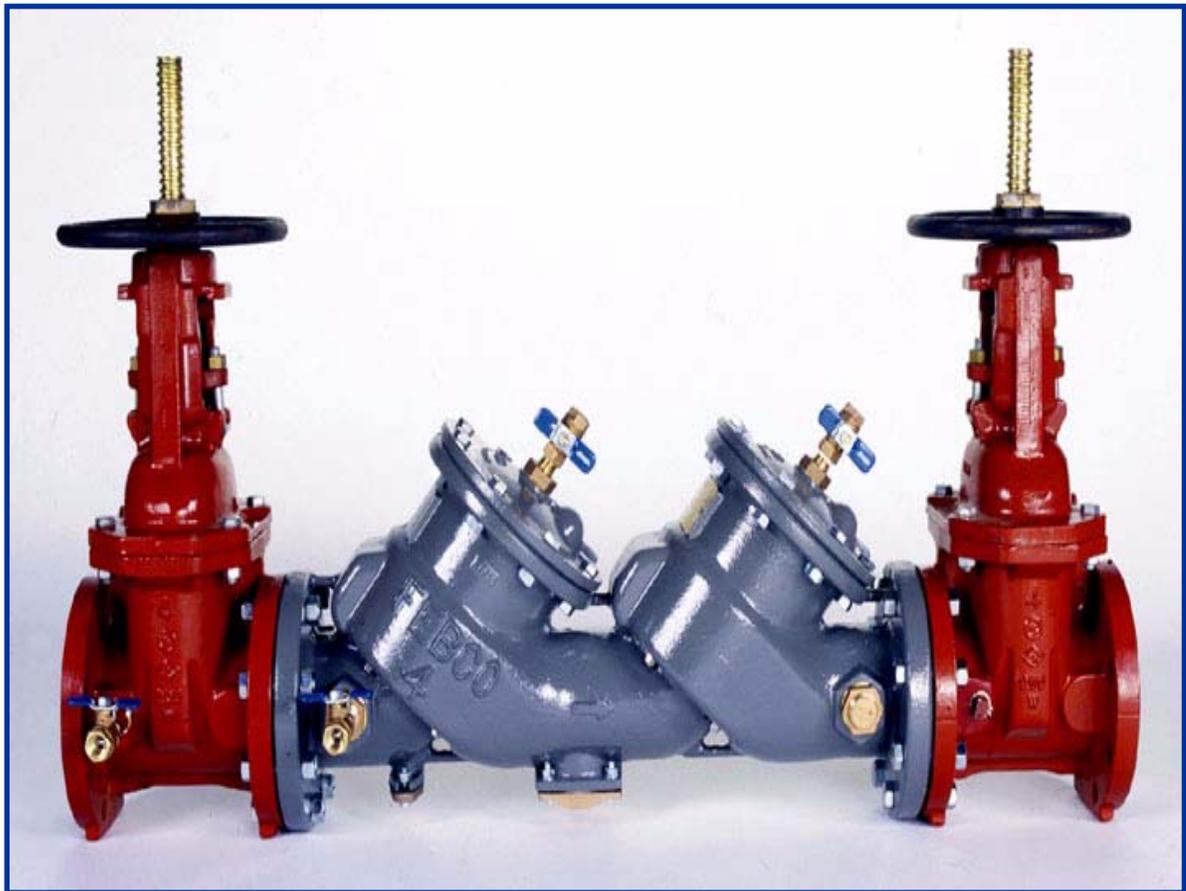


BACKFLOW AWARENESS

CONTINUING EDUCATION
PROFESSIONAL DEVELOPMENT COURSE



 **Technical
Learning
College**

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Contributing Editors

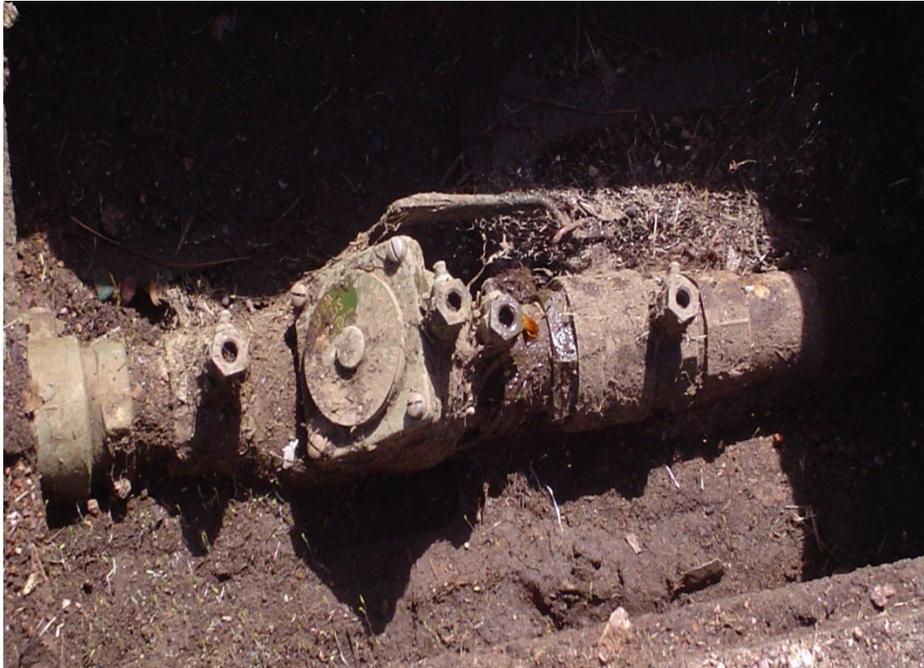
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Dr. Pete Greer S.M.E., Retired biology instructor, chemistry and biological review.

Jack White, Environmental, Health, Safety expert, City of Phoenix. Art Credits.



A RP buried inside a water meter box, broken shut-offs and not tested for over 20 years. The best thing to do is remove out this assembly and install a completely new assembly above ground and test the assembly.

Careful to document the location, serial number and other information for the water provider. The owner of the backflow preventer will feel ripped-off because he did not realize the potential hazard, so you need to carefully and skillfully explain the necessity of the replacement and relocation.

Often, your water provider will support you in a correct decision but sometimes, these “officials” don’t know or don’t care about the condition or location of assemblies. I have seen water providers do the dumbest things and the next day, change their minds and blame the tester for the problem.

Document everything and prepare to be held accountable for every decision.

Important Information about this Manual

This manual has been prepared to educate operators in the general awareness of cross-connections and backflow prevention. The scope of cross-connection control and backflow prevention is quite large, requiring a major effort to bring it under control. Water customers health and safety, as well as that of the operators, depend upon careful application of backflow prevention methods and effective cross-connection control procedures/programs. The manner in which we deal with such hazards will affect the earth and its inhabitants for many generations to come.

This manual covers general laws, regulations, required procedures and work rules relating to cross-connection control. It should be noted, however, that the regulation of backflow prevention and plumbing codes is an ongoing process and subject to change over time. For this reason, a list of resources is provided to assist in obtaining the most up-to-date information on various subjects.

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.

It cannot be assumed that this manual contains all measures and concepts required for specific conditions or circumstances. This document should be used for educational purposes and is not considered a legal document.

Individuals who are responsible for cross-connection control, backflow prevention or water distribution should obtain and comply with the most recent federal, state, and local regulations relevant to these sites and are urged to consult with OSHA, the EPA and other appropriate federal, state and local agencies.



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.

A second certificate of completion for a second State Agency \$50 processing fee.

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

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

Technical Learning College's Scope and Function

Welcome to the Program,

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

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

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

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

Flexible Learning

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

Course Structure

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

Classroom of One

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

Satisfaction Guaranteed

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



Top, a highly trained General Backflow Assembly Tester is working on a fireline assembly.

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
Telephone (866) 557-1746

CEU Course Description

Backflow Awareness CEU Training Course

Review of backflow and plumbing related fundamentals and principles. This course will cover the basics of backflow prevention, cross-connection control, water quality issues and hydraulic fundamentals. Task Analysis and Training Needs Assessments have been conducted to determine or set Needs-To-Know for this course.

The following is a listing of some of those who have conducted extensive valid studies from which TLC has based this program upon: the Environmental Protection Agency (EPA), the Arizona Department of Environmental Quality (ADEQ), the Texas Commission of Environmental Quality (TCEQ) and the American Boards of Certification (ABC). ***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.

Prerequisites: None

Course Procedures for Registration and Support

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

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 assigned to the student.

Instructions for Written Assignments

The Backflow Awareness CEU training course uses a multiple choice answer key. You can find a copy of the exam 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.

Feedback Mechanism (examination procedures)

Each student will receive a feedback form as part of their study packet. You will be able to find this form in the front of the course assignment or lesson.

Security and Integrity

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

Grading Criteria

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

Required Texts

The **Backflow Awareness** 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 the student's responsibility to give the completion certificate to the appropriate agencies.

ADA Compliance

TLC will make reasonable accommodations for persons with documented disabilities. Students should notify TLC and their instructors of any special needs. Course content may vary from this outline to meet the needs of this particular group. This course is also available in Spanish. Please check with your State for special instructions.

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

If you should need any assistance, please email all concerns and the final test to: info@tlch2o.com.

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 with opportunities to apply and understand the theory and skills needed for operator certification and environmental education,

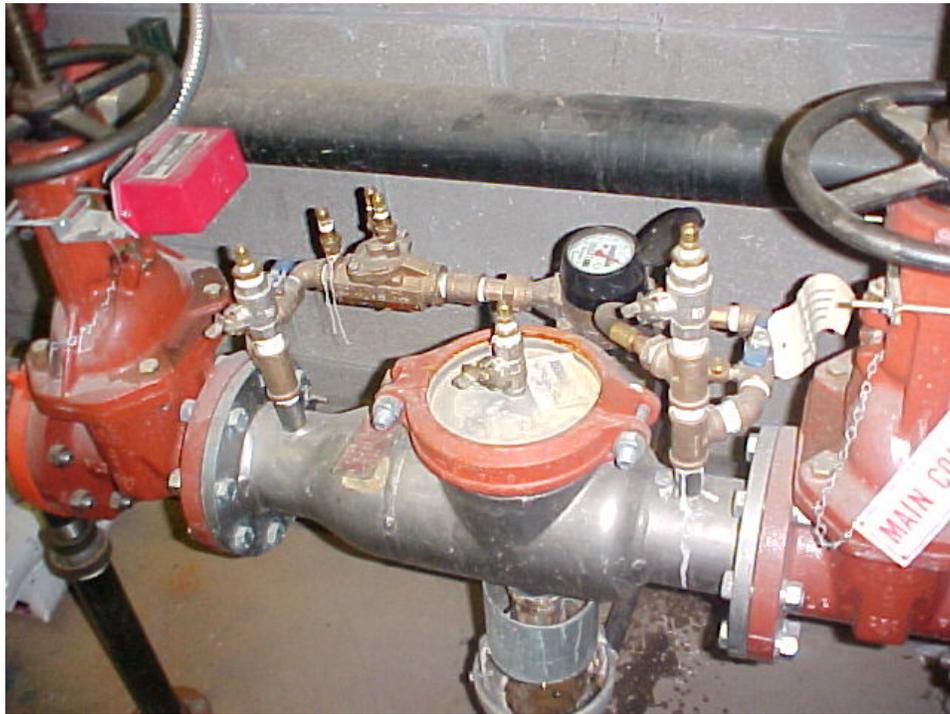
To provide opportunities for TLC students to learn and practice environmental educational skills with members of the community for the purpose of sharing diverse perspectives and experience,

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

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

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RPDA, Two Reduced Pressure Principle Backflow Assemblies together on a Fireline. Ames SS Assembly. Below an Antifreeze Loop with check valve on a Fireline. Notice the OS&Y Valves (Outside Screw and Yoke).



Backflow Introduction

Backflow Prevention, also referred to as Cross-Connection Control, addresses a serious health issue. This issue was addressed on the federal level by passage of the "**Federal Safe Drinking Water Act**" as developed by the Environmental Protection Agency (E.P.A.) and passed into law on December 16, 1974. This Act tasked each state with primary enforcement responsibility for a program to assure access to safe drinking water by all citizens. Such state program regulations as adopted are required to be at least as stringent as the federal regulations as developed and enforced by the E.P.A.

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

Sources of pollution which may result in a danger to health are not always obvious and such cross-connections are certainly not usually intentional. They are usually the result of oversight or a non-professional installation. As source examples, within a business environment the pollutant source may involve the unintentional cross-connection of internal or external piping with chemical processes or a heating boiler. In a residential environment the pollutant source may be an improper cross-connection with a landscape sprinkler system or reserve tank fire protection system. Or, a situation as simple as leaving a garden hose nozzle submerged in a bucket of liquid or attached to a chemical sprayer.

Another potential hazard source within any environment may be a cross-connection of piping involving a water well located on the property. This is a special concern with older residences or businesses, which may have been served by well water prior to connection to the developed water system. There are many other potential sources of pollutant hazards. Control of cross-connections is possible but only through knowledge and vigilance. Public education is essential, for many that are educated in piping and plumbing installations fail to recognize cross-connection dangers.



Another buried RP inside a pit, all we can see is a test cock, all RPs need to be installed 12 inches above the ground. This device was buried in ground and not tested for over 25 years. Owners are required to test their devices once a year at a minimum.



Top photo, a Hot Box a good method of keeping the assembly from freezing during the winter. Bottom, electrical heat tape method for freeze protection.



Actual Backflow Events

Paraquat

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

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

Someone left open a gate valve between an agricultural herbicide holding tank and the Town's water system and, thus, created a cross-connection. Coincidentally, water pressure in the Town temporarily decreased due to failure of a pump in the Town's water system. The herbicide Paraquat was backsiphoned into the Town's water system. Upon restoration of pressure in the Town's water system, Paraquat flowed throughout much of the Town's water system.

Fortunately, this incident did not cause any serious illness or death. The incident did, however, create an expensive burden on the Town. Tanker trucks were used temporarily to provide potable water, and the Town flushed and sampled its water system extensively.

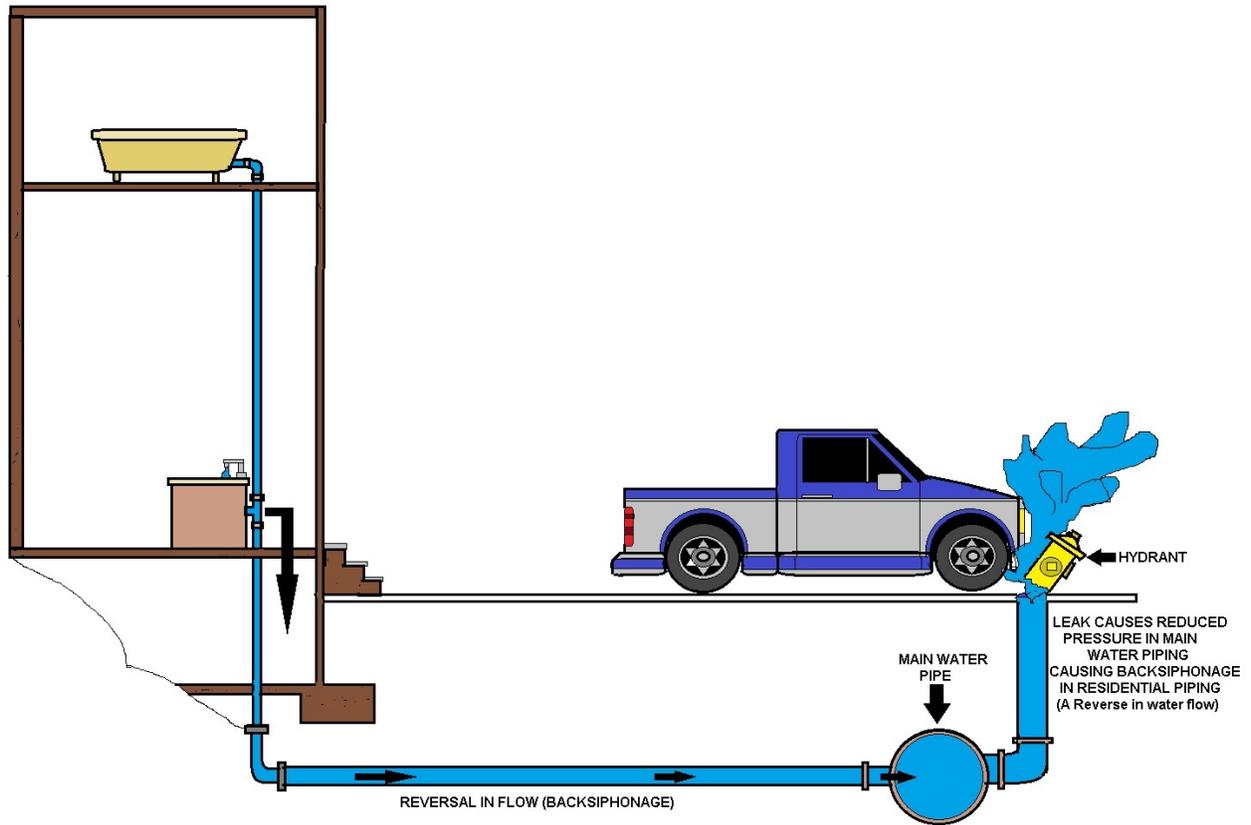
Mortuary

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

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

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

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



BACKSIPHONAGE

Recent Backflow Situations

Oregon 1993

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

California 1994

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

New York 1994

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

Nebraska 1994

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

California 1994

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

California 1994

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

Iowa 1994

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

Indiana 1994

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

Washington 1994

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

Ohio 1994

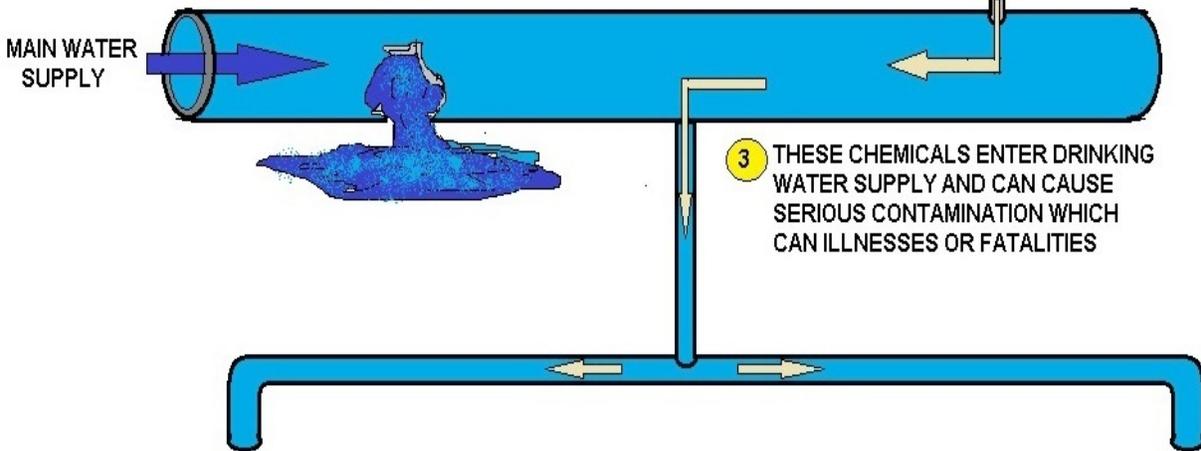
An ice machine connected to a sewer sickened dozens of people attending a convention.

2 REVERSE PRESSURE IS CAUSED BY A DROP IN WATER PRESSURE. THIS DROP CAN CAUSE CHEMICALS TO BE DRAWN INTO THE DRINKING WATER SUPPLY.

(This is referred to as: Cross Connection)



1 WATER PRESSURE IS REDUCED BY BREAK IN MAIN WATER SUPPLY



3 THESE CHEMICALS ENTER DRINKING WATER SUPPLY AND CAN CAUSE SERIOUS CONTAMINATION WHICH CAN ILLNESSES OR FATALITIES

Hydraulic Principles Section

Hydraulics

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

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

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

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

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

Hydrostatics

Hydrostatics is about the pressures exerted by a fluid at rest. Any fluid is meant, not just water. Research and careful study on water yields many useful results of its own, however, such as forces on dams, buoyancy and hydraulic actuation, and is well worth studying for such practical reasons. Hydrostatics is an excellent example of deductive mathematical physics, one that can be understood easily and completely from a very few fundamentals, and in which the predictions agree closely with experiment.

There are few better illustrations of the use of the integral calculus, as well as the principles of ordinary statics, available to the student. A great deal can be done with only elementary mathematics. Properly adapted, the material can be used from the earliest introduction of school science, giving an excellent example of a quantitative science with many possibilities for hands-on experiences.

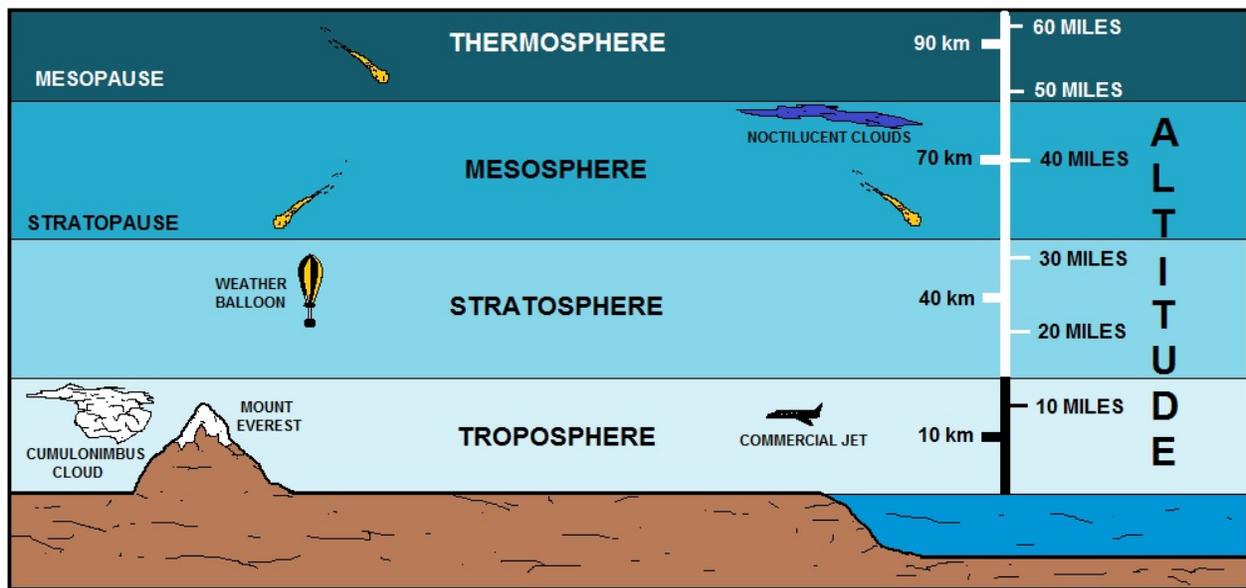
The definition of a fluid deserves careful consideration. Although time is not a factor in hydrostatics, it enters in the approach to hydrostatic equilibrium. It is usually stated that a fluid is a substance that cannot resist a shearing stress, so that pressures are normal to confining surfaces. Geology has now shown us clearly that there are substances which can resist shearing forces over short time intervals, and appear to be typical solids, but which flow like liquids over long time intervals. Such materials include wax and pitch, ice, and even rock.



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

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

Viscosity may be the physical property that varies over the largest numerical range, competing with electrical resistivity. There are several familiar topics in hydrostatics which often appears in expositions of introductory science, and which are also of historical interest and can enliven their presentation. Let's start our study with the principles of our atmosphere.



ATMOSPHERE DIAGRAM

Atmospheric Pressure

The atmosphere is the entire mass of air that surrounds the earth. While it extends upward for about 500 miles, the section of primary interest is the portion that rests on the earth's surface and extends upward for about 7 1/2 miles. This layer is called the troposphere.

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

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

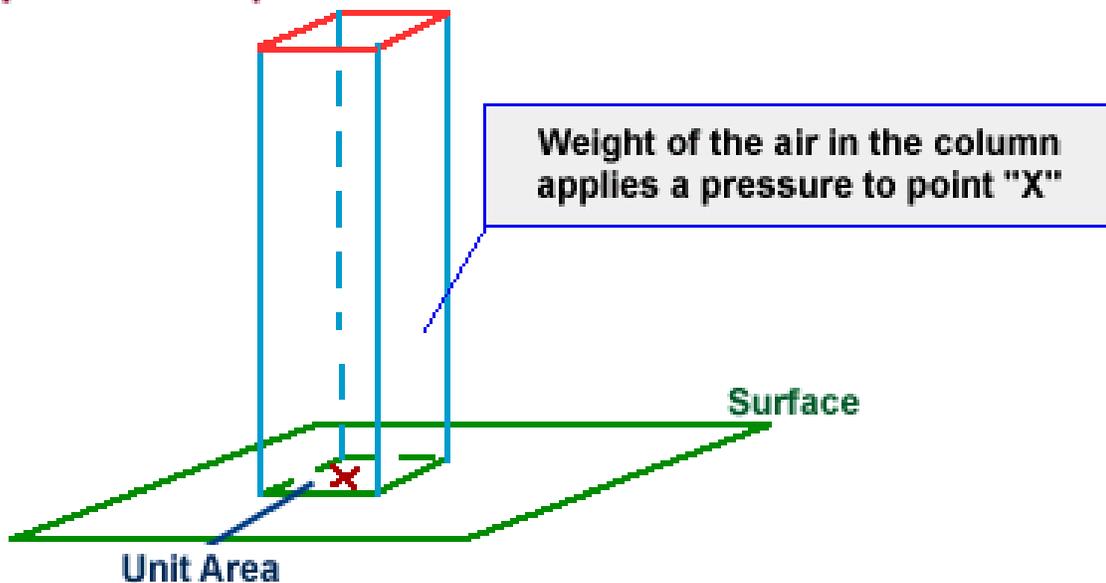
Atmospheric pressure can be measured by any of several methods. The common laboratory method uses the mercury column barometer. The height of the mercury column serves as an indicator of atmospheric pressure. At sea level and at a temperature of 0° Celsius (C), the height of the mercury column is approximately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

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

The atmospheric pressure does not vary uniformly with altitude. It changes very rapidly. Atmospheric pressure is defined as the force per unit area exerted against a surface by the weight of the air above that surface.

In the diagram, the pressure at point "X" increases as the weight of the air above it increases. The same can be said about decreasing pressure, where the pressure at point "X" decreases if the weight of the air above it also decreases.

Top of the Atmosphere



Barometric Loop

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

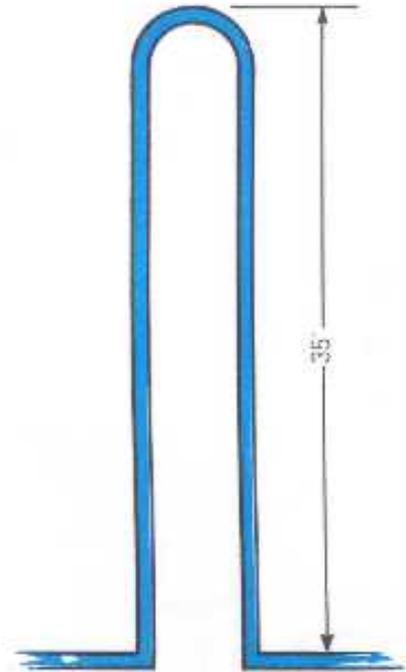
Its operation, in the protection against backsiphonage, is based upon the principle that a water column, at sea level pressure, will not rise above 33.9 feet. In general, barometric loops are locally fabricated, and are 35 feet high.

Pressure may be referred to using an absolute scale, pounds per square inch absolute (**psia**), or gauge scale, (**psiag**).

Absolute pressure and gauge pressure are related.

Absolute pressure is equal to gauge pressure plus the atmospheric pressure. At sea level, the atmospheric pressure is 14.7 psia.

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



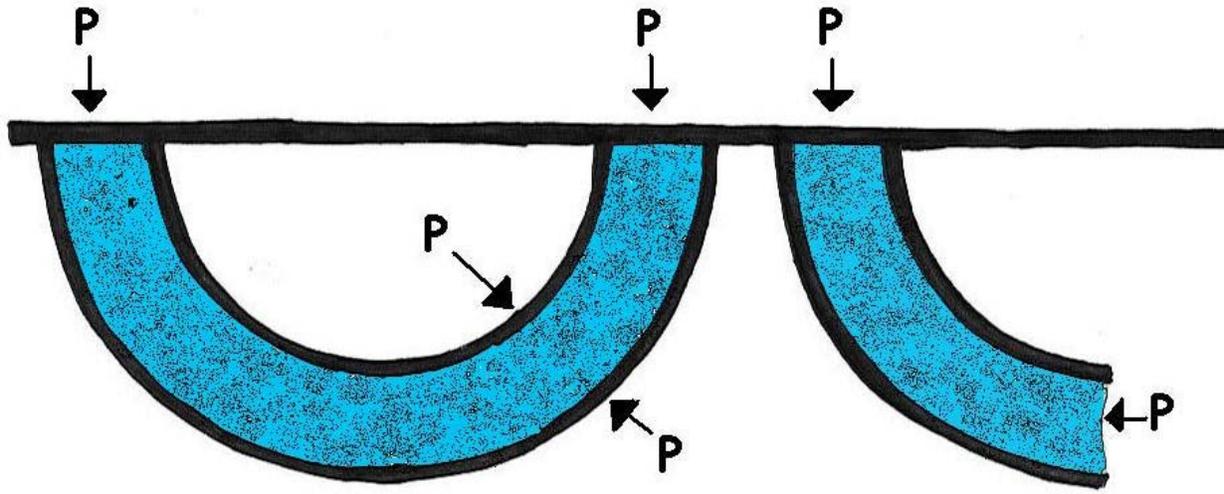
UNIT	ABBREVIATION	EQUIVALENT NUMBER OF PASCALS
ATMOSPHERE	atm	1 atm = 101,325 Pa
BAR	bar	1 bar = 100,025 Pa
MILLIMETER OF MERCURY	mmHg	1 mmHg = 133.322 Pa
INCHES OF MERCURY	inHg	1 inHg = 3386 Pa
PASCAL	Pa	1
KILOPASCAL	kPa	1 kPa = 1000 Pa
POUNDS PER SQUARE INCH	psi	1 psi = 6,893 Pa
TORR	torr	1 torr = 133.322 Pa



DIFFERENT UNITS OF PRESSURE

Pressure

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



EQUALITY OF PRESSURE

A fluid, therefore, is a substance that cannot exert any permanent forces tangential to a boundary. Any force that it exerts on a boundary must be normal to the boundary. Such a force is proportional to the area on which it is exerted, and is called a pressure. We can imagine any surface in a fluid as dividing the fluid into parts pressing on each other, as if it were a thin material membrane, and so think of the pressure at any point in the fluid, not just at the boundaries. In order for any small element of the fluid to be in equilibrium, the pressure must be the same in all directions (or the element would move in the direction of least pressure), and if no other forces are acting on the body of the fluid, the pressure must be the same at all neighboring points.

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

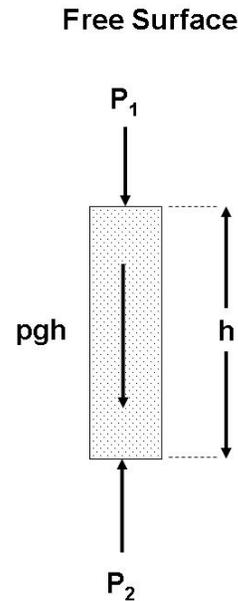
On earth, fluids are also subject to the force of gravity, which acts vertically downward, and has a magnitude $\gamma = \rho g$ per unit volume, where g is the acceleration of gravity, approximately 981 cm/s^2 or 32.15 ft/s^2 , ρ is the density, the mass per unit volume, expressed in g/cm^3 , kg/m^3 , or slug/ft^3 , and γ is the specific weight, measured in lb/in^3 , or lb/ft^3 (pcf). Gravitation is an example of a body force that disturbs the equality of pressure in a fluid. The presence of the gravitational body force causes the pressure to increase with depth, according to the equation $dp = \rho g dh$, in order to support the water above.

We call this relation the barometric equation, for when this equation is integrated, we find the variation of pressure with height or depth. If the fluid is incompressible, the equation can be integrated at once, and the pressure as a function of depth h is $p = \rho gh + p_0$.

The density of water is about 1 g/cm^3 , or its specific weight is 62.4 pcf . We may ask what depth of water gives the normal sea-level atmospheric pressure of 14.7 psi , or 2117 psf .

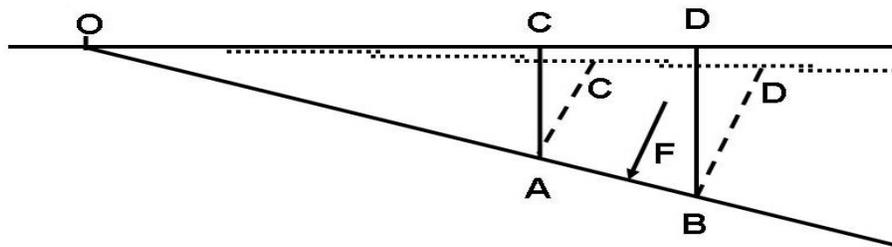
This is simply $2117 / 62.4 = 33.9 \text{ ft}$ of water. This is the maximum height to which water can be raised by a suction pump, or, more correctly, can be supported by atmospheric pressure. Professor James Thomson (brother of William Thomson, Lord Kelvin) illustrated the equality of pressure by a "curtain-ring" analogy shown in the diagram. A section of the toroid was identified, imagined to be solidified, and its equilibrium was analyzed.

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



Increase of Pressure with Depth

This can be extended to any direction whatever, so Pascal's Principle is established. This demonstration is similar to the usual one using a triangular prism and considering the forces on the end and lateral faces separately.



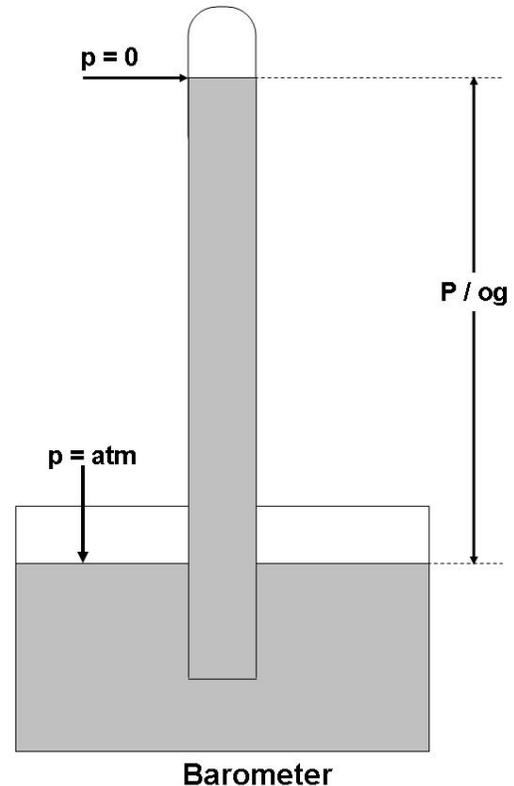
Thrust on a Plane

Free Surface Perpendicular to Gravity

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

Geometric Arguments

Ingenious geometric arguments can be used to substitute for easier, but less transparent arguments using calculus. For example, the force acting on one side of an inclined plane surface whose projection is AB can be found as in the diagram on the previous page. O is the point at which the prolonged projection intersects the free surface. The line AC' perpendicular to the plane is made equal to the depth AC of point A, and line BD' is similarly drawn equal to BD. The line OD' also passes through C', by proportionality of triangles OAC' and OAD'. Therefore, the thrust F on the plane is the weight of a prism of fluid of cross-section AC'D'B, passing through its centroid normal to plane AB. Note that the thrust is equal to the density times the area times the depth of the center of the area; its line of action does not pass through the center, but below it, at the center of thrust. The same result can be obtained with calculus by summing the pressures and the moments, of course.



Atmospheric Pressure and its Effects

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

Now start the pump. When it has sucked all the air out above the water, the pressure on the surface of the water inside the pipe is zero, and the pressure at the level of the water on the outside of the pipe is still the atmospheric pressure. Of course, there is the vapor pressure of the water to worry about if you want to be precise, but we neglect this complication in making our point. We require a column of water 33.9 ft high inside the pipe, with a vacuum above it, to balance the atmospheric pressure. Now do the same thing with liquid mercury, whose density at 0 °C is 13.5951 times that of water. The height of the column is 2.494 ft, 29.92 in, or 760.0 mm.

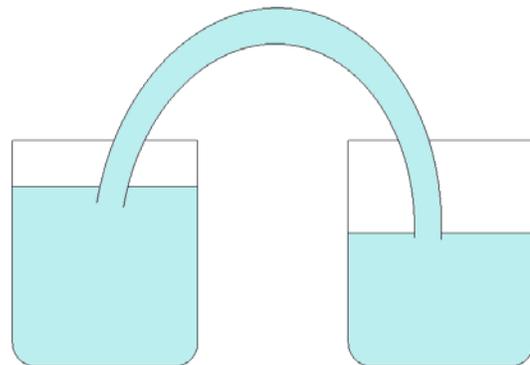
Standard Atmospheric Pressure

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

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

An aneroid barometer uses a partially evacuated chamber of thin metal that expands and contracts according to the external pressure. This movement is communicated to a needle that revolves in a dial. The materials and construction are arranged to give a low temperature coefficient. The instrument must be calibrated before use, and is usually arranged to read directly in elevations. An aneroid barometer is much easier to use in field observations, such as in reconnaissance surveys. In a particular case, it would be read at the start of

the day at the base camp, at various points in the vicinity, and then finally at the starting point, to determine the change in pressure with time. The height differences can be calculated from $h = 60,360 \log (P/p) [1 + (T + t - 64)/986]$ feet, where P and p are in the same units, and T , t are in °F. An absolute pressure is referring to a vacuum, while a gauge pressure is referring to the atmospheric pressure at the moment. A negative gauge pressure is a (partial) vacuum. When a vacuum is stated to be so many inches, this means the pressure below the atmospheric pressure of about 30 in. A vacuum of 25 inches is the same thing as an absolute pressure of 5 inches (of mercury).



Siphon

Vacuum

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

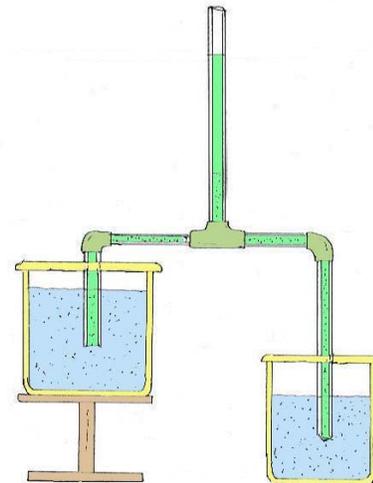
Water Pressure

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

Pressures are very frequently stated in terms of the height of a fluid. If it is the same fluid whose pressure is being given, it is usually called "head," and the factor connecting the head and the pressure is the weight density ρg . In the English engineer's system, weight density is in pounds per cubic inch or cubic foot. A head of 10 ft is equivalent to a pressure of 624 psf, or 4.33 psi. It can also be considered an energy availability of ft-lb per lb. Water with a pressure head of 10 ft can furnish the same energy as an equal amount of water raised by 10 ft. Water flowing in a pipe is subject to head loss because of friction.

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

Another application of pressure is the siphon. The name is Greek for the tube that was used for drawing wine from a cask. This is a tube filled with fluid connecting two containers of fluid, normally rising higher than the water levels in the two containers, at least to pass over their rims. In the diagram, the two water levels are the same, so there will be no flow. When a siphon goes below the free water levels, it is called an inverted siphon. If the levels in the two basins are not equal, fluid flows from the basin with the higher level into the one with the lower level, until the levels are equal.



PASCAL'S SIPHON

A siphon can be made by filling the tube, closing the ends, and then putting the ends under the surface on both sides. Alternatively, the tube can be placed in one fluid and filled by sucking on it. When it is full, the other end is put in place. The analysis of the siphon is easy, and should be obvious. The pressure rises or falls as described by the barometric equation through the siphon tube. There is obviously a maximum height for the siphon which is the same as the limit of the suction pump, about 34 feet. Inverted siphons are sometimes used in pipelines to cross valleys. Differences in elevation are usually too great to use regular siphons to cross hills, so the fluids must be pressurized by pumps so the pressure does not fall to zero at the crests.

Liquids at Rest

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

Pressure and Force

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

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

Force means a total push or pull. It is the push or pull exerted against the total area of a particular surface and is expressed in pounds or grams. Pressure means the amount of push or pull (force) applied to each unit area of the surface and is expressed in pounds per square inch (lb/in²) or grams per square centimeter (gm/cm²). Pressure maybe exerted in one direction, in several directions, or in all directions.

Computing Force, Pressure, and Area

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

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

Development of Hydraulics

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

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

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

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

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

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

Evangelista Torricelli

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

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

Burgomeister of Magdeburg

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



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

Torr

The mm of mercury is sometimes called a torr after Torricelli, and Pascal also has been honored by a unit of pressure, a newton per square meter or 10 dyne/cm^2 . A cubic centimeter of air weighs 1.293 mg under standard conditions, and a cubic meter 1.293 kg, so air is by no means even approximately weightless, though it seems so.

The weight of a sphere of air as small as 10 cm in diameter is 0.68 g, easily measurable with a chemical balance. The pressure of the atmosphere is also considerable, like being 34 ft under water, but we do not notice it. A bar is 106 dyne/cm^2 , very close to a standard atmosphere, which is 1.01325 bar. In meteorology, the millibar, mb, is used. $1 \text{ mb} = 1.333 \text{ mmHg} = 100 \text{ Pa} = 1000 \text{ dyne/cm}^2$.

A kilogram-force per square centimeter is $981,000 \text{ dyne/cm}^2$, also close to one atmosphere. In Europe, it has been considered approximately 1 atm, as in tire pressures and other engineering applications. As we have seen, in English units the atmosphere is about 14.7 psi, and this figure can be used to find other approximate equivalents.

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

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

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

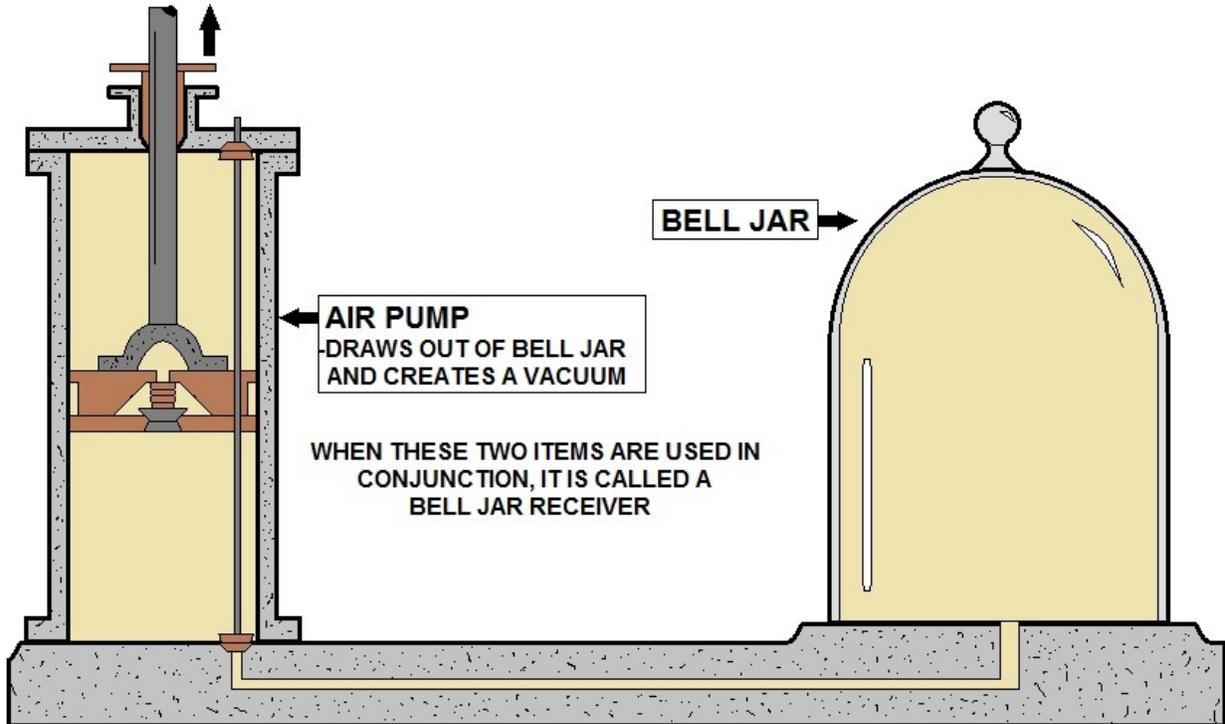
In an isothermal atmosphere, the pressure decreases exponentially. The quantity $H = RT/Mg$ is called the "height of the homogeneous atmosphere" or the scale height, and is about 8 km at $T = 273K$.

This quantity gives the rough scale of the decrease of pressure with height. Of course, the real atmosphere is by no means isothermal close to the ground, but cools with height nearly linearly at about $6.5^\circ\text{C}/\text{km}$ up to an altitude of about 11 km at middle latitudes, called the tropopause. Above this is a region of nearly constant temperature, the stratosphere, and then at some higher level the atmosphere warms again to near its value at the surface. Of course, there are variations from the average values. When the temperature profile with height is known, we can find the pressure by numerical integration quite easily.

Meteorology

The atmospheric pressure is of great importance in meteorology, since it determines the winds, which generally move at right angles to the direction of most rapid change of pressure, that is, along the isobars, which are contours of constant pressure. Certain typical weather patterns are associated with relatively high and relatively low pressures, and how they vary with time. The barometric pressure may be given in popular weather forecasts, though few people know what to do with it. If you live at a high altitude, your local weather reporter may report the pressure to be, say, 29.2 inches, but if you have a real barometer, you may well find that it is closer to 25 inches. At an elevation of 1500 m (near Denver, or the top of the Puy de Dôme), the atmospheric pressure is about 635 mm, and water boils at 95°C .

In fact, altitude is quite a problem in meteorology, since pressures must be measured at a common level to be meaningful. The barometric pressures quoted in the news are reduced to sea level by standard formulas that amount to assuming that there is a column of air from your feet to sea level with a certain temperature distribution, and adding the weight of this column to the actual barometric pressure. This is only an arbitrary 'fix' and leads to some strange conclusions, such as the permanent winter highs above high plateaus that are really imaginary.



BELL JAR RECEIVER

Pascal's Law

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

Pressure due to the weight of a liquid, at any level, depends on the depth of the fluid from the surface. If the exposed face of the pressure gauges are moved closer to the surface of the liquid, the indicated pressure will be less. When the depth is doubled, the indicated pressure is doubled. Thus the pressure in a liquid is directly proportional to the depth.

Consider a container with vertical sides that is 1 foot long and 1 foot wide. Let it be filled with water 1 foot deep, providing 1 cubic foot of water. 1 cubic foot of water weighs 62.4 pounds. Using this information and equation, $P = F/A$, we can calculate the pressure on the bottom of the container.

Since there are 144 square inches in 1 square foot, this can be stated as follows: the weight of a column of water 1 foot high, having a cross-sectional area of 1 square inch, is 0.433 pound. If the depth of the column is tripled, the weight of the column will be 3×0.433 , or 1.299 pounds, and the pressure at the bottom will be 1.299 lb/in² (psi), since pressure equals the force divided by the area.

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

Gravity

Gravity is one of the four forces of nature. The strength of the gravitational force between two objects depends on their masses. The more massive the objects are, the stronger the gravitational attraction.

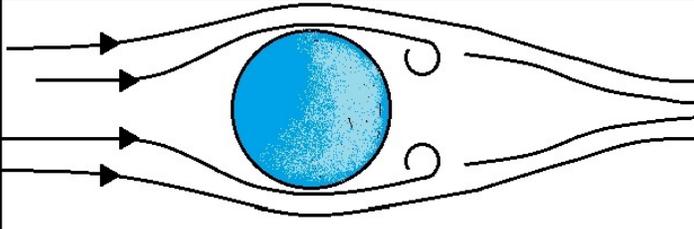
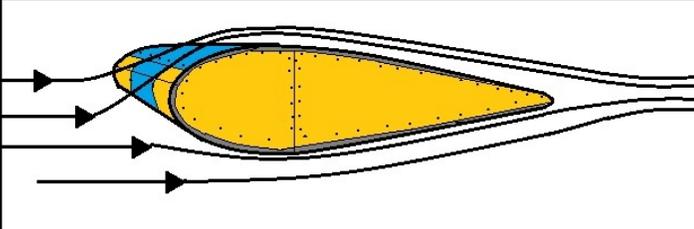
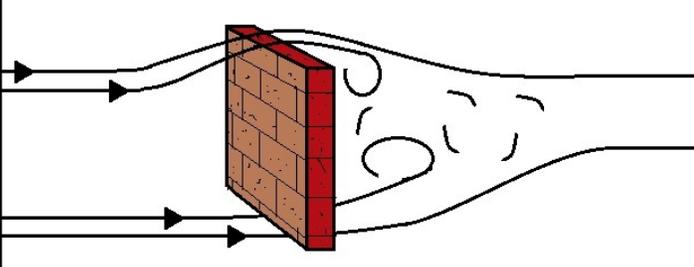
When you pour water out of a container, the earth's gravity pulls the water towards the ground. The same thing happens when you put two buckets of water, with a tube between them, at two different heights. You must work to start the flow of water from one bucket to the other, but then gravity takes over and the process will continue on its own.

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

Static Pressure

Static pressure exists in addition to any dynamic factors that may also be present at the same time. Pascal's law states that a pressure set up in a fluid acts equally in all directions and at right angles to the containing surfaces. This covers the situation only for fluids at rest or practically at rest. It is true only for the factors making up static head. Obviously, when velocity becomes a factor it must have a direction, and as previously explained, the force related to the velocity must also have a direction, so that Pascal's law alone does not apply to the dynamic factors of fluid power.

The dynamic factors of inertia and friction are related to the static factors. Velocity head and friction head are obtained at the expense of static head. However, a portion of the velocity head can always be reconverted to static head. Force, which can be produced by pressure or head when dealing with fluids, is necessary to start a body moving if it is at rest, and is present in some form when the motion of the body is arrested; therefore, whenever a fluid is given velocity, some part of its original static head is used to impart this velocity, which then exists as velocity head.

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

DRAG FORCE (VISCOUS)

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



Volume and Velocity of Flow

The volume of a liquid passing a point in a given time is known as its *volume of flow* or flow rate. The volume of flow is usually expressed in gallons per minute (gpm) and is associated with relative pressures of the liquid, such as 5 gpm at 40 psi.

The *velocity of flow* or velocity of the fluid is defined as the average speed at which the fluid moves past a given point. It is usually expressed in feet per second (fps) or feet per minute (fpm). Velocity of flow is an important consideration in sizing the hydraulic lines.

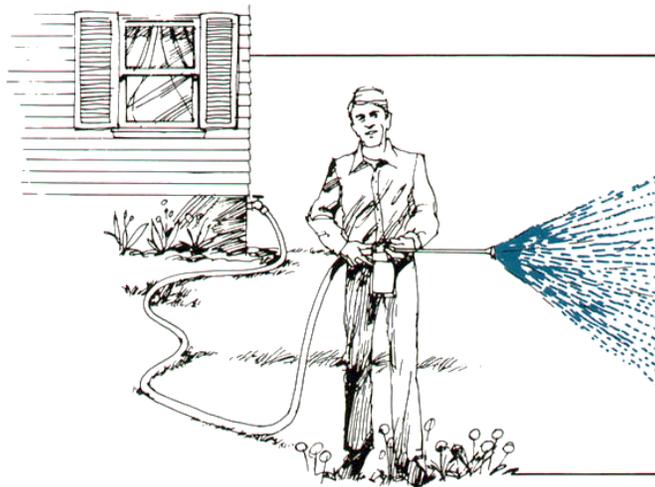
Volume and velocity of flow are often considered together. With other conditions unaltered—that is, with volume of input unchanged—the velocity of flow increases as the cross section or size of the pipe decreases, and the velocity of flow decreases as the cross section increases. For example, the velocity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

Bernoulli's Principle

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

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

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



Action of a spray atomizer.

Bernoulli's principle also tells us why windows tend to explode, rather than implode in hurricanes: the very high speed of the air just outside the window causes the pressure just outside to be much less than the pressure inside, where the air is still.

The difference in force pushes the windows outward, and hence they explode. If you know that a hurricane is coming it is therefore better to open as many windows as possible, to equalize the pressure inside and out.

Another example of Bernoulli's principle at work is in the lift of aircraft wings and the motion of "curve balls" in baseball. In both cases the design is such as to create a speed differential of the flowing air past the object on the top and the bottom - for aircraft wings this comes from the movement of the flaps, and for the baseball it is the presence of ridges. Such a speed differential leads to a pressure difference between the top and bottom of the object, resulting in a net force being exerted, either upwards or downwards.

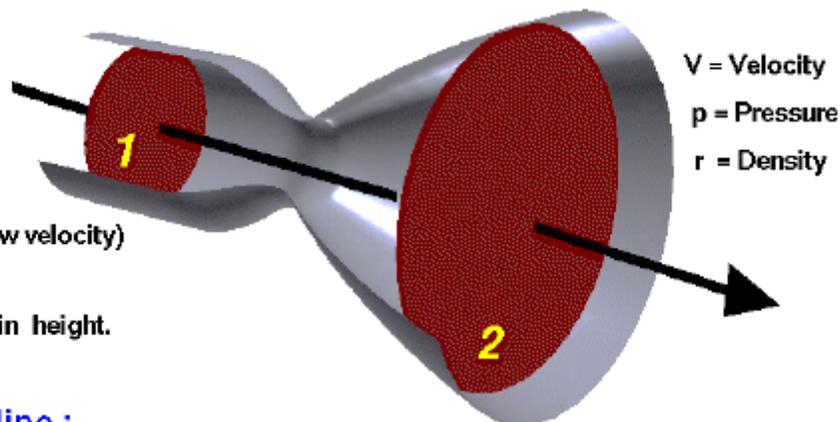


Bernoulli's Equation

Glenn
Research
Center

Restrictions :

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

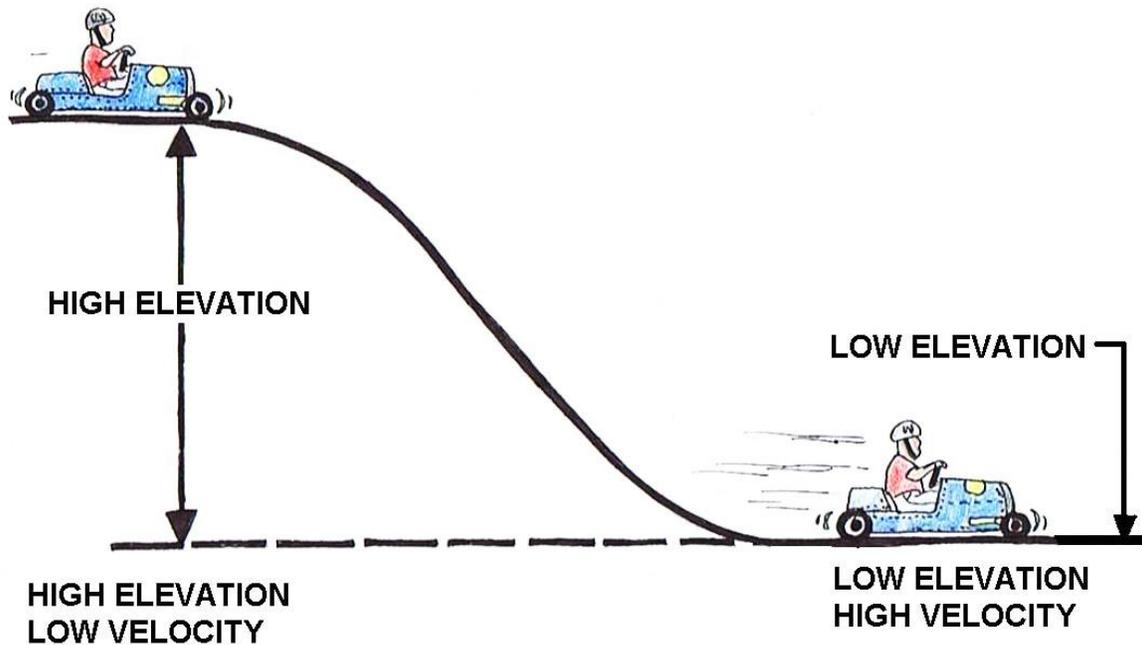


Along a streamline :

static pressure + dynamic pressure = total pressure

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

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



Understanding the Venturi

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

It is clear that all the flow must pass from the larger section to the smaller section. Or in other words, the flow rate will remain the same in the large and small portions of the tube. The flow rate is the same rate, but the velocity changes. The velocity is greater in the small portion of the tube. There is a relationship between the pressure energy and the velocity energy; if velocity increases the pressure energy must decrease.

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

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



If you ever need to prove for a need for backflow protection, visit your local fair grounds or trailer park. I guarantee that you'll find all you need at the concession stand and most health departments and plumbing officials either do not know or could care less. Here is a photograph of a drinking water and sewer connection in the same meter box with the sewer backing up.

The white garden hose is for drinking water and it is back siphoning the sewage water, the sheen is a reflection of the water pulsating in and out of the meter box.

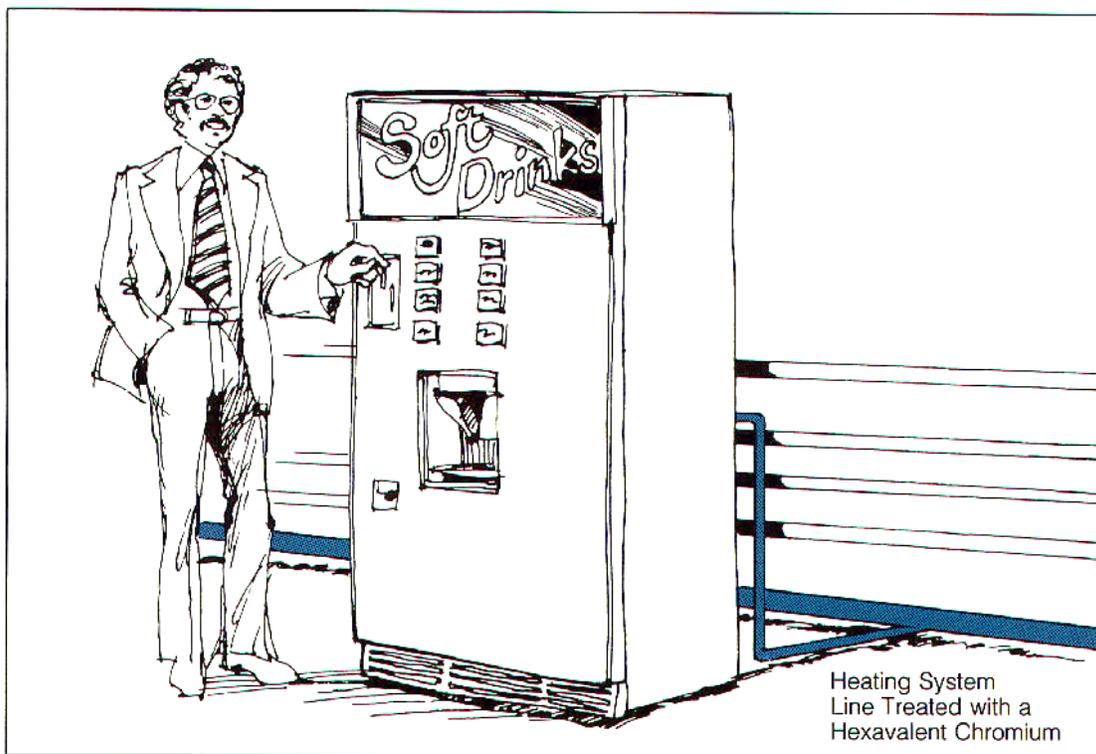
What is backflow? *Reverse flow condition.*

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

Common Cross-Connection Terms

Cross-Connection

A cross-connection is any temporary or permanent connection between a public water system or consumer's potable (i.e., drinking) water system and any source or system containing non-potable water or other substances. An example is the piping between a public water system or consumer's potable water system and an auxiliary water system, cooling system, or irrigation system.

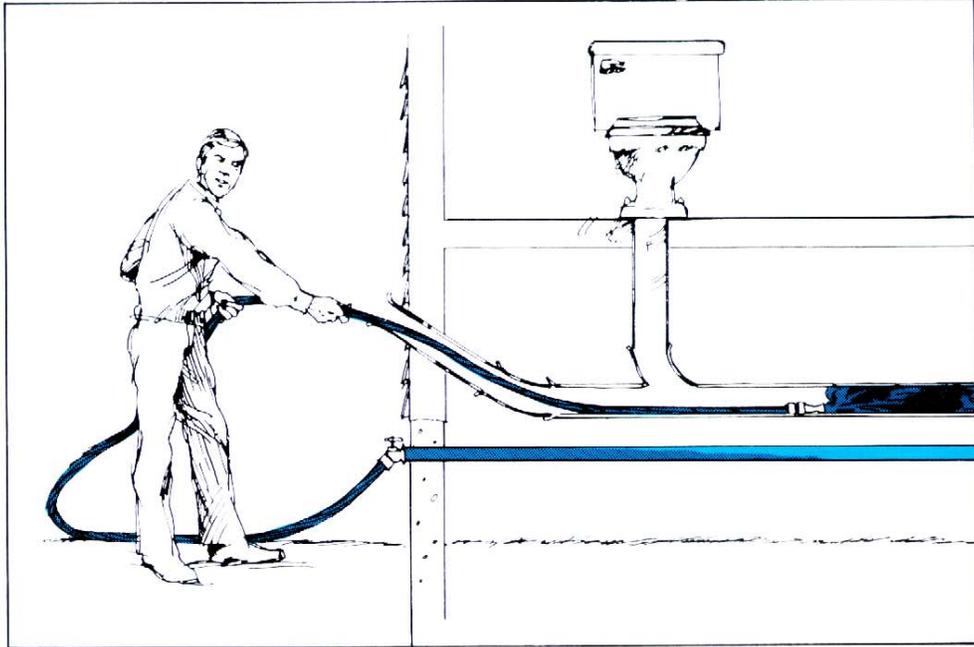
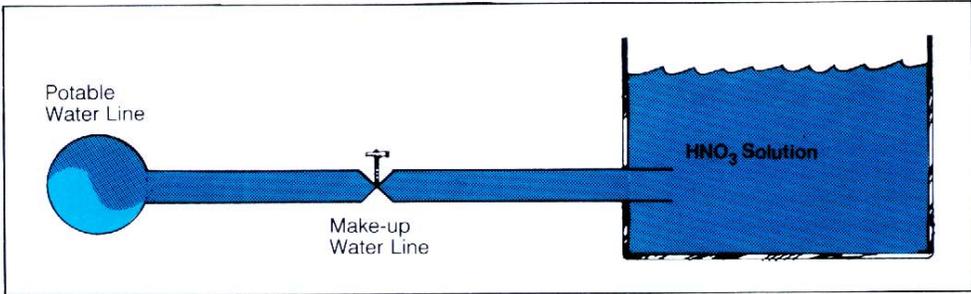
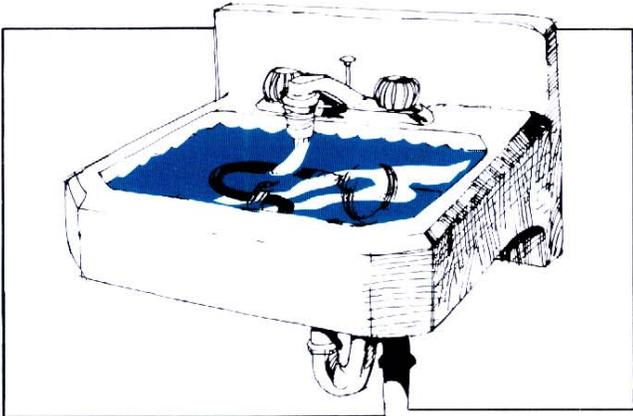


Several cross-connections have been made to soda machines, the one to worry about is when you have a copper water line hooked to CO₂ without a backflow preventer. The reason is that the CO₂ will mix in the water and create copper carbonic acid which can be deadly. This is one reason that you will see clear plastic lines at most soda machines and no copper lines. Most codes require a stainless steel RP backflow assembly at soda machines.

Why does a soft drink dispensing machine require backflow protection?

Soft drink dispensers (post-mix carbonators) use carbonated water mixed under pressure with syrup and water to provide soft drinks beverages. Many, if not most water pipes are made of copper. When carbonated water comes into contact with copper, it chemically dissolves the copper from the pipe. This copper-carbonate solution has been proven to be a risk to the digestive system.

Common Cross-Connections

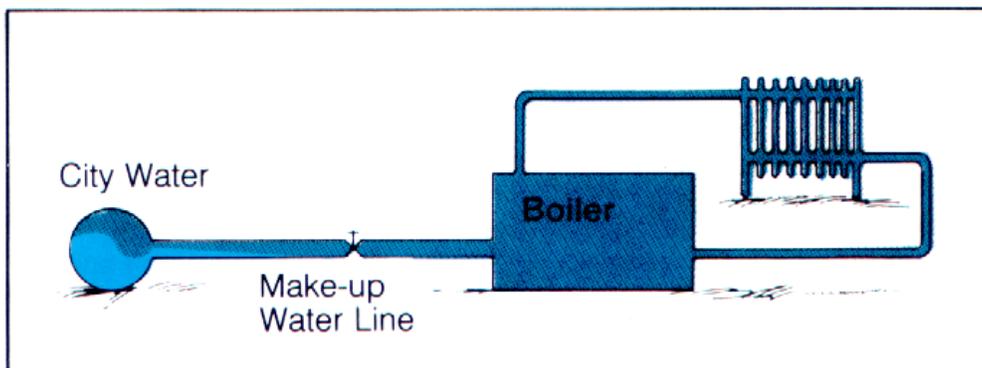


Bottom, a direct connection between water and sewage. A perfect cross-connection and it happens all day long.

Backflow

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

Backsiphonage

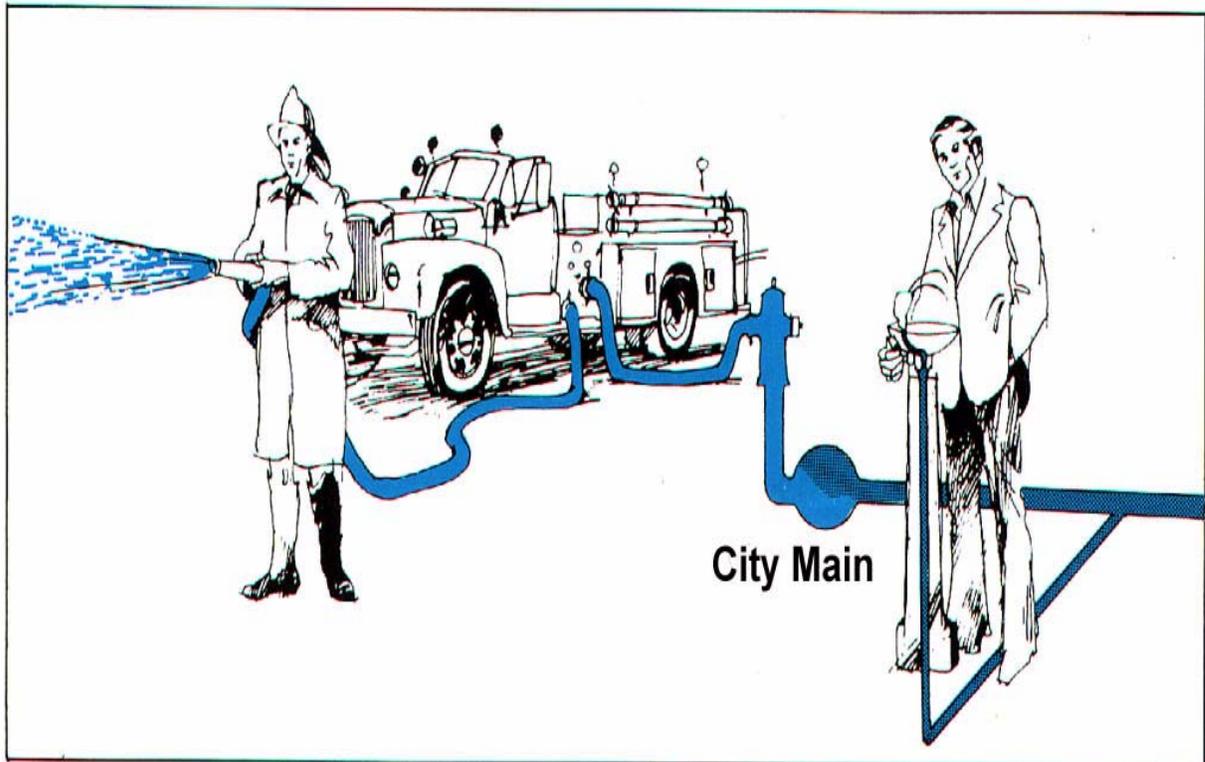


Backpressure caused by heat.

Backsiphonage

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

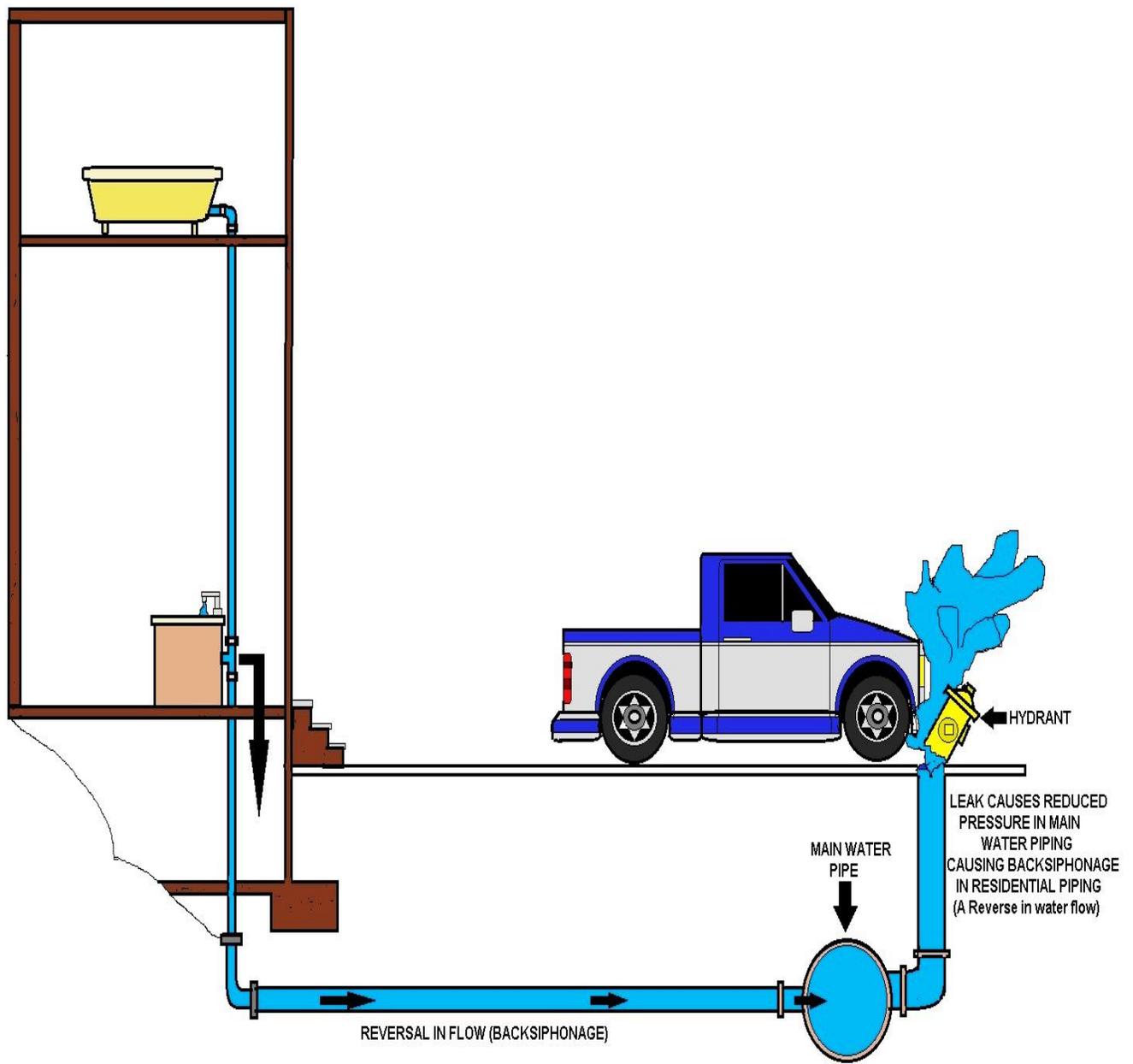
Backsiphonage can occur when there is a stoppage of water supply due to nearby firefighting, a break in a water main, etc.



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

Backpressure is rarer, but does happen in areas of high elevation, like tall buildings or buildings with pumps.

A good example is the pressure exerted by a building that is 100 feet tall is about 43 PSI, the water main feeding the building is at 35 PSI. The water will flow back to the water main. Never drink water or coffee inside a funeral home, vet clinic or hospital.

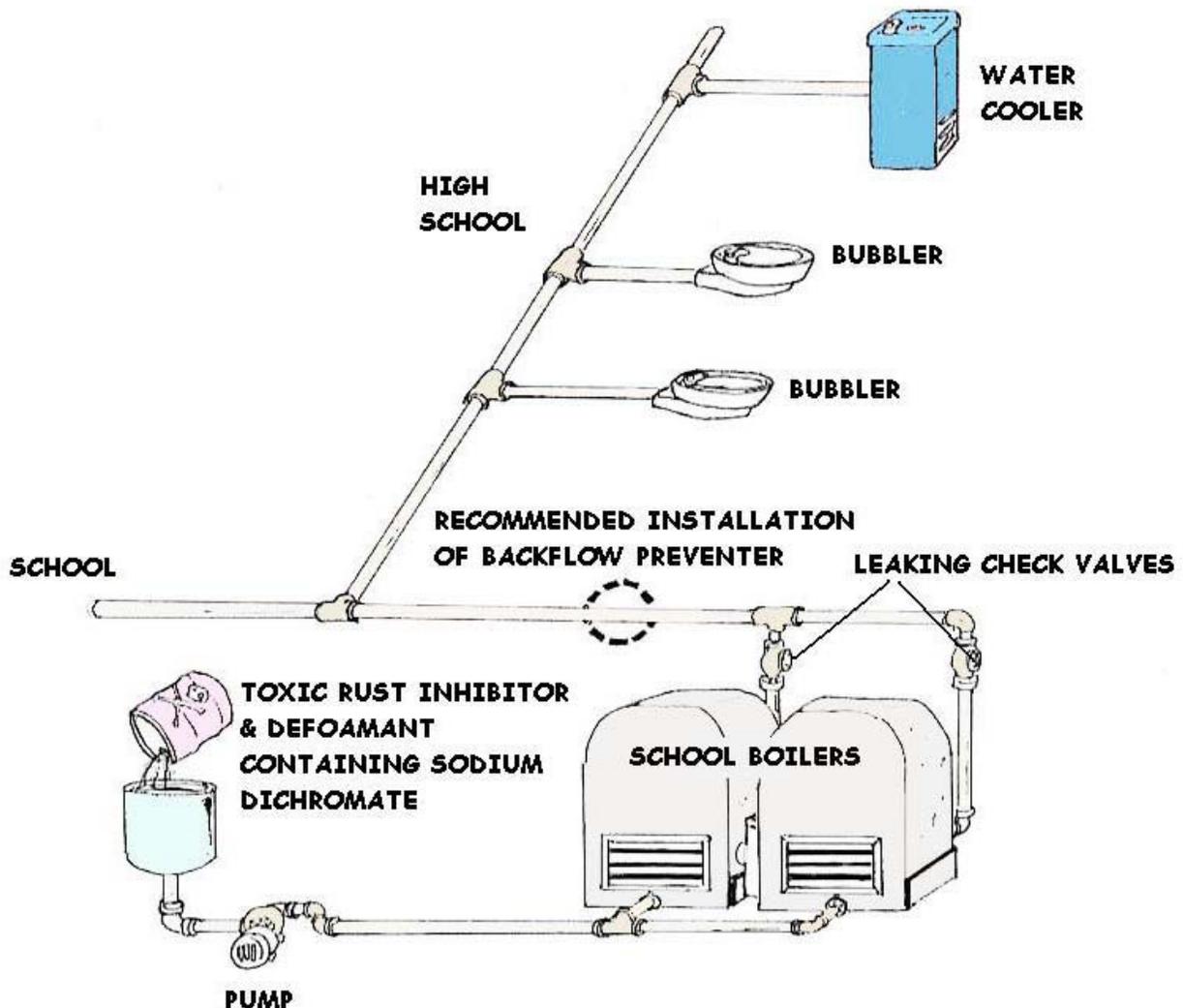


BACKSIPHONAGE

Backpressure

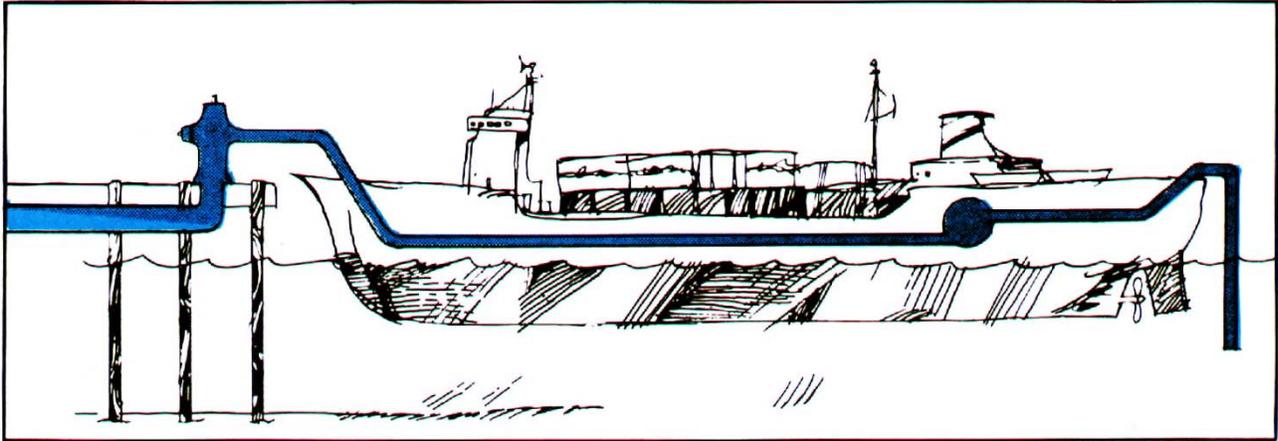
Backpressure backflow is backflow caused by a downstream pressure that is greater than the upstream or supply pressure in a public water system or consumer's potable water system. Backpressure (i.e., downstream pressure that is greater than the potable water supply pressure) can result from an increase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

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



Backpressure Examples

Booster pumps, pressure vessels, elevation, heat



Here we see the backpressure of salt water back into the public water system from a ship's pressure pump. Most water providers are now requiring a RP assembly at the hydrant.

What is a Backflow Preventer?

A backflow preventer is a means or mechanism to prevent backflow. The basic means of preventing backflow is an air gap, which either eliminates a cross-connection or provides a barrier to backflow.

The basic mechanism for preventing backflow is a mechanical backflow preventer, which provides a physical barrier to backflow. The principal types of mechanical backflow preventer are the reduced-pressure principle assembly, the pressure vacuum breaker assembly, and the double check valve assembly.

Residential Dual Check Valve

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

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

Types of Backflow Prevention Methods and Assemblies

Backflow Devices

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

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

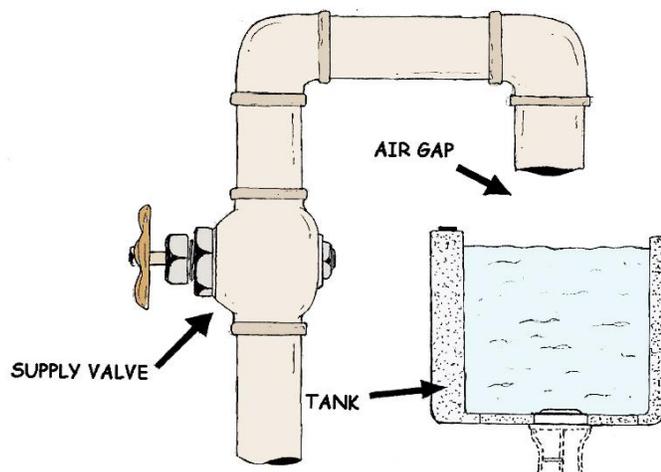
The type of device selected for a particular installation depends on several factors. First, the degree of hazard must be assessed. A high hazard facility is one in which a cross connection could be hazardous to health, such as a chrome plating shop or a sewage treatment plant. A low hazard situation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

Second, the plumbing arrangement must be considered.

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

Approved Air Gap Separation (AG)

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



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



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

Air Gap

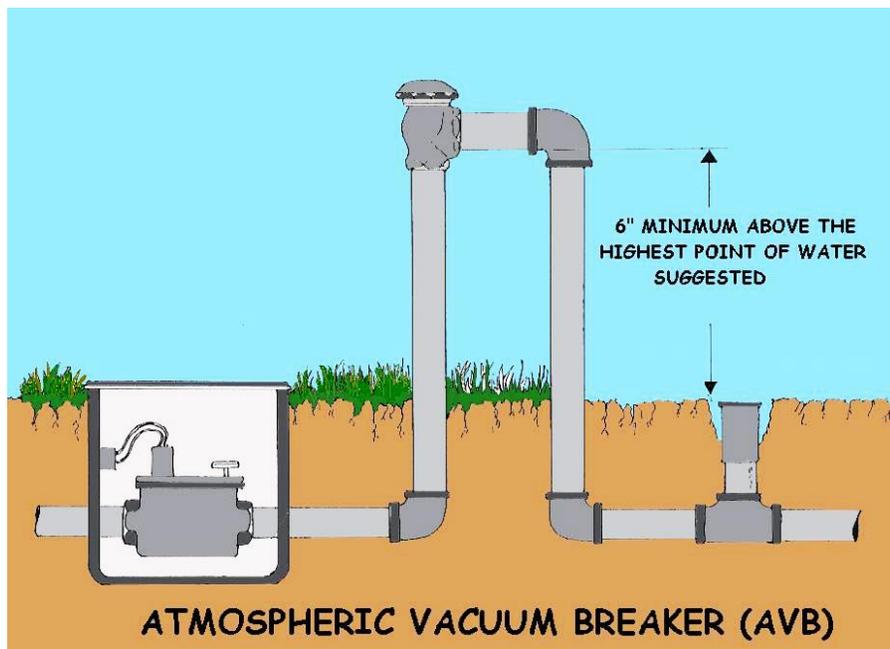
An air gap is a physical disconnection between the free flowing discharge end of a potable water pipeline and the top of an open receiving vessel. The air gap must be at least two times the diameter of the supply pipe and not less than one inch. This type of protection is acceptable for high hazard installations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

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



Vacuum Breakers

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



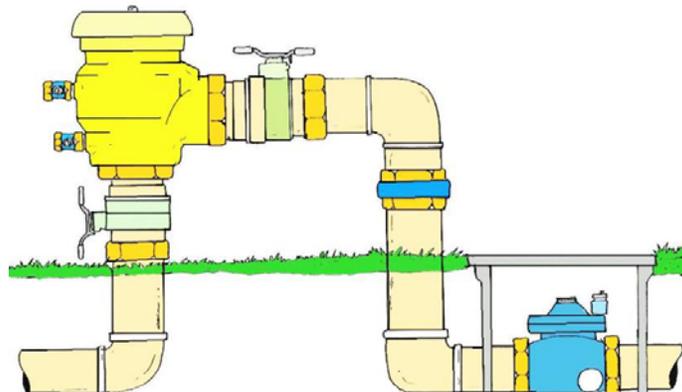
Atmospheric Vacuum Breaker (AVB) The Atmospheric Vacuum Breaker contains a float check (poppet), a check seat, and an air inlet port. The device allows air to enter the water line when the line pressure is reduced to a gauge pressure of zero or below. The air inlet valve is not internally loaded. To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

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

Pressure Vacuum Breaker Assembly (PVB)

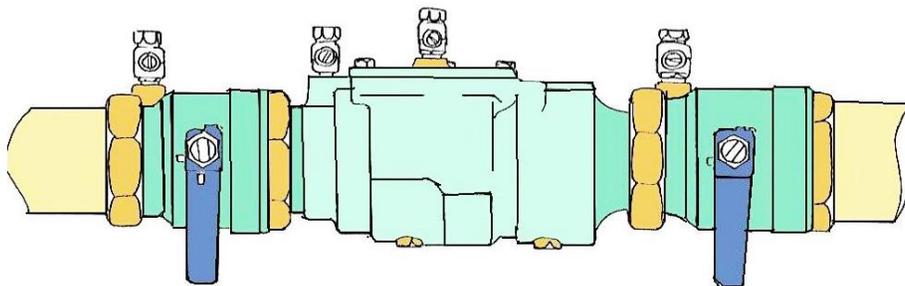
The Pressure Vacuum Breaker Assembly consists of a spring loaded check valve, an independently operating air inlet valve, two resilient seated shutoff valves, and two properly located resilient seated test cocks. It shall be installed as a unit as shipped by the manufacturer. The air inlet valve is internally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

PRESSURE VACUUM BREAKER ASSEMBLY



Double Check Valve Assembly (DC)

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



DOUBLE CHECK VALVE ASSEMBLY

Reduced Pressure Backflow Assembly (RP)

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

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

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



Two brand new RPs.

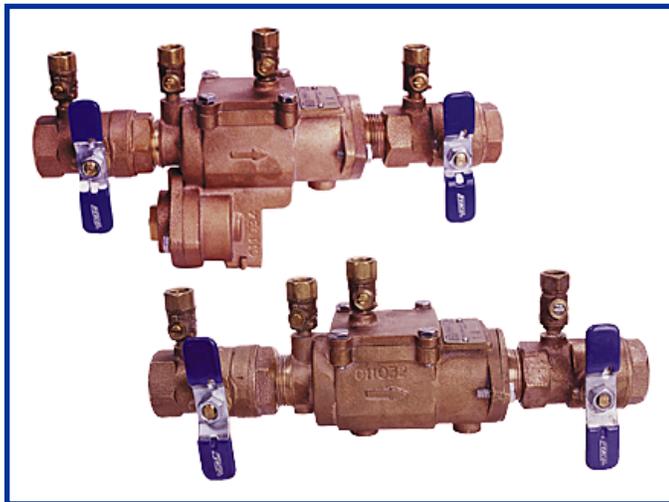
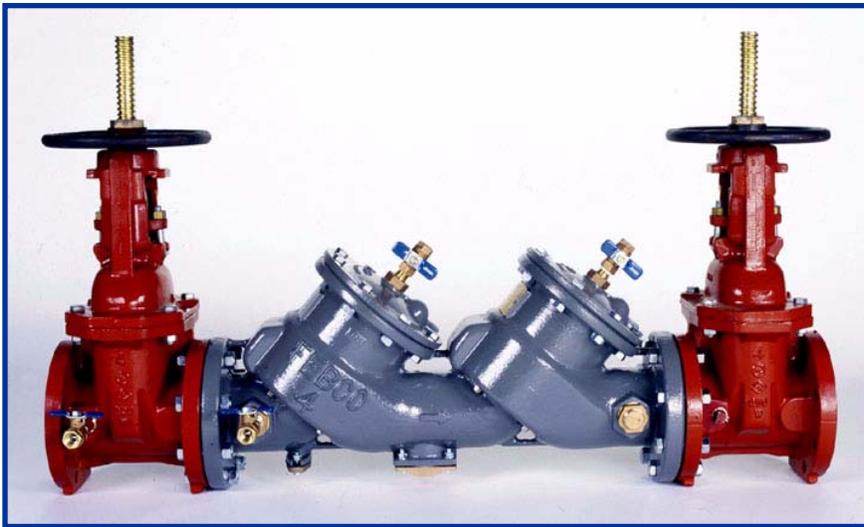
Different Types of RPs

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

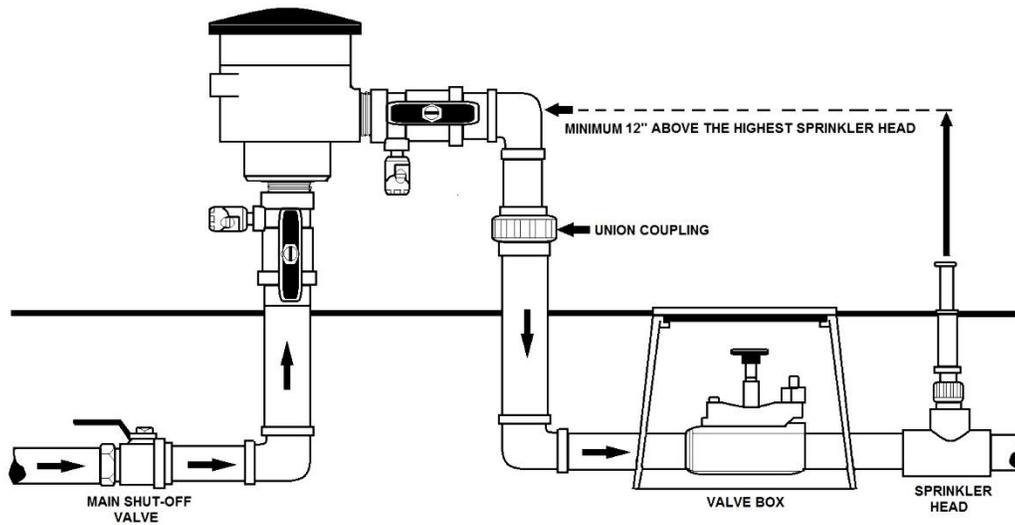
The reduced pressure device can be used for high hazard situations under both backpressure and backsiphonage conditions. Under normal conditions, the second check valve should prevent backflow.

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

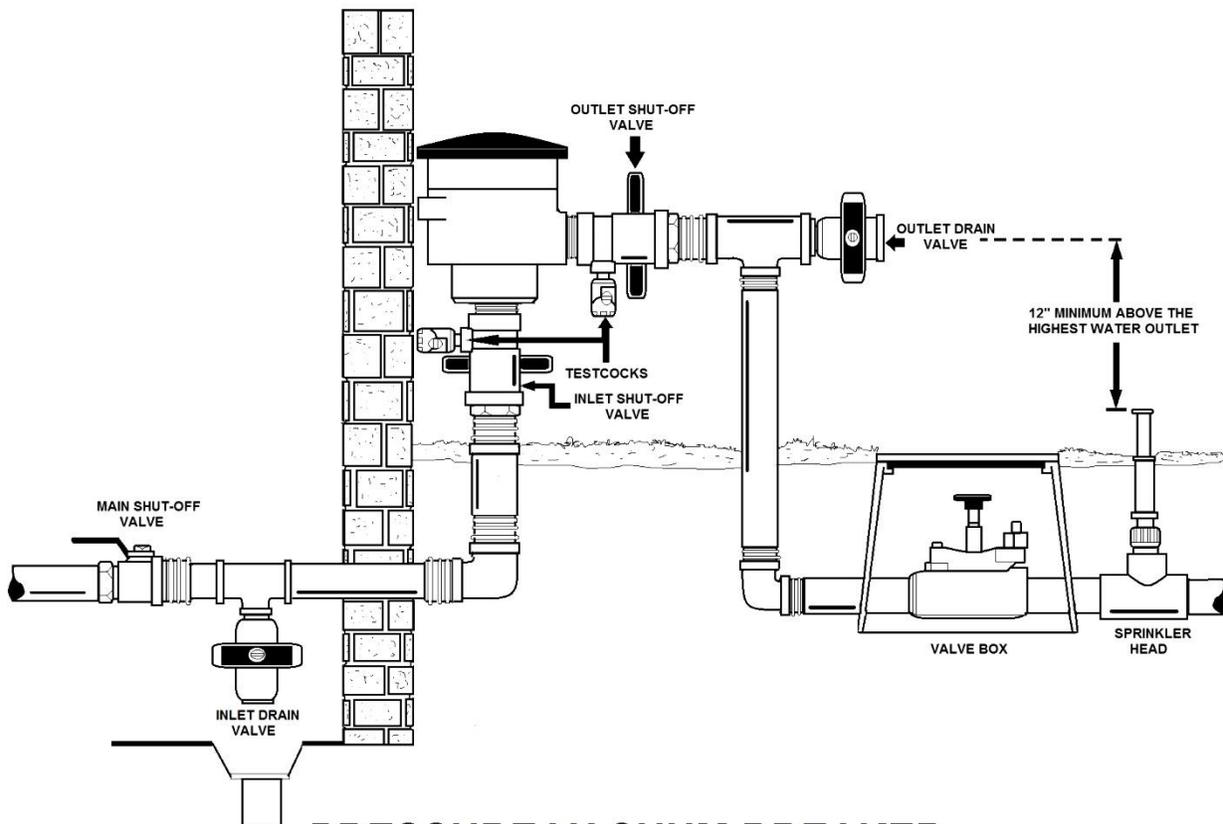
The reduced pressure zone port opens anytime pressure in the zone comes within 2 psi of the supply pressure.



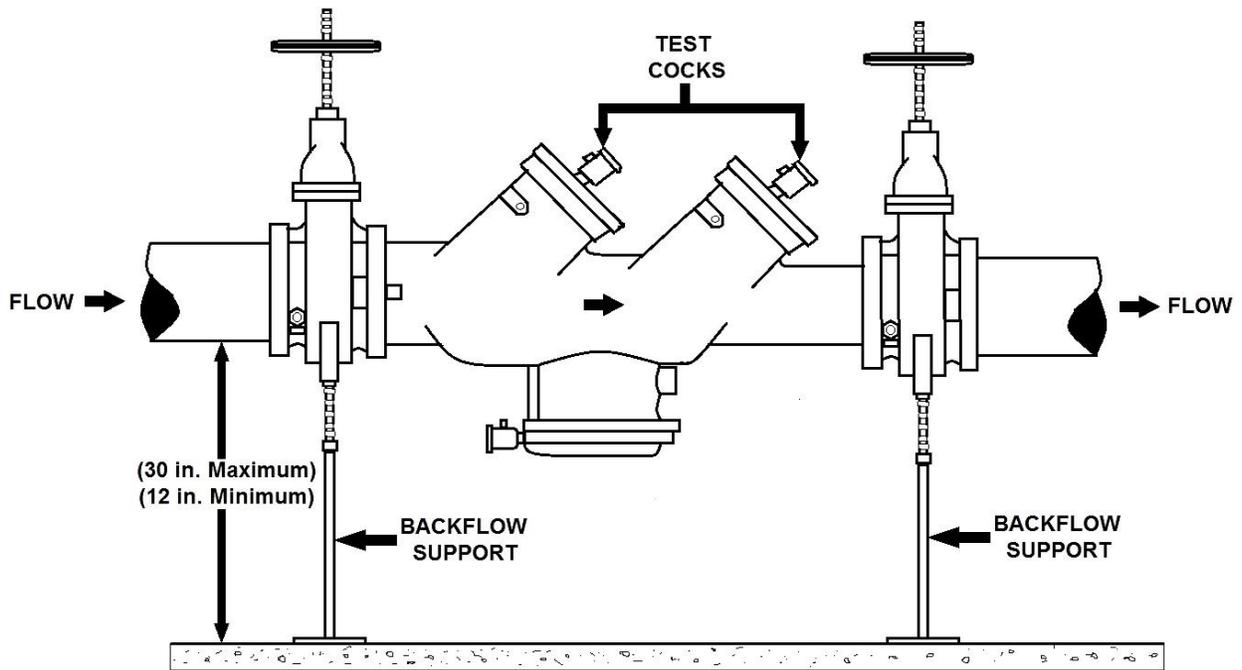
Standard Installation Details



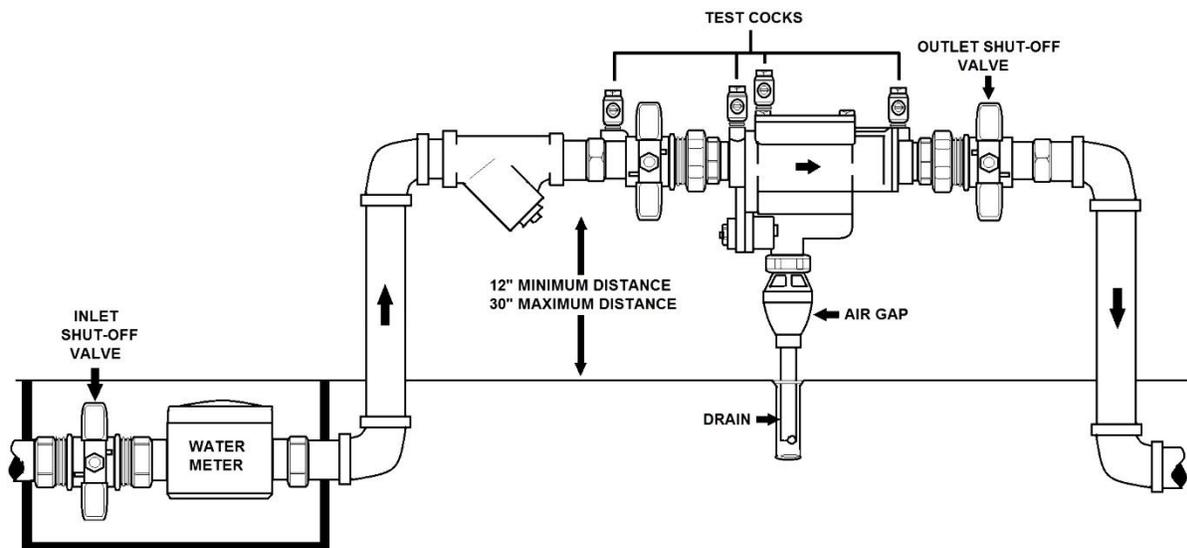
**PRESSURE VACUUM BREAKER
BACKFLOW PREVENTER**



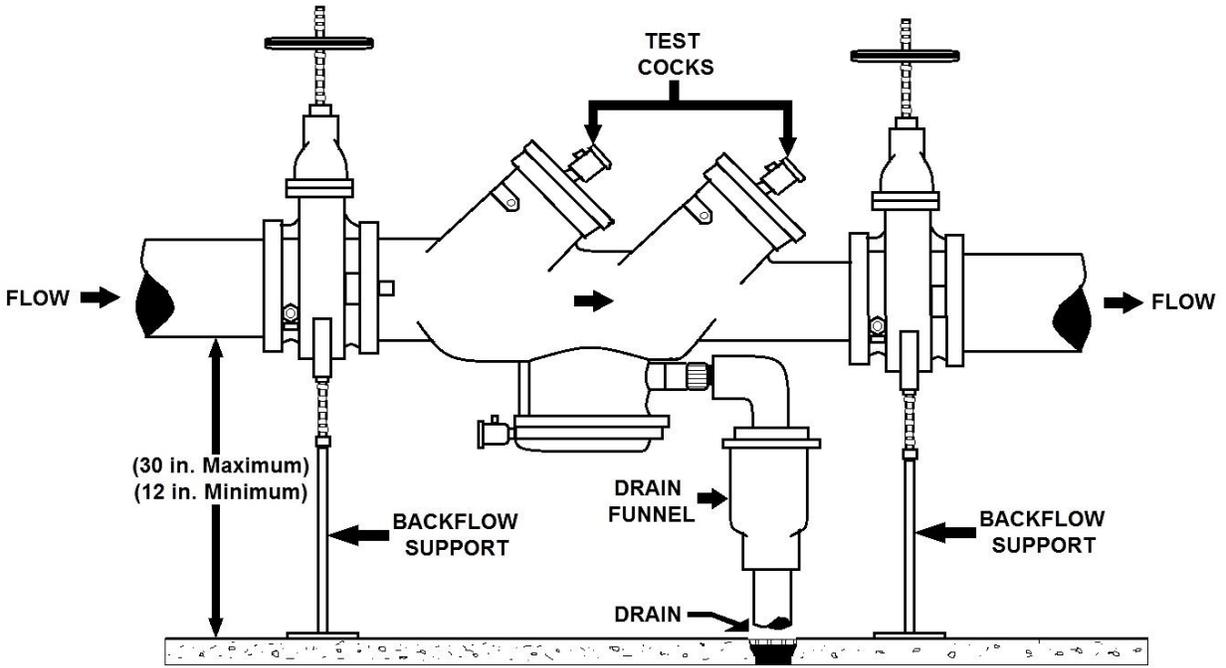
PRESSURE VACUUM BREAKER



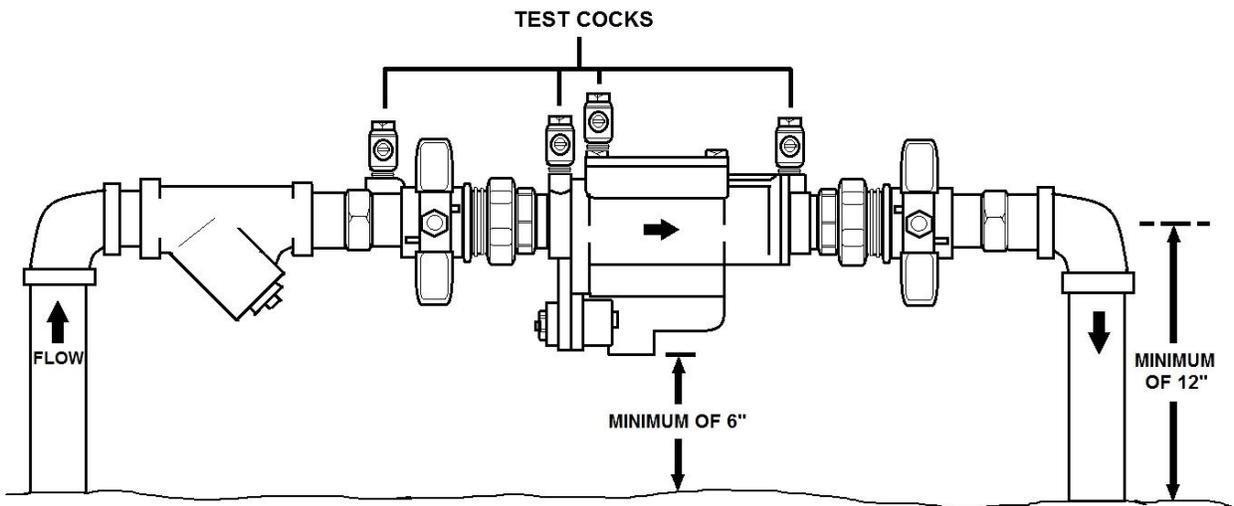
DOUBLE CHECK VALVE



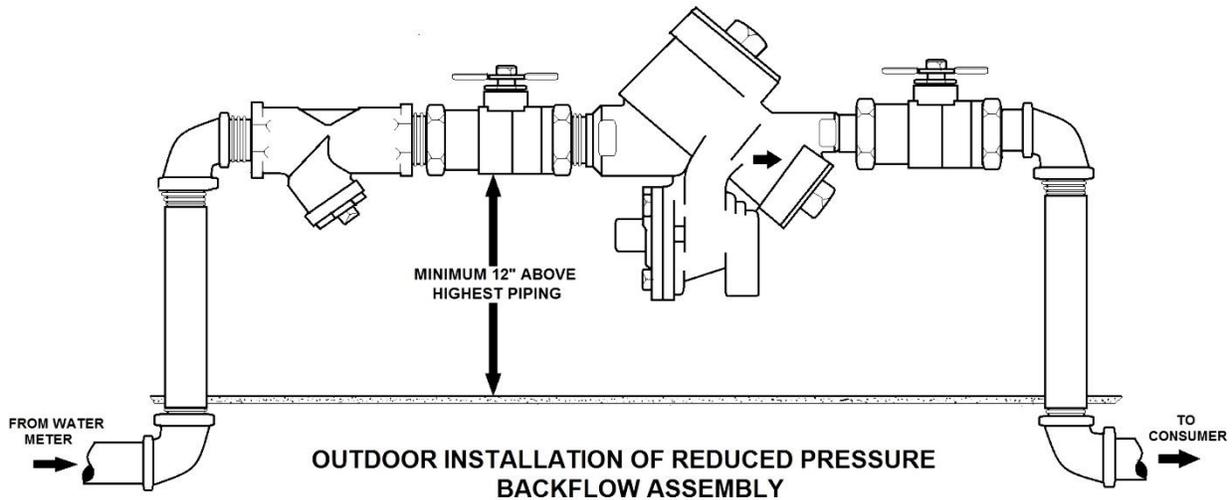
**REDUCED PRESSURE
BACKFLOW PREVENTER**



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



REDUCED PRESSURE BACKFLOW PREVENTER



Texas Students Only Special Notice to all TCEQ Students

§ 344.51. SPECIFIC CONDITIONS AND CROSS-CONNECTION CONTROL.

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

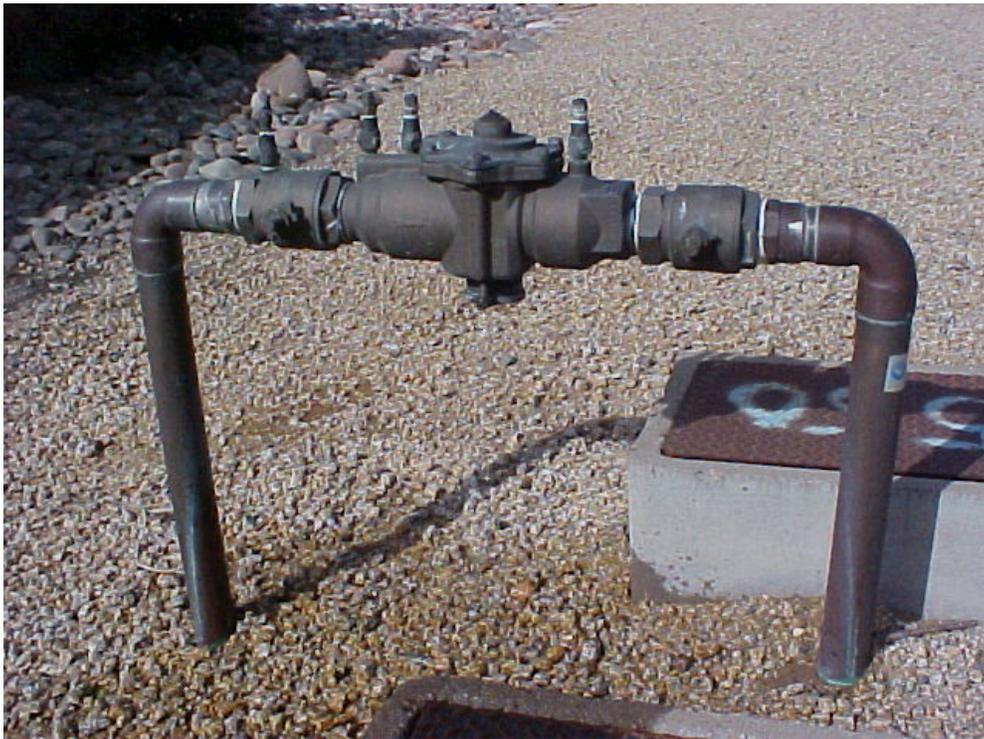
- (1) all irrigation piping and valves must meet the separation distances from the On-Site Sewage Facilities system as required for a private water line in §285.91(10) of this title (relating to Minimum Required Separation Distances for On-Site Sewage Facilities);
- (2) any connections using a private or public potable water source must be connected to the water source through a reduced pressure principle backflow prevention assembly as defined in §344.50 of this title (relating to Backflow Prevention Methods); and
- (3) any water from the irrigation system that is applied to the surface of the area utilized by the On-Site Sewage Facility system must be controlled on a separate irrigation zone or zones so as to allow complete control of any irrigation to that area so that there will not be excess water that would prevent the On-Site Sewage Facilities system from operating effectively.

Why do Backflow Preventors have to be Tested Periodically?

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

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

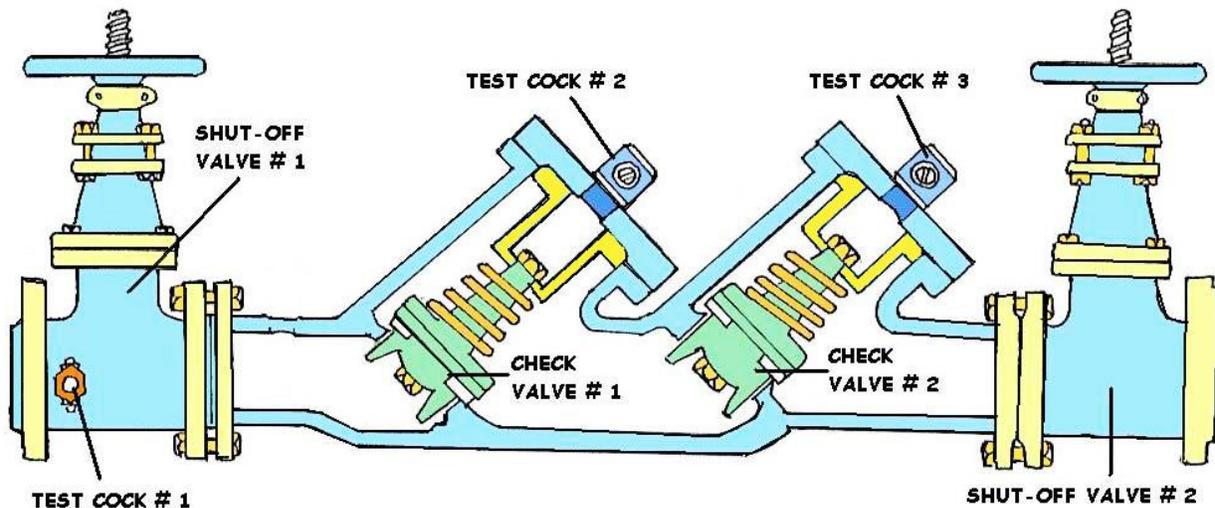
If a device is not tested annually, Public Works or the Water Purveyor will notify the property owner, asking them to comply. If the property owner does not voluntarily test their device, the City may be forced to turn off water service to that property. State law requires the City to discontinue water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



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



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



DOUBLE-CHECK BACKFLOW ASSEMBLY

Fireline Backflow Assemblies



Inline and vertical Reduced Pressure Backflow Assembly

Fire Suppression Systems

- ✓ Properly designed and installed fixed fire suppression systems enhance fire safety in the workplace. Automatic sprinkler systems throughout the workplace are among the most reliable fire fighting means. The fire sprinkler system detects the fire, sounds an alarm and puts the water where the fire and heat are located.
- ✓ Automatic fire suppression systems require proper maintenance to keep them in serviceable condition. When it is necessary to take a fire suppression system out of service while business continues, the employer must temporarily substitute a fire watch of trained employees standing by to respond quickly to any fire emergency in the normally protected area. The fire watch must interface with the employers' fire prevention plan and emergency action plan.
- ✓ Signs must be posted about areas protected by total flooding fire suppression systems which use agents that are a serious health hazard such as carbon dioxide, Halon 1211, etc. Such automatic systems must be equipped with area pre-discharge alarm systems to warn employees of the impending discharge of the system and allow time to evacuate the area. There must be an emergency action plan to provide for the safe evacuation of employees from within the protected area. Such plans are to be part of the overall evacuation plan for the workplace facility.



Halon Systems

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Fire System Classifications

Industrial fire protection systems will usually consist of sprinklers, hose connections, and hydrants. Sprinkler system may be dry or wet, open or closed. Systems of fixed-spray nozzles may be used indoors or outdoors for protection of flammable-liquid and other hazardous processes. It is standard practice, especially in cities, to equip automatic sprinkler systems with fire department pumper connections.

For cross-connection control, fire protection systems may be classified on the basis of water source and arrangement of supplies as follows:

1. **Class 1**--direct connections from public water mains only; no pumps, tanks, or reservoirs; no physical connection from other water supplies; no antifreeze or other additives of any kind; all sprinkler drains discharging to atmosphere, dry wells, or other safe outlets.
2. **Class 2**--same as class 1, except that booster pumps may be installed in the connections from the street mains (Booster pumps do not affect the potability of the system; it is necessary, however, to avoid drafting so much water that pressure in the water main is reduced below 10 psi.)
3. **Class 3**--direct connection from public water supply main plus one or more of the following: elevated storage tanks; fire pumps taking suction from above-ground covered reservoirs or tanks; and pressure tanks (All storage facilities are filled or connected to public water only, the water in the tanks to be maintained in potable conditions. Otherwise, Class 3 systems are the same as Class 1.)
4. **Class 4**--directly supplied from public mains similar to Classes 1 and 2, and with an auxiliary water supply on or available to the premises; or an auxiliary water supply may be located within 1,700 ft. of the pumper connection.
5. **Class 5**--directly supplied from public mains, and interconnected with auxiliary supplies, such as: pumps taking suction from reservoirs exposed to contamination, or rivers and ponds; driven wells; mills or other industrial water systems; or where antifreeze or other additives are used.
6. **Class 6**--combined industrial and fire protection systems supplied from the public water mains only, with or without gravity storage or pump suction tanks.

Industrial Fluids - shall mean any fluid or solution which may chemically, biologically or otherwise contaminated or polluted in a form or concentration such as would constitute a health, system, pollutional or plumbing hazard if introduced into an approved water supply.

This may include, but not be limited to: polluted or contaminated used water; all types of process waters and "**used waters**" originating from the public water system which may deteriorate in sanitary quality; chemicals in fluids from: plating acids and alkalis; circulated cooling waters connected to an open cooling tower and/or cooling waters that are chemically or biologically treated or stabilized with toxic substances; contaminated natural waters such as from wells, springs, streams, rivers, bays, harbors, seas, irrigation canals or systems, etc.; oils, gases, glycerin, paraffins, caustic and acid solutions and other liquid and gaseous fluids used in industrial or other processes or for fire fighting purposes.

In some states like Arizona, Fire lines need backflow prevention assemblies for certain criteria: a. Class 1 and 2 fire systems are not currently required to have any backflow prevention equipment at the service connection other than the equipment that is required for those systems under the state fire code standards. b. Class 3 fire systems may be converted to Class 1 or 2 systems by removing the tank. However, you must have the approval of the fire authority. c. Class 4 and 5 must comply with backflow requirements. Class 5 includes those fire systems that use antifreeze or other additives (RPDA required). This may apply to residential homes over 3,000 sq. ft. d. Class 6 fire systems require an on-site review to determine backflow requirements.



Double Check Backflow Assembly (Notice chain common on OS&Y)

Types of Pipes

Several types of pipe are used in water distribution systems, but only the most common types used by operators will be discussed. These piping materials include copper, plastic, galvanized steel, and cast iron. Some of the main characteristics of pipes made from these materials are presented below.

Plastic pipe has been used extensively in current construction. Available in different lengths and sizes, it is lighter than steel or copper and requires no special tools to install. Plastic pipe has several advantages over metal pipe: it is flexible; it has superior resistance to rupture from freezing; it has complete resistance to corrosion; and, in addition, it can be installed aboveground or below ground.

One of the most versatile plastic and polyvinyl resin pipes is the polyvinyl chloride (**PVC**). PVC pipes are made of tough, strong thermoplastic material that has an excellent combination of physical and chemical properties. Its chemical resistance and design strength make it an excellent material for application in various mechanical systems.

Sometimes polyvinyl chloride is further chlorinated to obtain a stiffer design, a higher level of impact resistance, and a greater resistance to extremes of temperature. A **CPVC** pipe (a chlorinated blend of PVC) can be used not only in cold-water systems, but also in hot-water systems with temperatures up to 210°F. Economy and ease of installation make plastic pipe popular for use in either water distribution and supply systems or sewer drainage systems.

Galvanized pipe is commonly used for the water distributing pipes inside a building to supply hot and cold water to the fixtures. This type of pipe is manufactured in 21-ft lengths. It is **GALVANIZED** (coated with zinc) both inside and outside at the factory to resist corrosion. Pipe sizes are based on nominal **INSIDE** diameters. Inside diameters vary with the thickness of the pipe. Outside diameters remain constant so that pipe can be threaded for standard fittings.

Ductile/Cast-iron pipe, sometimes called cast-iron pressure pipe, is used for water mains and frequently for service pipe up to a building. Unlike cast-iron soil pipe, cast-iron water pipe is manufactured in 20-ft lengths rather than 5-ft lengths.

Besides bell-and-spigot joints, cast-iron water pipes and fittings are made with flanged, mechanical, or screwed joints. The screwed joints are used only on small-diameter pipe.

Copper is one of the most widely used materials for tubing. This is because it does not rust and is highly resistant to any accumulation of scale particles in the pipe. This tubing is available in three different types: **K, L, and M**.

K has the thickest walls, and M, the thinnest walls, with L's thickness in between the other two. The thin walls of copper tubing are soldered to copper fittings.

Soldering allows all the tubing and fittings to be set in place before the joints are finished. Generally, faster installation will be the result.

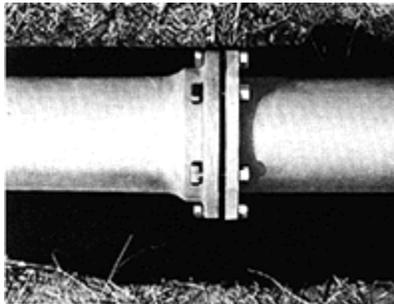
Type K copper tubing is available in either rigid (hard temper) or flexible (soft temper) and is primarily used for underground service in the water distribution systems. Soft temper tubing is available in 40- or 60-ft coils, while hard temper tubing comes in 12- and 20-ft straight lengths. Type L copper tubing is also available in either hard or soft temper and either in coils or in straight lengths. The soft temper tubing is often used as replacement plumbing because of the tube's flexibility, which allows easier installation.

Type L copper tubing is widely used in water distribution systems.

Type M copper tubing is made in hard temper only and is available in straight lengths of 12 and 20 ft. It has a thin wall and is used for branch supplies where water pressure is low, but it is NOT used for mains and risers. It is also used for chilled water systems, for exposed lines in hot-water heating systems, and for drainage piping.

Fittings

Fittings vary according to the type of piping material used. The major types commonly used in water service include elbows, tees, unions, couplings, caps, plugs, nipples, reducers, and adapters.



Caps— A pipe cap is a fitting with a female (inside) thread. It is used like a plug, except that the pipe cap screws on the male thread of a pipe or nipple.

Couplings— The three common types of couplings are straight coupling, reducer, and eccentric reducer. The **STRAIGHT COUPLING** is for joining two lengths of pipe in a straight run that does not require additional fittings. A run is that portion of a pipe or fitting continuing in a straight line in the direction of flow. A **REDUCER** is used to join two pipes of different sizes. The **ECCENTRIC REDUCER** (also called a **BELL REDUCER**) has two female (inside) threads of different sizes with centers so designed that when they are joined, the two pieces of pipe will not be in line with each other, but they can be installed so as to provide optimum drainage of the line.

Elbows (Ells) 90° and 45°.— These fittings (fig. 8-5, close to middle of figure) are used to change the direction of the pipe either 90 or 45 degrees. **REGULAR** elbows have female threads at both outlets.

Street elbows change the direction of a pipe in a close space where it would be impossible or impractical to use an elbow and nipple. Both 45- and 90-degree street elbows are available with one female and one male threaded end. The **REDUCING** elbow is similar to the 90-degree elbow except that one opening is smaller than the other.

A nipple is a short length of pipe (12 in. or less) with a male thread on each end. It is used for extension from a fitting.

At times, you may use the **DIELECTRIC** or **INSULATING TYPE** of fittings. These fittings connect underground tanks or hot-water tanks. They are also used when pipes of dissimilar metals are connected.

Tees — A tee is used for connecting pipes of different diameters or for changing the direction of pipe runs. A common type of pipe tee is the **STRAIGHT** tee, which has a straight-through portion and a 90-degree takeoff on one side. All three openings of the straight tee are of the same size. Another common type is the **REDUCING** tee, similar to the straight tee just described, except that one of the threaded openings is of a different size than the other.

Unions— There are two types of pipe unions. The **GROUND JOINT UNION** consists of three pieces, and the **FLANGE UNION** is made in two parts. Both types are used for joining two pipes together and are designed so that they can be disconnected easily. When joined, the two pieces of pipe will not be in line with each other, but they can be installed so as to provide optimum drainage of the line.

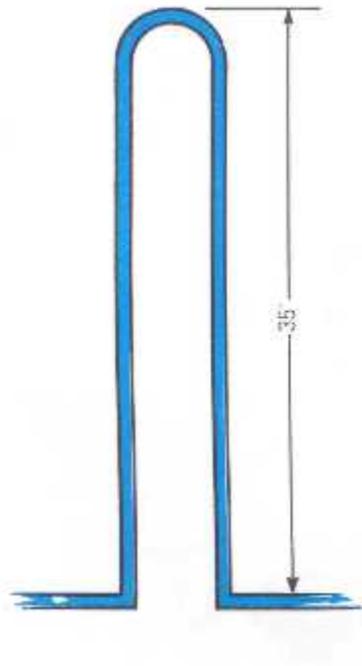
Thermal Expansion Tank (*Closed Loop System*)

However, the installation of backflow preventors may require some modification to your home plumbing. Prior to the installation of the backflow device, the volume of water in your home's pipes, which can expand when heated, could easily flow back into the public water system. With the installation of the backflow preventer, the water pressure in your home may build up, particularly when the hot water system is activated. To prevent thermal expansion, the Administrative Authority or Water Provider will suggest having a thermal expansion tank installed.

If after the backflow prevention device is installed you notice your faucets leak or the emergency relief valve on the hot water tank is continuously activated, you should call a plumbing professional, as damage to your system may occur. For many homeowners, merely lowering the temperature on the hot water tank will eliminate the need for plumbing work. A setting between 115-125 degrees is considered appropriate for most household users.

A thermal expansion tank is a small tank with an air/ water bladder. The air in the bladder can be compressed, enabling the water to expand into this tank, relieving pressure on other fixtures. This tank is to be located on the cold water side of the hot water tank.

Barometric Loop



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

Its operation, in the protection against backsiphonage, is based upon the principle that a water column, at sea level pressure, will not rise above 33.9 feet.

In general, barometric loops are locally fabricated, and are 35 feet high.

Cross-Connection Control Responsibility

The Public Water Purveyor

The primary responsibility of the water purveyor is to develop and maintain a program to prevent or control contamination from water sources of lesser quality or other contamination sources from entering into the public water system.

Under the provisions of the Safe Drinking Water Act of 1974 (**SDWA**) and current Groundwater Protection rules, the Federal Government through the EPA, (Environmental Protection Agency), set national standards of safe drinking water. The separate states are responsible for the enforcement of these standards as well as the supervision of public water systems and the sources of drinking water.

The water purveyor or supplier is held responsible for compliance to the provisions of the Safe Drinking Water Act, to provide a warranty that water quality by their operation is in conformance with EPA standards at the source, and is delivered to the customer without the quality being the compromised as its delivery through the distribution system.

This is specified in the Code of Federal Regulations (Volume 40, Paragraph 141.2 Section c):

Maximum contaminant level means the permissible level of a contaminant in water which is delivered to the free flowing outlet of the ultimate user of a public water system, except in the case of turbidity where the maximum permissible level is measured at the point of entry (**POE**) to the distribution system.

Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded from this definition.

The Water Consumer

Has the responsibility to prevent contaminants from entering into the public water system by way of their individual plumbing system, and retain the expenses of installation, maintenance, and testing of the approved backflow prevention assemblies installed on their individual water service line.

The Certified General Backflow Tester

Has the responsibility to test, maintain, inspect, repair, and report/notify on approved backflow prevention assemblies as authorized by the persons that have jurisdiction over those assemblies.

Why do water suppliers need to control cross-connections and protect their public water systems against backflow?

Backflow into a public water system can pollute or contaminate the water in that system (i.e., backflow into a public water system can make the water in that system unusable or unsafe to drink), and each water supplier has a responsibility to provide water that is usable and safe to drink under all foreseeable circumstances.

Furthermore, consumers generally have absolute faith that water delivered to them through a public water system is always safe to drink. For these reasons, each water supplier must take reasonable precautions to protect its public water system against backflow.

What should water suppliers do to control cross-connections and protect their public water systems against backflow?

Water suppliers usually do not have the authority or capability to repeatedly inspect every consumer's premises for cross-connections and backflow protection.

Alternatively, each water supplier should ensure that a proper backflow preventer is installed and maintained at the water service connection to each system or premises that poses a significant hazard to the public water system.

Generally, this would include the water service connection to each dedicated fire protection system or irrigation piping system and the water service connection to each of the following types of premises:

- (1) premises with an auxiliary or reclaimed water system;
- (2) industrial, medical, laboratory, marine or other facilities where objectionable substances are handled in a way that could cause pollution or contamination of the public water system;
- (3) premises exempt from the State Plumbing Code and premises where an internal backflow preventer required under the State Plumbing Code is not properly installed or maintained;
- (4) classified or restricted facilities; and
- (5) tall buildings.

Each water supplier should also ensure that a proper backflow preventer is installed and maintained at each water loading station owned or operated by the water supplier.

Cross-Connection Control Program Section

All public water system operators are required to maintain an active cross connection control program to identify and eliminate or isolate all cross connections within their systems. This program should provide for inspections of premises which may contain cross connections, installation of approved backflow prevention devices and annual testing of installed devices.

A cross connection ordinance (or other enabling authority) that prohibits water service to any premise on which a cross connection exists without proper protection is required. The ordinance can also specify who will do the inspections and can specify testing of devices. Only backflow prevention devices that are approved by the State Environmental Quality or Health Division may be installed. Backflow prevention devices must be tested annually by certified testers to be sure the devices are functioning properly.

Responsibility Administration of a Cross-Connection Program

Under the provisions of the Safe Drinking Water Act of 1974, the Federal Government has established, through the EPA (**Environmental Protection Agency**), national standards of safe drinking water. The states are responsible for the enforcement of these standards as well as the supervision of public water supply systems and the sources of drinking water.

The water purveyor (supplier) is held responsible for compliance to the provisions of the Safe Drinking Water Act, to include a warranty that water quality provided by his operation is in conformance with the EPA standards at the source, and is delivered to the customer without the quality being compromised as a result of its delivery through the distribution system. As specified in the Code of Federal Regulations

(Volume 40, Paragraph 141.2, Section (c)) *“Maximum contaminant level, means the maximum permissible level of a contaminant in water which is delivered to the free flowing outlet of the ultimate user of a public water system, except in the case of turbidity where the maximum permissible level is measured at the point of entry to the distribution system.*

Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded from this definition.”

Containment

There are several options that are open to a water purveyor when considering cross-connection protection to commercial, industrial, and residential customers. He may elect to work initially on the “**containment**” theory. This approach utilizes a minimum of backflow devices and isolates the customer from the water main. It virtually insulates the customer from potentially contaminating or polluting the public water supply system.

While it is recognized that “**containment**” does not protect the customer within his building, it does effectively remove him from possible contamination to the public water supply system.

If the water purveyor elects to protect his customers on a domestic internal protective basis and/or “**fixture outlet protective basis**,” then cross-connection control protective devices are placed at internal high hazard locations as well as at all locations where cross-connections exist at the “**last free-flowing outlet**.”

This approach entails extensive cross-connective survey work on behalf of the water superintendent as well as constant policing of the plumbing within each commercial, industrial and residential account.

In large water supply systems, fixture outlet protection cross-connection control philosophy, in itself, is a virtual impossibility to achieve and police due to the quantity of systems involved, the complexity of the plumbing systems inherent in many industrial sites, and the fact that many plumbing changes are made within industrial and commercial establishments that do not require the water department to license or otherwise endorse or ratify when contemplated or completed.

Containment Protection *Secondary protection*

This approach utilizes a minimum of backflow devices and isolates the customer from the water main. It virtually insulates the customer from potentially contaminating or polluting the public water supply system.

Containment protection does not protect the customer within his own building, it does effectively remove him from the possibility public water supply contamination.

Containment protection is usually a backflow prevention device as close as possible to the customer’s water meter and is often referred to as “**Secondary Protection**”.

This type of backflow protection is excellent for water purveyors and is the least expense to the water customer but does not protect the occupants of the building.

Internal Protection, *Primary protection*

The water purveyor may elect to protect his customers on a domestic internal protective basis and/or “**fixture outlet protective basis**,” in this case cross-connection-control devices (backflow preventors) are placed at internal hazard locations and at all locations where cross-connections may exist including the “**last free flowing outlet**.”

This type of protection entails extensive cross-connection survey work usually preformed by a plumbing inspector or a Cross-Connection Specialist.

In a large water supply system, internal protection in itself is virtually impossible to achieve and police due to the quantity of systems involved, the complexity of the plumbing systems inherent in many industrial sites, and the fact that many plumbing changes are made within commercial establishments that do not get the plumbing department’s approval or require that the water department inspects when the work is completed.

Internal protection is the most expensive and best type of backflow protection for both the water purveyor and the customer alike, but is very difficult to maintain.

In order for the purveyor to provide maximum protection of the water distribution system, consideration should be given to requiring the owner of the premises to provide at his own expense, adequate proof that his internal water supply system complies with the local or state plumbing code(s). In addition, he may be required to install, test, maintain all backflow protection assemblies.

Method of Action

In addition, internal plumbing cross-connection control survey work is generally foreign to the average water purveyor and is not normally a portion of his job description or duties. While it is admirable for the water purveyor to accept and perform survey work, he should be aware that he runs the risk of additional liability in an area that may be in conflict with plumbing inspectors, maintenance personnel and other public health officials.

Even where extensive “**fixture outlet protection**,” cross-connection control programs are in effect through the efforts of an aggressive and thorough water supply cross-connection control program, the water authorities should also have an active “**containment**” program in order to address the many plumbing changes that are made and that are inherent within commercial and industrial establishments.

In essence, fixture outlet protection becomes an extension beyond the “**containment**” program.

Also, in order for the supplier of water to provide maximum protection of the water distribution system, consideration should be given to requiring the owner of a premise (commercial, industrial, or residential) to provide at his own expense, adequate proof that his internal water system complies with the local or state plumbing code(s).

In addition, he may be required to install, have tested, and maintain, all backflow protection devices that would be required - at his own expense!

The supplier of water should have the right of entry to determine degree of hazard and the existence of cross-connections in order to protect the potable water system.

By so doing he can assess the overall nature of the facility and its potential impact on the water system (determine degree of hazard), personally see actual cross-connections that could contaminate the water system, and take appropriate action to insure the elimination of the cross-connection or the installation of required backflow devices.

To assist the water purveyor in the total administration of a cross-connection control program requires that all public health officials, plumbing inspectors, building managers, plumbing installers, and maintenance men participate and share in the responsibility to protect the public health and safety of individuals from cross-connections and contamination or pollution of the public water supply system.

A complete cross-connection control program requires a carefully planned and executed initial action plan followed by aggressive implementation and constant follow-up. Proper staffing and education of personnel is a requirement to insure that an effective program is achieved.

A recommended plan of action for a cross-connection control program should include the following characteristics:

- (1) Establish a cross-connection control ordinance at the local level and have it approved by the water commissioners, town manager, etc., and ensure that it is adopted by the town or private water authority as a legally enforceable document.
- (2) Conduct public informative meetings that define the proposed cross-connection control program, review the local cross-connection control ordinance, and answer all questions that may arise concerning the reason for the program, why and how the survey will be conducted, and the potential impact upon the industrial, commercial and residential water customers. Have state authorities and the local press and radio attend the meeting.
- (3) Place written notices of the pending cross-connection control program in the local newspaper, and have the local radio station make announcements about the program as a public service notice.
- (4) Send employees who will administer the program, to a course, or courses, on backflow tester certification, backflow survey courses, backflow device repair courses, etc.
- (5) Equip the water authority with backflow device test kits.
- (6) Conduct meeting(s) with the local plumbing inspection people, building inspectors, and licensed plumbers in the area who will be active in the inspection, installations and repair of backflow devices. Inform them of the intent of the program and the part that they can play in the successful implementation of the program.
- (7) Prior to initiating a survey of the established commercial and industrial installations, prepare a list of these establishments from existing records, then prioritize the degree of

hazard that they present to the water system, i.e., plating plants, hospitals, car wash facilities, industrial metal finishing and fabrication, mortuaries, etc.

These will be the initial facilities inspected for cross-connections and will be followed by less hazardous installations.

(8) Ensure that any new construction plans are reviewed by the water authority to assess the degree of hazard and ensure that the proper backflow preventer is installed concurrent with the potential degree of hazard that the facility presents.

(9) Establish a residential backflow protection program that will automatically ensure that a residential backflow device is installed automatically at every new residence.

(10) As water meters are repaired or replaced at residences, ensure that a residential backflow preventer is set with the new or reworked water meter. Be sure to have the owner address thermal expansion provisions.

Cross-Connection Control Survey Work

(1) Prepare a listing of all testable backflow devices in the community and ensure that they are tested by certified test personnel at the time intervals consistent with the local cross-connection control ordinance.

(2) Prepare and submit testing documentation of backflow devices to the State authority responsible for monitoring this data.

(3) Survey all commercial and industrial facilities and require appropriate backflow protection based upon the containment philosophy and/or internal protection and fixture outlet protection.

Follow up to ensure that the recommended devices are installed and tested on both an initial basis and a periodic basis consistent with the cross-connection control ordinance.

The surveys should be conducted by personnel experienced in commercial and industrial processes. The owners or owner's representatives should be questioned as to what the water is being used for in the facility and what hazards the operations may present to the water system (both within the facility and to the water distribution system) in the event that a back-siphonage or backpressure condition were to exist concurrent with a non-protected cross-connection.

In the event that experienced survey personnel are not available within the water authority to conduct the survey, consideration should be given to having a consulting firm perform the survey on behalf of the water department.

Cross-connection control survey work should only be performed by personnel knowledgeable about commercial and industrial potential cross-connections as well as general industrial uses for both potable and process water.

If “**containment**” is the prime objective of the survey, then only sufficient time need be spent in the facility to determine the degree of hazard inherent within the facility or operation. Once this is determined, a judgment can be made by the cross-connection control inspector as to what type of backflow protective device will be needed at the potable supply entrance, or immediately downstream of the water meter.

In the event that the cross-connection control program requires “**total**” protection to the last free flowing outlet, then the survey must be conducted in depth to visually inspect for all cross-connections within the facility and make recommendations and requirements for fixture outlet protective devices, internal protective devices, and containment devices.

It is recommended that consideration be given to the following objectives when performing a cross-connection control survey:

- (1) Determine if the survey will be conducted with a pre-arranged appointment or unannounced.
- (2) Upon entry, identify yourself and the purpose of the visitation and request to see the plant manager, owner, or maintenance supervisor in order to explain the purpose of the visit and why the cross-connection survey will be of benefit to him.
- (3) Ask what processes are involved within the facility and for what purpose potable water is used, i.e., do the boilers have chemical additives? Are air conditioning cooling towers in use with chemical additives? Do they use water savers with chemical additives? Do they have a second source of water (raw water from wells, etc.) in addition to the potable water supply? Does the process water cross-connect with potentially hazardous chemical etching tanks, etc.?
- (4) Request “**as-built**” engineering drawings of the potable water supply in order to trace out internal potable lines and potential areas of cross-connections.
- (5) Initiate the survey by starting at the potable entrance supply (the water meter in most cases) and then proceed with the internal survey in the event that total internal protective devices and fixture outlet protective devices are desired.
- (6) Survey the plant facilities with the objective of looking for cross-connections at all potable water outlets such as:
 - **Hose bibbs**
 - **Slop sinks**
 - **Wash room facilities**
 - **Cafeteria and kitchens**
 - **Fire protection and Siamese outlets**
 - **Irrigation outlets**
 - **Boiler rooms**
 - **Mechanical rooms**
 - **Laundry facilities (hospitals)**
 - **Production floor**
- (7) Make a sketch of all areas requiring backflow protection devices.
- (8) Review with the host what you have found and explain the findings to him. Inform him that he will receive a written report documenting the findings together with a written recommendation for corrective action. Attempt to answer all questions at this time.

Developing a Cross-Connection Control Program

Introduction

Establishing a cross connection control program for a small water utility can be a daunting task. The responsibility of creating and implementing the program will often fall on the operator, who will most likely be responsible for water, sewer, roads, parks and other public work projects as well.

This can seem overwhelming, but with an organized approach an effective program can be established.

What is a Cross-Connection?

Before anyone can start a cross connection program, he or she must understand what cross connections are, why they are dangerous, and how they can be corrected. Therefore, the first step must be education. The approach to learning about cross connection control will vary depending on time and funding constraints.

The best approach will be to attend a training course that is specifically designed to teach cross connection control practices for public water systems. If this is not possible, then the operator will have to pursue other avenues. Some agencies and organizations offer training courses that include sessions on cross connection control for little or no cost. Some areas have committees, associations or other groups dedicated to cross connection control.

These groups can be a great source of information and networking. Many cross connection control publications and videos are available. It is also advisable for the operator to contact neighboring water utilities for information on their cross connection control programs.

Legal Authority

Once the operator has a good understanding of cross connection control, the next task will be to prepare a written document that will establish legal authority for the program. This may be in the form of an ordinance, resolution, by-law, etc., depending on the organization of the water system.

This document will define the utility's cross connection control requirements, such as what circumstances will require the installation of a backflow preventer; who will be responsible for the installation, testing and maintenance costs; program enforcement; approval of backflow preventors and installation requirements.

This document must avoid conflicts with other agencies. It is important to consider the requirements of local building, plumbing and fire codes in addition to Health Services requirements. It is useful to obtain copies of ordinances from nearby utilities and consider their requirements. It is preferable for utilities to have similar requirements when possible. This will minimize confusion for those who work in several districts and are expected to be familiar with local requirements, such as backflow assembly testers, plumbers and vendors. It will also help avoid critical comparisons between utilities.

"The Board"

A cross connection ordinance will be useless without the approval of the board of directors or city council.

This fact can present problems of its own. As is often the case, the operator will be given the responsibility of running a cross connection control program but will not have the authority to create and enforce the ordinance. For this reason, it is extremely important to have the support of the board.

Board members must be educated about cross connection control. They need to understand the hazards cross connections present to the safety of the water supply, and the liability they are vulnerable to in the event of a backflow incident. Once they understand the importance of a cross connection control program, they can be strong allies in adopting an effective ordinance and implementing the program.

Organize the Program

Once an ordinance has been adopted, it must be implemented. This requires an organized approach. The responsibilities of each person involved in the program must be clearly defined; a system for coordinating with other agencies must be developed; a plan to educate the public must be in place; an efficient system for keeping records is critical; and various form letters and notices will need to be developed.

Work Responsibilities

It is important to identify who is responsible for each element in the cross connection control program. Who will determine when a backflow preventer is required? Who will prioritize installations? Who will verify the correct installation of the backflow preventer? Who will test backflow preventors?

Who will send out letters and notices? Who will track the testing and maintenance of the backflow preventors in the system? Who will respond to customer inquiries and complaints? These are all questions that need to be answered before the program is presented to the customers.

Agency Coordination

Working with other agencies can be a great benefit to the cross connection control program. The local building department plan review process can be a useful tool. If an agreement can be made to include the water utility in the plan review process, any needed backflow preventors can be included in the planning stage. A good relationship with local plumbing inspectors can be a great benefit to the program. They can serve as extra eyes to spot any variations from building plans that might create a need for backflow prevention. Working with fire officials is extremely important.

The installation of backflow preventors on fire lines will increase the pressure loss, and this needs to be considered in the system design. Good working relationships with these

officials will eliminate the headache of retrofitting a new building, and the bad publicity that follows a lack of coordination between agencies.

Public Education

Public education is an important aspect of cross connection control that is too often overlooked or minimized. This can have disastrous consequences. If a customer receives a notice to install a backflow preventer with no explanation, they will often have a negative response. It is important to educate the customers to the dangers of cross connections and the importance of installing backflow preventors when needed.

It is also very important to explain the program priorities so the customers don't feel singled out. If one customer is notified to install a backflow preventer and their neighbor isn't, they will want to know why. It is better for the utility to answer these questions with public education, rather than leave the customers wondering, or worse yet, doubting the sensibility of the cross connection control program. Most customers will be willing to support the cross connection control program when they understand that the safety of their drinking water is at stake.

Record-keeping, Forms and Notices

An active cross connection control program will generate information that must be organized and tracked. It is important to give careful consideration to record keeping methods before information begins to accumulate.

Once information is stored, changing the format becomes quite difficult. A system needs to be in place for notifying customers when backflow preventors must be installed, tested or repaired, and for tracking the responses. Backflow preventors must be tested regularly, so a system of tracking due dates is needed in order to send notices on time.

Certain letters will be sent out frequently, so it is helpful to have a standard form prepared for these occasions. Cross connection software is available to assist with this aspect of the program. The software is available in a wide range of prices and capabilities.

Cross-Connection Program Implementation

Once these preparations have been completed, the cross connection control program is ready for implementation. Public education can be initiated to gain customer support for the program.

The operator will be ready to identify cross connection hazards in the system and begin the process of eliminating or isolating them. As the program begins to function, the utility will be prepared to handle the paper flow and phone calls that are generated.

Summary

Creating an effective cross connection control program is an important and challenging responsibility. An organized approach in the beginning will help avoid many problems and conflicts once the program begins to function.

Water Quality Inspector-Backflow Unit Program Duty *Example*

The technical and administrative demands for a Backflow Prevention Program are extensive for a water system the size of the City of Sunflower. These responsibilities cannot be met merely by delegating additional duties among existing staff and field personnel. Personnel possessing the appropriate administrative, technical and clerical skills need to be organized as a "***Backflow Prevention Unit***" to form the nucleus for such a program.

General Duties - Responsible for the enforcement of the City's Backflow Prevention Program and policy that include: system review, determining new service and retrofit replacements; field investigation and correction of backflow occurrences; and the review of testing and repair reports to ensure compliance.

Specific Duties:

- (1) Conduct surveys of commercial and industrial water users to determine backflow prevention compliance.
- (2) Meet with affected business groups to explain and promote the City's backflow prevention objectives.
- (3) Act as Department representatives involving various requests regarding backflow prevention requirements.
- (4) Review test report forms of backflow prevention devices.
- (5) Investigate reported incidents of cross-connections or backflow problems.
- (6) Perform quality assurance tests on backflow prevention assemblies repaired by certified general testers.
- (7) Establish and update maintenance history files of backflow prevention assemblies.
- (8) Monitor and track progress of retrofit requirements placed on individual commercial and industrial users.
- (9) Remain current with backflow technology in order to answer general and technical inquiries about backflow prevention requirements.
- (10) Maintain General Tester certification.

Evaluation of Hazard Policy *Example*

The Department shall evaluate potential hazard to the public water supply which may be created as a result of a condition on a user's premises. However, the Department shall not be responsible for abatement of cross-connection that may exist within the user's premises.

This evaluation shall give particular consideration to the premises that involve the following type of situations of water uses:

- (1) Premises where substances harmful to health are handled under pressure.
- (2) Premises that boost the pressure of water delivered by the public water system.
- (3) Premises which could expose the public water system to backflow.
- (4) Premises having an auxiliary water supply.
- (5) Premises where water from the public water system, under normal circumstances, could develop a polluted water source.
- (6) Premises where entry for investigation or information regarding water use is restricted.
- (7) Premises that contain a degree of piping system complexity and the potential for routine system modification.

1. Hazard Types

The type and degree of hazard potential to the public potable water supply and system from a customer's water supply system shall be determined using the following hazard factors:

- a. **Plumbing Hazard** - an actual or potential plumbing type cross-connection that is not properly protected by an approved backflow prevention method.
- b. **System Hazard** - an actual or potential threat that may cause severe damage to the physical facilities of the public water supply system or that may have a protracted effect on the quality of the water in the system.

2. Degree of Hazard

- a. **Pollution** - (non-health) an actual or potential threat to the physical facilities of the public water supply system or to the public water supply that, although not dangerous to health, would constitute a nuisance or be aesthetically objectionable, or could cause damage to the system or its appurtenances.
- b. **Contamination** - (health) any condition, device or practice that, in the judgment of the Department, may create a danger to the health and well-being of the public water users.

Backflow Requirements *Example*

TABLE 7.1

Facilities or Activities Requiring Backflow Assembly

The following criteria will be used to determine the backflow prevention requirements for all service connections:

1. Specified Facilities or Activities

When any of the following activities are conducted on premises served by the public potable water system, a potential hazard to the public potable water supply shall be presumed and a backflow prevention method, of the type specified for that activity herein, must be utilized or installed at the service connection for that premise.

- (1) Aircraft and missile plants: RP
- (2) Animal clinics and animal grooming shops: RP
- (3) Any premises where a cross-connection is maintained: RP
- (4) Automotive repair with steam cleaner, acid cleaning equipment, or solvent facilities: RP
- (5) Auxiliary water system: RP
- (6) Bottling plants, beverage or chemical: RP
- (7) Breweries: RP
- (8) Buildings with house pumps and/or potable water storage tank: RP
- (9) Buildings with landscape fountains, ponds, or baptismal tanks: Air Gap or RP
- (10) Building with sewage ejector: Air Gap or RP
- (11) Canneries, packing houses, and reduction plants: RP
- (12) Car wash facilities: RP
- (13) Centralized heating and air conditioning plants: RP
- (14) Chemical plants: RP
- (15) Chemically treated potable or nonpotable water system: RP
- (16) Civil works (government owned or operated facilities not open for inspection by the Department): RP
- (17) Commercial laundries: RP
- (18) Dairies and cold storage plants: RP
- (19) Dye works: RP
- (20) Film processing laboratories: RP
- (21) Fire system-American Water Works Association Classes 1, 2. Any system constructed of a piping material not approved as a potable water system material per the Uniform Plumbing Code as adopted by the City: DC
- (22) Fire system-American Water Work Association Classes 3, 4, 5, 6: RP
- (23) Food processing plants: RP
- (24) High schools, trade schools and colleges: RP
- (25) Holding tank disposal stations: RP
- (26) Hospitals and mortuaries: RP

- (27) Irrigation systems (not to include single family detached residences):
 - a. Premises having separate systems used in elevated areas: RP
 - b. Premises having nonpotable water piping (lawn sprinklers) two (2) inches and smaller: PVB
- (28) Laboratories using toxic materials: RP
- (29) Manufacturing, processing, and fabricating plants: RP
- (30) Medical and dental buildings, sanitariums, rest and convalescent homes engaged in diagnosis, care or treatment of human illness: RP
- (31) Motion picture studios: RP
- (32) Multiple Services Interconnected: RP or DC
- (33) Multiple Use Facilities/activities - When two or more of the activities listed above are conducted on the same premises and served by the same service connection, the most restrictive backflow prevention method required for any of the activities conducted on the premises shall be required at the service connection. The order of the most restrictive to least restrictive backflow prevention method shall be as follows:
 - (A) Air Gap (most restrictive)
 - (B) Reduced Pressure Principle Assembly (**RP**)
 - (C) Pressure vacuum Breaker Assembly (**PVB**)
 - (D) Double Check Valve Assembly (**DC**) (least restrictive)
- (34) Oil and gas production plants: RP
- (35) Paper and paper production plants: RP
- (36) Plating plants: RP
- (37) Portable insecticide and herbicide spray tanks: Air Gap or RP
- (38) Power plants: RP
- (39) Radioactive materials processing facilities: RP
- (40) Recreational vehicle parks, trailer parks (seasonal): RP (41) Restricted, classified, or other closed facilities: RP
- (42) Rubber plants: RP
- (43) Sand and gravel plants: RP
- (44) Sewage and storm drainage facilities: Air Gap or RP
- (45) Street sweepers, steel wheeled rollers: Air Gap or RP
- (46) Temporary Services-Construction water: Air Gap or RP
- (47) Water trucks, water tanks or hydraulic sewer cleaning equipment: Air Gap or RP

2. Non-Specified Facilities or Activities

The Department shall determine backflow prevention requirements for all other facilities or activities not specified herein. This determination will be on a case by case basis and shall require the consumer to comply with all other provisions within the policy.

3. Private Fire Hydrants

When a single fire service connection provides service solely to privately owned fire hydrants upon a premise no protection is required provided: 1) The fire system is designed, furnished, installed and tested in conformance with current department specifications. 2) The entire route of the service pipe shall constantly remain visible from the point of connection.

Installation Requirements *Example*

1. General Requirements:

(a) Backflow prevention assemblies shall be installed by the user, at the user's expense, in compliance with the standards and specifications adopted by the City, at the service connection. The assembly or assemblies shall be sized equivalent to the diameter of the service connection.

(b) All assemblies shall be installed in a manner as to be readily accessible for testing and maintenance. It will be located as close as practicable to the point of service delivery. A reduced pressure principle assembly, a double check valve assembly and a pressure vacuum breaker assembly shall be installed above ground. With the Department's approval, a double check valve assembly may be installed in below ground vault.

(c) An air-gap separation shall be located as close as practicable to the user's point of service delivery. All piping between the user's connection and receiving tank shall be entirely visible unless otherwise approved by the City.

(d) It shall be unlawful, and punishable as a misdemeanor, for any person to bypass or remove a backflow prevention method without the approval of the City.

(e) **Fire Protection Systems** - the user shall make proper application to the Fire Department for a permit prior to installation of an assembly on an existing fire system.

2. Continuous Water Supply

(a) **Domestic or Building Supply Systems** - when a customer desires a continuous water supply during testing and repairs, two or more backflow prevention assemblies shall be installed parallel to one another at the service connection to allow a continuous water supply during testing of the backflow prevention assemblies.

(b) **Fire Protection Systems** - where it is determined by the Sunflower Fire Department that a fire sprinkler system shall have a continuous water supply that may not be interrupted during testing and maintenance of the backflow prevention assembly, the user shall install two backflow prevention assemblies parallel to one another at the service connection.

The diameter of each assembly shall be as approved by the Fire Department.

Testing Frequency

1. General Requirements:

(a) The user shall test backflow prevention assemblies at least once a year. Affected user will be notified of the testing due date. If the test reveals the assembly to be defective or in unsatisfactory operating condition, the user shall perform any necessary repairs, including replacement of the assembly if necessary, which will return the assembly to satisfactory operating condition.

(b) As a condition of water service, the user is responsible for the effective operating condition of the backflow prevention assembly at all times.

(c) All expenses associated with the annual testing and maintenance of backflow prevention assemblies shall be the responsibility of the user.

(d) The Department reserves the right to require more testing.

Qualified Certified General Testers List *Policy Example*

The purpose of this list is to identify qualified general testers for user/customer to contact and hire for backflow assembly testing.

(a) The Department may recognize other agencies or organizations involved with the training and certification of testers.

(b) It is the responsibility of the certified general tester to submit accurate and current certification to the Backflow Unit of the Water Quality Division. A list of certified general testers will be maintained by the Department and made available upon request to all users required to install or maintain a backflow prevention assembly.

(c) The Department may disqualify a tester, at any time, without warning, for any malfeasance or misrepresentation.

Compliance Program *Example*

1. New Service Connections

(a) An approved backflow prevention assembly shall be installed and maintained at every service connection to a user's water system when the Department determines that the water supplied by the public water system may be subject to contamination, pollution or other deterioration in sanitary quality by conditions within the user's water system.

(b) The backflow prevention method to be utilized shall be determined by the Department. The method shall be sufficient to protect against the potential hazard, as determined by the Department, to the public water supply.

2. Existing Service Connections

(a) The provision herein shall apply to all new water customers and all water customers existing prior to enactment date of this policy.

(b) Backflow prevention assemblies installed prior to enactment of this policy that do not comply with these requirements shall be replaced at the user's expense with assemblies that comply with the standards set forth herein.

(c) All existing water service connections will be subject to a survey by the Water and Wastewater Department to identify water user premises where service protection is required. The selection of service connections to be surveyed will be determined by the Department and based on suspected hazards. A letter of notification will be sent to all users identified to install, upgrade, or utilize a backflow prevention assembly. The user shall have no more than twelve (12) months from the date of notification to comply with requirements set forth in this policy.

(d) A water user survey will automatically be initiated should a user apply for a building permit to install or modify existing plumbing. This investigation may be performed by the Development Services Department in conjunction with the plan review or the permit application process. The issuance of a building permit requiring that a backflow prevention assembly be installed, upgraded, or utilized shall constitute written notice and shall hold the user responsible to the provisions set forth in this policy.

(e) A permit from the Fire Department, Division of Fire Prevention, shall be secured prior to issuance of a Building Permit for any retrofit application.

Failure to Comply

1. Notice of Violation

(a) Prior to disconnecting any water service, the Department shall make written notification to the user describing the violation and give notice that the condition must be remedied within forty-five (45) days. If such condition is not remedied within (45) days, the Department shall send a second notice, by certified mail, notifying the user that water service will be discontinued in fifteen (15) days if the condition is not remedied within such time period.

2. Discontinuance of Water Service *Example*

(a) If the customer within the time specified in this section:

- fails to install a required backflow prevention assembly; or
- fails to properly test; or
- fails to properly maintain a backflow device; or
- bypasses or removes a backflow device; or
- fails to submit records of tests and repair of a backflow device; or
- has an identified unprotected cross-connection existing in the user's water system; then water service to that service connection shall be discontinued. Their service shall not be restored until the condition is remedied. See Appendix I - Section IV.

(b) Water services to a fire protection system shall not be subject to disconnection under this section. If the situation is not remedied within the time specified to the user, the user may be issued a citation for a misdemeanor offense. Each day the situation is allowed to continue thereafter shall constitute a separate violation of this section.

(c) The Department shall disconnect, without notice, water service to any customer when the Department discovers or determines that the customer's water system is contaminating the public water supply.

3. Citations *Example*

(a) If a situation, which would otherwise result in discontinuance of water service in section (2), subsection (b) above, is not remedied within the time provided in the notice sent to the customer, the customer may be issued a citation for a misdemeanor offense. Each day the situation is allowed to continue, thereafter, shall constitute a separate violation of this section.

(b) If a customer commits a deliberate act to fraud, misrepresent, falsify or act in an unauthorized capacity in violation of this policy relating to falsification of records, the deliberate bypass of a backflow prevention device, the illegal restoration of a service or the willful withholding or concealing of information or activity for the purpose of avoiding service protection requirements, a citation for a misdemeanor offense may be issued for each separate violation of this policy. See Appendix I - Section V.

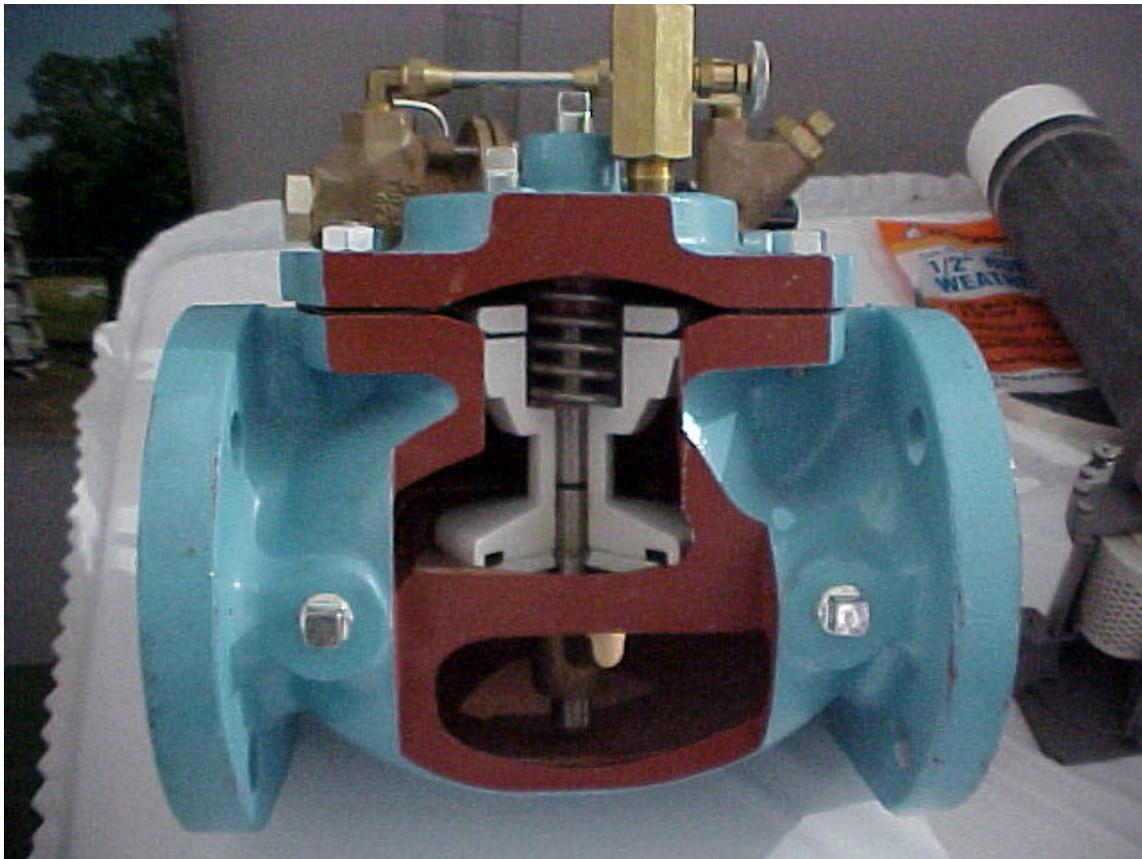
Records Requirements *Policy Example*

(a) The user/customer shall submit on forms approved by the Department, results of all tests, repairs to, or replacement of backflow prevention assemblies.

(b) Submitted records shall be completed and signed by a certified general tester.

(c) The user/customer shall be responsible for prompt submission of records to the Department after completion of the activity for which the record is made. Failure to submit records within the time frames established by the Department shall constitute a violation of this policy. Refer to Section VI.E., Failure to Comply, for more details.

(d) It is recommended records be kept by the user and tester for at least three (3) years.



PRV Valve is not a backflow preventer, but a Pressure Regulation Valve.



A Certified Tester is testing the integrity of this RP.



This is an Ames Silver Bullet on a fireline

Incident Response Plan *Example*

1. Introduction

This is a reference document to be used in incident and emergency incident response situations affecting public drinking water supplies. Although every effort has been made to make this document as complete as possible, the user must recognize that not every situation can be anticipated. The responder may be called upon to use their best judgment in a given situation.

(a) Incident Response *Example*

A customer complaint is usually handled by contacting Customer Services, 262-6215 between 8:00 a.m. and 5:30 p.m. on weekdays and Water Distribution, 261-8000 after 5:30 p.m. and on weekends. If the complaint concerns system problems (pressure, leaks) the complaint is referred to the Water Distribution Division.

If the complaint is in reference to the quality of the water (taste, odor, color), the complaint is referred to the Water Quality Division, Water Monitoring Unit.

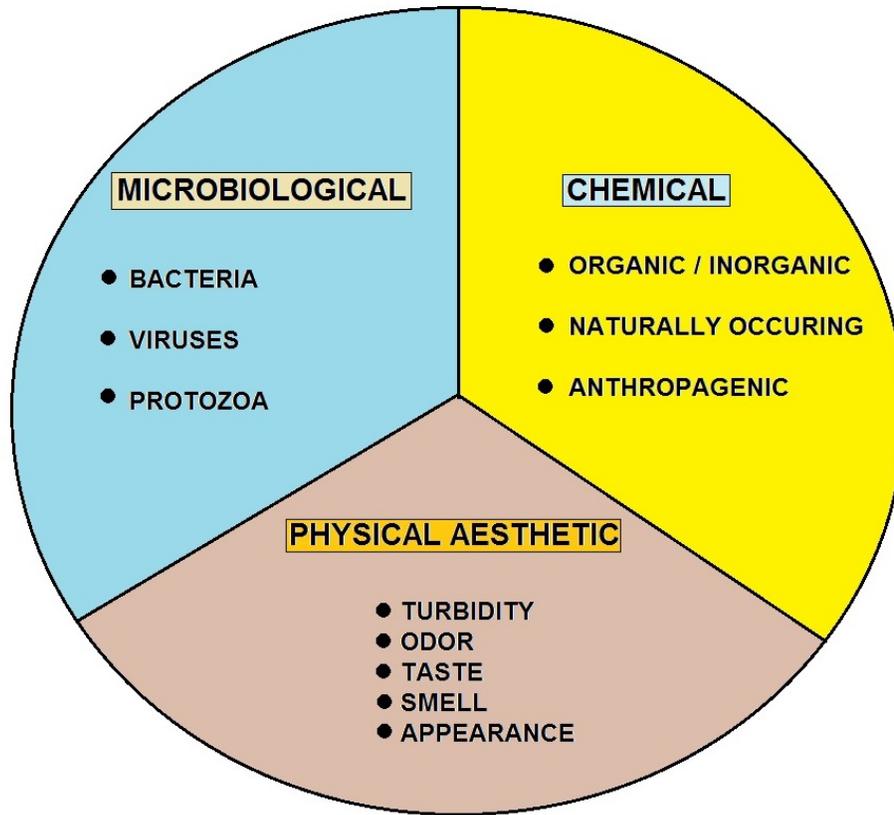
The Water Monitoring Unit will perform a phone interview to determine the seriousness and magnitude of the water quality problem. If it is felt that the situation warrants, a member of the Water Monitoring Unit will visit the site to perform an inspection and sample the water at the site.

The samples will be delivered to the Water Quality Laboratory for analysis. If the inspector suspects the water has been contaminated by an outside source through a possible cross-connection, the Backflow Prevention Unit will be notified.

Upon notification of a possible backflow incident, the Backflow Prevention Unit will visit the site, perform an inspection of the premise for possible cross-connections, and evaluate the water use within the premises. A determination of the proper backflow protection will be made and notification to install the assembly may be issued.

The water may be turned off at the service connection if it is determined that the user's water system is contaminating the public water system.

The appropriate Customer Services Area Field Supervisor will be notified of the water being turned off. Also notify Customer Services that the water was turned off.



WATER QUALITY BROKEN DOWN INTO 3 BROAD CATEGORIES

Emergency Incident Response *Example*

An emergency incident response to a possible backflow situation would be triggered if it involved a health hazard concerning the potable water system. Notification of such an incident could come from the Health Department directly to the Water Quality Division or from 911. The 911 dispatcher then notifies the City Operator that there is an incident involving the water distribution system, who in turn notifies the Water Distribution 24 hour Emergency Dispatcher.

This dispatcher then notifies the Water Distribution Superintendent, the Water Quality Superintendent and the Water and Wastewater Information Officer. The Water Distribution Superintendent notifies and dispatches the appropriate crews to isolate, flush, or neutralize the contamination. The Water Quality Superintendent will notify the Chief Water Quality Inspector who will then dispatch the Water Monitoring Unit and/or the Backflow Prevention Unit to perform their duties as described in the incident response section. The Water Quality Lab would submit a written report to the Water and Wastewater Information Officer who would handle all media contact. See Appendix I - Section VI.

2. Reports and Records *Example*

(a) Customer

In the event the customer's water system or the public water system is contaminated or polluted due to a cross-connection or other cause, and the customer has knowledge of such an event, the Department shall be promptly notified by the customer so that the appropriate measures may be taken to overcome the contamination. The customer shall submit a written incident report within 72 hours of first knowledge of the event.

The report shall address all of the following:

1. Date and time of discovery;
2. Nature of the problem;
3. Affected area;
4. Cause of the problem;
5. Public health impact;
6. Corrective action taken;
7. Date of completion of corrective actions.

(b) Water Purveyor

The water purveyor shall submit a written cross-connection incident report within five business days to the Department of Environmental Quality or equivalent agency and the local health authority whenever a cross-connection problem has occurred which resulted in contamination of the public water system.

The report shall address all of the following:

1. Date and time of discovery of the unprotected cross-connection;
2. Nature of the cross-connection problem;
3. Affected area;
4. Cause of the cross-connection problem;
5. Public health impacts;
6. Dates and text of any public health advisories issued;
7. Corrective actions taken; and
8. Date of completion of corrective actions.

Accurate records and reports must be written and maintained because unfortunately the end result of a backflow incident will probably be a court case, and the damages ensuing may be partly the water purveyor's responsibility.



Inside a Check Valve
This is not a backflow prevention assembly!

Notification Letters/Forms Examples and Related Documents



Frost protection

The following are several examples of backflow related letters and notices.

April 1, 2019

ABC Company
12345 North Beeline Highway
Sunflower, Arizona 85547

Dear Sirs:

Example of a regulatory letter

In order to protect the public water supply from contamination, State and local regulations require approved backflow prevention assemblies for your water service lines. These assemblies, which should be located on your domestic, fire sprinkler and/or landscape water supply lines, are due for an annual operation test. This test must be performed by a backflow prevention assembly tester who possesses a valid certification. A list of certified testers recognized by the Sunflower Water Department has been enclosed to assist you in selecting a qualified contractor.

Prices charged for installation, testing and/or repair of assemblies can vary widely between contractors. So, for your own protection, carefully check service costs and qualifications before employing a contractor for your assemblies. Generally, testing costs range from approximately \$35-50 per assembly. If needed, repairs are usually an additional expense.

You are responsible for submitting test results for your assemblies *on the proper form* to the Town of Sunflower Water Department no later than June 07, 2005. Test forms and information packages are available at no charge from the Town of Sunflower Water Department located at 303A North Beeline Highway.

If you have any questions about the testing requirements, or need additional information, please contact me at (520) 474-5242, Ext. 235 or Michael Ploughe at Ext. 284.

Sincerely,

Jim Bevan
Water Resources Specialist

< DATE >

<CERTIFIED MAIL>

< CONTACT >

OR

< TITLE >

< COMPANY NAME>

<HAND DELIVERED TO:>

< STREET ADDRESS >

< CITY AND STATE AND ZIP >

REMINDER NOTICE
Annual Testing Requirement

Dear-----:

In reviewing our files, we have been unable to find this year's test results for your backflow device(s) (see attached).

City Ordinances G3672 / G3674 require yearly testing of all containment backflow devices. These Ordinances also require reporting the results to:

City of Sunflower
Pollution Control Division
Backflow Prevention Unit
2303 West Beeline Street
Sunflower, AZ 85009

We are notifying each customer at least 30 days in advance of their yearly test date. If we have missed notifying you previously, please accept this letter as that notification. If you have forgotten to test or mail the test results, please consider this letter a reminder. We appreciate your continued co-operation.

Should you have any questions please contact me at (602) 534-2140. Our office hours are 8:00 a.m. to 5:00 p.m., Monday through Friday.

Sincerely,

Scott Stratton
Senior Water Quality Inspector
Backflow Prevention Unit

Enclosure

< DATE >

<CERTIFIED MAIL>

< CONTACT >

OR

< TITLE >

< COMPANY NAME>

<HAND DELIVERED TO:>

< STREET ADDRESS >

< CITY AND STATE AND ZIP >

NOTICE OF FAILURE TO COMPLY
Annual Testing Requirement

Two notices have been sent to you requesting the annual testing of the containment backflow prevention assembly(s) (see attached notices). We have not received the test report(s) as of the date of this letter.

This is the last notification. A passing test report for the containment device(s) must be received by <DATE>. The mailing address is:

City of Sunflower
Pollution Control Division
Backflow Prevention Unit
2303 West Beeline Street
Sunflower, AZ 85009

FAILURE TO COMPLY WITH THE REQUIREMENTS OF THIS LETTER MAY RESULT IN A REVIEW MEETING BEING SCHEDULED TO DISCUSS THE FOLLOWING APPLICABLE ENFORCEMENT ACTIONS OUTLINED IN CHAPTER 37 OF THE SUNFLOWERCITY CODE.

- A civil penalty not to exceed one thousand percent per billing period on the charges for all water used beginning from the date the corrective action was required and until the corrective action has been completed by the customer.
- Publication in the largest daily newspaper published in the City as a violator of the requirements of Chapter 37.
- TERMINATION OF WATER SERVICE.
- All costs, fees, expenses incurred, surcharges, and penalties relating to the termination and restoration of water service shall be paid by the customer prior to the water service being restored.

Should you have any questions regarding this Notice, please call me at 534-9506. Our office hours are 8:00 a.m. through 4:30 p.m., Monday through Friday.

Sincerely,

Bill Fields
Chief Water Quality Inspector
Backflow Prevention Unit

Enclosures

Date: December 11, 2019
To: Bill Fields, Public Works Director
From: Chris Binder, Water Resource Specialist
RE: Owner's refusal to install Required Backflow Prevention Assembly at Sunflower Car Wash - 114 W. Kiedel Street

Current State and Local Backflow Requirements

Current state drinking water regulations adopted by the Arizona Department of Environmental Quality require a water supplier to “protect its public water system from contamination caused by backflow through unprotected cross connections by requiring the installation and periodic testing of backflow prevention assemblies” (A.A.C., Title 18, Chapter 4, Article 1, Section R18-4-115). In addition, Sunflower Town Ordinance Number 422 adopts Resolution Number 1016 which establishes rules, regulations and penalties relative to cross connection control for users of the public water supply.

Section 13-4-3, Part I of Town of Sunflower Resolution Number 1016 [Discontinuance of Service] states the penalty for failure to comply with backflow prevention requirements as follows:

“Service of water to any premises may be discontinued by the Department if a backflow prevention assembly required by this ordinance is not installed, tested and maintained; if it has been found that a backflow prevention assembly has been removed or bypassed; or if a cross connection exists on the premises. Service will not be restored until such conditions or defects are corrected. Sunflower may also terminate a user's service upon twenty (20) days notice in writing in non-emergency.”

Procedure Used to Notify Sunflower Water Customers of Backflow Prevention Requirements

Sunflower Water Department staff has designed a backflow prevention program that is designed to help customers achieve compliance with state regulations and local ordinance. Customers who are required to install a backflow prevention assembly at their water meter are notified of the requirement as follows:

Water Department staff mailed a “First Notice” letter to customers who are required to install a backflow assembly at their water meter. If the customer does not comply with the requirement after 30 days, a “**Second Notice**” letter is mailed. If the water customer does not install and test the required backflow assembly after 60 days, a “**Water Service Shutoff Notice**” is mailed to the customer [Refer to copies of attached letters].

Water Department staff also telephone the water system customer to verify that they have received the backflow prevention letters, to answer their questions about the requirements and to advise them that their water service will be discontinued if the specified assemblies are not properly installed and tested.

Schedule of Notification for Sunflower Car Wash

On June 04, 1996, a first notice letter was mailed to the property owner of Sunflower Car Wash located at 114 West Kiedel Street. A second notice letter was mailed on July 29, 1996. The owner of the car wash, Mr. Duane Smith, did not respond to either letter. Finally, on November 07, 1996, Town staff mailed a letter to advise Mr. Jones that his water service would be discontinued if he did not comply with the backflow prevention requirements within thirty (30) days of the final notice.

Mike Ploughe, Hydrogeologist for the Sunflower Water Department, attempted to contact Mr. Jones several times after mailing the final notice. During the third week in November, 1996, Mr. Jones left a voice mail message at my extension, and said that he didn't think an assembly was needed at his car wash. I asked Mike Ploughe to contact him and schedule an on-site survey. Mike was unable to contact Mr. Jones until Tuesday, December 10, 1996.

On Wednesday morning, December 11, 1996, Mike surveyed the site, but was uncertain if the mixing basins for the car wash chemicals were properly air-gapped. As a result, I contacted Mr. Jones at the car wash in the afternoon and resurveyed the site. Several backflow hazards exist at the facility. First, the mixing basins for the car wash chemicals are not properly air-gapped. The water inlet for the basins is below the rim of the receiving vessel, which violates the air-gap requirements of the Uniform Plumbing Code. Furthermore, the car wash facility has two hose bibs with attached hoses that are not protected against backsiphonage.

Owner's Refusal To Comply With Backflow Prevention Requirements

When I showed Mr. Jones the backflow hazards and explained the requirements for installation and testing of a backflow prevention assembly, Mr. Jones told me that he would not comply with the requirements if it would cost him too much money.

He looked through a plumbing supply catalog for a few minutes and estimated that he would probably need to pay \$400-600 for the installation and an additional \$35 - 50 for the testing. Then he told me that he had already contacted his lawyer, and that we should shut off his water and he would see us in court.

Cross-Connection Specialist Job Description *Example*

JOB SUMMARY:

Performs specialized work analyzing industrial and commercial water systems and inspecting new installations to ensure compliance with permit requirements, ordinances and state and federal regulations regarding cross connection control.

ESSENTIAL FUNCTIONS:

1. Evaluates industrial and commercial on-site water systems for proper cross connection devices to protect the city water supply from contamination.
2. Inspects new plumbing installations for compliance with cross-connection ordinances and engineering standards and follows up on deficiencies.
3. Reviews civil and architectural drawings for compliance with backflow prevention ordinances, approved components and systems.
4. Explains to owners and managers approved methods for retrofit and negotiates compliance dates.
5. Develops and presents specialized training on cross connection control and back flow prevention.
6. Provides lead supervision to support staff and serves as a technical expert for General and Specialist Building Inspectors.
7. Conducts research on cross-connection issues, construction materials and potential hazards, and prepares reports.
8. Maintains files and prepares various activity reports; develops surveys, forms, schedules, graphics, permits and draft ordinances and special programs.
9. Reviews qualifications of independent testers and issues approvals to test in our jurisdiction.
10. Tests back flow prevention assemblies to ensure certified tester accuracy.
11. Explains, interprets and enforces the City Cross-Connection Code and other codes, ordinances and guidelines related to cross connection control; issues citations and prepares materials for court cases.
12. Investigates water quality complaints and takes appropriate action.
13. Provides quality customer service.

SECONDARY FUNCTIONS:

14. Performs other related duties as assigned.

KNOWLEDGE, SKILLS, ABILITIES:

Knowledge of:

Local ordinances, codes, state and federal regulations governing the causes and control of contamination of City potable water supply.

Complex piping systems and engineering principles applicable to commercial construction.

Techniques involved in testing, identifying and correcting problems with cross connection control devices.

Installations of the correct back flow prevention devices and the proper device application.

Legal requirements related to Building Code Enforcement.

Ability to:

Make decisions within area of specialization.

Use and maintain testing equipment.

Identify possible cross connections within user's system for conformance with specifications and ordinances.

Read and interpret plans for the proper cross connection control devices.

Conduct research.

Communicate effectively verbally and in writing.

Establish and maintain effective working relationships with business owners, managers, Engineers, State and City officials and testers.

Negotiate effectively and obtain regulatory compliance.

WORKING CONDITIONS:

Fieldwork, which requires some heavy lifting and climbing up and down, ladders with possible exposure to gases and chemicals and open trenches.

MINIMUM QUALIFICATIONS:

Two years of college coursework in Engineering, Building Construction or a related field, and four years technical experience in plumbing inspection, water or wastewater systems, or water distribution treatment experience in cross connection control preferred. Any equivalent combination of training and experience, which provides the required knowledge, skills, and abilities, is qualifying.

SPECIAL REQUIREMENTS:

Back flow Prevention Assembly Tester Certification within six months of appointment.

Driver's license.

Cross Connection Control Specialist Certification within six months of appointment.

ICBO Certification as a Plumbing Inspector within one year of appointment.

TOWN OF SUNFLOWER

Backflow Prevention Program (*Checklist Example*)

Developers, Contractors and Sunflower Residents:

An approved backflow prevention assembly may be required on your water service line(s) to protect the public water system from the possibility of contamination. The assemblies, required by State and local regulations are not needed on most single family residential water services, but are required for most industrial, commercial, irrigation and fire sprinkler service connections.

This information package is designed to explain the Town of Sunflower's Backflow Prevention Program and provide you with information you will need to install and test your backflow prevention assemblies.

Inside you will find the following information:

- X **Backflow: Protecting Our Water Quality:** General backflow prevention information.

- X **Program:** Outlines customer and Sunflower Water Department's responsibilities for backflow prevention.

- X **Customer Checklist:** Lists steps necessary for permitting, installation, testing and final approval.

- X **Permit Application:** Application and two signed forms needed to obtain an installation permit.

- X **Freeze and Theft Protection:** A list of manufacturers who produce heating devices and locking enclosures to safeguard your assemblies.

- X **Standard Details and Approved Assemblies:** Sunflower Water Department Standard Details for assembly installation and information on currently approved assemblies.

- X **Testers:** A directory of Sunflower Water Department approved Certified Backflow Testers. This list is presented in random order and may not include recent changes. Ask the contractor about current registration with Sunflower Water and insurance coverage before work is performed.

- X **Fire:** Special information relating to fire services and systems.

CUSTOMER CHECKLIST FOR NEW AND RETROFIT INSTALLATIONS *(Example)*

INSTALLATION OF A BACKFLOW PREVENTION ASSEMBLY REQUIRES THE FOLLOWING ITEMS:

STEP 1) Inspections Required: Install required assemblies and call the Backflow Prevention Staff at 978-5242, Ext. 379 to schedule an inspection.

- a) Inspection for Correct Installation (Use Attached Town of Sunflower Standard Details).
- b) Inspection of Underground Piping- **DO NOT BACKFILL THE TRENCH UNTIL SUNFLOWER WATER DEPARTMENT STAFF HAVE APPROVED YOUR INSTALLATION.**
- c) Inspection for Adequate Clearance from obstructions to permit proper testing.
- d) Inspection for use of assemblies approved by the University of Southern California Foundation for Cross Connection Control and Hydraulic Research (USC FCCCHR) approved assemblies [Call the Sunflower Water Department to check on current approvals].

* The Town of Sunflower will specify what types of assemblies are needed to protect each service connection during the plan review process. Specific locations of installed assemblies must be reported to the Water Department for testing and recordkeeping purposes. Assemblies must be installed as close to the service connection (downstream side of the water meter) as practical, unless an alternate installation location has been approved by the Sunflower Water Department. [Town Ordinance Article 13, Section 13-4-3, Number 422] [State of Arizona Administrative Code - Title 18, R18-4-115]

STEP 2) Testing Requirements:

- a) After the installation inspection and approval, each backflow prevention assembly must be tested by a certified contractor prior to active use (refer to attached list of backflow prevention assembly general testers). Water service will be discontinued if backflow assemblies are not properly tested prior to occupancy!
- b) Submit test reports to the Sunflower Water Department after completion of the tests (Use Attached Form) at the following address:

Attention: Backflow Prevention Program
Town of Sunflower Water Department
978A North Beeline Highway
Sunflower, Arizona 85547

- c) Annual testing of each assembly is required. Reminder notices will be sent by the Water Department.

STEP 3) Requirements for Final Approval:

- a) All Final Inspections and Testing Complete
- b) Chains and locks on fire lines to keep them in the open position and prevent system shut off.

If you have any questions about this program, please contact the Backflow Prevention Department at (520) 978-5242, Ext. 379.

Possible Bad Connection



Direct connection from hydrant to pump.



Air Gap



Fitting at hydrant



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

Closed-Loop Water System Form (*Example*)

WARNING - HOT WATER HEATER LEAK, RUPTURE OR EXPLOSION HAZARD!

Normally, cold water flows in from your water service line and fills your hot water heater. Then, as the water is heated, it expands and flows back out through the pipe towards the water meter. As long as the flow of the expanded water is not blocked, the water pressure in the service line remains normal. However, when a backflow preventer is installed, the hot expanded water can no longer escape out through the water meter. In this case, the only way to prevent excessive heat and pressure from building up in the service line is to install a temperature and pressure (**T&P**) relief valve on the water heater and an expansion tank to the water system (1991 Uniform Plumbing Code- Section 1007). Other forms of added protection include toilet tank relief valves and in-line relief valves.

The T&P relief valve should be checked regularly to ensure that it is functioning properly. This test should be performed on an annual basis when the backflow prevention assembly is tested.

If you understand this information, please sign and return this form to obtain your assembly installation permit. If you do not understand this information, please contact the Backflow Prevention Office at (520) 978-5242, Ext. 379.

I, the undersigned, do hereby state that I fully understand the potential hazards of a closed water system and the consequences which may occur if the temperature and pressure relief valve on my hot water heater is not functioning as designed OR if expansion tanks and/or relief valves are not added to the water system when needed.

SIGNATURE: _____

NAME: (Please print) _____ DATE: ___/___/___

ADDRESS: _____

CITY: _____ STATE: _____ ZIP CODE: _____

**A SIGNED COPY OF THIS FORM MUST BE SUBMITTED TO OBTAIN YOUR BACKFLOW ASSEMBLY INSTALLATION PERMIT

Fire Services and Systems Policy (*Example*)

- Class 1 and 2 fire systems are not currently required to have any backflow prevention equipment at the service connection other than the equipment that is required for those systems under the state fire code standards. However, backflow prevention assemblies may be required on all Class 1 and 2 fire systems after future legislative review. (Refer to the Suggested Removable Pipe Spool Installation for Class 1 and 2 Fire Sprinkler Systems@ - Standard Detail W1-07 in this information package).
- Class 3 fires systems may be converted to Class 1 or 2 systems by removing the tank. However, you must have the approval of the fire authority. Contact your fire authority prior to making any changes to your existing fire system. If the system cannot be modified, a backflow assembly will be required.
- Class 4 and 5 must comply with backflow requirements. Class 5 includes those fire systems that use antifreeze or other additives (**RPDA required**). This may apply to residential homes over 3000 sq. ft.
- Class 6 fire systems require an on-site review to determine backflow requirements.
- Customers who want to increase the size of an incoming service line must comply with backflow requirements prior to the completion of construction. Contact the Sunflower Water Department at 978-5242, Ext. 379 or e-mail for more information.
- Customers who will receive reclaimed water must comply with backflow prevention requirements prior to completion of construction and before receiving reclaimed water. Contact the Sunflower Water Department at 978-5242, Ext. 379 for more information.



Common with un-educated Inspectors, this line feeds an irrigation system.

Backflow Prevention Program *Responsibilities Example*

Customer Responsibilities

- Installation of Approved Backflow Assembly
- Maintenance, Repair and Annual Testing of Assembly
- Annual inspection of check valve assemblies for Class I and 2 fire sprinkler systems by an L-16 or C-16 contractor (Refer to Fire System Section in this information package)

Sunflower Water Department Responsibilities

- Assurance of Water Quality
- Enforcement of Laws, Ordinances and Codes
- Implementation of Backflow Prevention Program
- Inspections, Surveys and Water Service Evaluations
- Retain Inventory and Service Records of All Backflow Prevention Assemblies
- Submit Reports to the State



Rust Particles

Freeze and Theft Protection for Backflow Prevention Assemblies

Example

If a backflow prevention assembly is installed outside in a location subject to freezing weather, it must be protected to prevent damage and to ensure proper operation. Several manufacturers of enclosures designed to protect assemblies from freeze and theft damage are listed below:

- 1) Heat Hut from Northern Arizona Backflow, Inc.**
Flagstaff, Arizona
Contact: Rick Williams at (520) 527-8919

- 2) HydroCowl, Inc.**
Nashville, TN
(615) 833-0233 Fax: (615) 831-0156
1-800-245-6333

- 3) FreezeGuard from Astra Industrial Services**
1-800-776-1464 Fax: (805) 499-9084

- 4) Hot Box from Hot Box-NFE, Inc.**
250 N. Lane Avenue
Jacksonville, Florida 32254

(904) 786-0204 Fax: (904) 783-6965
1-800-736-0238

- 5) Just Set Thermo Shelters from Pennsylvania Insert Corporation**
Bridge Street
Spring City, Pennsylvania 19475
(610) 948-9688 Fax: (610) 948-9750

Facility owners may install assemblies inside the building with approval from the Backflow Prevention Section of the Sunflower Water Department at (520) 978-5242, Ext. 379, or e-mail .

All customers whether installing an assembly outdoors or indoors must complete and submit a copy of the attached Freeze Protection Installation Approval Form when applying for a backflow assembly permit.

Freeze Protection Installation Approval Form *Example*

Please check the appropriate box.

Outdoor Installation:

I, the undersigned, do hereby agree to install all required backflow prevention assemblies for my facility or residence in an *outdoor* location (as close to the meter as possible) with adequate freeze protection to prevent damage to the assembly and to ensure its proper operation. I understand that the Town of Sunflower Backflow Ordinance prohibits any taps between the water meter and backflow assembly or any bypass lines around the assembly and certify that no such taps or bypasses exist on my domestic, fire or irrigation water service lines.

Indoor Installation with Water Department Approval:

I, the undersigned, have obtained approval from the Backflow Prevention Section of the Water Department to install all required backflow prevention assemblies for my facility or residence *inside the building* in a location (as close to the meter as practical) that will protect the assembly from freeze damage. I understand that the Town of Sunflower Backflow Ordinance prohibits any taps between the water meter and backflow assembly or any bypass lines around the assembly and certify that no such taps or bypasses exist on my domestic, fire or irrigation water service lines. I also understand the potential for flooding that may result within my facility if an installed reduced pressure principle assembly reaches a full port dump condition. I agree to accept all responsibility for damage if this situation occurs.

SIGNATURE:

NAME: (Please print) _____ DATE: ___/___/___

ADDRESS: _____

CITY: _____ STATE: _____ ZIP CODE: _____

TELEPHONE: (____) _____

**A SIGNED COPY OF THIS FORM MUST BE SUBMITTED TO OBTAIN YOUR BACKFLOW

Assembly Installation Permit *Example*

BACKFLOW ASSEMBLY PERMIT APPLICATION

WATER CUSTOMER MAILING ADDRESS

ASSEMBLY INFORMATION

Name: _____
Address: _____
City, State, Zip _____

Serial No. _____
MFR: _____ Model _____ Size _____
Water Meter No : _____

PROJECT NAME:

PROJECT CONTRACTOR:

SERVICE ADDRESS:

CITY, STATE, ZIP:

CONTACT PERSON: _____ TELEPHONE:

PAGER:

ASSEMBLY LOCATION:

- 1) What type of assembly will be installed? (Please Check One)
- Reduced Pressure Principle Assembly (RP)
 - Double Check Valve Assembly (DC)
 - Pressure Vacuum Breaker (PVB)
 - Reduced Pressure Principle Detector Assembly (RPDA) - *Fire Systems Only*
 - Double Check Detector Assembly (DCDA) - *Fire Systems Only*

- 2) What size is your service line?
- 3/4 inch
 - 1 inch
 - 1 1/2 inch
 - 2 inch
 - 3 inch
 - 4 inch
 - Other, Please specify

- 3) Which Town of Sunflower Standard Detail will you be using to install the backflow prevention assembly?

- Reduced Pressure Principle Assembly (RP) - 3" and larger Detail # W1-01
- Double Check Valve Assembly (DC) - 3" and larger Detail # W1-02
- Reduced Pressure Principle Assembly (RP) - INDOOR - 2 1/2 " and less Detail # W1-03
- Reduced Pressure Principle Assembly (RP) - OUTDOOR - 2 1/2 " and less Detail # W1-04
- Double Check Valve Assembly (DC) - 2 1/2 " and less Detail # W1-05
- Pressure Vacuum Breaker (PVB) Detail # W1-06
- Suggested Spool Installation for Class 1 and 2 Fire Sprinkler System Detail # W1-07
- Safety Post - MAG STANDARD DETAIL #140

TOWN OF SUNFLOWER - BACKFLOW PREVENTION CODE OF CONDUCT FOR CERTIFIED TESTERS *Example*

Backflow prevention general testers recognized by the Town of Sunflower must test, repair, and install assemblies under the direction of the Town of Sunflower Water Department and according to Town of Sunflower Ordinance # Article 13, Section 13-4-3, Number 422. The backflow prevention program for the Town has been established as follows:

- X Monthly test notices will be mailed on the first day of each month to customers whose backflow prevention assemblies are due for testing in that month. A copy of the approved list of testers will be sent with the notification letter. The customer will be responsible for contacting a certified tester.
- X The Town will recognize testers who have been certified by AWWA, USC FCCCHR, ASETT Center, and the Pipe Industry Progress and Education Fund (P.I.P.E.) . A copy of the tester 's certification, the test gauge calibration certificate, insurance certificate and Plumber or Contractor 's License must be on file with the Town of Sunflower Water Department. Testers must use recognized test equipment and provide proof of its accuracy annually.
- X All backflow assemblies must be tested in accordance with the procedures outlined in Section 9 of the *9th edition* of the USC FCCCHR Manual of Cross Connection Control. In addition, testers must perform a backpressure check on each pressure vacuum breaker. Testers who are unsure of the current procedure to check for backpressure may contact the Sunflower Water Department at (520) 978-5242, Ext. 379.
- X The Town will provide test forms to testers. **Forms other than that provided by the Town will not be accepted.** Each form must be filled out correctly and completely after each test or repair is performed on any assembly within the jurisdiction of the Town of Sunflower.
- X All tests must be performed during the month for which they are designated. Early tests will not be accepted.
- X Completed **original** test forms must be returned by the certified tester to the Town by the due date indicated on the monthly mailing record. Any test performed during the appropriate time interval, but received after the due date will be considered late, and handled as follows:
 - 1) A written warning will be issued to the tester whenever the form is received late.
 - 2) Testers receiving two warnings within a six month period will have their certification suspended for a period of three months.
 - 3) Testers receiving two warnings within any six-month interval, after having a three month suspension, will have their certification revoked permanently.
 - 4) Tests performed after the monthly deadline, because of a delay caused by the owner, will not result in a written warning, if the tester provides a written explanation for the delay. The explanation shall be attached to the test form.
 - 5) Incomplete test forms will not be accepted.
- X Testers who dismantle an assembly are responsible for having replacement parts readily available so that the assembly may be restored to proper working condition within the same working day. Under no circumstances should a customer 's water be left shut off while a tester attempts to obtain repair parts.
- X A tester may be suspended or removed from the list of certified testers for improper testing, maintenance, reporting or any other practices determined to be improper by the Backflow Program Manager.

I, _____ have received a copy of the Town of Sunflower Backflow Prevention Ordinance and read the above information. As a certified tester recognized by the Town of Sunflower, I will follow all established laws and accepted practices for installation, testing and repair of backflow prevention assemblies.

Tester' s Signature _____ ***Date*** _____

BACKFLOW 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

ω = angular velocity (rad/s)

θ = angular displacement (rad)

t = time (s)

Angular velocity can be expressed as (angular acceleration = constant):

$$\omega = \omega_o + \alpha t \text{ (2b)}$$

where

ω_o = angular velocity at time zero (rad/s)

α = angular acceleration (rad/s²)

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.)

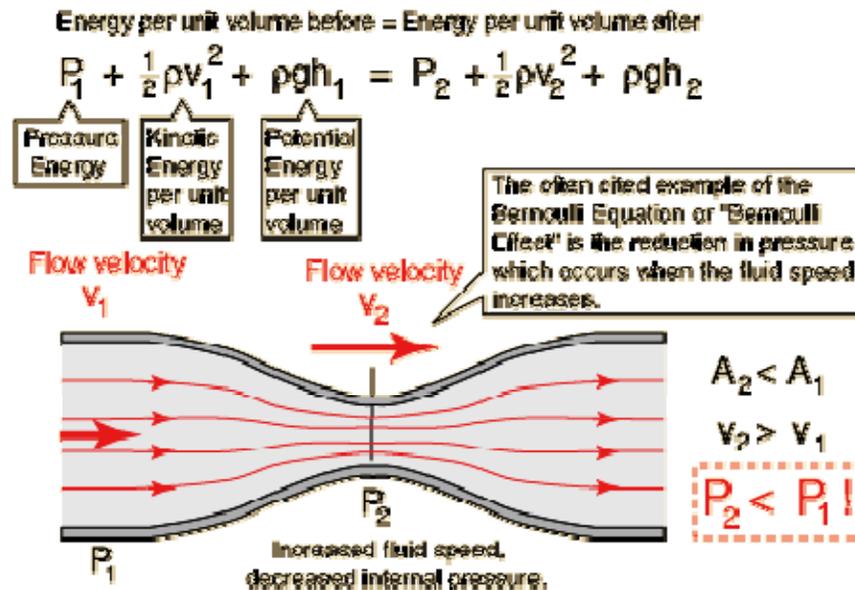
B

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

ρ = density

g = gravity

h = height

$$\frac{v^2}{2} + \frac{P}{\rho} + g \cdot h = \text{Constant} \quad (2)$$

$$\frac{v^2}{2 \cdot g} + \frac{P}{\gamma} + h = \text{Constant} \quad (3)$$

where

$\gamma = \rho \cdot g$

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

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

$$\frac{\rho \cdot v_1^2}{2} + P_1 = \frac{\rho \cdot v_2^2}{2} + P_2 = \text{Constant} \quad (6)$$

www.engineeringtoolbox.com

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.

Dynamic Pressure

(2) and (3) are two forms of the Bernoulli Equation for steady state incompressible flow. If we assume that the gravitational body force is negligible, (3) can be written as (4). Both elements in the equation have the unit of pressure and it's common to refer the flow velocity component as the **dynamic pressure** of the fluid flow (5).

Since energy is conserved along the streamline, (4) can be expressed as (6). Using the equation we see that increasing the velocity of the flow will reduce the pressure, decreasing the velocity will increase the pressure.

This phenomena can be observed in a **venturi meter** where the pressure is reduced in the constriction area and regained after. It can also be observed in a **pitot tube** where the **stagnation** pressure is measured. The stagnation pressure is where the velocity component is zero.

Bernoulli's Equation Continued:

Pressurized Tank

If the tanks are pressurized so that product of gravity and height ($g h$) is much less than the pressure difference divided by the density, (e4) can be transformed to (e6).

The velocity out from the tanks depends mostly on the pressure difference.

Example - outlet velocity from a pressurized tank

The outlet velocity of a pressurized tank where

$$p_1 = 0.2 \text{ MN/m}^2, p_2 = 0.1 \text{ MN/m}^2, A_2/A_1 = 0.01, h = 10 \text{ m}$$

can be calculated as

$$V_2 = [(2/(1-(0.01)^2) ((0.2 - 0.1) \times 10^6 / 1 \times 10^3 + 9.81 \times 10)]^{1/2} = \underline{19.9 \text{ m/s}}$$

Coefficient of Discharge - Friction Coefficient

Due to friction the real velocity will be somewhat lower than this theoretical example. If we introduce a **friction coefficient** c (coefficient of discharge), (e5) can be expressed as (e5b). The coefficient of discharge can be determined experimentally. For a sharp edged opening it may be as low as 0.6. For smooth orifices it may be between 0.95 and 1.

Bingham Plastic Fluids: Bingham Plastic Fluids have a yield value which must be exceeded before it will start to flow like a fluid. From that point the viscosity will decrease with increase of agitation. Toothpaste, mayonnaise and tomato catsup are examples of such products.

Boundary Layer: The layer of fluid in the immediate vicinity of a bounding surface.

Bulk Modulus and Fluid Elasticity: An introduction to and a definition of the Bulk Modulus Elasticity commonly used to characterize the compressibility of fluids.

The Bulk Modulus Elasticity can be expressed as

$$E = - dp / (dV / V) \quad (1)$$

where

E = bulk modulus elasticity

dp = differential change in pressure on the object

dV = differential change in volume of the object

V = initial volume of the object

The Bulk Modulus Elasticity can be alternatively expressed as

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

where

dp = differential change in density of the object

ρ = 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 N/m^2 (Pa)
- The imperial (BG) unit is lb_f/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, lb _f /in ²) x 10 ⁵	SI Units (Pa, N/m ²) x 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)

σ = surface tension (lb/ft, N/m)

θ = contact angle

ρ = density of liquid (lb/ft³, kg/m³)

g = acceleration due to gravity (32.174 ft/s², 9.81 m/s²)

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

ρ = density (kg/m³)

v = flow velocity (m/s)

E = bulk modulus elasticity (N/m²)

The bulk modulus elasticity has the dimension pressure and is commonly used to characterize the compressibility of a fluid.

The Cauchy Number is the square root of the Mach Number

$$M^2 = Ca \quad (3)$$

where

$C = \text{Mach Number}$

Cavitation: Under the wrong condition, cavitation will reduce the components life time dramatically. Cavitation may occur when the local static pressure in a fluid reach a level below the vapor pressure of the liquid at the actual temperature. According to the Bernoulli Equation this may happen when the fluid accelerates in a control valve or around a pump impeller. The vaporization itself does not cause the damage - the damage happens when the vapor almost immediately collapses after evaporation when the velocity is decreased and pressure increased. Cavitation means that cavities are forming in the liquid that we are pumping. When these cavities form at the suction of the pump several things happen all at once: We experience a loss in capacity. We can no longer build the same head (pressure). The efficiency drops. The cavities or bubbles will collapse when they pass into the higher regions of pressure causing noise, vibration, and damage to many of the components. The cavities form for five basic reasons and it is common practice to lump all of them into the general classification of cavitation.

This is an error because we will learn that to correct each of these conditions we must understand why they occur and how to fix them. Here they are in no particular order: Vaporization, Air ingestion, Internal recirculation, Flow turbulence and finally the Vane Passing Syndrome.

Avoiding Cavitation

Cavitation can in general be avoided by:

- increasing the distance between the actual local static pressure in the fluid - and the vapor pressure of the fluid at the actual temperature

This can be done by:

- reengineering components initiating high speed velocities and low static pressures
- increasing the total or local static pressure in the system
- reducing the temperature of the fluid

Reengineering of Components Initiating High Speed Velocity and Low Static Pressure

Cavitation and damage can be avoided by using special components designed for the actual rough conditions.

- Conditions such as huge pressure drops can - with limitations - be handled by Multi Stage Control Valves
- Difficult pumping conditions - with fluid temperatures close to the vaporization temperature - can be handled with a special pump - working after another principle than the centrifugal pump.

Cavitation Continued: Increasing the Total or Local Pressure in the System

By increasing the total or local pressure in the system, the distance between the static pressure and the vaporization pressure is increased and vaporization and cavitation may be avoided.

The ratio between static pressure and the vaporization pressure, an indication of the possibility of vaporization, is often expressed by the Cavitation Number. Unfortunately it may not always be possible to increase the total static pressure due to system classifications or other limitations. Local static pressure in the component may then be increased by lowering the component in the system. Control valves and pumps should in general be positioned in the lowest part of the system to maximize the static head. This is common for boiler feeding pumps receiving hot condensate (water close to 100 °C) from a condensate receiver.

Cavitation Continued: Reducing the Temperature of the Fluid

The vaporization pressure is highly dependent on the fluid temperature. Water, our most common fluid, is an example:

Temperature (°C)	Vapor Pressure (kN/m ²)
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

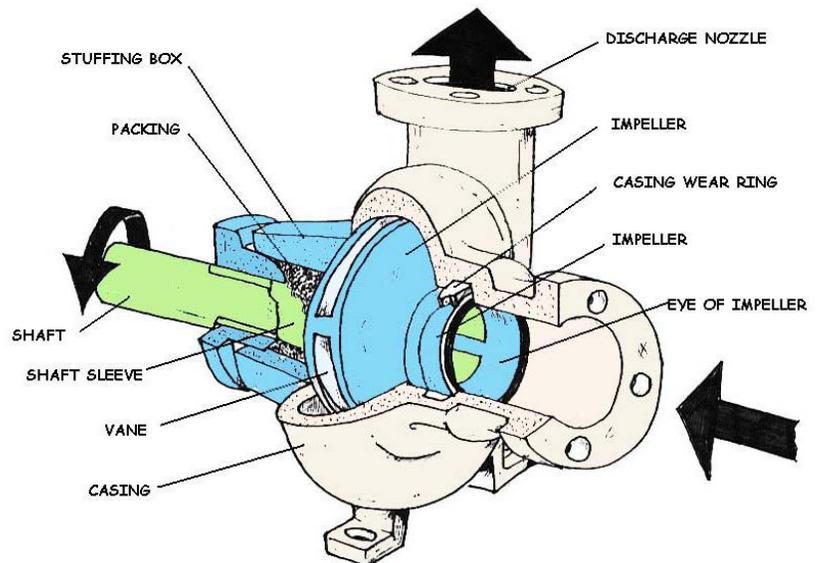
(Pa)

p_v = vapor pressure of the fluid (Pa)

ρ = density of the fluid (kg/m^3)

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 - ϵ/R - of the channel.

ϵ 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

λ = 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

Δp = pressure loss (Pa, N/m², lb_f/ft²)

λ = D'Arcy-Weisbach friction coefficient

l = length of duct or pipe (m, ft)

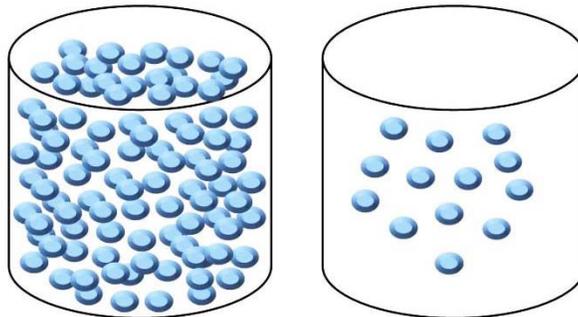
d_h = hydraulic diameter (m, ft)

ρ = density (kg/m³, lb/ft³)

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:

$$\text{Density} = \text{Mass/Volume}$$

The density can be expressed as

$$\rho = m / V = 1 / v_g (1)$$

where

ρ = density (kg/m³)

m = mass (kg)

V = volume (m³)

v_g = specific volume (m³/kg)

The SI units for density are kg/m³. The imperial (BG) units are lb/ft³ (slugs/ft³). 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/m³. 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/m³. Calculate the mass of 0.17 m³ 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:

$$F_d = c_d 1/2 \rho v^2 A \quad (1)$$

where

F_d = drag force (N)

c_d = drag coefficient

ρ = 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

$$p_d = 1/2 \rho v^2 \quad (1)$$

where

p_d = dynamic pressure (Pa)

ρ = density of fluid (kg/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

- CentiPois (cp) = CentiStokes (cSt) × Density
- SSU¹ = Centistokes (cSt) × 4.55
- Degree Engler¹ × 7.45 = Centistokes (cSt)
- Seconds Redwood¹ × 0.2469 = Centistokes (cSt)

¹centistokes greater than 50

There are two related measures of fluid viscosity - known as **dynamic (or absolute)** and **kinematic** viscosity.

Dynamic (absolute) Viscosity: The tangential force per unit area required to move one horizontal plane with respect to the other at unit velocity when maintained a unit distance apart by the fluid. The shearing stress between the layers of non-turbulent fluid moving in straight parallel lines can be defined for a Newtonian fluid as:

The dynamic or absolute viscosity can be expressed like

$$\tau = \mu \, dc/dy \quad (1)$$

where

τ = shearing stress

μ = dynamic viscosity

Equation (1) is known as the **Newton's Law of Friction**.

In the SI system the dynamic viscosity units are **N s/m²**, **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/cm²** 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)

ρ = density

γ = 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/ft² or N/m².

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 / γ -, **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 / γ - and elevation head - h - is called **the piezometric head**. The piezometric head in a flow can be measured through an flat opening parallel to the flow.

Energy and Hydraulic Grade Line Continued:

The Energy Line

The Energy Line is a line that represents the total head available to the fluid and can be expressed as:

$$EL = H = p / \gamma + v^2 / 2 g + h = \text{constant along a streamline (3)}$$

where

EL = Energy Line

For a fluid flow without any losses due to friction (major losses) or components (minor losses)

the energy line would be at a constant level. In the practical world the energy line decreases along the flow due to the losses.

A turbine in the flow will reduce the energy line and a pump or fan will increase the energy line.

The Hydraulic Grade Line

The Hydraulic Grade Line is a line that represent the total head available to the fluid minus the velocity head and can be expressed as:

$$HGL = p / \gamma + h \quad (4)$$

where

HGL = Hydraulic Grade Line

The hydraulic grade line lies one velocity head below the energy line.

Entrance Length and Developed Flow: Fluids need some length to develop the velocity profile after entering the pipe or after passing through components such as bends, valves, pumps, and turbines or similar.

The Entrance Length: The entrance length can be expressed with the dimensionless Entrance Length Number:

$$El = l_e / d \quad (1)$$

where

El = Entrance Length Number

l_e = length to fully developed velocity profile

d = tube or duct diameter

The Entrance Length Number for Laminar Flow

The Entrance length number correlation with the Reynolds Number for laminar flow can be expressed as:

$$El_{laminar} = 0.06 Re \quad (2)$$

where

Re = Reynolds Number

The Entrance Length Number for Turbulent Flow

The Entrance length number correlation with the Reynolds Number for turbulent flow can be expressed as:

$$El_{turbulent} = 4.4 Re^{1/6} \quad (3)$$

Entropy in Compressible Gas Flow: Calculating entropy in compressible gas flow Entropy change in compressible gas flow can be expressed as

$$ds = c_v \ln(T_2 / T_1) + R \ln(\rho_1 / \rho_2) \quad (1)$$

or

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

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

ρ = density of gas

p = absolute pressure

Equation of Continuity: The Law of Conservation of Mass states that mass can be neither created nor destroyed. Using the Mass Conservation Law on a **steady flow** process - flow where the flow rate doesn't change over time - through a control volume where the stored mass in the control volume doesn't change - implements that inflow equals outflow. This statement is called **the Equation of Continuity**. Common application where **the Equation of Continuity** can be used are pipes, tubes and ducts with flowing fluids and gases, rivers, overall processes as power plants, dairies, logistics in general, roads, computer networks and semiconductor technology and more.

The Equation of Continuity and can be expressed as:

$$\begin{aligned} m &= \rho_{i1} v_{i1} A_{i1} + \rho_{i2} v_{i2} A_{i2} + \dots + \rho_{in} v_{in} A_{im} \\ &= \rho_{o1} v_{o1} A_{o1} + \rho_{o2} v_{o2} A_{o2} + \dots + \rho_{om} v_{om} A_{om} \quad (1) \end{aligned}$$

where

m = mass flow rate (kg/s)

ρ = density (kg/m³)

v = speed (m/s)

A = area (m²)

With uniform density equation (1) can be modified to

$$\begin{aligned} q &= v_{i1} A_{i1} + v_{i2} A_{i2} + \dots + v_{in} A_{im} \\ &= v_{o1} A_{o1} + v_{o2} A_{o2} + \dots + v_{om} A_{om} \quad (2) \end{aligned}$$

where

q = flow rate (m³/s)

$\rho_{i1} = \rho_{i2} = \dots = \rho_{in} = \rho_{o1} = \rho_{o2} = \dots = \rho_{om}$

Example - Equation of Continuity

10 m³/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

$$v_{80} = (10 \text{ m}^3/\text{h})(1 / 3600 \text{ h/s}) / (3.14 \times 0.08 \text{ (m)} \times 0.08 \text{ (m)} / 4) \\ = \underline{0.55 \text{ m/s}}$$

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

ρ = 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 (ft²/s² = ft lb/slug or m²/s² = N m/kg)

Efficiency

According to (1) a larger amount of loss - w_{loss} - result in more shaft work required for the same rise of output energy. The efficiency of a **pump or fan process** can be expressed as:

$$\eta = (W_{shaft} - W_{loss}) / W_{shaft} \quad (3)$$

The efficiency of a **turbine process** can be expressed as:

$$\eta = W_{shaft} / (W_{shaft} + W_{loss}) \quad (4)$$

The Mechanical Energy Equation in Terms of Energy per Unit Volume

The mechanical energy equation for a **pump or a fan** (1) can also be written in terms of **energy per unit volume** by multiplying (1) with fluid density - ρ :

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

where

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

The dimensions of equation (5) are

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

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

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

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 ft³/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/ft³
- 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 $n^2 - n + 41$ are sometimes called "Euler numbers" (Flannery and Flannery 2000, p. 47).

F

Fecal Coliform: A group of bacteria that may indicate the presence of human or animal fecal matter in water.

Filtration: A series of processes that physically remove particles from water.

Flood Rim: The point of an object where the water would run over the edge of something and begin to cause a flood. See Air Break.

Fluids: A fluid is defined as a substance that continually deforms (flows) under an applied shear stress regardless of the magnitude of the applied stress. It is a subset of the phases of matter and includes liquids, gases, plasmas and, to some extent, plastic solids. Fluids are also divided into liquids and gases. Liquids form a free surface (that is, a surface not created by their container) while gases do not.

The distinction between solids and fluids is not so obvious. The distinction is made by evaluating the viscosity of the matter: for example silly putty can be considered either a solid or a fluid, depending on the time period over which it is observed. Fluids share the properties of not resisting deformation and the ability to flow (also described as their ability to take on the shape of their containers).

These properties are typically a function of their inability to support a shear stress in static equilibrium. While in a solid, stress is a function of strain, in a fluid, stress is a function of rate of strain. A consequence of this behavior is Pascal's law which entails the important role of pressure in characterizing a fluid's state. Based on how the stress depends on the rate of strain and its derivatives, fluids can be characterized as: Newtonian fluids: where stress is directly proportional to rate of strain, and Non-Newtonian fluids : where stress is proportional to rate of strain, its higher powers and derivatives (basically everything other than Newtonian fluid).

The behavior of fluids can be described by a set of partial differential equations, which are based on the conservation of mass, linear and angular momentum (Navier-Stokes equations) and energy. The study of fluids is fluid mechanics, which is subdivided into fluid dynamics and fluid statics depending on whether the fluid is in motion or not. Fluid **Related Information:** The Bernoulli Equation - A statement of the conservation of energy in a form useful for solving problems involving fluids. For a non-viscous, incompressible fluid in steady flow, the sum of pressure, potential and kinetic energies per unit volume is constant at any point. Equations in Fluid Mechanics - Continuity, Euler, Bernoulli, Dynamic and Total Pressure. Laminar, Transitional or Turbulent Flow? - It is important to know if the fluid flow is laminar, transitional or turbulent when calculating heat transfer or pressure and head loss.

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

G

Gas: A gas is one of the four major phases of matter (after solid and liquid, and followed by plasma) that subsequently appear as solid material when they are subjected to increasingly higher temperatures. Thus, as energy in the form of heat is added, a solid (e.g., ice) will first melt to become a liquid (e.g., water), which will then boil or evaporate to become a gas (e.g., water vapor). In some circumstances, a solid (e.g., "dry ice") can directly turn into a gas: this is called sublimation. If the gas is further heated, its atoms or molecules can become (wholly or partially) ionized, turning the gas into a plasma. **Relater Gas Information:** The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature

and pressure as expressed in the Ideal Gas Law. Properties of Gas Mixtures - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density. The Individual and Universal Gas Constant - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.

Gauge Pressure: Pressure differential above or below ambient atmospheric pressure.

H

Hazardous Atmosphere: An atmosphere which by reason of being explosive, flammable, poisonous, corrosive, oxidizing, irritating, oxygen deficient, toxic, or otherwise harmful, may cause death, illness, or injury.

Hazen-Williams Factor: Hazen-Williams factor for some common piping materials. Hazen-Williams coefficients are used in the Hazen-Williams equation for friction loss calculation in ducts and pipes.

Hazen-Williams Equation - Calculating Friction Head Loss in Water Pipes

Friction head loss (ft H₂O 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_{H₂O}/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 10⁵ (turbulent flow).

- 1 ft (foot) = 0.3048 m
- 1 in (inch) = 25.4 mm

- 1 gal (US)/min = $6.30888 \times 10^{-5} \text{ m}^3/\text{s}$ = $0.0227 \text{ m}^3/\text{h}$ = $0.0631 \text{ dm}^3(\text{liter})/\text{s}$ = $2.228 \times 10^{-3} \text{ ft}^3/\text{s}$
= $0.1337 \text{ ft}^3/\text{min}$ = $0.8327 \text{ Imperial gal (UK)/min}$

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:

$$p / \rho^k = \text{constant (2)}$$

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

μ = absolute or dynamic viscosity

ρ = density

In the SI-system the theoretical unit is m^2/s or commonly used **Stoke (St)** where

- $1 \text{ St} = 10^{-4} \text{ m}^2/\text{s}$

Since the Stoke is an unpractical large unit, it is usual divided by 100 to give the unit called **Centistokes (cSt)** where

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

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

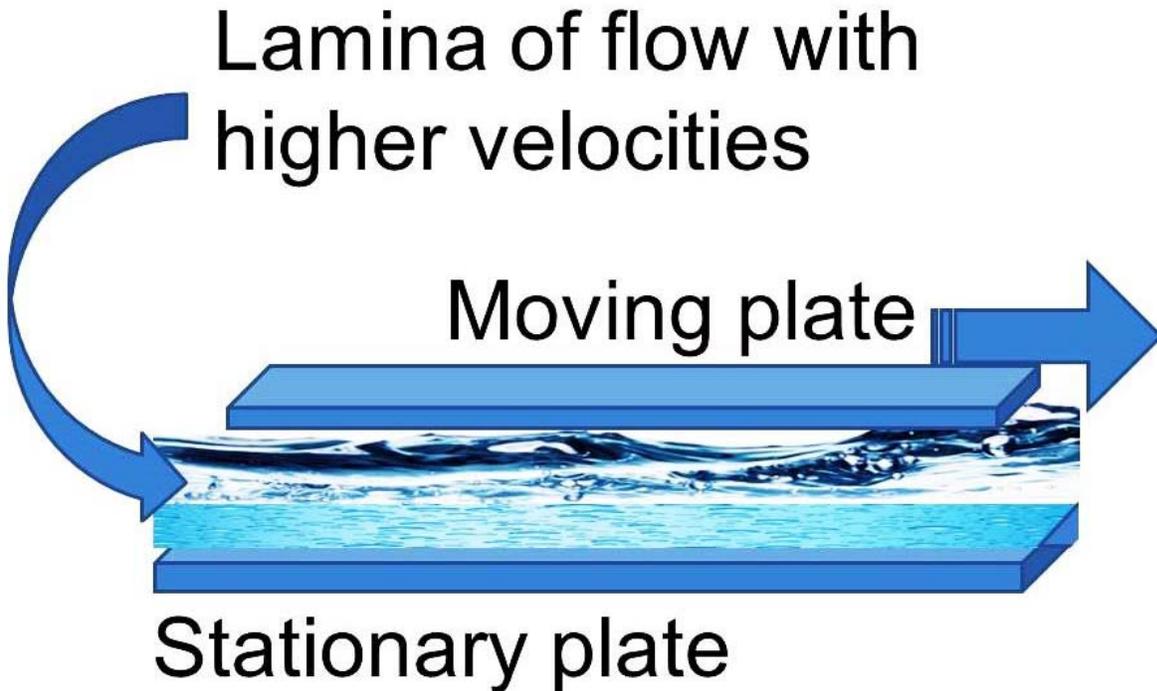
Since the specific gravity of water at 68.4°F (20.2°C) is almost one - 1, the kinematic viscosity of water at 68.4°F is for all practical purposes 1.0 cSt.

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 ∇^2 is the Laplacian.

Note that the operator ∇^2 is commonly written as Δ by mathematicians (Krantz 1999, p. 16).

Laplace's equation is a special case of the Helmholtz differential equation

$$\nabla^2 \psi + k^2 \psi = 0 \tag{2}$$

with $k = 0$, or Poisson's equation

$$\nabla^2 \psi = -4 \pi \rho \tag{3}$$

with $\rho = 0$.

The vector Laplace's equation is given by

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

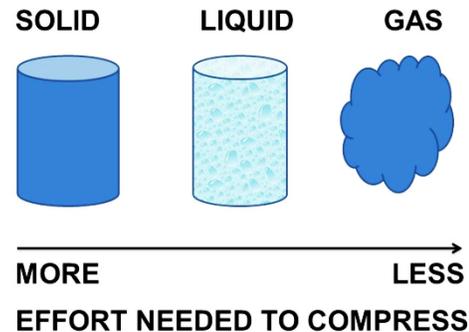
A function ψ which satisfies Laplace's equation is said to be harmonic. A solution to Laplace's equation has the property that the average value over a spherical surface is equal to the value

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 (ft², m²)

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 (ft³/s, m³/s)

A = cross-sectional area of flow (ft², m²)

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), CentiPoisies (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 (m³/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

ν = kinematic viscosity (Pa s)

α = thermal diffusivity (W/m K)

The Prandtl number can alternatively be expressed as

$$Pr = \mu c_p / k \quad (2)$$

where

μ = 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 ft² °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/in² (psi) or lb/ft² (psf), N/m² or kg/ms² (Pa)]

F = force [¹, N]

A = area [in² or ft², m²]

¹) In the English Engineering System special care must be taken for the force unit. The basic unit for mass is the pound mass (lb_m) and the unit for the force is the pound (lb) or pound force (lb_f).

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.

- $1 \text{ atm} = 1.01325 \text{ bar} = 101.3 \text{ kPa} = 14.696 \text{ psi (lb}_\text{f}/\text{in}^2) = 760 \text{ mmHg} = 10.33 \text{ mH}_2\text{O} = 760 \text{ torr} = 29.92 \text{ in Hg} = 1013 \text{ mbar} = 1.0332 \text{ kg}/\text{cm}^2 = 33.90 \text{ ftH}_2\text{O}$

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 cm² 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.

$$1 \text{ millibar} = 0.001 \text{ bar} = 0.750 \text{ torr} = 100 \text{ Pa}$$

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 (ρu^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)

ρ = density (kg/m^3 , lb_m/ft^3)

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

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

L = characteristic length (m, ft)

ν = kinematic viscosity (m^2/s , ft^2/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

$$\nu = 4.63 \mu / SG \quad (3)$$

where

ν = kinematic viscosity (SSU)

μ = 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

ρ = density of fluid or substance (kg/m^3)

ρ_{H_2O} = density of water (kg/m^3)

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^3 , 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:

$$SG = 7850 \text{ kg/m}^3 / 1000 \text{ kg/m}^3$$

$$= 7.85$$

(the density of water is 1000 kg/m^3)

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

γ = specific weight (kN/m^3)

g = acceleration of gravity (m/s^2)

The SI-units of specific weight are kN/m^3 . The imperial units are lb/ft^3 . The local acceleration g is under normal conditions 9.807 m/s^2 in SI-units and 32.174 ft/s^2 in imperial units.

Example - Specific Weight Water

Specific weight for water at 60 °F is 62.4 lb/ft³ in imperial units and 9.80 kN/m³ in SI-units.

Example - Specific Weight Some other Materials

Product	Specific Weight - γ	
	Imperial Units (lb/ft ³)	SI Units (kN/m ³)
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

γ = 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

γ = specific weight

g = acceleration of gravity

In general, the specific weight - γ - is constant for fluids. For gases the specific weight - γ - 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 - γ - required to give a pressure difference of $(p_2 - p_1)$.

Example - Pressure Head

A pressure difference of 5 psi (lbf/in²) 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/ft³) and specific weight of mercury is 847 (lb/ft³).

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

ω = 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

σ = 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/m² or alternatively ergs per square centimeter.
- 1 dynes/cm = 0.001 N/m = 0.0000685 lb_f/ft = 0.571 10⁻⁵ lb_f/in = 0.0022 poundal/ft = 0.00018 poundal/in = 1.0 mN/m = 0.001 J/m² = 1.0 erg/cm² = 0.00010197 kg_f/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 - σ - (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.

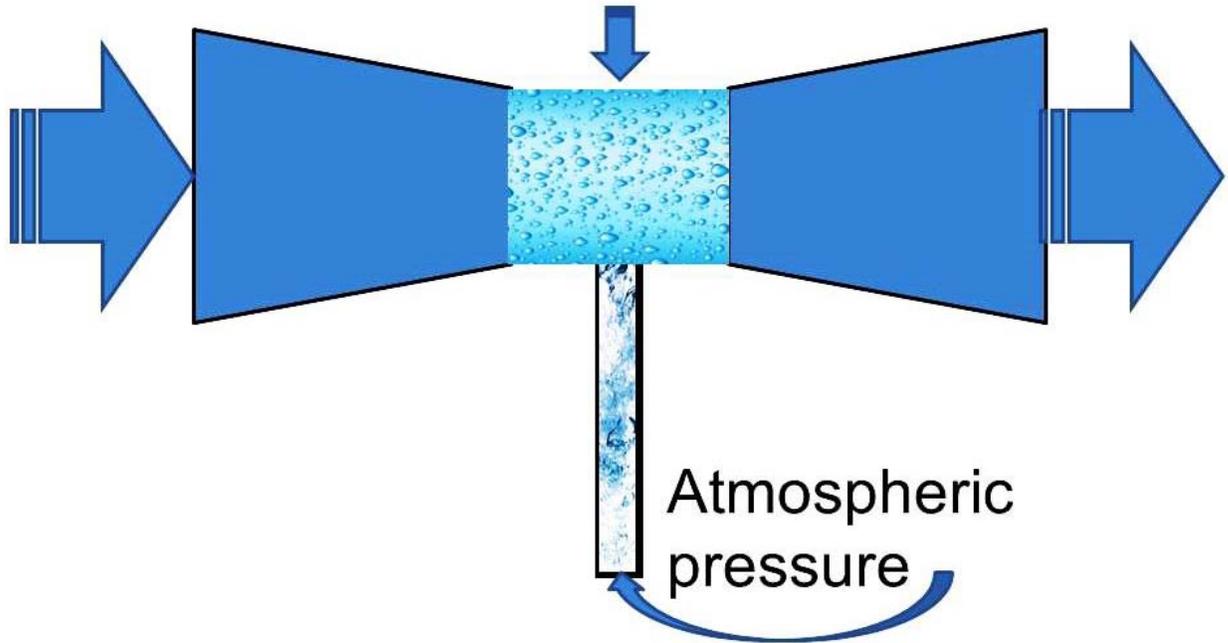
Vapor Pressure: For a particular substance at any given temperature there is a pressure at which the vapor of that substance is in equilibrium with its liquid or solid forms.

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.

Velocity increases – Pressure drops



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 η "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.

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

⇕

⇕

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

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/cm²], 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 ν "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 [m²/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 [cm²/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 [mm²/s] or centistoke [cSt].

Viscosity and Reference Temperatures: The viscosity of a fluid is highly temperature dependent and for either dynamic or kinematic viscosity to be meaningful, the **reference temperature** must be

quoted. In ISO 8217 the reference temperature for a residual fluid is 100°C. For a distillate fluid the reference temperature is 40°C.

- For a liquid - the kinematic viscosity will **decrease** with higher temperature.
- For a gas - the kinematic viscosity will **increase** with higher temperature.

Volute: The spiral-shaped casing surrounding a pump impeller that collects the liquid discharged by the impeller.

Vorticity: Vorticity is defined as the circulation per unit area at a point in the flow field.

Vortex: A vortex is a whirlpool in the water.

W

Water Freezing: The effects of water freezing in storage tanks can be minimized by alternating water levels in the tank.

Water Storage Facility Inspection: During an inspection of your water storage facility, you should inspect the Cathodic protection system including checking the anode's condition and the connections. The concentration of polyphosphates that is used for corrosion control in storage tanks is typically 5 mg/L or less. External corrosion of steel water storage facilities can be reduced with Zinc or aluminum coatings. All storage facilities should be regularly sampled to determine the quality of water that enters and leaves the facility. One tool or piece of measuring equipment is the Jackson turbidimeter, which is a method to measure cloudiness in water.

Wave Drag: Wave drag refers to a sudden and very powerful drag that appears on aircrafts flying at high-subsonic speeds.

Water Purveyor: The individuals or organization responsible to help provide, supply, and furnish quality water to a community.

Water Works: All of the pipes, pumps, reservoirs, dams and buildings that make up a water system.

Waterborne Diseases: A disease, caused by a virus, bacterium, protozoan, or other microorganism, capable of being transmitted by water (e.g., typhoid fever, cholera, amoebic dysentery, gastroenteritis).

Weber Number: A dimensionless value useful for analyzing fluid flows where there is an interface between two different fluids. Since the Weber Number represents an index of the inertial force to the surface tension force acting on a fluid element, it can be useful analyzing thin films flows and the formation of droplets and bubbles.

Math Conversion Factors

1 PSI = 2.31 Feet of Water
1 Foot of Water = .433 PSI
1.13 Feet of Water = 1 Inch of Mercury
454 Grams = 1 Pound
1 Gallon of Water = 8.34 lbs/gallon
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

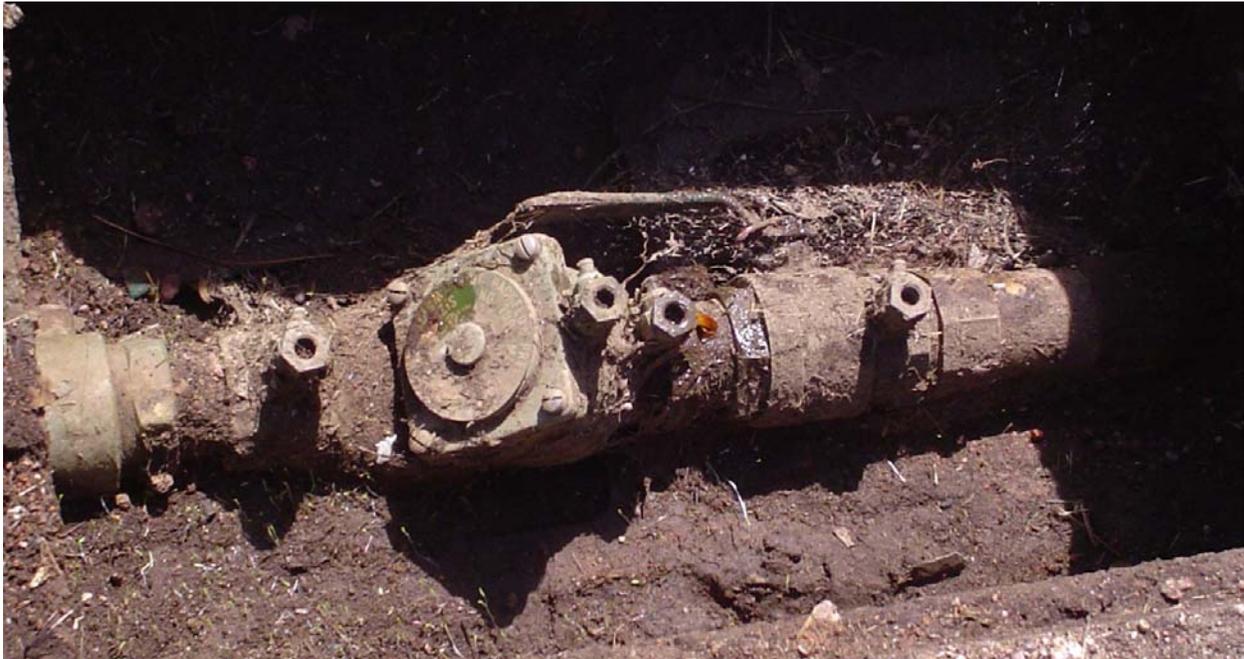
12 Inches = 1 Foot
3 Feet = 1 Yard
5280 Feet = 1 Mile

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



Another RP inside a water meter box, broken shut-offs and not tested for over 20 years. The best thing to do is rip out this assembly and install a completely new assembly above ground and test the assembly. Careful to document the location, serial number and other information for the water provider. The owner of the backflow preventer will feel ripped-off because he did not realize the potential hazard, so you need to carefully and skillfully explain the necessity of the replacement and relocation. Often, your water provider will support you in a correct decision but sometimes, these "officials" don't know or don't care about the condition or location of assemblies. I have seen water providers do the dumbest things and the next day, change their minds and blame the tester for the problem. CWA! Document everything and prepare to be underbid and held accountable.

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