

# **STORAGE FACILITIES**

## **CONTINUING EDUCATION PROFESSIONAL DEVELOPMENT COURSE**





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## **Important Information about this Manual**

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

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) or 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. make 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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**Some States and many employers require the final exam to be proctored.**

**Do not solely depend on TLC's Approval list for it may be outdated.**

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

### **Responsibility**

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

*Check with your state environmental agency for more information. You are solely responsible in ensuring that you abide with your jurisdiction or agency's rules and regulations.*



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# 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**

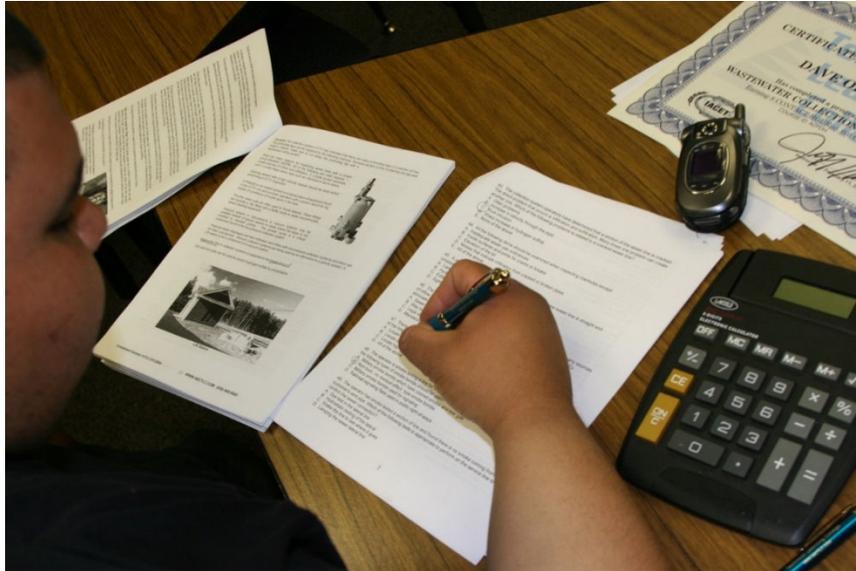
TLC's online courses combine the best of online delivery and traditional university textbooks. You can easily find the course syllabus, course content, assignments, and the post-exam (Assignment). This student-friendly course design allows you the most flexibility in choosing when and where you will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

### STORAGE FACILITIES CEU TRAINING COURSE

This short CEU course will cover water storage facilities and basic maintenance and operational concerns including the EPA lead reduction Act requirements.

#### Statement of Need

All water treatment and distribution system operators shall have a working knowledge of basics hydraulics, water quality concerns and maintenance concerns related to water storage facilities. This course will cover the lead reduction and sampling requirements of the Safe Drinking Water Act and water distribution and hydraulic principles.

#### Learning Objectives

1. Students will be able to understand, identify and explain water storage system layouts, principles and operational requirements.
2. Students will be able to understand, identify and explain various water storage reservoirs and tanks and related proper delivery and maintenance concerns of gravity fed water.
3. Students will be able to understand, identify and explain water storage and demand requirements, relating to pumps and boosters.
4. Students will be able to understand, identify and explain the purpose and concerns of operating hydropneumatic tanks.
5. Students will be able to understand, identify and explain storage related water quality issues and monitoring requirements.

***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 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

#### Instructions for Assignment

The ***Storage Facilities*** CEU training course uses a multiple choice type answer key. You can find a copy of the answer key in the front of the assignment in a 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 this manual or type out your own answer key. TLC would prefer that you type out and e-mail the final exam to TLC, but it is not required.

### **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.

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.

### **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 rear 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.

### **Disclaimer and Security Notice**

The student shall understand that it their responsibility to ensure that this CEU course is either approved or accepted in my State for CEU credit. The student shall understand and follow State laws and rules concerning distance learning courses and understand these rules change on a frequent basis and will not hold Technical Learning College responsible for any changes. The student shall understand that this type of study program deals with dangerous conditions and will not hold Technical Learning College, Technical Learning Consultants, Inc. (TLC) liable for any errors or omissions or advice contained in this CEU education training course or for any violation or injury caused by this CEU education training course material. The student shall contact TLC if they need help or assistance and double-check to ensure my registration page and assignment has been received and graded.

### **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 **Storage Facilities** 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. You will have 90 days from receipt of this manual to complete 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.*

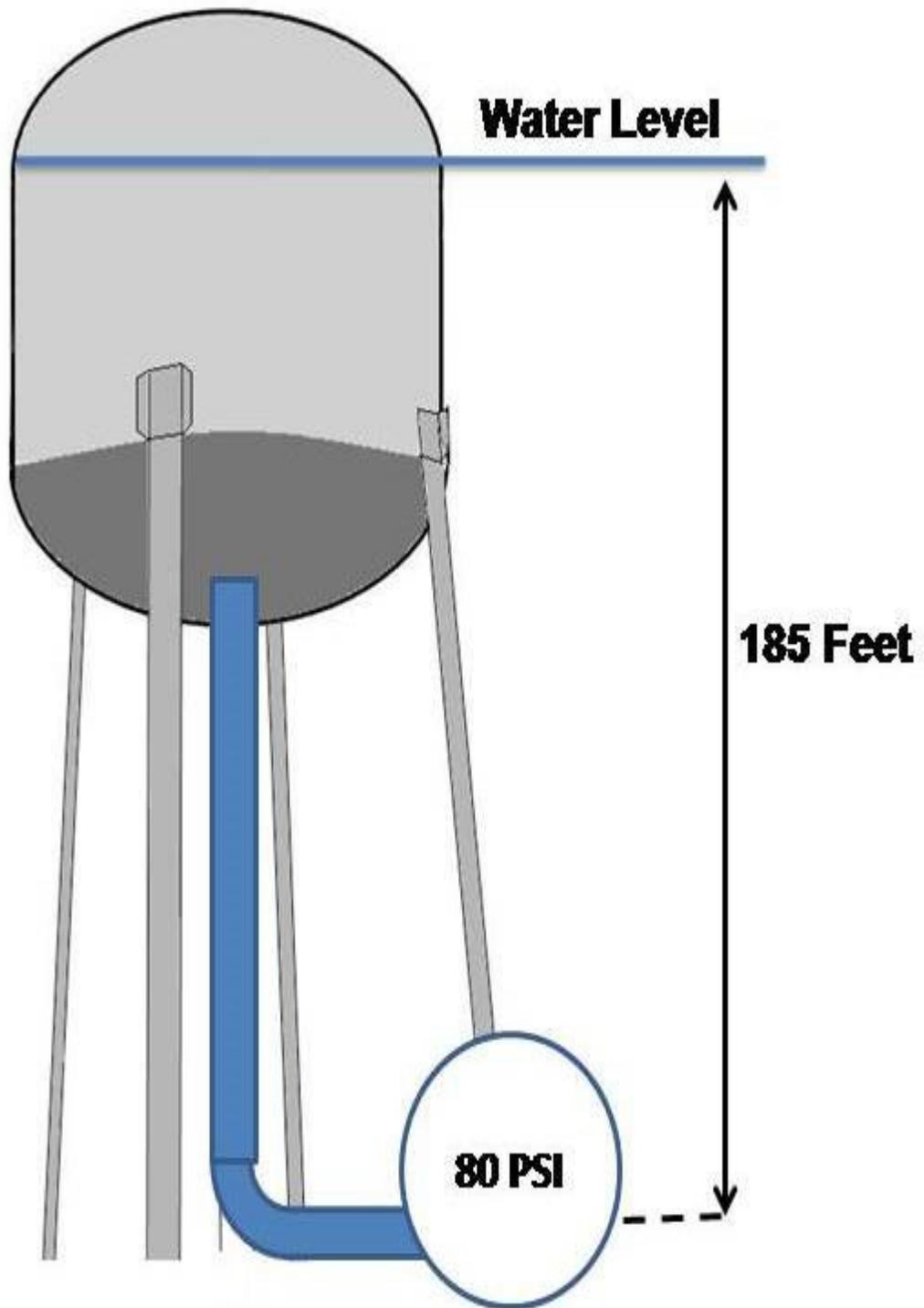
### **At the Finish of this Course...**

The student will be able to understand, identify and explain water storage system layouts, principles, operational requirements relating to various water storage reservoirs and tanks and related proper delivery and maintenance concerns of gravity fed water. The student will be able to understand, identify and explain water storage and demand requirements, relating to pumps, boosters, and concerns of operating hydropneumatic tanks. The student will be able to understand, identify and explain storage related water quality issues and monitoring requirements.



Please call TLC if you need any assistance with this course or assignment. Always check with your State agency to see if this course is accepted.

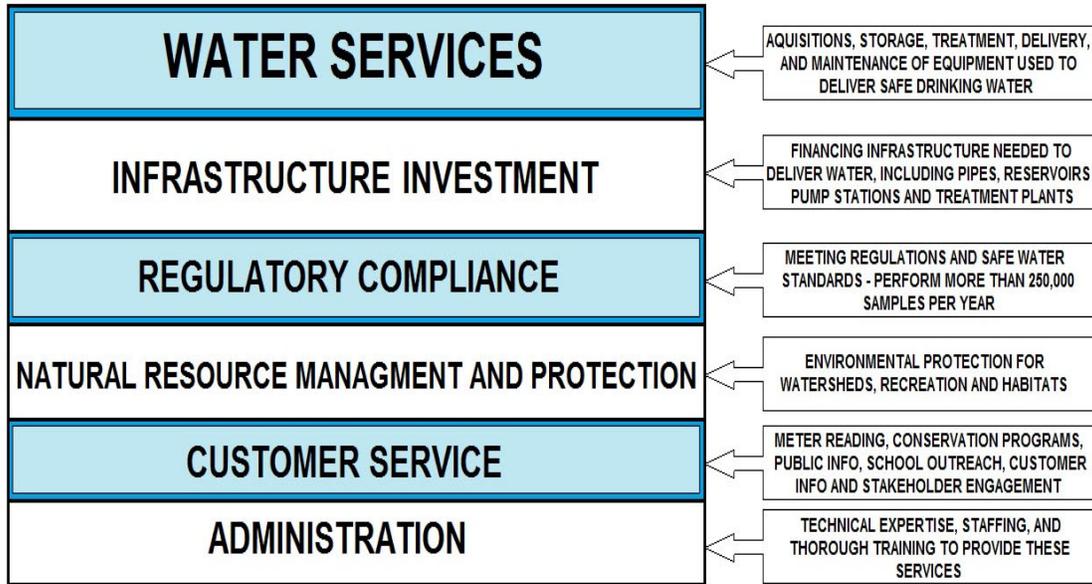
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# YOUR WATER SYSTEM



WHAT IS DONE TO BRING SAFE DRINKING WATER TO "YOU"

## **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**

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**

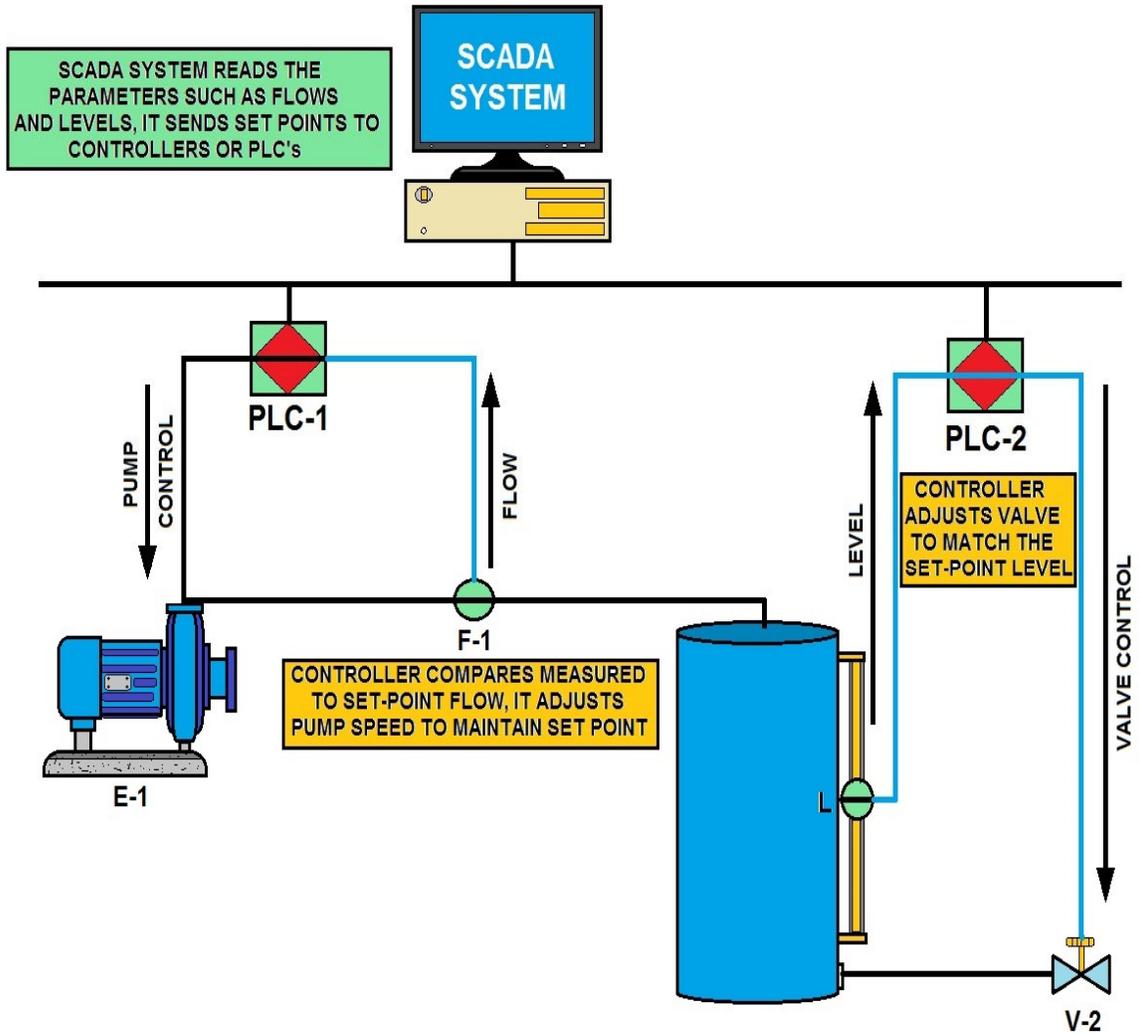
Pressure exerted by the atmosphere at any specific location. (Sea level pressure is approximately 14.7 pounds per square inch absolute, 1 bar = 14.5psi.)

### **Pressure, Gauge**

Pressure differential above or below ambient atmospheric pressure.

### **Pressure, Static**

The pressure in a fluid at rest.



## SCADA SYSTEM (SUPERVISORY CONTROL and DATA ACQUISITION)

# Water Storage Introduction



Water is placed in a closed tank or reservoir in order for disinfection to take place. The water then flows through pipes to homes and businesses in the community. Finished water storage facilities are an important component of the protective distribution system “barrier” that prevents contamination of water as it travels to the customer. Historically, finished water storage facilities have been designed to equalize water demands, reduce pressure fluctuations in the distribution system; and provide reserves for firefighting, power outages and other emergencies.

## **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.

## **Water Storage Facilities**

Water storage facilities and tanks vary in size, shape, and application. There are different types that are used in the water distribution systems, such as stand pipes, 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**
- **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, and oftentimes, 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 not be used for water storage.

The goal of the water tower or stand pipe 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**

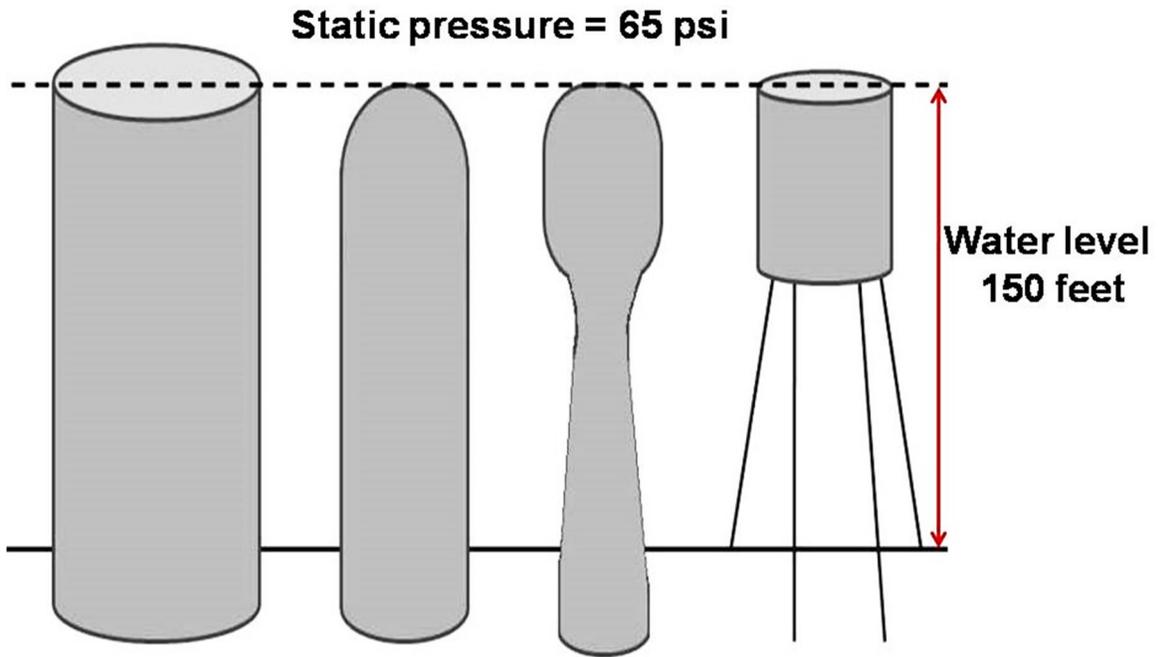
Steel reservoirs or tanks generally have lower construction and installation costs than concrete, but require more maintenance. To protect against corrosion, the exterior should be kept cleaned and painted. Interiors of steel reservoirs are commonly coated with an epoxy or enamel-type finish. Some coal-tar 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.

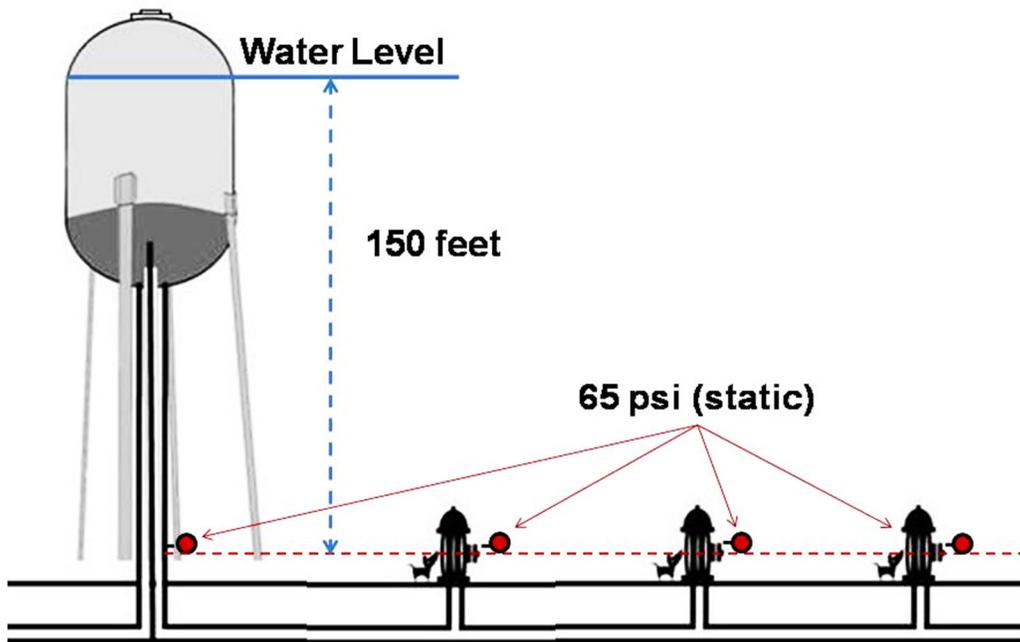
Steel tank should also have cathodic protection and be screened to keep birds and insects out. The maintenance program for reservoir tanks should call for annual draining for a complete inspection of the interior. Cleaning and disinfection prior to placing the reservoir or tank back in service is necessary.

Many storage facilities have been operated to provide adequate pressure and have been kept full to be better prepared for emergency conditions. This emphasis on hydraulic considerations in past designs has resulted in many storage facilities operating today with larger water storage capacity than is needed for non-emergency usage. Additionally, some storage facilities have been designed such that the high water level is below the hydraulic grade line of the system, making it very difficult to turn over the tank.

If the hydraulic grade line of the system drops significantly, very old water may enter the system. If tanks are kept full yet are underutilized, the stored water ages and water quality is affected.



### VARIOUS SHAPED STORAGE TANKS



### ELEVATED GRAVITY STORAGE TANK

## Categories of Finished Water Storage Facilities

The main categories of finished water storage facilities include ground storage and elevated storage. Finished water storage does not include facilities such as clearwells that are part of treatment or contact time requirements per the Surface Water Treatment Rules.

Ground storage tanks or reservoirs can be below ground, partially below ground, or constructed above ground level in the distribution system and may be accompanied by pump stations if not built at elevations providing the required system pressure by gravity.

Ground storage reservoirs can be either covered or uncovered. Covered reservoirs may have concrete, structural metal or flexible covers. The most common types of elevated storage are elevated steel tanks and standpipes. In recent years, elevated tanks supported by a single pedestal have been constructed where aesthetic considerations are an important part of the design process.

A standpipe is a tall cylindrical tank normally constructed of steel, although concrete may be used as well. The standpipe functions somewhat as a combination of ground and elevated storage.

Only the portion of the storage volume of a standpipe that provides water at or above the required system pressure is considered useful storage for pressure equalization purposes. The lower portion of the storage acts to support the useful storage and to provide a source of emergency water supply. Many standpipes were built with a common inlet and outlet.

Water quality problems in storage facilities can be classified as microbiological, chemical or physical. Excessive water age in many storage facilities is probably the most important factor related to water quality deterioration.

Long detention times, resulting in excessive water age, can be conducive to microbial growth and chemical changes.

### **The excess water age is caused by**

- 1) underutilization (i.e., water is not cycled through the facility),
- 2) short circuiting within the reservoir.

## Municipal Water Supply Systems

1. Raw water storage: Water supplies that are used to feed water to a filtration and treatment plant for purification in order to produce **finished water** that is used for domestic purposes including drinking water is classified as **raw water**. Raw water sources from streams, rivers, ponds, lakes, and even reservoirs are **not suitable** for any domestic purposes including water for cooking, bathing, and especially drinking. The one exception is individual well water that has been chlorinated and disinfected for individual household use in accordance with individual State Public Health regulations.

**Extreme caution:** Raw water or any water supply that has not been treated to Environmental Protection Agency (EPA) standards **is not** to be pumped into fire hydrants attached to a municipal water system. During the summer drought conditions of 2005 in the Middle Atlantic States, there were reports where community fire departments were pumping water from creeks and ponds into small water systems because there was no water in the reservoirs to supply the water piping system. This is considered a very dangerous situation, and such practices present serious health risks to persons using these water supplies.

Furthermore, all components of the water system are required by either State or Federal regulations to be completely disinfected along with biological testing before the water system can be placed back in service to provide treated water for human consumption.

A more positive approach to raw water supplies is to use raw water holding basins, ponds, or reservoirs as an alternative water supply source to meet unusual demand on the water system, including a major fire, situations when the main water supply is low, or any other emergency situation requiring large volumes of water such as a primary or secondary water main break.

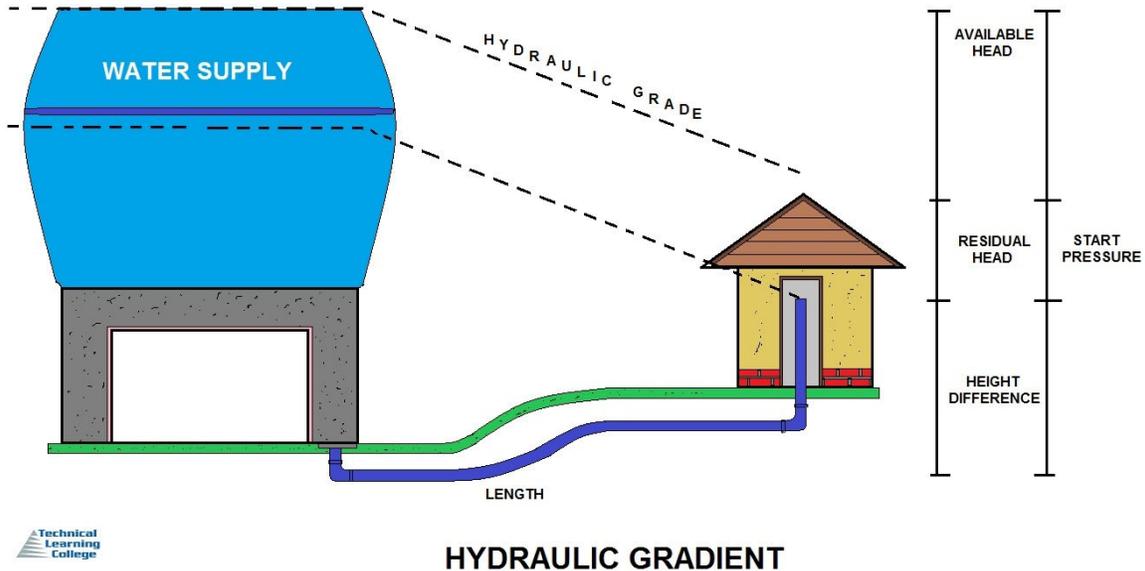
These raw water sources should be arranged so that the water flows by gravity, if possible, to the water treatment plant. If the terrain in the area of the treatment plant does not permit this height differential, then arrangements need to be made for stationary pumps or even fire department pumpers to pump water from the raw water source to the water treatment plant.

2. Finished water storage: The most common type of water storage on a municipal water system is the use of clear wells on the outboard side of water treatment plants, ground-level water-storage tanks and elevated water-storage tanks to store **finished water** that is suitable for domestic consumption. Therefore, an extremely important element in a water distribution system is **finished water storage**. Water system **storage facilities** have far-reaching effects on a given system's ability to provide adequate consumer consumption plus adequate water supplies for meeting fire-flow demand in addition to consumer consumption.

The two common finished water storage methods 1) ground-level storage, and 2) elevated storage, are presented below. Emphasis is placed on the relative merits of both methods.

## 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:

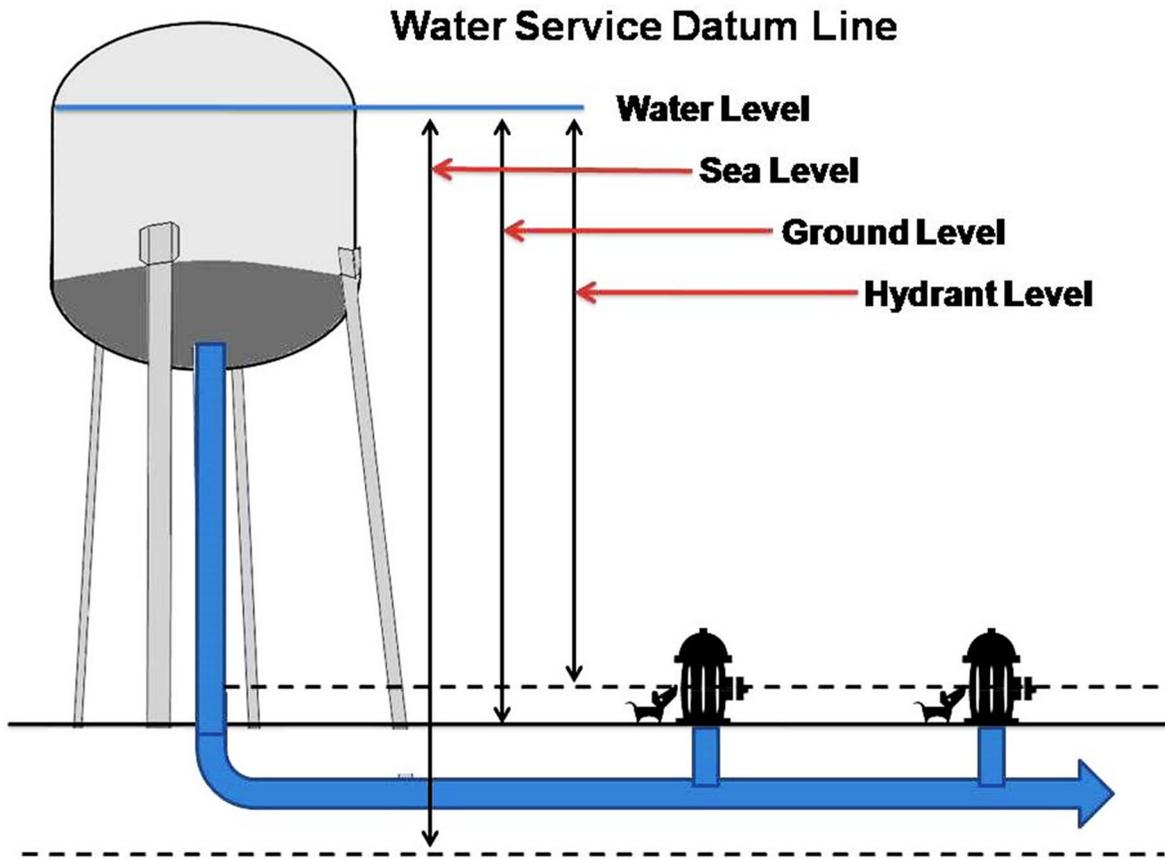
- Depressed disinfectant residual – Chlorine and chloramines undergo decay over time.
- Elevated DBP levels – The reaction between disinfectants and organic precursors occur over long periods.
- Elevated bacterial counts (i.e., heterotrophic plate count).
- Elevated nitrite/nitrate levels (nitrification) for chloraminating systems.

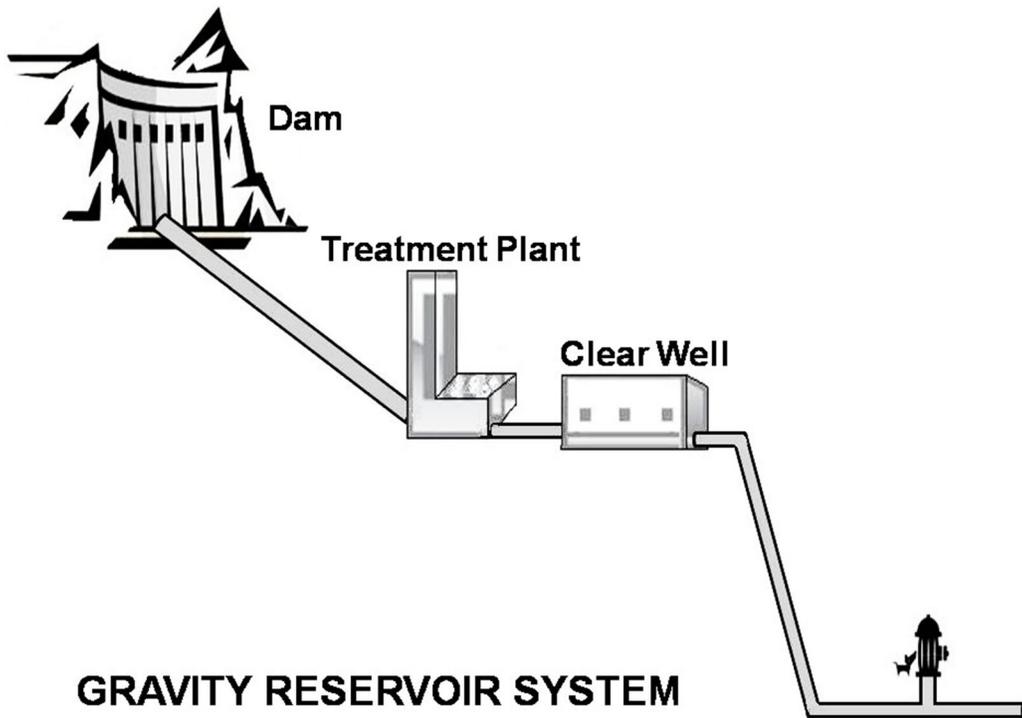
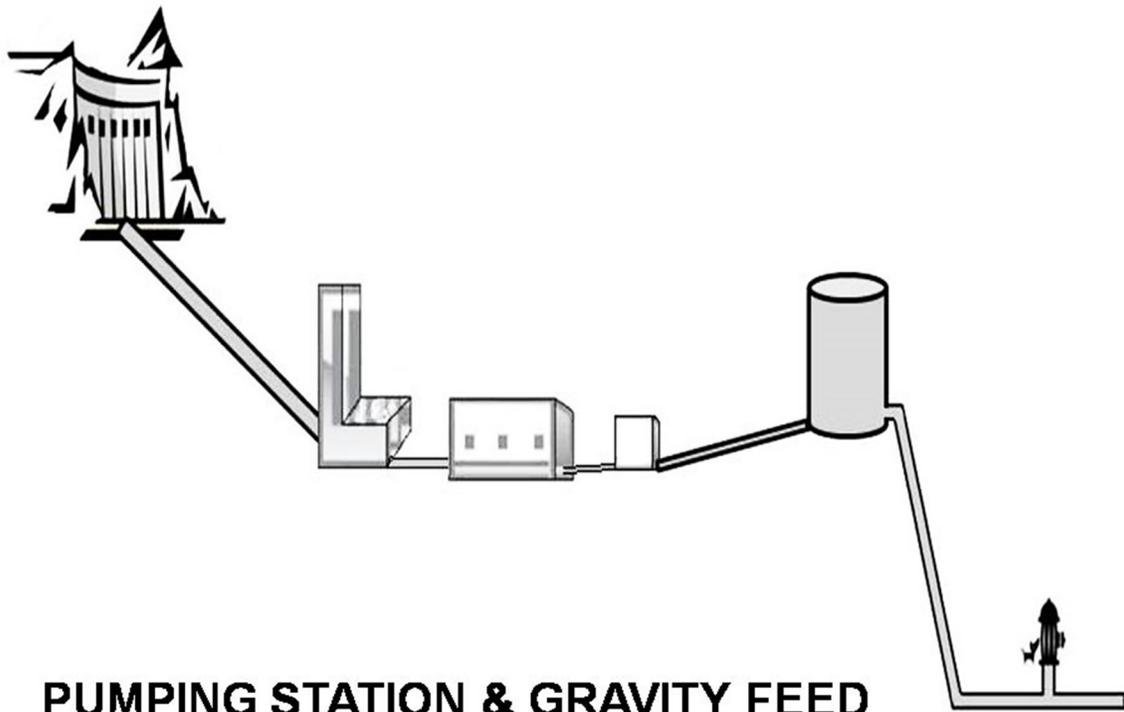


## References

*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 Ground Water and Drinking Water, Distribution System Issue Paper, Finished Water Storage Facilities*





## Storage Water Quality Problems



### **Turbidity**

Turbidity is caused by particles suspended in water. These particles scatter or reflect light rays, making the water appear cloudy. Turbidity is expressed in nephelometric turbidity units (ntu) and a reading in excess of 5 ntu is generally noticeable to water system customers.

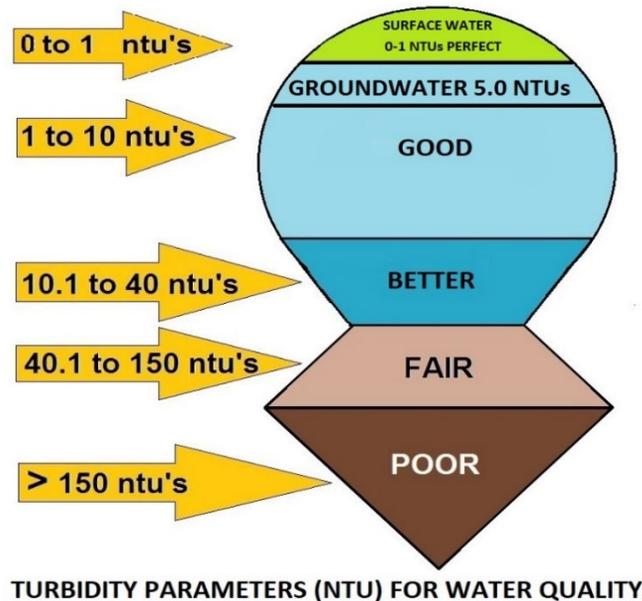
Besides the appearance being unpleasant to customers, turbidity in water is significant from a public health standpoint because suspended particles could shelter micro-organisms from the disinfectant and allow them to still be viable when they reach the customer.

EPA regulations direct that, for most water systems, the turbidity of water entering the distribution system must be equal or less than 0.5 ntu in at least 95 percent of the measurements taken each month. At no time may the turbidity exceed 5 ntu.

Turbidity changes in the distribution system can indicate developing problems. Increases in turbidity may be caused by changes in velocity or inadequate flushing following main replacement.

One physical characteristic of water is turbidity. A measure of the cloudiness of water caused by suspended particles. The cloudy appearance of water caused by the presence of tiny particles. High levels of turbidity may interfere with proper water treatment and monitoring. If high quality raw water is low in turbidity, there will be a reduction in water treatment costs. Turbidity is undesirable because it causes health hazards.

An MCL for turbidity established by the EPA because turbidity interferes with disinfection. This characteristic of water changes the most rapidly after a heavy rainfall. The following conditions may cause an inaccurate measure of turbidity; the temperature variation of a sample, a scratched or unclean sample tube in the nephelometer and selecting an incorrect wavelength of a light path.



**Surface Water System Compliance Information**  
*(Depends on Systems and Rule)*

- ▶ 0.34 NTU in 95% of samples, never to exceed 1.0 NTU spike
- ▶ Sample turbidity at each individual filter effluent
- ▶ Sample the combined filter turbidity at the clear well
- ▶ (Groundwater turbidity = 5.0 NTU)

**Turbidity Key**

- ▶ Turbidity can also be measured in ppm (parts per million) and its size is measured in microns. Turbidity can be particles in the water consisting of finely divided solids, larger than molecules, but not visible by the naked eye; ranging in size from .001 to .150mm (1 to 150 microns).
- ▶ 0.34 NTU in 95% of surface water samples, never to exceed 1.0 NTU spike

**Hardness**

Hardness is a measure of the concentration of calcium and magnesium in water. Water hardness usually comes from water contacting rock formations, such as water from wells in limestone formations. Soft ground water may occur where topsoil is thin and limestone formations are sparse or absent. Most surface water is of medium hardness.

Hard and soft water are both satisfactory for human consumption, but customers may object to very hard water because of the scale it forms in plumbing fixtures and on cooking utensils. Hardness is also a problem for some industrial and commercial users because of scale buildup in boilers and other equipment.

Water generally is considered most satisfactory for household use when the hardness is between 75 and 100 mg/L as calcium carbonate (CaCO<sub>3</sub>). Water with 300 mg/L of hardness usually is considered **hard**. Very soft water of 30 mg/L or less is found in some section of the United States. Soft water usually is quite corrosive, and may have to be treated to reduce the corrosivity.

**Iron**

Iron occurs naturally in rocks and soils and is one of the most abundant elements. It occurs in two forms. Ferrous iron (Fe<sup>2+</sup>) is in a dissolved state, and water containing ferrous iron is colorless. Ferric iron (Fe<sup>3+</sup>) has been oxidized, and water containing it is rust-colored. Water from some well sources contains significant levels of dissolved iron, which is colorless, but rapidly turns brown as air reaches the water and oxidizes the iron.

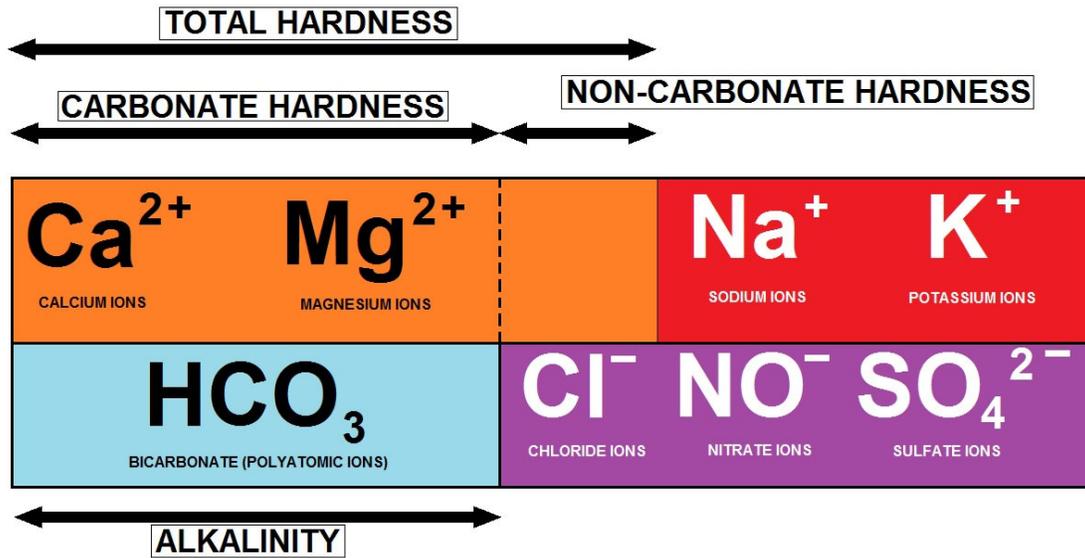
There are no known harmful effects to humans from drinking water containing iron, but NSDWR suggest a limit of 0.5 mg/L.

At high levels, the staining of plumbing fixtures and clothing becomes objectionable. Iron also provides nutrient source for some bacteria that grow in distribution systems and wells. Iron bacteria, such as *Gallionella*, cause red water, tastes and odors, clogged pipes, and pump failure.

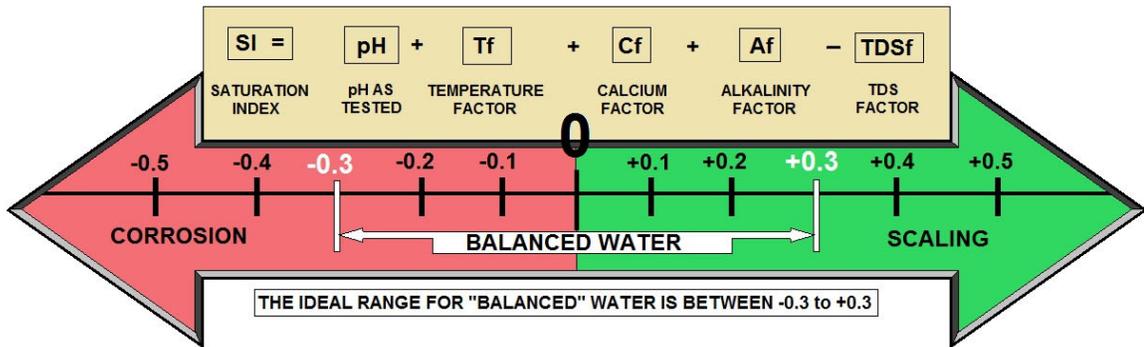
Whenever tests on water samples show increased iron concentrations between the point where water enters the distribution system and the consumer's tap, either corrosion, iron bacteria, or both are probably taking place. If the problem is caused by bacteria, flushing mains, shock chlorination, and carrying increased residual chlorine are alternatives to consider.

**Manganese**

Manganese in ground water creates problems similar to iron. It does not usually discolor the water, but will stain washed clothes and plumbing fixtures black; this is very unpopular with customers. Consumption of manganese has no known harmful effects on humans, but the NSDWR recommend a concentration not to exceed 0.05 mg/L to avoid customer complaints.



## CARBONATE HARDNESS CHART



## LANGELIER SATURATION INDEX

## Water Quality Safeguards



The **critical** safeguard for water distribution system operations are

- continuous positive pressure in the mains; 20 pounds per square inch (psi) minimum residual pressure is recommended;
- maintenance of chlorine residual;
- cross-connection control; and
- frequent testing.

Continuous positive pressure as recommended above is absolutely necessary to prevent backsiphonage and the entry of contaminants into the water system. This can be achieved primarily by maintaining an adequate water supply and storage capable of meeting peak water demands. If water demands are so great during peak demand periods that pressure declines in parts of the systems, either water use must be restricted or the water system must be upgraded to be capable of supplying more water.

System pressure also may be reduced during a main break because of the large amount of escaping water. The best safeguards against having serious pressure loss during a main break are to have adequate system storage and to be well-organized to shut down the leaking section of water main swiftly. The later involves having personnel on call at all time to respond to emergencies, knowing where all the valves are, and having a valve exercise program so that valves are sure to operate when needed.

The ultimate proof of the bacteriological safety of the water in the distribution system comes through frequent sampling. Samples collected to meet State requirements should be considered a minimum. Additional samples should be collected following construction and repair work as well as in response to customer complaints that could be the result of water system contamination. A distribution system can become contaminated from an outside source by accident or intention in the framework of the world climate today. Contamination problems need to be identified and appropriate action taken immediately after detection.

The design and evaluation of municipal water supply systems is based on both theoretical and applied hydraulics. Hydraulics is the branch of science that defines the mathematical laws of liquids at rest and in motion. This text material is confined to fundamental principles and what is generally referred to as **applied hydraulics**.

These fundamentals are essential for understanding many of the considerations involved in the design of a municipal water supply system, the periodic testing of water systems, and the proper evaluation of water systems to assess a given community's water supply with respect to providing adequate water supplies.

A municipal water supply system has the objective of providing an adequate and reliable water supply to meet the following demands:

- residential occupancy water consumption;
- commercial occupancy water consumption;
- industrial occupancy consumption;
- municipal and educational building use;
- Needed Fire Flows (NFFs) that are available from a planned location of fire hydrants throughout the municipality; and
- water for special community needs that include parks and recreation, street cleaning, decorative water fountains, sale of water to contractors through metered water from fire hydrants, etc.

The primary objective of the following material is to present the fundamental concept of hydraulics applied to municipal water systems, in order for municipal officials and fire officials to better understand the design and evaluation of public-sector water delivery systems.

Some fundamental hydraulic problems are provided to establish principles used to meet the above objective. A number of tables and charts are provided for future reference by the user of this material in actually working with a specific water supply system.

### **Reference**

*EPA Office of Water (4601M), Office of Ground Water and Drinking Water, Distribution System Issue Paper, Finished Water Storage Facilities*

*Water Supply Systems• Vol. II: Evaluation Methods October 2008 FEMA U.S. Fire Administration Harry E. Hickey, Ph.D.*

## Water Quality Monitoring



Water quality monitoring and modeling are useful tools to assess the impact storage may be having on water quality in a distribution system. Studies can be conducted to define current or potential water quality problems in storage facilities. Water quality monitoring at storage facilities is not required by any specific federal regulations.

Monitoring within a storage facility can supplement tank inlet or outlet monitoring where short-circuiting or lack of use may cause water quality to vary widely within the tank. When detailed investigation of a storage facility's impact is warranted, the ideal sampling program would capture water quality conditions throughout the storage facility, both vertically and spatially.

Kirmeyer et al. (1999) recommended the following monitoring parameters: free and total chlorine residual, temperature, HPC, total and fecal coliform bacteria, pH, turbidity, and total dissolved solids. Monitoring in storage facilities can often be a difficult task and can present a safety issue because sampling taps or access ports are often not installed during the initial construction and utility workers must generally climb the tank and collect grab samples through the roof access hatchways.

Direct monitoring may not detect all potential water quality problems. For example, tank effluent sampling can result in zero bacteria counts, but microorganisms can still be present as biofilms on tank surfaces, in tank sediment or in the water (Smith and Burlingame 1994).

According to Grayman and Kirmeyer (2002), modeling can provide information on what will happen in an existing, modified, or proposed facility under a range of operating situations. There are two primary types of models: physical scale models and mathematical models.

Physical scale models are constructed from materials such as wood or plastic. Dyes or chemicals are used to trace the movement of water through the model. In mathematical models, equations are written to simulate the behavior of water in a tank or reservoir. These models range from detailed representations of the hydraulic mixing phenomena in the facility called computational fluid dynamics (CFD) models to simplified conceptual representations of the mixing behavior called systems models. Information collected during monitoring studies can be used to calibrate and confirm both types of models.

### **Tank Inspections**

Like water quality monitoring, tank inspections provide information used to identify and evaluate current and potential water quality problems. Both interior and exterior inspections are employed to assure the tank's physical integrity, security, and high water quality. Inspection type and frequency are driven by many factors specific to each storage facility, including its type (i.e. standpipe, ground tank, etc.), vandalism potential, age, condition, cleaning program or maintenance history, water quality history, funding, staffing, and other utility criteria.

AWWA Manual M42, Steel Water Storage Tanks (1998) provides information regarding inspection during tank construction and periodic operator inspection of existing steel tanks. Specific guidance on the inspection of concrete tanks was not found in the literature. However, the former AWWA Standard D101 document may be used as a guide to inspect all appurtenances on concrete tanks.

Concrete condition assessments should be performed with guidance from the tank manufacturer. Soft, low alkalinity, low pH waters may dissolve the cementitious materials in a concrete reservoir causing a rough surface and exposing the sand and gravel.

The concern is that in extreme cases, the integrity of reinforcing bars may be compromised. Sand may collect on the bottom of the storage facility during this process. Routine inspections typically monitor the exterior of the storage facility and grounds for evidence of intrusion, vandalism, coating failures, security, and operational readiness. Based on a literature review and project survey, Kirmeyer et al. (1999) suggested that routine inspections be conducted on a daily to weekly basis. Where SCADA systems include electronic surveillance systems, alarm conditions may substitute for physical inspection.

Periodic inspections are designed to review areas of the storage facility not normally accessible from the ground and hence not evaluated by the routine inspections. These inspections usually require climbing the tank.

Periodic inspections, like routine inspections, are principally a visual inspection of tank integrity and operational readiness. Based on a literature review and project survey, Kirmeyer et al. (1999) suggested that periodic inspections be conducted every 1 to 4 months. Comprehensive inspections are performed to evaluate the current condition of storage facility components. These inspections often require the facility to be removed from service and drained unless robotic devices or divers are used.

The need for comprehensive inspections is generally recognized by the water industry. AWWA Manual M42 (1998) recommends that tanks be drained and inspected at least once every 3 years or as required by state regulatory agencies. Most states do not recommend inspection frequencies thereby leaving it to the discretion of the utility.

Uncovered finished water reservoirs have unique problems. Consequently, water utilities have ceased constructing such facilities. As noted previously, the IESWTR prohibits construction of new uncovered finished water reservoirs in the U.S. Under the LT2ESWTR, existing uncovered finished water reservoirs will be managed in accordance with a state approved plan, if the facility is not covered subsequent to the rule's implementation.

Flexible membrane covers are one means of enclosing uncovered reservoirs and these types of facilities also require specific routine, periodic, and comprehensive inspections to ensure the cover's integrity.

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## Storage Tank Maintenance Activities

Storage facility maintenance activities include cleaning, painting, and repair to structures to maintain serviceability. Based on a utility survey conducted by Kirmeyer et al. (1999), it appears that most utilities that have regular tank cleaning programs employ a cleaning interval of 2 to 5 years. This survey also showed that most tanks are painted (exterior coating) on an interval of 10 to 15 years.

The following existing standards are relevant to disinfection procedures and approval of coatings:

- ANSI/NSF Standard 61, and
- Ten States Standards (Great Lakes...1997)

### AWWA Manuals

§ AWWA M25 – Flexible-Membrane Covers and Linings for Potable-Water Reservoirs (1996)

§ AWWA M42 – Steel Water-Storage Tanks (1998)

### AWWA Standards

§ AWWA Standard C652-92 Disinfection of Storage Facilities (AWWA 1992) provides guidance for disinfection when returning a storage facility to service.

§ AWWA Standard D102 recognizes general types of interior coating systems including:

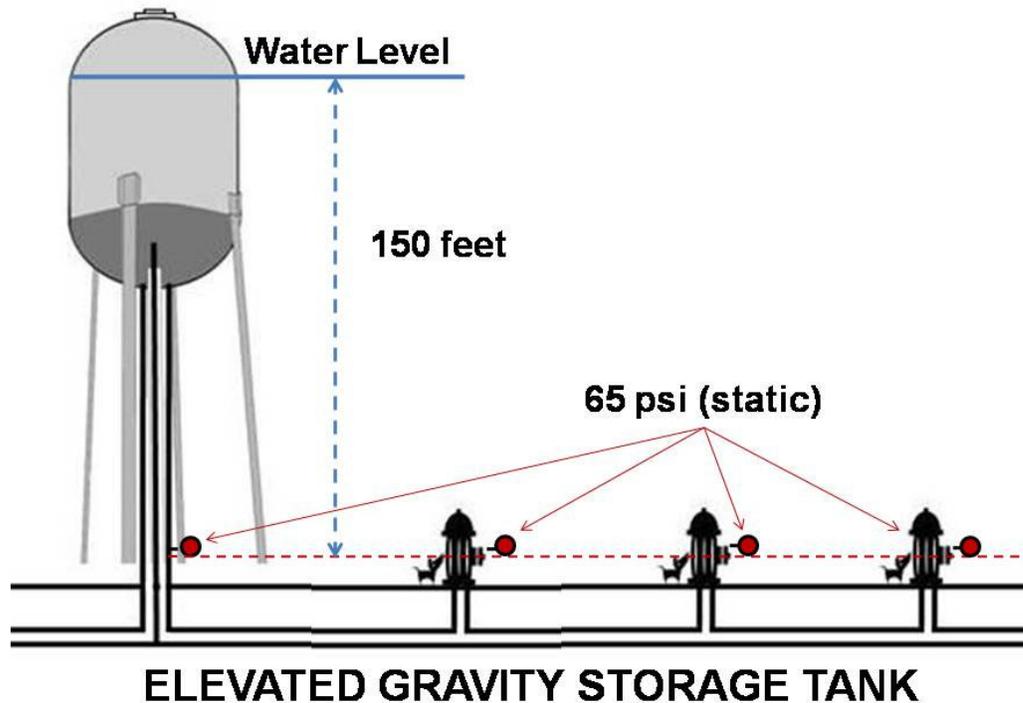
- ✓ Epoxy,
- ✓ Vinyl,
- ✓ Enamel, and
- ✓ Coal-Tar

Each of the coating systems listed under AWWA Standard D102 has provided satisfactory service when correctly applied (AWWA 1998). Other coating systems have been successfully used including chlorinated rubber, plural-component urethanes, and metalizing with anodic material (AWWA 1998). Epoxy and solvent-less polyurethanes interior coating systems are most likely to meet strict environmental guidelines and AWWA and NSF Standards (Jacobs 2000).

Spray metalizing using zinc, aluminum or a combination of both is also a promising alternative. Coal tar coating systems are not common in eastern U.S. as the coatings installed in the 1950s and 1960s have mostly been replaced or the tanks themselves have been removed from service. Coal tar is still in use in California where it is often applied over an epoxy system on tank floors (Lund, 2002).

Kirmeyer et al. (1999) recommended that covered facilities be cleaned every three to five years, or more often based on inspections and water quality monitoring, and that uncovered storage facilities be cleaned once or twice per year. Commercial diving contractors can be used to clean and inspect storage facilities that cannot be removed from service. AWWA Standard C652-92 provides guidelines for disinfection of all equipment used to clean storage facilities.

## Water Use or Demand



Water system demand 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 150 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).

## Disinfection of Water Storage Reservoirs

The distribution system is the piping that delivers water to service connections.

There are several types of piping material that can be used.

Each has its advantages and disadvantages.

The pipe material must have adequate strength to withstand external loads from backfill, traffic and earth movement, high burst strength to withstand high water pressure, smooth interior surfaces, corrosion resistant exteriors and tight joints.

A number of linings are also used to extend the life of the pipe and improve flow characteristics:

Reservoir size (gals.) Gallons of 5% bleach to add to achieve a 25ppm chlorine dose

<b>1,000</b>	<b>.5</b>
<b>2,000</b>	<b>1</b>
<b>3,000</b>	<b>1.5</b>
<b>4,000</b>	<b>2</b>
<b>5,000</b>	<b>2.5</b>
<b>10,000</b>	<b>5</b>
<b>20,000</b>	<b>10</b>
<b>30,000</b>	<b>15</b>
<b>40,000</b>	<b>20</b>
<b>50,000</b>	<b>25</b>

Reservoir size (gals.) Amount (in pounds of dry weight) of 65% strength dry chlorine powder (HTH) to add to achieve a 25ppm dose.

<b>10,000</b>	<b>3.5</b>
<b>20,000</b>	<b>6.5</b>
<b>30,000</b>	<b>10</b>
<b>40,000</b>	<b>13</b>
<b>50,000</b>	<b>16</b>
<b>100,000</b>	<b>32</b>
<b>200,000</b>	<b>64</b>
<b>300,000</b>	<b>100</b>
<b>400,000</b>	<b>130</b>
<b>500,000</b>	<b>160</b>

### Reference

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## Storage Pumping For Distribution

**There are two types of water supply distribution storage as defined above:**

1. Ground-level storage.
2. Elevated storage.

There also are two types of pumping supply systems. Both of the concepts are expanded upon below. One is a direct pumping system, in which the instantaneous system demand is met by pumping with no elevated storage provided. The second type is an indirect system in which the pumping station lifts water to a reservoir or elevated storage tank, which **floats** on the water system, based on demand, and provides system pressure by the gravity method.

### **1. Direct pumping.**

The direct pumping system is considered obsolete today, although there are some systems of this type still in existence. Variable-speed pumping units operated off of direct system pressure are also in use in some communities. Hydropneumatic tanks at the pumping station provide some storage capability.

These tanks permit the pumping station pumps to start and stop, based on a variable system pressure preset by controls operating off of the storage tank.

### **2. Indirect pumping.**

In an indirect system, the pumping station is not associated with the demands of the major load center. It is operated from the water level difference in the reservoir or elevated storage tank, enabling the prescribed water level in the tank to be maintained. The majority of systems have an elevated storage tank or a reservoir on high ground floating on the water system. This arrangement permits the pumping station to operate at a uniform rate, with the storage either making up or absorbing the difference between station discharge and system demand.

### **Supply Works**

A water system supply works evaluation examines the amount of potable water that can be delivered to the distribution system piping, often called the water mains. This evaluation considers a number of factors that affect the supply capacity:

- minimum storage of water;
- municipal water supply pumps;
- water filters and treatment facilities to provide potable water; and
- emergency water supplies.

Two special topics, Water System Supplies and Fire Department Supplies also are evaluated here. These topics are of importance to all communities, especially those that have relatively poor water delivery capability or cities that have areas where the available water supply does not meet NFF.

Furthermore, these two topics are most important for fire protection to areas that are beyond 1,000 feet of a recognized fire hydrant (i.e., a fire hydrant that delivers a minimum of 250 gpm for a 2-hour duration).

## **Evaluation of Municipal Water Storage**

Two variations of distribution storage design affect the operation and reliability of a water system's fire suppression capabilities. These two variations involve placement of the storage between the supply point and the major load center or beyond the major load center.

A numerical analysis of the following storage designs is presented to provide comparisons and contrasting approaches to the issue of not providing water storage or providing water storage in one of two different design approaches:

- System A: a pumping station to the major center of demand on the water system (load) with **no** elevated storage tank;
- System B: a pumping station to the major center of demand with an elevated storage tank between the supply and the demand point; and
- System C: a pumping station to the major center of water demand with an elevated storage tank beyond the demand point.

### **1. System criteria.**

- a. Normal minimum working pressure in the distribution system should be approximately 50 pounds per square inch (psi) and not less than 35 psi during a maximum hour. A normal working pressure in most systems will vary between 50 to 56 psi.
- b. Systems must be designed to maintain a minimum pressure of 20 psi at ground level at all points in the water distribution system under fire flow conditions.
- c. The maximum daily demand is considered to be 1.5 times the average daily demand.
- d. The maximum hourly demand is considered to be 2.25 times the average daily demand.

### **Reference**

*EPA Office of Water (4601M), Office of Ground Water and Drinking Water, Distribution System Issue Paper, Finished Water Storage Facilities*

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## Fire Water Main and Storage Capacity

The following elements comprise a water distribution system used to supply water to commerce, industry, residences, and fire hydrants:

- primary distribution pipe heading from the supply works;
- secondary feeder pipe looping around the major sections of the city
- distribution pipe laid along individual streets that should interconnect with the secondary feeders; and
- distribution pipe laid along individual streets.

The flow capability, or hydraulic characteristic, of water mains is used to determine the amount of water available at fire hydrants located near NFF sites. Fire-flow tests are conducted on one, or a set, of fire hydrants to measure the flow at a 20 psi residual pressure. These measured flows can be compared to NFFs at the same locations. Water tests need to be conducted and recorded for each NFF risk site.

### **The *Grading Schedule* adds the following instruction:**

If tests are made on two or more systems or service levels at the same location, credit will be given for the sum of the test results on each system, or service, up to the limit of the supply, for the flow duration.

The concept of available fire flow for **different** durations will be covered in the following review.

### **Evaluating Fire Hydrant Distribution**

The *Grading Schedule* provides the following information (that is not directly quoted): A review is conducted at each fire hydrant within 1,000 feet of a representative test site location (i.e., fire risk) measured as fire hose can be laid by fire apparatus in order to satisfy the determined NFF.

Proximity of fire hydrant distribution to NFF sites or fire-risk sites is the third factor in determining water system capability. Credit for fire hydrants is expressed in gpm, based on measured distance from the building site as established above. The flow and distance relationship is as follows:

#### **Credit Up To: Distance From the Risk Site**

- 1,000 gpm Within 300 ft of site location
- 670 gpm Within 301 ft to 600 ft of site location
- 250 gpm Within 601 ft to 1,000 ft of site location

The maximum credit for a fire hydrant is to be limited by the number and size of the outlets as follows:

#### **Hydrant Outlets Maximum Credit**

- At least one pumper outlet 1,000 gpm
- Two or more hose outlets 750 gpm
- One hose outlet only 500 gpm

### **Flow Test Objectives**

Fire hydrant flow tests conducted on public water supply systems are done for several reasons:

- 1) to determine the rate at which water is available at specific locations within a given distribution system;
- 2) to use flow-test data between two fire hydrants on the same water main to determine a pipe coefficient or to determine if control valves are completely open;
- 3) to determine water availability at the end of an existing pipeline for the determination of pipeline extensions;
- 4) for determining the need for booster pump applications;
- 5) to verify or calibrate the accuracy of water distribution system models; and
- 6) to determine a water flow and pressure profile where the water system supplies an automatic sprinkler system. The flow-test data may be used for the evaluation of new developments that would be supplied by the water system and for evaluating tradeoffs for providing water supplies for public fire protection and/or private fire protection in the form of automatic sprinkler systems.

Of particular interest to fire departments and insurance companies is the rate and quantity at which water is available to concentrated high-value areas, such as shopping centers, industrial parks, high-rise high-tech buildings, institutional buildings, and residential areas. Also see National Fire Protection Association (NFPA) 25, *Standard for Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*, which outlines testing requirements for private fire hydrants.

Fire hydrant flow tests should not be attempted until all the operational characteristics of a water system are known. Results may differ substantially, depending on the operation of pumping equipment, water levels in the system's storage facilities, rates of consumption, and points of demand on the water system. Even though it is possible to conduct accurate tests within acceptable tolerances, often the results obtained will vary from day to day, and even at different periods during the same day, because of the many variables involved.

### **Basic Hydraulic Concepts**

Persons involved in water supply testing and flow testing from fire hydrants need to understand some of the fundamentals of water as a fluid flowing through pipe and flowing out of orifices such as an outlet on a fire hydrant.

The Hazen-Williams Formula for evaluating water flow through pipes is the most practical and usable formula for analyzing water supply systems in relation to providing effective water supplies for fire protection. Many standards published by the NFPA, including those on sprinklers, water spray systems, and suburban and rural water supplies, make direct reference to the Hazen-Williams Formula for pipe configuration calculations.

It is the formula of choice for water system operators and field engineers to measure pressure loss in pipe sections and to verify the “c” value or the coefficient of roughness on the interior of pipe walls which signals a reduction in the actual pipe diameter.

The **Hazen-Williams Formula** is used widely for pipe flow problems involving municipal water supply system evaluations and sprinkler system piping design layout and evaluation. This is an empirical formula that evolved for water test work over a period of 30 years and is considered to be valid today for water distribution system analysis. The formula is presented as follows:

$$P=4.52xQ^{1.85}/c^{1.85}xd^{4.87}$$

Where:

P=pressure loss in psi per foot of pipe, often referred to as friction loss.

Q=flow of water in U.S. gallons of water per minute expressed as gpm.

c=roughness coefficient to be used with this formula; see further explanation below.

d=the actual internal diameter of the pipe; for practical hydraulics the published diameter of the pipe is used, not the actual manufacturers’ diameter. (A given brand of 6-inch pipe has an actual internal diameter of 5.871, which is indistinguishable from field hydraulic problems.)

NOTE: on a special understanding the correct use of this formula: If the constant for the pipe which is now an acceptable constant for all pipe from the perspective of practical hydraulics is canceled out, and the coefficient of roughness (c) is canceled out, and the diameter of the pipe being tested remains constant (i.e., all 8-inch pipe), it too can be canceled out. The remaining equation now reads

psi loss varies as  $Q^{1.85}$

This concept is very important because it permit preparing Log graphs that are based on this equation. This is useful for plotting flow data to show the relationship between flow and pressure loss through pipelines without doing a lot of mathematical calculations.

### **Cautions To Be Observed When Field Testing**

Opening a fire hydrant rapidly can cause a negative pressure fluctuation. Therefore, fire hydrants should be opened slowly until fully opened. Closing the hydrants is more critical, and it must be done very slowly until after the flow is diminished to about 20 percent of the full flow. Closing a hydrant rapidly causes a pressure surge, or water hammer; this could cause weakened water mains to **fail**.

Fire hydrants should be opened and closed one at a time to minimize the effect on the water distribution system. Dry-barrel hydrants must be opened fully because the drain valve mechanism operates with the main valve. A partially opened fire hydrant **could** force water thorough the drain outlets under pressure, eroding the thrust block support from behind the fire hydrant.

After the test, the hydrant barrel should be drained before tightening the outlet-nozzle cap; a tight outlet-nozzle cap could prevent proper drainage and possibly cause ice blockage in either the upper or lower barrels.

Gauge measurements should be taken only when the water is running clear, because sediment could damage the instruments.

### **Summary**

This topic is about conducting evaluations of municipal water systems by conducting water supply tests at regular intervals; semiannually is recommended. Most important is the concept of preparing a *Water Flow Test Summary Sheet* for each test location, along with the information discussed above. These sheets are very important for monitoring the municipal water system at specific locations over time. When flow curves at the same location over succeeding tests do not match, there is a need to know why they do not match and identified problems need immediate attention.

Responding fire companies to specific fire risks need to have current information about water supplies. Therefore, all first-due fire companies should have a set of flow test sheets to make informed decisions on fire suppression tactics. This type of evaluation should be part of any cost reduction program.

### **Reference**

*EPA Office of Water (4601M), Office of Ground Water and Drinking Water, Distribution System Issue Paper, Finished Water Storage Facilities*

*Water Supply Systems• Vol. II: Evaluation Methods October 2008 FEMA U.S. Fire Administration Harry E. Hickey, Ph.D.*

## 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.



Pressure Solenoid

### **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 are 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 trouble-shooting 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.

## Slam, Surge and Water Hammer

**When a valve is closed *instantaneously* there is a corresponding *instantaneous* pressure rise, causing a water hammer.**

Water hammer (or, more generally, fluid hammer) is a pressure surge or wave caused by the kinetic energy of a fluid in motion when it is forced to stop or change direction suddenly. It depends on the fluid compressibility where there are sudden changes in pressure. For example, if a valve is closed suddenly at the end of a pipeline system a water hammer wave propagates in the pipe. Moving water in a pipe has kinetic energy proportional to the mass of the water in a given volume times the square of the velocity of the water.

### **The Effects of Water Hammer and Pulsations**

Quick closing valves, positive displacement pumps, and vertical pipe runs can create damaging pressure spikes, leading to blown diaphragms, seals and gaskets, and also destroyed meters and gauges. Liquid, for all practical purposes, is not compressible; any energy that is applied to it is instantly transmitted. This energy becomes dynamic in nature when a force such as a quick closing valve or a pump applies velocity to the fluid.

### **Surge (Water Hammer)**

Surge (or water hammer, as it is commonly known) is the result of a sudden change in liquid velocity. Water hammer usually occurs when a transfer system is quickly started, stopped or is forced to make a rapid change in direction. Any of these events can lead to catastrophic system component failure. Without question, the primary cause of water hammer in process applications is the quick closing valve, whether manual or automatic. A valve closing in 1.5 sec. or less depending upon valve size and system conditions causes an abrupt stoppage of flow. The pressure spike (acoustic wave) created at rapid valve closure can be high as five (5) times the system working pressure.

For this reason, most pipe-sizing charts recommend keeping the flow velocity at or below 5 ft/s (1.5 m/s). If the pipe is suddenly closed at the outlet (downstream), the mass of water before the closure is still moving forward with some velocity, building up a high pressure and shock waves. In domestic plumbing this is experienced as a loud bang resembling a hammering noise. Water hammer can cause pipelines to break or even explode if the pressure is high enough.

Air traps or stand pipes (open at the top) are sometimes added as dampers to water systems to provide a cushion to absorb the force of moving water in order to prevent damage to the system. (At some hydroelectric generating stations, what appears to be a water tower is actually one of these devices.) The water hammer principle can be used to create a simple water pump called a hydraulic ram.

On the other hand, when a valve in a pipe is closed, the water downstream of the valve will attempt to continue flowing, creating a vacuum that may cause the pipe to collapse or implode. This problem can be particularly acute if the pipe is on a downhill slope. To prevent this, air and vacuum relief valves, or air vents, are installed just downstream of the valve to allow air to enter the line and prevent this vacuum from occurring.

Unrestricted, this pressure spike or wave will rapidly accelerate to the speed of sound in liquid, which can exceed 4000 ft/sec. It is possible to estimate the pressure increase by the following formula.

**Water Hammer Formula:  $P = (0.070) (V) (L) / t + P1$**

Where P = Increase in pressure  
P1 = Inlet Pressure  
V = Flow velocity in ft/sec  
t = Time in sec.(Valve closing time)  
L = Upstream Pipe Length in feet

Here's an example of pressure hammer when closing an EASMT solenoid valve, with a 50 ft long upstream pipe connection:

L = 50 ft  
V = 5.0 ft / sec( recommended velocity for PVC piping design)  
t = 40 ms (solenoid valve closing time is approx. 40-50 ms)  
P1 = 50 psi inlet pressure

therefore,  $P = 0.07 \times 5 \times 50 / 0.040 + P1$   
or  $P = 437.5 \text{ psi} + P1$

Total Pressure =  $437.5 + 50 = 487.5 \text{ psi}$

### **Pulsation**

Pulsation generally occurs when a liquid's motive force is generated by reciprocating or peristaltic positive displacement pumps. It is most commonly caused by the acceleration and deceleration of the pumped fluid. This uncontrolled energy appears as pressure spikes. Vibration is the visible example of pulsation and is the culprit that usually leads the way to component failure. Unlike centrifugal pumps (which produce normally non-damaging high-frequency but low-amplitude pulses), the amplitude is the problem because it's the pressure spike.

The peak, instantaneous pressure required to accelerate the liquid in the pipe line can be greater than ten (10) times the steady state flow pressure produced by a centrifugal pump. Damage to seals gauges, diaphragms, valves and joints in piping result from the pressure spikes created by the pulsating flow.

### **Remedy**

Suggest that you install a pulsation dampener or surge tank. Dampeners provide the most cost efficient and effective choice to prevent the damaging effects of pulsation. A surge suppressor is in design essentially the same as pulsation dampener. The difference primarily lies in sizing and pressurizing.

The most current pulsation dampener design is the hydro-pneumatic dampener, consisting of a pressure vessel containing a compressed gas, generally air or Nitrogen separated from the process liquid by a bladder or diaphragm.

## Pressure and Valve Actuators and Control Devices

Directional control valves route the fluid to the desired actuator. They usually consist of a spool inside a cast iron or steel housing. The spool slides to different positions in the housing, and intersecting grooves and channels route the fluid based on the spool's position.

The spool has a central (neutral) position maintained with springs; in this position the supply fluid is blocked, or returned to tank. Sliding the spool to one side routes the hydraulic fluid to an actuator and provides a return path from the actuator to the tank. When the spool is moved to the opposite direction the supply and return paths are switched. When the spool is allowed to return to the neutral (center) position the actuator fluid paths are blocked, locking it in position.

Directional control valves are usually designed to be stackable, with one valve for each hydraulic cylinder, and one fluid input supplying all the valves in the stack.

Tolerances are very tight in order to handle the high pressure and avoid leaking, spools typically have a clearance with the housing of less than a thousandth of an inch. The valve block will be mounted to the machine's frame with a three point pattern to avoid distorting the valve block and jamming the valve's sensitive components.

The spool position may be actuated by mechanical levers, hydraulic pilot pressure, or solenoids which push the spool left or right. A seal allows part of the spool to protrude outside the housing, where it is accessible to the actuator.

The main valve block is usually a stack of off the shelf directional control valves chosen by flow capacity and performance. Some valves are designed to be proportional (flow rate proportional to valve position), while others may be simply on-off. The control valve is one of the most expensive and sensitive parts of a hydraulic circuit.

Pressure reducing valves reduce the supply pressure as needed for various circuits. Pressure relief valves are used in several places in hydraulic machinery: on the return circuit to maintain a small amount of pressure for brakes, pilot lines, etc.; on hydraulic cylinders, to prevent overloading and hydraulic line/seal rupture; on the hydraulic reservoir, to maintain a small positive pressure which excludes moisture and contamination.

Sequence valves control the sequence of hydraulic circuits; to insure that one hydraulic cylinder is fully extended before another starts its stroke, for example. Shuttle valves provide a logical function.

Check valves are one way valves, allowing an accumulator to charge and maintain its pressure after the machine is turned off, for example.

Pilot controlled Check valves are one way valves that can be opened (for both directions) by a foreign pressure signal. For instance, if the load should not be held by the check valve anymore. Often the foreign pressure comes from the other pipe that is connected to the motor or cylinder.

### Counterbalance Valves

A counterbalance valve is, in fact, a special type of pilot controlled check valve. Whereas the check valve is open or closed, the counterbalance valve acts a bit like a pilot controlled flow control.

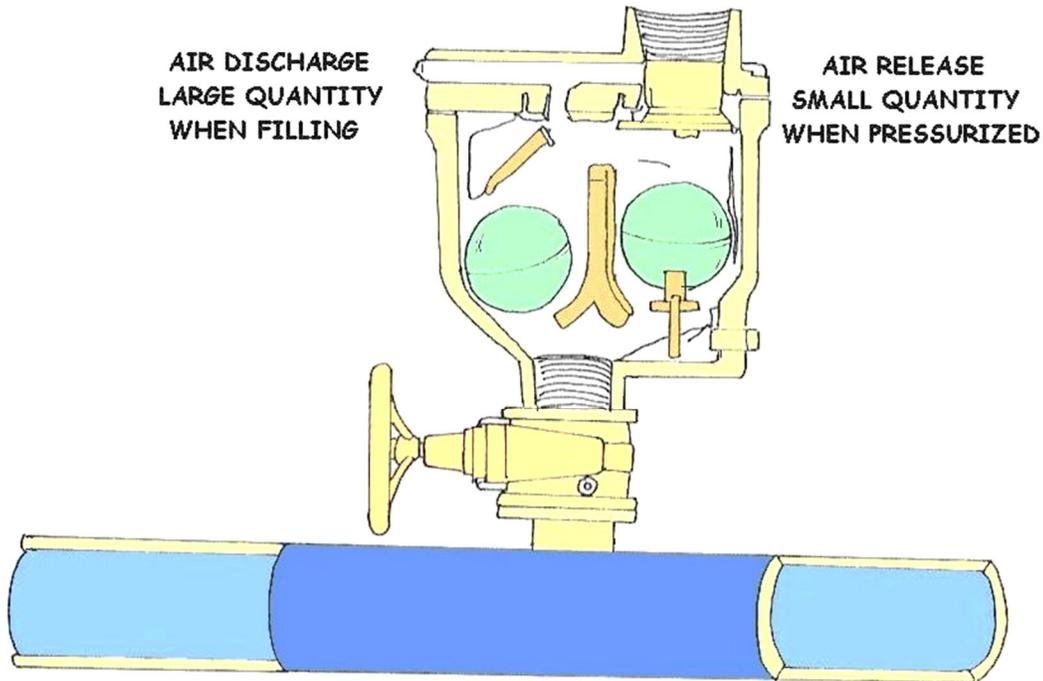
Cartridge valves are in fact the inner part of a check valve; they are off the shelf components with a standardized envelope, making them easy to populate a proprietary valve block. They are available in many configurations: on/off, proportional, pressure relief, etc. They generally screw into a valve block and are electrically controlled to provide logic and automated functions.

Hydraulic fuses are in-line safety devices designed to automatically seal off a hydraulic line if pressure becomes too low, or safely vent fluid if pressure becomes too high.

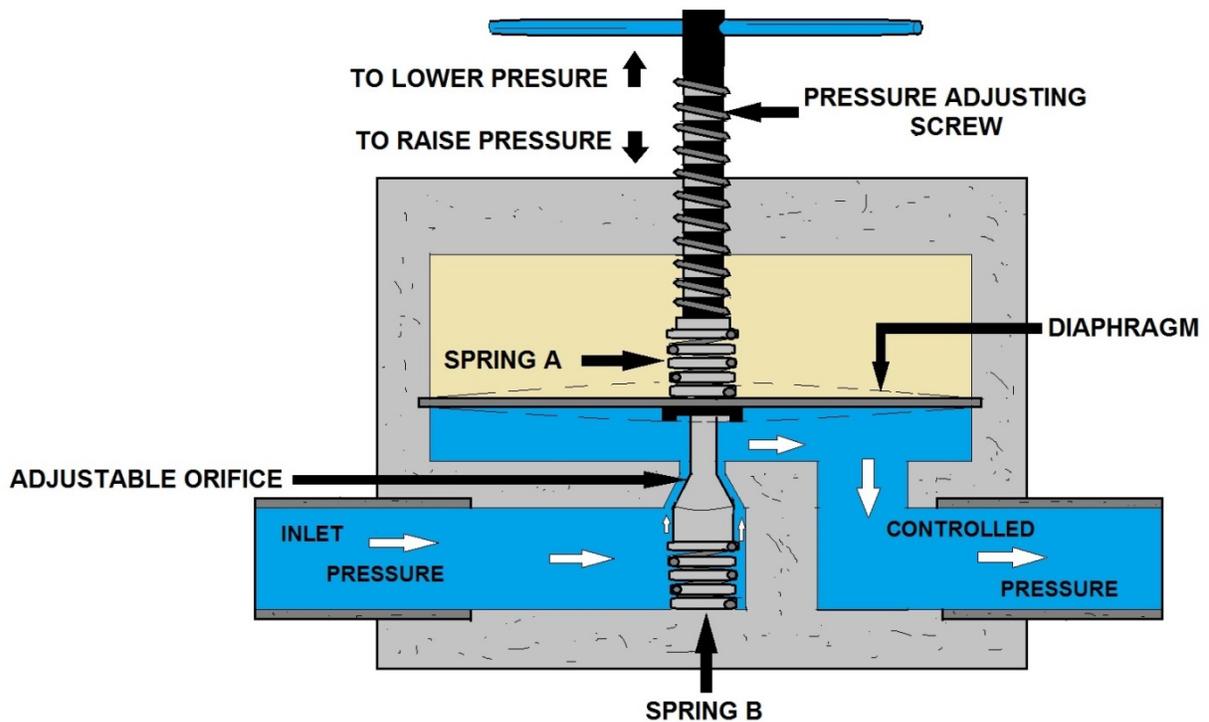
### Auxiliary Valves

Complex hydraulic systems will usually have auxiliary valve blocks to handle various duties unseen to the operator, such as accumulator charging, cooling fan operation, air conditioning power, etc... They are usually custom valves designed for a particular machine, and may consist of a metal block drilled with ports and channels. Cartridge valves are threaded into the ports and may be electrically controlled by switches or a microprocessor to route fluid power as needed.

## COMBINATION AIR VALVE



## Pressure Reducing Valves - Rotary Valve



### PRESSURE -REGULATING VALVE EXAMPLE

#### Pressure Relief Valve

Pressure relief valves are used to release excess pressure that may develop as a result of a sudden change in the velocity of the water flowing in the pipe.

PRVs assist in a variety of functions, from keeping system pressures safely below a desired upper limit to maintaining a set pressure in part of a circuit. Types include relief, reducing, sequence, counterbalance, and unloading. All of these are normally closed valves, except for reducing valves, which are normally open. For most of these valves, a restriction is necessary to produce the required pressure control. One exception is the externally piloted unloading valve, which depends on an external signal for its actuation.

The most practical components for maintaining secondary, lower pressure in a hydraulic system are pressure-reducing valves. Pressure-reducing valves are normally open, 2-way valves that close when subjected to sufficient downstream pressure. There are two types: direct acting and pilot operated.

**Direct acting** - A pressure-reducing valve limits the maximum pressure available in the secondary circuit regardless of pressure changes in the main circuit, as long as the work load generates no back flow into the reducing valve port, in which case the valve will close.

The pressure-sensing signal comes from the downstream side (secondary circuit). This valve, in effect, operates in reverse fashion from a relief valve (which senses pressure from the inlet and is normally closed).

As pressure rises in the secondary circuit, hydraulic force acts on area A of the valve, closing it partly. Spring force opposes the hydraulic force, so that only enough oil flows past the valve to supply the secondary circuit at the desired pressure. The spring setting is adjustable.

When outlet pressure reaches that of the valve setting, the valve closes except for a small quantity of oil that bleeds from the low-pressure side of the valve, usually through an orifice in the spool, through the spring chamber, to the reservoir.

Should the valve close fully, leakage past the spool could cause pressure build-up in the secondary circuit. To avoid this, a bleed passage to the reservoir keeps it slightly open, preventing a rise in downstream pressure above the valve setting. The drain passage returns leakage flow to reservoir. (Valves with built-in relieving capability also are available to eliminate the need for this orifice.)

### **Constant and Fixed Pressure Reduction**

Constant-pressure-reducing valves supply a preset pressure, regardless of main circuit pressure, as long as pressure in the main circuit is higher than that in the secondary. These valves balance secondary-circuit pressure against the force exerted by an adjustable spring which tries to open the valve.

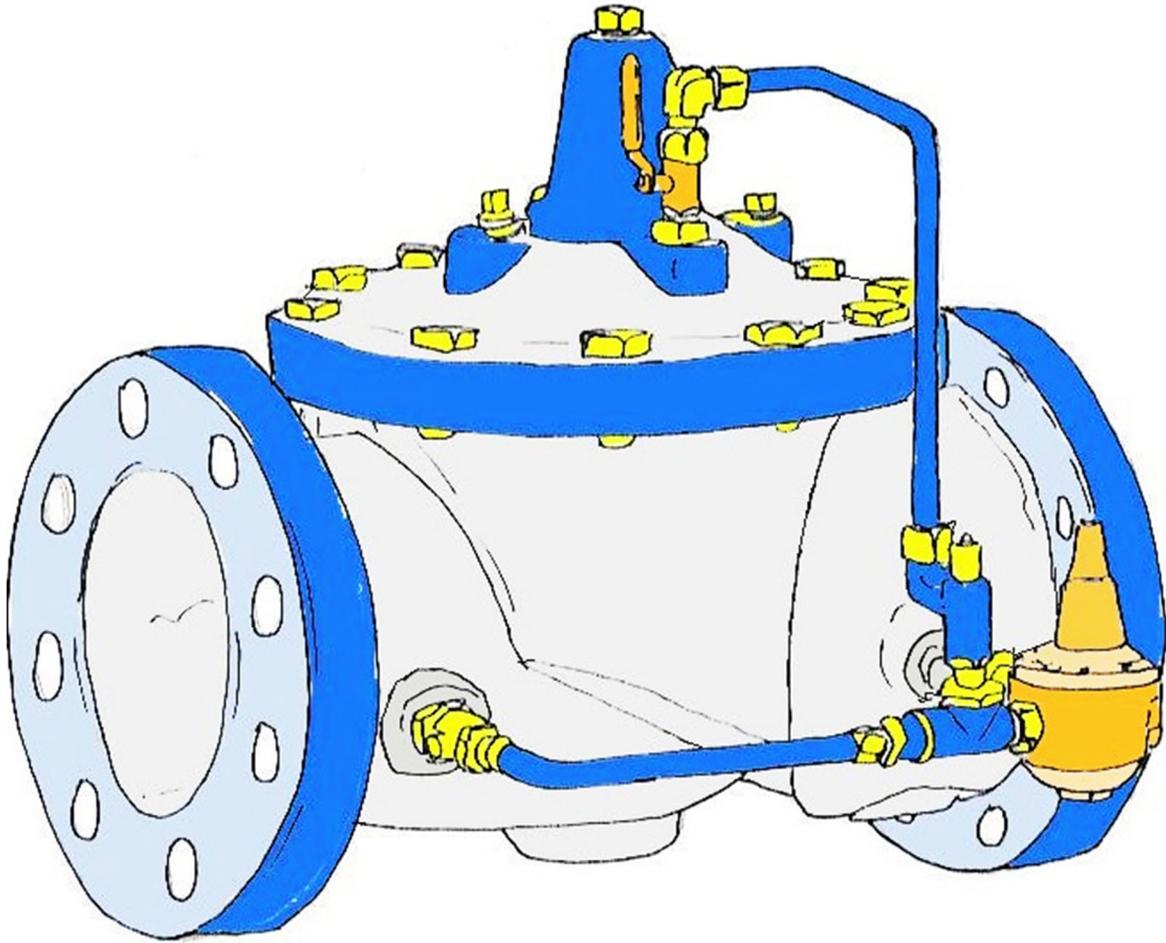
When pressure in the secondary circuit drops, spring force opens the valve enough to increase pressure and keep a constant reduced pressure in the secondary circuit. Fixed pressure reducing valves supply a fixed amount of pressure reduction regardless of the pressure in the main circuit. For instance, assume a valve is set to provide reduction of 250 psi.

If main system pressure is 2,750 psi, reduced pressure will be 2,500 psi; if main pressure is 2,000 psi, reduced pressure will be 1,750 psi. This valve operates by balancing the force exerted by the pressure in the main circuit against the sum of the forces exerted by secondary circuit pressure and the spring. Because the pressurized areas on both sides of the poppet are equal, the fixed reduction is that exerted by the spring.

### **How do Pressure Relief Valves Operate?**

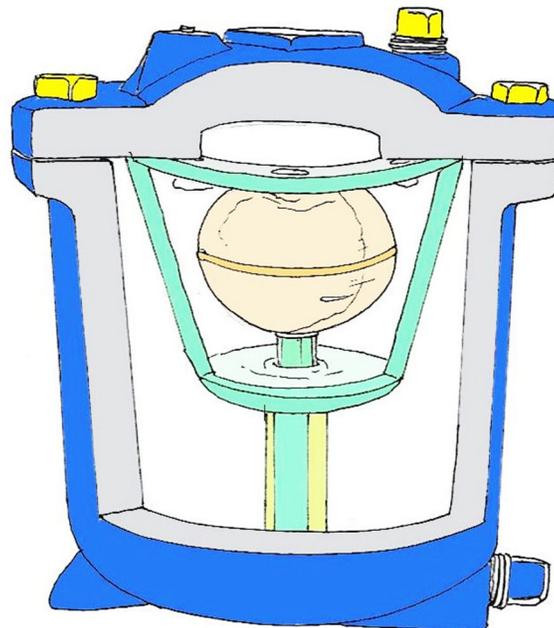
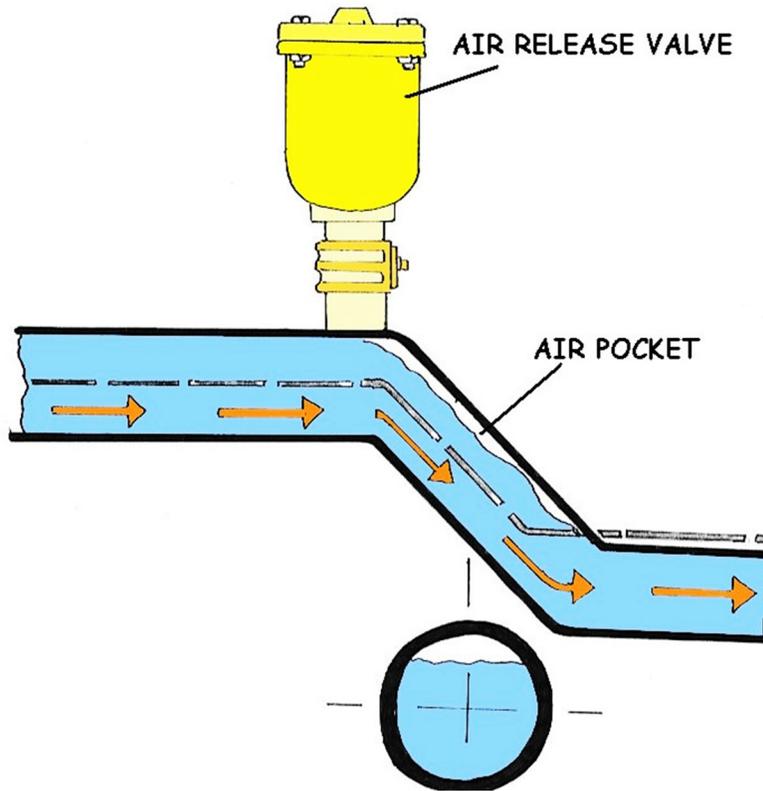
Most pressure relief valves consist of a main valve and pilot control system. The basic main Cla-Val valve is called a Hytrol Valve. Often a small box can be connected to an existing pilot PRV valve to control the main Pressure Reducing Valve on the pipe network. This single box contains both the control electronics and an integral data logger to save the cost and space of having both a controller and a separate data logger.

There are basically two types of PRV controllers, either time-based (to reduce the pipe pressure at low demand times, e.g. at night) or flow modulated controllers which can realize leakage savings throughout the day and night (by adjusting the pressure according to the demand to prevent excessive pressure at any time of the day or night).

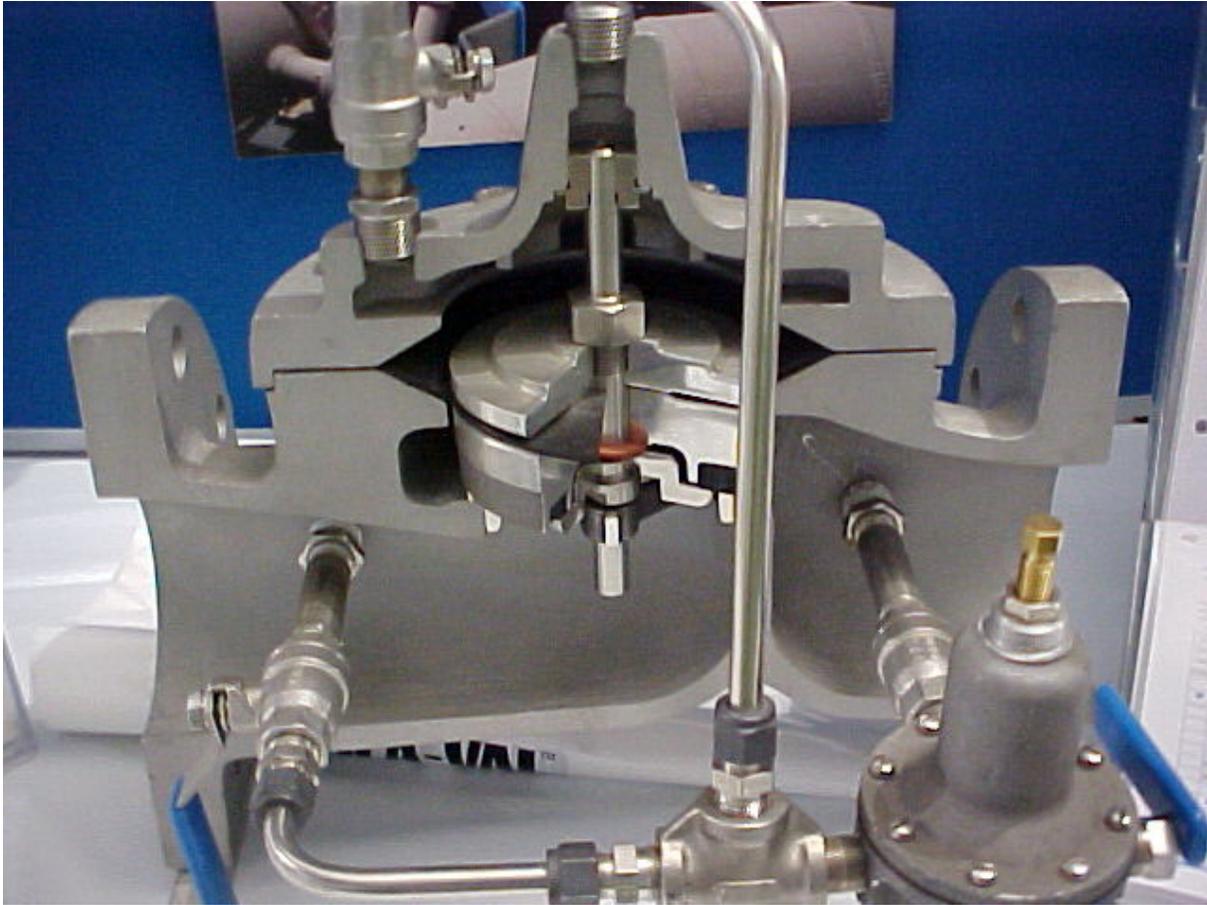


## **PRESSURE REDUCING VALVE EXAMPLE**

When no pressure is in the valve, the spring and the weight of the diaphragm assembly holds the valve closed.

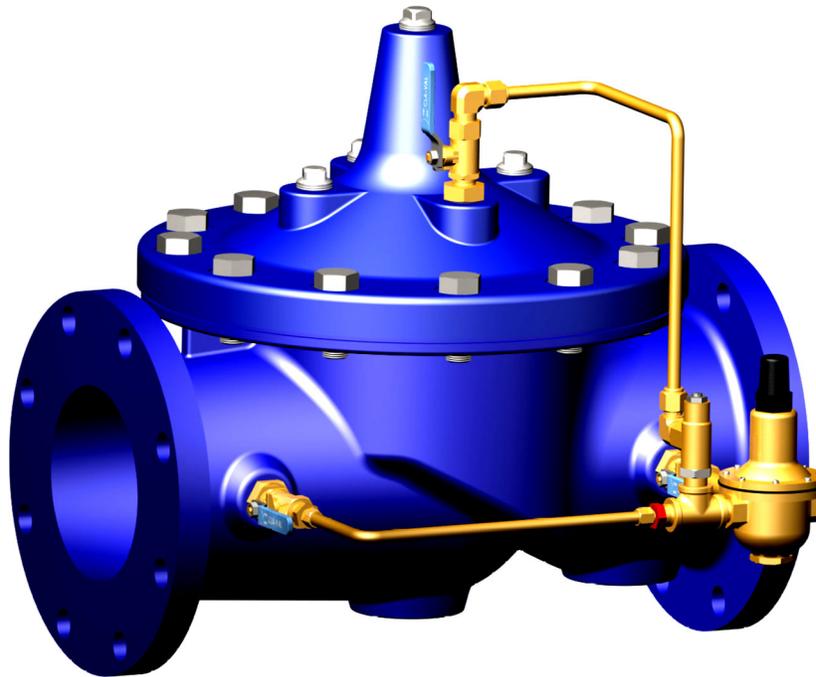


**INTERNAL VIEW OF A COMBINATION AIR VALVE**



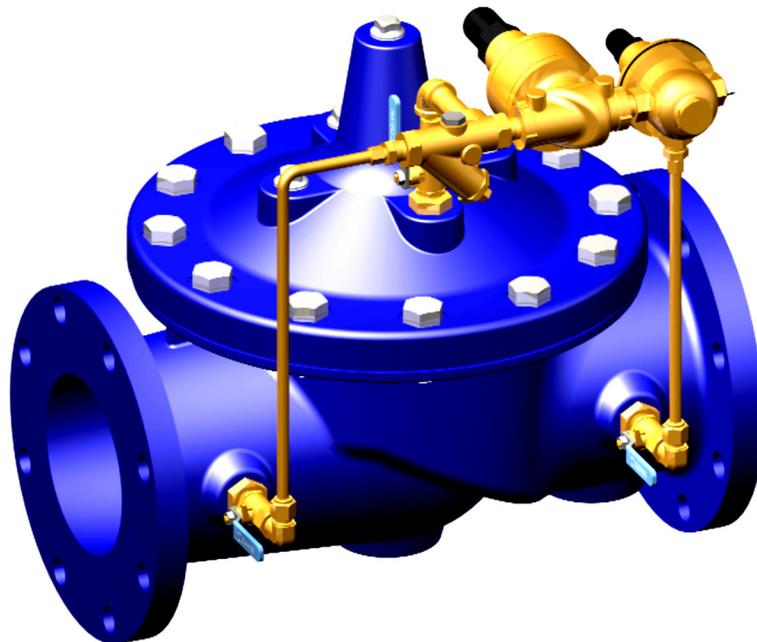
Municipal water distribution systems often have widely varying flow rates ranging from 7:00 am peak demand (or even fire-flow) to minimal 2:00 am demand. One valve size cannot accurately control the wide range of flows.

A low flow bypass pressure reducing valve is often used to control pressure at the low flow conditions. Both valves are open at maximum flow demand. The small valve is set at a slightly higher pressure than the larger valve.



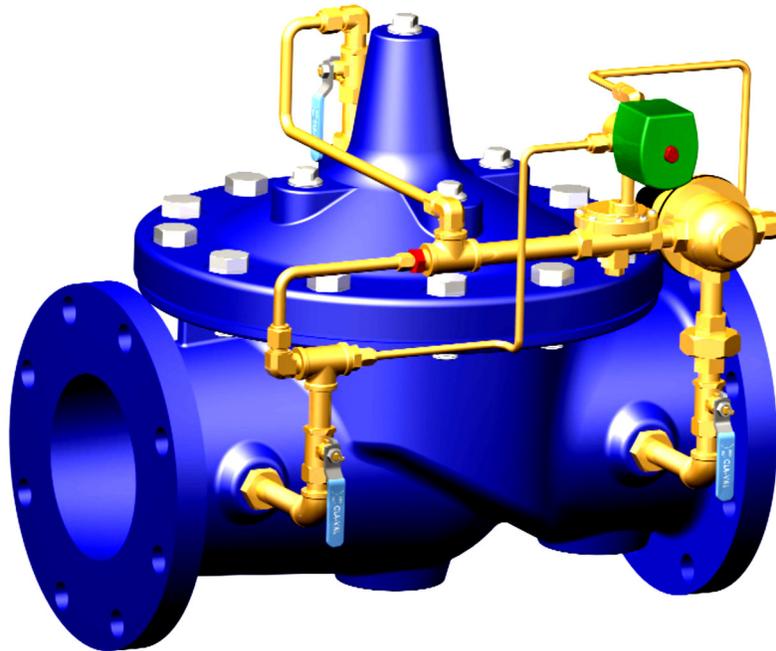
**Pressure Reducing Valve**

- Holds downstream pressure to a pre-determined limit.
- Optional check feature.
- Fully supported frictionless diaphragm.



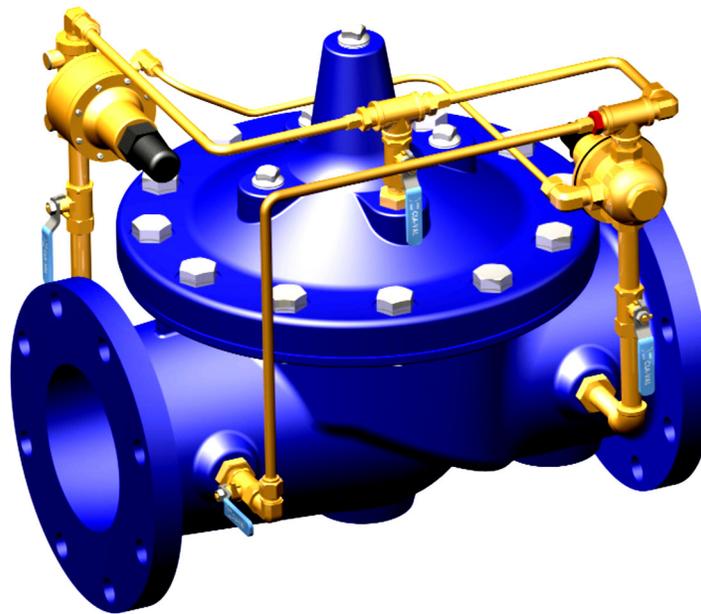
**Pressure Reducing/Pressure Sustaining Control Valve**

- Maintains downstream pressure regardless of fluctuating demand and sustains upstream pressure to a pre-set minimum.
- Optional check feature.



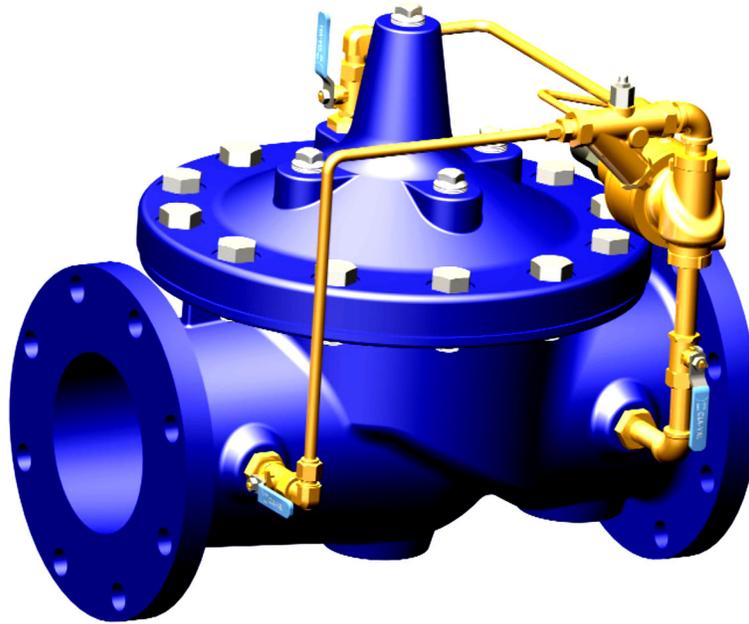
**Pressure Reducing & Solenoid Shut-Off Valve Cla-Val 93 Series**

- Ideal for reducing high transmission line pressures to lower distribution system pressures.
- Solenoid can be remotely activated.



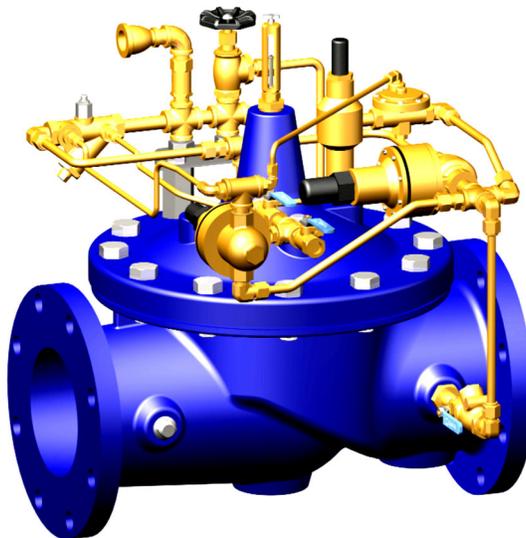
**Pressure Reducing & Surge Control Valve Cla-Val 94 Series**

- Integral surge pilot opens to prevent rapid pressure increases.
- Optional check feature.



**Pressure Relief/Pressure Sustaining Valve Cla-Val 50 Series**

- Completely automatic operation.
- Accurate pressure control.
- Fast opening maintains line pressure.
- Slow closing prevents surges.
- Optional check feature.



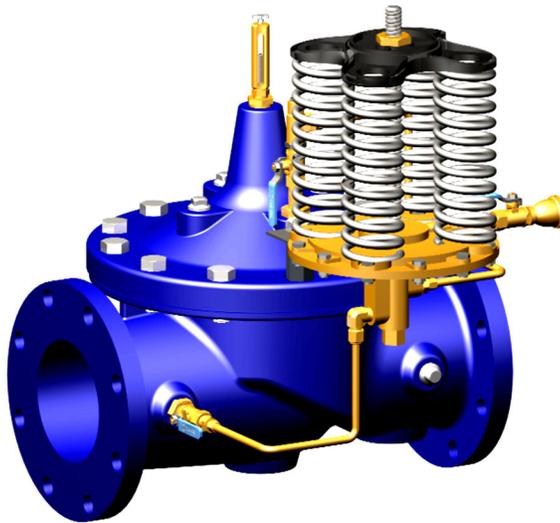
**Surge Anticipator Valve Cla-Val 52 Series**

- Protects pumping equipment and pipelines from damage caused by rapid flow velocity changes.
- Opens on initial low pressure wave.
- Closes slowly to prevent subsequent surges.



**Float Valve Cla-Val 124 Series**

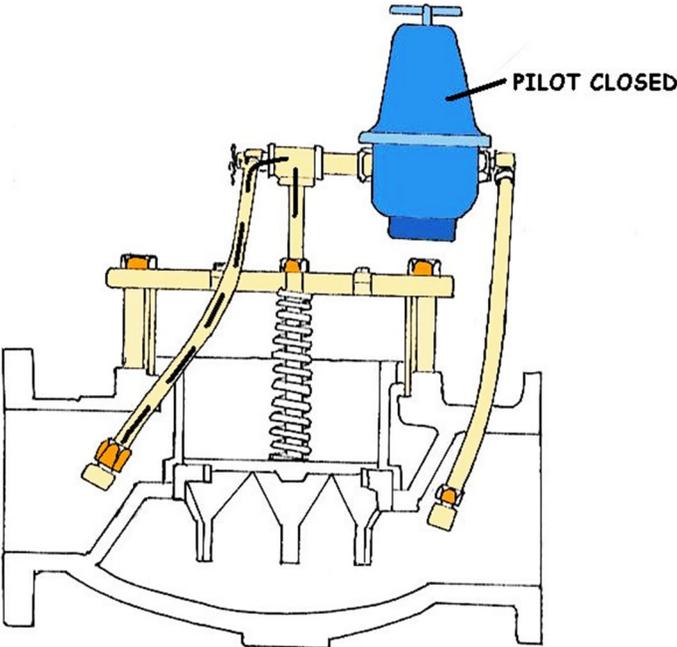
- Accurate and repeatable level control in tanks to pre-set high and low points
- Reliable drip-tight shut-off.
- On-Off non-modulating action.
- Use Model 428-01 for modulating service.



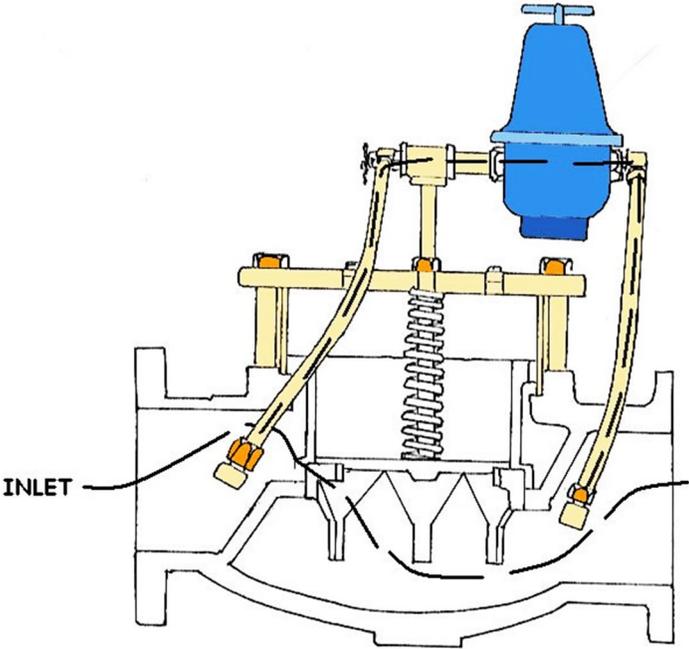
**Altitude Control Valve Cla-Val 210 Series**

- Provides accurate and repeatable tank level control.
- Optional check valve feature.
- Delayed opening option available.
- One-way and two-way flow pilot systems available.

REDUCED PRESSURE VALVE OPERATION  
( VALVE CLOSED )



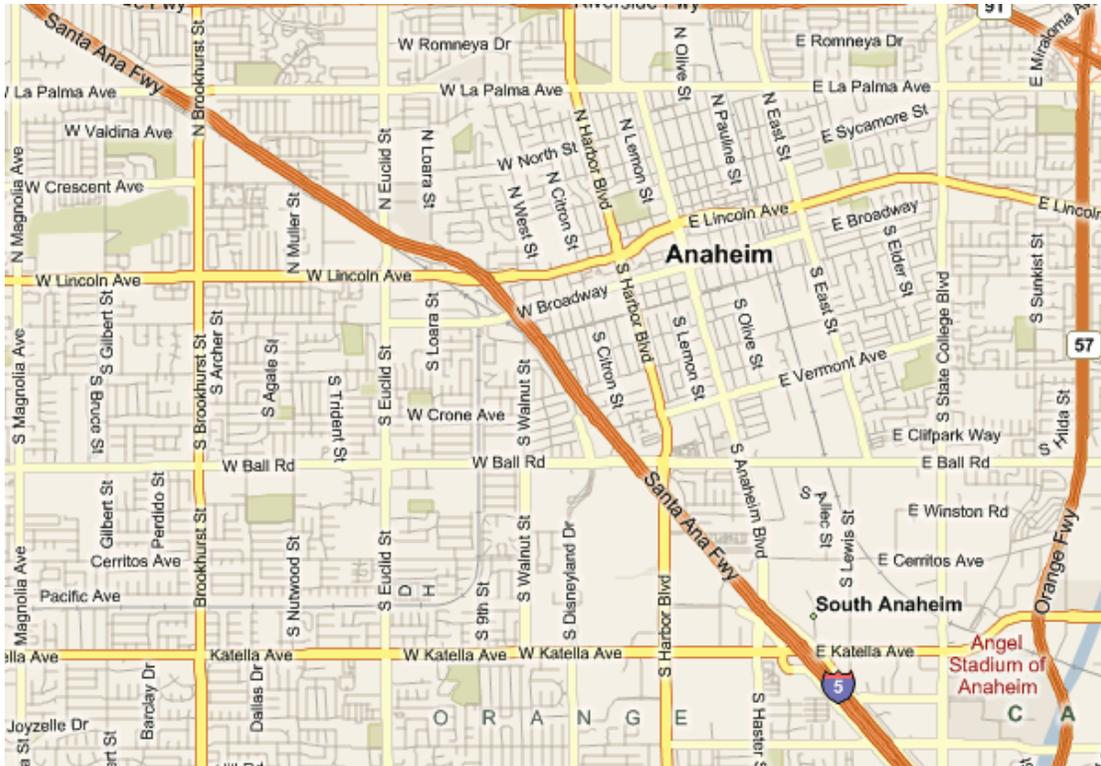
REDUCED PRESSURE VALVE OPERATION  
( VALVE OPEN )



## System Layouts

There are three general ways systems are laid out to deliver water (picture your quarter section layouts). They include:

- A. Tree systems
- B. Loop or Grid systems
- C. Dead-end systems - *Undesirable, taste and odor problems.*



### Tree System

Older water systems frequently were expanded without planning and developed into a treelike system. This consists of a single main that decreases in size as it leaves the source and progresses through the area originally served. Smaller pipelines branch off the main and divide again, much like the trunk and branches of a tree.

A treelike system is not desirable because the size of the old main limits the expansion of the system needed to meet increasing demands. In addition, there are many dead ends in the system where water remains for long periods, causing undesirable tastes and odors in nearby service lines.

The most reliable means to provide water for firefighting is by designing redundancy into the system. There are several advantages gained by laying out water mains in a loop or grid, with feeder and distributor mains interconnecting at roadway intersections and other regular intervals.

**Friction Loss**

Water will still be distributed through the system if a single section fails. The damaged section can be isolated and the remainder of the system will still carry water.

Water supplied to fire hydrants will feed from multiple directions. Thus during periods of peak fire flow demand, there will be less impact from "friction loss" in water mains as the velocity within any given section of main will be less since several mains will be sharing the supply.

**Water System Supply Component**

It is necessary to understand the types of community water supply systems and the arrangement of components prior to discussing the evaluation concepts associated with them.

There are two basic types of water supply systems:

1. Gravity-feed system.
2. Pressure-feed system, where pressure is developed by stationary pumps.

Each of these basic types of supply systems can be subdivided according to the type of potable water and nonpotable water in storage:

- reservoirs that hold nonpotable water for gravity feed;
- elevated tanks, standpipe tanks, and impounding tanks that store potable or finished water for gravity feed;
- pumping stations that are supplied by ground-water sources: lake, river, ponds, etc.; and
- pump(s) at well sites.

In any of the above systems, pumps may be used to pump nonpotable water to a filtration system or purifying system, followed by pumping potable water to holding tanks or directly into the water supply distribution system.

## Distribution System Troubleshooting Section

### Problem

1. Dirty water complaints
2. Red water complaints
3. No or low water pressure
4. Excessive water usage.

### Possible Cause

- 1A. Localized accumulations of debris, solids/particulates in distribution mains
- 1B. Cross connection between water system and another system carrying non-potable water.
- 2A. Iron content of water from source is high. Iron precipitates in mains and accumulates.
- 2B. Cast iron, ductile iron, or steel mains are corroding causing "rust" in the water.
- 3A. Source of supply, storage or pumping station interrupted.
- 3B. System cannot supply demands.
- 3C. Service line, meter, or connections shutoff, or clogged with debris.
- 3D. Broken or leaking distribution pipes.
- 3E. Valve in system closed or broken.
- 4A. More connections have been added to the system.
- 4B. Excessive leakage (>15% of production) is occurring, meters are not installed or not registering properly.
- 4C. Illegal connections have been made.

### Possible Solution

- 1A. Collect and preserve samples for analysis if needed. Isolate affected part of main and flush.
- 1B. Collect and preserve samples for analysis if needed. Conduct survey of system for cross connections. Contact State Drinking Water Agency.
- 2A. Collect and test water samples from water source and location of complaints for iron. If high at both sites, contact regulatory agency, TA provider, consulting engineer or water conditioning company for assistance with iron removal treatment.
- 2B. Collect and analyze samples for iron and corrosion parameters. Contact State Drinking Water Agency, TA provider, consulting engineer or water conditioning company for assistance with corrosion control treatment.
- 3A. Check source, storage and pumping stations. Correct or repair as needed.
- 3B. Check to see if demands are unusually high. If so, try to reduce demand. Contact State Drinking Water Agency, TA provider or consulting engineer.
- 3C. Investigate and open or unclog service.
- 3D. Locate and repair break or leak.
- 3E. Check and open closed isolation and pressure-reducing valves. Repair or contact contractor if valves are broken.
- 4A. Compare increase in usage over time with new connections added over same period. If correlation evident take action to curtail demand or increase capacity if needed. Contact State Drinking Water Agency, TA provider or consulting engineer.
- 4B. Conduct a water audit to determine the cause. If leakage, contact regulatory agency, and consulting engineer or leak detection contractor.
- 4C. Conduct survey to identify connections.

## Minimum Storage

Minimum storage available for public fire protection should be examined in terms of the type of distribution system. It may be helpful to refer to the figures illustrating basic types of water systems. Every water system for communities over 50 population has to have a water storage component in order to provide even minimum fire protection water supplies

On this matter, the *Grading Schedule* states that the average daily **minimum** water storage maintained is the **maximum** amount that can be credited. This concept can be understood through the following explanation.

The amount of water in storage for a given distribution system is constantly changing due to residential, business, and industrial consumption and, as needed, fire-flow consumption. As previously identified, consumption varies by the time of the day and the day of the week. Consequently, finished water (referring to water that has been suitably treated to meet EPA Safe Drinking Water Standards), in storage also varies by the time of day and the day of the week. The insurance community grading process is interested in the **average** minimum storage as a benchmark for both water system adequacy and reliability.

To determine minimum storage, it is necessary to maintain **accurate** records on storage facilities including clear wells, standpipe tanks, and gravity tanks. Chart recorders linked to each storage facility typically are used to cover the capacity range of the specific storage tank. The recorded minimum amount of water in storage for each day is expressed in gallons or millions of gallons.

For each year being evaluated, all daily minimum amounts are totaled and divided by 365 days to provide the average minimum water in storage. This is the amount of water credited as available for consumer consumption and fire flow at any given time. Obviously, consumer consumption does not stop when there is a fire in the community.

The ISO *Grading Schedule* does specify some conditions and exceptions to the concept of minimum storage:

- The absolute minimum water supply under extreme dry weather conditions should not be considered; this is a judgment item.
- Only the portion of water in storage that can be delivered at the required pressure of 20 psi at representative tests sites is to be considered.
- Water loss due to a pipe rupture should not be considered in the evaluation.
- Water supply available during periods when water tanks are being cleaned and painted has to be carefully evaluated by an ISO field representative.
- It should be recognized that direct pumping systems from treated water supplies, or nonpotable water that is treated during the pumping process, generally are limited by both water storage and pumping capacity. The pumping limitation is discussed below.

## Municipal Stationary Pumps

Municipal pumps may interface with a water distribution system supply in several ways. Some of these ways are illustrated above. The most common uses of pumps at the supply works follow:

- Pumps take water from an impounding source (lakes, rivers, streams, etc.) and send the water through pipes to a filtration/treatment plant.
- Pumps take treated water from clear wells and pump directly into the water delivery system piping network.
- Pumps take treated water from clear wells and pump to elevated or standpipe tanks.
- Pumps take water from wells and pump it through purifiers and then to the water distribution system.
- The Grading Schedule indicates that stationary municipal pumps should be credited at their effective capacities when delivering at normal operating pressures as specified by the pump manufacturer. This information needs to be taken from the manufacturer's pump specification plate and manufacturer's pump curves. This information is to be available at the water supply works. Each water supply pump needs to be tested annually to match points on the manufacturer's pump curve with actual flow capability.

The **actual** flow capability of one or more pumps at the supply works may be limited by the following factors:

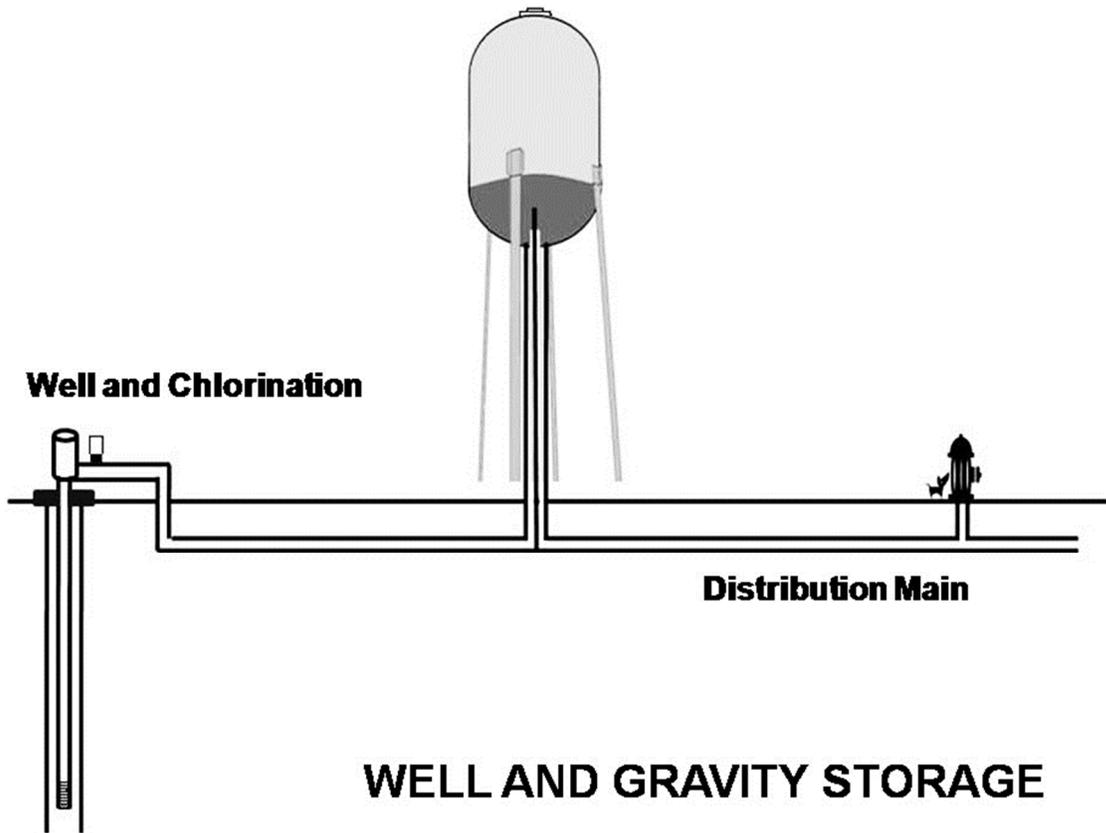
- size and length of the suction pipe to the pump;
- filter arrangements;
- Venturi fittings for chlorinators, water softeners, fluorides, and other additives;
- head loss characteristics on the discharge side of the pumps; and
- minimum stored water capacity may limit pump capability when pumping from this source.

The following explanatory information should be of assistance in the determination of creditable pump capacity:

- The total pumping capacity should be the sum of **all** pump facilities available at the test location expressed in gpm.
- When there are two or more pump lifts in a series, the effective pump capacity is the capacity of the lift with the lowest total capacity.
- When the same pumps can operate in two or more lifts, they are to be credited in each lift to determine the lift with the lowest total capacity.

### Reference

*Water Supply Systems• Vol. II: Evaluation Methods October 2008 FEMA U.S. Fire Administration Harry E. Hickey, Ph.D.*



## Service Pumping Station

### High-level service pumps may be needed to:

- a. Pump water up to service areas that have higher elevations than other areas of a community.
- b. Fill gravity tanks that float on the water supply distribution system.
- c. When service pumping stations are used to distribute water, and no water storage is provided, the pumps force water directly into the water mains. From a water system evaluation perspective, there is no outlet for the water except as it furnishes consumer consumption for actual fire flows. Variable speed pumps or multiple pumps may be required to provide adequate water delivery service because of fluctuating demands.

The efficiency and expense of this pumping equipment needs to be considered carefully. For example, it is a disadvantage that the peak power demand of the water plant is likely to occur during periods of high electrical consumption, and thus increase power costs. Furthermore, systems with little or no storage should be provided with standby electrical generating capability or pumps driven directly by internal combustion engines. These standby generators and engines needs to be tested routinely (e.g., several hours per week).

An extremely important element in a water distribution system is water storage. System storage facilities have a far-reaching effect on a system's ability to provide adequate consumer consumption during periods of high demand while meeting fire protection requirements. The two common storage methods are ground-level storage and elevated storage.

The primary emphasis is to evaluate the impact of fire-flow requirements on water storage capacity. Storage capacity is aggregated into three categories:

- 1) equalization,
- 2) fire demand, and
- 3) reserve storage.

Reserve storage corresponds to capacity that is not used for either a joint equalization or simply fire-flow demand and includes both ineffective storage and emergency (other than fire) storage. In order to develop a general relationship, the following assumptions were made

- The tank or reservoir is completely and instantaneously mixed during the fill cycle.
- The storage facility operates with a 12-hour draw and 12-hour fill cycle at constant fill and draw rate with the water level variation over the full range of the equalization storage volume.
- The water level in the tank is at its maximum level at the start of the draw cycle and again at the end of the fill cycle.

### Determining Existing Community Water Supply Adequacy and Reliability

A community water supply system is one of the most important factors in both public and private fire protection. Fire departments and fire protection engineers, as well as those responsible for the design, operation, and maintenance of water systems, are concerned with two aspects of the total water supply system: its adequacy and its reliability.

Adequacy, in the case of a water system supplying water for normal consumer consumption and for fire protection, means having the capability of simultaneously supplying water for maximum consumption demands plus water that may be needed to combat and extinguish a major fire within the area served by the water system. Adequacy concerns itself with sufficient flow and pressure on all installed fire hydrants on the water system; the minimum residual pressure on each fire hydrant under flow conditions is to be 20 pounds per square inch (psi) residual pressure.

Reliability of a community water system is having the capability of supplying the maximum daily consumption plus a required fire-flow demand, even in the event of a malfunction or the outage of important system components, such as a pipeline break, valve failure, power outage, or stationary pump outage. Reliability is a more subjective evaluation and requires both a **what-if** look at the water system and a determination of what to do about the **what-if** happening.

Today, the reliability of community water systems has to be extended to the consideration that the water supply sources maybe contaminated through terrorist operations or depleted through overt operations.

This topic examines the objectives of water supply testing, using fire hydrants to determine water supply capability throughout a given water distribution system, some applications of fundamental hydraulics, flow test procedures, and graphical solutions to test for water flow problems. The results of this type of analysis are essential to understanding a given water system's capability to provide both consumer consumption and needed fires flows at representative locations throughout the built areas of the community.

### **Municipal water supply systems are concerned with two classifications of water storage.**

1. Raw water storage: Water supplies that are used to feed water to a filtration and treatment plant for purification in order to produce **finished water** that is used for domestic purposes including drinking water is classified as **raw water**. Raw water sources from streams, rivers, ponds, lakes, and even reservoirs are **not suitable** for any domestic purposes including water for cooking, bathing, and especially drinking. The one exception is individual well water that has been chlorinated and disinfected for individual household use in accordance with individual State Public Health regulations.

**Extreme caution:** Raw water or any water supply that has not been treated to Environmental Protection Agency (EPA) standards **is not** to be pumped into fire hydrants attached to a municipal water system. During the summer drought conditions of 2005 in the Middle Atlantic States, there were reports where community fire departments were pumping water from creeks and ponds into small water systems because there was no water in the reservoirs to supply the water piping system. This is considered a very dangerous situation, and such practices present serious health risks to persons using these water supplies.

Furthermore, all components of the water system are required by either State or Federal regulations to be completely disinfected along with biological testing before the water system can be placed back in service to provide treated water for human consumption.

A more positive approach to raw water supplies is to use raw water holding basins, ponds, or reservoirs as an alternative water supply source to meet unusual demand on the water system, including a major fire, situations when the main water supply is low, or any other emergency situation requiring large volumes of water such as a primary or secondary water main break. These raw water sources should be arranged so that the water flows by gravity, if possible, to the water treatment plant. If the terrain in the area of the treatment plant does not permit this height differential, then arrangements need to be made for stationary pumps, or even fire department pumpers to pump water from the raw water source to the water treatment plant.

2. Finished water storage: The most common type of water storage on a municipal water system is the use of clear wells on the outboard side of water treatment plants, ground-level water-storage tanks and elevated water-storage tanks to store **finished water** that is suitable for domestic consumption. Therefore, an extremely important element in a water distribution system is **finished water storage**. Water system **storage facilities** have far-reaching effects on a given system's ability to provide adequate consumer consumption plus adequate water supplies for meeting fire-flow demand in addition to consumer consumption. The two common finished water storage methods 1) ground-level storage, and 2) elevated storage, are presented below. Emphasis is placed on the relative merits of both methods.

### **Functions of Distribution Storage**

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 repumped and repressurized 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.

## **EPA Rules for 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 have 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. Work ahead on projects if you can because that inventory will be wasted if you don't use it before January 2014.

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  $\geq 10 \mu\text{g/dL}$  as well as levels that are higher than the U.S. GM level for children ( $1.4 \mu\text{g/dL}$ ) but are  $< 10 \mu\text{g/dL}$ .

## 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  $\mu\text{mol/L}$ ; 0.24–0.47  $\mu\text{mol/L}$ ; 0.48–1.43  $\mu\text{mol/L}$ ; 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.



**Working in an illegal excavation, no shoring, ladders or hard hats.**

*This course contains EPA's SDWA federal rule requirements. Please be aware that each state implements drinking water regulations that may be more stringent than EPA's regulations. Check with your state environmental agency for more information.*

# 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.)

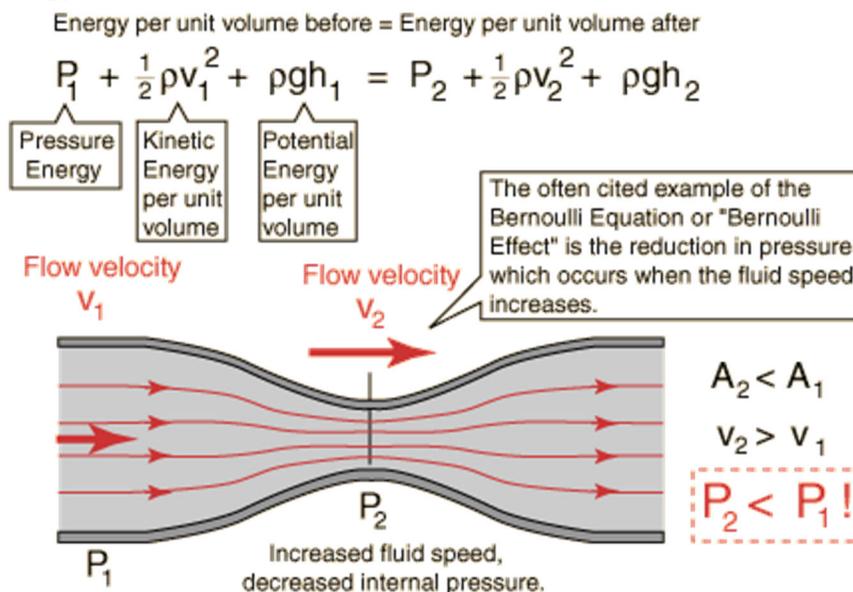
**B**

**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

$$\gamma = \rho \cdot g$$

$$\frac{\rho \cdot v^2}{2} + p = \text{Constant} \quad (4)$$

$$\frac{\rho \cdot v^2}{2} = p_d \quad (5)$$

$$\frac{\rho \cdot v_1^2}{2} + p_1 = \frac{\rho \cdot v_2^2}{2} + p_2 = \text{Constant} \quad (6)$$

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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

$$E = - dp / (d\rho / \rho) \quad (2)$$

where

$d\rho$  = 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)
- $1 \text{ lb}_f/\text{in}^2$  (psi) =  $6.894 \times 10^3 \text{ N/m}^2$  (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, $\text{lb}_f/\text{in}^2$ ) $\times 10^5$	SI Units (Pa, $\text{N/m}^2$ ) $\times 10^9$
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

$C$  = 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)

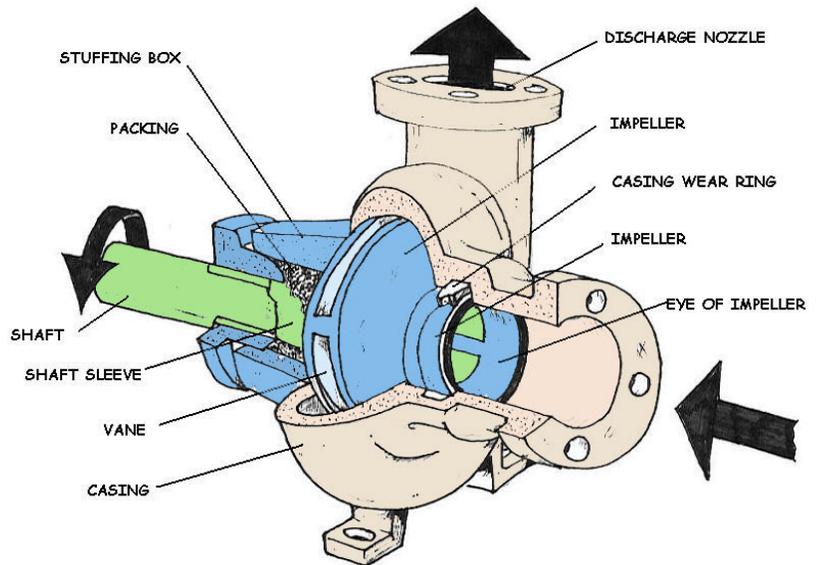
$p_v$  = vapor pressure of the fluid (Pa)

$\rho$  = 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)

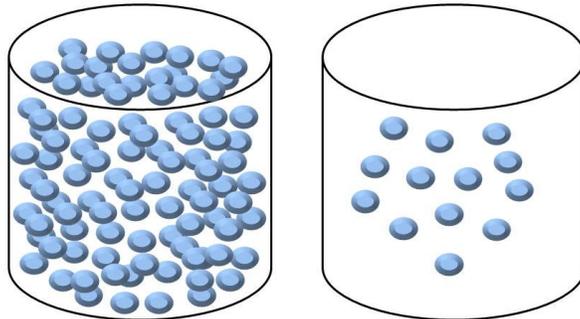
$d_h$  = hydraulic diameter (m, ft)

$\rho$  = 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  
 $\rho$  = density (kg/m<sup>3</sup>)  
 $m$  = mass (kg)  
 $V$  = volume (m<sup>3</sup>)  
 $v_g$  = specific volume (m<sup>3</sup>/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

$$\begin{aligned} \rho &= [18.5 \text{ (g)} / 1000 \text{ (g/kg)}] / [23.4 \text{ (ml)} / 1000 \text{ (ml/l)} 1000 \text{ (l/m}^3\text{)} ] \\ &= 18.5 \cdot 10^{-3} \text{ (kg)} / 23.4 \cdot 10^{-6} \text{ (m}^3\text{)} \\ &= \underline{790 \text{ kg/m}^3} \end{aligned}$$

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!

$$\begin{aligned} m &= 0.17 \text{ (m}^3\text{)} 4507 \text{ (kg/m}^3\text{)} \\ &= \underline{766.2 \text{ kg}} \end{aligned}$$

**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) × Density
- SSU<sup>1</sup> = Centistokes (cSt) × 4.55
- Degree Engler<sup>1</sup> × 7.45 = Centistokes (cSt)
- Seconds Redwood<sup>1</sup> × 0.2469 = Centistokes (cSt)

<sup>1</sup>centistokes 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  
 $EL = \text{Energy Line}$

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  
 $HGL = \text{Hydraulic Grade Line}$

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  
 $El = \text{Entrance Length Number}$   
 $l_e = \text{length to fully developed velocity profile}$   
 $d = \text{tube or duct diameter}$

### **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  
 $Re = \text{Reynolds Number}$

### **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

$$ds = c_p \ln(T_2 / T_1) - R \ln(p_2 / p_1) \quad (2)$$

where

$ds$  = entropy change

$c_v$  = specific heat capacity at a constant volume process

$c_p$  = 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:

$$m = \rho_{i1} v_{i1} A_{i1} + \rho_{i2} v_{i2} A_{i2} + \dots + \rho_{in} v_{in} A_{in}$$

$$= \rho_{o1} v_{o1} A_{o1} + \rho_{o2} v_{o2} A_{o2} + \dots + \rho_{om} v_{om} A_{om} \quad (1)$$

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

$$q = v_{i1} A_{i1} + v_{i2} A_{i2} + \dots + v_{in} A_{in}$$

$$= v_{o1} A_{o1} + v_{o2} A_{o2} + \dots + v_{om} A_{om} \quad (2)$$

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

$$v_{100} = (10 \text{ m}^3/\text{h})(1 / 3600 \text{ h/s}) / (3.14 \times 0.1 \text{ (m)} \times 0.1 \text{ (m)} / 4)$$

$$= \underline{0.35 \text{ m/s}}$$

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

$$v_{100} = (10 \text{ m}^3/\text{h})(1 / 3600 \text{ h/s}) / (3.14 \times 0.08 \text{ (m)} \times 0.08 \text{ (m)} / 4)$$

$$= \underline{0.55 \text{ m/s}}$$

**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 ( $\text{ft}^2/\text{s}^2 = \text{ft lb}/\text{slug}$  or  $\text{m}^2/\text{s}^2 = \text{N m}/\text{kg}$ )

### 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 -  $\rho$ :

$$\rho_{in} + \rho v_{in}^2 / 2 + \gamma h_{in} + \rho W_{shaft} = \rho_{out} + \rho v_{out}^2 / 2 + \gamma h_{out} + W_{loss} \quad (5)$$

where

$$\gamma = \rho g = \text{specific weight}$$

The dimensions of equation (5) are

$$\text{energy per unit volume (ft.lbf/ft}^3 = \text{lb/ft}^2 \text{ or N.m/m}^3 = \text{N/m}^2)$$

### 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

$$\gamma = \rho g = \text{specific weight}$$

$$h_{shaft} = W_{shaft} / g = \text{net shaft energy head inn per unit mass for a pump, fan or similar}$$

$$h_{loss} = W_{loss} / g = \text{loss head due to friction}$$

The dimensions of equation (6) are

$$\text{energy per unit weight (ft.lbf/lb} = \text{ft or N.m/N} = \text{m)}$$

Head is the energy per unit weight.

$h_{shaft}$  can also be expressed as:

$$h_{shaft} = W_{shaft} / g = W_{shaft} / m g = W_{shaft} / \gamma Q \quad (7)$$

where

$$W_{shaft} = \text{shaft power}$$

$$m = \text{mass flow rate}$$

$$Q = \text{volume flow rate}$$

### 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:

$$h_{shaft} = h_{out} + h_{loss}$$

or

$$h_{loss} = h_{shaft} - h_{out} \quad (8)$$

Equation (7) gives:

- $$h_{shaft} = W_{shaft} / \gamma Q = (4 \text{ hp})(550 \text{ ft}\cdot\text{lb/s}/\text{hp}) / (62.4 \text{ lb}/\text{ft}^3)(2 \text{ ft}^3/\text{s}) = 17.6 \text{ ft}$$
- specific weight of water 62.4 lb/ft<sup>3</sup>
  - 1 hp (English horse power) = 550 ft. lb/s

Combined with (8):

$$h_{loss} = (17.6 \text{ ft}) - (10 \text{ ft}) = 7.6 \text{ ft}$$

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  $x^2 - x + 41$  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 =  $6.30888 \times 10^{-5} \text{ m}^3/\text{s}$  = 0.0227 m<sup>3</sup>/h = 0.0631 dm<sup>3</sup>(liter)/s =  $2.228 \times 10^{-3} \text{ ft}^3/\text{s}$  = 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.

**Isentropic 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

$$1 \text{ St} = 100 \text{ cSt}$$

$$1 \text{ cSt} = 10^{-6} m^2/s$$

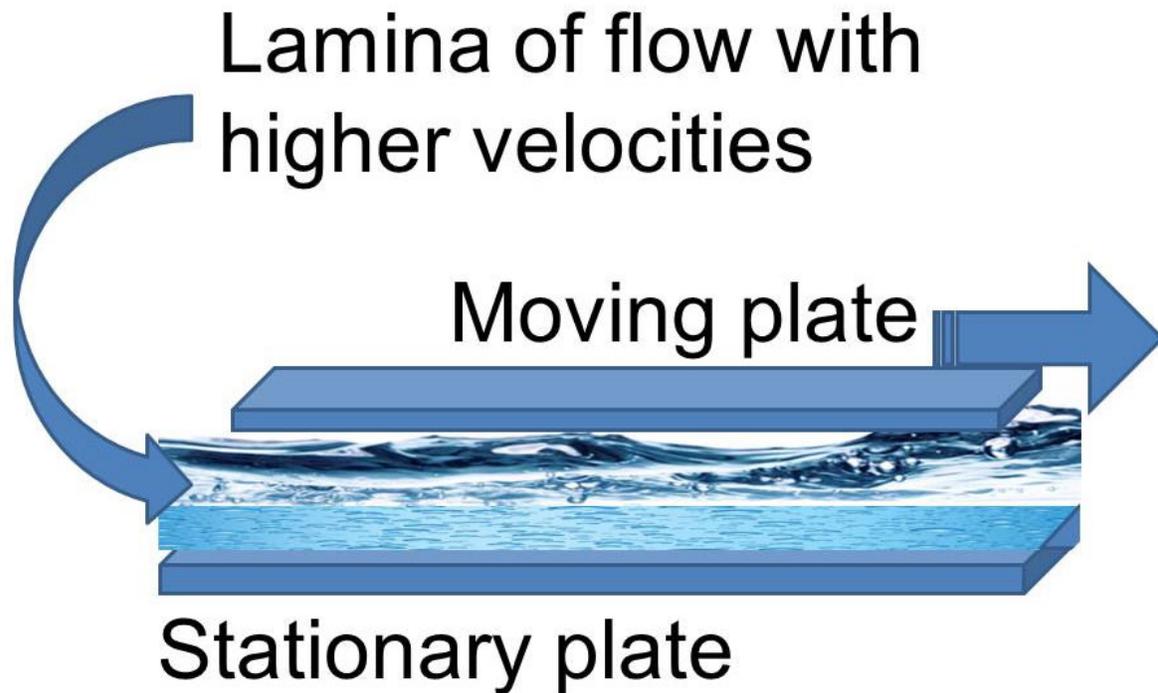
Since the specific gravity of water at 68.4°F (20.2°C) is almost one - 1, the kinematic viscosity of water at 68.4°F is for all practical purposes 1.0 cSt.

**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

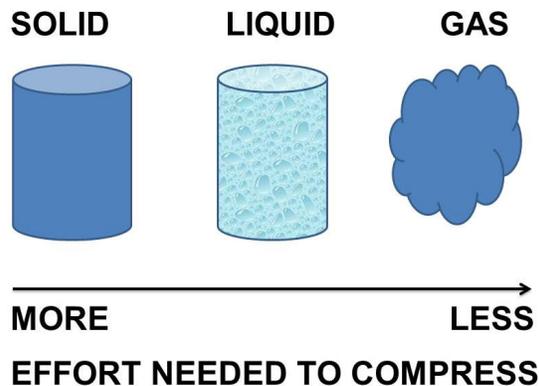
$$\nabla^2 \mathbf{F} = 0. \tag{4}$$

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.  $1 \text{ atm} = 760 \text{ torr} = 14.696 \text{ psi}$

**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 ( $\text{kg/m}^3$ ,  $\text{lb}_m/\text{ft}^3$ )

$u$  = velocity (m/s, ft/s)

$\mu$  = dynamic viscosity ( $\text{Ns/m}^2$ ,  $\text{lb}_m/\text{s ft}$ )

$L$  = 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 Furol).

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 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.

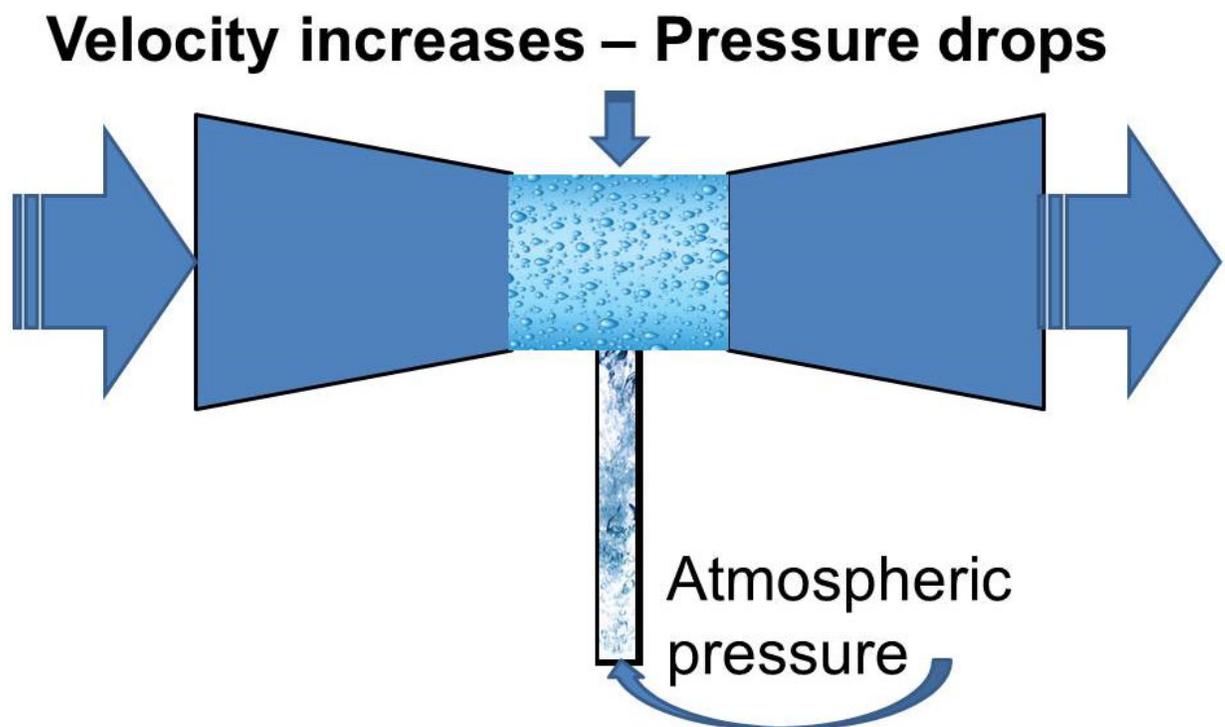
**Vane:** That portion of an impeller which throws the water toward the volute.

**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.

$$\eta = \left( \frac{F}{A} \right) \div \left( \frac{\Delta v_x}{\Delta z} \right) \quad \text{or} \quad \eta = \left( \frac{F}{A} \right) \div \left( \frac{dv_x}{dz} \right)$$

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.

$$\frac{F}{A} = \eta \frac{\Delta v_x}{\Delta z} \quad \text{or} \quad \frac{F}{A} = \eta \frac{dv_x}{dz}$$

$$\Downarrow \qquad \qquad \qquad \Downarrow$$

$$F = m \frac{\Delta v}{\Delta t} \quad \text{or} \quad F = m \frac{dv}{dt}$$

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 [ $\text{cm}^2/\text{s}$ ], 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 [ $\text{mm}^2/\text{s}$ ] 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  $100^\circ\text{C}$ . For a distillate fluid the reference temperature is  $40^\circ\text{C}$ .

- 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.

## Appendixes and Charts

### Density of Common Liquids

The density of some common liquids can be found in the table below:

Liquid	Temperature - <i>t</i> - (°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
Sulphuric 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
	300	18.9	1.1	8.5	10.0	11.6	12.4	23.0
8	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
	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



## 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

$V_0$  = 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 - $\mu$ - $10^{-5}$ (lb.s/ft <sup>2</sup> )	Kinematic Viscosity - $\nu$ - $10^{-5}$ (ft <sup>2</sup> /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 <sup>2</sup> )	Kinematic Viscosity - $\nu$ - $10^{-6}$ (m <sup>2</sup> /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  
 5280 Feet = 1 Mile

## AREA

144 Square Inches = 1 Square Foot  
 43,560 Square Feet = 1 Acre

## VOLUME

1000 Milliliters = 1 Liter  
 3.785 Liters = 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

### Flowrate

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

**POUNDS PER DAY** = Concentration (mg/L) X Flow (MG) X 8.34  
**AKA Solids Applied Formula** = Flow X Dose X 8.34

**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) =  $\frac{2.83 (\text{Diameter, in})^2 (\text{Distance, in})}{\text{Height, in}}$

**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)** =  $\frac{\text{Cross Sectional Area of Flow (ft)}}{\text{Wetted pipe Perimeter (ft)}}$

**MIXTURE STRENGTH (%)** =  $\frac{(\text{Volume 1, gal}) (\text{Strength 1, \%}) + (\text{Volume 2, gal}) (\text{Strength 2, \%})}{(\text{Volume 1, gal}) + (\text{Volume 2, gal})}$

**INJURY FREQUENCY RATE** =  $\frac{(\text{Number of Injuries})}{\text{Number of hours worked per year}} \times 1,000,000$

**HYDRAULIC RADIUS (ft)** =  $\frac{\text{Flow Area (ft. 2)}}{\text{Wetted Perimeter (ft.)}}$

## References

### **Several Photographs and Reference were provided by**

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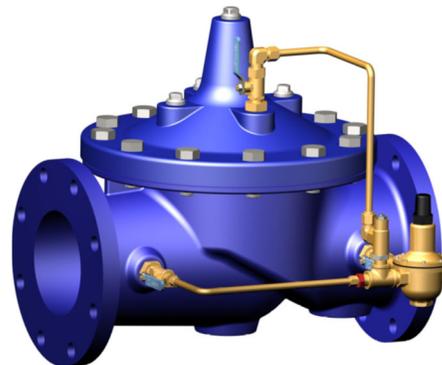
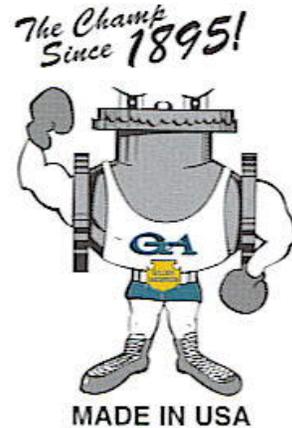
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