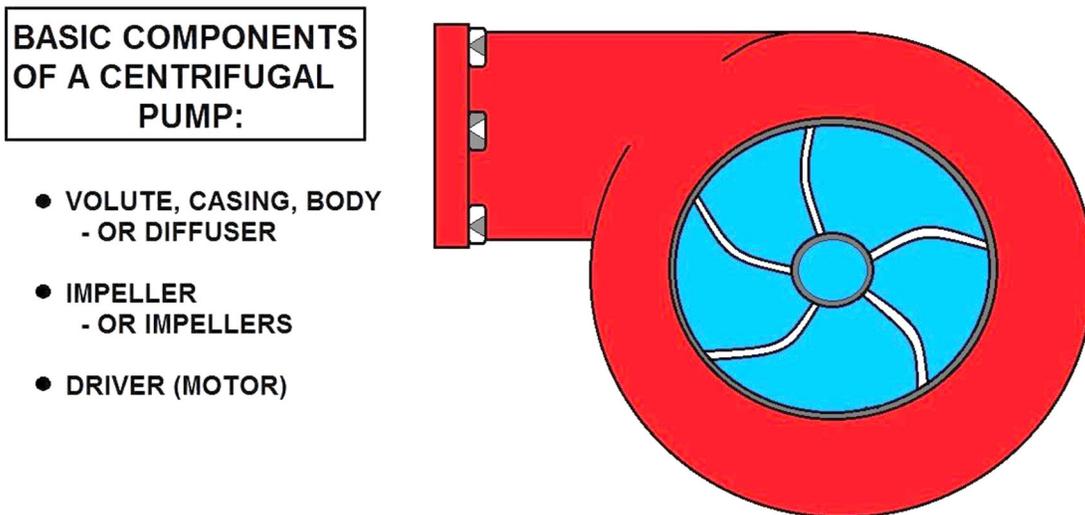
## Centrifugal Pump Sub-Section

By definition, a centrifugal pump is a machine, a machine that imparts energy to a fluid. This energy infusion can cause a liquid to flow, rise to a higher level, or both.

The centrifugal pump is an extremely simple machine. It is a member of a family known as rotary machines and consists of two basic parts: 1) the rotary element or impeller and 2) the stationary element or casing (volute). The figure at the bottom of the page is a cross section of a centrifugal pump and shows the two basic parts.

In operation, a centrifugal pump “slings” liquid out of the impeller via centrifugal force. One fact that must always be remembered: A pump does not create pressure, it only provides flow. Pressure is just an indication of the amount of resistance to flow.

Centrifugal pumps may be classified in several ways. For example, they may be either SINGLE STAGE or MULTI-STAGE. A single-stage pump has only one impeller. A multi-stage pump has two or more impellers housed together in one casing.



### BASICS OF A CENTRIFUGAL PUMP

As a rule, each impeller acts separately, discharging to the suction of the next stage impeller. This arrangement is called series staging. Centrifugal pumps are also classified as horizontal or vertical, depending upon the position of the pump shaft.

#### Impellers

The impellers used on centrifugal pumps may be classified as *single suction* or *double suction*. The single-suction impeller allows liquid to enter the eye from one side only. The double-suction impeller allows liquid to enter the eye from two directions.

Impellers are also classified as *closed* or *open*. Closed impellers have side walls that extend from the eye to the outer edge of the vane tips. Open impellers do not have these side walls. Some small pumps with single-suction impellers have only a casing wearing ring and no impeller ring. In this type of pump, the casing wearing ring is fitted into the end plate.

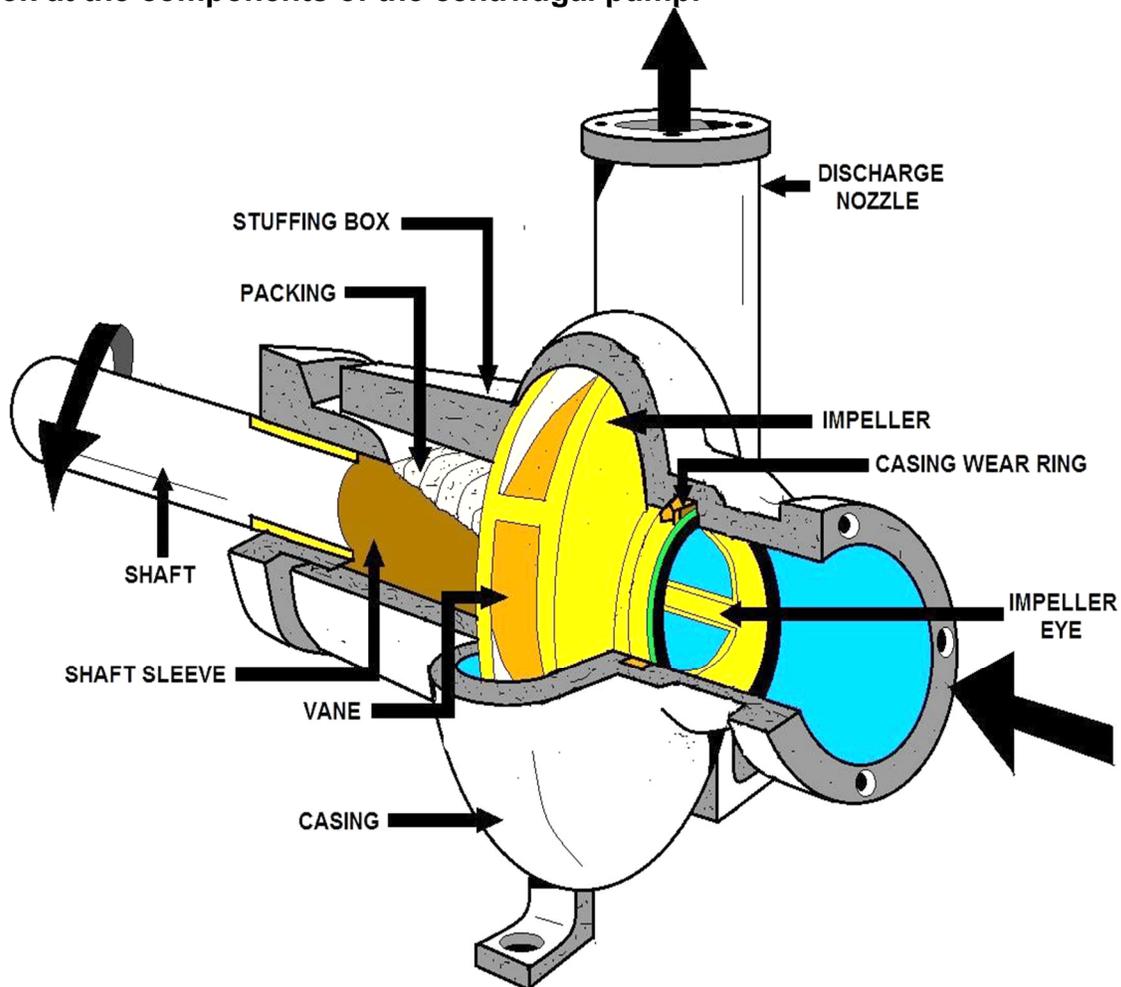
Recirculation lines are installed on some centrifugal pumps to prevent the pumps from overheating and becoming vapor bound, in case the discharge is entirely shut off or the flow of fluid is stopped for extended periods.

Seal piping is installed to cool the shaft and the packing, to lubricate the packing, and to seal the rotating joint between the shaft and the packing against air leakage. A lantern ring spacer is inserted between the rings of the packing in the stuffing box.

Seal piping leads the liquid from the discharge side of the pump to the annular space formed by the lantern ring. The web of the ring is perforated so that the water can flow in either direction along the shaft (between the shaft and the packing).

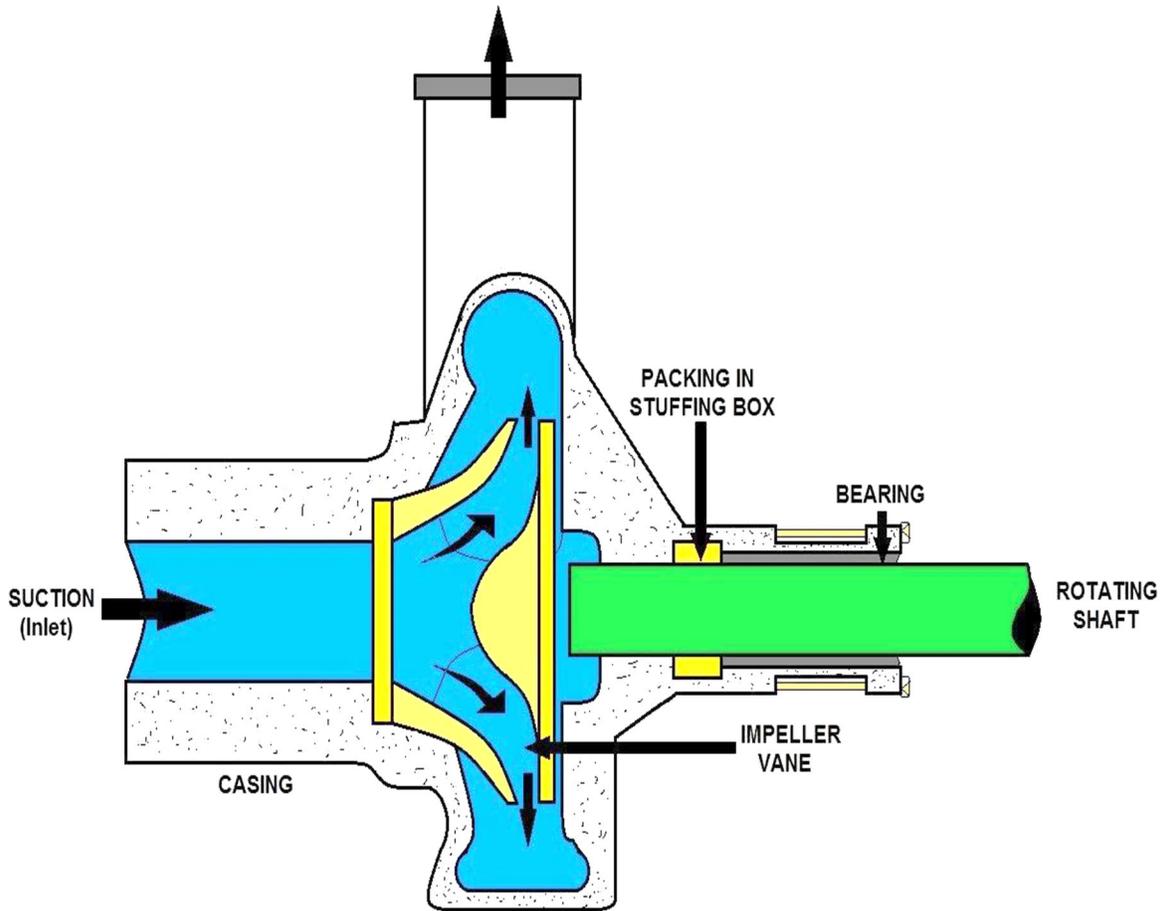
Water flinger rings are fitted on the shaft between the packing gland and the pump bearing housing. These flingers prevent water in the stuffing box from flowing along the shaft and entering the bearing housing.

**Look at the components of the centrifugal pump.**

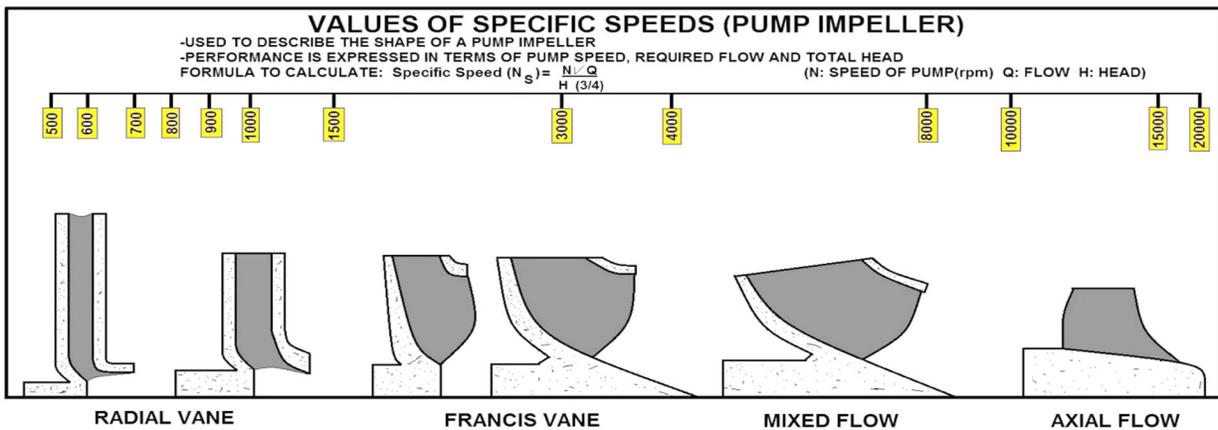


**CENTRIFUGAL PUMP BREAKDOWN DIAGRAM #1**

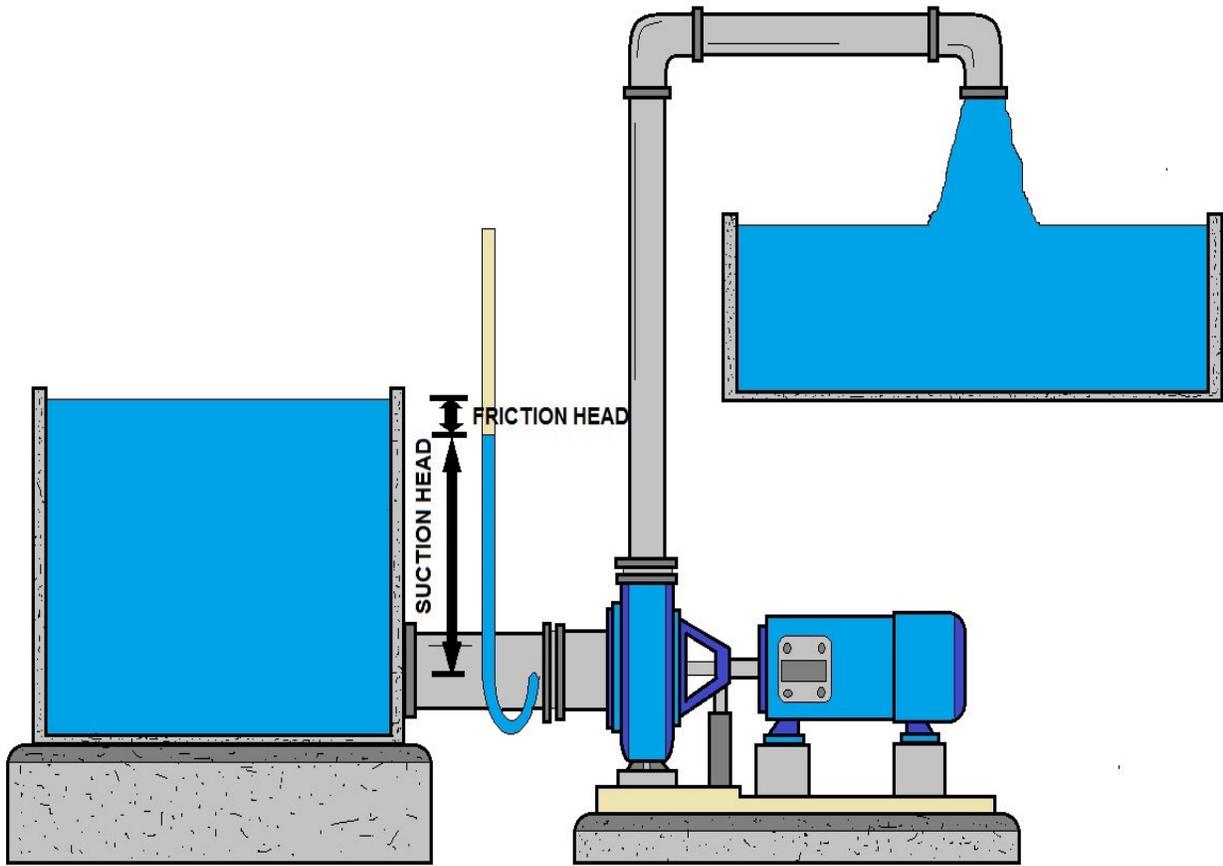
As the impeller rotates, it sucks the liquid into the center of the pump and throws it out under pressure through the outlet. The casing that houses the impeller is referred to as the volute, the impeller fits on the shaft inside. The volute has an inlet and outlet that carries the water as shown below.



**CENTRIFUGAL PUMP BREAKDOWN DIAGRAM #2**



**IMPELLER SPECIFIC SPEEDS - IMPELLER VANE CROSS SECTION**



**SUCTION HEAD (Suction Lift)**

## Vertical Turbine Pump Sub-Section

Vertical turbine pumps are available in deep well, shallow well, or canned configurations. VHS or VSS motors will be provided to fulfill environmental requirements. Submersible motors are also available. These pumps are also suitable industrial, municipal, commercial and agricultural applications.

Deep well turbine pumps are adapted for use in cased wells or where the water surface is below the practical limits of a centrifugal pump. Turbine pumps are also used with surface water systems. Since the intake for the turbine pump is continuously under water, priming is not a concern. Turbine pump efficiencies are comparable to, or greater than most centrifugal pumps. They are usually more expensive than centrifugal pumps and more difficult to inspect and repair. The turbine pump has three main parts: (1) the head assembly, (2) the shaft and column assembly and (3) the pump bowl assembly. The head is normally cast iron and designed to be installed on a foundation. It supports the column, shaft, and bowl assemblies, and provides a discharge for the water. It also will support an electric motor, a right angle gear drive or a belt drive.

### Bowl Assembly

The bowl assembly is the heart of the vertical turbine pump. The impeller and diffuser type casing is designed to deliver the head and capacity that the system requires in the most efficient way. Vertical turbine pumps can be multi-staged, allowing maximum flexibility both in the initial pump selection and in the event that future system modifications require a change in the pump rating. The submerged impellers allow the pump to be started without priming. The discharge head changes the direction of flow from vertical to horizontal, and couples the pump to the system piping, in addition to supporting and aligning the driver.

### Drivers

A variety of drivers may be used; however, electric motors are most common. For the purposes of this manual, all types of drivers can be grouped into two categories:

1. Hollow shaft drivers where the pump shaft extends through a tube in the center of the rotor and is connected to the driver by a clutch assembly at the top of the driver.
2. Solid shaft drivers where the rotor shaft is solid and projects below the driver mounting base. This type of driver requires an adjustable flanged coupling for connecting to the pump.

### Discharge Head Assembly

The discharge head supports the driver and bowl assembly as well as supplying a discharge connection (the “NUF” type discharge connection which will be located on one of the column pipe sections below the discharge head). A shaft sealing arrangement is located in the discharge head to seal the shaft where it leaves the liquid chamber. The shaft seal will usually be either a mechanical seal assembly or stuffing box.

### Column Assembly

The shaft and column assembly provides a connection between the head and pump bowls. The line shaft transfers the power from the motor to the impellers and the column carries the water to the surface. The line shaft on a turbine pump may be either water lubricated or oil lubricated.

The oil-lubricated pump has an enclosed shaft into which oil drips, lubricating the bearings. The water-lubricated pump has an open shaft. The bearings are lubricated by the pumped water. If there is a possibility of fine sand being pumped, select the oil lubricated pump because it will keep the sand out of the bearings. If the water is for domestic or livestock use, it must be free of oil and a water-lubricated pump must be used.

Line shaft bearings are commonly placed on 10-foot centers for water-lubricated pumps operating at speeds under 2,200 RPM and at 5-foot centers for pumps operating at higher speeds. Oil-lubricated bearings are commonly placed on 5-foot centers.

A pump bowl encloses the impeller. Due to its limited diameter, each impeller develops a relatively low head. In most deep well turbine installations, several bowls are stacked in series one above the other. This is called staging. A four-stage bowl assembly contains four impellers, all attached to a common shaft and will operate at four times the discharge head of a single-stage pump.

Impellers used in turbine pumps may be either semi-open or enclosed. The vanes on semi-open impellers are open on the bottom and they rotate with a close tolerance to the bottom of the pump bowl. The tolerance is critical and must be adjusted when the pump is new.

During the initial break-in period the line shaft couplings will tighten, therefore, after about 100 hours of operation, the impeller adjustments should be checked. After break-in, the tolerance must be checked and adjusted every three to five years or more often if pumping sand.

**Column assembly is of two basic types, either of which may be used:**

1. Open line shaft construction utilizes the fluid being pumped to lubricate the line shaft bearings.
2. Enclosed line shaft construction has an enclosing tube around the line shaft and utilizes oil, grease or injected liquid (usually clean water) to lubricate the line shaft bearings.

**Column assembly will consist of:**

- 1) column pipe, which connects the bowl assembly to the discharge head,
- 2) shaft, connecting the bowl shaft to the driver and,
- 3) may contain bearings, if required, for the particular unit. Column pipe may be either threaded or flanged.

**Note: Some units will not require column assembly, having the bowl assembly connected directly to the discharge head instead.**

**Bowl Assemblies**

The bowl consists of:

- 1) impellers rigidly mounted on the bowl shaft, which rotate and impart energy to the fluid,
- 2) bowls to contain the increased pressure and direct the fluid,
- 3) suction bell or case which directs the fluid into the first impeller, and
- 4) bearings located in the suction bell (or case) and in each bowl.

Both types of impellers may cause inefficient pump operation if they are not properly adjusted. Mechanical damage will result if the semi-open impellers are set too low and the vanes rub against the bottom of the bowls. The adjustment of enclosed impellers is not as critical; however, they must still be checked and adjusted.

Impeller adjustments are made by tightening or loosening a nut on the top of the head assembly. Impeller adjustments are normally made by lowering the impellers to the bottom of the bowls and adjusting them upward.

The amount of upward adjustment is determined by how much the line shaft will stretch during pumping. The adjustment must be made based on the lowest possible pumping level in the well. The proper adjustment procedure is often provided by the pump manufacturer.

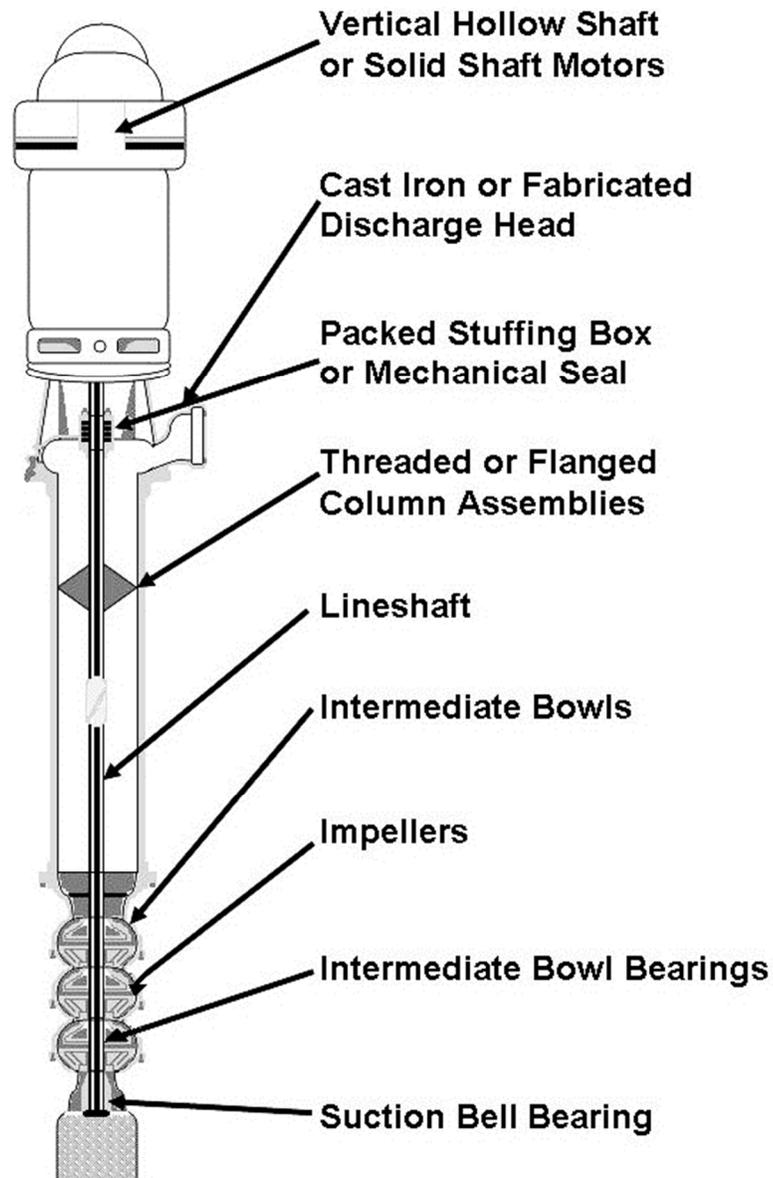
## Vertical Turbine Pump



Large Diameter Submersible Pump, Motor, and Column Pipe

Larger check valve installed on submersible pump to prevent water hammer (notice motor shaft splines.)

## Common Elements of Vertical Turbines



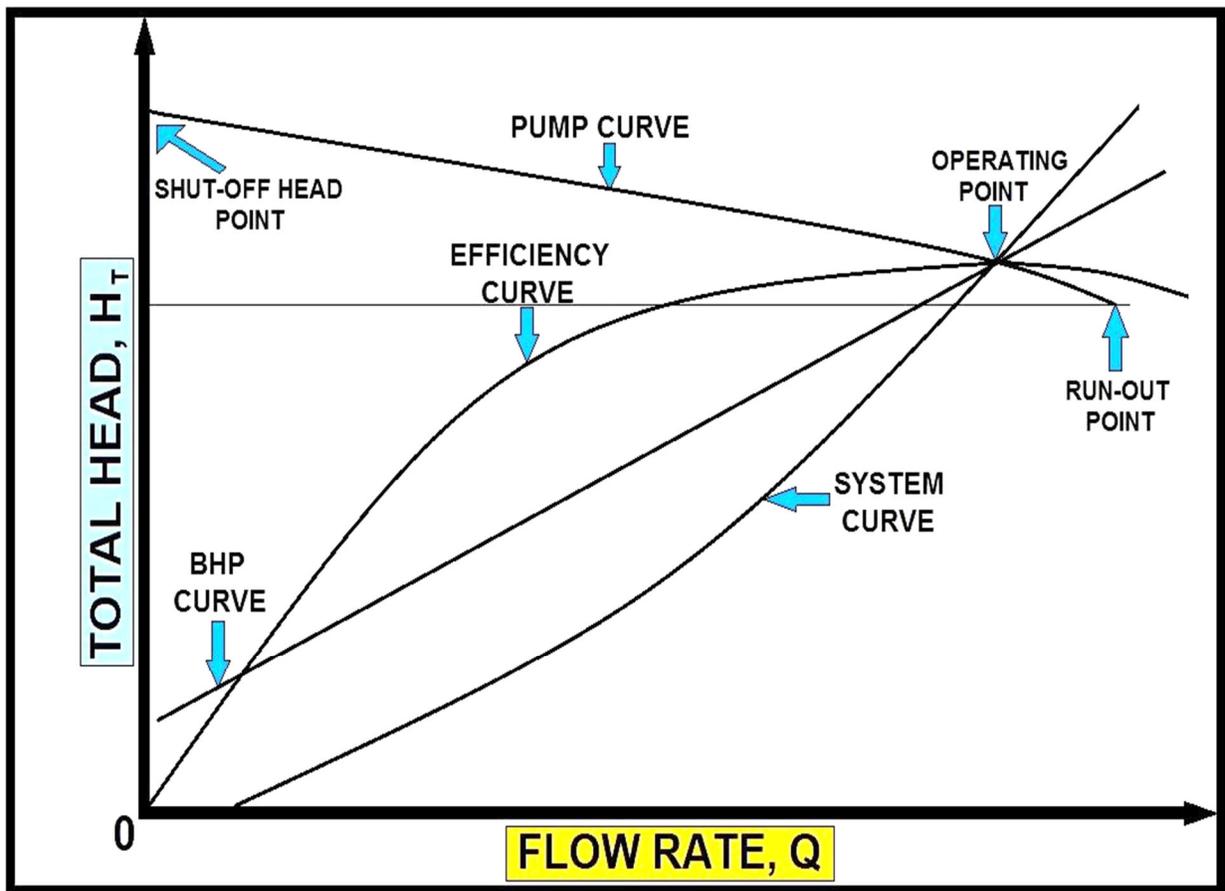
Below - A Small Closed Pump Impeller



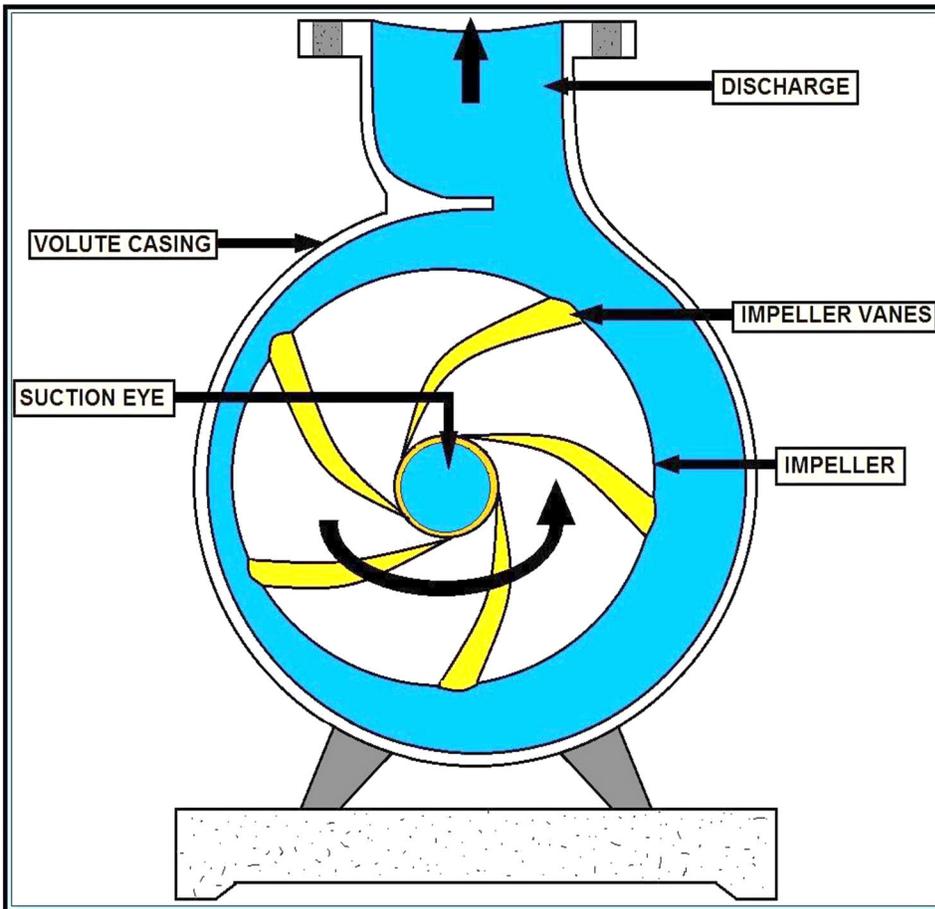
## Pump Performance and Curves

Let's look at the big picture. Before you make that purchase of the pump and motor you need to know the basics such as:

- Total dynamic head, the travel distance
- Capacity, how much water you need to provide
- Efficiency, help determine the impeller size
- HP, how many squirrels you need
- RPM, how fast the squirrels run



**PUMP PERFORMANCE CURVE (CENTRIFUGAL PUMP)**



- LIQUID FORCED INTO IMPELLER
- VANES PASS KINETIC ENERGY TO LIQUID BEING PUMPED: LIQUID IS ROTATED AND LEAVES THE IMPELLER
- VOLUTE CASING CONVERTS THE KINETIC ENERGY INTO PRESSURE ENERGY

## HOW A CENTRIFUGAL PUMP WORKS

## Motor and Pump Calculations

The centrifugal pump pumps the difference between the suction and the discharge heads. There are three kinds of discharge head:

- **Static head.** The height we are pumping to or the height to the discharge piping outlet that is filling the tank from the top. Note: that if you are filling the tank from the bottom, the static head will be constantly changing.
- **Pressure head.** If we are pumping to a pressurized vessel (like a boiler) we must convert the pressure units (psi. or Kg.) to head units (feet or meters).
- **System or dynamic head.** Caused by friction in the pipes, fittings, and system components. We get this number by making the calculations from published charts.

### Suction head is measured the same way.

- If the liquid level is above the pump center line, that level is a positive suction head. If the pump is lifting a liquid level from below its center line, it is a negative suction head.
- If the pump is pumping liquid from a pressurized vessel, you must convert this pressure to a positive suction head. A vacuum in the tank would be converted to a negative suction head.
- Friction in the pipes, fittings, and associated hardware is a negative suction head.
- Negative suction heads are added to the pump discharge head, positive suction heads are subtracted from the pump discharge head.

**Total Dynamic Head (TDH)** is the total height that a fluid is to be pumped, taking into account friction losses in the pipe.

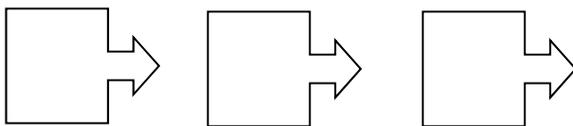
$$\text{TDH} = \text{Static Lift} + \text{Static Height} + \text{Friction Loss}$$

where:

*Static Lift* is the height the water will rise before arriving at the pump (also known as the 'suction head').

*Static Height* is the maximum height reached by the pipe after the pump (also known as the 'discharge head').

*Friction Loss* is the head equivalent to the energy losses due to viscose drag of fluid flowing in the pipe (both on the suction and discharge sides of the pump). It is calculated via a formula or a chart, taking into account the pipe diameter and roughness and the fluid flow rate, density, and viscosity.



**Motor hp**

**Brake hp**

**Water hp**

## Horsepower

Work involves the operation of force over a specific distance. The rate of doing work is called power.

The rate in which a horse could work was determined to be about 550 ft-lbs./sec or 33,000 ft-lbs./min.

$$1 \text{ hp} = 33,000 \text{ ft-lbs./min}$$

## Motor Horsepower (mhp)

$$1 \text{ hp} = 746 \text{ watts or } .746 \text{ Kilowatts}$$

MHP refers to the horsepower supplied in the form of electrical current. The efficiency of most motors range from 80-95%. (Manufactures will list efficiency %)

## Brake Horsepower (bhp)

$$\text{Brake hp} = \frac{\text{Water hp}}{\text{Pump Efficiency}}$$

BHP refers to the horsepower supplied to the pump from the motor. As the power moves through the pump, additional horsepower is lost, resulting from slippage and friction of the shaft and other factors.

## Water Horsepower

$$\text{Water hp} = \frac{(\text{flow gpm})(\text{total hd})}{3960}$$

Water horsepower refers to the actual horse power available to pump the water.

## Horsepower and Specific Gravity

The specific gravity of a liquid is an indication of its density or weight compared to water. The difference in specific gravity, include it when calculating ft-lbs./min pumping requirements.

$$\frac{(\text{ft})(\text{lbs./min})(\text{sp.gr.})}{33,000 \text{ ft-lbs./min/hp}} = \text{whp}$$

## MHP and Kilowatt requirements

$$1 \text{ hp} = 0.746 \text{ kW or } \frac{(\text{hp}) (746 \text{ watts/hp})}{1000 \text{ watts/kW}}$$

## Well Calculations

### 1. Well drawdown

Drawdown ft = Pumping water level, ft - Static water level, ft

### 2. Well yield

Well yield, gpm =  $\frac{\text{Flow, gallons}}{\text{Duration of test, min}}$

### 3. Specific yield

Specific yield, gpm/ft =  $\frac{\text{Well yield, gpm}}{\text{Drawdown, ft}}$

### 4. Deep well turbine pump calculations.

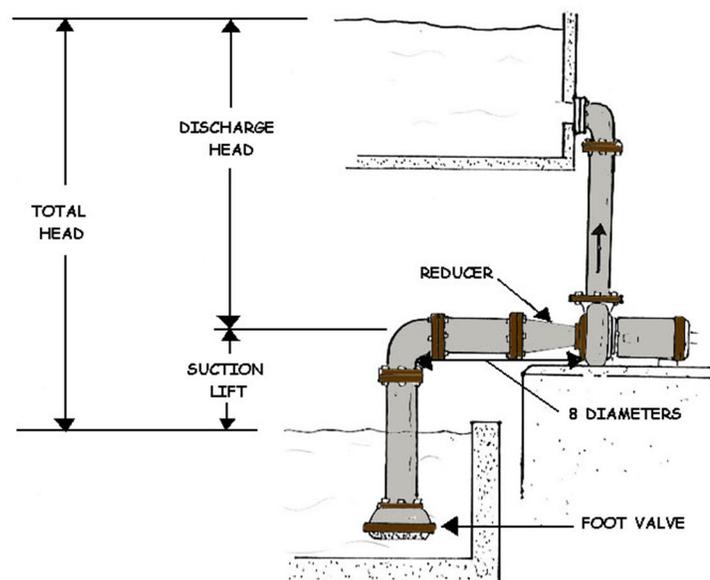
Discharge head, ft = (pressure measured) ( 2.31 ft/psi)

Field head, ft = pumping water + discharge head, ft

Bowl head, ft = field head + column friction

1 psi = 2.31 feet of head

1 foot of head = .433 psi



### **Example 1**

A centrifugal pump is located at an elevation of 722 ft. This pump is used to move water from reservoir **A** to reservoir **B**. The water level in reservoir **A** is 742 ft and the water level in reservoir **B** is 927 ft. Based on these conditions answer the following questions:

- 1. If the pump is not running and pressure gauges are installed on the suction and discharge lines, what pressures would the gauges read?**

**Suction side:**

**Discharge side:**

- 2. How can you tell if this is a suction head condition?**
- 3. Calculate the following head measurements:**

**SSH:**

**SDH:**

**TSH:**

- 4. Convert the pressure gauge readings to feet:**

**6 psi:**

**48 psi:**

**110 psi:**

- 5. Calculate the following head in feet to psi:**

**20 ft:**

**205 ft:**

**185 ft:**

## NPSH - Net Positive Suction Head

A pump creates a partial vacuum and atmospheric pressure forces water into the suction of the pump, and NPSH describes the concept. NPSH(r) is the Net Positive Suction Head Required by the pump, which is read from the pump performance curve. (Think of NPSH(r) as friction loss caused by the entry to the pump suction.)

NPSH (a) is the Net Positive Suction Head Available, which is calculated as follows:

$$\text{NPSH (a)} = p + s - v - f$$

Where:

'p'= atmospheric pressure,

's'= static suction (If liquid is below pump, it is shown as a negative value)

'v'= liquid vapor pressure

'f'= friction loss

NPSH (a) must exceed NPSH(r) to allow pump operation without cavitation. (It is advisable to allow approximately 1 meter difference for most installations.) The other important fact to remember is that water will boil at much less than 100 deg C<sup>o</sup> if the pressure acting on it is less than its vapor pressure, i.e. water at 95 deg C is just hot water at sea level, but at 1500m above sea level it is boiling water and vapor.

The vapor pressure of water at 95 degrees C is 84.53 kPa, there was enough atmospheric pressure at sea level to contain the vapor, but once the atmospheric pressure is dropped at a higher elevation, the vapor is able to escape. This is why vapor pressure is always considered in NPSH calculations when temperatures exceed 30 to 40 degrees C.

## Suction Lift

Suction conditions are some of the most important factors affecting centrifugal pump operation. If they are ignored during the design or installation stages of an application, they will probably come back to haunt you.

A pump cannot pull or "suck" a liquid up its suction pipe because liquids do not exhibit tensile strength. Therefore, they cannot transmit tension or be pulled. When a pump creates a suction, it is simply reducing local pressure by creating a partial vacuum. Atmospheric or some other external pressure acting on the surface of the liquid pushes the liquid up the suction pipe into the pump.

Atmospheric pressure at sea level is called absolute pressure (PSIA) because it is a measurement using absolute zero (a perfect vacuum) as a base. If pressure is measured using atmospheric pressure as a base it is called gauge pressure (PSIG or simply PSI).

Atmospheric pressure, as measured at sea level, is 14.7 PSIA. In feet of head it is:

$$\text{Head} = \text{PSI} \times 2.31 / \text{Specific Gravity}$$

**For Water it is:**

$$\text{Head} = 14.7 \times 2.31 / 1.0 = 34 \text{ Ft}$$

Thus, 34 feet is the theoretical maximum suction lift for a pump pumping cold water at sea level. No pump can attain a suction lift of 34 ft; however, well designed ones can reach 25 ft quite easily.

You will note, from the equation above, that specific gravity can have a major effect on suction lift. For example, the theoretical maximum lift for brine (Specific Gravity = 1.2) at sea level is 28 ft. The realistic maximum is around 20ft. Remember to always factor in specific gravity if the liquid being pumped is anything but clear, cold (68 degrees F) water.

In addition to pump design and suction piping, there are two physical properties of the liquid being pumped that affect suction lift:

**1) Maximum suction lift** is dependent upon the pressure applied to the surface of the liquid at the suction source. Maximum suction lift decreases as pressure decreases.

**2) Maximum suction lift** is dependent upon the vapor pressure of the liquid being pumped. The vapor pressure of a liquid is the pressure necessary to keep the liquid from vaporizing (boiling) at a given temperature. Vapor pressure increases as liquid temperature increases. Maximum suction lift decreases as vapor pressure rises.

It follows then, that the maximum suction lift of a centrifugal pump varies inversely with altitude. Conversely, maximum suction lift will increase as the external pressure on its source increases (for example: a closed pressure vessel).

## **Cavitation - Two Main Causes:**

A. NPSH (r) EXCEEDS NPSH (a)

Due to low pressure the water vaporizes (boils), and higher pressure implodes into the vapor bubbles as they pass through the pump, causing reduced performance and potentially major damage.

B. Suction or discharge recirculation. The pump is designed for a certain flow range, if there is not enough or too much flow going through the pump, the resulting turbulence and vortexes can reduce performance and damage the pump.

## **Affinity Laws**

The Centrifugal Pump is a very capable and flexible machine. Because of this it is unnecessary to design a separate pump for each job. The performance of a centrifugal pump can be varied by changing the impeller diameter or its rotational speed. Either change produces approximately the same results. Reducing impeller diameter is probably the most common change and is usually the most economical. The speed can be altered by changing pulley diameters or by changing the speed of the driver. In some cases both speed and impeller diameter are changed to obtain the desired results.

When the driven speed or impeller diameter of a centrifugal pump changes, operation of the pump changes in accordance with three fundamental laws. These laws are known as the "Laws of Affinity". They state that:

- 1) Capacity varies directly as the change in speed
- 2) Head varies as the square of the change in speed
- 3) Brake horsepower varies as the cube of the change in speed

**If, for example, the pump speed were doubled:**

- 1) Capacity will double
- 2) Head will increase by a factor of 4 (2 to the second power)
- 3) Brake horsepower will increase by a factor of 8 (2 to the third power)

These principles apply regardless of the direction (up or down) of the speed or change in diameter.

Consider the following example. A pump operating at 1750 RPM, delivers 210 GPM at 75' TDH, and requires 5.2 brake horsepower. What will happen if the speed is increased to 2000 RPM? First we find the speed ratio.

$$\text{Speed Ratio} = 2000/1750 = 1.14$$

**From the Laws of Affinity:**

1) Capacity varies directly or:  
 $1.14 \times 210 \text{ GPM} = 240 \text{ GPM}$

2) Head varies as the square or:  
 $1.14 \times 1.14 \times 75 = 97.5' \text{ TDH}$

3) BHP varies as the cube or:  
 $1.14 \times 1.14 \times 1.14 \times 5.2 = 7.72 \text{ BHP}$

Theoretically the efficiency is the same for both conditions. By calculating several points a new curve can be drawn.

Whether it be a speed change or change in impeller diameter, the Laws of Affinity give results that are approximate. The discrepancy between the calculated values and the actual values obtained in test are due to hydraulic efficiency changes that result from the modification. The Laws of Affinity give reasonably close results when the changes are not more than 50% of the original speed or 15% of the original diameter.

**Affinity Laws - Centrifugal Pumps**

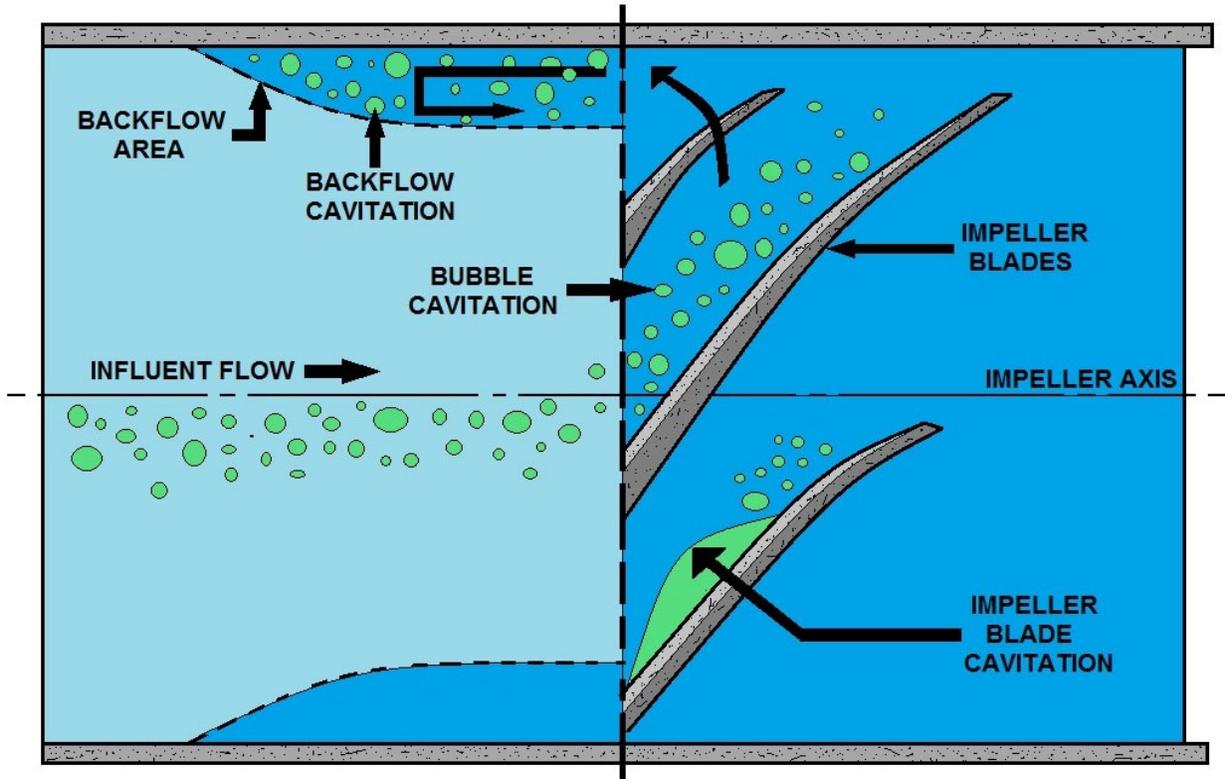
If the speed or impeller diameter of a pump changes, we can calculate the resulting performance change using:

**Affinity laws**

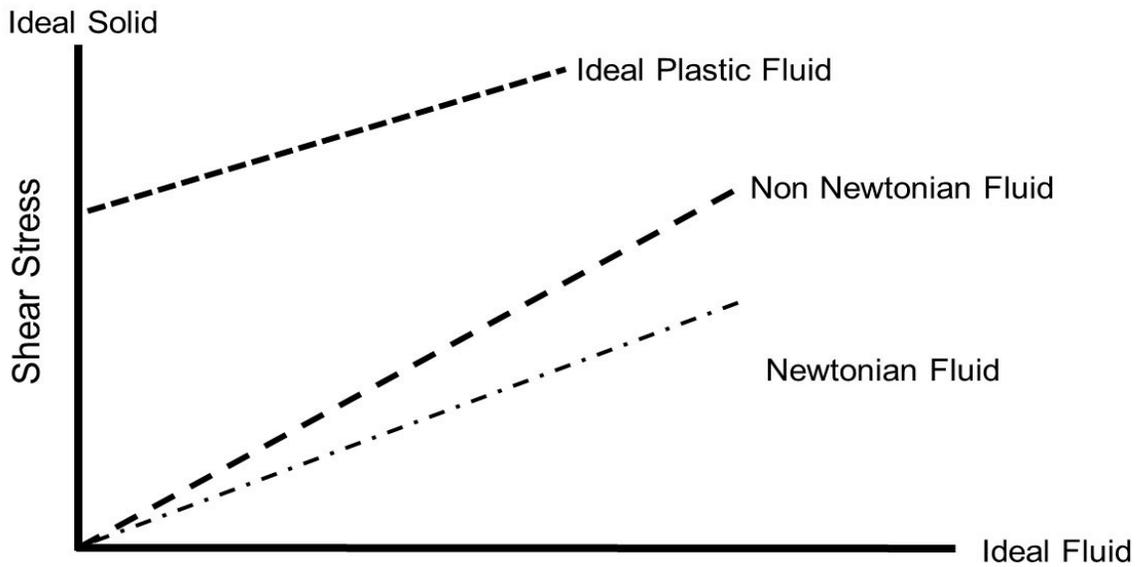
- a. The flow changes proportionally to speed  
i.e.: double the speed / double the flow
- b. The pressure changes by the square of the difference  
i.e.: double the speed / multiply the pressure by 4
- c. The power changes by the cube of the difference  
i.e.: double the speed / multiply the power by 8

**Notes:**

1. These laws apply to operating points at the same efficiency.
2. Variations in impeller diameter greater than 10% are hard to predict due to the change in relationship between the impeller and the casing. For rough calculations you can adjust a duty point or performance curve to suit a different speed. NPSH (r) is affected by speed / impeller diameter change = **DANGER!**



**PUMP CAVITATION**



**VELOCITY GRADIENT**

## Pump Casing Sub-Section

There are many variations of centrifugal pumps. The most common type is an end suction pump. Another type of pump used is the split case. There are many variations of split case, such as; two-stage, single suction, and double suction. Most of these pumps are horizontal.

There are variations of vertical centrifugal pumps. The line shaft turbine is really a multistage centrifugal pump.

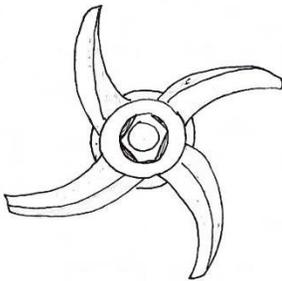
### Impeller

In most centrifugal pumps, the impeller looks like a number of cupped vanes on blades mounted on a disc or shaft. Notice in the picture below how the vanes of the impeller force the water into the outlet of the pipe.

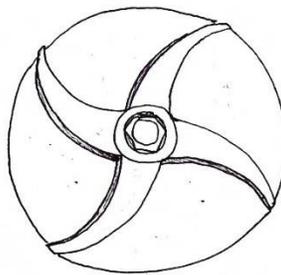
The shape of the vanes of the impeller is important. As the water is being thrown out of the pump, this means you can run centrifugal pumps with the discharged valve closed for a **SHORT** period of time. Remember the motor sends energy along the shaft, and if the water is in the volute too long it will heat up and create steam. Not good!

***Impellers are designed in various ways. We will look at:***

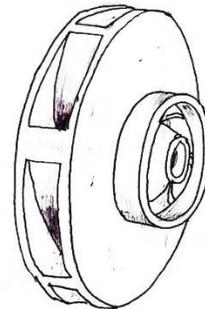
- Closed impellers
- Semi-open impellers
- Opened impellers, and
- Recessed impellers



**OPEN**



**SEMI-OPEN**



**CLOSED**

### IMPELLER TYPES

The impellers all cause a flow from the eye of the impeller to the outside of the impeller. These impellers cause what is called radial flow, and they can be referred to as radial flow impellers.

The critical distance of the impeller and how it is installed in the casing will determine if it is high volume / low pressure or the type of liquid that could be pumped.

**Axial flow** impellers look like a propeller and create a flow that is parallel to the shaft.

## Packing Seals



**PUMP PACKING BOX WITH ADJUSTMENT LOCK NUTS**

### **How can we prevent the water from leaking along the shaft?**

A special seal is used to prevent liquid leaking out along the shaft. There are two types of seals commonly used:

- **Packing seal**
- **Mechanical seal**

### **Leakage**

During pump operation, a certain amount of leakage around the shafts and casings normally takes place.

### **This leakage must be controlled for two reasons:**

- (1) to prevent excessive fluid loss from the pump, and
- (2) to prevent air from entering the area where the pump suction pressure is below atmospheric pressure.

The amount of leakage that can occur without limiting pump efficiency determines the type of shaft sealing selected. Shaft sealing systems are found in every pump. They can vary from simple packing to complicated sealing systems.

Packing is the most common and oldest method of sealing. Leakage is checked by the compression of packing rings that causes the rings to deform and seal around the pump shaft and casing.

The packing is lubricated by liquid moving through a lantern ring in the center of the packing. The sealing slows down the rate of leakage. It does not stop it completely, since a certain amount of leakage is necessary during operation. Mechanical seals are rapidly replacing conventional packing on centrifugal pumps.

**Some of the reasons for the use of mechanical seals are as follows:**

1. Leaking causes bearing failure by contaminating the oil with water. This is a major problem in engine-mounted water pumps.
2. Properly installed mechanical seals eliminate leakoff on idle (vertical) pumps. This design prevents the leak (water) from bypassing the water flinger and entering the lower bearings.

**Leakoff causes two types of seal leakage:**

- a. Water contamination of the engine lubrication oil.
- b. Loss of treated fresh water that causes scale buildup in the cooling system.

**Lantern Rings**

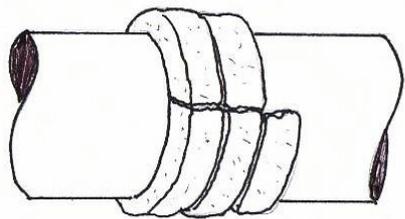
Lantern rings are used to supply clean water along the shaft. This helps to prevent grit and air from reaching the area. Another component is the slinger ring. The slinger ring is an important part of the pump because it is used to protect the bearings. Other materials can be used to prevent this burier.

**Wear Rings**

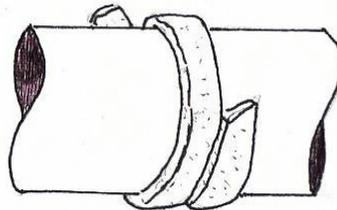
Not all centrifugal pumps have wear rings. However, when they are included, they are usually replaceable. Wear rings can be located on the suction side and head side of the volute. Wear rings could be made of the same metal but of different alloys. The wear ring on the head side is usually a harder alloy. It's called a "WEAR RING" and what would be the purpose?



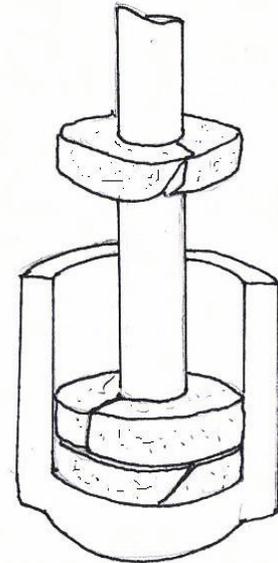
Finger is shown pointing to a Lantern Ring. This old school method of sealing a pump is still out there. Notice the packing on both sides of the ring. The packing joints need to be staggered and the purpose of this device is to allow pressurized cooling water to the Stuffing Box.



**INCORRECT**  
(butt joint)

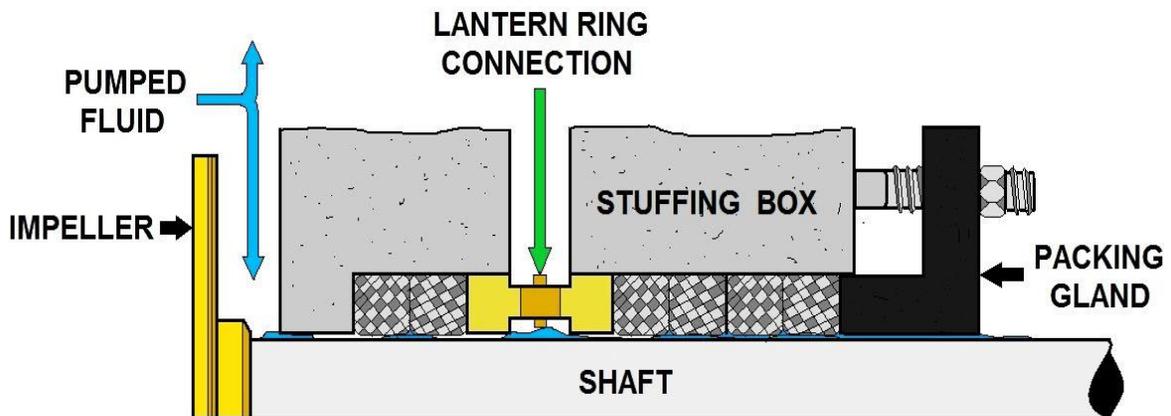


**CORRECT**  
(skive joint)  
(stagger @ 45 degree angle)



### Skive Packing Procedure

**Install one ring at a time:** Make sure it is clean, and has not picked up any dirt in handling. If desired, lubricate the shaft inside of the stuffing box. Seat rings firmly (except PTFE filament and Graphite yarn packing, which should be snugged up very gently, then tightened gradually after the pump is on stream). Joints of successive rings should be staggered and kept at least 90° apart. Each individual ring should be firmly seated with a tamping tool. When enough rings have been individually seated so that the nose of the gland will reach them, individual tamping should be supplemented by the gland.



**LANTERN RING BETWEEN PACKING FOR COOL / CLEAN FLUID BARRIER**

## Mechanical Seals

Mechanical seals are rapidly replacing conventional packing as the means of controlling leakage on rotary and positive-displacement pumps. Mechanical seals eliminate the problem of excessive stuffing box leakage, which causes failure of pump and motor bearings and motor windings.

### Mechanical Seals

There are many types of mechanical seals. The photograph below illustrates the basic components of a mechanical seal. Similar to the packing seal, clean water is fed at a pressure greater than that of the liquid being pumped. There is little or no leakage through the mechanical seal. The wearing surface must be kept extremely clean. Even fingerprints on the wearing surface can introduce enough dirt to cause problems.

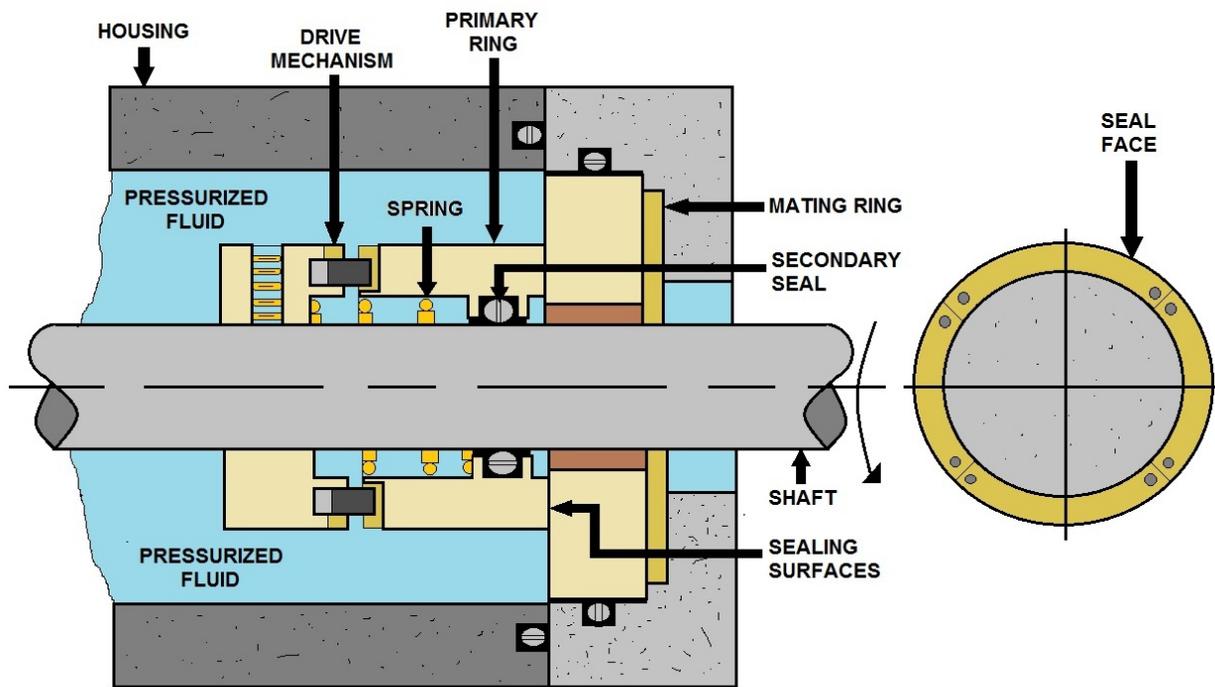


### MECHANICAL SEALS

Mechanical seals are ideal for pumps that operate in closed systems (such as fuel service and air-conditioning, chilled-water, and various cooling systems). They not only conserve the fluid being pumped, but also improve system operation.

The type of material used for the seal faces will depend upon the service of the pump. Most water service pumps use a carbon material for one of the seal faces and ceramic (tungsten carbide) for the other. When the seals wear out, they are simply replaced.

You should replace a mechanical seal whenever the seal is removed from the shaft for any reason, or whenever leakage causes undesirable effects on equipment or surrounding spaces. Do not touch a new seal on the sealing face because body acid and grease or dirt will cause the seal to pit prematurely and leak.



## MECHANICAL SEAL

### Stub or Step Sleeves

Mechanical shaft seals are positioned on the shaft by stub or step sleeves. Mechanical shaft seals must not be positioned by setscrews. Shaft sleeves are chamfered (beveled) on the outboard ends for easy mechanical seal mounting.

Mechanical shaft seals serve to ensure that position liquid pressure is supplied to the seal faces under all conditions of operation. They also ensure adequate circulation of the liquid at the seal faces to minimize the deposit of foreign matter on the seal parts.

## Motor Coupling Sub-Section

The pump coupling serves two main purposes:

- It couples or joins the two shafts together to transfer the rotation from motor to impeller.
- It compensates for small amounts of misalignment between the pump and the motor.

Remember that any coupling is a device in motion. If you have a 4-inch diameter coupling rotating at 1800 rpm, its outer surface is traveling about 20 mph. With that in mind, can you think of safety considerations?

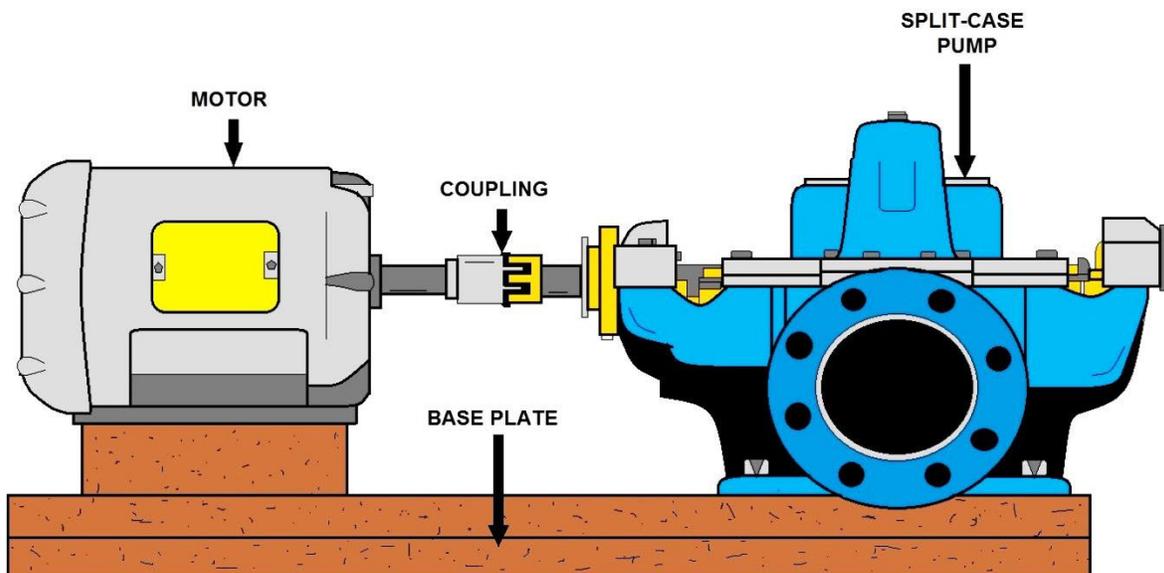
There are three commonly used types of couplings: **Rigid**, **Flexible** and **V-belts**.

### Rigid Coupling

Rigid couplings are most commonly used on vertically mounted pumps. The rigid coupling is usually specially keyed or constructed for joining the coupling to the motor shaft and the pump shaft. There are two types of rigid couplings: the flanged coupling, and the split coupling.

### Flexible Coupling

The flexible coupling provides the ability to compensate for small shaft misalignments. Shafts should be aligned as close as possible, regardless. The greater the misalignment, the shorter the life of the coupling. Bearing wear and life are also affected by misalignment.



**FLEXIBLE COUPLED PUMP AND MOTOR**

## Alignment of Flexible and Rigid Couplings

Both flexible and rigid couplings must be carefully aligned before they are connected.

Misalignment will cause excessive heat and vibration, as well as bearing wear. Usually, the noise from the coupling will warn you of shaft misalignment problems.

**Three types of shaft alignment problems are shown in the pictures below:**



ANGULAR MISALIGNMENT



ANGULAR AND PARALLEL



PARALLEL MISALIGNMENT

Different couplings will require different alignment procedures. We will look at the general procedures for aligning shafts.

1. Place the coupling on each shaft.
2. Arrange the units so they appear to be aligned. (Place shims under the legs of one of the units to raise it.)
3. Check the run-out, or difference between the driver and driven unit, by rotating the shafts by hand.
4. Turn both units so that the maximum run-out is on top.

Now you can check the units for both parallel and angular alignment. Many techniques are used, such as: straight edge, needle deflection (dial indicators), calipers, tapered wedges, and laser alignment.

### V-Belt Drive Couplings

V-belt drives connect the pump to the motor. A pulley is mounted on the pump and motor shaft. One or more belts are used to connect the two pulleys. Sometimes a separately mounted third pulley is used. This idler pulley is located off centerline between the two pulleys, just enough to allow tensioning of the belts by moving the idler pulley. An advantage of driving a pump with belts is that various speed ratios can be achieved between the motor and the pump. Alignment is still important, but less critical using v-belts.

### Shaft Bearings

There are three types of bearings commonly used: ball bearings, roller bearings, and sleeve bearings. Regardless of the particular type of bearings used within a system--whether it is ball bearings, a sleeve bearing, or a roller bearing--the bearings are designed to carry the loads imposed on the shaft.

Bearings must be lubricated. Without proper lubrication, bearings will overheat and seize.

Proper lubrication means using the correct type and the correct amount of lubrication. Similar to motor bearings, shaft bearings can be lubricated either by oil or by grease.

## Maintenance Sub-Section

### Maintenance of Centrifugal Pumps

When properly installed, maintained and operated, centrifugal pumps are usually trouble-free. Some of the most common preventative and corrective maintenance actions that you may be required to perform are discussed in the following sections.

**Repacking** - Lubrication of the pump packing is extremely important. The quickest way to wear out the packing is to forget to open the water piping to the seals or stuffing boxes. If the packing is allowed to dry out, it will score the shaft. When operating a centrifugal pump, be sure there is always a slight trickle of water coming out of the stuffing box or seal. How often the packing in a centrifugal pump should be renewed depends on several factors, such as the type of pump, condition of the shaft sleeve, and hours in use.



To ensure the longest possible service from pump packing, make certain the shaft or sleeve is smooth when the packing is removed from a gland. Rapid wear of the packing will be caused by roughness of the shaft sleeve (or shaft where no sleeve is installed). If the shaft is rough, it should be sent to the machine shop for a finishing cut to smooth the surface. If it is very rough, or has deep ridges in it, it will have to be renewed. It is absolutely necessary to use the correct packing.

When replacing packing, be sure the packing fits uniformly around the stuffing box. If you have to flatten the packing with a hammer to make it fit, **YOU ARE NOT USING THE RIGHT SIZE**. Pack the box loosely, and set up the packing gland lightly. Allow a liberal leak-off for stuffing boxes that operate above atmospheric pressure.

Next, start the pump. Let it operate for about 30 minutes before you adjust the packing gland for the desired amount of leak-off. This gives the packing time to run-in and swell. You may then begin to adjust the packing gland. Tighten the adjusting nuts one flat at a time. Wait about 30 minutes between adjustments. Be sure to tighten the same amount on both adjusting nuts. If you pull up the packing gland unevenly (or cocked), it will cause the packing to overheat and score the shaft sleeves. Once you have the desired leak-off, check it regularly to make certain that sufficient flow is maintained.

### Last Word on Mechanical Seals

Mechanical seals are rapidly replacing conventional packing as the means of controlling leakage on rotary and positive-displacement pumps. Mechanical seals eliminate the problem of excessive stuffing box leakage, which causes failure of pump and motor bearings and motor windings.

Mechanical seals are ideal for pumps that operate in closed systems (such as fuel service and air-conditioning, chilled-water, and various cooling systems). They not only conserve the fluid being pumped, but also improve system operation.



The type of material used for the seal faces will depend upon the service of the pump. Most water service pumps use a carbon material for one of the seal faces and ceramic (tungsten carbide) for the other. When the seals wear out, they are simply replaced.

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Mechanical shaft seals are positioned on the shaft by stub or step sleeves. Mechanical shaft seals must not be positioned by setscrews. Shaft sleeves are chamfered (beveled) on outboard ends for easy mechanical seal mounting.

Mechanical shaft seals serve to ensure that liquid pressure is supplied to the seal faces under all conditions of operation. They also ensure adequate circulation of the liquid at the seal faces to minimize the deposit of foreign matter on the seal parts.

## Pump Troubleshooting Sub-Section

Some of the operating problems you may encounter with centrifugal pumps as an Operator, together with the probable causes, are discussed in the following paragraphs.

If a centrifugal pump **DOES NOT DELIVER ANY LIQUID**, the trouble may be caused by

- (1) insufficient priming;
- (2) insufficient speed of the pump;
- (3) excessive discharge pressure, such as might be caused by a partially closed valve or some other obstruction in the discharge line;
- (4) excessive suction lift;
- (5) clogged impeller passages;
- (6) the wrong direction of rotation (this may occur after motor overhaul);
- (7) clogged suction screen (if used);
- (8) ruptured suction line; or
- (9) loss of suction pressure.

If a centrifugal pump delivers some liquid but operates at **INSUFFICIENT CAPACITY**, the trouble may be caused by

- (1) air leakage into the suction line;
- (2) air leakage into the stuffing boxes in pumps operating at less than atmospheric pressure;
- (3) insufficient pump speed;
- (4) excessive suction lift;
- (5) insufficient liquid on the suction side;
- (6) clogged impeller passages;
- (7) excessive discharge pressure; or
- (8) mechanical defects, such as worn wearing rings, impellers, stuffing box packing, or sleeves.

If a pump **DOES NOT DEVELOP DESIGN DISCHARGE PRESSURE**, the trouble may be caused by

- (1) insufficient pump speed;
  - (2) air or gas in the liquid being pumped;
  - (3) mechanical defects, such as worn wearing rings, impellers, stuffing box packing, or sleeves;
- or
- (4) reversed rotation of the impeller (3-phase electric motor-driven pumps).

If a pump **WORKS FOR A WHILE AND THEN FAILS TO DELIVER LIQUID**, the trouble may be caused by

- (1) air leakage into the suction line;
- (2) air leakage in the stuffing boxes;
- (3) clogged water seal passages;
- (4) insufficient liquid on the suction side; or
- (5) excessive heat in the liquid being pumped.

If a motor-driven centrifugal pump **DRAWS TOO MUCH POWER**, the trouble will probably be indicated by overheating of the motor. The basic causes may be

- (1) operation of the pump to excess capacity and insufficient discharge pressure;
- (2) too high viscosity or specific gravity of the liquid being pumped; or
- (3) misalignment, a bent shaft, excessively tight stuffing box packing, worn wearing rings, or other mechanical defects.

**VIBRATION** of a centrifugal pump is often caused by

- (1) misalignment;
- (2) a bent shaft;
- (3) a clogged, eroded, or otherwise unbalanced impeller; or
- (4) lack of rigidity in the foundation. Insufficient suction pressure may also cause vibration and cavitation, as well as noisy operation and fluctuating discharge pressure, particularly in pumps that handle hot or volatile liquids.

If the pump fails to build up pressure when the discharge valve is opened and the pump comes up to normal operating speed, proceed as follows:

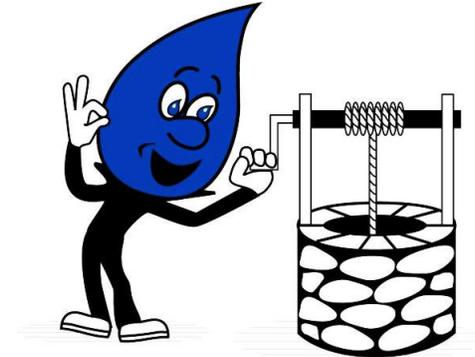
1. Shut the pump discharge valve.
2. Secure the pump.
3. Open all valves in the pump suction line.
4. Prime the pump (*fill casing with the liquid being pumped*) and be sure that all air is expelled through the air cocks on the pump casing.
5. Restart the pump. If the pump is electrically driven, be sure the pump is rotating in the correct direction.
6. Open the discharge valve to “load” the pump. If the discharge pressure is not normal when the pump is up to its proper speed, the suction line may be clogged, or an impeller may be broken. It is also possible that air is being drawn into the suction line or into the casing. If any of these conditions exist, stop the pump and continue troubleshooting according to the technical manual for that unit.

## Troubleshooting Table for Well/Pump Problems

1. Well pump will not start.
2. Well pump will not shut off.
3. Well pump starts and stops too frequently (excessive cycle rate).
4. Sand sediment is present in the water.
5. Well pump operates with reduced flow.
6. Well house flooded without recent precipitation.
7. Red or black water complaints.
8. Raw water appears turbid or a light tan color following rainfall.
9. Coliform tests are positive.

### Possible Causes

- 1A. Circuit breaker or overload relay tripped.
- 1B. Fuse(s) burned out.
- 1C. No power to switch box.
- 1D. Short, broken or loose wire.
- 1E. Low voltage.
- 1F. Defective motor.
- 1G. Defective pressure switch.
- 2A. Defective pressure switch.
- 2B. Cut-off pressure setting too high.
- 2C. Float switch or pressure transducer not functioning.
- 3A. Pressure switch settings too close.
- 3B. Pump foot valve leaking.
- 3C. Water-logged hydropneumatic tank.
- 4A. Problems with well screen or gravel envelope.
- 5A. Valve on discharge partially closed or line clogged.
- 5B. Well is over-pumped.
- 5C. Well screen clogged.
- 6A. Check valve not operating properly.
- 6B. Leakage occurring in discharge piping or valves.
- 7A. Water contains excessive iron (red brown) and/or manganese (black water).
- 7B. Complainant's hot water needs maintenance.
- 8A. Surface water entering or influencing well.
- 9A. Sample is invalid.
- 9B. Sanitary protection of well has been breached.



### Possible Solutions

- 1A. Reset breaker or manual overload relay.
- 1B. Check for cause and correct, replace fuse(s).
- 1C. Check incoming power supply. Contact power company.
- 1D. Check for shorts and correct, tighten terminals, replace broken wires.
- 1E. Check incoming line voltage. Contact power company if low.
- 1F. Contact electrical contractor.
- 1G. Check voltage of incoming electric supply with pressure switch closed. Contact power company if voltage low. Perform maintenance on switch if voltage normal.
- 2A. Check switch for proper operation. Replace switch.
- 2B. Adjust setting.
- 2C. Check and replace components or cable as needed.

- 3A. Adjust settings.
- 3B. Check for backflow. Contact well contractor.
- 3C. Check air volume. Add air if needed. If persistent, check air compressor, relief valve, air lines and connections, and repair if needed.
- 4A. Contact well contractor.
- 5A. Open valve, unclog discharge line.
- 5B. Check static water level and compare to past readings. If significantly lower, notify well contractor.
- 5C. Contact well contractor.
- 6A. Repair or replace check valve.
- 6B. Inspect and repair/replace as necessary.
- 7A. Test for iron and manganese at well. If levels exceed 0.3 mg/L iron or 0.005mg/L manganese, contact regulatory agency, TA provider or water treatment contractor.
- 7B. Check hot water heater and flush if needed.
- 8A. Check well for openings that allow surface water to enter. Check area for sinkholes, fractures, or other physical evidence of surface water intrusion. Check water turbidity. Notify regulatory agency if >0.5 NTU. Check raw water for coliform bacteria. Notify regulatory agency immediately if positive.
- 9A. Check sampling technique, sampling container, and sampling location and tap.
- 9B. Notify regulatory agency immediately and re-sample for re-testing.



This brush is used to dislodge debris inside well casing. Just a big toilet cleaning brush.

## Pump Not Delivering Water

If your pump is not delivering water, verify that the pump shaft is turning in the direction of the arrow on the pump casing. As viewed from the motor end, the rotation is usually clockwise, but check the startup instructions that came with the pump.

On three-phase motors, swap any two power leads to change rotation. It is recommended that a qualified electrician perform this task.

If the pump does not prime, check for air leaks on discharge valves. Many all-metal gate-type valves will not seal properly to create a vacuum. Sand or other debris lodged between the rubber flap and the valve seat will prevent check valves from sealing and forming a tight joint. See if the rubber face is cracked or chipped and not seating. Replace the gate valve or check valve. Check connections between pump and primer. On a hand primer, if grass or other debris is lodged in the check valve, air is pulled back into the pump at every stroke and the pump will not prime. After proper priming, fill the system slowly.

### Pump Maintenance Tasks

#### Twice a Year:

- Thoroughly clean suction and discharge piping and connections, removing moss and debris.
- Tighten all drain and fill plugs in the pump volute case to avoid air and water leaks. Use a pipe thread compound on all pipe threads.
- Check for cracks or holes in the pump case.
- Clean trash screening device and screens on the suction pipe.

### Servicing Impeller and Wear Rings

If you suspect that your pump impeller is clogged or damaged, or that the wear rings are worn, you can dismantle the pump. This will take some work and is best done in the shop. Or have a qualified pump repair shop undertake this procedure.

Always follow the directions in the manufacturer's manual, if available, instead of the following simplified directions.

- Remove suction cover or volute case.
- Remove debris from impeller and volute. Remove pebbles lodged between vanes.
- Check wear at the impeller eye and vanes. If worn, repair or replace the impeller.
- Re-machine or replace wear ring if clearance is greater than 1/32 inch per side.
- Replace suction cover or volute. Use a new gasket.

### On the Suction Side of Pump:

- A well designed and screened sump that keeps trash away.
- Suction line joints that are airtight under a vacuum.
- No high spots where air can collect.
- A suction line water velocity of five feet per second (fps) or less; two to three fps is best.
- A suction entrance at least two pipe bell diameters from sump inlet.
- A suction lift (vertical distance from water surface to pump impeller) less than 15 to 20 feet.
- An eccentric reducer to keep air from becoming trapped in the reducer fitting.
- A vacuum gauge to indicate whether the primer is pulling a vacuum or just moving air through the pump.

### **On the Discharge Side of Pump:**

- A valve size that is the same diameter as the mainline.
- A non-slam check valve to prevent back spin when shutting off the pump.
- An air relief device when a buried mainline is used.
- A discharge line water velocity of less than seven fps. Five fps is best.
- An energy efficient 1800 rpm motor with a 15 percent safety factor.
- A simple shade over the motor.

### **Turbine Pump Installation**

The properly constructed well should also:

- Be at least six inches in diameter larger than the outside diameter of the well casing when a gravel pack is required.
- Have horizontal well screen slots that continue below the pumping water level. The openings should hold back at least 85 percent of the surrounding material.

### **Control Panel for Electric Motors**

The importance of a properly installed control panel cannot be overemphasized for personal safety and for protecting your investment in your pump and motor. Your control panel should:

- Have a shade over it to keep thermal breakers cool.
- Be mounted on secure poles or foundation.
- Have any missing knockout plugs and other holes in the starting switch box replaced and screened or puttied against rodents, insects, and dirt.
- Have a small hole (3/16-inch diameter) in the bottom of the panel to allow moisture to drain.

Your control panel should include the following controls at a minimum:

- Circuit breaker(s) for overload currents.
- Lightning arrester.
- Surge protector.
- Phase failure relay, to protect the motor from phase reversal or failure and from low voltage.
- A pressure switch to shut off the motor if pumping pressure drops to undesirable levels.

### **Casing**

Casing is the tubular structure that is placed in the drilled well to maintain the well opening. Along with grout, the casing also confines the groundwater to its zone underground and prevents contaminants from mixing with the water. Some states or local governing agencies have laws that require minimum lengths for casing.

The most common materials for well casing are carbon steel, plastic (most commonly, but not exclusively, PVC), and stainless steel. Different geologic formations dictate what type of casing can be used. For example, parts of the country where hard rock lies underground are known strictly as “steel states.”

Residents in some areas have a choice between steel and PVC, both of which have advantages. PVC is lightweight, resistant to corrosion, and relatively easy for contractors to install. However, it is not as strong and not as resistant to heat as steel. Steel, though, is susceptible to corrosion, can have scale build-up, and can cost more than PVC. Some contractors also use concrete, fiberglass, and asbestos cement casing.

## **Caps**

On the top of the casing should be an approved well cap. It should fit snugly so debris, insects, or small animals can't find their way into the well system.

Well caps are usually aluminum or a thermoplastic, and include a vented screen so that the pressure difference between the inside and outside of the well casing may be equalized when water is pumped from the well.

The casing and cap should extend at least 6 to 8 inches above the ground. If the well is near a river or stream, it should extend at least past the flood level to prevent overflows from contaminating the groundwater.

## **Well Screens**

Well screens are filtering devices used to prevent excess sediment from entering the well. They attach to the bottom of the casing, allowing water to move through the well, while keeping out most gravel and sand. The most popular screens are continuous slot, slotted pipe, and perforated pipe.

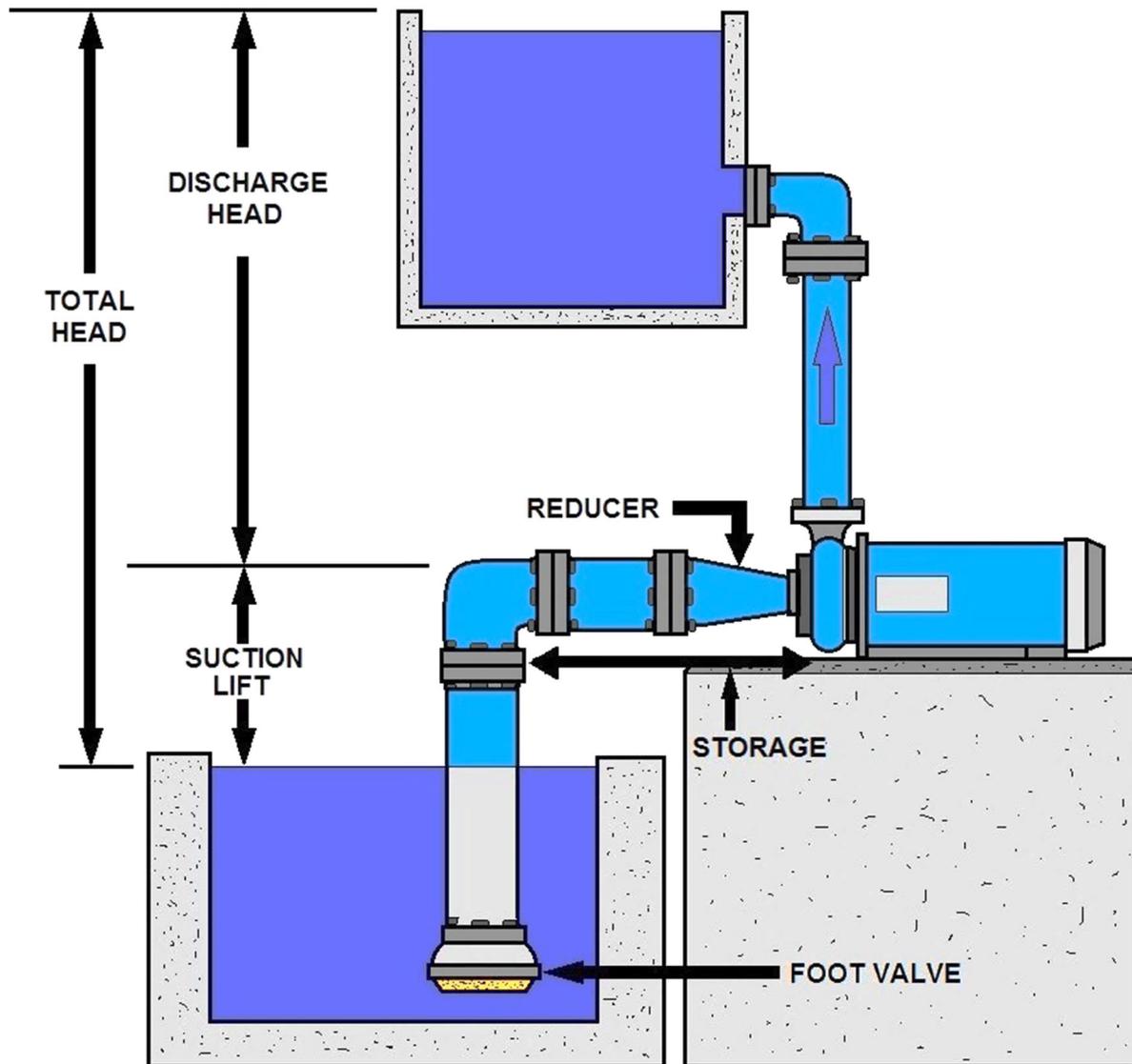
Perforated pipe is a length of casing that has holes or slots drilled into the pipe. It is not efficient for aquifers that feature a lot of sand and gravel because it has wide openings.

There is less open area in the other two types of screens. Continuous slot screens are made of wire or plastic wrapped around a series of vertical rods. Slotted pipe screens, which have the least amount of open area, feature machine-cut slots into steel or plastic casing at set distances.

## **Pitless Adapters**

Pitless adapters provide wells with a sanitary — and frost-proof — seal between the well casing and the water line running to the well system owner's house.

After a frost line is determined for the area where the well is being installed, the adapter is connected to the well casing below the frost line. Water from the well is then diverted horizontally at the adapter to prevent it from freezing.



## PUMPING FACTORS

## SCADA - Simply Explained



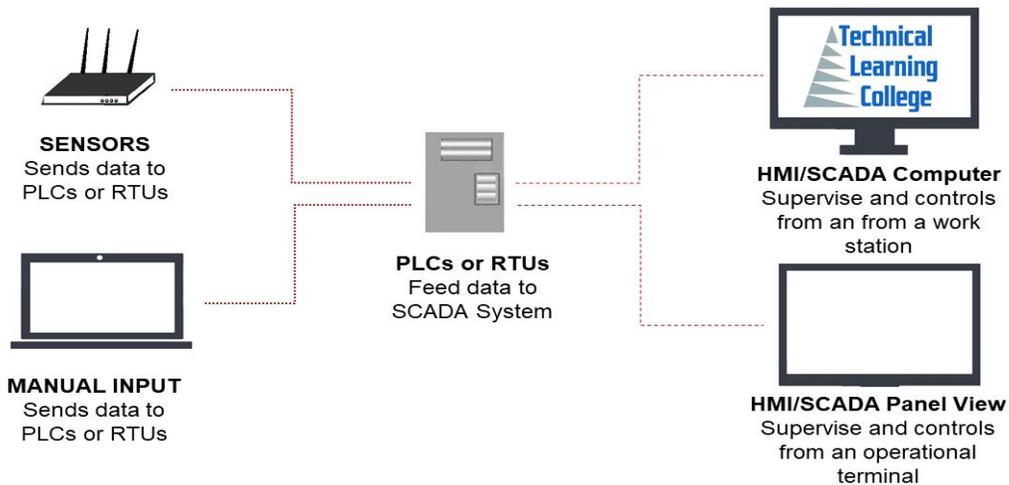
Supervisory control and data acquisition – SCADA refers to ICS (industrial control systems) used to control infrastructure processes (water treatment, wastewater treatment, gas pipelines, wind farms, etc.), facility-based processes (airports, space stations, ships, etc.) or industrial processes (production, manufacturing, refining, power generation, etc.).

Supervisory Control and Data Acquisition (SCADA) is a control system architecture that uses computers, networked data communications and graphical user interfaces for high-level process supervisory management, but uses other peripheral devices such as programmable logic controller (PLC) and discrete PID controllers to interface with the process plant or machinery. The use of SCADA has been also considered for management and operations of project-driven-process in construction.

### **The following subsystems are usually present in SCADA systems:**

- The apparatus used by a human operator; all the processed data are presented to the operator
- A supervisory system that gathers all the required data about the process
- Remote Terminal Units (RTUs) connected to the sensors of the process, which helps to convert the sensor signals to the digital data and send the data to supervisory stream.
- Programmable Logic Controller (PLCs) used as field devices
- Communication infrastructure connects the Remote Terminal Units to supervisory system.

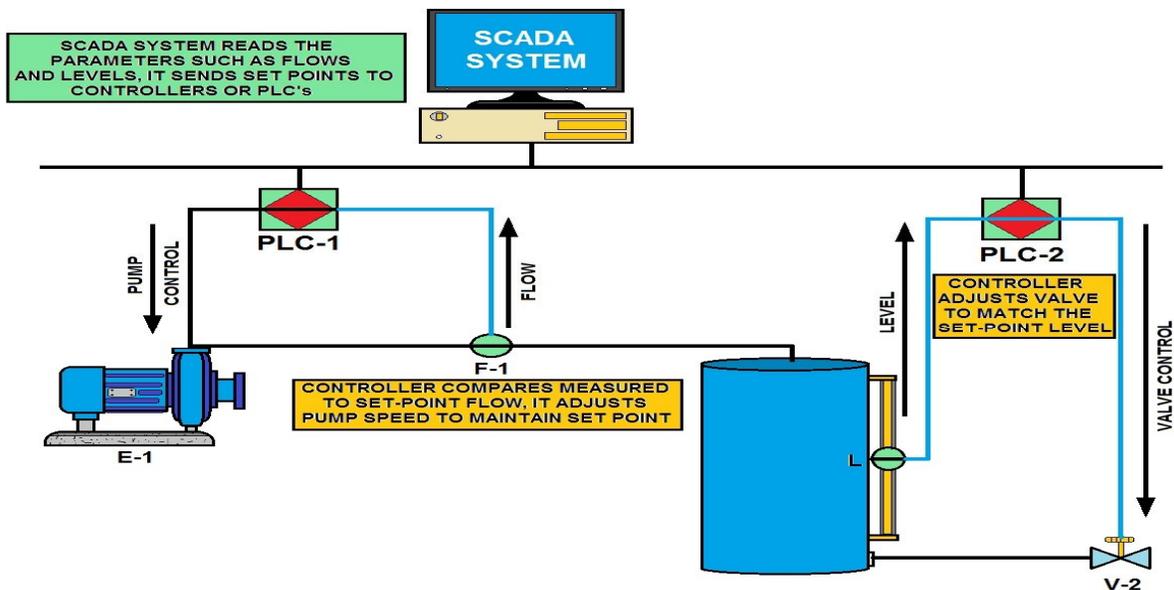
Generally, a SCADA system does not control the processes in real time – it usually refers to the system that coordinates the processes in real time.



## BASIC SCADA DIAGRAM

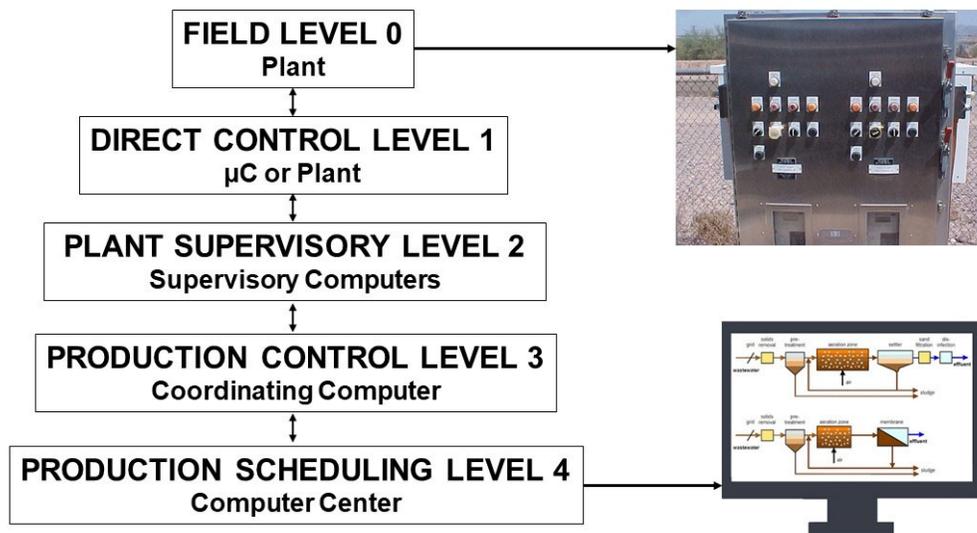
### Remote Operation

SCADA is a real time control tool. It is not supposed to be a tool for detailed analysis of past performance but you the operator are able to research past performance to be able to react to current conditions. Thus, some form of trending is included with SCADA. The trending function is as close to analysis as most SCADA software get. Let us say a water treatment operator wants to examine chemical usage in GAC filters and determine how each filter behaved over the past six weeks. In this case, SCADA is your tool of choice. Some SCADA let you look at these three filters and compare their performance with some time period in the past.



**SCADA SYSTEM**  
(SUPERVISORY CONTROL and DATA ACQUISITION)

## SCADA Systems Concepts



### FUNCTION LEVELS OF CONTROL OPERATION

SCADA refers to the centralized systems that control and monitor the entire sites, or they are the complex systems spread out over large areas. Nearly all the control actions are automatically performed by the remote terminal units (RTUs) or by the programmable logic controllers (PLCs). The restrictions to the host control functions are supervisory level intervention or basic overriding.

For example, the PLC (in an industrial process) controls the flow of cooling water, the SCADA system allows any changes related to the alarm conditions and set points for the flow (such as high temperature, loss of flow, etc.) to be recorded and displayed.

Data acquisition starts at the PLC or RTU level, which includes the equipment status reports, and meter readings. Data is then formatted in such way that the operator of the control room can make the supervisory decisions to override or adjust normal PLC (RTU) controls, by using the HMI.

SCADA systems mostly implement the distributed databases known as tag databases, containing data elements called points or tags. A point is a single output or input value controlled or monitored by the system. Points are either 'soft' or 'hard'.

The actual output or input of a system is represented by a hard point, whereas the soft point is a result of different math and logic operations applied to other points. These points are usually stored as timestamp-value pairs.

Series of the timestamp-value pairs gives history of the particular point. Storing additional metadata with the tags is common (these additional data can include comments on the design time, alarm information, path to the field device or the PLC register).

The key attribute of a SCADA system is its ability to perform a supervisory operation over a variety of other proprietary devices.

SCADA systems typically use a tag database, which contains data elements called tags or points, which relate to specific instrumentation or actuators within the process system according to such as the Piping and instrumentation diagram. Data is accumulated against these unique process control equipment tag references.

### **Referring to the Diagram**

**Level 0** contains the field devices such as flow and temperature sensors, and final control elements, such as control valves.

**Level 1** contains the industrialized input/output (I/O) modules, and their associated distributed electronic processors.

**Level 2** contains the supervisory computers, which collate information from processor nodes on the system, and provide the operator control screens.

**Level 3** is the production control level, which does not directly control the process, but is concerned with monitoring production and targets.

**Level 4** is the production scheduling level.

Level 1 contains the programmable logic controllers (PLCs) or remote terminal units (RTUs).

Level 2 contains the SCADA software and computing platform. The SCADA software exists only at this supervisory level as control actions are performed automatically by RTUs or PLCs. SCADA control functions are usually restricted to basic overriding or supervisory level intervention.

For example, a PLC may control the flow of cooling water through part of an industrial process to a set point level, but the SCADA system software will allow operators to change the set points for the flow.

The SCADA also enables alarm conditions, such as loss of flow or high temperature, to be displayed and recorded. A feedback control loop is directly controlled by the RTU or PLC, but the SCADA software monitors the overall performance of the loop.

Levels 3 and 4 are not strictly process control in the traditional sense, but are where production control and scheduling takes place.

Data acquisition begins at the RTU or PLC level and includes instrumentation readings and equipment status reports that are communicated to level 2 SCADA as required.

Data is then compiled and formatted in such a way that a control room operator using the HMI (Human Machine Interface) can make supervisory decisions to adjust or override normal RTU (PLC) controls. Data may also be fed to a historian, often built on a commodity database management system, to allow trending and other analytical auditing.

## Well Selection Section



**A drill rig in the snow.**

Basically, a well is a hole drilled into an aquifer. A pipe and a pump are used to pull water out of the ground, and a screen filters out unwanted particles that could clog the pipe. Wells come in different shapes and sizes, depending on the type of material the well is drilled into and how much water is being pumped out.

### **Three Basic Types of Wells**

- **Bored or shallow wells** are usually bored into an unconfined water source, generally found at depths of 100 feet or less.
- **Consolidated or rock wells** are drilled into a formation consisting entirely of a natural rock formation that contains no soil and does not collapse. Their average depth is about 250 feet.
- **Unconsolidated or sand wells** are drilled into a formation consisting of soil, sand, gravel or clay material that collapses upon itself.

## Selecting an Optimum Pumping Rate

Before a well can be completed with the necessary pumping equipment, it should be tested for capacity and proper operation. When the well was drilled, the driller and geologist kept close watch of the amount of water production that had been obtained. The development techniques used can also be useful in estimating a well's production rate. However, the driller will normally know what to expect based on his experience, and the geologist or **hydrologist** will also obtain information on other nearby wells to bracket the expected production rate. If the well was drilled with air rotary, the **airlift** at the time of drilling also can serve as a baseline to estimate the well's production rate. Either way, the well is normally pump tested following well development.

A **pumping test** is normally conducted for at least eight hours in order to estimate a well's maximum production rate. Ideally, a twenty-four hour step test is conducted. A step test is a **variable rate** pumping test, typically conducted for 24 hours at up to six different pumping rates. Typically, the well will be pumped at the lower estimated maximum pumping rate for the first four hours.

The pumping rate is then adjusted upwards in equal amounts every four hours until 24 hours of pumping have been completed. The personnel conducting the test keep track of the water levels in the well to ensure that the steps are not too large and not too small.

In the end, the optimum pumping rate is selected following a careful review and comparison of the water level data for each rate. The well's **specific capacity (Sc)** is then determined. Specific capacity is the gallons per minute the well can produce per foot of drawdown. Specific capacities for each of the pumping steps are compared. The highest Sc observed is normally associated with the optimum pumping rate. That rate should also have resulted in **stabilized** pumping levels or **drawdown**.

Well pumping test being conducted in photograph below. (Notice the portable electric generator for powering the pump. The Hydrogeologist is using a depth probe to measure the drop in the static water level.)



## Selection of Pumping Equipment

The proper selection of pumping equipment for a well is of great importance. The primary factors that must be considered before selecting the well pump are: flow rate, line pressure, pumping lift (total dynamic head), power requirements (and limitations), and size of piping. Each of these components must be considered together when selecting well pumps.

### Pumping Lift and Total Dynamic or Discharge Head

The most important components in selecting the correct pump for your application are: **total pumping lift** and **total dynamic or discharge head**. Total dynamic head refers to the total equivalent feet of lift that the pump must overcome in order to deliver water to its destination, including frictional losses in the delivery system.

### Basic Pump Operating Characteristics

"Head" is a term commonly used with pumps. Head refers to the height of a vertical column of water. Pressure and head are interchangeable concepts in irrigation, because a column of water 2.31 feet high is equivalent to 1 pound per square inch (PSI) of pressure. The total head of a pump is composed of several types of head that help define the pump's operating characteristics.

### Total Dynamic Head

The total dynamic head of a pump is the sum of the total static head, the pressure head, the friction head, and the velocity head.

**The Total Dynamic Head (TDH) is the sum of the total static head, the total friction head and the pressure head.**

### Total Static Head

The total static head is the total vertical distance the pump must lift the water. When pumping from a well, it would be the distance from the pumping water level in the well to the ground surface plus the vertical distance the water is lifted from the ground surface to the discharge point. When pumping from an open water surface, it would be the total vertical distance from the water surface to the discharge point.

### Pressure Head

The pressure head at any point where a pressure gauge is located can be converted from pounds per square inch (PSI) to feet of head by multiplying by 2.31. For example, 20 PSI is equal to 20 times 2.31 or 46.2 feet of head. Most city water systems operate at 50 to 60 PSI, which, as illustrated in Table 1, explains why the centers of most city water towers are about 130 feet above the ground.

**Table 1. Pounds per square inch (PSI) and equivalent head in feet of water.**

PSI	Head (feet)
0	0
5	11.5
10	23.1
15	34.6
20	46.2
25	57.7
30	69.3

35	80.8
40	92.4
45	104
50	115
55	127
60	138
65	150
70	162
75	173
80	185
85	196
90	208
95	219
100	231

### **Friction Head**

Friction head is the energy loss or pressure decrease due to friction when water flows through pipe networks. The velocity of the water has a significant effect on friction loss. Loss of head due to friction occurs when water flows through straight pipe sections, fittings, valves, around corners, and where pipes increase or decrease in size. Values for these losses can be calculated or obtained from friction loss tables. The friction head for a piping system is the sum of all the friction losses.

### **Velocity Head**

Velocity head is the energy of the water due to its velocity. This is a very small amount of energy and is usually negligible when computing losses in an irrigation system.

### **Suction Head**

A pump operating above a water surface is working with a suction head. The suction head includes not only the vertical suction lift, but also the friction losses through the pipe, elbows, foot valves, and other fittings on the suction side of the pump. There is an allowable limit to the suction head on a pump and the net positive suction head (NPSH) of a pump sets that limit.

The theoretical maximum height that water can be lifted using suction is 33 feet. Through controlled laboratory tests, manufacturers determine the NPSH curve for their pumps. The NPSH curve will increase with increasing flow rate through the pump. At a certain flow rate, the NPSH is subtracted from 33 feet to determine the maximum suction head at which that pump will operate. For example, if a pump requires a minimum NPSH of 20 feet the pump would have a maximum suction head of 13 feet. Due to suction pipeline friction losses, a pump rated for a maximum suction head of 13 feet may effectively lift water only 10 feet. To minimize the suction pipeline friction losses, the suction pipe should have a larger diameter than the discharge pipe.

Operating a pump with suction lift greater than it was designed for, or under conditions with excessive vacuum at some point in the impeller, may cause cavitation. Cavitation is the implosion of bubbles of air and water vapor and makes a very distinct noise like gravel in the pump. The implosion of numerous bubbles will eat away at an impeller and it eventually will be filled with holes.

### Pump Power Requirements

The power added to water as it moves through a pump can be calculated with the following formula:

$$\text{WHP} = \frac{Q \times \text{TDH}}{3960} \quad (1)$$

where:

WHP = Water Horse Power  
Q = Flow rate in gallons per minute (GPM)  
TDH = Total Dynamic Head (feet)

However, the actual power required to run a pump will be higher than this because pumps and drives are not 100 percent efficient. The horsepower required at the pump shaft to pump a specified flow rate against a specified TDH is the **Brake Horsepower (BHP)** which is calculated with the following formula:

$$\text{BHP} = \frac{\text{WHP}}{\text{Pump Eff.} \times \text{Drive Eff.}} \quad (2)$$

**BHP** -- Brake Horsepower (continuous horsepower rating of the power unit).

**Pump Eff.** -- Efficiency of the pump usually read from a pump curve and having a value between 0 and 1.

**Drive Eff.** -- Efficiency of the drive unit between the power source and the pump. For direct connection this value is 1, for right angle drives the value is 0.95 and for belt drives it can vary from 0.7 to 0.85.

### Effect of Speed Change on Pump Performance

The performance of a pump varies with the speed at which the impeller rotates. **Theoretically**, varying the pump speed will result in changes in flow rate, TDH and BHP according to the following formulas:

$$\left(\frac{\text{RPM}_2}{\text{RPM}_1}\right) \times \text{GPM}_1 = \text{GPM}_2 \quad (3)$$

$$\left(\frac{\text{RPM}_2}{\text{RPM}_1}\right)^2 \times \text{TDH}_1 = \text{TDH}_2 \quad (4)$$

$$\left(\frac{\text{RPM}_2}{\text{RPM}_1}\right)^3 \times \text{BPH}_1 = \text{BPH}_2 \quad (5)$$

where:

RPM<sub>1</sub> = Initial revolutions per minute setting  
RPM<sub>2</sub> = New revolutions per minute setting  
GPM = Gallons per Minute

(subscripts same as for RPM)  
TDH = Total Dynamic Head  
(subscripts same as for RPM)  
BHP = Brake Horsepower  
(subscripts same as for RPM)

As an example, if the RPM are increased by 50 percent, the flow rate will increase by 50 percent, the TDH will increase 2.25 times, and the required BHP will increase 3.38 times that required at the lower speed. It is easy to see that with a speed increase the BHP requirements of a pump will increase at a faster rate than the head and flow rate changes.

### **Pump Efficiency**

Manufacturers determine by tests the operating characteristics of their pumps and publish the results in pump performance charts commonly called "pump curves."

**A typical pump curve for a horizontal centrifugal pump. NPSH is the Net Positive Suction Head required by the pump and TDSL is the Total Dynamic Suction Lift available (both at sea level).**

All pump curves are plotted with the flow rate on the horizontal axis and the TDH on the vertical axis. The curves are often shown for a centrifugal pump tested at different RPM. Each curve indicates the GPM versus TDH relationship at the tested RPM. In addition, pump efficiency lines have been added and wherever the efficiency line crosses the pump curve lines **that** number is what the efficiency is at that point. Brake horsepower (BHP) curves have also been added; they slant down from left to right. The BHP curves are calculated using the values from the efficiency lines. At the top of the chart is an NPSH curve with its scale on the right side of the chart.

### **Reading a Pump Curve**

When the desired flow rate and TDH are known, these curves are used to select a pump. The pump curve shows that a pump will operate over a wide range of conditions. However, it will operate at peak efficiency only in a narrow range of flow rate and TDH. As an example of how a pump characteristic curve is used, let's use the pump curve to determine the horsepower and efficiency of this pump at a discharge of 900 gallons per minute (GPM) and 120 feet of TDH.

**Solution:** Follow the dashed vertical line from 900 GPM until it crosses the dashed horizontal line from the 120 feet of TDH. At this point the pump is running at a peak efficiency just below 72 percent, at a speed of 1600 RPM. If you look at the BHP curves, this pump requires just less than 40 BHP on the input shaft. A more accurate estimate of BHP can be calculated with equations 1 and 2.

Using equation 1, the WHP would be  $[900 \times 120] / 3960$  or 27.3, and from equation 2 the BHP would be  $27.3 / 0.72$  or 37.9, assuming the drive efficiency is 100 percent. The NPSH curve was used to calculate the Total Dynamic Suction Lift (TDSL) markers at the bottom of the chart. Notice that the TDSL at 1400 GPM is 10 feet, but at 900 GPM the TDSL is over 25 feet.

### Changing Pump Speed

In addition, suppose this pump is connected to a diesel engine. By varying the RPM of the engine we can vary the flow rate, the TDH and the BHP requirements of this pump. As an example, let's change the speed of the engine from 1600 RPM to 1700 RPM. What effect does this have on the GPM, TDH and BHP of the pump?

**Solution:** We will use equations 3, 4 and 5 to calculate the change. Using equation 3, the change in GPM would be  $(1700/1600) \times 900$ , which equals 956 GPM. Using equation 4, the change in TDH would be  $(1700/1600)^2 \times 120$ , which equals 135.5 feet of TDH. Using equation 5, the change in BHP would be  $(1700/1600)^3 \times 37.9$ , which equals 45.5 BHP. This point is plotted on Figure 2 as the circle with the dot in the middle. Note that the new operating point is up and to the right of the old point and that the efficiency of the pump has remained the same. When a pump has been selected for installation, a copy of the pump curve should be provided by the installer. In addition, if the impeller(s) was trimmed, this information should also be provided. This information will be valuable in the future, especially if repairs have to be made.

### Determining Friction Losses

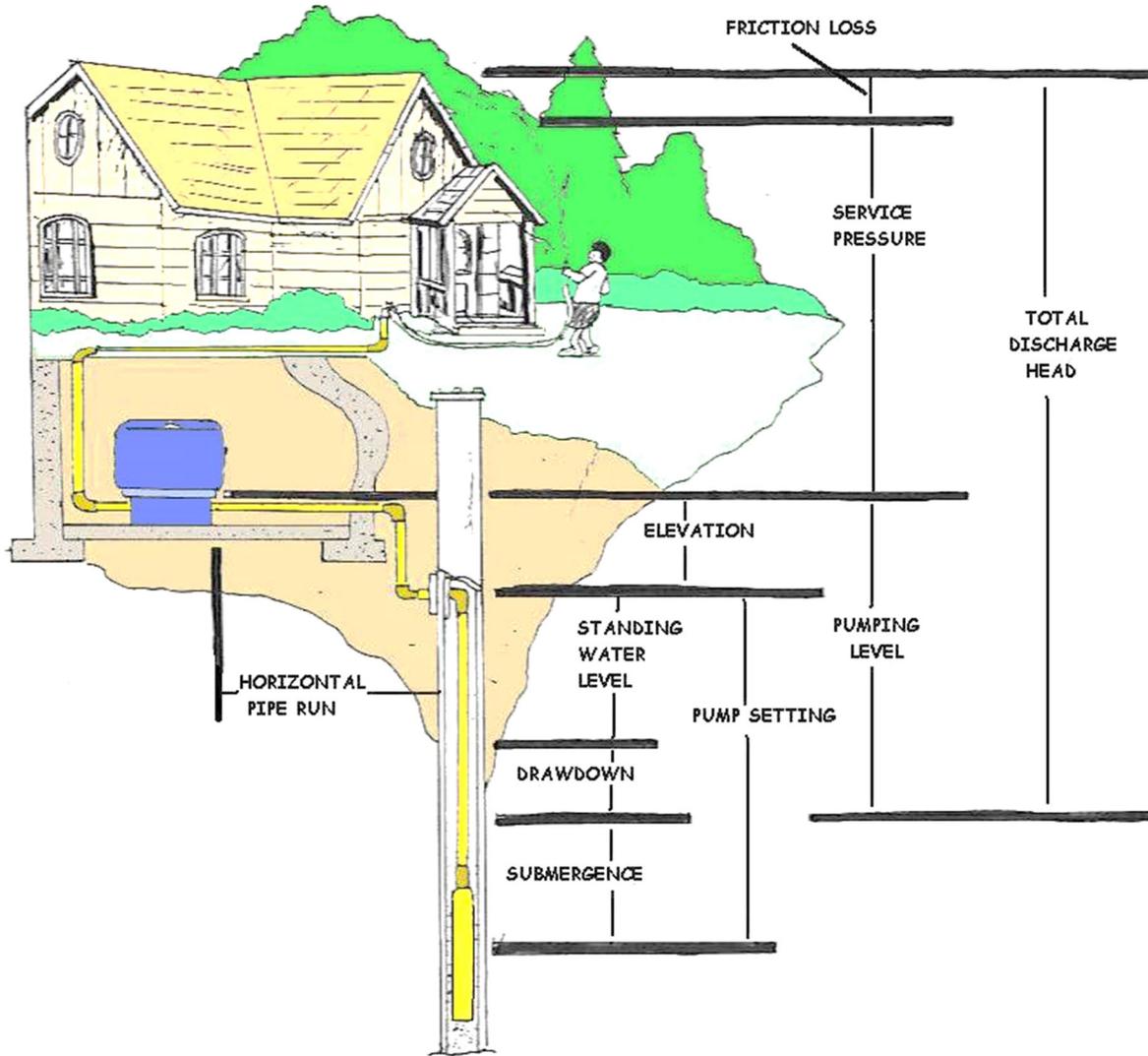
A well system installer and/or engineer can help in determining the friction losses in the distribution system. There are numerous friction loss tables with values of equivalent feet of head for given flow rates and types and diameters of pipe available. However, unless great distances or small diameter pipes are used, friction loss is almost negligible. The lift requirements for the pump primarily include the height to which the pump must deliver the water from the wellhead, plus the distance from the pumping level to the land surface.

**For example:** A municipal supply well has been tested and determined to yield 500gpm. The well was constructed with 10 inch casing that has been perforated from 200 to 500 feet below the ground surface within an unconfined aquifer. The static water level has been measured at 100 feet while the drawdown at 500gpm has been estimated at 80 feet. The full level of the storage tank for the well exerts about 87psi at the wellhead and is connected to the well via a 12-inch distribution main. Three-phase power is available and 4-inch column pipe is to be used down the hole. The pump intake is to be set at 180 feet.

Before we can select an appropriate pump, we first need to determine what the total dynamic head is. After referring to a friction loss table for flow in 4 inch and 12-inch pipe; we determine that the friction losses in the 4 inch pipe will be about 24 feet per 100 foot, while losses in the 12 inch main are negligible.

This leads us to determine that there will be about 43 feet of friction loss through the 4-inch pipe. We also know that the total lift is equal to the drawdown, plus the distance to the land surface from the static water level, plus the vertical distance to the full level of the storage tank. We know from physics that for every foot of water there is .433psi of pressure or 2.31ft of head for every 1 psi. The line pressure at the well head is equal to the height of the column of water above the well head, which gives us a line pressure at the well head of 87psi or 200 feet of water. The total lift from the pump to the wellhead 180 feet and equivalent to 78psi. So the total dynamic head is equivalent to a lift of 380 feet or an equivalent pressure of about 165psi at the pump, plus about 43 feet of friction loss. Therefore, in order to pump 500gpm under these circumstances, the pump that is selected should have its most efficient operating range in the neighborhood of 423 feet total lift. We then look at *performance curves* from the various pump manufacturers to determine the best pump and power combination for the application.

Because this is a municipal supply well that is pumping directly into the distribution system, we will choose a submersible turbine for the job rather than a line shaft turbine, which must be lubricated. Upon looking at the *curves* for this application, one will find that a 75HP, 8in, 5 stage, submersible pump will do the job most efficiently without risking the over-pumping of the well.



Elements of Total Dynamic Head for the proper selection of pumping equipment.



A new 8-inch submersible pump and motor with 6 inch column pipe about to be installed in a high capacity municipal supply well.

## The Well Head Assembly

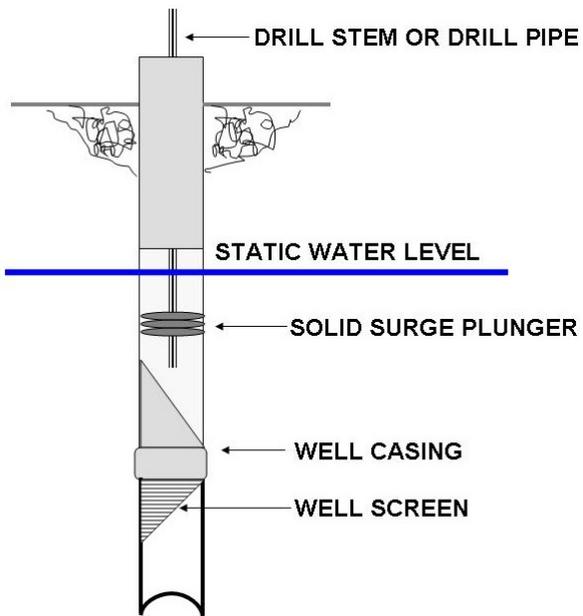
An approved well cap or seal is to be installed at the *wellhead* to prevent any contamination from entering the well through the top once construction is complete. When the well is completed with pumping equipment a well vent is also required.

The well *vent pipe* should be at least  $\frac{1}{2}$  inch in diameter, 8 inches above the finished grade, and be turned down, with the opening screened with a minimum 24-mesh durable screen to prevent entry of insects. Only approved well casing material meeting the requirements of the Code may be utilized.

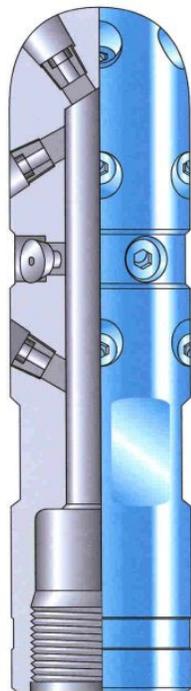
In addition, frost protection should be provided by use of insulation or pump house. Turbine and submersible pumps are normally used. Any pressure, vent, and electric lines to and from the pump should enter the casing only through a watertight seal.

Pumps and pressure tanks may be located in basements and enclosures. However, wells should not be located within vaults or pits, except with a *variance permit*. If the pump discharge line passes through the well casing underground, an approved *pitless adapter* should be installed. The *well manifold* should include an air relief valve, flow meter, sample port, isolation valve, and a check valve. If the well should need rehabilitation, additional construction, or repair, it must be done in compliance with the State or Local Water Well Construction Codes.

## Surge of Air Developing a Well.



**Jetting Nozzle**  
that can be →  
attached to  
drill pipe.



In the best of situations, a combination of methods can be used to ensure the efficient development and operation of a well.

## Pump Surging/Raw-hiding or Backwashing

**Pump surging** (sometimes called **Rawhiding**) involves the repeated pumping and resting of the well for well development purposes. A column of water that is withdrawn through a pump is allowed to surge back into the well by turning the pump on and off repeatedly. However, sufficient time for the pump motor to stop reverse rotation must be allowed, such that pump damage can be avoided. Occasionally, water is pumped to waste until it is clear of sediment before again shutting the pump off. This is done to permanently remove the sediments that are being developed by the backwashing action. The process continues until sufficient quantities of water produced are consistently clean.

**Surge-blocks, swabs, or plungers** are disc shaped devices made to fit tightly within the well. Their edges are usually fitted with rubber or leather rings to make a tight seal against the well casing. Pipe sections are then attached to the surge-block to lower it into the well, above the well screen, and about 15 feet below the water level. The assembly is then repeatedly lifted up and down.

The up and down action of the surge-block creates suction and compression strokes that force water in and out of the well through the screened interval, gravel pack, and aquifer. It works like a plunger in the way that it removes small obstructions and sediments from the well. The surge-block is slowly lowered each time resistance begins to decrease.

Once the top of the screen is reached, the assembly may be removed and accumulated sediment either bailed or airlifted out of the well. Surging within known problem areas of the screened interval may be conducted also. The cycle of swabbing and removing sediment should be continued until resistance to the action of the swab or block is significantly lower than at the start of development. The development is complete when the amount of sediment removed is both significantly and consistently less than when surging began.

**Airlifting** (or **Air surging**) involves the introduction of large short blasts of air within the well that lifts the column of water to the surface and then drop it back down again. Continuous airlifting or **air pumping** from the bottom of the well is then used occasionally to lift sediments out of the well. Airlift development is most often used following initial pump surging, and is employed to confirm that the well is productive, since the injection of air into a plugged well may result in casing or screen failure.

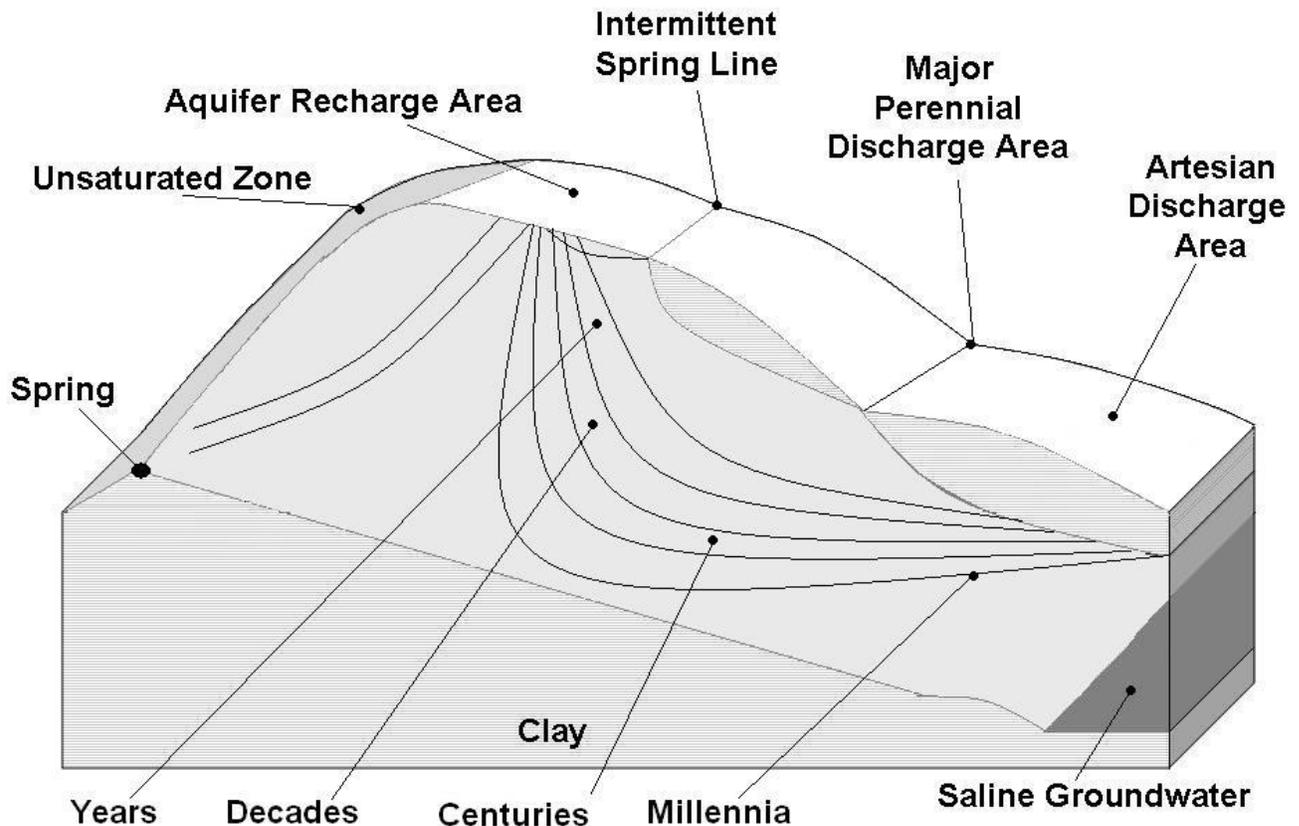
Air lifting development is most often done with a rotary drilling rig through the drill string. Sometimes special air diffusers or jets are used to direct the bursts of air into preferred directions (see jetting). Piping is inserted into the well and intermittent blasts of air are introduced as the piping is slowly lowered into the well. Sometimes surfactant or drill foam is added to aid in the efficiency of sediment removal and cleaning of the well. Air surging development is much the same as drilling the well with air rotary; only the well has already been constructed.

Specialized air development units are available independent of a drilling rig, which may be used as well. The great thing about air rotary drilled wells is that they are essentially developed while drilling, particularly in hard rock formations, when greater than 100 gallons per minute is being lifted to the surface. The development of a filter pack (if used) in such wells is still recommended.

**Jetting** is a type of well development technique in which water and/or air is *jetted* or sprayed horizontally into the well screen. This method is especially suited for application in *stratified* and *unconsolidated* formations. The water or air is forced through *nozzles* in a specially designed *jetting tool* (or simply drilled pipe and fittings) at high velocities. Normally, air lifting or pumping is used in conjunction with jetting methods in order to minimize potential damage to the well bore. Jetting with water alone can be so powerful that the sediment, which is supposed to be removed, can be forced into the formation causing clogging problems. This is why pumping or airlifting while jetting with water is so important. Jetting is normally conducted from the bottom of the well screen upwards.

### Rotary Rig

A rotary rig is often used to provide the fluid or air with sustained pressure while the tool is slowly raised up through the screen. As jetting proceeds, sediment is occasionally removed from the bottom of the well bore thru the use of a bailer or airlifting. Several passes should be made over the length of screen until sediment generation drops off. Air is normally used for jetting in shallow aquifers (less than 300 feet of submergence) due to limited supply pressures. Jetting in PVC constructed wells is not recommended since the high velocities of fluid and sediment can erode and possibly cut through the plastic well screen. In addition, wells constructed with louvered or slotted screen limit the effectiveness of jetting. In these types of wells, surging may be more effective.



## Water Storage Section

Water storage facilities and tanks are required for pressure and firefighting demands and vary in size, shape, and application. There are different types that are used in the water distribution systems, such as standpipes, elevated tanks and reservoirs, hydropneumatic tanks and surge tanks.

These tanks serve multiple purposes in the distribution system. Just the name alone can give you an idea of its purpose.

- **SURGE tanks**
- **RESERVOIRS** – Large concrete or steel underground facilities
- **ELEVATED tanks** -Water towers and Standpipes

### Surge Tanks

What really causes water main breaks - **ENERGY** - when released in a confined space, such as a water distribution system? Shock waves are created when hydrants, valves, or pumps are opened and closed quickly, trapping the kinetic energy of moving water within the confined space of a piping system.

These shock waves can create a turbulence that travels at the speed of sound, seeking a point of release.

The release the surge usually finds is an elevated tank, but the surge doesn't always find this release quickly enough. Something has to give, often times, it's your pipe fittings.

Distribution operators are aware of this phenomenon! It's called **WATER HAMMER**.

This banging can be heard as water hammer.

Try it at home - turn on your tap, then turn it off very quickly. You should hear a bang, and maybe even several. If you turn the tap off more slowly, it should stay quiet, as the liquid in the pipes slows down more gradually.

**A Surge tank should never be used for water storage.**

The goal of the water tower or standpipe is to store water high in the air, where it has lots of gravitational potential energy. This stored energy can be converted to pressure potential energy or kinetic energy for delivery to homes.

Since height is everything, building a cylindrical water tower is inefficient. Most of the water is then near the ground. By making the tower wider near the top, it puts most of its water high up.



## **Storage Reservoirs**

Storage reservoirs allow the system to meet the fluctuations in demand described earlier. It is recommended that the volume of storage be equal to from one to three days of the system's average daily use.

It is also recommended that storage reservoirs be located at a high enough elevation to allow the water to flow by gravity to the distribution system.

This, coupled with restricted usage on the part of the consumers, should provide an uninterrupted water supply in the event of pump failure, loss of power or an acute contamination event or cross-connection. Also, if applicable, some storage for fire protection should be provided.

Reservoirs are also used as detention basins to provide the required chlorine contact time necessary to ensure the adequacy of disinfection. As such, the contact time in a reservoir is greatly improved when the reservoir is constructed with a separate inlet and outlet pipe, preferably located on opposite sides of the reservoir and at different levels. Also, baffles inside the reservoir (walls, curtains, or spirals) increase the contact time by preventing the water from leaving the reservoir too quickly (known as "short-circuiting").

## **Steel Reservoirs**

Steel reservoirs or tanks generally have lower construction and installation costs than concrete, but require more maintenance.

To protect against corrosion, the exterior should be kept cleaned and painted. Interiors of steel reservoirs are commonly coated with an epoxy or enamel-type finish. Some coal-tar linings used in the past have apparently degraded over time and are implicated in the release of small amounts of solvents into the stored water.

Steel reservoirs are usually welded or bolted together and are manufactured in a variety of sizes. Small steel reservoirs can be manufactured off-site and then trucked and lifted into place. Steel tanks should be inspected once a year and repainted every 5-7 years.

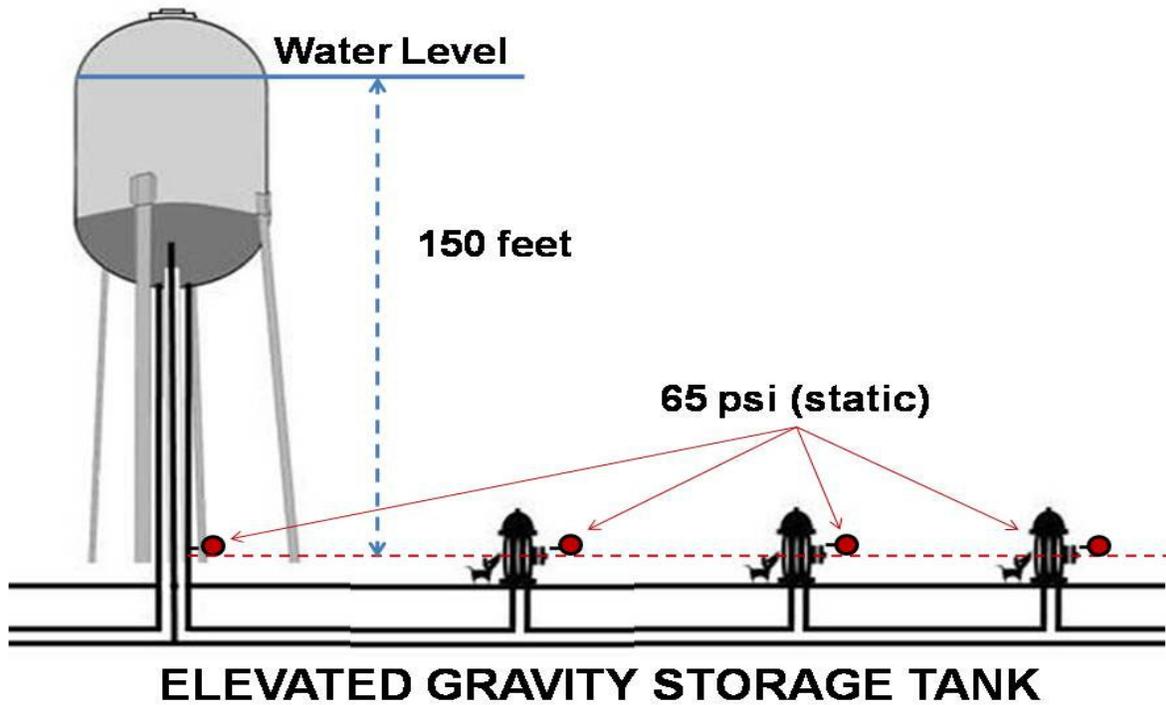
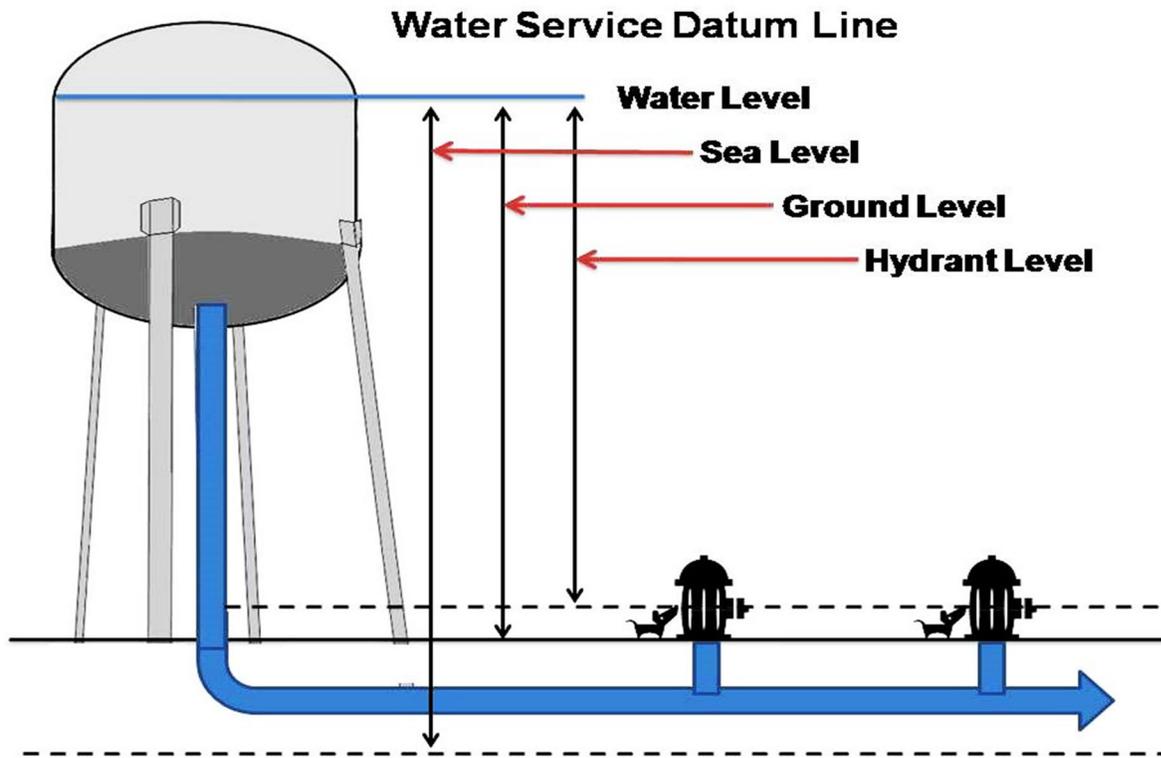
Steel tank should also have cathodic protection and be screened to keep birds and insects out. The maintenance program for reservoir tanks should call for annual draining for a complete inspection of the interior.

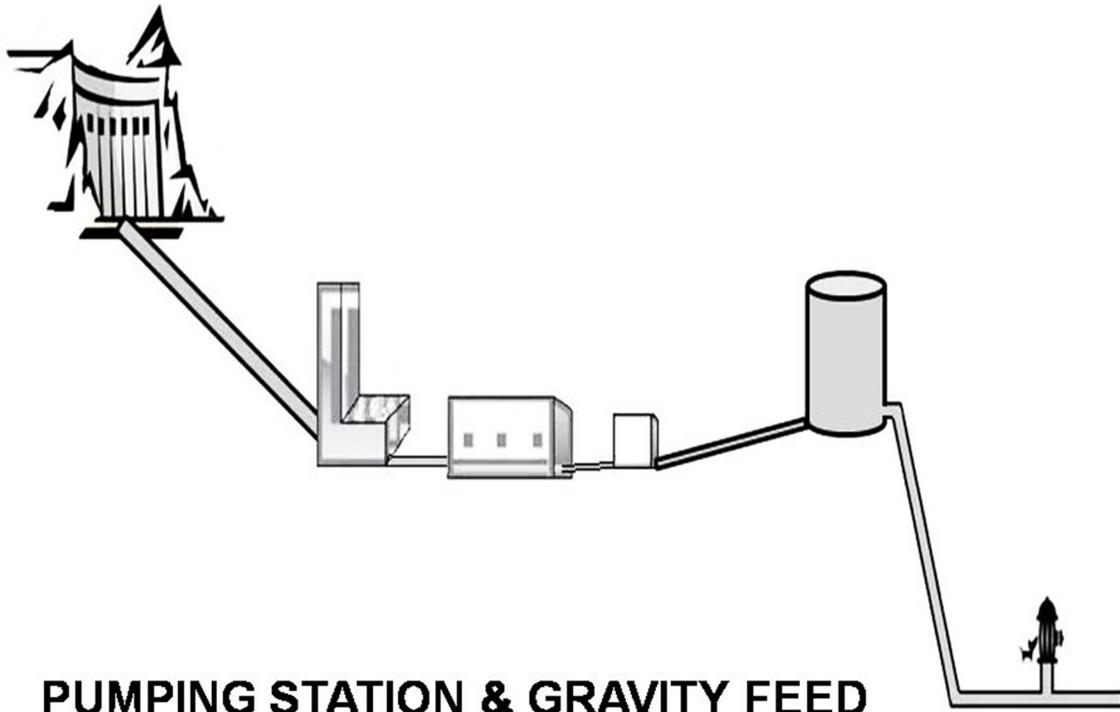
Cleaning and disinfection prior to placing the reservoir or tank back in service is necessary.

### **Disinfection by chlorine can be accomplished by one of three methods:**

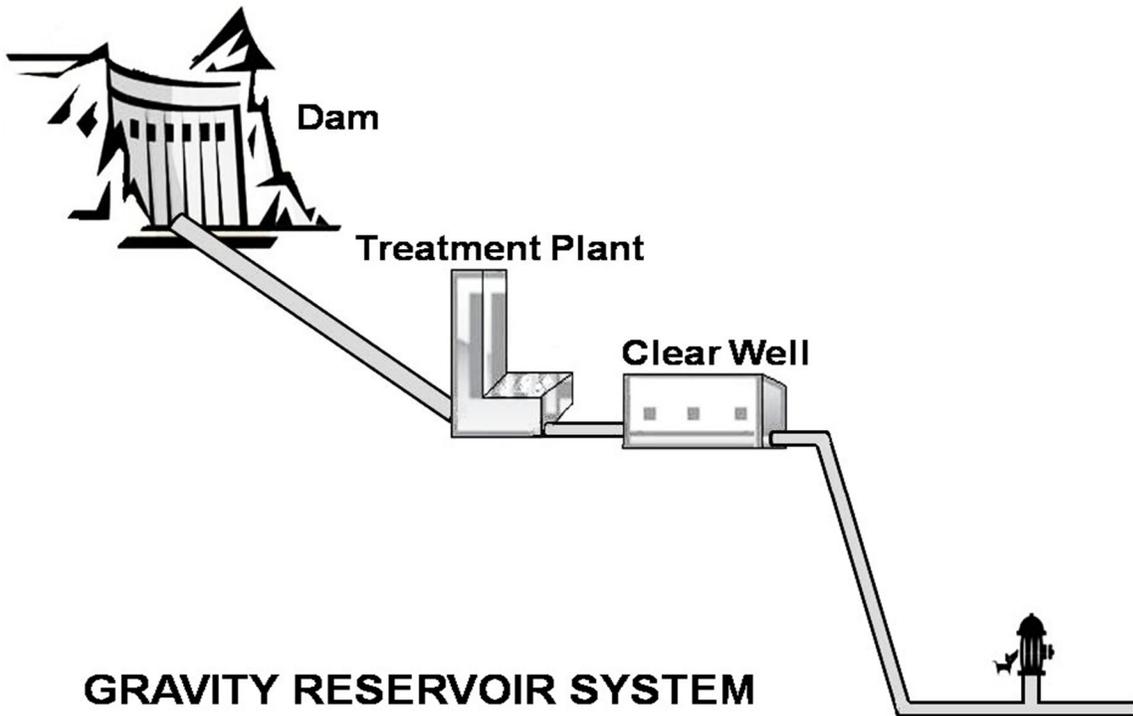
1. Fill the tank or reservoir with a 25 mg/1 chlorine solution and leave it for 24 hours.
2. Fill the reservoir with a 50 mg/1 chlorine solution and leave it for 3 hours.
3. Spray or brush on a 200 mg/1 chlorine solution and allow it to remain for 3 hours.

The chlorinated water shall be disposed of in a manner that will not have an adverse effect on the environment. Check with your state environmental, health or drinking water section.





**PUMPING STATION & GRAVITY FEED**



**GRAVITY RESERVOIR SYSTEM**

## Distribution Storage Functions

Storage within a distribution system enables the system to process water at times when treatment facilities otherwise would be idle. It is then possible to distribute and store water at one or more locations in the service area that are closer to the user.



### 1. Advantages.

The principal advantages of distribution storage include the fact that storage equalizes demands on supply sources, production works, and transmission and distribution mains. As a result, the sizes or capacities of these elements need not be so large. Additionally, system flows and pressures are improved and stabilized to better serve the customers throughout the service area. Finally, reserve supplies are provided in the distribution system for emergencies, such as firefighting and power outages.

### 2. Meeting system demands and required fire flow.

The location, capacity, and elevation (if in fact elevated) of distribution storage are closely associated with system demands and the variations in demand that occur throughout the day in different parts of the distribution system. System demands can be determined only after a careful analysis of an entire distribution system. However, some general rules may serve as a guide to such analysis.

## **Elevated and Ground-Level Storage**

Storage within the distribution system normally is provided in one of two ways: elevated storage or ground storage with high-service pumping. It should be noted that elevated storage provides the best, most reliable and most useful form of storage, particularly for structural fire suppression.

### **Elevated Storage**

Properly sized elevated water tanks provide dedicated fire storage and are used to maintain constant pressure on the water supply distribution system.

Domestic water supplies are regularly fed to the system from the top 10 to 15 feet of water in the elevated tanks. As the water level in the tank drops, the tank controls call for additional high-service pumps to start in order to satisfy the system demand and refill the tanks. The high-service pumps are constant-speed units, which can operate at their highest efficiency point virtually all the time. The remaining water in the tanks (70 to 75 percent) normally is held in reserve as dedicated fire storage. This reserve will feed into the system automatically as the fire-flow demand and the domestic use at a specific time exceed the capacity of the system's high-service pumps.

### **Ground Storage**

Since water kept in ground storage is not under any significant pressure, it must be delivered to the point of use by pumping equipment. This arrangement limits the water distribution system's effectiveness for fire suppression in three ways:

1. There must be sufficient excess pumping capacity to deliver the peak demand for normal uses as well as any fire demand, which requires a generally unused investment in pumping capacity. The pumps are activated periodically to redistribute the water in the holding tank to avoid stagnation of the water.
2. Standby power sources and standby pumping systems must be maintained at all times because the system cannot function without the pumps.
3. The distribution lines to all points in the water distribution system must be significantly oversized to handle peak delivery use plus fire flow, no matter where the fire might occur near one or more fire hydrants on the piping system.

However, in hilly areas it is frequently possible to install ground reservoirs at sufficient elevation so that the water would "float" on the distribution system. This eliminates the need for pumps at the ground-storage facility. If the desired overflow elevation can be achieved on a hill, a considerably larger storage capacity can be installed when compared to an elevated tank. This may result in placement of the storage facility on a hill in a less desirable location.

Such a placement would provide larger storage capacity than could be achieved by an elevated storage tank(s), or it should provide the equivalent storage more economically. When ground-level storage is used in areas of high fire risks, the energy that would be needed to deliver the water is lost on the initial delivery of water to the tank.

The water supply must be re-pumped and re-pressurized with the consequent addition of more standby generators and more standby pumps. In addition, the system's high-service pumps must be either variable speed or controlled by discharge valves to maintain constant system pressures.

This equipment is expensive, uses additional electrical power, and requires extensive operation and maintenance. Frequently, the additional capital costs for pumps, generators, and backup systems, and the long-term energy costs, significantly increase the costs of a ground-storage system.

### **Chemical Contaminants in Storage Tanks**

Coating materials are used to prevent corrosion of steel storage tanks and to prevent moisture migration in concrete tanks. Through the 1970's, coatings used in finished water storage facilities were primarily selected because of their corrosion resistance and ease of application. This led to the use of industrial products like coal tars, greases, waxes and lead paints as interior tank coatings. These products offered exceptional corrosion performance but unknowingly contributed significant toxic chemicals to the drinking water.

Grease coatings can differ greatly in their composition from vegetable to petroleum based substances and can provide a good food source for bacteria, resulting in reduced chlorine residuals and objectionable tastes and odors in the finished water (Kirmeyer et al. 1999).

### **Indicators of Water Quality Problems within Storage Facilities**

There are several indicators that may suggest water quality problems are occurring within storage facilities. These include aesthetic considerations that may be identified by consumers, as well as the results of storage facility monitoring efforts. It should be noted that indicators can be triggered by factors other than water age, such as insufficient source water treatment, pipe materials, and condition/age of distribution system and storage facility.

#### **Aesthetic Indicators**

The following indicators may be identified during water consumption:

- Poor taste and odor – Aged, stale water provides an environment conducive to the growth and formation of taste and odor causing microorganisms and substances.
- Improperly cured coatings can impart taste and odor to the stored water.
- Sediment accumulation – Improperly applied coatings can slough off reservoirs and accumulate at the bottom. Sediment carried into the storage facility from the bulk water can accumulate within the reservoir if reservoir maintenance and cleaning are not routinely performed.

#### **Water Temperature**

Stagnant water will approach the ambient temperature. Temperature stratification within reservoirs will impede mixing. Turnover due to stratification can entrain accumulated sediment.

#### **Monitoring Indicators**

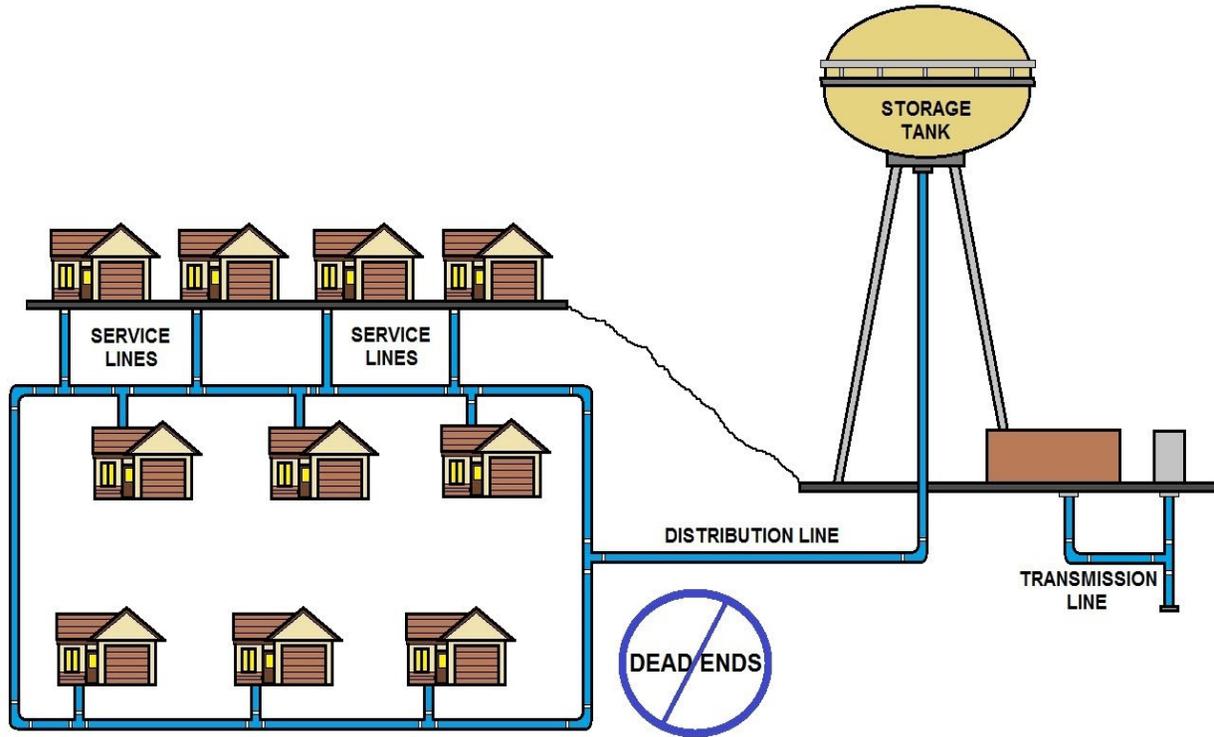
The following indicators require sample collection and analysis:

- Depressed disinfectant residual – Chlorine and chloramines undergo decay over time.
- Elevated DBP levels – The reaction between disinfectants and organic precursors occur over long periods.
- Elevated bacterial counts (i.e., heterotrophic plate count).
- Elevated nitrite/nitrate levels (nitrification) for chloraminating systems.

**References**

*Water Supply Systems• Vol. II: Evaluation Methods October 2008 FEMA U.S. Fire Administration Harry E. Hickey, Ph.D.*

*EPA Office of Water (4601M), Office of Groundwater and Drinking Water, Distribution System Issue Paper, Finished Water Storage Facilities*



**EXAMPLE OF BASIC WATER DISTRIBUTION SYSTEM**

## Hydropneumatic Tank Section

### Hydropneumatic Tanks Out of Service for Maintenance Effects on the Water Supply

Whenever a tank must be taken out of service for maintenance, the operator should insure that the water pressure is maintained by other back-up tanks in the system. If this is not possible, customers should be given as much advance notice as possible, maintenance should be conducted during periods of low water demand, and the maintenance should be conducted as quickly as possible to reduce the time without water service.

### Troubleshooting Hydropneumatic Tank Problems

The purpose of a hydropneumatic tank is to provide air for the water system. It is the responsibility of the operator to perform basic troubleshooting of problems in hydropneumatic tank systems. The operator has to decide, based on his/her own training and capability when a problem requires assistance from another operator or an outside expert.

Operators should not hesitate to seek assistance if they are uncomfortable with a particular problem or situation. Remember, the goal is to provide a safe and consistent supply of water and this cannot always be accomplished by one or two individuals who may have many other responsibilities. Corrective action should only be performed by individuals who are trained and skilled in that particular area.

Corrective actions by unskilled individuals could result in personal injury or serious damage to the water system equipment. The following troubleshooting table is provided to assist operators of small water systems to troubleshoot basic problem with hydropneumatic tanks.

It must be recognized that problems occurring in hydropneumatic tanks could also be related to the well, water supply pump and controls, and the distribution system, therefore other troubleshooting tables included in this manual should be consulted in addition to the troubleshooting table for hydropneumatic tanks.

### Troubleshooting Table for Hydropneumatic Tanks Problem

1. Well pump will not start.
2. Well pump will not shut off.
3. Well pump starts and stops too frequently (Excessive cycle rate).
4. Sand / sediment is present in the water.
5. Air is present in the water.
6. Oil is present in the water.
7. Dirt and or bacteria present in the water.
8. Excessively high distribution system pressure (greater than 70 psi).
9. Excessively low distribution system pressure (normal working pressure below 40 psi or occasional pressures below 20 psi during peak usage).
10. Corrosion present on outside of tank.
11. Tank is unstable and can be easily be moved, or tank is supported by the piping.

## Possible Hydropneumatic Tank Problem Causes

- 1A. Circuit breaker or overload relay tripped.
- 1B. Fuse(s) burned out.
- 1C. No power to switch box.
- 1D. Short, broken or loose wire.
- 1E. Low voltage.
- 1F. Defective motor.
- 1G. Defective pressure switch.
- 2A. Defective pressure switch.
- 2B. Cut-off pressure setting too high.
- 2C. Float switch or pressure transducer not functioning.
- 3A. Leaking foot valve or check valve.
- 3B. Defective pressure switch or automatic control system. High or Low pressure cutoff switches may need to be adjusted.
- 3C. Excessive water use or major leak in water distribution system.
- 3D. Water-logged hydropneumatic tank.
- 3E. Air-logged hydropneumatic tank.
- 4A. Problems with well screen or gravel
- 4B. If there is iron or manganese in the well water and it is not removed before the hydropneumatic tank, and the air in the hydropneumatic tank comes into direct contact with the water in the tank, then the iron and manganese could be oxidizing and settling in the tank. Also, sediment could be present in the distribution system.
- 5A. If there is a check valve between the well pump and the hydropneumatic tank, and air is present on the well side of the check valve, then the pump may be breaking suction. In this case, the water level in well is near or below the pump intake.
- 5B. If there is a check valve between the well pump and the hydropneumatic tank, and air is present only on the hydropneumatic tank side of the check valve and in the distribution system, then air from hydropneumatic may be tank entering water.
- 6A. Oil leaking from air compressor.
- 7A. Refer to troubleshooting table on "*hypochlorinators*."
- 7B. Replace filter. Also review troubleshooting table on "*hypochlorinators*." Notify water system specialist.
- 8A. See Problem Item #2 in this troubleshooting table.
- 9A. Refer to troubleshooting guide section "*Pumps*." Notify supervisor.
- 10A. Clean area with a wire brush. Prime and paint the surface with. Do not chip rust from the tank unless it is drained and out of service. If chipping is required, contact a tank corrosion specialist. The tank may not be structurally sound and re-pressurizing could cause further damage or personal injury. Note: 50 psi exerts a pressure of 3.5 tons per square foot! Never paint the tank interior without first consulting the state regulatory authority.
- 11A. Provide suitable and permanent supports so the tank cannot be moved and the piping is not supporting the weight of the tank. This may require taking the system out of service while these repairs are made. Never try to move a tank that is pressurized. Notify your water system specialist.

## Possible Hydropneumatic Tank Solutions

- 1A. Reset breaker or manual overload relay.
- 1B. Check for cause and correct, replace fuse(s).
- 1C. Check incoming power supply. Contact power company.
- 1D. Check for shorts and correct, tighten terminals, replace broken wires.
- 1E. Check incoming line voltage. Contact power company if low.
- 1F. Contact electrical contractor.
- 1G. Check voltage of incoming electric supply with pressure switch closed. Contact power company if voltage low. Perform maintenance on switch if voltage normal. Refer to troubleshooting table on "Pumps."
- 3A. Contact well specialist.
- 3B. Contact well specialist or electrician.
- 3C. Locate and repair leak.
- 3D. Check air-to-water ratio from sight tube (if provided). If the tube is completely filled with water or if the water level exceeds 2/3 of the volume of the tank, then air will have to be introduced into the tank. Check tank and air system for leaks. The optimum air-to-water ratio in the hydropneumatic tank should be 2/3 water to 1/3 air. If the problem persists or if there is no sight tube, notify water system specialist.
- 3E. Check air-to-water ratio from sight tube (if provided). If the tube is completely filled with air or if the water level is less than 1/2 of the volume of the tank, then air will have to be bled from the tank. The optimum air-to-water ratio should be 2/3 water to 1/3 air. If the problem persists or if there is no sight tube, notify water system specialist.
- 4A. Contact well contractor.
- 4B. Check air-to-water ratio from sight tube (if provided). If the tube is completely filled with air or if the water level is less than 1/2 of the volume of the tank, then air will have to be bled from the tank. The optimum air-to-water ratio should be 2/3 water to 1/3 air. If the problem persists or if there is no sight tube, notify water system specialist. If there is a physical separation between the air and water in the tank, then the separator could have broken. Notify water system specialist.
- 5A. Partially throttle discharge valve. Notify supervisor or well service company.
- 5B. Improve removal of iron and manganese. If the hydropneumatic tank is equipped with a drain, open the drain valve and discharge the sediment to waste.
- 6A. Check the oil separator on the discharge side to the air compressor. Notify water system specialist. Consider replacing the unit with a non-oil lubricated type unit.
- 7A. Inadequate disinfection.
- 7B. Intake filters on air compressor broken or dirty.
- 8A. Automatic pressure controls needs adjustment or cut-out sequence is not functioning.
- 9A. Automatic pressure controls needs adjustment or cut-in sequence is not functioning.
- 10A. Inadequate protective coating (paint).
- 11A. Tank supports are inadequate.

**Note:** If the water supply pump is running constantly, excessive pressures can develop in the hydropneumatic tank and distribution system. The tank should be equipped with a pressure relief valve that opens at approximately 100 psi. This may protect the tank from damage but it is possible that the distribution system could be damaged if pressures exceed normal working pressures. Check for leaks throughout the service area. Notify electrician experienced with industrial controls.

## **Water Use or Demand**

Water system demand (usage) comes from a number of sources including residential, commercial, industrial and public consumers as well as some unavoidable loss and waste. If fire protection is desired, that could also represent a rather significant (although not continuous) demand upon the system. The combination of storage reservoirs and distribution lines must be capable of meeting consumers' needs for quality, quantity and pressure at all times. The quantity of water used in any community varies from 50 to 500 gallons per person per day.

A common design assumption is to use from 100 to 200 gallons per person per day for average domestic use. The maximum daily use is approximately 2 to 3 times the average daily use. Maximum daily use is usually encountered during the summer months and can vary widely depending on irrigation practices.

### **Water Pressure**

For ordinary domestic use, water pressure should be between 25 and 45 psi. A minimum of 60 psi at a fire hydrant is usually adequate, since that allows for up to 20 psi pressure drop in fire hoses.

In commercial and industrial districts, it may be common to have 75 psi or higher. 20 psi is considered the minimum required at any point in the water system, so that backflow and infiltration is prevented.

Pressure is provided by the direct force of the water (such as water from a pump), or by the height of the water (such as a storage reservoir). 2.31 feet of water is equal to 1 psi, or 1 foot of water is equal to about a half a pound (.433 pounds to be exact).

### **Storage and Distribution**

The cost of supplying water to the users of any water system includes the installation of storage and distribution facilities. Also, there are on-going maintenance costs associated with cleaning, repairing and replacing these facilities. The distribution system must also protect water quality between the source and the customer's tap.

Proper construction is important in maintaining system integrity. Care must be taken that no foreign material is introduced into the system during pipe laying operations. Pipe ends should be covered at the end of the work day or during interruptions of construction.

All pipes, joints and fittings should be pressure tested and disinfected with a 5% chlorine solution such as household bleach before backfilling. It is also important that all materials in contact with potable water meet the requirements of the National Sanitation Foundation (NSF) or American Water Works Association (AWWA) or have equivalent third-party certification. This includes solders (must be lead-free), pipes, joining and sealing materials, and protective coatings.

## **New EPA Rules for Distribution Reduction of Lead in Drinking Water Act**

Congress passed Public Law 111-380 or The Reduction of Lead in Drinking Water Act, in 2010. It went into effect Jan. 4, 2014, which means municipalities, water districts and developers who work with and pay for water infrastructure need to lead compliance.

Lead, a metal found in natural deposits, is commonly used in household plumbing materials and water service lines. The greatest exposure to lead is swallowing or breathing in lead paint chips and dust.

But lead in drinking water can also cause a variety of adverse health effects. In babies and children, exposure to lead in drinking water above the action level can result in delays in physical and mental development, along with slight deficits in attention span and learning abilities. In adults, it can cause increases in blood pressure. Adults who drink this water over many years could develop kidney problems or high blood pressure.

Lead is rarely found in source water, but enters tap water through corrosion of plumbing materials. Homes built before 1986 are more likely to have lead pipes, fixtures and solder. However, new homes are also at risk: even legally “lead-free” plumbing may contain up to 8 percent lead. The most common problem is with brass or chrome-plated brass faucets and fixtures which can leach significant amounts of lead into the water, especially hot water.

Congress enacted the Reduction of Lead in Drinking Water Act on January 4, 2011, to amend Section 1417 of the Safe Drinking Water Act (SDWA) regarding the use and introduction into commerce of lead pipes, plumbing fittings or fixtures, solder and flux. The Act established an effective date of January 4, 2014, which provided a three year timeframe for affected parties to transition to the new requirements.

### **Pervasive Environmental Contaminant**

Lead is a pervasive environmental contaminant. The adverse health effects of lead exposure in children and adults are well documented, and no safe blood lead threshold in children has been identified. Lead can be ingested from various sources, including lead paint and house dust contaminated by lead paint, as well as soil, drinking water, and food. The concentration of lead, total amount of lead consumed, and duration of lead exposure influence the severity of health effects. Because lead accumulates in the body, all sources of lead should be controlled or eliminated to prevent childhood lead poisoning.

Beginning in the 1970s, lead concentrations in air, tap water, food, dust, and soil began to be substantially reduced, resulting in significantly reduced blood lead levels (BLLs) in children throughout the United States. However, children are still being exposed to lead, and many of these children live in housing built before the 1978 ban on lead-based residential paint. These homes might contain lead paint hazards, as well as drinking water service lines made from lead, lead solder, or plumbing materials that contain lead. Adequate corrosion control reduces the leaching of lead plumbing components or solder into drinking water.

The majority of public water utilities are in compliance with the Safe Drinking Water Act Lead and Copper Rule (LCR) of 1991. However, some children are still exposed to lead in drinking water. EPA is reviewing LCR, and additional changes to the rule are expected that will further protect public health. Childhood lead poisoning prevention programs should be made aware of the results

of local public water system lead monitoring measurement under LCR and consider drinking water as a potential cause of increased BLLs, especially when other sources of lead exposure are not identified.

This review describes a selection of peer-reviewed publications on childhood lead poisoning, sources of lead exposure for adults and children, particularly children aged <6 years, and LCR. What is known and unknown about tap water as a source of lead exposure is summarized, and ways that children might be exposed to lead in drinking water are identified.

This report does not provide a comprehensive review of the current scientific literature but builds on other comprehensive reviews, including the *Toxicological Profile for Lead* and the 2005 CDC statement *Preventing Lead Poisoning Among Young Children*). When investigating cases of children with BLLs at or above the reference value established as the 97.5 percentile of the distribution of BLLs in U.S. children aged 1–5 years, drinking water should be considered as a source. The recent recommendations from the CDC Advisory Committee on Childhood Lead Poisoning Prevention to reduce or eliminate lead sources for children before they are exposed underscore the need to reduce lead concentrations in drinking water as much as possible.

## **Background**

Lead is a relatively corrosion-resistant, dense, ductile, and malleable metal that has been used by humans for at least 5,000 years. During this time, lead production has increased from an estimated 10 tons per year to 1,000,000 tons per year, accompanying population and economic growth.

The estimated average BLL for Native Americans before European settlement in the Americas was calculated as 0.016  $\mu\text{g}/\text{dL}$ . During 1999–2004, the estimated average BLL was 1.9  $\mu\text{g}/\text{dL}$  for the non-institutionalized population aged 1–5 years in the United States, approximately 100 times higher than ancient background levels, indicating that substantial sources of lead exposure exist in the environment.

## **January 4, 2014**

On January 4, 2014, the "Reduction of Lead in Drinking Water Act" became effective nationwide. This amendment to the 1974 Safe Drinking Water Act reduces the allowable lead content of drinking water pipes, pipe fittings and other plumbing fixtures. Specifically, as of January 4, 2014, it shall be illegal to install pipes, pipe fittings, and other plumbing fixtures that are not "lead free." "Lead free" is defined as restricting the permissible levels of lead in the wetted surfaces of pipes, pipe fittings, other plumbing fittings and fixtures to a weighted average of not more than 0.25%.

This new requirement does not apply to pipes, pipe fittings, plumbing fittings or fixtures that are used exclusively for non-potable services such as manufacturing, industrial processing, irrigation, outdoor watering, or any other uses where water is not anticipated to be used for human consumption. The law also excludes toilets, bidets, urinals, fill valves, flushometer valves, tub fillers, shower valves, service saddles, or water distribution main gate valves that are 2 inches in diameter or larger.

Accordingly, effective January 4, 2014, only accepted products that are "lead free" may be utilized with regards to any plumbing providing water for human consumption (unless meeting the exception outlined above). Installers and inspectors may check their products to determine if they meet these requirements by looking to see if the products are certified to the following standards:

- A. NSF/ANSI 61-G;
- B. NSF/ANSI 61, section 9-G; OR
- C. Both NSF/ANSI 61 AND NSF/ANSI 372.

As existing products may still be utilized for non-potable purposes. The burden of following these requirements shall be on installers. Plumbing inspectors (who will be covering these requirements in continuing education) shall have the right to question installers, who must be able to prove that no non-compliant products are installed on or after January 4, 2014.

#### **What does the law say?**

It reduces the maximum amount of lead that can be used in the wetted surfaces of service brass from 8 percent to 0.25 percent. It prohibits the sale of traditional brass pipe fittings, valves and meters for potable water applications as well as their installation after Jan. 4, 2014.

#### **Does The Reduction of Lead in Drinking Water Act apply to all water infrastructure?**

No. Service brass used in industrial or non-potable infrastructure is exempt from the law. Also, the law only applies to wetted surfaces. Saddles and other exterior pipe are also exempt.

#### **Are there any exceptions to the New Regulations?**

Exceptions to the new lead-free law include: pipes, pipe fittings, plumbing fittings, or fixtures, including backflow preventers, that are used exclusively for non-potable services such as manufacturing, industrial processing, irrigation, outdoor watering, or any other uses where the water is not anticipated to be used for human consumption. In addition, toilets, bidets, urinals, fill valves, flushometer valves, tub fillers, shower valves, service saddles, or water distribution main gate valves that are 2 inches in diameter or larger are excluded from the new lead-free law.

#### **Who does the New Regulations apply to?**

If you use or introduce into commerce any pipe, valves, plumbing fittings or fixtures, solder, or flux intended to convey or dispense water for human consumption, your products must comply with the law. Additionally, if you introduce into commerce solder or flux, your products must comply with the law.

#### **If I am a homeowner, how do I know my water system is lead-free?**

Many manufacturers have already complied with the January 4th, 2014 implementation date of the federal "Reduction of Lead in Drinking Water Act." Even without federal certification requirements regarding the lead content of plumbing products, California's mandate for third-party certification will be followed by most manufacturers seeking a single approval path that covers both federal and state requirements. For that reason, it is important to use and install only clearly marked low-lead products.

If you are a homeowner and are concerned about potential lead exposure from your private water system, have your water tested by a state certified water testing laboratory in your area.

**Is there a difference between low-lead and no-lead brass?**

No. There are several terms flying around to refer to the low-lead service brass products – no lead, lead free, low lead, and others. They all refer to the same products: service brass with 0.25 percent or less lead on wetter surfaces.

**How are the new alloys different?**

Functionally, there is almost no difference. For water utilities and contractors working with the material, it will handle just like traditional service brass. The difference is in the manufacturing. Lead has traditionally been used to fill gaps, seal the surface and create a smooth pipe interior that doesn't have gaps or pits where debris can settle and erode the metal.

Instead of lead, manufacturers will have to use different and more expensive materials and take more care in the manufacturing process. That means the cost of the new low-lead brass will be 25 to 40 percent higher than traditional brass pipe fittings and meters.

**What are the biggest concerns for developers, municipalities and water districts?**

There are two big concerns that should inspire anyone responsible for laying water infrastructure to act soon. If you have inventory of traditional service brass, now is the time to find a place to use it.

The second concern is cost. If you don't have an inventory of traditional brass but you have upcoming projects, this might be the ideal time to start them. Order traditional brass pipe fittings and meters from suppliers who are offering their traditional service brass at steep discounts ahead of the new law. After the law goes into effect, service brass costs will skyrocket and significantly increase your costs.

**Lead-free Alternatives**

There are several materials that utilities should consider when selecting a lead-free meter alternative. Various options include epoxy coated ductile and cast iron, stainless steel, low lead bronze and composite.

When choosing a lead-free alternative material, utilities must consider traditional meter requirements such as strong flow capability and durability. However, the difference between lead-free and zero lead meters should also be considered. Some "lead-free" meters contain as much as 0.25 percent lead.

While a 0.25 percentage of lead in meters allows utilities to meet current regulations, implementing these "lead-free" meters could put utilities at risk for the cost of another meter change out should future regulations require complete lead elimination from water meters. Most water meters are expected to last more than 20 years, meaning that the next amendment to SDWA could come before the meter fleet must be replaced. This could be potentially devastating for utility companies still using older systems should completely lead-free meters become mandated.

**Composite Meters**

Composite meters are one example of a zero lead alternative that is not susceptible to future no-lead regulations. This meter material is also gaining popularity due to its strength and cost stability. Composite meters do not depend on metal pricing fluctuations and, more importantly, have zero lead as opposed to low lead or even bronze meters.

Made of materials that have already proven their strength and durability in the automotive and valve industries, composite meters boast longevity and resistance to corrosion from aggressive water and from the chlorinated chemicals used to make water drinkable. Composite meters are also equipped to withstand the pressure required to maintain a water system.

Composite meters are constructed using a blend of plastic and fiberglass. When compared to bronze water meter products, composites are lighter and require less time and energy to manufacture, ship and install. Composite meters attached with composite threads have been found to eliminate the “friction feeling” typically experienced with metal threads and metal couplings, facilitating easier installation.

Through comprehensive testing, composite meters have demonstrated a burst pressure that is significantly greater than bronze and an equal longevity. Composite technology today allows for better, more environmentally friendly composite products that will last up to 25 years in residential applications. Manufacturers have a wide range of “lead-free” or zero lead products on the market and it is critical that utilities consider all of their options when selecting a new fleet of meters.

Most importantly, everyone deserves access to safe, clean water. It is essential that manufacturers continually develop and deliver products that meet the highest standards for safety, quality, reliability and accuracy to ensure availability to, and conservation of, this most precious resource.

### **Lead in Drinking Water**

Lead is unlikely to be present in source water unless a specific source of contamination exists. However, lead has long been used in the plumbing materials and solder that are in contact with drinking water as it is transported from its source into homes. Lead leaches into tap water through the corrosion of plumbing materials that contain lead. The greater the concentration of lead in drinking water and the greater amount of lead-contaminated drinking water consumed, the greater the exposure to lead. In children, lead in drinking water has been associated both with BLLs  $\geq 10$   $\mu\text{g}/\text{dL}$  as well as levels that are higher than the U.S. GM level for children (1.4  $\mu\text{g}/\text{dL}$ ) but are  $< 10$   $\mu\text{g}/\text{dL}$ .

### **History of Studies on Lead in Water**

In 1793, the Duke of Württemberg, Germany, warned against the use of lead in drinking water pipes, and in 1878, lead pipes were outlawed in the area as a result of concerns about the adverse health effects of lead in water. In the United States, the adverse health consequences of lead-contaminated water were recognized as early as 1845. A survey conducted in 1924 in the United States indicated that lead service lines were more prevalent in New England, the Midwest, Montana, New York, Oklahoma, and Texas.

A nationwide survey conducted in 1990 indicated that 3.3 million lead service lines were in use, and the areas where they were most likely to be used were, again, the Midwestern and northeastern regions of the United States. This survey also estimated that approximately 61,000 lead service lines had been removed through voluntary programs during the previous 10 years.

Research on exposure to lead in water increased as concern about the topic increased, and efforts were made to establish a level of lead in water that, at the time of the studies, was considered acceptable. A 1972 study in Edinburgh, Scotland, obtained 949 first-flush water samples (i.e., samples of water from the tap that have been standing in the plumbing pipes for at least 6 hours) matched with 949 BLLs, as well as 205 running water samples matched to 205 BLLs .

No dose-response relationship could be determined when comparing BLLs with four levels of lead in both first-flush water and in running water ( $<0.24 \mu\text{mol/L}$ ;  $0.24\text{--}0.47 \mu\text{mol/L}$ ;  $0.48\text{--}1.43 \mu\text{mol/L}$ ; and  $\geq 1.44 \mu\text{mol/L}$ ).

The study concluded that the findings challenged whether it was necessary to lower the water lead concentration to  $<100$  ppb, which at that time was the acceptable concentration established by the World Health Organization. However, the study also reported that low levels of environmental lead exposure could have adverse health effects; therefore, knowing the degree of lead exposure from household water relative to other sources is important. Another study, in 1976, of 129 randomly selected homes in Caernarvonshire, England, reported a similar finding, describing the relationship between blood and water lead as slight.

### **Monitoring and Reporting**

To ensure that drinking water supplied by **all** public water supply systems as defined by the EPA meet Federal and State requirements, water system operators are required to collect samples regularly and have the water tested. The regulations specify minimum sampling frequencies, sampling locations, testing procedures, methods of keeping records, and frequency of reporting to the State. The regulations also mandate special reporting procedures to be followed if a contaminant exceeds an MCL.

All systems must provide periodic monitoring for microbiological contaminants and some chemical contaminants. The frequency of sampling and the chemicals that must be tested for depend on the physical size of the water system, the water source, and the history of analyses. General sampling procedures are covered in more detail under the topic of Public Health Considerations to follow.

State policies vary on providing laboratory services. Some States have laboratory facilities available to perform all required analyses or, in some cases, a certain number of the required analyses for a system. In most States, there is a charge for all or some of the laboratory services. Sample analyses that are required and cannot be performed by a State laboratory must be taken or sent to a State-certified private laboratory.

If the analysis of a sample exceeds an MCL, resampling is required, and the State should be contacted immediately for special instructions. There is always the possibility that such a sample was caused by a sampling or laboratory error, but it must be handled as though it actually was caused by contamination of the water supply. The results of all water analyses must be periodically sent to the State of origin. Failure to have the required analysis performed or to report the results to the State usually will result in the water system being required to provide PN. States typically have special forms for submitting data, and specify a number of days following the end of the monitoring period by which the form is due.

### **General Disinfection Requirements**

Disinfection is absolutely required for all water systems using surface water sources. Various chemicals other than chlorine can be used for treatment of surface water, but as the water enters the distribution system, it must carry a continuous chlorine residual that will be retained throughout the distribution system. Water samples from points on the distribution system must be analyzed periodically to make sure an adequate chlorine residual is being maintained.

In spite of the fact that use of chlorine has almost completely eliminated occurrences of waterborne diseases in the United States, there is no concern for byproducts formed when chlorine reacts with naturally occurring substances in raw water (such as decaying vegetation containing humic and fulvic acids).

The first group of byproduct chemicals identified was tri-halo-methane (THM), a group of organic chemicals that are known carcinogens (cancer-forming) to some animals, so they are assumed also to be carcinogenic to humans. Other byproducts of disinfection have been identified that may be harmful, and there also is concern now that disinfectants themselves may cause some adverse health reactions.

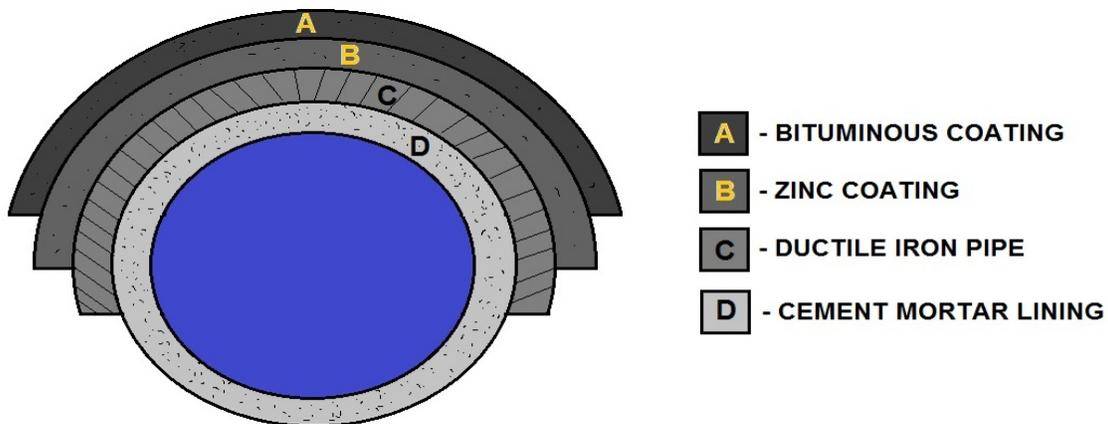
### Consumer Confidence Reports

One of the very significant provisions of the 1996 SDWA amendments is the consumer confidence report (CCR) requirement. The purpose of the CCR is to provide all water customers with basic facts regarding their drinking water so that individuals can make decisions about water consumption based on their personal health. This directive has been likened to the requirement that packaged food companies disclose what is in their food product.

The reports must be prepared yearly by every community water supply system. Water systems serving more than 10,000 people must mail the report to customers. Small systems must notify customers as directed by the State primacy agency. Beginning in the year 2000, reports were to be delivered by July 1 of the calendar year.

A water system that only distributes purchased water (i.e., a satellite system) must prepare the report for their consumers. Information on the source water and chemical analyses must be furnished to the satellite system by the system selling the water (parent company).

Some States are preparing much of the information for their water systems, but the system operator still must add local information. Templates for preparing a report also are available from the American Water Works Association (AWWA) and the National Rural Water Association (NRWA). Water system operators should keep in mind that CCRs provide an opportunity to educate consumers about the sources and quality of their drinking water. Educated consumers are more likely to help protect drinking water sources and be more understanding of the need to upgrade the water system to make their drinking water safe.



## DUCTILE PIPE DETAIL



# Glossary

## A

**Absolute Pressure:** The pressure above zone absolute, i.e. the sum of atmospheric and gauge pressure. In vacuum related work it is usually expressed in millimeters of mercury. (mmHg).

**Aerodynamics:** The study of the flow of gases. The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law.

**Aeronautics:** The mathematics and mechanics of flying objects, in particular airplanes.

**Air Break:** A physical separation which may be a low inlet into the indirect waste receptor from the fixture, or device that is indirectly connected. You will most likely find an air break on waste fixtures or on non-potable lines. You should never allow an air break on an ice machine.

**Air Gap Separation:** A physical separation space that is present between the discharge vessel and the receiving vessel, for an example, a kitchen faucet.

**Altitude-Control Valve:** If an overflow occurs on a storage tank, the operator should first check the altitude-control valve. Altitude-Control Valve is designed to, 1. Prevent overflows from the storage tank or reservoir, or 2. Maintain a constant water level as long as water pressure in the distribution system is adequate.

**Angular Motion Formulas:** Angular velocity can be expressed as (angular velocity = constant):

$$\omega = \theta / t \text{ (2a)}$$

where

$\omega$  = angular velocity (rad/s)

$\theta$  = angular displacement (rad)

$t$  = time (s)

Angular velocity can be expressed as (angular acceleration = constant):

$$\omega = \omega_o + \alpha t \text{ (2b)}$$

where

$\omega_o$  = angular velocity at time zero (rad/s)

$\alpha$  = angular acceleration (rad/s<sup>2</sup>)

Angular displacement can be expressed as (angular acceleration = constant):

$$\theta = \omega_o t + 1/2 \alpha t^2 \text{ (2c)}$$

Combining 2a and 2c:

$$\omega = (\omega_o^2 + 2 \alpha \theta)^{1/2}$$

Angular acceleration can be expressed as:

$$\alpha = d\omega / dt = d^2\theta / dt^2 \text{ (2d)}$$

where

$d\theta$  = change of angular displacement (rad)

$dt$  = change in time (s)

**Atmospheric Pressure:** Pressure exerted by the atmosphere at any specific location. (Sea level pressure is approximately 14.7 pounds per square inch absolute, 1 bar = 14.5psi.)

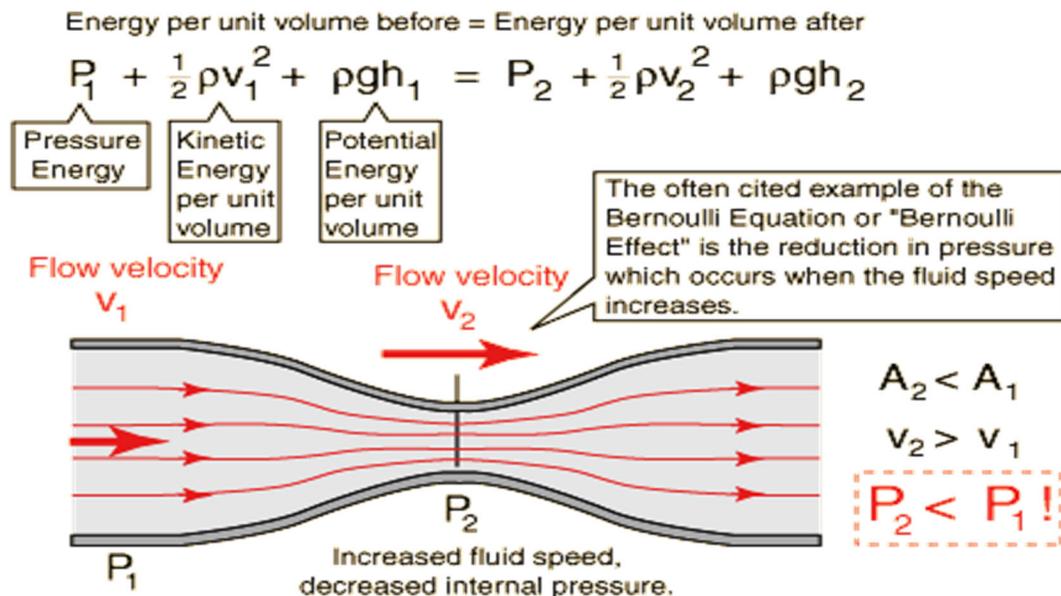
**B**

**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. Is a condition in which the pressure in the distribution system is less than atmospheric pressure. In other words, something is “sucked” into the system because the main is under a vacuum.

**Bernoulli's Equation:** Describes the behavior of moving fluids along a streamline. The Bernoulli Equation can be considered to be a statement of the conservation of energy principle appropriate for flowing fluids. The qualitative behavior that is usually labeled with the term "**Bernoulli effect**" is the lowering of fluid pressure in regions where the flow velocity is increased. This lowering of pressure in a constriction of a flow path may seem counterintuitive, but seems less so when you consider pressure to be energy density. In the high velocity flow through the constriction, kinetic energy must increase at the expense of pressure energy.



A special form of the Euler's equation derived along a fluid flow streamline is often called the **Bernoulli Equation**.

$$\frac{\partial}{\partial s} \left( \frac{v^2}{2} + \frac{p}{\rho} + g \cdot h \right) = 0 \quad (1)$$

where

$v$  = flow speed

$p$  = pressure

$\rho$  = density

$g$  = gravity

$h$  = height

$$\frac{v^2}{2} + \frac{p}{\rho} + g \cdot h = \text{Constant} \quad (2)$$

$$\frac{v^2}{2 \cdot g} + \frac{p}{\gamma} + h = \text{Constant} \quad (3)$$

where

$$\gamma = \rho \cdot g$$

$$\frac{\rho \cdot v^2}{2} + p = \text{Constant} \quad (4)$$

$$\frac{\rho \cdot v^2}{2} = p_d \quad (5)$$

$$\frac{\rho \cdot v_1^2}{2} + p_1 = \frac{\rho \cdot v_2^2}{2} + p_2 = \text{Constant} \quad (6)$$

[www.engineeringtoolbox.com](http://www.engineeringtoolbox.com)

For steady state incompressible flow the Euler equation becomes (1). If we integrate (1) along the streamline it becomes (2). (2) can further be modified to (3) by dividing by gravity.

**Head of Flow:** Equation (3) is often referred to as the **head** because all elements have the unit of length.

### ***Bernoulli's Equation Continued:***

#### **Dynamic Pressure**

(2) and (3) are two forms of the Bernoulli Equation for steady state incompressible flow. If we assume that the gravitational body force is negligible, (3) can be written as (4). Both elements in the equation have the unit of pressure and it's common to refer the flow velocity component as the **dynamic pressure** of the fluid flow (5).

Since energy is conserved along the streamline, (4) can be expressed as (6). Using the equation we see that increasing the velocity of the flow will reduce the pressure, decreasing the velocity will increase the pressure.

This phenomena can be observed in a **venturi meter** where the pressure is reduced in the constriction area and regained after. It can also be observed in a **pitot tube** where the **stagnation** pressure is measured. The stagnation pressure is where the velocity component is zero.

### ***Bernoulli's Equation Continued:***

#### **Pressurized Tank**

If the tanks are pressurized so that product of gravity and height ( $g h$ ) is much less than the pressure difference divided by the density, (e4) can be transformed to (e6). The velocity out from the tanks depends mostly on the pressure difference.

#### ***Example - outlet velocity from a pressurized tank***

The outlet velocity of a pressurized tank where

$$p_1 = 0.2 \text{ MN/m}^2, p_2 = 0.1 \text{ MN/m}^2, A_2/A_1 = 0.01, h = 10 \text{ m}$$

can be calculated as

$$V_2 = [(2/(1-(0.01)^2) ((0.2 - 0.1) \times 10^6 / 1 \times 10^3 + 9.81 \times 10)]^{1/2} = \underline{19.9 \text{ m/s}}$$

#### **Coefficient of Discharge - Friction Coefficient**

Due to friction the real velocity will be somewhat lower than this theoretical example. If we introduce a **friction coefficient**  $c$  (coefficient of discharge), (e5) can be expressed as (e5b). The coefficient of discharge can be determined experimentally. For a sharp edged opening it may be as low as 0.6. For smooth orifices it may be between 0.95 and 1.

**Bingham Plastic Fluids:** Bingham Plastic Fluids have a yield value which must be exceeded before it will start to flow like a fluid. From that point the viscosity will decrease with increase of agitation. Toothpaste, mayonnaise and tomato catsup are examples of such products.

**Boundary Layer:** The layer of fluid in the immediate vicinity of a bounding surface.

**Bulk Modulus and Fluid Elasticity:** An introduction to and a definition of the Bulk Modulus Elasticity commonly used to characterize the compressibility of fluids.

The Bulk Modulus Elasticity can be expressed as

$$E = - dp / (dV / V) \quad (1)$$

where

$E$  = bulk modulus elasticity

$dp$  = differential change in pressure on the object

$dV$  = differential change in volume of the object

$V$  = initial volume of the object

The Bulk Modulus Elasticity can be alternatively expressed as

$$E = - dp / (dp / \rho) \quad (2)$$

where

$dp$  = differential change in density of the object

$\rho$  = initial density of the object

An increase in the pressure will decrease the volume (1). A decrease in the volume will increase the density (2).

- The SI unit of the bulk modulus elasticity is  $\text{N/m}^2$  (Pa)
- The imperial (BG) unit is  $\text{lb}_f/\text{in}^2$  (psi)

- 1 lb<sub>f</sub>/in<sup>2</sup> (psi) = 6.894 10<sup>3</sup> N/m<sup>2</sup> (Pa)

A large Bulk Modulus indicates a relatively incompressible fluid.

Bulk Modulus for some common fluids can be found in the table below:

Bulk Modulus - $E$	Imperial Units - BG (psi, lb <sub>f</sub> /in <sup>2</sup> ) x 10 <sup>5</sup>	SI Units (Pa, N/m <sup>2</sup> ) x 10 <sup>9</sup>
Carbon Tetrachloride	1.91	1.31
Ethyl Alcohol	1.54	1.06
Gasoline	1.9	1.3
Glycerin	6.56	4.52
Mercury	4.14	2.85
SAE 30 Oil	2.2	1.5
Seawater	3.39	2.35
Water	3.12	2.15

## C

**Capillarity:** (or capillary action) The ability of a narrow tube to draw a liquid upwards against the force of gravity.

The height of liquid in a tube due to capillarity can be expressed as

$$h = 2 \sigma \cos\theta / (\rho g r) \quad (1)$$

where

$h$  = height of liquid (ft, m)

$\sigma$  = surface tension (lb/ft, N/m)

$\theta$  = contact angle

$\rho$  = density of liquid (lb/ft<sup>3</sup>, kg/m<sup>3</sup>)

$g$  = acceleration due to gravity (32.174 ft/s<sup>2</sup>, 9.81 m/s<sup>2</sup>)

$r$  = radius of tube (ft, m)

**Cauchy Number:** A dimensionless value useful for analyzing fluid flow dynamics problems where compressibility is a significant factor.

The Cauchy Number is the ratio between inertial and the compressibility force in a flow and can be expressed as

$$C = \rho v^2 / E \quad (1)$$

where

$\rho$  = density (kg/m<sup>3</sup>)

$v$  = flow velocity (m/s)

$E$  = bulk modulus elasticity (N/m<sup>2</sup>)

The bulk modulus elasticity has the dimension pressure and is commonly used to characterize the compressibility of a fluid.

The Cauchy Number is the square root of the Mach Number

$$M^2 = Ca \quad (3)$$

where

$C = \text{Mach Number}$

**Cavitation:** Under the wrong condition, cavitation will reduce the components life time dramatically. Cavitation may occur when the local static pressure in a fluid reach a level below the vapor pressure of the liquid at the actual temperature. According to the Bernoulli Equation this may happen when the fluid accelerates in a control valve or around a pump impeller. The vaporization itself does not cause the damage - the damage happens when the vapor almost immediately collapses after evaporation when the velocity is decreased and pressure increased. Cavitation means that cavities are forming in the liquid that we are pumping. When these cavities form at the suction of the pump several things happen all at once: We experience a loss in capacity. We can no longer build the same head (pressure). The efficiency drops. The cavities or bubbles will collapse when they pass into the higher regions of pressure causing noise, vibration, and damage to many of the components. The cavities form for five basic reasons and it is common practice to lump all of them into the general classification of cavitation.

This is an error because we will learn that to correct each of these conditions we must understand why they occur and how to fix them. Here they are in no particular order: Vaporization, Air ingestion, Internal recirculation, Flow turbulence and finally the Vane Passing Syndrome.

### **Avoiding Cavitation**

Cavitation can in general be avoided by:

- increasing the distance between the actual local static pressure in the fluid - and the vapor pressure of the fluid at the actual temperature

This can be done by:

- reengineering components initiating high speed velocities and low static pressures
- increasing the total or local static pressure in the system
- reducing the temperature of the fluid

### **Reengineering of Components Initiating High Speed Velocity and Low Static Pressure**

Cavitation and damage can be avoided by using special components designed for the actual rough conditions.

- Conditions such as huge pressure drops can - with limitations - be handled by Multi Stage Control Valves
- Difficult pumping conditions - with fluid temperatures close to the vaporization temperature - can be handled with a special pump - working after another principle than the centrifugal pump.

**Cavitation Continued: Increasing the Total or Local Pressure in the System**

By increasing the total or local pressure in the system, the distance between the static pressure and the vaporization pressure is increased and vaporization and cavitation may be avoided.

The ratio between static pressure and the vaporization pressure, an indication of the possibility of vaporization, is often expressed by the Cavitation Number. Unfortunately it may not always be possible to increase the total static pressure due to system classifications or other limitations. Local static pressure in the component may then be increased by lowering the component in the system. Control valves and pumps should in general be positioned in the lowest part of the system to maximize the static head. This is common for boiler feeding pumps receiving hot condensate (water close to 100 °C) from a condensate receiver.

**Cavitation Continued: Reducing the Temperature of the Fluid**

The vaporization pressure is highly dependent on the fluid temperature. Water, our most common fluid, is an example:

Temperature (°C)	Vapor Pressure (kN/m <sup>2</sup> )
0	0.6
5	0.9
10	1.2
15	1.7
20	2.3
25	3.2
30	4.3
35	5.6
40	7.7
45	9.6
50	12.5
55	15.7
60	20
65	25
70	32.1
75	38.6
80	47.5
85	57.8
90	70
95	84.5
100	101.33

As we can see - the possibility of evaporation and cavitation increases dramatically with the water temperature.

Cavitation can be avoided by locating the components in the coldest part of the system. For example, it is common to locate the pumps in heating systems at the "cold" return lines. The situation is the same for control valves. Where it is possible they should be located on the cold side of heat exchangers.

**Cavitations Number:** A "special edition" of the dimensionless Euler Number.

The Cavitations Number is useful for analyzing fluid flow dynamics problems where cavitations may occur. The Cavitations Number can be expressed as

$$Ca = (p_r - p_v) / 1/2 \rho v^2 \quad (1)$$

where

$Ca$  = Cavitations number

$p_r$  = reference pressure

(Pa)

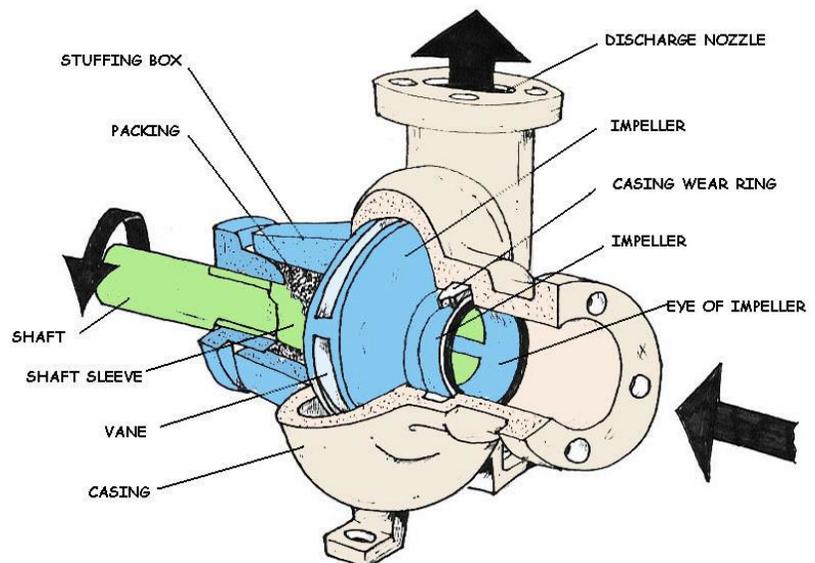
$p_v$  = vapor pressure of the fluid (Pa)

$\rho$  = density of the fluid

(kg/m<sup>3</sup>)

$v$  = velocity of fluid (m/s)

**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.



**Chezy Formula:** Conduits flow and mean velocity. The Chezy formula can be used to calculate mean flow velocity in conduits and is expressed as

$$v = c (R S)^{1/2} \quad (1)$$

where

$v$  = mean velocity (m/s, ft/s)

$c$  = the Chezy roughness and conduit coefficient

$R$  = hydraulic radius of the conduit (m, ft)

$S$  = slope of the conduit (m/m, ft/ft)

In general the Chezy coefficient -  $c$  - is a function of the flow Reynolds Number -  $Re$  - and the relative roughness -  $\epsilon/R$  - of the channel.  $\epsilon$  is the characteristic height of the roughness elements on the channel boundary.

**Coanda Effect:** The tendency of a stream of fluid to stay attached to a convex surface, rather than follow a straight line in its original direction.

**Colebrook Equation:** The friction coefficients used to calculate pressure loss (or major loss) in ducts, tubes and pipes can be calculated with the Colebrook equation.

$$1 / \lambda^{1/2} = -2 \log ( (2.51 / (Re \lambda^{1/2})) + (k / d_h) / 3.72 ) \quad (1)$$

where

$\lambda$  = D'Arcy-Weisbach friction coefficient

$Re$  = Reynolds Number

$k$  = roughness of duct, pipe or tube surface (m, ft)

$d_h$  = hydraulic diameter (m, ft)

The Colebrook equation is only valid at turbulent flow conditions.

Note that the friction coefficient is involved on both sides of the equation and that the equation must be solved by iteration.

The Colebrook equation is generic and can be used to calculate the friction coefficients in different kinds of fluid flows - air ventilation ducts, pipes and tubes with water or oil, compressed air and much more.

**Common Pressure Measuring Devices:** The Strain Gauge is a common measuring device used for a variety of changes such as head. As the pressure in the system changes, the diaphragm expands which changes the length of the wire attached. This change of length of the wire changes the Resistance of the wire, which is then converted to head. Float mechanisms, diaphragm elements, bubbler tubes, and direct electronic sensors are common types of level sensors.

**Compressible Flow:** We know that fluids are classified as Incompressible and Compressible fluids. Incompressible fluids do not undergo significant changes in density as they flow. In general, liquids are incompressible; water being an excellent example. In contrast compressible fluids do undergo density changes.

Gases are generally compressible; air being the most common compressible fluid we can find. Compressibility of gases leads to many interesting features such as shocks, which are absent for incompressible fluids. Gas dynamics is the discipline that studies the flow of compressible fluids and forms an important branch of Fluid Mechanics. In this book we give a broad introduction to the basics of compressible fluid flow.

In a compressible flow the compressibility of the fluid must be taken into account. The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law. Properties of **Gas Mixtures** - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density. The Individual and **Universal Gas Constant** - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.



## D

**Darcy-Weisbach Equation:** The **pressure loss** (or major loss) in a pipe, tube or duct can be expressed with the D'Arcy-Weisbach equation:

$$\Delta p = \lambda (l / d_h) (\rho v^2 / 2) (1)$$

where

$\Delta p$  = pressure loss (Pa, N/m<sup>2</sup>, lb<sub>f</sub>/ft<sup>2</sup>)

$\lambda$  = D'Arcy-Weisbach friction coefficient

$l$  = length of duct or pipe (m, ft)

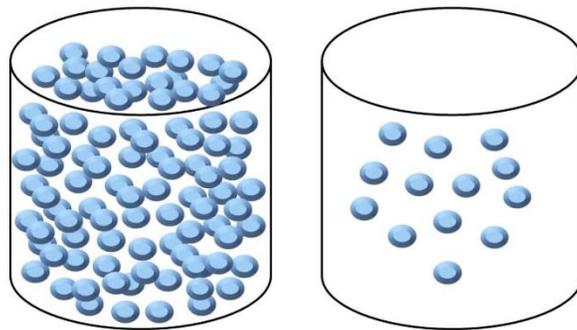
$d_h$  = hydraulic diameter (m, ft)

$\rho$  = density (kg/m<sup>3</sup>, lb/ft<sup>3</sup>)

**Note!** Be aware that there are two alternative friction coefficients present in the literature. One is 1/4 of the other and (1) must be multiplied with four to achieve the correct result. This is important to verify when selecting friction coefficients from Moody diagrams.

**Density:** Is a physical property of matter, as each element and compound has a unique density associated with it.

Density defined in a qualitative manner as the measure of the relative "heaviness" of objects with a constant volume. For example: A rock is obviously more dense than a crumpled piece of paper of the same size. A Styrofoam cup is less dense than a ceramic cup. Density may also refer to how closely "packed" or "crowded" the material appears to be - again refer to the Styrofoam vs. ceramic cup. Take a look at the two boxes below.



Each box has the same volume. ***If each ball has the same mass, which box would weigh more? Why?***

The box that has more balls has more mass per unit of volume. This property of matter is called density. The density of a material helps to distinguish it from other materials. Since mass is usually expressed in grams and volume in cubic centimeters, density is expressed in grams/cubic centimeter. We can calculate density using the formula:

$$\text{Density} = \text{Mass} / \text{Volume}$$

The density can be expressed as

$$\rho = m / V = 1 / v_g (1)$$

where

$$\rho = \text{density (kg/m}^3\text{)}$$

$$m = \text{mass (kg)}$$

$$V = \text{volume (m}^3\text{)}$$

$$v_g = \text{specific volume (m}^3\text{/kg)}$$

The SI units for density are kg/m<sup>3</sup>. The imperial (BG) units are lb/ft<sup>3</sup> (slugs/ft<sup>3</sup>). While people often use pounds per cubic foot as a measure of density in the U.S., pounds are really a measure of force, not mass. Slugs are the correct measure of mass. You can multiply slugs by 32.2 for a rough value in pounds. The higher the density, the tighter the particles are packed inside the substance. Density is a physical property constant at a given temperature and density can help to identify a substance.

**Example - Use the Density to Identify the Material:**

An unknown liquid substance has a mass of 18.5 g and occupies a volume of 23.4 ml. (milliliter).

The density can be calculated as

$$\rho = [18.5 \text{ (g)} / 1000 \text{ (g/kg)}] / [23.4 \text{ (ml)} / 1000 \text{ (ml/l)} 1000 \text{ (l/m}^3\text{)} ]$$

$$= 18.5 \cdot 10^{-3} \text{ (kg)} / 23.4 \cdot 10^{-6} \text{ (m}^3\text{)}$$

$$= \underline{790 \text{ kg/m}^3}$$

If we look up densities of some common substances, we can find that ethyl alcohol, or ethanol, has a density of 790 kg/m<sup>3</sup>. Our unknown liquid may likely be ethyl alcohol!

**Example - Use Density to Calculate the Mass of a Volume**

The density of titanium is 4507 kg/m<sup>3</sup>. Calculate the mass of 0.17 m<sup>3</sup> titanium!

$$m = 0.17 \text{ (m}^3\text{)} 4507 \text{ (kg/m}^3\text{)}$$

$$= \underline{766.2 \text{ kg}}$$

**Dilatant Fluids:** Shear Thickening Fluids **or** Dilatant Fluids increase their viscosity with agitation. Some of these liquids can become almost solid within a pump or pipe line. With agitation, cream becomes butter and Candy compounds, clay slurries and similar heavily filled liquids do the same thing.

**Disinfect:** To kill and inhibit growth of harmful bacterial and viruses in drinking water.

**Disinfection:** The treatment of water to inactivate, destroy, and/or remove pathogenic bacteria, viruses, protozoa, and other parasites.

**Distribution System Water Quality:** Can be adversely affected by improperly constructed or poorly located blowoffs of vacuum/air relief valves. Air relief valves in the distribution system lines must be placed in locations that cannot be flooded. This is to prevent water contamination. The common customer complaint of Milky Water or Entrained Air is sometimes solved by the installation of air relief valves. The venting of air is not a major concern when checking water levels in a storage tank.

If the vent line on a ground level storage tank is closed or clogged up, a vacuum will develop in the tank may happen to the tank when the water level begins to lower.

**Drag Coefficient:** Used to express the drag of an object in moving fluid. Any object moving through a fluid will experience a drag - the net force in direction of flow due to the pressure and shear stress forces on the surface of the object.

The drag force can be expressed as:

$$F_d = c_d \frac{1}{2} \rho v^2 A \quad (1)$$

where

$F_d$  = drag force (N)

$c_d$  = drag coefficient

$\rho$  = density of fluid

$v$  = flow velocity

$A$  = characteristic frontal area of the body

The drag coefficient is a function of several parameters as shape of the body, Reynolds Number for the flow, Froude number, Mach Number and Roughness of the Surface.

The characteristic frontal area -  $A$  - depends on the body.

**Dynamic or Absolute Viscosity:** The viscosity of a fluid is an important property in the analysis of liquid behavior and fluid motion near solid boundaries. The viscosity of a fluid is its resistance to shear or flow and is a measure of the adhesive/cohesive or frictional properties of a fluid. The resistance is caused by intermolecular friction exerted when layers of fluids attempts to slide by another.

**Dynamic Pressure:** Dynamic pressure is the component of fluid pressure that represents a fluids kinetic energy. The dynamic pressure is a defined property of a moving flow of gas or liquid and can be expressed as

$$p_d = \frac{1}{2} \rho v^2 \quad (1)$$

where

$p_d$  = dynamic pressure (Pa)

$\rho$  = density of fluid ( $\text{kg}/\text{m}^3$ )

$v$  = velocity (m/s)

**Dynamic, Absolute and Kinematic Viscosity:** The viscosity of a fluid is an important property in the analysis of liquid behavior and fluid motion near solid boundaries. The viscosity is the fluid resistance to shear or flow and is a measure of the adhesive/cohesive or frictional fluid property. The resistance is caused by intermolecular friction exerted when layers of fluids attempts to slide by another.

Viscosity is a measure of a fluid's resistance to flow.

The knowledge of viscosity is needed for proper design of required temperatures for storage, pumping or injection of fluids.

Common used units for viscosity are

- CentiPoises (cp) = CentiStokes (cSt)  $\times$  Density
- SSU<sup>1</sup> = Centistokes (cSt)  $\times$  4.55
- Degree Engler<sup>1</sup>  $\times$  7.45 = Centistokes (cSt)
- Seconds Redwood<sup>1</sup>  $\times$  0.2469 = Centistokes (cSt)

1centistokes greater than 50

There are two related measures of fluid viscosity - known as **dynamic (or absolute)** and **kinematic** viscosity.

**Dynamic (absolute) Viscosity:** The tangential force per unit area required to move one horizontal plane with respect to the other at unit velocity when maintained a unit distance apart by the fluid. The shearing stress between the layers of non-turbulent fluid moving in straight parallel lines can be defined for a Newtonian fluid as:

The dynamic or absolute viscosity can be expressed like

$$\tau = \mu \, dc/dy \quad (1)$$

where

$\tau$  = shearing stress

$\mu$  = dynamic viscosity

Equation (1) is known as the **Newton's Law of Friction**.

In the SI system the dynamic viscosity units are **N s/m<sup>2</sup>**, **Pa s** or **kg/m s** where

- $1 \text{ Pa s} = 1 \text{ N s/m}^2 = 1 \text{ kg/m s}$

The dynamic viscosity is also often expressed in the metric CGS (centimeter-gram-second) system as **g/cm.s**, **dyne.s/cm<sup>2</sup>** or **poise (p)** where

- $1 \text{ poise} = \text{dyne s/cm}^2 = \text{g/cm s} = 1/10 \text{ Pa s}$

For practical use the Poise is too large and its usual divided by 100 into the smaller unit called the **centiPoise (cP)** where

- $1 \text{ p} = 100 \text{ cP}$

Water at 68.4°F (20.2°C) has an absolute viscosity of one - 1 - centiPoise.

## 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.

**Elevation Head:** The energy possessed per unit weight of a fluid because of its elevation. 1 foot of water will produce .433 pounds of pressure head.

**Energy:** The ability to do work. Energy can exist in one of several forms, such as heat, light, mechanical, electrical, or chemical. Energy can be transferred to different forms. It also can exist in one of two states, either potential or kinetic.

**Energy and Hydraulic Grade Line:** The hydraulic grade and the energy line are graphical forms of the Bernoulli equation. For steady, in viscid, incompressible flow the total energy remains constant along a stream line as expressed through the Bernoulli

**Equation:**

$$p + 1/2 \rho v^2 + \gamma h = \text{constant along a streamline (1)}$$

where

$p$  = static pressure (relative to the moving fluid)

$\rho$  = density

$\gamma$  = specific weight

$v$  = flow velocity

$g$  = acceleration of gravity

$h$  = elevation height

Each term of this equation has the dimension *force per unit area* - psi, lb/ft<sup>2</sup> or N/m<sup>2</sup>.

**The Head**

By dividing each term with the specific weight -  $\gamma = \rho g$  - (1) can be transformed to express the "head":

$$p / \gamma + v^2 / 2 g + h = \text{constant along a streamline} = H \text{ (2)}$$

where

$H$  = the total head

Each term of this equation has the dimension length - ft, m.

**The Total Head**

(2) states that the sum of **pressure head** -  $p / \gamma$  -, **velocity head** -  $v^2 / 2 g$  - and **elevation head** -  $h$  - is constant along the stream line. This constant can be called **the total head** -  $H$  -.

The total head in a flow can be measured by the stagnation pressure using a pitot tube.

**Energy and Hydraulic Grade Line Continued:**

**The Piezometric Head**

The sum of pressure head -  $p / \gamma$  - and elevation head -  $h$  - is called **the piezometric head**. The piezometric head in a flow can be measured through an flat opening parallel to the flow.

**Energy and Hydraulic Grade Line Continued:**

**The Energy Line**

The Energy Line is a line that represents the total head available to the fluid and can be expressed as:

$$EL = H = p / \gamma + v^2 / 2 g + h = \text{constant along a streamline (3)}$$

where

$EL$  = Energy Line

For a fluid flow without any losses due to friction (major losses) or components (minor losses) the energy line would be at a constant level. In the practical world the energy line decreases along the flow due to the losses.

A turbine in the flow will reduce the energy line and a pump or fan will increase the energy line.

### The Hydraulic Grade Line

The Hydraulic Grade Line is a line that represent the total head available to the fluid minus the velocity head and can be expressed as:

$$HGL = p / \gamma + h \quad (4)$$

where

*HGL = Hydraulic Grade Line*

The hydraulic grade line lies one velocity head below the energy line.

**Entrance Length and Developed Flow:** Fluids need some length to develop the velocity profile after entering the pipe or after passing through components such as bends, valves, pumps, and turbines or similar.

**The Entrance Length:** The entrance length can be expressed with the dimensionless Entrance Length Number:

$$El = l_e / d \quad (1)$$

where

*El = Entrance Length Number*

*l<sub>e</sub> = length to fully developed velocity profile*

*d = tube or duct diameter*

### The Entrance Length Number for Laminar Flow

The Entrance length number correlation with the Reynolds Number for laminar flow can be expressed as:

$$El_{laminar} = 0.06 Re \quad (2)$$

where

*Re = Reynolds Number*

### The Entrance Length Number for Turbulent Flow

The Entrance length number correlation with the Reynolds Number for turbulent flow can be expressed as:

$$El_{turbulent} = 4.4 Re^{1/6} \quad (3)$$

### Entropy in Compressible Gas Flow: Calculating entropy in compressible gas flow

Entropy change in compressible gas flow can be expressed as

$$ds = c_v \ln(T_2 / T_1) + R \ln(\rho_1 / \rho_2) \quad (1)$$

or

$$ds = c_p \ln(T_2 / T_1) - R \ln(\rho_2 / \rho_1) \quad (2)$$

where

*ds = entropy change*

*c<sub>v</sub> = specific heat capacity at a constant volume process*

*c<sub>p</sub> = specific heat capacity at a constant pressure process*

$T$  = absolute temperature  
 $R$  = individual gas constant  
 $\rho$  = density of gas  
 $p$  = absolute pressure

**Equation of Continuity:** The Law of Conservation of Mass states that mass can be neither created nor destroyed. Using the Mass Conservation Law on a **steady flow** process - flow where the flow rate doesn't change over time - through a control volume where the stored mass in the control volume doesn't change - implements that inflow equals outflow. This statement is called **the Equation of Continuity**. Common application where **the Equation of Continuity** can be used are pipes, tubes and ducts with flowing fluids and gases, rivers, overall processes as power plants, dairies, logistics in general, roads, computer networks and semiconductor technology and more.

**The Equation of Continuity** and can be expressed as:

$$\begin{aligned}
 m &= \rho_{i1} v_{i1} A_{i1} + \rho_{i2} v_{i2} A_{i2} + \dots + \rho_{in} v_{in} A_{in} \\
 &= \rho_{o1} v_{o1} A_{o1} + \rho_{o2} v_{o2} A_{o2} + \dots + \rho_{om} v_{om} A_{om} \quad (1)
 \end{aligned}$$

where

$m$  = mass flow rate (kg/s)

$\rho$  = density (kg/m<sup>3</sup>)

$v$  = speed (m/s)

$A$  = area (m<sup>2</sup>)

With uniform density equation (1) can be modified to

$$\begin{aligned}
 q &= v_{i1} A_{i1} + v_{i2} A_{i2} + \dots + v_{in} A_{in} \\
 &= v_{o1} A_{o1} + v_{o2} A_{o2} + \dots + v_{om} A_{om} \quad (2)
 \end{aligned}$$

where

$q$  = flow rate (m<sup>3</sup>/s)

$\rho_{i1} = \rho_{i2} = \dots = \rho_{in} = \rho_{o1} = \rho_{o2} = \dots = \rho_{om}$

### Example - Equation of Continuity

10 m<sup>3</sup>/h of water flows through a pipe of 100 mm inside diameter. The pipe is reduced to an inside dimension of 80 mm. Using equation (2) the velocity in the 100 mm pipe can be calculated as

$$(10 \text{ m}^3/\text{h})(1 / 3600 \text{ h/s}) = v_{100} (3.14 \times 0.1 \text{ (m)} \times 0.1 \text{ (m)} / 4)$$

or

$$\begin{aligned}
 v_{100} &= (10 \text{ m}^3/\text{h})(1 / 3600 \text{ h/s}) / (3.14 \times 0.1 \text{ (m)} \times 0.1 \text{ (m)} / 4) \\
 &= \underline{0.35 \text{ m/s}}
 \end{aligned}$$

Using equation (2) the velocity in the 80 mm pipe can be calculated

$$(10 \text{ m}^3/\text{h})(1 / 3600 \text{ h/s}) = v_{80} (3.14 \times 0.08 \text{ (m)} \times 0.08 \text{ (m)} / 4)$$

or

$$\begin{aligned}
 v_{100} &= (10 \text{ m}^3/\text{h})(1 / 3600 \text{ h/s}) / (3.14 \times 0.08 \text{ (m)} \times 0.08 \text{ (m)} / 4) \\
 &= \underline{0.55 \text{ m/s}}
 \end{aligned}$$

**Equation of Mechanical Energy:** The Energy Equation is a statement of the first law of thermodynamics. The energy equation involves energy, heat transfer and work. With certain limitations the mechanical energy equation can be compared to the Bernoulli Equation and transferred to the Mechanical Energy Equation in Terms of Energy per Unit Mass.

The mechanical energy equation for a **pump or a fan** can be written in terms of **energy per unit mass**:

$$p_{in} / \rho + v_{in}^2 / 2 + g h_{in} + w_{shaft} = p_{out} / \rho + v_{out}^2 / 2 + g h_{out} + w_{loss} \quad (1)$$

where

$p$  = static pressure

$\rho$  = density

$v$  = flow velocity

$g$  = acceleration of gravity

$h$  = elevation height

$w_{shaft}$  = net shaft energy in per unit mass for a pump, fan or similar

$w_{loss}$  = loss due to friction

The energy equation is often used for incompressible flow problems and is called the **Mechanical Energy Equation** or the **Extended Bernoulli Equation**.

The mechanical energy equation for a **turbine** can be written as:

$$p_{in} / \rho + v_{in}^2 / 2 + g h_{in} = p_{out} / \rho + v_{out}^2 / 2 + g h_{out} + w_{shaft} + w_{loss} \quad (2)$$

where

$w_{shaft}$  = net shaft energy out per unit mass for a turbine or similar

Equation (1) and (2) dimensions are

energy per unit mass ( $ft^2/s^2 = ft \cdot lb/slug$  or  $m^2/s^2 = N \cdot m/kg$ )

### Efficiency

According to (1) a larger amount of loss -  $w_{loss}$  - result in more shaft work required for the same rise of output energy. The efficiency of a **pump or fan process** can be expressed as:

$$\eta = (w_{shaft} - w_{loss}) / w_{shaft} \quad (3)$$

The efficiency of a **turbine process** can be expressed as:

$$\eta = w_{shaft} / (w_{shaft} + w_{loss}) \quad (4)$$

### The Mechanical Energy Equation in Terms of Energy per Unit Volume

The mechanical energy equation for a **pump or a fan** (1) can also be written in terms of **energy per unit volume** by multiplying (1) with fluid density -  $\rho$ :

$$p_{in} + \rho v_{in}^2 / 2 + \gamma h_{in} + \rho w_{shaft} = p_{out} + \rho v_{out}^2 / 2 + \gamma h_{out} + w_{loss} \quad (5)$$

where

$\gamma = \rho g$  = specific weight

The dimensions of equation (5) are

energy per unit volume ( $ft \cdot lb/ft^3 = lb/ft^2$  or  $N \cdot m/m^3 = N/m^2$ )

### The Mechanical Energy Equation in Terms of Energy per Unit Weight involves Heads

The mechanical energy equation for a **pump or a fan** (1) can also be written in terms of **energy per unit weight** by dividing with gravity -  $g$ :

$$p_{in} / \gamma + v_{in}^2 / 2 g + h_{in} + h_{shaft} = p_{out} / \gamma + v_{out}^2 / 2 g + h_{out} + h_{loss} \quad (6)$$

where

$\gamma = \rho g = \text{specific weight}$

$h_{\text{shaft}} = W_{\text{shaft}} / g = \text{net shaft energy head inn per unit mass for a pump, fan or similar}$

$h_{\text{loss}} = W_{\text{loss}} / g = \text{loss head due to friction}$

The dimensions of equation (6) are

*energy per unit weight (ft.lb/lb = ft or N.m/N = m)*

Head is the energy per unit weight.

$h_{\text{shaft}}$  can also be expressed as:

$$h_{\text{shaft}} = W_{\text{shaft}} / g = W_{\text{shaft}} / m g = W_{\text{shaft}} / \gamma Q \quad (7)$$

where

$W_{\text{shaft}} = \text{shaft power}$

$m = \text{mass flow rate}$

$Q = \text{volume flow rate}$

### Example - Pumping Water

Water is pumped from an open tank at level zero to an open tank at level 10 ft. The pump adds four horsepowers to the water when pumping 2 ft<sup>3</sup>/s.

Since  $v_{in} = v_{out} = 0$ ,  $p_{in} = p_{out} = 0$  and  $h_{in} = 0$  - equation (6) can be modified to:

$$h_{\text{shaft}} = h_{\text{out}} + h_{\text{loss}}$$

or

$$h_{\text{loss}} = h_{\text{shaft}} - h_{\text{out}} \quad (8)$$

Equation (7) gives:

$$h_{\text{shaft}} = W_{\text{shaft}} / \gamma Q = (4 \text{ hp})(550 \text{ ft.lb/s/hp}) / (62.4 \text{ lb/ft}^3)(2 \text{ ft}^3/\text{s}) = 17.6 \text{ ft}$$

- specific weight of water 62.4 lb/ft<sup>3</sup>
- 1 hp (English horse power) = 550 ft. lb/s

Combined with (8):

$$h_{\text{loss}} = (17.6 \text{ ft}) - (10 \text{ ft}) = 7.6 \text{ ft}$$

The pump efficiency can be calculated from (3) modified for head:

$$\eta = ((17.6 \text{ ft}) - (7.6 \text{ ft})) / (17.6 \text{ ft}) = 0.58$$

**Equations in Fluid Mechanics:** Common fluid mechanics equations - Bernoulli, conservation of energy, conservation of mass, pressure, Navier-Stokes, ideal gas law, Euler equations, Laplace equations, Darcy-Weisbach Equation and the following:

#### The Bernoulli Equation

- The Bernoulli Equation - A statement of the conservation of energy in a form useful for solving problems involving fluids. For a non-viscous, incompressible fluid in steady flow, the sum of pressure, potential and kinetic energies per unit volume is constant at any point.

#### Conservation laws

- The conservation laws states that particular measurable properties of an isolated physical system does not change as the system evolves.
- Conservation of energy (including mass)

- Fluid Mechanics and Conservation of Mass - The law of conservation of mass states that mass can neither be created nor destroyed.
- The Continuity Equation - The Continuity Equation is a statement that mass is conserved.

#### **Darcy-Weisbach Equation**

- Pressure Loss and Head Loss due to Friction in Ducts and Tubes - Major loss - head loss or pressure loss - due to friction in pipes and ducts.

#### **Euler Equations**

- In fluid dynamics, the Euler equations govern the motion of a compressible, inviscid fluid. They correspond to the Navier-Stokes equations with zero viscosity, although they are usually written in the form shown here because this emphasizes the fact that they directly represent conservation of mass, momentum, and energy.

#### **Laplace's Equation**

- The Laplace Equation describes the behavior of gravitational, electric, and fluid potentials.

#### **Ideal Gas Law**

- The Ideal Gas Law - For a perfect or ideal gas, the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law.
- Properties of Gas Mixtures - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density.
- The Individual and Universal Gas Constant - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.

#### **Navier-Stokes Equations**

- The motion of a non-turbulent, Newtonian fluid is governed by the Navier-Stokes equations. The equation can be used to model turbulent flow, where the fluid parameters are interpreted as time-averaged values.

#### **Mechanical Energy Equation**

- The Mechanical Energy Equation - The mechanical energy equation in Terms of Energy per Unit Mass, in Terms of Energy per Unit Volume and in Terms of Energy per Unit Weight involves Heads.

#### **Pressure**

- Static Pressure and Pressure Head in a Fluid - Pressure and pressure head in a static fluid.

**Euler Equations:** In fluid dynamics, the Euler equations govern the motion of a compressible, inviscid fluid. They correspond to the Navier-Stokes equations with zero viscosity, although they are usually written in the form shown here because this emphasizes the fact that they directly represent conservation of mass, momentum, and energy.

**Euler Number:** The Euler numbers, also called the secant numbers or zig numbers, are defined for  $|x| < \pi/2$  by

$$\operatorname{sech} x - 1 \equiv -\frac{E_1^* x^2}{2!} + \frac{E_2^* x^4}{4!} - \frac{E_3^* x^6}{6!} + \dots$$

$$\sec x - 1 \equiv \frac{E_1^* x^2}{2!} + \frac{E_2^* x^4}{4!} + \frac{E_3^* x^6}{6!} + \dots,$$

where  $\operatorname{sech}(z)$  the hyperbolic secant and  $\sec$  is the secant. Euler numbers give the number of odd alternating permutations and are related to Genocchi numbers. The base  $e$  of the natural logarithm is sometimes known as Euler's number. A different sort of Euler number, the Euler number of a finite complex  $K$ , is defined by

$$\chi(K) = \sum (-1)^p \operatorname{rank}(C_p(K)).$$

This Euler number is a topological invariant. To confuse matters further, the Euler characteristic is sometimes also called the "Euler number," and numbers produced by the prime-generating polynomial  $n^2 - n + 41$  are sometimes called "Euler numbers" (Flannery and Flannery 2000, p. 47).

## F

**Fecal Coliform:** A group of bacteria that may indicate the presence of human or animal fecal matter in water.

**Filtration:** A series of processes that physically remove particles from water.

**Flood Rim:** The point of an object where the water would run over the edge of something and begin to cause a flood. See Air Break.

**Fluids:** A fluid is defined as a substance that continually deforms (flows) under an applied shear stress regardless of the magnitude of the applied stress. It is a subset of the phases of matter and includes liquids, gases, plasmas and, to some extent, plastic solids. Fluids are also divided into liquids and gases. Liquids form a free surface (that is, a surface not created by their container) while gases do not.

The distinction between solids and fluids is not so obvious. The distinction is made by evaluating the viscosity of the matter: for example silly putty can be considered either a solid or a fluid, depending on the time period over which it is observed. Fluids share the properties of not resisting deformation and the ability to flow (also described as their ability to take on the shape of their containers).

These properties are typically a function of their inability to support a shear stress in static equilibrium. While in a solid, stress is a function of strain, in a fluid, stress is a function of rate of strain. A consequence of this behavior is Pascal's law which entails the important role of pressure in characterizing a fluid's state.

Based on how the stress depends on the rate of strain and its derivatives, fluids can be characterized as: Newtonian fluids: where stress is directly proportional to rate of strain, and Non-Newtonian fluids : where stress is proportional to rate of strain, its higher powers and derivatives (basically everything other than Newtonian fluid).

The behavior of fluids can be described by a set of partial differential equations, which are based on the conservation of mass, linear and angular momentum (Navier-Stokes equations) and energy. The study of fluids is fluid mechanics, which is subdivided into fluid dynamics and fluid statics depending on whether the fluid is in motion or not. Fluid **Related Information:** The Bernoulli Equation - A statement of the conservation of energy in a form useful for solving problems involving fluids. For a non-viscous, incompressible fluid in steady flow, the sum of pressure, potential and kinetic energies per unit volume is constant at any point. Equations in Fluid Mechanics - Continuity, Euler, Bernoulli, Dynamic and Total Pressure. Laminar, Transitional or Turbulent Flow? - It is important to know if the fluid flow is laminar, transitional or turbulent when calculating heat transfer or pressure and head loss.

**Friction Head:** The head required to overcome the friction at the interior surface of a conductor and between fluid particles in motion. It varies with flow, size, type and conditions of conductors and fittings, and the fluid characteristics.

## G

**Gas:** A gas is one of the four major phases of matter (after solid and liquid, and followed by plasma) that subsequently appear as solid material when they are subjected to increasingly higher temperatures. Thus, as energy in the form of heat is added, a solid (e.g., ice) will first melt to become a liquid (e.g., water), which will then boil or evaporate to become a gas (e.g., water vapor). In some circumstances, a solid (e.g., "dry ice") can directly turn into a gas: this is called sublimation. If the gas is further heated, its atoms or molecules can become (wholly or partially) ionized, turning the gas into a plasma. **Relater Gas Information:** The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law. Properties of Gas Mixtures - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density. The Individual and Universal Gas Constant - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.

**Gauge Pressure:** Pressure differential above or below ambient atmospheric pressure.

## H

**Hazardous Atmosphere:** An atmosphere which by reason of being explosive, flammable, poisonous, corrosive, oxidizing, irritating, oxygen deficient, toxic, or otherwise harmful, may cause death, illness, or injury.

**Hazen-Williams Factor:** Hazen-Williams factor for some common piping materials. Hazen-Williams coefficients are used in the Hazen-Williams equation for friction loss calculation in ducts and pipes.

### Hazen-Williams Equation - Calculating Friction Head Loss in Water Pipes

Friction head loss (ft H<sub>2</sub>O per 100 ft pipe) in water pipes can be obtained by using the empirical Hazen-Williams equation. The Darcy-Weisbach equation with the Moody diagram are considered to be the most accurate model for estimating frictional head loss in steady pipe flow. Since the approach requires a not so efficient trial and error solution, an alternative empirical head loss calculation that does not require the trial and error solutions, as the Hazen-Williams equation, may be preferred:

$$f = 0.2083 (100/c)^{1.852} q^{1.852} / d_h^{4.8655} \quad (1)$$

where

$f$  = friction head loss in feet of water per 100 feet of pipe (ft<sub>H<sub>2</sub>O</sub>/100 ft pipe)

$c$  = Hazen-Williams roughness constant

$q$  = volume flow (gal/min)

$d_h$  = inside hydraulic diameter (inches)

Note that the Hazen-Williams formula is empirical and lacks physical basis. Be aware that the roughness constants are based on "normal" condition with approximately 1 m/s (3 ft/sec).

The Hazen-Williams formula is not the only empirical formula available. Manning's formula is common for gravity driven flows in open channels.

The flow velocity may be calculated as:

$$v = 0.4087 q / d_h^2$$

where

$v$  = flow velocity (ft/s)

The Hazen-Williams formula can be assumed to be relatively accurate for piping systems where the Reynolds Number is above  $10^5$  (turbulent flow).

- 1 ft (foot) = 0.3048 m
- 1 in (inch) = 25.4 mm
- 1 gal (US)/min =  $6.30888 \times 10^{-5}$  m<sup>3</sup>/s = 0.0227 m<sup>3</sup>/h = 0.0631 dm<sup>3</sup>(liter)/s =  $2.228 \times 10^{-3}$  ft<sup>3</sup>/s = 0.1337 ft<sup>3</sup>/min = 0.8327 Imperial gal (UK)/min

**Note!** The Hazen-Williams formula gives accurate head loss due to friction for fluids with kinematic viscosity of approximately 1.1 cSt. More about fluids and kinematic viscosity.

The results for the formula are acceptable for cold water at 60° F (15.6° C) with kinematic viscosity 1.13 cSt. For hot water with a lower kinematic viscosity (0.55 cSt at 130° F (54.4° C)) the error will be significant. Since the Hazen Williams method is only valid for water flowing at ordinary temperatures between 40 to 75° F, the Darcy Weisbach method should be used for other liquids or gases.

**Head:** The height of a column or body of fluid above a given point expressed in linear units. Head is often used to indicate gauge pressure. Pressure is equal to the height times the density of the liquid. The measure of the pressure of water expressed in feet of height of water. 1 psi = 2.31 feet of water. There are various types of heads of water depending upon what is being measured. Static (water at rest) and Residual (water at flow conditions).

**Hydraulics:** Hydraulics is a branch of science and engineering concerned with the use of liquids to perform mechanical tasks.

**Hydrodynamics:** Hydrodynamics is the fluid dynamics applied to liquids, such as water, alcohol, and oil.

## I

**Ideal Gas:** The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law. Properties of Gas Mixtures - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density. The Individual and Universal Gas Constant - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.

**Iisentropic Compression/Expansion Process:** If the compression or expansion takes place under constant volume conditions - the process is called **isentropic**. The isentropic process on the basis of the Ideal Gas Law can be expressed as:

$$p / \rho^k = \text{constant} \quad (2)$$

where

$k = c_p / c_v$  - the ratio of specific heats - the ratio of specific heat at constant pressure -  $c_p$  - to the specific heat at constant volume -  $c_v$

**Irrigation:** Water that is especially furnished to help provide and sustain the life of growing plants. It comes from ditches. It is sometimes treated with herbicides and pesticides to prevent the growth of weeds and the development of bugs in a lawn and a garden.

## K

**Kinematic Viscosity:** The ratio of absolute or dynamic viscosity to density - a quantity in which no force is involved. Kinematic viscosity can be obtained by dividing the absolute viscosity of a fluid with its mass density as

$$v = \mu / \rho \quad (2)$$

where

$v$  = kinematic viscosity

$\mu$  = absolute or dynamic viscosity

$\rho$  = density

In the SI-system the theoretical unit is  $m^2/s$  or commonly used **Stoke (St)** where

- $1 \text{ St} = 10^{-4} m^2/s$

Since the Stoke is an unpractical large unit, it is usual divided by 100 to give the unit called **Centistokes (cSt)** where

$$1 \text{ St} = 100 \text{ cSt}$$

$$1 \text{ cSt} = 10^{-6} m^2/s$$

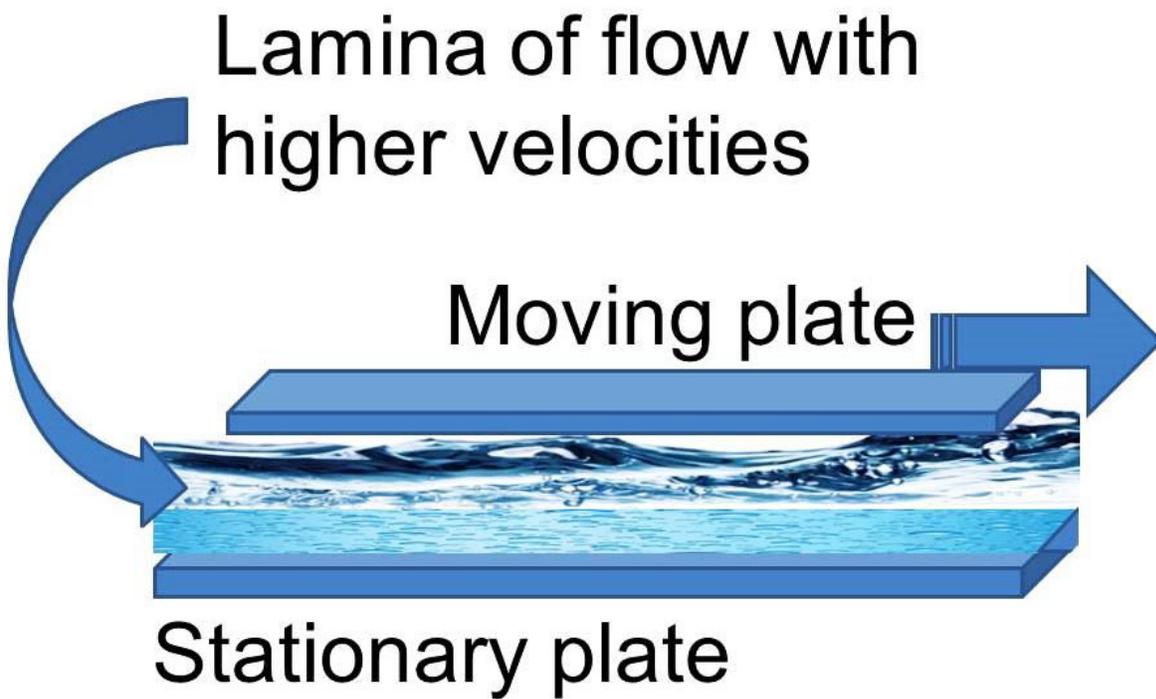
Since the specific gravity of water at 68.4°F (20.2°C) is almost one - 1, the kinematic viscosity of water at 68.4°F is for all practical purposes 1.0 cSt.

**Kinetic Energy:** The ability of an object to do work by virtue of its motion. The energy terms that are used to describe the operation of a pump are pressure and head.

**Knudsen Number:** Used by modelers who wish to express a non-dimensionless speed.

## L

**Laminar Flow:** The resistance to flow in a liquid can be characterized in terms of the viscosity of the fluid if the flow is smooth. In the case of a moving plate in a liquid, it is found that there is a layer or lamina which moves with the plate, and a layer which is essentially stationary if it is next to a stationary plate. There is a gradient of velocity as you move from the stationary to the moving plate, and the liquid tends to move in layers with successively higher speed. This is called laminar flow, or sometimes "streamlined" flow. Viscous resistance to flow can be modeled for laminar flow, but if the lamina break up into turbulence, it is very difficult to characterize the fluid flow.



The common application of laminar flow would be in the smooth flow of a viscous liquid through a tube or pipe. In that case, the velocity of flow varies from zero at the walls to a maximum along the centerline of the vessel. The flow profile of laminar flow in a tube can be calculated by dividing the flow into thin cylindrical elements and applying the viscous force to them. Laminar, Transitional or Turbulent Flow? - It is important to know if the fluid flow is laminar, transitional or turbulent when calculating heat transfer or pressure and head loss.

**Laplace's Equation:** Describes the behavior of gravitational, electric, and fluid potentials.

The scalar form of Laplace's equation is the partial differential equation

$$\nabla^2 \psi = 0, \tag{1}$$

where  $\nabla^2$  is the Laplacian.

Note that the operator  $\nabla^2$  is commonly written as  $\Delta$  by mathematicians (Krantz 1999, p. 16). Laplace's equation is a special case of the Helmholtz differential equation

$$\nabla^2 \psi + k^2 \psi = 0 \tag{2}$$

with  $k = 0$ , or Poisson's equation

$$\nabla^2 \psi = -4 \pi \rho \tag{3}$$

with  $\rho = 0$ .

The vector Laplace's equation is given by

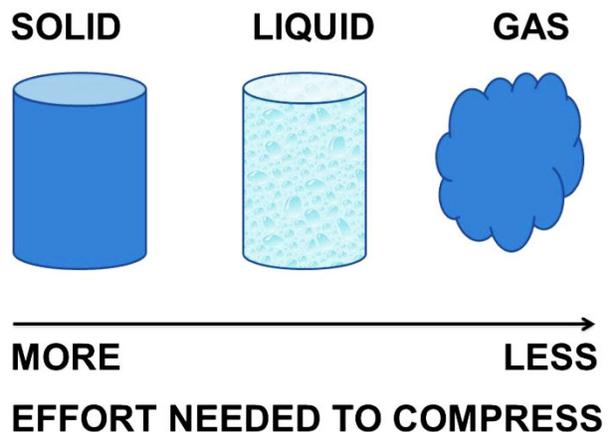
$$\nabla^2 \mathbf{F} = \mathbf{0}. \tag{4}$$

A function  $\psi$  which satisfies Laplace's equation is said to be harmonic. A solution to Laplace's equation has the property that the average value over a spherical surface is equal to the value at the center of the sphere (Gauss's harmonic function theorem). Solutions have no local maxima or minima. Because Laplace's equation is linear, the superposition of any two solutions is also a solution.

**Lift (Force):** Lift consists of the sum of all the aerodynamic forces normal to the direction of the external airflow.

**Liquids:** An in-between state of matter. They can be found in between the solid and gas states. They don't have to be made up of the same compounds. If you have a variety of materials in a liquid, it is called a solution. One characteristic of a liquid is that it will fill up the shape of a container. If you pour some water in a cup, it will fill up the bottom of the cup first and then fill the rest. The water will also take the shape of the cup. It fills the bottom first because of **gravity**. The top part of a liquid will usually have a flat surface. That flat surface is because of gravity too. Putting an ice cube (solid) into a cup will leave you with a cube in the middle of the cup; the shape won't change until the ice becomes a liquid.

Another trait of liquids is that they are difficult to compress. When you compress something, you take a certain amount and force it into a smaller space. Solids are very difficult to compress and gases are very easy. Liquids are in the middle but tend to be difficult. When you compress something, you force the atoms closer together. When pressure goes up, substances are compressed. Liquids already have their atoms close together, so they are hard to compress. Many shock absorbers in cars compress liquids in tubes.



A special force keeps liquids together. Solids are stuck together and you have to force them apart. Gases bounce everywhere and they try to spread themselves out. Liquids actually want to stick together. There will always be the occasional evaporation where extra energy gets a molecule excited and the molecule leaves the system. Overall, liquids have **cohesive** (sticky) forces at work that hold the molecules together. Related Liquid Information: Equations in Fluid Mechanics - Continuity, Euler, Bernoulli, Dynamic and Total Pressure

## M

**Mach Number:** When an object travels through a medium, then its Mach number is the ratio of the object's speed to the speed of sound in that medium.

**Magnetic Flow Meter:** Inspection of magnetic flow meter instrumentation should include checking for corrosion or insulation deterioration.

**Manning Formula for Gravity Flow:** Manning's equation can be used to calculate cross-sectional average velocity flow in open channels

$$v = k_n/n R^{2/3} S^{1/2} \quad (1)$$

where

$v$  = cross-sectional average velocity (ft/s, m/s)

$k_n = 1.486$  for English units and  $k_n = 1.0$  for SI units

$A$  = cross sectional area of flow (ft<sup>2</sup>, m<sup>2</sup>)

$n$  = Manning coefficient of roughness

$R$  = hydraulic radius (ft, m)

$S$  = slope of pipe (ft/ft, m/m)

The volume flow in the channel can be calculated as

$$q = A v = A k_n/n R^{2/3} S^{1/2} \quad (2)$$

where

$q$  = volume flow (ft<sup>3</sup>/s, m<sup>3</sup>/s)

$A$  = cross-sectional area of flow (ft<sup>2</sup>, m<sup>2</sup>)

**Maximum Contamination Levels or (MCLs):** The maximum allowable level of a contaminant that federal or state regulations allow in a public water system. If the MCL is exceeded, the water system must treat the water so that it meets the MCL. Or provide adequate backflow protection.

**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.

**Mg/L:** milligrams per liter

**Microbe, 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.

**ML:** milliliter

## N

**Navier-Stokes Equations:** The motion of a non-turbulent, Newtonian fluid is governed by the Navier-Stokes equation. The equation can be used to model turbulent flow, where the fluid parameters are interpreted as time-averaged values.

**Newtonian Fluid:** Newtonian fluid (named for Isaac Newton) is a fluid that flows like water—its shear stress is linearly proportional to the velocity gradient in the direction perpendicular to the plane of shear. The constant of proportionality is known as the viscosity. Water is Newtonian, because it continues to exemplify fluid properties no matter how fast it is stirred or mixed.

Contrast this with a non-Newtonian fluid, in which stirring can leave a "hole" behind (that gradually fills up over time - this behavior is seen in materials such as pudding, or to a less rigorous extent, sand), or cause the fluid to become thinner, the drop in viscosity causing it to flow more (this is seen in non-drip paints). For a Newtonian fluid, the viscosity, by definition, depends only on temperature and pressure (and also the chemical composition of the fluid if the fluid is not a pure substance), not on the forces acting upon it. If the fluid is incompressible and viscosity is constant across the fluid, the equation governing the shear stress. Related Newtonian Information: A Fluid is Newtonian if viscosity is constant applied to shear force. Dynamic, Absolute and Kinematic Viscosity - An introduction to dynamic, absolute and kinematic viscosity and how to convert between CentiStokes (cSt), CentiPoises (cP), Saybolt Universal Seconds (SSU) and degree Engler.

**Newton's Third Law:** Newton's third law describes the forces acting on objects interacting with each other. Newton's third law can be expressed as

- *"If one object exerts a force  $F$  on another object, then the second object exerts an equal but opposite force  $F$  on the first object"*

Force is a convenient abstraction to represent mentally the pushing and pulling interaction between objects.

It is common to express forces as vectors with magnitude, direction and point of application. The net effect of two or more forces acting on the same point is the vector sum of the forces.

**Non-Newtonian Fluid:** Non-Newtonian fluid viscosity changes with the applied shear force.

## O

**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.

## P

**Pascal's Law:** A pressure applied to a confined fluid at rest is transmitted with equal intensity throughout the fluid.

**Pathogens:** Disease-causing pathogens; waterborne pathogens. A pathogen is a bacterium, virus or parasite that causes or is capable of causing disease. Pathogens may contaminate water and cause waterborne disease.

**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.

**pH:** A measure of the acidity of water. 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. pH (Power of Hydroxyl Ion Activity).

**Pipeline Appurtenances:** Pressure reducers, bends, valves, regulators (which are a type of valve), etc.

**Peak Demand:** The maximum momentary load placed on a water treatment plant, pumping station or distribution system is the Peak Demand.

**Pipe Velocities:** For calculating fluid pipe velocity.

### Imperial units

A fluids flow velocity in pipes can be calculated with Imperial or American units as

$$v = 0.4085 q / d^2 \quad (1)$$

where

$v$  = velocity (ft/s)

$q$  = volume flow (US gal. /min)

$d$  = pipe inside diameter (inches)

### SI units

A fluids flow velocity in pipes can be calculated with SI units as

$$v = 1.274 q / d^2 \quad (2)$$

where

$v$  = velocity (m/s)

$q$  = volume flow (m<sup>3</sup>/s)

$d$  = pipe inside diameter (m)

**Pollution:** To make something unclean or impure. Some states will have a definition of pollution that relates to non-health related water problems, like taste and odors. See Contaminated.

**Positive Flow Report-back Signal:** When a pump receives a signal to start, a light will typically be illuminated on the control panel indicating that the pump is running. In order to be sure that the pump is actually pumping water, a Positive flow report-back signal should be installed on the control panel.

**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.

**PPM:** Abbreviation for parts per million.

**Prandtl Number:** The Prandtl Number is a dimensionless number approximating the ratio of momentum diffusivity and thermal diffusivity and can be expressed as

$$Pr = \nu / \alpha \quad (1)$$

where

$Pr$  = Prandtl's number

$\nu$  = kinematic viscosity (Pa s)

$\alpha$  = thermal diffusivity (W/m K)

The Prandtl number can alternatively be expressed as

$$Pr = \mu c_p / k \quad (2)$$

where

$\mu$  = absolute or dynamic viscosity (kg/m s, cP)

$c_p$  = specific heat capacity (J/kg K, Btu/(lb °F))

$k$  = thermal conductivity (W/m K, Btu/(h ft<sup>2</sup> °F/ft))

The Prandtl Number is often used in heat transfer and free and forced convection calculations.

**Pressure:** An introduction to pressure - the definition and presentation of common units as psi and Pa and the relationship between them.

The pressure in a fluid is defined as

*"the normal force per unit area exerted on an imaginary or real plane surface in a fluid or a gas"*

The equation for pressure can be expressed as:

$$p = F / A \quad (1)$$

where

$p$  = pressure [lb/in<sup>2</sup> (psi) or lb/ft<sup>2</sup> (psf), N/m<sup>2</sup> or kg/ms<sup>2</sup> (Pa)]

$F$  = force [<sup>1</sup>, N]

$A$  = area [in<sup>2</sup> or ft<sup>2</sup>, m<sup>2</sup>]

<sup>1</sup>) In the English Engineering System special care must be taken for the force unit. The basic unit for mass is the pound mass (lb<sub>m</sub>) and the unit for the force is the pound (lb) or pound force (lb<sub>f</sub>).

### **Absolute Pressure**

The **absolute pressure** -  $p_a$  - is measured relative to the *absolute zero pressure* - the pressure that would occur at absolute vacuum.

## Gauge Pressure

A **gauge** is often used to measure the pressure difference between a system and the surrounding atmosphere. This pressure is often called the **gauge pressure** and can be expressed as

$$p_g = p_a - p_o \quad (2)$$

where

$p_g$  = gauge pressure

$p_o$  = atmospheric pressure

## Atmospheric Pressure

The atmospheric pressure is the pressure in the surrounding air. It varies with temperature and altitude above sea level.

### Standard Atmospheric Pressure

The **Standard Atmospheric Pressure** (atm) is used as a reference for gas densities and volumes. The Standard Atmospheric Pressure is defined at sea-level at 273°K (0°C) and is **1.01325 bar** or 101325 Pa (absolute). The temperature of 293°K (20°C) is also used.

In imperial units the Standard Atmospheric Pressure is 14.696 psi.

- $1 \text{ atm} = 1.01325 \text{ bar} = 101.3 \text{ kPa} = 14.696 \text{ psi (lb/in}^2\text{)} = 760 \text{ mmHg} = 10.33 \text{ mH}_2\text{O} = 760 \text{ torr} = 29.92 \text{ in Hg} = 1013 \text{ mbar} = 1.0332 \text{ kg/cm}^2 = 33.90 \text{ ftH}_2\text{O}$

**Pressure Head:** The height to which liquid can be raised by a given pressure.

**Pressure Regulation Valves:** Control water pressure and operate by restricting flows. They are used to deliver water from a high pressure to a low-pressure system. The pressure downstream from the valve regulates the amount of flow. Usually, these valves are of the globe design and have a spring-loaded diaphragm that sets the size of the opening.

**Pressure Units:** Since 1 Pa is a small pressure unit, the unit hectopascal (hPa) is widely used, especially in meteorology. The unit kilopascal (kPa) is commonly used designing technical applications like HVAC systems, piping systems and similar.

- $1 \text{ hectopascal} = 100 \text{ pascal} = 1 \text{ millibar}$
- $1 \text{ kilopascal} = 1000 \text{ pascal}$

### Some Pressure Levels

- 10 Pa - The pressure at a depth of 1 mm of water
- 1 kPa - Approximately the pressure exerted by a 10 g mass on a 1 cm<sup>2</sup> area
- 10 kPa - The pressure at a depth of 1 m of water, or the drop in air pressure when going from sea level to 1000 m elevation
- 10 MPa - A "high pressure" washer forces the water out of the nozzles at this pressure
- 10 GPa - This pressure forms diamonds

### Some Alternative Units of Pressure

- $1 \text{ bar} = 100,000 \text{ Pa}$
- $1 \text{ millibar} = 100 \text{ Pa}$
- $1 \text{ atmosphere} = 101,325 \text{ Pa}$
- $1 \text{ mm Hg} = 133 \text{ Pa}$
- $1 \text{ inch Hg} = 3,386 \text{ Pa}$

A **torr** (torr) is named after Torricelli and is the pressure produced by a column of mercury 1 mm high equals to 1/760th of an atmosphere. 1 atm = 760 torr = 14.696 psi

**Pounds per square inch** (psi) was common in U.K. but has now been replaced in almost every country except in the U.S. by the SI units. The Normal atmospheric pressure is 14.696 psi, meaning that a column of air on one square inch in area rising from the Earth's atmosphere to space weighs 14.696 pounds.

The **bar** (bar) is common in the industry. One bar is 100,000 Pa, and for most practical purposes can be approximated to one atmosphere even if

$$1 \text{ Bar} = 0.9869 \text{ atm}$$

There are 1,000 **millibar** (mbar) in one bar, a unit common in meteorology.

$$1 \text{ millibar} = 0.001 \text{ bar} = 0.750 \text{ torr} = 100 \text{ Pa}$$

## Q

## R

**Residual Disinfection/Protection:** A required level of disinfectant that remains in treated water to ensure disinfection protection and prevent recontamination throughout the distribution system (i.e., pipes).

**Reynolds Number:** The Reynolds number is used to determine whether a flow is laminar or turbulent. The Reynolds Number is a non-dimensional parameter defined by the ratio of dynamic pressure ( $\rho u^2$ ) and shearing stress ( $\mu u / L$ ) - and can be expressed as

$$\begin{aligned} Re &= (\rho u^2) / (\mu u / L) \\ &= \rho u L / \mu \\ &= u L / \nu \quad (1) \end{aligned}$$

where

$Re$  = Reynolds Number (non-dimensional)

$\rho$  = density ( $\text{kg}/\text{m}^3$ ,  $\text{lb}_m/\text{ft}^3$ )

$u$  = velocity (m/s, ft/s)

$\mu$  = dynamic viscosity ( $\text{Ns}/\text{m}^2$ ,  $\text{lb}_m/\text{s ft}$ )

$L$  = characteristic length (m, ft)

$\nu$  = kinematic viscosity ( $\text{m}^2/\text{s}$ ,  $\text{ft}^2/\text{s}$ )

**Richardson Number:** A dimensionless number that expresses the ratio of potential to kinetic energy.

## S

**Sanitizer:** A chemical which disinfects (kills bacteria), kills algae and oxidizes organic matter.

**Saybolt Universal Seconds (or SUS, SSU):** Saybolt Universal Seconds (or SUS) is used to measure viscosity. The efflux time is Saybolt Universal Seconds (SUS) required for 60 milliliters of a petroleum product to flow through the calibrated orifice of a Saybolt Universal viscometer, under carefully controlled temperature and as prescribed by test method ASTM D 88. This method has largely been replaced by the kinematic viscosity method. Saybolt Universal Seconds is also called the SSU number (Seconds Saybolt Universal) or SSF number (Saybolt Seconds Furo).

Kinematic viscosity versus dynamic or absolute viscosity can be expressed as

$$v = 4.63 \mu / SG \quad (3)$$

where

$v$  = kinematic viscosity (SSU)

$\mu$  = dynamic or absolute viscosity (cP)

**Scale:** Crust of calcium carbonate, the result of unbalanced pool 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. You will often find major scale deposits inside a backflow prevention assembly.

**Shock:** Also known as superchlorination or break point chlorination. Ridding a pool of organic waste through oxidization by the addition of significant quantities of a halogen.

**Shock Wave:** A shock wave is a strong pressure wave produced by explosions or other phenomena that create violent changes in pressure.

**Solder:** A fusible alloy used to join metallic parts. Solder for potable water pipes shall be lead-free.

**Sound Barrier:** The sound barrier is the apparent physical boundary stopping large objects from becoming supersonic.

**Specific Gravity:** The Specific Gravity - SG - is a dimensionless unit defined as the ratio of density of the material to the density of water at a specified temperature. Specific Gravity can be expressed as

$$SG = \rho / \rho_{H_2O} \quad (3)$$

where

SG = specific gravity

$\rho$  = density of fluid or substance (kg/m<sup>3</sup>)

$\rho_{H_2O}$  = density of water (kg/m<sup>3</sup>)

It is common to use the density of water at 4° C (39°F) as a reference - at this point the density of water is at the highest. Since Specific Weight is dimensionless it has the same value in the metric SI system as in the imperial English system (BG). At the reference point the Specific Gravity has same numerically value as density.

#### **Example - Specific Gravity**

If the density of iron is 7850 kg/m<sup>3</sup>, 7.85 grams per cubic millimeter, 7.85 kilograms per liter, or 7.85 metric tons per cubic meter - the specific gravity of iron is:

$$SG = 7850 \text{ kg/m}^3 / 1000 \text{ kg/m}^3$$

$$= \underline{7.85}$$

(the density of water is 1000 kg/m<sup>3</sup>)

**Specific Weight:** Specific Weight is defined as weight per unit volume. Weight is a **force**.

- Mass and Weight - the difference! - What is weight and what is mass? An explanation of the difference between weight and mass.

Specific Weight can be expressed as

$$\gamma = \rho g \quad (2)$$

where

$\gamma$  = specific weight (kN/m<sup>3</sup>)

$g$  = acceleration of gravity (m/s<sup>2</sup>)

The SI-units of specific weight are kN/m<sup>3</sup>. The imperial units are lb/ft<sup>3</sup>. The local acceleration  $g$  is under normal conditions 9.807 m/s<sup>2</sup> in SI-units and 32.174 ft/s<sup>2</sup> in imperial units.

**Example - Specific Weight Water**

Specific weight for water at 60 °F is 62.4 lb/ft<sup>3</sup> in imperial units and 9.80 kN/m<sup>3</sup> in SI-units.

**Example - Specific Weight Some other Materials**

Product	Specific Weight - $\gamma$	
	Imperial Units (lb/ft <sup>3</sup> )	SI Units (kN/m <sup>3</sup> )
Ethyl Alcohol	49.3	7.74
Gasoline	42.5	6.67
Glycerin	78.6	12.4
Mercury	847	133
SAE 20 Oil	57	8.95
Seawater	64	10.1
Water	62.4	9.80

**Static Head:** The height of a column or body of fluid above a given point

**Static Pressure:** The pressure in a fluid at rest.

**Static Pressure and Pressure Head in Fluids:** The pressure indicates the normal force per unit area at a given point acting on a given plane. Since there is no shearing stresses present in a fluid at rest - the pressure in a fluid is independent of direction.

For fluids - liquids or gases - at rest the pressure gradient in the vertical direction depends only on the specific weight of the fluid.

How pressure changes with elevation can be expressed as

$$dp = - \gamma dz \quad (1)$$

where

$dp$  = change in pressure

$dz$  = change in height

$\gamma$  = specific weight

The pressure gradient in vertical direction is negative - the pressure decrease upwards.

**Specific Weight:** Specific Weight can be expressed as:

$$\gamma = \rho g \quad (2)$$

where

$\gamma$  = specific weight

$g$  = acceleration of gravity

In general the specific weight -  $\gamma$  - is constant for fluids. For gases the specific weight -  $\gamma$  - varies with the elevation.

**Static Pressure and Pressure Head in Fluids Continued:**

**Static Pressure in a Fluid:** For an incompressible fluid - as a liquid - the pressure difference between two elevations can be expressed as:

$$p_2 - p_1 = -\gamma (z_2 - z_1) \quad (3)$$

where

$p_2$  = pressure at level 2

$p_1$  = pressure at level 1

$z_2$  = level 2

$z_1$  = level 1

(3) can be transformed to:

$$p_1 - p_2 = \gamma (z_2 - z_1) \quad (4)$$

or

$$p_1 - p_2 = \gamma h \quad (5)$$

where

$h = z_2 - z_1$  difference in elevation - the depth down from location  $z_2$ .

or

$$p_1 = \gamma h + p_2 \quad (6)$$

**Static Pressure and Pressure Head in Fluids Continued:**

**The Pressure Head**

(6) can be transformed to:

$$h = (p_2 - p_1) / \gamma \quad (6)$$

$h$  express **the pressure head** - the height of a column of fluid of specific weight -  $\gamma$  - required to give a pressure difference of  $(p_2 - p_1)$ .

**Example - Pressure Head**

A pressure difference of 5 psi (lbf/in<sup>2</sup>) is equivalent to

$$5 \text{ (lbf/in}^2\text{)} \cdot 12 \text{ (in/ft)} \cdot 12 \text{ (in/ft)} / 62.4 \text{ (lb/ft}^3\text{)} = \underline{11.6} \text{ ft of water}$$

$$5 \text{ (lbf/in}^2\text{)} \cdot 12 \text{ (in/ft)} \cdot 12 \text{ (in/ft)} / 847 \text{ (lb/ft}^3\text{)} = \underline{0.85} \text{ ft of mercury}$$

when specific weight of water is 62.4 (lb/ft<sup>3</sup>) and specific weight of mercury is 847 (lb/ft<sup>3</sup>).

**Streamline - Stream Function:** A streamline is the path that an imaginary particle would follow if it was embedded in the flow.

**Strouhal Number:** A quantity describing oscillating flow mechanisms. The Strouhal Number is a dimensionless value useful for analyzing oscillating, unsteady fluid flow dynamics problems.

The Strouhal Number can be expressed as

$$St = \omega l / v \quad (1)$$

where

$St$  = Strouhal Number

$\omega$  = oscillation frequency

$l$  = characteristic length

$v$  = flow velocity

The Strouhal Number represents a measure of the ratio of inertial forces due to the unsteadiness of the flow or local acceleration to the inertial forces due to changes in velocity from one point to another in the flow field.

The vortices observed behind a stone in a river, or measured behind the obstruction in a vortex flow meter, illustrate these principles.

**Stuffing Box:** That portion of the pump which houses the packing or mechanical seal.

**Submerged:** To cover with water or liquid substance.

**Supersonic Flow:** Flow with speed above the speed of sound, 1,225 km/h at sea level, is said to be supersonic.

**Surface Tension:** Surface tension is a force within the surface layer of a liquid that causes the layer to behave as an elastic sheet. The cohesive forces between liquid molecules are responsible for the phenomenon known as surface tension. The molecules at the surface do not have other like molecules on all sides of them and consequently they cohere more strongly to those directly associated with them on the surface. This forms a surface "film" which makes it more difficult to move an object through the surface than to move it when it is completely submerged. Surface tension is typically measured in dynes/cm, the force in dynes required to break a film of length 1 cm. Equivalently, it can be stated as surface energy in ergs per square centimeter. Water at 20°C has a surface tension of 72.8 dynes/cm compared to 22.3 for ethyl alcohol and 465 for mercury.

Surface tension is typically measured in *dynes/cm* or *N/m*.

Liquid	Surface Tension	
	N/m	dynes/cm
Ethyl Alcohol	0.0223	22.3
Mercury	0.465	465
Water 20°C	0.0728	72.75
Water 100°C	0.0599	58.9

Surface tension is the energy required to stretch a unit change of a surface area. Surface tension will form a drop of liquid to a sphere since the sphere offers the smallest area for a definite volume.

Surface tension can be defined as

$$\sigma = F_s / l \quad (1)$$

where

$\sigma$  = surface tension (N/m)

$F_s$  = stretching force (N)

$l$  = unit length (m)

### Alternative Units

Alternatively, surface tension is typically measured in dynes/cm, which is

- the force in dynes required to break a film of length 1 cm
- or as surface energy J/m<sup>2</sup> or alternatively ergs per square centimeter.
- 1 dynes/cm = 0.001 N/m = 0.0000685 lb<sub>f</sub>/ft = 0.571 10<sup>-5</sup> lb<sub>f</sub>/in = 0.0022 poundal/ft = 0.00018 poundal/in = 1.0 mN/m = 0.001 J/m<sup>2</sup> = 1.0 erg/cm<sup>2</sup> = 0.00010197 kg<sub>f</sub>/m

Common Imperial units used are lb/ft and lb/in.

Water surface tension at different temperatures can be taken from the table below:

Temperature (°C)	Surface Tension - $\sigma$ - (N/m)
0	0.0757
10	0.0742
20	0.0728
30	0.0712
40	0.0696
50	0.0679
60	0.0662
70	0.0644
80	0.0626
90	0.0608
100	0.0588

### Surface Tension of some common Fluids

- benzene : 0.0289 (N/m)
- diethyl ether : 0.0728 (N/m)
- carbon tetrachloride : 0.027 (N/m)
- chloroform : 0.0271 (N/m)
- ethanol : 0.0221 (N/m)
- ethylene glycol : 0.0477 (N/m)
- glycerol : 0.064 (N/m)
- mercury : 0.425 (N/m)
- methanol : 0.0227 (N/m)

- propanol : 0.0237 (N/m)
- toluene : 0.0284 (N/m)
- water at 20°C : 0.0729 (N/m)

**Surge Tanks:** Surge tanks can be used to control Water Hammer. A limitation of hydropneumatic tanks is that they do not provide much storage to meet peak demands during power outages and you have very limited time to do repairs on equipment.

## T

**Telemetry Systems:** The following are common pressure sensing devices: Helical Sensor, Bourdon Tube, and Bellows Sensor. The most frequent problem that affects a liquid pressure-sensing device is air accumulation at the sensor. A diaphragm element being used as a level sensor would be used in conjunction with a pressure sensor. Devices must often transmit more than one signal. You can use several types of systems including: Polling, Scanning and Multiplexing. Transmitting equipment requires installation where temperature will not exceed 130 degrees F.

**Thixotropic Fluids: Shear Thinning Fluids or Thixotropic Fluids** reduce their viscosity as agitation or pressure is increased at a constant temperature. Ketchup and mayonnaise are examples of thixotropic materials. They appear thick or viscous but are possible to pump quite easily.

**Transonic:** Flow with speed at velocities just below and above the speed of sound is said to be transonic.

**Turbidity:** A measure of the cloudiness of water caused by suspended particles.

## U

**U-Tube Manometer:** Pressure measuring devices using liquid columns in vertical or inclined tubes are called manometers. One of the most common is the water filled u-tube manometer used to measure pressure difference in pitot or orifices located in the airflow in air handling or ventilation systems.

## V

**Valve:** A device that opens and closes to regulate the flow of liquids. Faucets, hose bibs, and Ball are examples of valves.

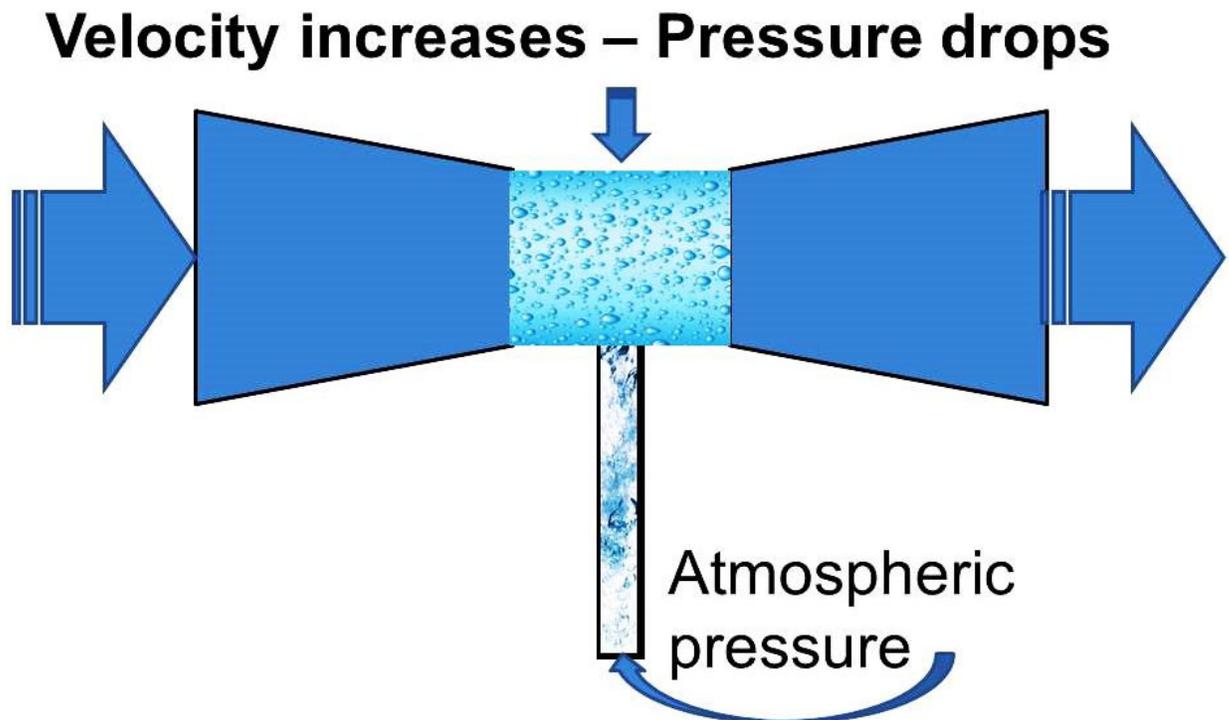
**Vane:** That portion of an impeller which throws the water toward the volute.

**Vapor Pressure:** For a particular substance at any given temperature there is a pressure at which the vapor of that substance is in equilibrium with its liquid or solid forms.

**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:** A system for speeding the flow of the fluid, by constricting it in a cone-shaped tube. Venturi are used to measure the speed of a fluid, by measuring the pressure changes from one point to another along the venture. A venturi can also be used to inject a liquid or a gas into another liquid. A pump forces the liquid flow through a tube connected to:

- A venturi to increase the speed of the fluid (restriction of the pipe diameter)
- A short piece of tube connected to the gas source
- A second venturi that decrease the speed of the fluid (the pipe diameter increase again)
- After the first venturi the pressure in the pipe is lower, so the gas is sucked in the pipe. Then the mixture enters the second venturi and slow down. At the end of the system a mixture of gas and liquid appears and the pressure rise again to its normal level in the pipe.
- This technique is used for ozone injection in water.



The newest injector design causes complete mixing of injected materials (air, ozone or chemicals), eliminating the need for other in-line mixers. Venturi injectors have no moving parts and are maintenance free. They operate effectively over a wide range of pressures (from 1 to 250 psi) and require only a minimum pressure difference to initiate the vacuum at the suction part. Venturis are often built in thermoplastics (PVC, PE, PVDF), stainless steel or other metals.

The cavitation effect at the injection chamber provides an instantaneous mixing, creating thousands of very tiny bubbles of gas in the liquid. The small bubbles provide an increased gas exposure to the liquid surface area, increasing the effectiveness of the process (i.e. ozonation).

**Vibration:** A force that is present on construction sites and must be considered. The vibrations caused by backhoes, dump trucks, compactors and traffic on job sites can be substantial.

**Viscosity:** Informally, viscosity is the quantity that describes a fluid's resistance to flow. Fluids resist the relative motion of immersed objects through them as well as to the motion of layers with differing velocities within them. Formally, viscosity (represented by the symbol  $\eta$  "eta") is the ratio of the shearing stress ( $F/A$ ) to the velocity gradient ( $\Delta v_x/\Delta z$  or  $dv_x/dz$ ) in a fluid.

$$\eta = (F/A) \div (\Delta v_x/\Delta z) \quad \text{or} \quad \eta = (F/A) \div (dv_x/dz)$$

$$A \quad \Delta z \qquad A \quad dz$$

The more usual form of this relationship, called Newton's equation, states that the resulting shear of a fluid is directly proportional to the force applied and inversely proportional to its viscosity. The similarity to Newton's second law of motion ( $F = ma$ ) should be apparent.

$$\frac{F}{A} = \eta \frac{\Delta v_x}{\Delta z} \quad \text{or} \quad \frac{F}{A} = \eta \frac{dv_x}{dz}$$

$$\Downarrow \qquad \Downarrow$$

$$F = m \frac{\Delta v}{\Delta t} \quad \text{or} \quad F = m \frac{dv}{dt}$$

The SI unit of viscosity is the pascal second [Pa·s], which has no special name. Despite its self-proclaimed title as an international system, the International System of Units has had very little international impact on viscosity. The pascal second is rarely used in scientific and technical publications today. The most common unit of viscosity is the dyne second per square centimeter [dyne·s/cm<sup>2</sup>], which is given the name poise [P] after the French physiologist Jean Louis Poiseuille (1799-1869). Ten poise equal one pascal second [Pa·s] making the centipoise [cP] and millipascal second [mPa·s] identical.

$$\begin{aligned} 1 \text{ pascal second} &= 10 \text{ poise} = 1,000 \text{ millipascal second} \\ 1 \text{ centipoise} &= 1 \text{ millipascal second} \end{aligned}$$

There are actually two quantities that are called viscosity. The quantity defined above is sometimes called dynamic viscosity, absolute viscosity, or simple viscosity to distinguish it from the other quantity, but is usually just called viscosity. The other quantity called kinematic viscosity (represented by the symbol  $\nu$  "nu") is the ratio of the viscosity of a fluid to its density.

$$\nu = \frac{\eta}{\rho}$$

Kinematic viscosity is a measure of the resistive flow of a fluid under the influence of gravity. It is frequently measured using a device called a capillary viscometer -- basically a graduated can with a narrow tube at the bottom. When two fluids of equal volume are placed in identical capillary viscometers and allowed to flow under the influence of gravity, a viscous fluid takes longer than a less viscous fluid to flow through the tube. Capillary viscometers are discussed in more detail later in this section. The SI unit of kinematic viscosity is the square meter per second [m<sup>2</sup>/s], which has no special name. This unit is so large that it is rarely used. A more common unit of kinematic viscosity is the square centimeter per second [cm<sup>2</sup>/s], which is given the name stoke [St] after the English scientist George Stoke. This unit is also a bit too large and so the most common unit is probably the square millimeter per second [mm<sup>2</sup>/s] or centistoke [cSt].

**Viscosity and Reference Temperatures:** The viscosity of a fluid is highly temperature dependent and for either dynamic or kinematic viscosity to be meaningful, the **reference temperature** must be quoted. In ISO 8217 the reference temperature for a residual fluid is 100°C. For a distillate fluid the reference temperature is 40°C.

- For a liquid - the kinematic viscosity will **decrease** with higher temperature.
- For a gas - the kinematic viscosity will **increase** with higher temperature.

**Volute:** The spiral-shaped casing surrounding a pump impeller that collects the liquid discharged by the impeller.

**Vorticity:** Vorticity is defined as the circulation per unit area at a point in the flow field.

**Vortex:** A vortex is a whirlpool in the water.

## **W**

**Water Freezing:** The effects of water freezing in storage tanks can be minimized by alternating water levels in the tank.

**Water Storage Facility Inspection:** During an inspection of your water storage facility, you should inspect the Cathodic protection system including checking the anode's condition and the connections. The concentration of polyphosphates that is used for corrosion control in storage tanks is typically 5 mg/L or less. External corrosion of steel water storage facilities can be reduced with Zinc or aluminum coatings. All storage facilities should be regularly sampled to determine the quality of water that enters and leaves the facility. One tool or piece of measuring equipment is the Jackson turbidimeter, which is a method to measure cloudiness in water.

**Wave Drag:** Wave drag refers to a sudden and very powerful drag that appears on aircrafts flying at high-subsonic speeds.

**Water Purveyor:** The individuals or organization responsible to help provide, supply, and furnish quality water to a community.

**Water Works:** All of the pipes, pumps, reservoirs, dams and buildings that make up a water system.

**Waterborne Diseases:** 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).

**Weber Number:** A dimensionless value useful for analyzing fluid flows where there is an interface between two different fluids. Since the Weber Number represents an index of the inertial force to the surface tension force acting on a fluid element, it can be useful analyzing thin films flows and the formation of droplets and bubbles.



## Appendixes and Charts

### Density of Common Liquids

The density of some common liquids can be found in the table below:

Liquid	Temperature - $t$ - (°C)	Density - $\rho$ - (kg/m <sup>3</sup> )
Acetic Acid	25	1049
Acetone	25	785
Acetonitrile	20	782
Alcohol, ethyl	25	785
Alcohol, methyl	25	787
Alcohol, propyl	25	780
Ammonia (aqua)	25	823
Aniline	25	1019
Automobile oils	15	880 - 940
Beer (varies)	10	1010
Benzene	25	874
Benzyl	15	1230
Brine	15	1230
Bromine	25	3120
Butyric Acid	20	959
Butane	25	599
n-Butyl Acetate	20	880
n-Butyl Alcohol	20	810
n-Butylchloride	20	886
Caproic acid	25	921
Carbolic acid	15	956
Carbon disulfide	25	1261
Carbon tetrachloride	25	1584
Carene	25	857
Castor oil	25	956
Chloride	25	1560
Chlorobenzene	20	1106
Chloroform	20	1489
Chloroform	25	1465
Citric acid	25	1660
Coconut oil	15	924
Cotton seed oil	15	926
Cresol	25	1024
Creosote	15	1067
Crude oil, 48° API	60°F	790
Crude oil, 40° API	60°F	825
Crude oil, 35.6° API	60°F	847

Crude oil, 32.6° API	60°F	862
Crude oil, California	60°F	915
Crude oil, Mexican	60°F	973
Crude oil, Texas	60°F	873
Cumene	25	860
Cyclohexane	20	779
Cyclopentane	20	745
Decane	25	726
Diesel fuel oil 20 to 60	15	820 - 950
Diethyl ether	20	714
o-Dichlorobenzene	20	1306
Dichloromethane	20	1326
Diethylene glycol	15	1120
Dichloromethane	20	1326
Dimethyl Acetamide	20	942
N,N-Dimethylformamide	20	949
Dimethyl Sulfoxide	20	1100
Dodecane	25	755
Ethane	-89	570
Ether	25	73
Ethylamine	16	681
Ethyl Acetate	20	901
Ethyl Alcohol	20	789
Ethyl Ether	20	713
Ethylene Dichloride	20	1253
Ethylene glycol	25	1097
Fluorine refrigerant R-12	25	1311
Formaldehyde	45	812
Formic acid 10%oncentration	20	1025
Formic acid 80%oncentration	20	1221
Freon - 11	21	1490
Freon - 21	21	1370
Fuel oil	60°F	890
Furan	25	1416
Furforol	25	1155
Gasoline, natural	60°F	711
Gasoline, Vehicle	60°F	737
Gas oils	60°F	890
Glucose	60°F	1350 - 1440
Glycerin	25	1259
Glycerol	25	1126
Heptane	25	676
Hexane	25	655
Hexanol	25	811

Hexene	25	671
Hydrazine	25	795
Iodine	25	4927
Ionene	25	932
Isobutyl Alcohol	20	802
Iso-Octane	20	692
Isopropyl Alcohol	20	785
Isopropyl Myristate	20	853
Kerosene	60°F	817
Linolenic Acid	25	897
Linseed oil	25	929
Methane	-164	465
Methanol	20	791
Methyl Isoamyl Ketone	20	888
Methyl Isobutyl Ketone	20	801
Methyl n-Propyl Ketone	20	808
Methyl t-Butyl Ether	20	741
N-Methylpyrrolidone	20	1030
Methyl Ethyl Ketone	20	805
Milk	15	1020 - 1050
Naphtha	15	665
Naphtha, wood	25	960
Napthalene	25	820
Ocimene	25	798
Octane	15	918
Olive oil	20	800 - 920
Oxygen (liquid)	-183	1140
Palmitic Acid	25	851
Pentane	20	626
Pentane	25	625
Petroleum Ether	20	640
Petrol, natural	60°F	711
Petrol, Vehicle	60°F	737
Phenol	25	1072
Phosgene	0	1378
Phytadiene	25	823
Pinene	25	857
Propane	-40	583
Propane, R-290	25	494
Propanol	25	804
Propylenearbonate	20	1201
Propylene	25	514
Propylene glycol	25	965
Pyridine	25	979

Pyrrole	25	966
Rape seed oil	20	920
Resorcinol	25	1269
Rosin oil	15	980
Sea water	25	1025
Silane	25	718
Silicone oil		760
Sodium Hydroxide (caustic soda)	15	1250
Sorbaldehyde	25	895
Soya bean oil	15	924 - 928
Stearic Acid	25	891
Sulfuric Acid 95%onc.	20	1839
Sugar solution 68 brix	15	1338
Sunflower oil	20	920
Styrene	25	903
Terpinene	25	847
Tetrahydrofuran	20	888
Toluene	20	867
Toluene	25	862
Triethylamine	20	728
Trifluoroacetic Acid	20	1489
Turpentine	25	868
Water - pure	4	1000
Water - sea	77°F	1022
Whale oil	15	925
o-Xylene	20	880

$1 \text{ kg/m}^3 = 0.001 \text{ g/cm}^3 = 0.0005780 \text{ oz/in}^3 = 0.16036 \text{ oz/gal (Imperial)} = 0.1335 \text{ oz/gal (U.S.)} = 0.0624 \text{ lb/ft}^3 =$   
 $0.000036127 \text{ lb/in}^3 = 1.6856 \text{ lb/yd}^3 = 0.010022 \text{ lb/gal (Imperial)} = 0.008345 \text{ lb/gal (U.S.)} = 0.0007525 \text{ ton/yd}^3$

## Dynamic or Absolute Viscosity Units Converting Table

The table below can be used to convert between common dynamic or absolute viscosity units.

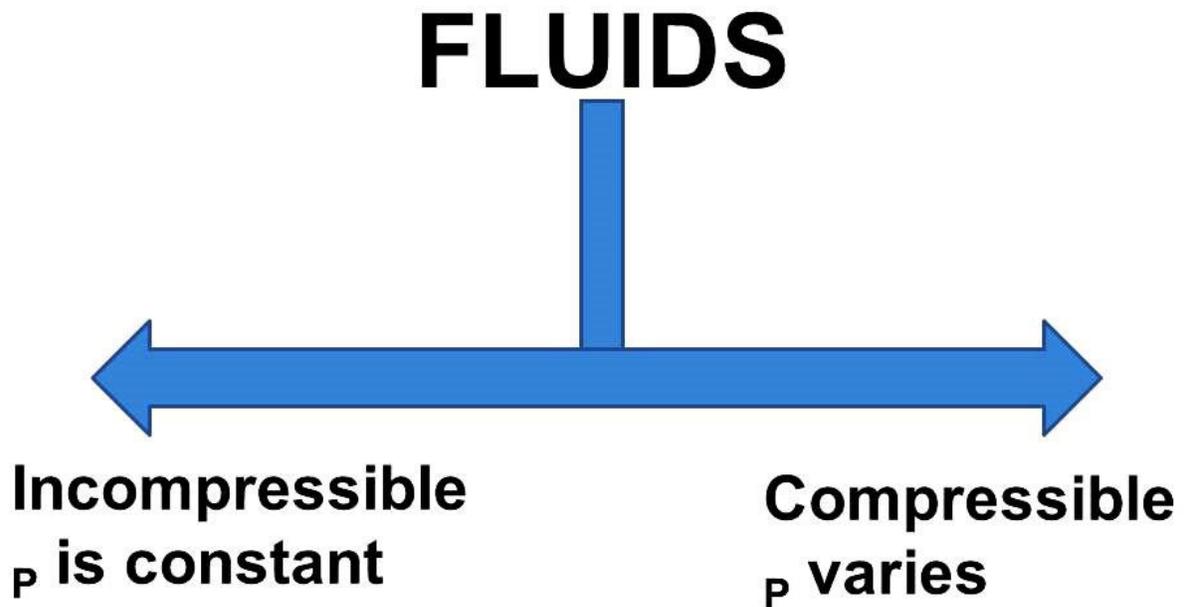
Multiply by	Convert to				
Convert from	Poiseuille (Pa s)	Poise (dyne s / cm <sup>2</sup> = g / cm s)	centiPoise	kg / m h	kg <sub>f</sub> s / m <sup>2</sup>
Poiseuille (Pa s)	1	10	10 <sup>3</sup>	3.63 10 <sup>3</sup>	0.102
Poise (dyne s / cm <sup>2</sup> = g / cm s)	0.1	1	100	360	0.0102
centiPoise	0.001	0.01	1	3.6	0.00012
kg / m h	2.78 10 <sup>-4</sup>	0.00278	0.0278	1	2.83 10 <sup>-5</sup>
kg <sub>f</sub> s / m <sup>2</sup>	9.81	98.1	9.81 10 <sup>3</sup>	3.53 10 <sup>4</sup>	1
lb <sub>f</sub> s / inch <sup>2</sup>	6.89 10 <sup>3</sup>	6.89 10 <sup>4</sup>	6.89 10 <sup>6</sup>	2.48 10 <sup>7</sup>	703
lb <sub>f</sub> s / ft <sup>2</sup>	47.9	479	4.79 10 <sup>4</sup>	1.72 10 <sup>5</sup>	0.0488
lb <sub>f</sub> h / ft <sup>2</sup>	1.72 10 <sup>5</sup>	1.72 10 <sup>6</sup>	1.72 10 <sup>8</sup>	6.21 10 <sup>8</sup>	1.76 10 <sup>4</sup>
lb / ft s	1.49	14.9	1.49 10 <sup>3</sup>	5.36 10 <sup>3</sup>	0.152
lb / ft h	4.13 10 <sup>-4</sup>	0.00413	0.413	1.49	4.22 10 <sup>-5</sup>
Multiply by	Convert to				
Convert from	lb <sub>f</sub> s / inch <sup>2</sup>	lb <sub>f</sub> s / ft <sup>2</sup>	lb <sub>f</sub> h / ft <sup>2</sup>	lb / ft s	lb / ft h
Poiseuille (Pa s)	1.45 10 <sup>-4</sup>	0.0209	5.8 10 <sup>-6</sup>	0.672	2.42 10 <sup>3</sup>
Poise (dyne s / cm <sup>2</sup> = g / cm s)	1.45 10 <sup>-5</sup>	0.00209	5.8 10 <sup>-7</sup>	0.0672	242
centiPoise	1.45 10 <sup>-7</sup>	2.9 10 <sup>-5</sup>	5.8 10 <sup>-9</sup>	0.000672	2.42
kg / m h	4.03 10 <sup>-8</sup>	5.8 10 <sup>-6</sup>	1.61 10 <sup>-9</sup>	0.000187	0.672
kg <sub>f</sub> s / m <sup>2</sup>	0.00142	20.5	5.69 10 <sup>-5</sup>	6.59	2.37 10 <sup>4</sup>
lb <sub>f</sub> s / inch <sup>2</sup>	1	144	0.04	4.63 10 <sup>3</sup>	1.67 10 <sup>7</sup>
lb <sub>f</sub> s / ft <sup>2</sup>	0.00694	1	0.000278	32.2	1.16 10 <sup>5</sup>
lb <sub>f</sub> h / ft <sup>2</sup>	25	3.6 10 <sup>3</sup>	1	1.16 10 <sup>5</sup>	4.17 10 <sup>8</sup>
lb / ft s	0.000216	0.0311	8.63 10 <sup>-6</sup>	1	3.6 10 <sup>3</sup>
lb / ft h	6 10 <sup>-8</sup>	1.16 10 <sup>5</sup>	2.4 10 <sup>-9</sup>	0.000278	1

## Friction Loss Chart

The table below can be used to indicate the friction loss - feet of liquid per 100 feet of pipe - in standard schedule 40 steel pipes.

Pipe Size (inches)	Flow Rate		Kinematic Viscosity - SSU					
	(gpm)	(l/s)	31 (Water)	100 (~Cream)	200 (~Vegetable oil)	400 (~SAE 10 oil)	800 (~Tomato juice)	1500 (~SAE 30 oil)
1/2	3	0.19	10.0	25.7	54.4	108.0	218.0	411.0
3/4	3	0.19	2.5	8.5	17.5	35.5	71.0	131.0
	5	0.32	6.3	14.1	29.3	59.0	117.0	219.0
1	3	0.19	0.8	3.2	6.6	13.4	26.6	50.0
	5	0.32	1.9	5.3	11.0	22.4	44.0	83.0
	10	0.63	6.9	11.2	22.4	45.0	89.0	165.0
	15	0.95	14.6	26.0	34.0	67.0	137.0	
	20	1.26	25.1	46	46.0	90.0	180.0	
1 1/4	5	0.32	0.5	1.8	3.7	7.6	14.8	26.0
	10	0.63	1.8	3.6	7.5	14.9	30.0	55.0
	15	0.95	3.7	6.4	11.3	22.4	45.0	84.0
1 1/2	10	0.63	0.8	1.9	4.2	8.1	16.5	31.0
	15	0.95	1.7	2.8	6.2	12.4	25.0	46.0
	20	1.26	2.9	5.3	8.1	16.2	33.0	61.0
	30	1.9	6.3	11.6	12.2	24.3	50.0	91.0
	40	2.5	10.8	19.6	20.8	32.0	65.0	121.0
2	20	1.26	0.9	1.5	3.0	6.0	11.9	22.4
	30	1.9	1.8	3.2	4.4	9.0	17.8	33.0
	40	2.5	3.1	5.8	5.8	11.8	24.0	44.0
	60	3.8	6.6	11.6	13.4	17.8	36.0	67.0
	80	5.0	1.6	3.0	3.2	4.8	9.7	18.3
2 1/2	30	1.9	0.8	1.4	2.2	4.4	8.8	16.6
	40	2.5	1.3	2.5	3.0	5.8	11.8	22.2
	60	3.8	2.7	5.1	5.5	8.8	17.8	34.0
	80	5.0	4.7	8.3	9.7	11.8	24.0	44.0
	100	6.3	7.1	12.2	14.1	14.8	29.0	55.0
3	60	3.8	0.9	1.8	1.8	3.7	7.3	13.8
	100	6.3	2.4	4.4	5.1	6.2	12.1	23.0
	125	7.9	3.6	6.5	7.8	8.1	15.3	29.0
	150	9.5	5.1	9.2	10.4	11.5	18.4	35.0
	175	11.0	6.9	11.7	13.8	15.8	21.4	40.0
	200	12.6	8.9	15.0	17.8	20.3	25.0	46.0
4	80	5.0	0.4	0.8	0.8	1.7	3.3	6.2
	100	6.3	0.6	1.2	1.3	2.1	4.1	7.8
	125	7.9	0.9	1.8	2.1	2.6	5.2	9.8
	150	9.5	1.3	2.4	2.9	3.1	6.2	11.5
	175	11.0	1.8	3.2	4.0	4.0	7.4	13.7

	200	12.6	2.3	4.2	5.1	5.1	8.3	15.5
	250	15.8	3.5	6.0	7.4	8.0	10.2	19.4
6	125	7.9	0.1	0.3	0.3	0.52	1.0	1.9
	150	9.5	0.2	0.3	0.4	0.6	1.2	2.3
	175	11.0	0.2	0.4	0.5	0.7	1.4	2.6
	200	12.6	0.3	0.6	0.7	0.8	1.6	3.0
	250	15.8	0.5	0.8	1.0	1.0	2.1	3.7
8	300	18.9	1.1	8.5	10.0	11.6	12.4	23.0
	400	25.2	1.1	1.9	2.3	2.8	3.2	6.0
	250	15.8	0.1	0.2	0.3	0.4	0.7	1.2
10	300	18.9	0.3	1.2	1.4	1.5	2.5	4.6
	400	25.2	0.3	0.5	0.6	0.7	1.1	2.0
10	300	18.9	0.1	0.3	0.4	0.4	0.8	1.5
	400	25.2	0.1	0.2	0.2	0.2	0.4	0.8



## Hazen-Williams Coefficients

Hazen-Williams factor for some common piping materials. Hazen-Williams coefficients are used in the Hazen-Williams equation for friction loss calculation in ducts and pipes. Coefficients for some common materials used in ducts and pipes can be found in the table below:

Material	Hazen-Williams Coefficient - C -
Asbestos Cement	140
Brass	130 - 140
Brick sewer	100
Cast-Iron - new unlined (CIP)	130
Cast-Iron 10 years old	107 - 113
Cast-Iron 20 years old	89 - 100
Cast-Iron 30 years old	75 - 90
Cast-Iron 40 years old	64-83
Cast-Iron, asphalt coated	100
Cast-Iron, cement lined	140
Cast-Iron, bituminous lined	140
Cast-Iron, wrought plain	100
Concrete	100 - 140
Copper or Brass	130 - 140
Ductile Iron Pipe (DIP)	140
Fiber	140
Galvanized iron	120
Glass	130
Lead	130 - 140
Plastic	130 - 150
Polyethylene, PE, PEH	150
PVC, CPVC	150
Smooth Pipes	140
Steel new unlined	140 - 150
Steel	
Steel, welded and seamless	100
Steel, interior riveted, no projecting rivets	100
Steel, projecting girth rivets	100
Steel, vitrified, spiral-riveted	90 - 100
Steel, corrugated	60
Tin	130
Vitrified Clays	110
Wood Stave	110 - 120

## Pressure Head

A pressure difference of 5 psi (lbf/in<sup>2</sup>) is equivalent to

$$5 \text{ (lbf/in}^2\text{)} \cdot 12 \text{ (in/ft)} \cdot 12 \text{ (in/ft)} / 62.4 \text{ (lb/ft}^3\text{)} = \underline{11.6 \text{ ft of water}}$$

$$5 \text{ (lbf/in}^2\text{)} \cdot 12 \text{ (in/ft)} \cdot 12 \text{ (in/ft)} / 847 \text{ (lb/ft}^3\text{)} = \underline{0.85 \text{ ft of mercury}}$$

When specific weight of water is 62.4 (lb/ft<sup>3</sup>) and specific weight of mercury is 847 (lb/ft<sup>3</sup>).

Heads at different velocities can be taken from the table below:

Velocity (ft/sec)	Head Water (ft)
0.5	0.004
1.0	0.016
1.5	0.035
2.0	0.062
2.5	0.097
3.0	0.140
3.5	0.190
4.0	0.248
4.5	0.314
5.0	0.389
5.5	0.470
6.0	0.560
6.5	0.657
7.0	0.762
7.5	0.875
8.0	0.995
8.5	1.123
9.0	1.259
9.5	1.403
10.0	1.555
11.0	1.881
12.0	2.239
13.0	2.627
14.0	3.047
15.0	3.498
16.0	3.980
17.0	4.493
18.0	5.037
19.0	5.613
20.0	6.219
21.0	6.856
22.0	7.525

1 ft (foot) = 0.3048 m = 12 in = 0.3333 yd.



## Thermal Properties of Water

Temperature - $t$ - (°C)	Absolute pressure - $p$ - (kN/m <sup>2</sup> )	Density - $\rho$ - (kg/m <sup>3</sup> )	Specific volume - $v$ - (m <sup>3</sup> /kgx10 <sup>-3</sup> )	Specific Heat - $c_p$ - (kJ/kgK)	Specific entropy - $e$ - (kJ/kgK)
0	0.6	1000	100	4.217	0
5	0.9	1000	100	4.204	0.075
10	1.2	1000	100	4.193	0.150
15	1.7	999	100	4.186	0.223
20	2.3	998	100	4.182	0.296
25	3.2	997	100	4.181	0.367
30	4.3	996	100	4.179	0.438
35	5.6	994	101	4.178	0.505
40	7.7	991	101	4.179	0.581
45	9.6	990	101	4.181	0.637
50	12.5	988	101	4.182	0.707
55	15.7	986	101	4.183	0.767
60	20.0	980	102	4.185	0.832
65	25.0	979	102	4.188	0.893
70	31.3	978	102	4.190	0.966
75	38.6	975	103	4.194	1.016
80	47.5	971	103	4.197	1.076
85	57.8	969	103	4.203	1.134
90	70.0	962	104	4.205	1.192
95	84.5	962	104	4.213	1.250
100	101.33	962	104	4.216	1.307
105	121	955	105	4.226	1.382
110	143	951	105	4.233	1.418
115	169	947	106	4.240	1.473
120	199	943	106	4.240	1.527
125	228	939	106	4.254	1.565
130	270	935	107	4.270	1.635
135	313	931	107	4.280	1.687
140	361	926	108	4.290	1.739
145	416	922	108	4.300	1.790
150	477	918	109	4.310	1.842
155	543	912	110	4.335	1.892
160	618	907	110	4.350	1.942
165	701	902	111	4.364	1.992
170	792	897	111	4.380	2.041
175	890	893	112	4.389	2.090
180	1000	887	113	4.420	2.138
185	1120	882	113	4.444	2.187
190	1260	876	114	4.460	2.236

195	1400	870	115	4.404	2.282
200	1550	863	116	4.497	2.329
220					
225	2550	834	120	4.648	2.569
240					
250	3990	800	125	4.867	2.797
260					
275	5950	756	132	5.202	3.022
300	8600	714	140	5.769	3.256
325	12130	654	153	6.861	3.501
350	16540	575	174	10.10	3.781
360	18680	526	190	14.60	3.921

**SOLID**



**LIQUID**



**GAS**



  
**MORE** **LESS**  
**EFFORT NEEDED TO COMPRESS**

## Viscosity Converting Chart

The viscosity of a fluid is its resistance to shear or flow, and is a measure of the fluid's adhesive/cohesive or frictional properties. This arises because of the internal molecular friction within the fluid producing the frictional drag effect. There are two related measures of fluid viscosity which are known as **dynamic** and **kinematic** viscosity.

**Dynamic viscosity** is also termed "**absolute viscosity**" and is the tangential force per unit area required to move one horizontal plane with respect to the other at unit velocity when maintained a unit distance apart by the fluid.

Centipoise (CPS) Millipascal (mPas)	Poise (P)	Centistokes (cSt)	Stokes (S)	Saybolt Seconds Universal (SSU)
1	0.01	1	0.01	31
2	0.02	2	0.02	34
4	0.04	4	0.04	38
7	0.07	7	0.07	47
10	0.1	10	0.1	60
15	0.15	15	0.15	80
20	0.2	20	0.2	100
25	0.24	25	0.24	130
30	0.3	30	0.3	160
40	0.4	40	0.4	210
50	0.5	50	0.5	260
60	0.6	60	0.6	320
70	0.7	70	0.7	370
80	0.8	80	0.8	430
90	0.9	90	0.9	480
100	1	100	1	530
120	1.2	120	1.2	580
140	1.4	140	1.4	690
160	1.6	160	1.6	790
180	1.8	180	1.8	900
200	2	200	2	1000
220	2.2	220	2.2	1100
240	2.4	240	2.4	1200
260	2.6	260	2.6	1280
280	2.8	280	2.8	1380
300	3	300	3	1475
320	3.2	320	3.2	1530
340	3.4	340	3.4	1630
360	3.6	360	3.6	1730

380	3.8	380	3.8	1850
400	4	400	4	1950
420	4.2	420	4.2	2050
440	4.4	440	4.4	2160
460	4.6	460	4.6	2270
480	4.8	480	4.8	2380
500	5	500	5	2480
550	5.5	550	5.5	2660
600	6	600	6	2900
700	7	700	7	3380
800	8	800	8	3880
900	9	900	9	4300
1000	10	1000	10	4600
1100	11	1100	11	5200
1200	12	1200	12	5620
1300	13	1300	13	6100
1400	14	1400	14	6480
1500	15	1500	15	7000
1600	16	1600	16	7500
1700	17	1700	17	8000
1800	18	1800	18	8500
1900	19	1900	19	9000
2000	20	2000	20	9400
2100	21	2100	21	9850
2200	22	2200	22	10300
2300	23	2300	23	10750
2400	24	2400	24	11200

## Various Flow Section Channels and their Geometric Relationships:

Area, wetted perimeter and hydraulic diameter for some common geometric sections like

- rectangular channels
- trapezoidal channels
- triangular channels
- circular channels.

### Rectangular Channel

#### Flow Area

Flow area of a rectangular channel can be expressed as

$$A = b h \quad (1)$$

where

$A$  = flow area ( $m^2$ ,  $in^2$ )

$b$  = width of channel ( $m$ ,  $in$ )

$h$  = height of flow ( $m$ ,  $in$ )

#### Wetted Perimeter

Wetted perimeter of a rectangular channel can be expressed as

$$P = b + 2 h \quad (1b)$$

where

$P$  = wetted perimeter ( $m$ ,  $in$ )

#### Hydraulic Radius

Hydraulic radius of a rectangular channel can be expressed as

$$R_h = b h / (b + 2 h) \quad (1c)$$

where

$R_h$  = hydraulic radius ( $m$ ,  $in$ )

### Trapezoidal Channel

#### Flow Area

Flow area of a trapezoidal channel can be expressed as

$$A = (a + z h) h \quad (2)$$

where

$z$  = see figure above ( $m$ ,  $in$ )

#### Wetted Perimeter

Wetted perimeter of a trapezoidal channel can be expressed as

$$P = a + 2 h (1 + z^2)^{1/2} \quad (2b)$$

#### Hydraulic Radius

Hydraulic radius of a trapezoidal channel can be expressed as

$$R_h = (a + z h) h / a + 2 h (1 + z^2)^{1/2} \quad (2c)$$

## **Triangular Channel**

### **Flow Area**

Flow area of a triangular channel can be expressed as

$$A = z h^2 \quad (3)$$

where

$z$  = see figure above (m, in)

### **Wetted Perimeter**

Wetted perimeter of a triangular channel can be expressed as

$$P = 2 h (1 + z^2)^{1/2} \quad (3b)$$

### **Hydraulic Radius**

Hydraulic radius of a triangular channel can be expressed as

$$R_h = z h / 2 (1 + z^2)^{1/2} \quad (3c)$$

## **Circular Channel**

### **Flow Area**

Flow area of a circular channel can be expressed as

$$A = D^2/4 (\alpha - \sin(2 \alpha)/2) \quad (4)$$

where

$D$  = diameter of channel

$$\alpha = \cos^{-1}(1 - h/r)$$

### **Wetted Perimeter**

Wetted perimeter of a circular channel can be expressed as

$$P = \alpha D \quad (4b)$$

### **Hydraulic Radius**

Hydraulic radius of a circular channel can be expressed as

$$R_h = D/8 [1 - \sin(2 \alpha) / (2 \alpha)] \quad (4c)$$

**Velocity Head:** Velocity head can be expressed as

$$h = v^2/2g \quad (1)$$

where

$v$  = velocity (ft, m)

$g$  = acceleration of gravity (32.174 ft/s<sup>2</sup>, 9.81 m/s<sup>2</sup>)

Heads at different velocities can be taken from the table below:

Velocity - $v$ - (ft/sec)	Velocity Head - $v^2/2g$ - (ft Water)
0.5	0.004
1.0	0.016
1.5	0.035
2.0	0.062
2.5	0.097
3.0	0.140
3.5	0.190
4.0	0.248
4.5	0.314
5.0	0.389
5.5	0.470
6.0	0.560
6.5	0.657
7.0	0.762
7.5	0.875
8.0	0.995
8.5	1.123
9.0	1.259
9.5	1.403
10.0	1.555
11.0	1.881
12.0	2.239
13.0	2.627
14.0	3.047
15.0	3.498
16.0	3.980
17.0	4.493
18.0	5.037
19.0	5.613
20.0	6.219
21.0	6.856
22.0	7.525

## Some Commonly used Thermal Properties for Water

- Density at 4 °C - 1,000 kg/m<sup>3</sup>, 62.43 Lbs./Cu.Ft., 8.33 Lbs./Gal., 0.1337 Cu.Ft./Gal.
- Freezing temperature - 0 °C
- Boiling temperature - 100 °C
- Latent heat of melting - 334 kJ/kg
- Latent heat of evaporation - 2,270 kJ/kg
- Critical temperature - 380 - 386 °C
- Critical pressure - 23.520 kN/m<sup>2</sup>
- Specific heat capacity water - 4.187 kJ/kgK
- Specific heat capacity ice - 2.108 kJ/kgK
- Specific heat capacity water vapor - 1.996 kJ/kgK
- Thermal expansion from 4 °C to 100 °C -  $4.2 \times 10^{-2}$
- Bulk modulus elasticity - 2,068,500 kN/m<sup>2</sup>

## Reynolds Number

Turbulent or laminar flow is determined by the dimensionless **Reynolds Number**.

The Reynolds number is important in analyzing any type of flow when there is substantial velocity gradient (i.e., shear.) It indicates the relative significance of the viscous effect compared to the inertia effect. The Reynolds number is proportional to inertial force divided by viscous force.

A definition of the Reynolds' Number:

The flow is

- **laminar** if  $Re < 2300$
- **transient** if  $2300 < Re < 4000$
- **turbulent** if  $4000 < Re$

The table below shows Reynolds Number for one liter of water flowing through pipes of different dimensions:

		Pipe Size								
(inches)	1	1 ?	2	3	4	6	8	10	12	18
(mm)	25	40	50	75	100	150	200	250	300	450
Reynolds number with <b>one (1) liter/min</b>	835	550	420	280	210	140	105	85	70	46
Reynolds number with <b>one (1) gal/min</b>	3800	2500	1900	1270	950	630	475	380	320	210

## Linear Motion Formulas

Velocity can be expressed as (velocity = constant):

$$v = s / t \text{ (1a)}$$

*where*

*v = velocity (m/s, ft/s)*

*s = linear displacement (m, ft)*

*t = time (s)*

Velocity can be expressed as (acceleration = constant):

$$v = V_0 + a t \text{ (1b)}$$

*where*

*V<sub>0</sub> = linear velocity at time zero (m/s, ft/s)*

Linear displacement can be expressed as (acceleration = constant):

$$s = V_0 t + 1/2 a t^2 \text{ (1c)}$$

Combining 1a and 1c to express velocity

$$v = (V_0^2 + 2 a s)^{1/2} \text{ (1d)}$$

Velocity can be expressed as (velocity variable)

$$v = ds / dt \text{ (1f)}$$

*where*

*ds = change of displacement (m, ft)*

*dt = change in time (s)*

Acceleration can be expressed as

$$a = dv / dt \text{ (1g)}$$

*where*

*dv = change in velocity (m/s, ft/s)*

## Water - Dynamic and Kinematic Viscosity

Dynamic and Kinematic Viscosity of Water in Imperial Units (BG units):

Temperature - $t$ - ( $^{\circ}F$ )	Dynamic Viscosity - $\mu$ - $10^{-5}$ (lbs./ft $^2$ )	Kinematic Viscosity - $\nu$ - $10^{-5}$ (ft $^2$ /s)
32	3.732	1.924
40	3.228	1.664
50	2.730	1.407
60	2.344	1.210
70	2.034	1.052
80	1.791	0.926
90	1.500	0.823
100	1.423	0.738
120	1.164	0.607
140	0.974	0.511
160	0.832	0.439
180	0.721	0.383
200	0.634	0.339
212	0.589	0.317

Dynamic and Kinematic Viscosity of Water in SI Units:

Temperature - $t$ - ( $^{\circ}C$ )	Dynamic Viscosity - $\mu$ - $10^{-3}$ (N.s/m $^2$ )	Kinematic Viscosity - $\nu$ - $10^{-6}$ (m $^2$ /s)
0	1.787	1.787
5	1.519	1.519
10	1.307	1.307
20	1.002	1.004
30	0.798	0.801
40	0.653	0.658
50	0.547	0.553
60	0.467	0.475
70	0.404	0.413
80	0.355	0.365
90	0.315	0.326
100	0.282	0.294

## Water and Speed of Sound

Speed of sound in water at temperatures between 32 - 212°F (0-100°C) - imperial and SI units

Speed of Sound in Water - in imperial units (BG units)

Temperature - <i>t</i> - (°F)	Speed of Sound - <i>c</i> - (ft/s)
32	4,603
40	4,672
50	4,748
60	4,814
70	4,871
80	4,919
90	4,960
100	4,995
120	5,049
140	5,091
160	5,101
180	5,095
200	5,089
212	5,062

Speed of Sound in Water - in SI units

Temperature - <i>t</i> - (°C)	Speed of Sound - <i>c</i> - (m/s)
0	1,403
5	1,427
10	1,447
20	1,481
30	1,507
40	1,526
50	1,541
60	1,552
70	1,555
80	1,555
90	1,550
100	1,543

# 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  
 2.54 CM = Inch  
 1 Gallon of Water = 8.34 Pounds  
 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  
 5,280 Feet = 1 Mile

## AREA

144 Square Inches = 1 Square Foot  
 43,560 Square Feet = 1 Acre

## VOLUME

1000 Milliliters = 1 Liter  
 3.785 Liters = 1 Gallon  
 231 Cubic Inches = 1 Gallon  
 7.48 Gallons = 1 Cubic Foot of Water  
 62.38 Pounds = 1 Cubic Foot of Water

## 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)

**PIPE VOLUME:** .785 X Diameter<sup>2</sup> X Length = ? To obtain gallons multiply by 7.48

**SPHERE:**  $\frac{(3.14) (\text{Diameter})^3}{(6)}$       Circumference = 3.14 X Diameter

## General Conversions

Multiply	→	to get
to get	←	Divide
cc/min	1	mL/min
cfm (ft <sup>3</sup> /min)	28.31	L/min
cfm (ft <sup>3</sup> /min)	1.699	m <sup>3</sup> /hr
cfh (ft <sup>3</sup> /hr)	472	mL/min
cfh (ft <sup>3</sup> /hr)	0.125	GPM
GPH	63.1	mL/min
GPH	0.134	cfh
GPM	0.227	m <sup>3</sup> /hr
GPM	3.785	L/min
oz/min	29.57	mL/min

**POUNDS PER DAY** = Flow (MG) X Concentration (mg/L) X 8.34  
**AKA Solids Applied Formula** = Flow X Dose X 8.34

**PERCENT EFFICIENCY** =  $\frac{\text{In} - \text{Out}}{\text{In}} \times 100$

**TEMPERATURE:**  $^{\circ}\text{F} = (^{\circ}\text{C} \times 9/5) + 32$        $9/5 = 1.8$   
 $^{\circ}\text{C} = (^{\circ}\text{F} - 32) \times 5/9$        $5/9 = .555$

**CONCENTRATION:** Conc. (A) X Volume (A) = Conc. (B) X Volume (B)

**FLOW RATE (Q):**  $Q = A \times V$  (Quantity = Area X Velocity)

**FLOW RATE (gpm):** Flow Rate (gpm) =  $\frac{2.83 (\text{Diameter, in})^2 (\text{Distance, in})}{\text{Height, in}}$

**% SLOPE** =  $\frac{\text{Rise (feet)}}{\text{Run (feet)}} \times 100$

**ACTUAL LEAKAGE** =  $\frac{\text{Leak Rate (GPD)}}{\text{Length (mi.)} \times \text{Diameter (in)}}$

**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** =  $\frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960}$

**BRAKE HORSEPOWER** =  $\frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960 \times \text{Pump Efficiency}}$

**MOTOR HORSEPOWER** =  $\frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960 \times \text{Pump Eff.} \times \text{Motor Eff.}}$

**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 (%)** =  $\frac{(\text{Volume 1, gal}) (\text{Strength 1, \%}) + (\text{Volume 2, gal}) (\text{Strength 2, \%})}{(\text{Volume 1, gal}) + (\text{Volume 2, gal})}$

**DETENTION TIME (hrs.)** =  $\frac{\text{Volume of Basin (gals)} \times 24 \text{ hrs.}}{\text{Flow (GPD)}}$

$$\text{SLOPE} = \frac{\text{Rise (ft)}}{\text{Run (ft)}}$$

$$\text{SLOPE (\%)} = \frac{\text{Rise (ft)} \times 100}{\text{Run (ft)}}$$

**POPULATION EQUIVALENT (PE):**

- 1 PE = .17 Pounds of BOD per Day
- 1 PE = .20 Pounds of Solids per Day
- 1 PE = 100 Gallons per Day

$$\text{LEAKAGE (GPD/inch)} = \frac{\text{Leakage of Water per Day (GPD)}}{\text{Sewer Diameter (inch)}}$$

$$\text{CHLORINE DEMAND (mg/L)} = \text{Chlorine Dose (mg/L)} - \text{Chlorine Residual (mg/L)}$$

**MANNING'S EQUATION**

$\tau Q$  = Allowable time for decrease in pressure from 3.5 PSI to 2.5 PSI

$\tau q$  = As below

$$\tau Q = (0.022) (d_1^2 L_1) / Q \quad \tau q = \frac{[0.085] [(d_1^2 L_1)]}{q}$$

Q = 2.0 cfm air loss

$\theta$  = .0030 cfm air loss per square foot of internal pipe surface

$\delta$  = Pipe diameter (inches)

L = Pipe Length (feet)

$$V = \frac{1.486 R^{2/3} S^{1/2}}{v}$$

V = Velocity (ft./sec.)

v = Pipe Roughness

R = Hydraulic Radius (ft)

S = Slope (ft/ft)

$$\text{HYDRAULIC RADIUS (ft)} = \frac{\text{Flow Area (ft. }^2\text{)}}{\text{Wetted Perimeter (ft.)}}$$

$$\text{WIDTH OF TRENCH (ft)} = \text{Base (ft)} + (2 \text{ Sides}) \times \frac{\text{Depth (ft }^2\text{)}}{\text{Slope}}$$



## Formula/Conversion Table

$$\text{Acid Feed Rate} = \frac{(\text{Waste Flow}) (\text{Waste Normality})}{\text{Acid Normality}}$$

$$\text{Alkalinity} = \frac{(\text{mL of Titrant}) (\text{Acid Normality}) (50,000)}{\text{mL of Sample}}$$

$$\text{Amperage} = \text{Voltage} \div \text{Ohms}$$

$$\text{Area of Circle} = (0.785)(\text{Diameter}^2) \text{ OR } (\pi)(\text{Radius}^2)$$

$$\text{Area of Rectangle} = (\text{Length})(\text{Width})$$

$$\text{Area of Triangle} = \frac{(\text{Base}) (\text{Height})}{2}$$

$$\text{C Factor Slope} = \text{Energy loss, ft.} \div \text{Distance, ft.}$$

$$\text{C Factor Calculation} = \text{Flow, GPM} \div [193.75 (\text{Diameter, ft.})^{2.63} (\text{Slope})^{0.54}]$$

$$\text{Chemical Feed Pump Setting, \% Stroke} = \frac{(\text{Desired Flow}) (100\%)}{\text{Maximum Flow}}$$

$$\text{Chemical Feed Pump Setting, mL/min} = \frac{(\text{Flow, MGD}) (\text{Dose, mg/L}) (3.785\text{L/gal}) (1,000,000 \text{ gal/MG})}{(\text{Liquid, mg/mL}) (24 \text{ hr / day}) (60 \text{ min/hr})}$$

$$\text{Chlorine Demand (mg/L)} = \text{Chlorine dose (mg/L)} - \text{Chlorine residual (mg/L)}$$

$$\text{Circumference of Circle} = (3.141)(\text{Diameter})$$

$$\text{Composite Sample Single Portion} = \frac{(\text{Instantaneous Flow}) (\text{Total Sample Volume})}{(\text{Number of Portions}) (\text{Average Flow})}$$

$$\text{Detention Time} = \frac{\text{Volume}}{\text{Flow}}$$

$$\text{Digested Sludge Remaining, \%} = \frac{(\text{Raw Dry Solids}) (\text{Ash Solids}) (100\%)}{(\text{Digested Dry Solids}) (\text{Digested Ash Solids})}$$

$$\text{Discharge} = \frac{\text{Volume}}{\text{Time}}$$

$$\text{Dosage, lbs/day} = (\text{mg/L})(8.34)(\text{MGD})$$

$$\text{Dry Polymer (lbs.)} = (\text{gal. of solution})(8.34 \text{ lbs/gal})(\% \text{ polymer solution})$$

$$\text{Efficiency, \%} = \frac{(\text{In} - \text{Out}) (100\%)}{\text{In}}$$

$$\text{Feed rate, lbs/day} = \frac{(\text{Dosage, mg/L}) (\text{Capacity, MGD}) (8.34 \text{ lbs/gals})}{(\text{Available fluoride ion}) (\text{Purity})}$$

$$\text{Feed rate, gal/min (Saturator)} = \frac{(\text{Plant capacity, gal/min.}) (\text{Dosage, mg /L})}{18,000 \text{ mg/L}}$$

$$\text{Filter Backwash Rate} = \frac{\text{Flow}}{\text{Filter Area}}$$

$$\text{Filter Yield, lbs/hr/sq. ft} = \frac{(\text{Solids Loading, lbs/day}) (\text{Recovery, \%} / 100\%)}{(\text{Filter operation, hr/day}) (\text{Area, ft}^2)}$$

$$\text{Flow, cu. ft./sec.} = (\text{Area, Sq. Ft.})(\text{Velocity, ft./sec.})$$

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

$$\text{Gallons/Capita/Day} = \frac{\text{Gallons / day}}{\text{Population}}$$

$$\text{Hardness} = \frac{(\text{mL of Titrant}) (1,000)}{\text{mL of Sample}}$$

$$\text{Horsepower (brake)} = \frac{(\text{Flow, gpm}) (\text{Head, ft})}{(3,960) (\text{Efficiency})}$$

$$\text{Horsepower (motor)} = \frac{(\text{Flow, gpm}) (\text{Head, ft})}{(3960) (\text{Pump, Eff.}) (\text{Motor, Eff.})}$$

$$\text{Horsepower (water)} = \frac{(\text{Flow, gpm}) (\text{Head, ft})}{(3960)}$$

$$\text{Hydraulic Loading Rate} = \frac{\text{Flow}}{\text{Area}}$$

$$\text{Leakage (actual)} = \text{Leak rate (GPD)} \div [\text{Length (mi.)} \times \text{Diameter (in.)}]$$

$$\text{Mean} = \text{Sum of values} \div \text{total number of values}$$

$$\text{Mean Cell Residence Time (MCRT)} = \frac{\text{Suspended Solids in Aeration System, lbs}}{\text{SS Wasted, lbs / day} + \text{SS lost, lbs / day}}$$

$$\text{Organic Loading Rate} = \frac{\text{Organic Load, lbs BOD / day}}{\text{Volume}}$$

$$\text{Oxygen Uptake} = \frac{\text{Oxygen Usage}}{\text{Time}}$$

$$\text{Percent efficiency} = [(\text{In} - \text{Out}) \div \text{In}] \times 100$$

$$\text{Pounds per day} = (\text{Flow, MGD}) (\text{Dose, mg/L}) (8.34)$$

$$\text{Population Equivalent} = \frac{(\text{Flow MGD}) (\text{BOD, mg/L}) (8.34 \text{ lbs / gal})}{\text{Lbs BOD / day / person}}$$

$$\text{RAS Suspended Solids, mg/l} = \frac{1,000,000}{\text{SVI}}$$

$$\text{RAS Flow, MGD} = \frac{(\text{Infl. Flow, MGD}) (\text{MLSS, mg/l})}{\text{RAS Susp. Sol., mg/l} - \text{MLSS, mg/l}}$$

$$\text{RAS Flow \%} = \frac{(\text{RAS Flow, MGD}) (100 \%)}{\text{Infl. Flow, MGD}}$$

$$\text{Reduction in Flow, \%} = \frac{(\text{Original Flow} - \text{Reduced Flow}) (100\%)}{\text{Original Flow}}$$

$$\text{Slope} = \frac{\text{Drop or Rise}}{\text{Run or Distance}}$$

$$\text{Sludge Age} = \frac{\text{Mixed Liquor Solids, lbs}}{\text{Primary Effluent Solids, lbs / day}}$$

$$\text{Sludge Index} = \frac{\% \text{ Settleable Solids}}{\% \text{ Suspended Solids}}$$

$$\text{Sludge Volume Index} = \frac{(\text{Settleable Solids, \%}) (10,000)}{\text{MLSS, mg/L}}$$

$$\text{Solids, mg/L} = \frac{(\text{Dry Solids, grams}) (1,000,000)}{\text{mL of Sample}}$$

$$\text{Solids Applied, lbs/day} = (\text{Flow, MGD})(\text{Concentration, mg/L})(8.34 \text{ lbs/gal})$$

$$\text{Solids Concentration} = \frac{\text{Weight}}{\text{Volume}}$$

$$\text{Solids Loading, lbs/day/sq. ft} = \frac{\text{Solids Applied, lbs / day}}{\text{Surface Area, sq. ft}}$$

$$\text{Surface Loading Rate} = \frac{\text{Flow}}{\text{Rate}}$$

$$\text{Total suspended solids (TSS), mg/L} = \frac{(\text{Dry weight, mg})(1,000 \text{ mL/L})}{(\text{Sample vol., mL})}$$

$$\text{Velocity} = \frac{\text{Flow}}{\text{Area}} \quad \text{O R} \quad \frac{\text{Distance}}{\text{Time}}$$

$$\text{Volatile Solids, \%} = \frac{(\text{Dry Solids} - \text{Ash Solids}) (100\%)}{\text{Dry Solids}}$$

$$\text{Volume of Cone} = (1/3)(0.785)(\text{Diameter}^2)(\text{Height})$$

$$\text{Volume of Cylinder} = (0.785)(\text{Diameter}^2)(\text{Height}) \text{ OR } (\pi)(r^2)(h)$$

$$\text{Volume of Rectangle} = (\text{Length})(\text{Width})(\text{Height})$$

$$\text{Volume of Sphere} = [(\pi)(\text{diameter}^3)] \div 6$$

$$\text{Waste Milliequivalent} = (\text{mL}) (\text{Normality})$$

$$\text{Waste Normality} = \frac{(\text{Titrant Volume}) (\text{Titrant Normality})}{\text{Sample Volume}}$$

$$\text{Weir Overflow Rate} = \frac{\text{Flow}}{\text{Weir Length}}$$

## Conversion Factors

1 acre = 43,560 square feet

1 cubic foot = 7.48 gallons

1 foot = 0.305 meters

1 gallon = 3.79 liters

1 gallon = 8.34 pounds

1 grain per gallon = 17.1 mg/L

1 horsepower = 0.746 kilowatts

1 million gallons per day = 694.45 gallons per minute

1 pound = 0.454 kilograms

1 pound per square inch = 2.31 feet of water

1% = 10,000 mg/L

Degrees Celsius = (Degrees Fahrenheit - 32) (5/9)

Degrees Fahrenheit = (Degrees Celsius \* 9/5) + 32

64.7 grains = 1 cubic foot

1,000 meters = 1 kilometer

1,000 grams = 1 kilogram

1,000 milliliters = 1 liter

144 square inches = 1 square foot

1.55 cubic feet per second = 1 MGD

1 meter = 3.28 feet

$\pi = 3.141$

## Math Review Section-Practice Exam

Math Problems with Complete Solution can be found at the rear of this section.  
Please try to work the problems without looking at the solution.

### Cube Formula

$$V = (L) (W) (D)$$

$$\text{Volume} = \text{Length} \times \text{Width} \times \text{Depth}$$

### Cylinder Formula

$$V = (.785) (D^2) (d)$$

### *Build it, Fill it and Dose it.*

1. Convert 10 cubic feet to gallons of water.

There is 7.48 gallons in one cubic foot.

2. The liquid in a tank weighs 800 pounds, how many gallons are in the tank?

3. Convert a flow rate of 953 gallons per minute to million gallons per day.  
There is 1440 minutes in a day.

4. Convert a flow rate of 610 gallons per minute to millions of gallons per day.

5. Convert a flow of 550 gallons per minute to gallons per second?

6. Now, convert this number to liters per second.

7. A tank is 6' X 15' x 7' and can hold a maximum of \_\_\_\_\_ gallons of water.  
 $V = (L) (W) (D) \times 7.48 =$

8. A tank is 25' X 75' X 10' what is the volume of water in gallons?  
 $V = (L) (W) (D) \times 7.48 =$

9. In Liters?

$$V = (L) (W) (D) \times 7.48 = \underline{\hspace{2cm}} \times 3.785$$

10. A tank holds 67,320 gallons of water. The length is 60' and the width is 15'. How deep is the tank?

$$\text{Gallons } \underline{\hspace{2cm}} \div 7.48 = \underline{\hspace{2cm}} \quad 60 \times 15 =$$

11. The diameter of a tank is 60' and the depth is 25'. How many gallons does it hold?

Cylinder Formula

$$V = (.785) (D^2) (d)$$

$$.785 \times 60' \times 60' \times 25' \times 7.48 =$$

**Math Problems with Complete Solution can be found at the rear of this section. Please try to work the problems without looking at the solution.**

### Cubic Feet Information

There is no universally agreed symbol but the following are used:

cubic feet, cubic foot, cubic ft

cu ft, cu feet, cu foot

ft<sup>3</sup>, feet<sup>3</sup>, foot<sup>3</sup>

feet<sup>3</sup>, foot<sup>3</sup>, ft<sup>3</sup>

feet/-3, foot/-3, ft/-3

### Water Treatment Production Math Numbering System

In water treatment, we express our production numbers in Million Gallon numbers. Example 2,000,000 or 2 million gallons would be expressed as 2 MG or 2 MGD.

Hints. A million has six zeros, you can always divide your final number by 1,000,000 or move the decimal point to the left six places. Example 528,462 would be expressed .56 MGD.

12. The diameter of a tank is 15 Centimeters or cm and the depth is 25 cm, what is the volume in liters?

$$2.54\text{cm} = 1 \text{ inch}, 12 \text{ inches} = 1 \text{ foot}$$

$$15 \text{ cm} \div 2.54 \text{ cm} \div 12 \text{ inches} = .492 \text{ feet}$$

$$.785 \times .492' \times .492' \times \underline{\hspace{2cm}}' = \underline{\hspace{2cm}} \times 7.48 = \underline{\hspace{2cm}} \times 3.785 \text{ L} =$$

## Percentage and Fractions

Let's look again at the sequence of numbers 1000, 100, 10, 1, and continue the pattern to get new terms by dividing previous terms by 10:

$$\begin{aligned}.1 &= 1/10 \\ .01 &= 1/100 \\ .001 &= 1/1000\end{aligned}$$



So just as the digits to the left of the decimal represent 1's, 10's, 100's, and so forth, digits to the right of the decimal point represent 1/10's, 1/100's, 1/1000's, and so forth.

Let's express 5% as a decimal.  $5 \div 100 = 0.05$  or you can move the decimal point to the left two places.

### Changing a fraction to a decimal:

**Divide the numerator by the denominator**

A.  $5/10$  (five tenths) = five divided by ten:

$$\begin{array}{r} .5 \\ \text{-----} \\ 10 \overline{) 5.0} \\ \underline{50} \\ \text{----} \end{array}$$

So  $5/10$  (five tenths) =  $.5$  (five tenths).

B. How about  $1/2$  (one half) or 1 divided by 2 ?

$$\begin{array}{r} .5 \\ \text{-----} \\ 2 \overline{) 1.0} \\ \underline{10} \\ \text{----} \end{array}$$

So  $1/2$  (one half) =  $.5$  (five tenths)

*Notice that equivalent fractions convert to the same decimal representation.*

$8/12$  is a good example.  $8 \div 12 = .66666666$  or rounded off to  $.667$

How about  $6/12$  or 6 inches?  $.5$  or half a foot

***This is not your final assignment...please download the assignment off the website.***

## Flow and Velocity

This depends on measuring the average velocity of flow and the cross-sectional area of the channel and calculating the flow from:

$$Q(\text{m}^3/\text{s}) = A(\text{m}^2) \times V(\text{m}/\text{s})$$

Or

$$Q = A \times V$$

**Q CFM = Cubic Ft, Inches, Yards of time, Sec, Min, Hrs, Days**

**A = Area, squared Length X Width**

**V f/m = Inch, Ft, Yards, Per Time, Sec, Min, Ft or Speed**

13. A channel is 3 feet wide and has water flowing to a depth of 2.5 feet. If the velocity through the channel is 2 fps or feet per second, what is the cfs flow rate through the channel?

$$Q = A \times V$$

Q = 7.5 sq. ft. X 2 fps What is Q?

$$A = 3' \times 2.5' = 7.5$$

$$V = 2 \text{ fps}$$

14. A channel is 40 inches wide and has water flowing to a depth of 1.5 ft. If the velocity of the water is 2.3 fps, what is the cfs flow in the channel? **Q = A X V**

**First we must convert 40 inches to feet.**

$$40 \div 12'' = 3.333 \text{ feet}$$

$$A = 3.333' \times 1.5' = 4.999 \text{ or round up to } 5$$

$$V = 2.3 \text{ fps}$$

We can round this answer up.

15. A channel is 3 feet wide and has a water flow at a velocity of 1.5 fps. If the flow through the channel is 8.1 cfs, what is the depth of the water?

$$Q = 8.1 \text{ cfs}$$

$$V = 1.5 \text{ fps}$$

$$A = ?$$

$$8.1 \div 1.5 = \underline{\hspace{2cm}} \text{ Total Area}$$

16. The flow through a 6 inch diameter pipe is moving at a velocity of 3 ft/sec. What is the cfs flow rate through the pipeline?

$$Q =$$

$$A = .785 \times .5' \times .5' =$$

$$V = 3 \text{ fps}$$

***This is not your final assignment...please download the assignment off the website.***

17. An 8 inch diameter pipe has water flowing at a velocity of 3.4 fps. What is the gpm flow rate through the pipe?

$$Q = \underline{\hspace{2cm}} \text{ cfs} \times 60 \text{ sec/min} \times 7.48 = \underline{\hspace{2cm}} \text{ gpm}$$

$$A = .785 \times .667' \times .667'$$

$$V = 3.4 \text{ fps}$$

18. A 6 inch diameter pipe delivers 280 gpm. What is the velocity of flow in the pipe in ft/sec?

$$\text{Take the water out of the pipe. } 280 \text{ gpm} \div 7.48 \div 60 \text{ sec/min} = \underline{\hspace{2cm}} \text{ cfs}$$

$$Q =$$

$$A = .785 \times .5' \times .5' =$$

$$V =$$

19. A new section of 12 inch diameter pipe is to be disinfected before it is placed in service. If the length is 2000 feet, how many gallons of 5% NaOCl will be need for a dosage of 200 mg/L?

### Cylinder Formula

$$V = (.785) (D^2) (d)$$

$$.785 \times 1' \times 1' \times 2000' = \underline{\hspace{2cm}} \text{ cu.ft.} \times 7.48 = \underline{\hspace{2cm}} \div 1,000,000 = \underline{\hspace{2cm}} \text{ MG}$$

**Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal if 100% concentrate. If not, divide the lbs/day by the given %**

$$0.0117436 \text{ MG} \times 200 \text{ mg/L} \times 8.34 = \underline{\hspace{2cm}} \text{ lbs/day} \div .05 =$$

20. A section of 6 inch diameter pipe is to be filled with water. The length of the pipe is 1320 feet long. How many kilograms of chlorine will be needed for a chlorine dose of 3 mg/L?

$$.785 \times .5' \times .5' \times 1320' \times 7.48 = \underline{\hspace{2cm}} \text{ Make it MGD}$$

**Pounds per day formula = Flow X Dose X 8.34 X .454 Grams per pound**

21. Determine the chlorinator setting in pounds per 24 hour period to treat a flow of 3.4 MGD with a chlorine dose of 3.35 mg/L?

**Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal**

22. To correct an odor problem, you use chlorine continuously at a dosage of 15 mg/L and a flow rate of 85 GPM. Approximately how much will odor control cost annually if chlorine is \$0.17 per pound?

$$85 \text{ gpm} \times 1440 \text{ min/day} = \underline{\hspace{2cm}} \text{ gpd} \div 1,000,000 = \underline{\hspace{2cm}} \text{ MGD}$$

$$\underline{\hspace{2cm}} \text{ MGD} \times 15 \text{ mg/L} \times 8.34 \text{ lbs/gal} \times \$0.17 \text{ per pound} \times 365 \text{ days/year} =$$

23. A wet well measures 8 feet by 10 feet and 3 feet in depth between the high and low levels. A pump empties the wet well between the high and low levels 9 times per hour, 24 hours a day. Neglecting inflow during the pumping cycle, calculate the flow into the pump station in millions of gallons per day (MGD).

Build it, fill it and do what it says, hint:  $X 9 X 24$

**Math problems with complete solution can be found at the rear of this section. Please try to work the problems without looking at the solution.**

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24. A sewage treatment plant has a flow of 0.7 MGD and a BOD of 225 mg/L. On the basis of a national average of 0.2 lbs BOD per capita per day, what is the approximate population equivalent of the plant?

25. What is the detention time of a clarifier with a 250,000 gallon capacity if it receives a flow of 3.0 MGD?

**DT= Volume in Gallons X 24 Divided by MGD**

**.25 MG X 24 hrs. ÷ 3.0 MGD = \_\_\_\_\_ Hours of DT**

Always convert gallons to MG



## **Crazy Math Section**

The metric system is known for its simplicity. All units of measurement in the metric system are based on decimals—that is, units that increase or decrease by multiples of ten. A series of Greek decimal prefixes is used to express units of ten or greater; a similar series of Latin decimal prefixes is used to express fractions. For example, *deca* equals ten, *hecto* equals one hundred, *kilo* equals one thousand, *mega* equals one million, *giga* equals one billion, and *tera* equals one trillion. For units below one, *deci* equals one-tenth, *centi* equals one-hundredth, *milli* equals one-thousandth, *micro* equals one-millionth, *nano* equals one-billionth, and *pico* equals one-trillionth.

26. How many grams equal 4,500 mg?

Just simply divide by 1,000.

**Math Problems with Complete Solution can be found at the rear of this section. Please try to work the problems without looking at the solution.**

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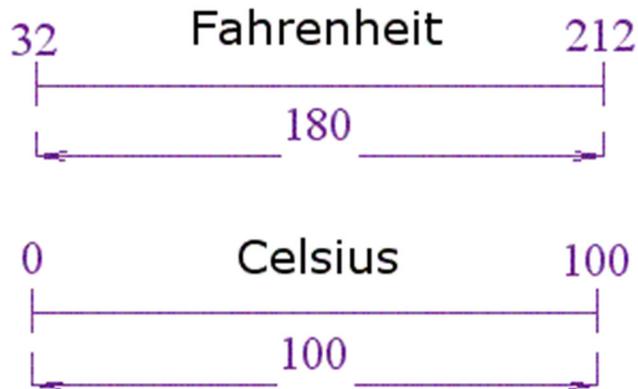


## Temperature

There are two main temperature scales. The **Fahrenheit Scale** (used in the US), and the **Celsius Scale** (part of the Metric System, used in most other Countries)

They both measure the same thing (temperature!), just using different numbers.

- If you freeze water, it measures 0° in Celsius, but 32° in Fahrenheit
- If you boil water, it measures 100° in Celsius, but 212° in Fahrenheit
- The difference between freezing and boiling is 100° in Celsius, but 180° in Fahrenheit.



### Conversion Method

Looking at the diagram, notice:

- The scales start at a different number (32 vs. 0), so we will need to add or subtract 32
- The scales rise at a different rate (180 vs. 100), so we will also need to multiply

And this is how it works out:

To convert from Celsius to Fahrenheit, first multiply by 180/100, then add 32

To convert from Fahrenheit to Celsius, first subtract 32, then multiply by 100/180

Note: 180/100 can be simplified to **9/5**, and likewise 100/180=**5/9**.

$$^{\circ}\text{F} = (^{\circ}\text{C} \times 9/5) + 32 \quad 9/5 = 1.8$$

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) \times 5/9 \quad 5/9 = .555$$

27. Convert 20 degrees Celsius to degrees Fahrenheit.

$$20^{\circ} \times 1.8 + 32 = \text{F}$$

28. Convert 4 degrees Celsius to degrees Fahrenheit.

$$4^{\circ} \times 1.8 + 32 = \text{F}$$



## Water Treatment Filters

29. A 19 foot wide by 31 foot long rapid sand filter treats a flow of 2,050 gallons per minute. Calculate the filtration rate in gallons per minute per square foot of filter area.

**GPM ÷ Square Feet**

30. A 26 foot wide by 36 foot wide long rapid sand filter treats a flow of 2,500 gallons per minute. Calculate the filtration rate in gallons per minute per square foot of filter area.

## Chemical Dose

31. A pond has a surface area of 51,500 square feet and the desired dose of a chemical is 6.5 lbs per acre. How many pounds of the chemical will be needed?

43,560 Square feet in an acre

$$51,500 \div 43,560 = \underline{\hspace{2cm}} \times 6.5 =$$

32. A pond having a volume of 6.85 acre feet equals how many millions of gallons?

33. Alum is added in a treatment plant process at a concentration of 10.5 mg/L. What should the setting on the feeder be in pounds per day if the plant is treating 3.5 MGD?

**Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal**

## Q=AV Review

34. An 8 inch diameter pipe has water flowing at a velocity of 3.4 fps. What is the GPM flow rate through the pipe?

$$Q = 1.18 \text{ CFS} \times 60 \text{ Seconds} \times 7.48 \text{ GAL/CU.FT} = 532 \text{ GPM}$$

$$A = .785 \times .667 \times .667 \times 1 = .349 \text{ Sq. Ft.}$$

$$V = 3.4 \text{ Feet per second}$$

35. A 6 inch diameter pipe delivers 280 GPM. What is the velocity of flow in the pipe in Ft/Sec?  
280 GPM ÷ 60 seconds in a minute ÷ 7.48 gallons in a cu.ft. = .623 CFS

$$Q = .623$$

$$A = .785 \times .5 \times .5 = .196 \text{ Sq. Ft.}$$

$$V = 3.17 \text{ Ft/Second}$$



## Collections

36. A 24-inch sewer carries an average daily flow of 5 MGD. If the average daily flow per person from the area served is 110 GPCD (gallons per capita per day), approximately how many people discharge into the wastewater collection system?

5,000,000 divided by 110 =

37. Using a dose rate of 5 mg/L, how many pounds of chlorine per day should be used if the flow rate is 1.2 MGD?

**Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal**

38. What capacity blower will be required to ventilate a manhole which is 3.5 feet in diameter and 17 feet deep? The air exchange rate is 16 air changes per hour.

$.785 \times 3.5' \times 3.5' \times 17' \times 16 =$  \_\_\_\_\_ CFH

39. Approximately how many feet of drop are in 455 feet of 8-inch sewer with a 0.0475 ft/ft. slope?

**SLOPE =  $\frac{\text{Rise (ft)}}{\text{Run (ft)}}$**

**SLOPE (%) =  $\frac{\text{Rise (ft)} \times 100}{\text{Run (ft)}}$**

455' X 0.0475 =

40. How much brake horsepower is required to meet the following conditions: 250 gpm, total head = 110 feet? The submersible pump that is being specified is a combined 64% efficient?

$(250 \times 110) \div (3960 \times .64)$

41. How wide is a trench at ground surface if a sewer trench is 2 feet wide at the bottom, 10 feet deep and the sides have been sloped at a 4/5 horizontal to 1 vertical (3/4:1) ratio?

(3/4:1) or  $3 \div 4 = .75$  X every foot of depth

42. A float arrives in a manhole 550 feet down stream three minutes and thirty seconds from its release point. What is the velocity in ft/sec.?

**Velocity ft/sec = distance ÷ time**

550' ÷ 3 min stop convert min to sec.  $3 \times 60 = 180 + 30 = 210 \text{ sec}$

550' ÷ 210 sec = \_\_\_\_\_ fps

43. A new sewer line plan calls out a 0.6% slope of the line. An elevation reading of 108.8 feet at the manhole discharge and an elevation of 106.2 feet at a distance of 200 feet from the manhole are recorded. What is the existing slope of the line that has been installed?

$$\text{SLOPE} = \frac{\text{Rise (ft)}}{\text{Run (ft)}}$$

$$\text{SLOPE (\%)} = \frac{\text{Rise (ft)} \times 100}{\text{Run (ft)}}$$

44. A triangular pile of spoil is 12 feet high and 12 feet wide at the base. The pile is 60' long. If the dump truck hauls 9 cubic yards of dirt, how many truck loads will it take to remove all of the spoil?

Given the base and the height of a triangle, we can find the area. Given the area and either the base or the height of a triangle, we can find the other dimension. The formula for area of a triangle is:

$$A = \frac{1}{2} \cdot b \cdot h \quad \text{Or} \quad A = \frac{b \cdot h}{2} \quad \text{where } b \text{ is the base, } h \text{ is the height.}$$

12' X 12' ÷ 2 X 60' = \_\_\_\_\_ cu.ft. (27cu.ft./cu.yrd.)

45. A red dye is poured into an upstream manhole connected to a 12 inch sewer. The dye first appears in a manhole 400 feet downstream 3 minutes later. After 3 minutes and 40 seconds the dye disappears. Estimate the flow velocity in feet per second?

**Velocity ft/sec = distance ÷ time**

**Make sure and convert time and average it.**

**Math problems with complete solution can be found at the rear of this section.  
Please try to work the problems without looking at the solution.  
This is not your final assignment...please download the assignment off the website.**

46. Calculate the total dosage in pounds of a chemical. Assume the sewer is completely filled with the concentration. Pipe diameter: 18 inches, Pipe length: 420 feet, Dose: 120 mg/L.

Figure out the volume first.

$.785 \times 1.5' \times 1.5' \times 420' \times 7.48 =$  \_\_\_\_\_ convert to MG

**Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal**

**Math problems with complete solution can be found at the rear of this section.  
Please try to work the problems without looking at the solution.**

## Short Answers

1.  $7.48 \times 10 = 74.8$
2.  $800 \div 8.34 = 95.92$  gallons
3. 1372320 or 1.3 MGD
4.  $610 \times 1441 = 878400$  or 0.87 MGD
5.  $550 \div 60 = 9.167$  gpm
6.  $9.167 \times 3.785 = 34.697$  Liters
7. 630 Area 4712 gallons
8.  $18,750 \text{ cu. ft.} \times 7.48 = 140250$  gallons
9.  $140250 \times 3.785 = 530846$  Liters
10. 10 feet deep
11. 528462 or .5 MG
12.  $1.166 \text{ Gallons} \times 3.785 = 4.412$  Liters
13. 15 cfs
14. 11.49 cfs
15. 1.8'
16. .58875 cfs
17. 533 gpm
18. 3.2 ft/sec
19. 46.9 gal
20. .02 kg
21. 94.9 lbs/day
22. \$950.12
23. .388 or .39 MGD
24. 6567.75
25. 2 hrs.
26. 4.5 grams
27. 68° F
28. 39°F
29. 3.48 gpm/sq.ft.
30. 2.67 gpm/sq.ft.
31. 7.68 lbs
32. 2.231 MG
33. 306.495
34. 532 gpm
35. 3.2 fps
36. 45454.5 people
37. 50.04 lbs
38. 2615.6 cfh
39. 21.61 ft
40. 10.85 bhp
41. 17 ft
42. 2.62 fps
43. .013 or 1.3%
44. 17.7 or 18 trucks
45. 2 fps
46. 5.55 lbs

**Math problems with complete solution can be found on the next page.**

## Math Problems with Complete Solution

### Volume in Cubic Feet

#### Cube Formula

$$V = (L) (W) (D)$$

$$\text{Volume} = \text{Length} \times \text{Width} \times \text{Depth}$$

#### Cylinder Formula

$$V = (.785) (D^2) (d)$$

#### *Build it, Fill it and Dose it.*

1. Convert 10 cubic feet to gallons of water.

There is 7.48 gallons in one cubic foot.

$$\frac{7.48}{1} \div \frac{X}{10} = 74.8 \text{ gallons}$$

Or simply 10 times 7.48 = 74.8 gallons

2. The liquid in a tank weighs 800 pounds, how many gallons are in the tank?

$$800 \text{ lbs} \div 8.34 \text{ lbs/gal} = 95.92 \text{ gallons of water}$$

3. Convert a flow rate of 953 gallons per minute to million gallons per day.  
There is 1440 minutes in a day.

$$953 \text{ Gal/Min} \times 1440 \text{ Min/Day} = 1,372,320 \text{ gal/day}$$

$$1,372,320 \div 1,000,000 = 1.37 \text{ MGD}$$

4. Convert a flow rate of 610 gallons per minute to millions of gallons per day.

$$610 \text{ gal/min} \times 1440 \text{ min/day} = 878,400 \text{ gal/day}$$

$$878,400 \div 1,000,000 = .878 \text{ MGD}$$

5. Convert a flow of 550 gallons per minute to gallons per second?

$$550 \text{ gal/min} \div 60 \text{ sec/min} = 9.17 \text{ gal/sec or } 9.167 \text{ gal/sec.}$$

6. Now, convert this number to liters per second.

9.17 gal/sec X 3.79 Liters/gal + 34.75 Liter/sec or 34.697

7. A tank is 6' X 15' x 7' and can hold a maximum of \_\_\_\_\_ gallons of water.

$$V = (L) (W) (D) \times 7.48 =$$

$$(6 \times 15 \times 7) \times 7.48 = 4,712 \text{ gallons}$$

8. A tank is 25' X 75' X 10' what is the volume of water in gallons?

$$V = (L) (W) (D) \times 7.48 =$$

$$(25 \times 75 \times 10) \times 7.48 = 140,250 \text{ gallons}$$

9. In Liters?

$$V = (L) (W) (D) \times 7.48 = \text{_____} \times 3.785$$

$$(25 \times 75 \times 10) \times 7.48 = 140,250 \text{ gallons} \times 3.785 = 530,846 \text{ Liters}$$

10. A tank holds 67,320 gallons of water. The length is 60' and the width is 15'. How deep is the tank?

$$\text{Gallons } \text{_____} \div 7.48 = \text{_____} \quad 60 \times 15 =$$

$$\frac{67,320 \text{ gal}}{7.48 \text{ gal/cu.ft.}} = 9000 \text{ cu.ft.} = (60 \times 15) \times 900 \quad \frac{9000}{900} = 10$$

11. The diameter of a tank is 60' and the depth is 25'. How many gallons does it hold?

Cylinder Formula

$$V = (.785) (D^2) (d)$$

$$.785 \times 60' \times 60' \times 25' \times 7.48 =$$

Or

$$.785 \times (60 \times 60) \times 25 \times 7.48 = 528,462 \text{ gallons}$$

## Math Problems with Complete Solution

### Water Treatment Production Math Numbering System

In water treatment, we express our production numbers in Million Gallon numbers. Example 2,000,000 or 2 million gallons would be expressed as 2 MG or 2 MGD.

Hints. A million has six zeros, you can always divide your final number by 1,000,000 or move the decimal point to the left six places. Example 528,462 would be expressed .56 MGD.

12. The diameter of a tank is 15 Centimeters or cm and the depth is 25 cm, what is the volume in liters?

2.54cm = 1 inch, 12 inches = 1 foot

15 cm ÷ 2.54 cm ÷ 12 inches = .492 feet

$$.785 \times .492 \times .492 \times \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \times 7.48 = \underline{\hspace{1cm}} \times 3.785 \text{ L} =$$

$$.785 \times .492 \times .492 \times 0.82 = .1558165 \times 7.48 = 1.1655074 \times 3.785 \text{ L} = 4.4114455$$

13. A channel is 3 feet wide and has water flowing to a depth of 2.5 feet. If the velocity through the channel is 2 fps or feet per second, what is the cfs flow rate through the channel?

$$Q = A \times V$$

$$Q = 15$$

$$A = 3' \times 2.5' = 7.5$$

$$V = 2 \text{ fps}$$

Or

Area is 7.5 cubic feet

Velocity is 2 fps

Area X Velocity = Quantity

14. A channel is 40 inches wide and has water flowing to a depth of 1.5 ft. If the velocity of the water is 2.3 fps, what is the cfs flow in the channel?  $Q = A \times V$

**First we must convert 40 inches to feet.**

$$40 \div 12" = 3.333 \text{ feet}$$

$$A = 3.333' \times 1.5' = 4.999 \text{ or round up to } 5$$

$$V = 2.3 \text{ fps}$$

We can round this answer up.

Area X Velocity = Quantity

$$5 \times 2.3 = 11.5 \text{ or } 11.49$$

15. A channel is 3 feet wide and has a water flow at a velocity of 1.5 fps. If the flow through the channel is 8.1 cfs, what is the depth of the water?

$$Q = 8.1 \text{ cfs}$$

$$V = 1.5 \text{ fps}$$

$$A = ?$$

$$8.1 \div 1.5 = \underline{\hspace{2cm}} \text{ Total Area}$$

$$\text{Area} \div \text{Quantity} = \text{Velocity}$$

$$8.1 \div 1.5 = 5.4 \text{ cubic feet or Area}$$

16. The flow through a 6 inch diameter pipe is moving at a velocity of 3 ft/sec. What is the cfs flow rate through the pipeline?

$$Q =$$

$$A = .785 \times .5' \times .5' =$$

$$V = 3 \text{ fps}$$

$$\text{Area} \times \text{Velocity} = \text{Quantity}$$

$$0.19625 \times 3 = 0.58875 \text{ cfs}$$

17. An 8 inch diameter pipe has water flowing at a velocity of 3.4 fps. What is the gpm flow rate through the pipe?

$$Q = \underline{\hspace{2cm}} \text{ cfs} \times 60 \text{ sec/min} \times 7.48 = \underline{\hspace{2cm}} \text{ gpm}$$

$$A = .785 \times .667' \times .667'$$

$$V = 3.4 \text{ fps}$$

$$\text{Area} \div \text{Quantity} = \text{Velocity}$$

$$0.3492 \div 3.4 \text{ fps} = 1.1874 \text{ cfs} \times 60 \text{ sec/min} \times 7.48 = 532.85126 \text{ or } 533 \text{ gpm}$$

18. A 6 inch diameter pipe delivers 280 gpm. What is the velocity of flow in the pipe in ft/sec?

$$\text{Take the water out of the pipe. } 280 \text{ gpm} \div 7.48 \div 60 \text{ sec/min} = \underline{\hspace{2cm}} \text{ cfs}$$

$$Q =$$

$$A = .785 \times .5' \times .5' =$$

$$V =$$

$$\text{Quantity} \div \text{Area} = \text{Velocity}$$

$$\text{Quantity} = .624 \text{ CFS}$$

$$\text{Area} = 0.19625$$

$$\text{Velocity} = 3.17 \text{ or } 3.2 \text{ Feet per second}$$

19. A new section of 12 inch diameter pipe is to be disinfected before it is placed in service. If the length is 2000 feet, how many gallons of 5% NaOCl will be need for a dosage of 200 mg/L?

**Cylinder Formula**

**V= (.785) (D<sup>2</sup>) (d)**

.785 X 1' X 1' X 2000' = \_\_\_\_\_ cu.ft. X 7.48 = \_\_\_\_\_ ÷ 1,000,000 = \_\_\_\_\_ MG

**Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal if 100% concentrate. If not, divide the lbs/day by the given %**

0.0117436 MG X 200 mg/L X 8.34 = \_\_\_\_\_ lbs/day ÷ .05 =

.785 X 1' X 1' X 2000' = 1570 cu.ft. X 7.48 = 11744 ÷ 1,000,000 = 0.0117436 MG

**Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal if 100% concentrate. If not, divide the lbs/day by the given %**

0.0117436 MG X 200 mg/L X 8.34 = 19.588 lbs/day ÷ .05 or 5% = 391.76 lbs ÷ 8.34 lb/gal = 46.9 gallons

20. A section of 6 inch diameter pipe is to be filled with water. The length of the pipe is 1320 feet long. How many kilograms of chlorine will be needed for a chlorine dose of 3 mg/L?

.785 X .5' X .5' X 1320' X 7.48 = \_\_\_\_\_ Make it MGD

**Pounds per day formula = Flow X Dose X 8.34 X .454 Grams per pound**

.785 X .5' X .5' X 1320' X 7.48 = 1937.69 Make it MGD Divide by 1 million = 0.00194 X .454 =

21. Determine the chlorinator setting in pounds per 24 hour period to treat a flow of 3.4 MGD with a chlorine dose of 3.35 mg/L?

**Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal**

3.4 mgd X 3.35 mg/L X 8.34 Lbs/gal = 94.99 lbs

22. To correct an odor problem, you use chlorine continuously at a dosage of 15 mg/L and a flow rate of 85 GPM. Approximately how much will odor control cost annually if chlorine is \$0.17 per pound?

$$85 \text{ gpm} \times 1440 \text{ min/day} = \text{_____} \text{ gpd} \div 1,000,000 = \text{_____} \text{ MGD}$$
$$\text{_____} \text{ MGD} \times 15 \text{ mg/L} \times 8.34 \text{ lbs/gal} \times \$0.17 \text{ per pound} \times 365 \text{ days/year} =$$

$$85 \text{ gpm} \times 1440 \text{ min/day} = 122,400 \text{ gpd} \div 1,000,000 = 0.1224 \text{ MGD}$$

$$.1224 \text{ MGD} \times 15 \text{ mg/L} \times 8.34 \text{ lbs/gal} \times \$0.17 \text{ per pound} \times 365 \text{ days/year} = \$950.12$$

23. A wet well measures 8 feet by 10 feet and 3 feet in depth between the high and low levels. A pump empties the wet well between the high and low levels 9 times per hour, 24 hours a day. Neglecting inflow during the pumping cycle, calculate the flow into the pump station in millions of gallons per day (MGD).

Build it, fill it and do what it says, hint:  $X \ 9 \ X \ 24$

$L \ X \ W \ X \ H$

$$(8 \ X \ 10 \ X \ 3) = 240 \text{ CF} \times 7.48 \text{ gal/cf} = 1795.2 \ X \ 9 \ X \ 24 = 387763 \text{ gallons/day or rounds to } .388 \text{ MGD}$$

24. A sewage treatment plant has a flow of 0.7 MGD and a BOD of 225 mg/L. On the basis of a national average of 0.2 lbs BOD per capita per day, what is the approximate population equivalent of the plant?

Population equivalent

$$\frac{(0.7 \text{ MGD}) (22.5 \text{ mg/L}) (8.34 \text{ Lbs/gal})}{0.2 \text{ Lbs BOD/Day/Person}} = 6,567.75 \text{ people}$$

25. What is the detention time of a clarifier with a 250,000 gallon capacity if it receives a flow of 3.0 MGD?

**DT= Volume in Gallons X 24 Divided by MGD**

$$.25 \text{ MG} \times 24 \text{ hrs.} \div 3.0 \text{ MGD} = \text{_____} \text{ Hours of DT}$$

Always convert gallons to MG

$$.25 \text{ MG} \times 24 \text{ hrs.} \div 3.0 \text{ MGD} = 2 \text{ Hours of DT}$$

26. How many grams equal 4,500 mg?

Just simply divide by 1,000.

$$4,500 \div 1,000 = 4.5 \text{ grams}$$

27. Convert 20 degrees Celsius to degrees Fahrenheit.

$$20^{\circ} \text{ C} \times 1.8 + 32 = 68 \text{ F}$$

28. Convert 4 degrees Celsius to degrees Fahrenheit.

$$4^{\circ} \text{ C} \times 1.8 + 32 = 39.2 \text{ or } 39 \text{ degrees}$$

## Math Problems with Complete Solution Water Treatment Filters

29. A 19 foot wide by 31 foot long rapid sand filter treats a flow of 2,050 gallons per minute. Calculate the filtration rate in gallons per minute per square foot of filter area.

**GPM ÷ Square Feet**

$$(19 \times 31) = 589 \text{ sq. ft}$$

$$2050 \text{ gal/min} \div 589 \text{ sq. ft} = 3.48 \text{ gpm/sq. ft.}$$

30. A 26 foot wide by 36 foot wide long rapid sand filter treats a flow of 2,500 gallons per minute. Calculate the filtration rate in gallons per minute per square foot of filter area.

$$(26 \times 36) = 936 \text{ Sq. Ft}$$

**GPM ÷ Square Feet**

$$2,500 \text{ gal/min} \div 936 \text{ sq. ft} = 2.678 \text{ gpm/sq. ft.}$$

## Chemical Dose

31. A pond has a surface area of 51,500 square feet and the desired dose of a chemical is 6.5 lbs per acre. How many pounds of the chemical will be needed?

43,560 Square feet in an acre

$$51,500 \div 43,560 = \underline{\hspace{2cm}} \times 6.5 =$$

$$51,500 \text{ sq.ft.} \div 43,560 = 1.18 \times 6.5 = 7.68 \text{ lbs}$$

32. A pond having a volume of 6.85 acre feet equals how many millions of gallons?

$$1 \text{ acre foot} = 325851 \times 6.85 = 2.231 \text{ MG}$$

33. Alum is added in a treatment plant process at a concentration of 10.5 mg/L. What should the setting on the feeder be in pounds per day if the plant is treating 3.5 MGD?

**Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal = Pounds per day formula**

$$3.5 \text{ MGD} \times 10.5 \text{ Mg/L} \times 8.34 \text{ Lbs/gal} = 306.495 \text{ pounds}$$

## Q=AV Review

34. An 8 inch diameter pipe has water flowing at a velocity of 3.4 fps. What is the GPM flow rate through the pipe?

$$Q = 1.18 \text{ CFS} \times 60 \text{ Seconds} \times 7.48 \text{ GAL/CU.FT} = 532 \text{ GPM}$$

$$A = .785 \times .667 \times .667 \times 1 = .349 \text{ Sq. Ft.}$$

$$V = 3.4 \text{ Feet per second}$$

$$V \times A = Q$$

$$\text{Velocity } 3.4 \text{ fps} \times .349 \text{ Sq.ft} = 1.1866 \text{ CFS} \times 60 \text{ seconds} \times 7.48 \text{ gal/Cu.ft} = 532.5 \text{ or } 533$$

35. A 6 inch diameter pipe delivers 280 GPM. What is the velocity of flow in the pipe in Ft/Sec?

$$280 \text{ GPM} \div 60 \text{ seconds in a minute} \div 7.48 \text{ gallons in a cu.ft.} = .623 \text{ CFS}$$

$$Q = .623$$

$$A = .785 \times .5 \times .5 = .196 \text{ Sq. Ft.}$$

$$V = 3.17 \text{ Ft/Second}$$

$$\text{Quantity} \div \text{Area} = \text{Velocity}$$

$$0.623 \text{ CFS} \div 0.196 \text{ SQ FT} = 3.18 \text{ or } 3.2 \text{ FPS}$$

## Collections

36. A 24-inch sewer carries an average daily flow of 5 MGD. If the average daily flow per person from the area served is 110 GPCD (gallons per capita per day), approximately how many people discharge into the wastewater collection system?

$$5,000,000 \text{ divided by } 110 = 45,454 \text{ people}$$

37. Using a dose rate of 5 mg/L, how many pounds of chlorine per day should be used if the flow rate is 1.2 MGD?

**Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal = Pounds per day formula**

$$1.2 \times 5 \text{ mg/l} \times 8.34 = 50.04 \text{ lbs}$$

38. What capacity blower will be required to ventilate a manhole which is 3.5 feet in diameter and 17 feet deep? The air exchange rate is 16 air changes per hour.

$$.785 \times 3.5' \times 3.5' \times 17' \times 16 = \underline{\hspace{2cm}} \text{ CFH}$$

$$.785 \times 3.5' \times 3.5' \times 17' \times 16 = 2615.6 \text{ CFH}$$

$$Q = .785 (D^2) \times \text{Depth}$$

39. Approximately how many feet of drop are in 455 feet of 8-inch sewer with a 0.0475 ft/ft. slope?

$$\text{SLOPE} = \frac{\text{Rise (ft)}}{\text{Run (ft)}}$$

$$\text{SLOPE (\%)} = \frac{\text{Rise (ft)} \times 100}{\text{Run (ft)}}$$

$$455' \times 0.0475 = 21.6 \text{ feet}$$

40. How much brake horsepower is required to meet the following conditions: 250 gpm, total head = 110 feet? The submersible pump that is being specified is a combined 64% efficient?

$$(250 \times 110) \div (3960 \times .64)$$

or

$$\frac{(250 \times 110)}{(3960 \times .64)} = 10.85$$

$$\text{BRAKE HORSEPOWER} = \frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3961 \times \text{Pump Efficiency}}$$

41. How wide is a trench at ground surface if a sewer trench is 2 feet wide at the bottom, 10 feet deep and the sides have been sloped at a 4/5 horizontal to 1 vertical (3/4:1) ratio?

$$(3/4:1) \text{ or } 3 \div 4 = .75 \times \text{every foot of depth}$$

$$0.75 \times 10 \text{ ft} = 7.5 \text{ feet} \times 2 \text{ sides} + 2 \text{ feet on the bottom.}$$

or

$$0.75 \times 10 \text{ ft} = 7.5 \times 2 \text{ sides} = 15 \text{ ft} + 2 \text{ feet} = 17 \text{ feet}$$

42. A float arrives in a manhole 550 feet down stream three minutes and thirty seconds from its release point. What is the velocity in ft/sec.?

$$\text{Velocity ft/sec} = \text{distance} \div \text{time}$$

$$550' \div 3 \text{ min stop convert min to sec. } 3 \times 60 = 180 + 30 = 210 \text{ sec}$$

$$550' \div 210 \text{ sec} = 2.62 \text{ fps}$$

Or

$$\frac{550 \text{ ft}}{210 \text{ sec}}$$

43. A new sewer line plan calls out a 0.6% slope of the line. An elevation reading of 108.8 feet at the manhole discharge and an elevation of 106.2 feet at a distance of 200 feet from the manhole are recorded. What is the existing slope of the line that has been installed?

$$\text{SLOPE} = \frac{\text{Rise (ft)}}{\text{Run (ft)}}$$

$$\text{SLOPE (\%)} = \frac{\text{Rise (ft)} \times 100}{\text{Run (ft)}}$$

$$108.8 - 106.2 = 2.6 \text{ feet of drop or rise}$$

$$2.6 \text{ rise} \div 200 \text{ feet of run} = 0.013 \text{ slope or } 1.3 \% \text{ slope}$$

44. A triangular pile of spoil is 12 feet high and 12 feet wide at the base. The pile is 60' long. If the dump truck hauls 9 cubic yards of dirt, how many truck loads will it take to remove all of the spoil?

Given the base and the height of a triangle, we can find the area. Given the area and either the base or the height of a triangle, we can find the other dimension. The formula for area of a triangle is:

$$A = \frac{1}{2} \cdot b \cdot h \quad \text{Or} \quad A = \frac{b \cdot h}{2} \quad \text{where } b \text{ is the base, } h \text{ is the height.}$$

$$12' \times 12' \times 60' \div 2 = 4320 \text{ cu.ft (27cuft/cu.yard)}$$

$$4320 \div 27 = 160 \text{ cubic yards}$$

$$160 \text{ cubic yards} \div 9 \text{ cubic yard dump trucks}$$

$$17.77777 \text{ dump trucks or } 18 \text{ dump trucks}$$

45. A red dye is poured into an upstream manhole connected to a 12 inch sewer. The dye first appears in a manhole 400 feet downstream 3 minutes later. After 3 minutes and 40 seconds the dye disappears. Estimate the flow velocity in feet per second?

**Velocity ft/sec = distance ÷ time**

**Make sure and convert time and average it.**

$$\begin{aligned} 3 \text{ Minutes} &= 180 \text{ Seconds} \\ + 3 \text{ Minutes} &= 40 \text{ Seconds} = 220 \text{ Seconds} \\ \hline 400 \text{ Seconds} \div 2 &= 200 \text{ Seconds Average} \end{aligned}$$

**distance ÷ time = Velocity ft/sec**

$$400 \div 200 = 2 \text{ fps}$$

46. Calculate the total dosage in pounds of a chemical. Assume the sewer is completely filled with the concentration. Pipe diameter: 18 inches, Pipe length: 420 feet, Dose: 120 mg/L.

Figure out the volume first.

$.785 \times 1.5' \times 1.5' \times 420' \times 7.48 = 5549$  convert to MG

**First  $.785 (1.5) (1.5) 420 \times 7.48 = 5549$  convert to MGD  $.005549$**

**Second**

**Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal = Pounds per day formula =  
 $.005549 \times 120 \times 8.34 = 5.55$  lbs**



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