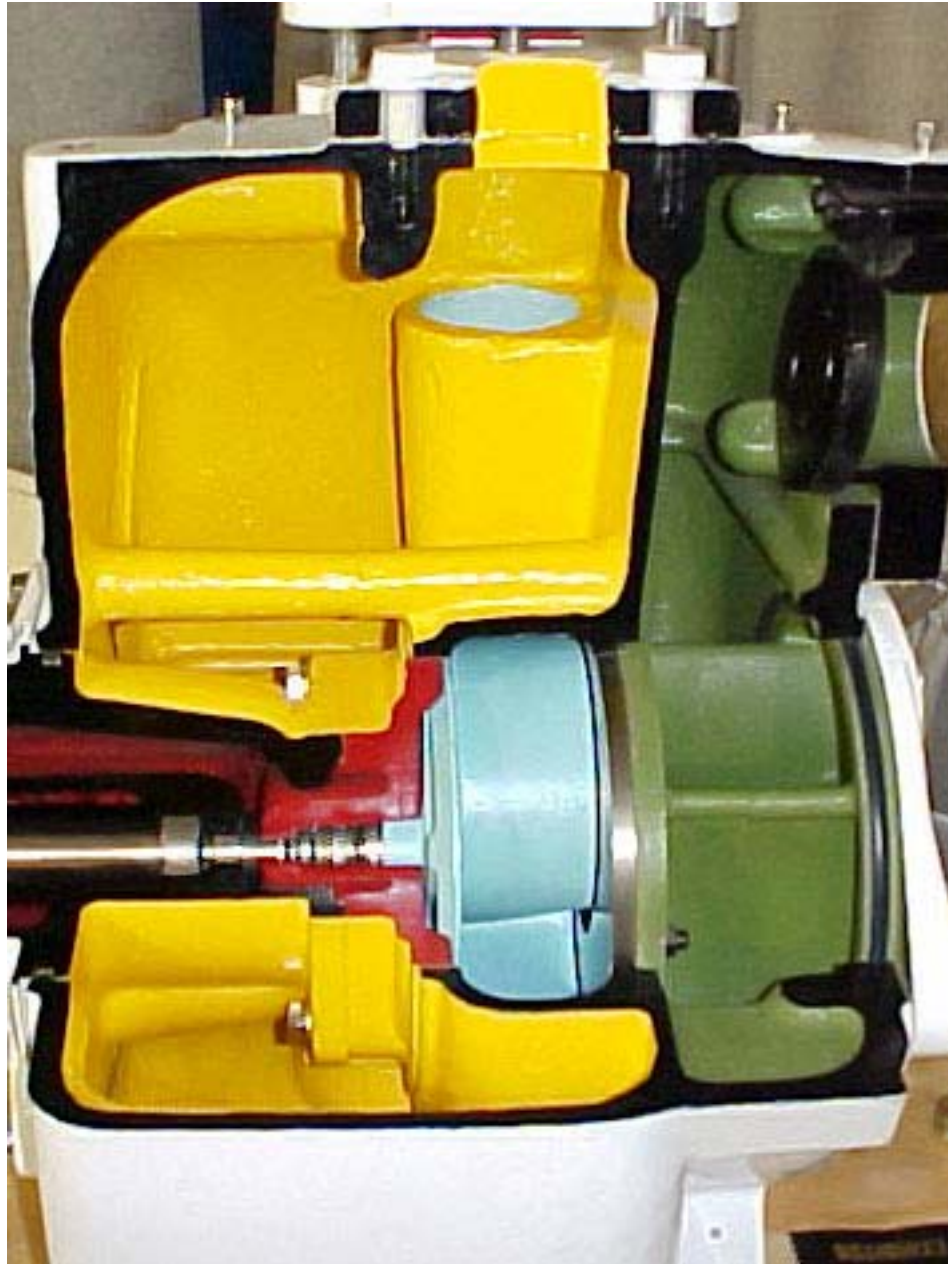


PUMPING PRINCIPLES

CONTINUING EDUCATION PROFESSIONAL DEVELOPMENT COURSE



Printing and Saving Instructions

It is recommended that you download this pdf document and assignment to your computer desktop and open it with Adobe Acrobat DC reader.

Adobe Acrobat DC reader is a free computer software program and you can find it at Adobe Acrobat's website.

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

Printing Instructions: Once you have purchased the program, we will give you permission to print this document. If you are going to print this document, it was designed to be printed double-sided or duplexed but can be printed single-sided.

Link to Assignment...

<http://www.tlch2o.com/PDF/Pumping%20Ass.pdf>

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State Approval Listing URL...

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

All downloads are electronically tracked and monitored for security purposes.

Important Information about this Manual

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

This manual should not be used as a guidance document for employees who are involved with cross-connection control. It is not designed to meet the requirements of the United States Environmental Protection Agency (**EPA**), the Department of Labor-Occupational Safety and Health Administration (**OSHA**), or your state environmental or health agency. Technical Learning College or Technical Learning Consultants, Inc. makes no warranty, guarantee or representation as to the absolute correctness or appropriateness of the information in this manual and assumes no responsibility in connection with the implementation of this information.

It cannot be assumed that this manual contains all measures and concepts required for specific conditions or circumstances. This document should be used for educational purposes and is not considered a legal document. Individuals who are responsible for hydraulic equipment, cross-connection control, backflow prevention or water distribution should obtain and comply with the most recent federal, state, and local regulations relevant to these sites and are urged to consult with OSHA, the EPA and other appropriate federal, state and local agencies.

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

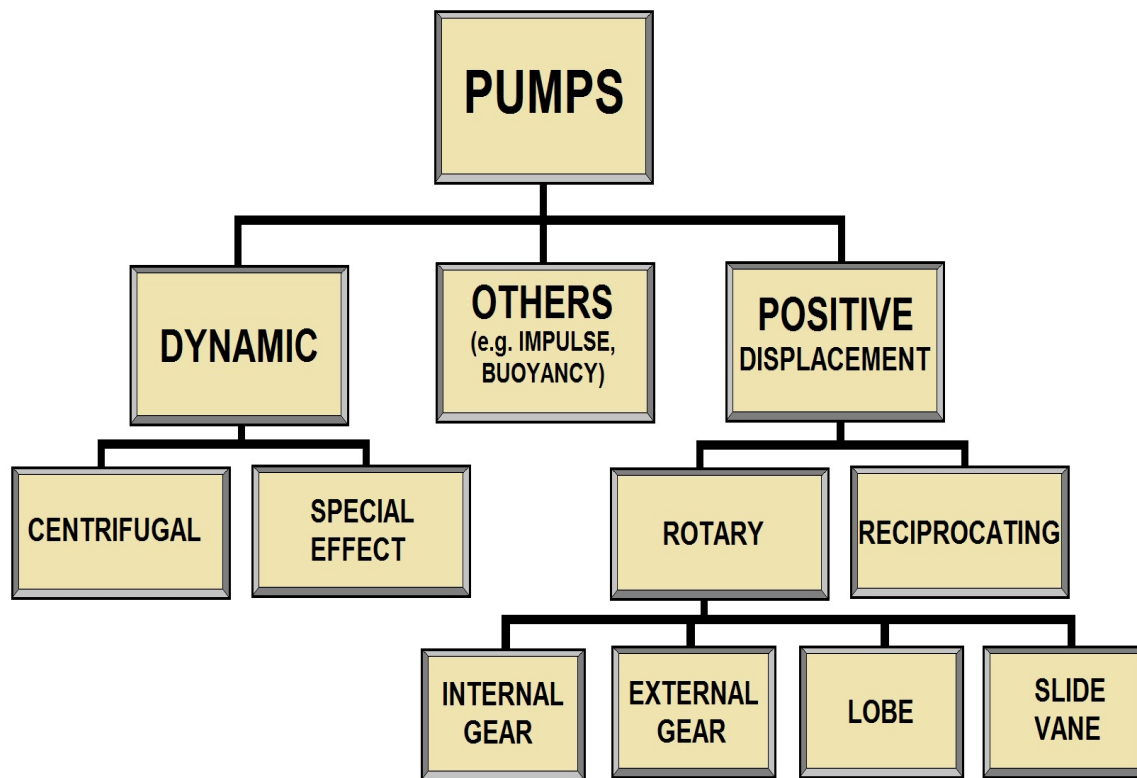
Do not solely depend on TLC's Approval list for it may be outdated.

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.

Responsibility

This course contains EPA's federal rule requirements. Please be aware that each state implements drinking water/wastewater/safety regulations that may be more stringent than EPA's or OSHA's regulations. Check with your state environmental agency for more information. You are solely responsible in ensuring that you abide with your jurisdiction or agency's rules and regulations.



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Technical Learning College's Scope and Function

Welcome to the Program,

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

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

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

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

Flexible Learning

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

Course Structure

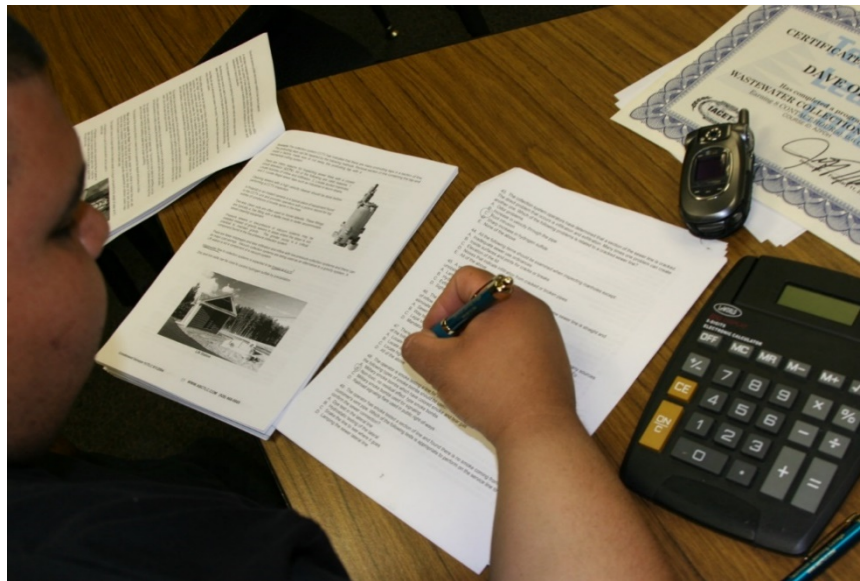
TLC's online courses combine the best of online delivery and traditional university textbooks. You can easily find the course syllabus, course content, assignments, and the post-exam (Assignment). This student friendly course design allows you the most flexibility in choosing when and where you will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

Classroom of One

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

Satisfaction Guaranteed

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



We welcome you to do the electronic version of the assignment and submit the answer key and registration to us either by fax or e-mail. If you need this assignment graded and a certificate of completion within a 48-hour turn around, prepare to pay an additional rush charge of \$50.

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

Course Description

Pumping Principles CEU Training Course

Review of pump operation, starting with hydraulic fundamentals and advancing to the electrical power and other related components of pumping water. The student will develop an understanding of the engineering science pertaining to liquid pressure, flow and pumping dynamics'. This course will cover the basics of hydraulic fundamentals commonly related to the study of the mechanical properties of water. This course will also examine hydrostatics or fluid mechanics as well as the history and development of pumps, hydraulics and the science of fluids. This training course will present several familiar topics in pumping along with hydraulics and hydrostatics that often appear in most educational expositions of introductory science, and which are also of historical interest and can enliven a student's educational experience. ***You will not need any other materials for this course.***

Water Distribution, Well Drillers, Pump Installers, Water Treatment Operators, Wastewater Treatment Operators, Wastewater Collection Operators, Industrial Wastewater Operators and General Backflow Assembly Testers. The target audience for this course is the person interested in working in a water or wastewater treatment or distribution/collection facility and/or wishing to maintain CEUs for certification license or to learn how to do the job safely and effectively, and/or to meet education needs for promotion.

Final Examination for Credit

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

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 or a unique number assigned to the student.

Instructions for Assignment

The Pumping Principles CEU training course uses a multiple choice type answer key. You can find a copy of the answer key in Word format on TLC's website under the Assignment Page. You can also find complete course support under the Assignment Page. You can write your answers in this manual or type out your own answer key.

TLC would prefer that you type out and fax or e-mail the final exam to TLC, but it is not required. 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.

Feedback Mechanism (examination procedures)

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

Security and Integrity

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

Grading Criteria

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

Required Texts

The ***Pumping Principles*** CEU training course will not require any other materials. This course comes complete. No other materials are needed.

Recordkeeping and Reporting Practices

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

ADA Compliance

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

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,

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.

Table of Contents

| | |
|--------------------------------|-----|
| Hydraulic Principles | 15 |
| Atmospheric Pressure..... | 17 |
| Pressure..... | 21 |
| Geometric Arguments..... | 23 |
| Vacuum..... | 24 |
| Development of Hydraulics..... | 27 |
| Hydraulic Levels..... | 31 |
| Dudley Castle Engine..... | 35 |
| Hydrostatic Paradox..... | 39 |
| How Buoyancy Works..... | 40 |
| Hydrometer..... | 43 |
| Pascal's Law..... | 47 |
| Bernoulli's Principles..... | 48 |
| Archimedes..... | 53 |
| Backflow Introduction..... | 57 |
| Actual Events..... | 58 |
| Cross-Connection Terms..... | 60 |
| Backpressure..... | 64 |
| Pump Operation..... | 67 |
| Pump Definitions..... | 69 |
| Basic Pump..... | 71 |
| Water Well Pumps..... | 73 |
| Submersible Pumps..... | 75 |
| Pumping Fundamentals..... | 77 |
| Motor..... | 79 |
| Electrical Glossary..... | 83 |
| Lubrication..... | 89 |
| Couplings..... | 91 |
| Pump Categories..... | 93 |
| Mechanical Seals..... | 96 |
| Pump Casing..... | 97 |
| Positive Displacement..... | 99 |
| Troubleshooting..... | 107 |
| | |
| Glossary..... | 111 |
| Appendixes..... | 153 |
| Math Exercise..... | 175 |
| References..... | 187 |

Common Hydraulic Terms

Head

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

Head, Friction

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

Head, static

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

Hydraulics

Engineering science pertaining to liquid pressure and flow.

Hydrokinetics

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

Pascal's Law

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

Pressure

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

Pressure, Absolute

The pressure above zone absolute, i.e. the sum of atmospheric and gage pressure. In vacuum related work, it is usually expressed in millimeters of mercury. (mmHg).

Pressure, Atmospheric

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

Pressure, Gauge

Pressure differential above or below ambient atmospheric pressure.

Pressure, Static

The pressure in a fluid at rest.

Hydraulic Principles Section

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.

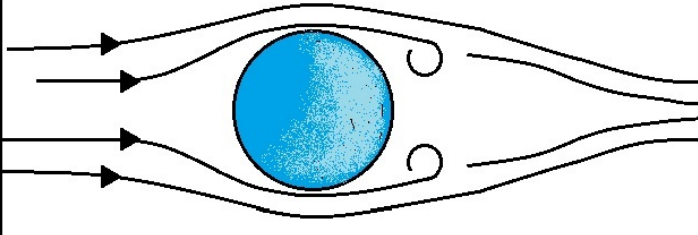
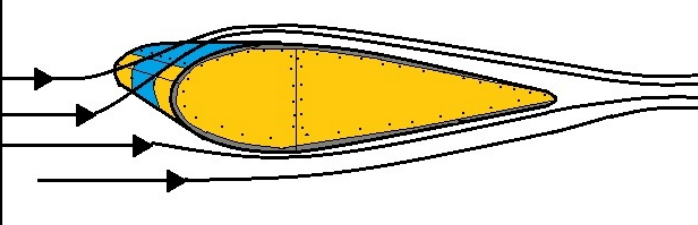
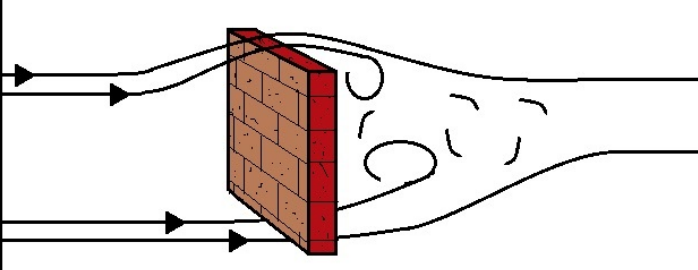
The definition of a fluid deserves careful consideration. Although time is not a factor in hydrostatics, it enters in the approach to hydrostatic equilibrium. It is usually stated that a fluid is a substance that cannot resist a shearing stress, so that pressures are normal to confining surfaces. Geology 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.

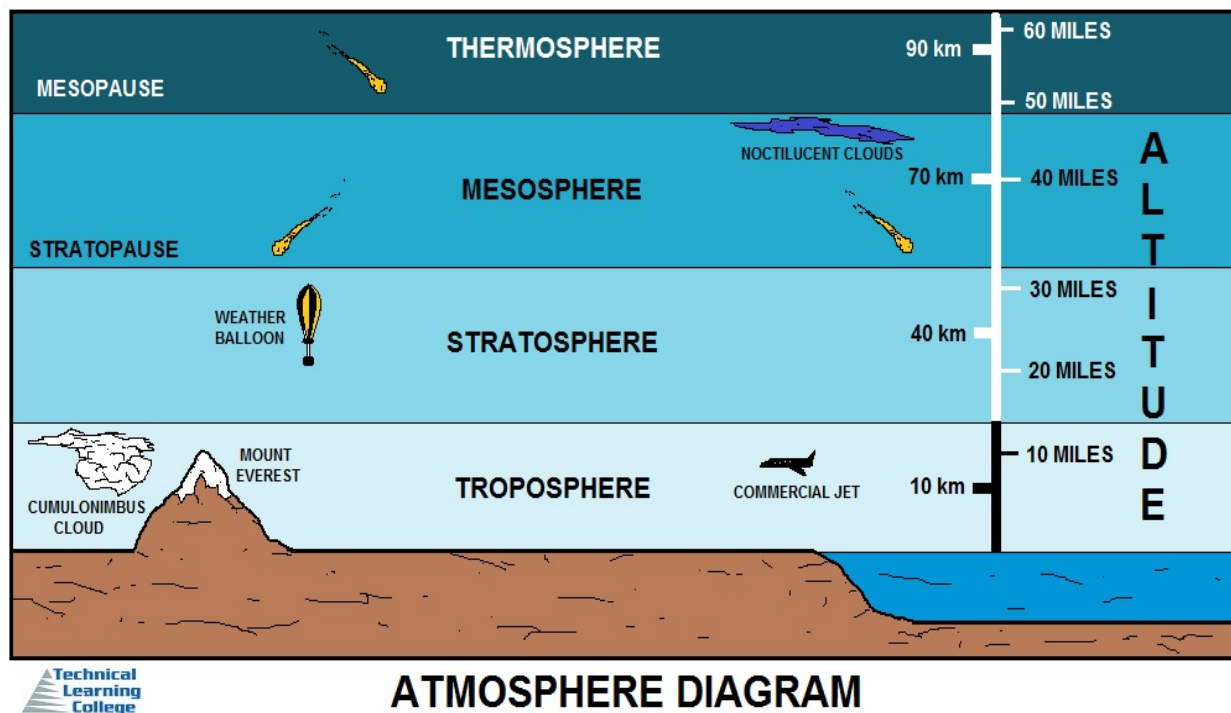
| | |
|---|---|
|  | <p>SPHERE</p> <p>-ROUND OBJECTS SUCH AS BASEBALLS / SOFTBALLS EXPERIENCE A MEDIUM AMOUNT OF DRAG</p> |
|  | <p>AIRFOIL</p> <p>-THE SHAPE OF AIRPLANE WINGS MINIMIZE DRAG</p> |
|  | <p>SQUARE</p> <p>-FLAT OBJECTS, SUCH AS BOXES OR WALLS EXPERIENCE A VERY HIGH AMOUNT OF DRAG</p> |

DRAG FORCE (VISCOUS)

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



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.

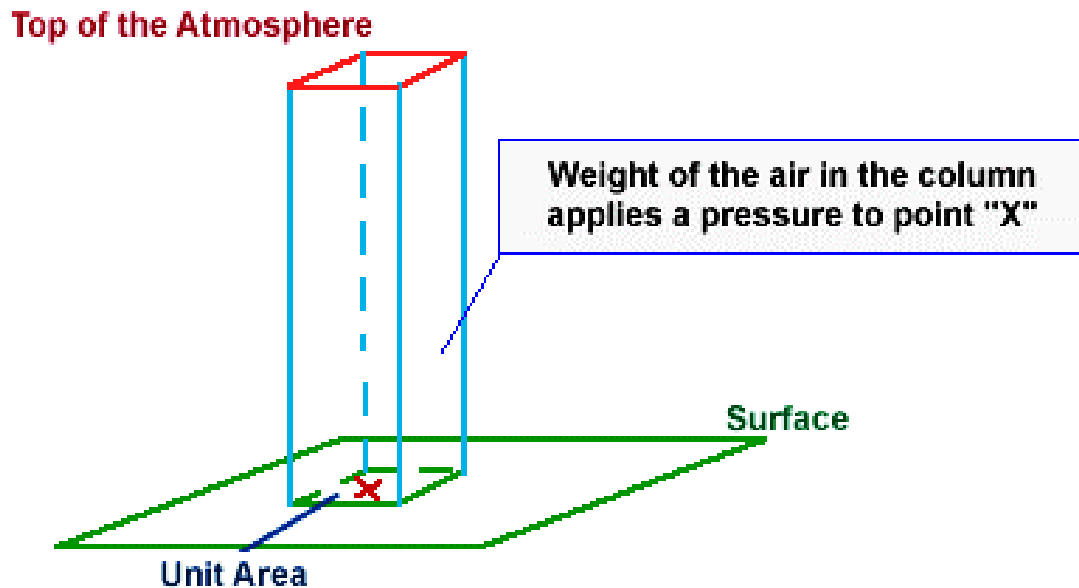
Atmospheric pressure can be measured by any of several methods. The common laboratory method uses the mercury column barometer. The height of the mercury column serves as an indicator of atmospheric pressure. At sea level and at a temperature of 0° Celsius (**C**), the height of the mercury column is 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.



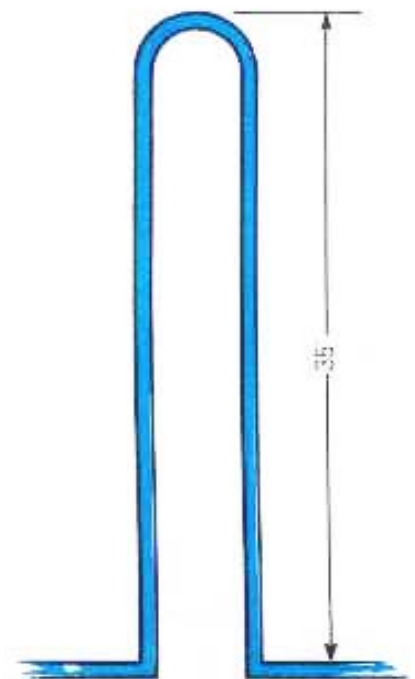
Barometric Loop

The barometric loop consists of a continuous section of supply piping that abruptly rises to a height of approximately 35 feet and then returns back down to the originating level.

It is a loop in the piping system that effectively protects against backsiphonage. It may not be used to protect against back-pressure.

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

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



Absolute pressure and gauge pressure are related.

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

Absolute pressure is the total pressure.

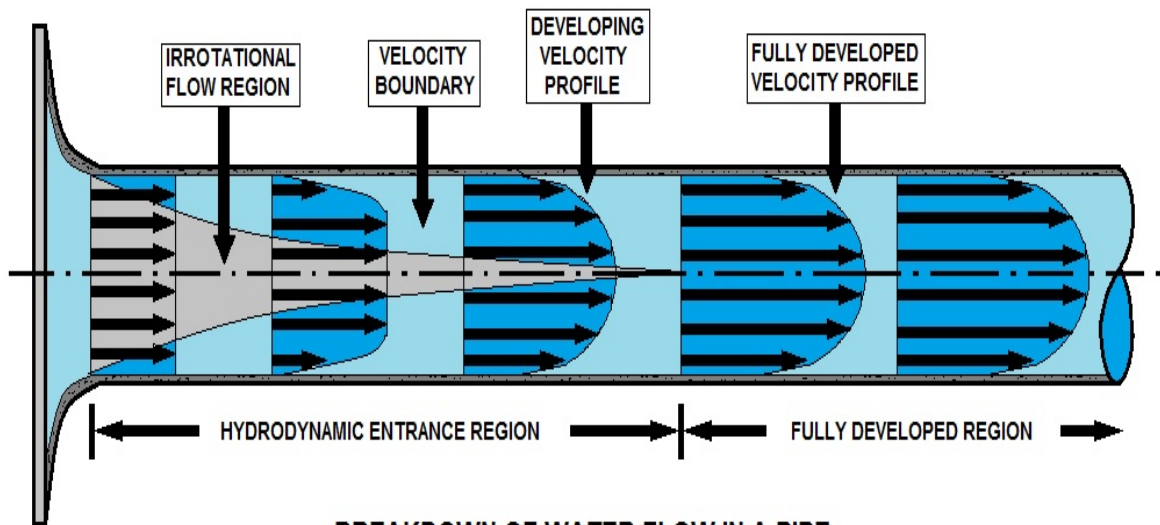
Gauge pressure is simply the pressure read on the gauge. If there is no pressure on the gauge other than atmospheric, the gauge will read zero.

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 |



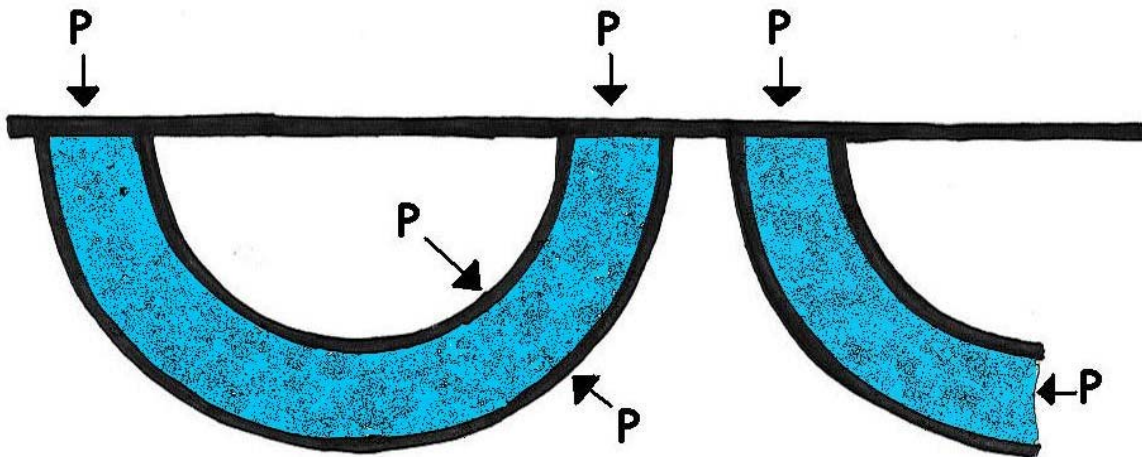
DIFFERENT UNITS OF PRESSURE



BREAKDOWN OF WATER FLOW IN A PIPE

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/cm², N/cm² (pascal), pounds/in² (psi) or pounds/ft² (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.

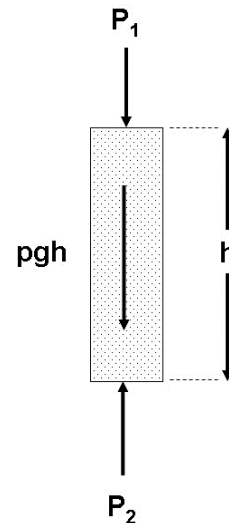
On earth, fluids are also subject to the force of gravity, which acts vertically downward, and has a magnitude $\gamma = \rho g$ per unit volume, where g is the acceleration of gravity, approximately 981 cm/s^2 or 32.15 ft/s^2 , ρ is the density, the mass per unit volume, expressed in g/cm^3 , kg/m^3 , 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.

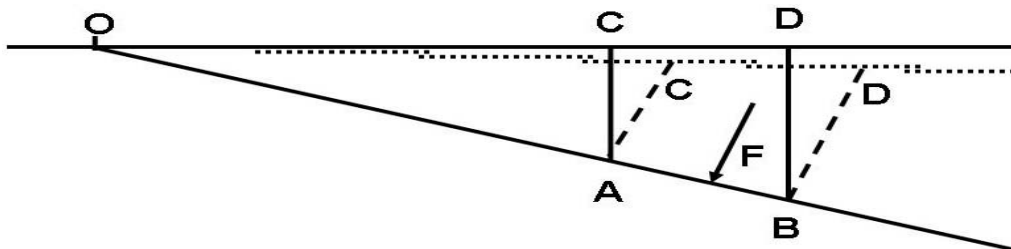
The forces exerted on the curved surfaces have no component along the normal to a plane section, so the pressures at any two points of a plane must be equal, since the fluid represented by the curtain ring was in equilibrium.

Free Surface



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

Increase of Pressure with Depth



Thrust on a Plane

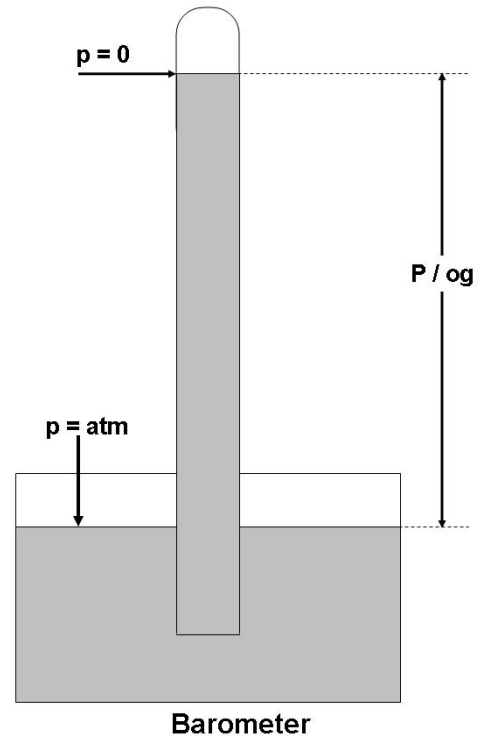
Free Surface Perpendicular to Gravity

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

Geometric Arguments

Ingenious geometric arguments can be used to substitute for easier, but less transparent arguments using calculus. For example, the force acting on one side of an inclined plane surface whose projection is AB can be found as in the diagram on the previous page. O is the point at which the prolonged projection intersects the free surface. The line AC' perpendicular to the plane is made equal to the depth AC of point A, and line BD' is similarly drawn equal to BD. The line OD' also passes through C', by proportionality of triangles OAC' and OAD'. Therefore, the thrust F on the plane is the weight of a prism of fluid of cross-section AC'D'B, passing through its centroid normal to plane AB.

Note that the thrust is equal to the density times the area times the depth of the center of the area; its line of action does not pass through the center, but below it, at the center of thrust. The same result can be obtained with calculus by summing the pressures and the moments.



Atmospheric Pressure and its Effects

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

Now start the pump. When it has sucked all the air out above the water, the pressure on the surface of the water inside the pipe is zero, and the pressure at the level of the water on the outside of the pipe is still the atmospheric pressure.

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

Standard Atmospheric Pressure

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

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

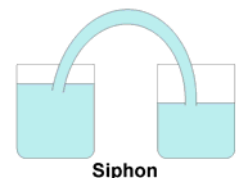
An aneroid barometer uses a partially evacuated chamber of thin metal that expands and contracts according to the external pressure. This movement is communicated to a needle that revolves in a dial. The materials and construction are arranged to give a low temperature coefficient. The instrument must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

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

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

Vacuum

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



Water Pressure

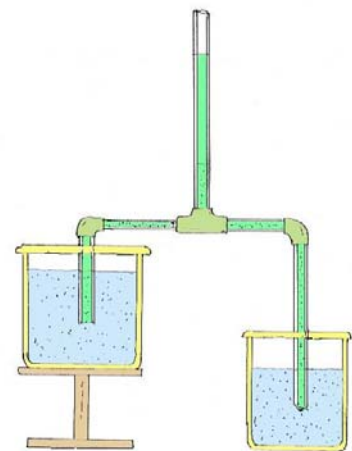
The weight of a cubic foot of water is 62.4 pounds per square foot. The base can be subdivided into 144-square inches with each subdivision being subjected to a pressure of 0.433 psig. Suppose you placed another cubic foot of water on top of the first cubic foot. The pressure on the top surface of the first cube which was originally atmospheric, or 0 psig, would now be 0.433 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 0.433 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 γ . 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 62.4 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

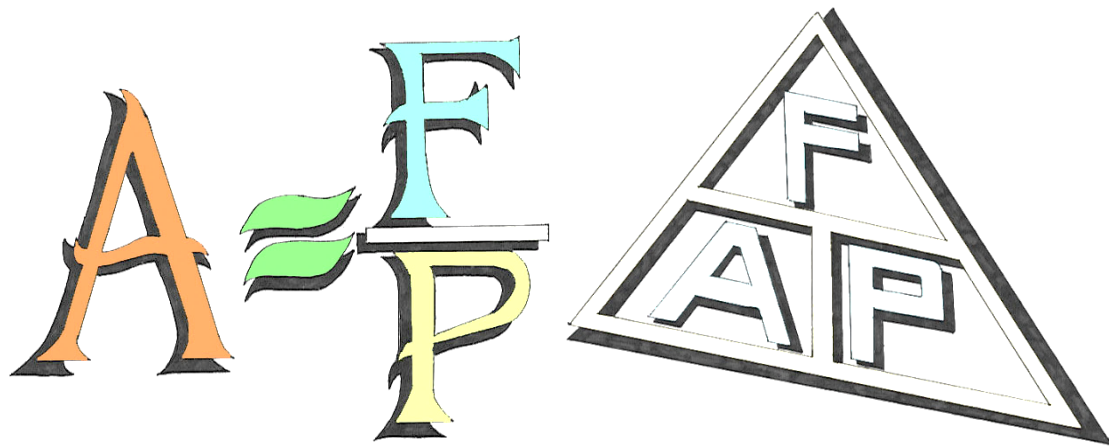
Pressure is the force that pushes water through pipes. Water pressure determines the flow of water from the tap. If pressure is not sufficient then the flow can reduce to a trickle and it will take a long time to fill a kettle or a cistern.

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:



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 Torricelli, French physicist, Edme Mariotte, and later, Daniel Bernoulli conducted experiments to study the elements of force in the discharge of water through small openings in the sides of tanks and through short pipes. During the same period, Blaise Pascal, a French scientist, discovered the fundamental law for the science of hydraulics. Pascal's law states that increase in pressure on the surface of a confined fluid is transmitted undiminished throughout the confining vessel or system.

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

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

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

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

Evangelista Torricelli

Evangelista Torricelli (1608-1647), Galileo's student and secretary and a member of the Florentine Academy of Experiments, invented the mercury barometer in 1643, and brought the weight of the atmosphere to light. The mercury column was held up by the pressure of the atmosphere, not by horror vacui as Aristotle had supposed. Torricelli's early death was a blow to science, but his ideas were furthered by Blaise Pascal (1623-1662). Pascal had a barometer carried up the 1465 m high Puy de Dôme, an extinct volcano in the Auvergne just west of his home of Clermont-Ferrand in 1648 by Périer, his brother-in-law. Pascal's experimentum crucis is one of the triumphs of early modern science. The Puy de Dôme is not the highest peak in the Massif Central--the Puy de Sancy, at 1866 m is, but it was the closest. Clermont is now the center of the French pneumatics industry.

Burgomeister of Magdeburg

The remarkable Otto von Guericke (1602-1686), Burgomeister of Magdeburg, Saxony, took up the cause, making the first vacuum pump, which he used in vivid demonstrations of the pressure of the atmosphere to the Imperial Diet at Regensburg in 1654. Famously, he evacuated a sphere consisting of two well-fitting hemispheres about a foot in diameter, and showed that 16 horses, 8 on each side, could not pull them apart. An original vacuum pump and hemispheres from 1663 are shown at the right (photo edited from the Deutsches Museum; see on right). He also showed that air had weight, and how much force it did require to separate evacuated hemispheres.



Then, in England, Robert Hooke (1635-1703) made a vacuum pump for Robert Boyle (1627-1691). Christian Huygens (1629-1695) became interested in a visit to London in 1661 and had a vacuum pump built for him. By this time, Torricelli's doctrine had triumphed over the Church's support for horror vacui. This was one of the first victories for rational physics over the illusions of experience, and is well worth consideration.

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

Torr

The mm of mercury is sometimes called a torr after Torricelli, and Pascal also has been honored by a unit of pressure, a newton per square meter or 10 dyne/cm². 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/cm², very close to a standard atmosphere, which is 1.01325 bar. In meteorology, the millibar, mb, is used. 1 mb = 1.333 mmHg = 100 Pa = 1000 dyne/cm².

A kilogram-force per square centimeter is 981,000 dyne/cm², 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 psi = 51.7 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 tsi = 2240 psi, 1 tsf = 15.5 psi (about an atmosphere!). The fluid in question here is air, which is by no means incompressible. As we rise in the atmosphere and the pressure decreases, the air also expands.

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

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

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

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

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

Meteorology

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

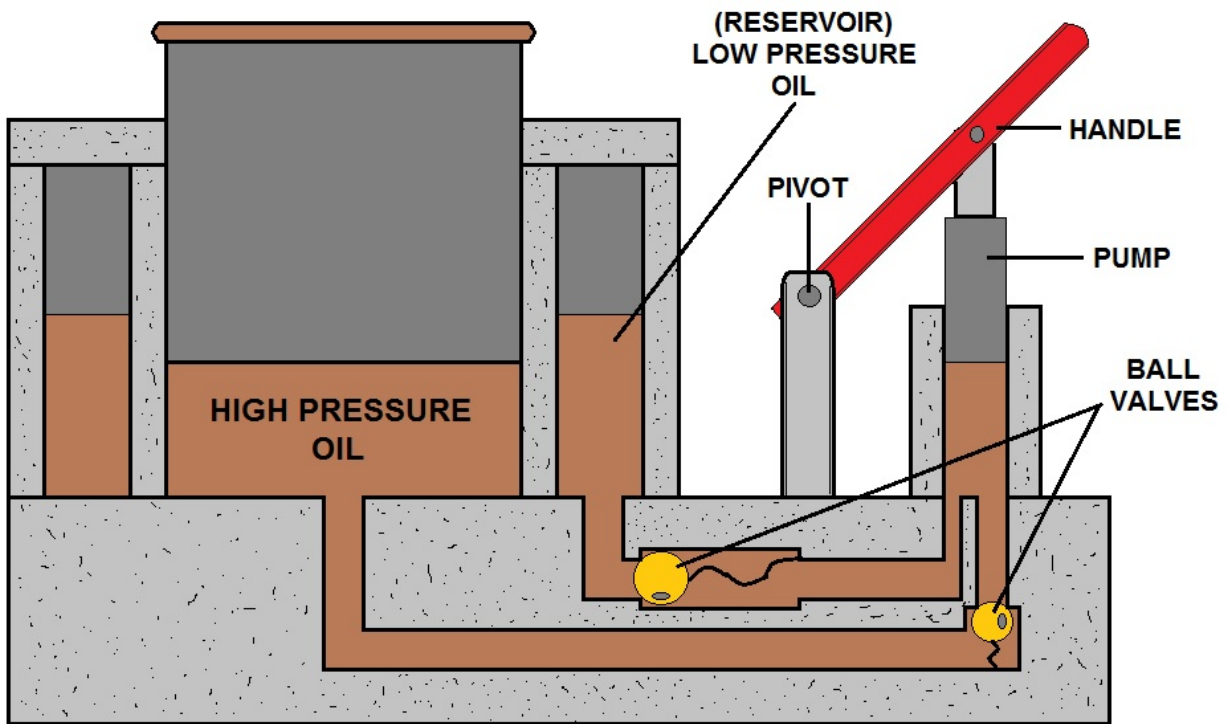
Certain typical weather patterns are associated with relatively high and relatively low pressures, and how they vary with time. The barometric pressure may be given in popular weather forecasts, though few people know what to do with it. If you live at a high altitude, your local weather reporter may report the pressure to be, say, 29.2 inches, but if you have a real barometer, you may well find that it is closer to 25 inches. At an elevation of 1500 m (near Denver, or the top of the Puy de Dôme), the atmospheric pressure is about 635 mm, and water boils at $95^\circ C$.

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

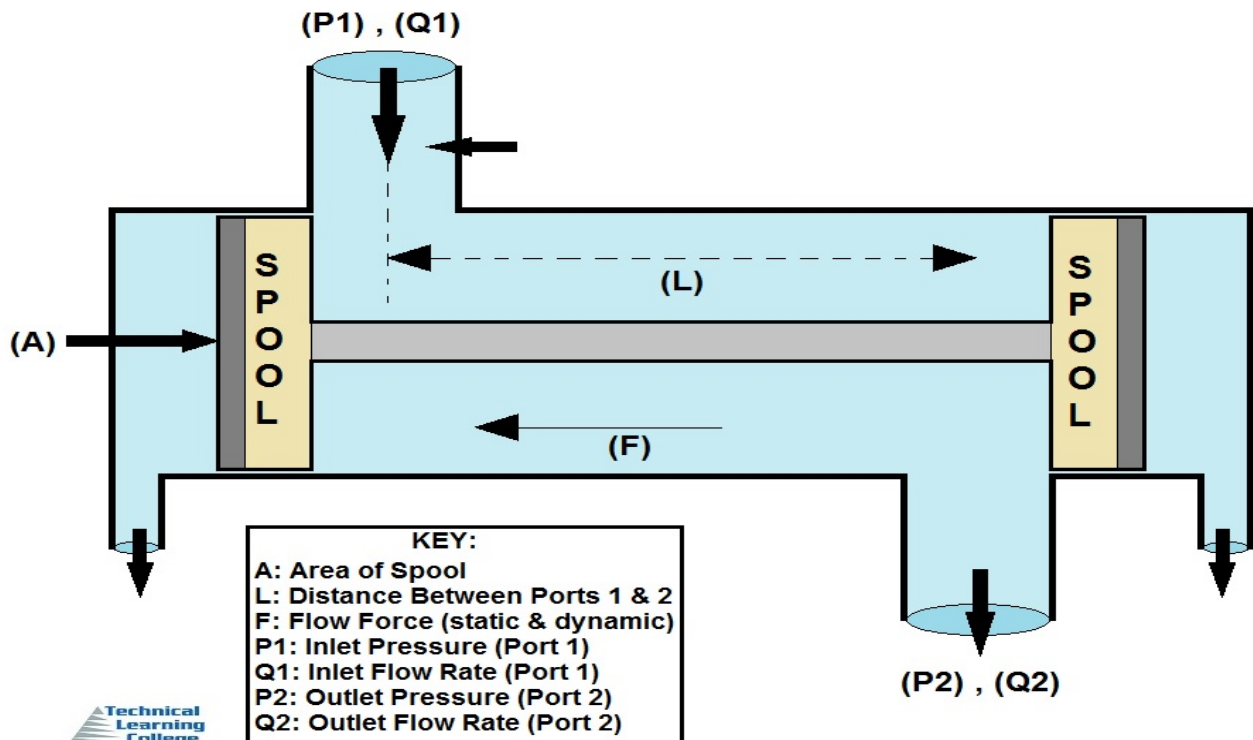
The barometric pressures quoted in the news are reduced to sea level by standard formulas that amount to assuming that there is a column of air from your feet to sea level with a certain temperature distribution, and adding the weight of this column to the actual barometric pressure.



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.



BASIC HYDRAULICS/LEVER PRINCIPAL

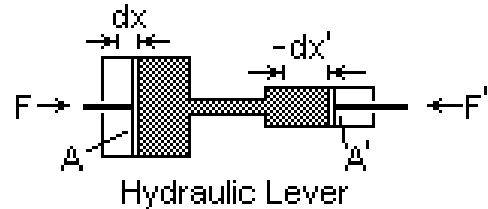


BASIC HYDRAULIC PRINCIPAL

The Hydraulic Lever

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

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



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

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

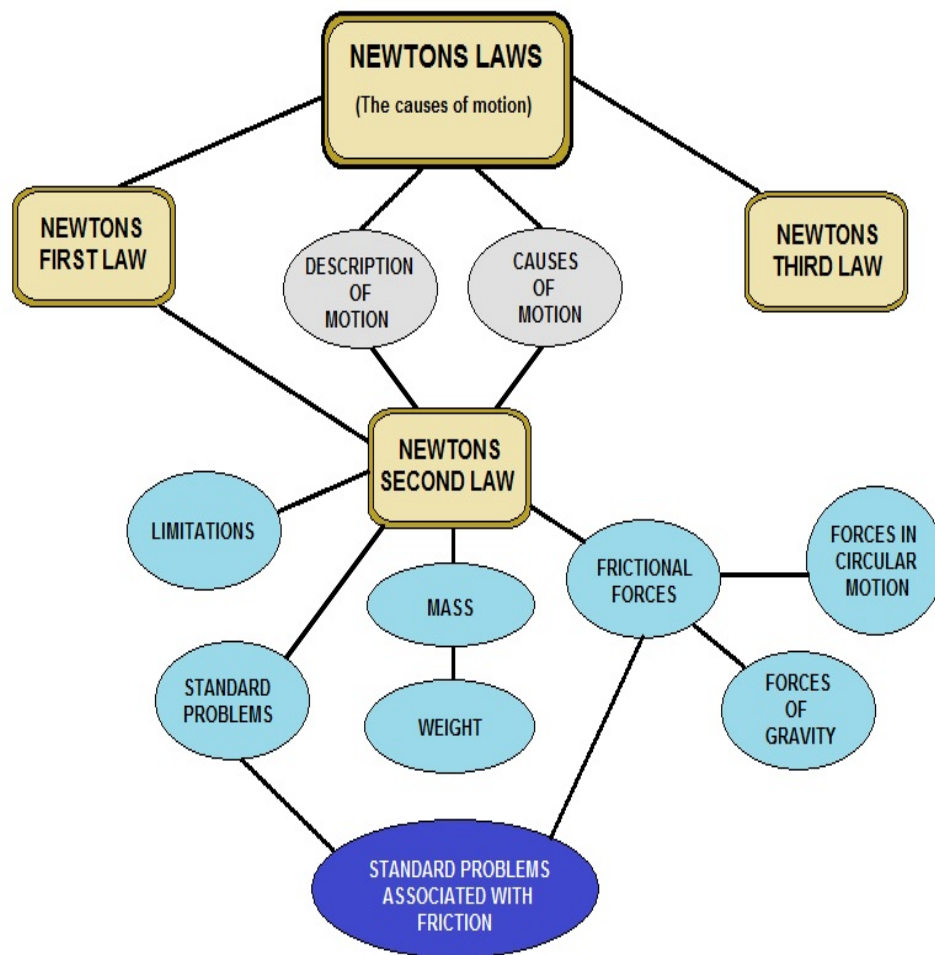
Bramah Hydraulic Press

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

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

In the presence of gravity, $p' = p + \rho gh$, where h is the difference in elevation of the two cylinders. Now, $p' dV' = -dV (p + \rho gh) = -p dV - (\rho dV) gh$, or the net work done in the process is $p' dV' + p dV = -dM gh$, where dM is the mass of fluid displaced from the lower cylinder to the upper cylinder.

Again, energy is conserved if we take into account the potential energy of the fluid. Pumps are seen to fall within the province of hydrostatics if their operation is quasi-static, which means that dynamic or inertia forces are negligible.



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

NEWTON'S THREE LAWS OF MOTION

Pumps - Short Introduction

Pumps are used to move or raise fluids. They are not only very useful, but are excellent examples of hydrostatics. Pumps are of two general types, hydrostatic or positive displacement pumps, and pumps depending on dynamic forces, such as centrifugal pumps.

Here we will only consider positive displacement pumps, which can be understood purely by hydrostatic considerations. They have a piston (or equivalent) moving in a closely-fitting cylinder and forces are exerted on the fluid by motion of the piston. We have already seen an important example of this in the hydraulic lever or hydraulic press, which we have called quasi-static.

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

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

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

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

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

The force pump, however, can give an arbitrarily large pressure to the discharged fluid, as in the case of a diesel engine injector.

A nozzle can be used to convert the pressure to velocity, to produce a jet, as for firefighting. Fire fighting force pumps usually have two cylinders feeding one receiver alternately. The air space in the receiver helps to make the water pressure uniform.

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

The Roots blower can either exhaust a receiver or provide air under moderate pressure, in large volumes. The bellows is a very old device, requiring no accurate machining. The single valve is

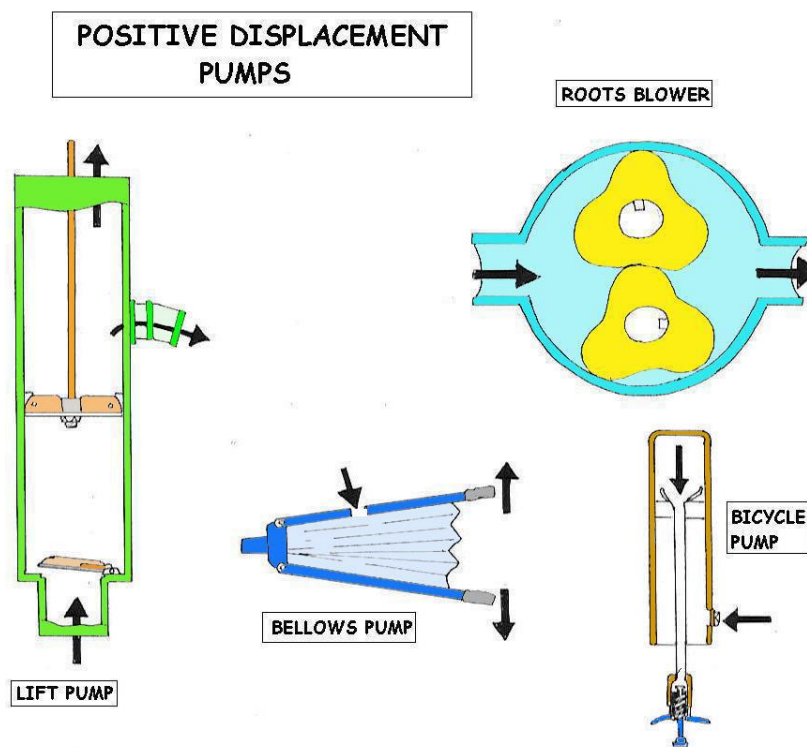
in one or both sides of the expandable chamber.

Another valve can be placed at the nozzle if required. The valve can be a piece of soft leather held close to holes in the chamber.

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

Diaphragm and vane pumps are not shown, but they act the same way by varying the volume of a chamber, and directing the flow with check valves.

Pumps were applied to the dewatering of mines, a very necessary process as mines became deeper. Newcomen's atmospheric engine was invented to supply the power for pumping.



Dudley Castle Engine

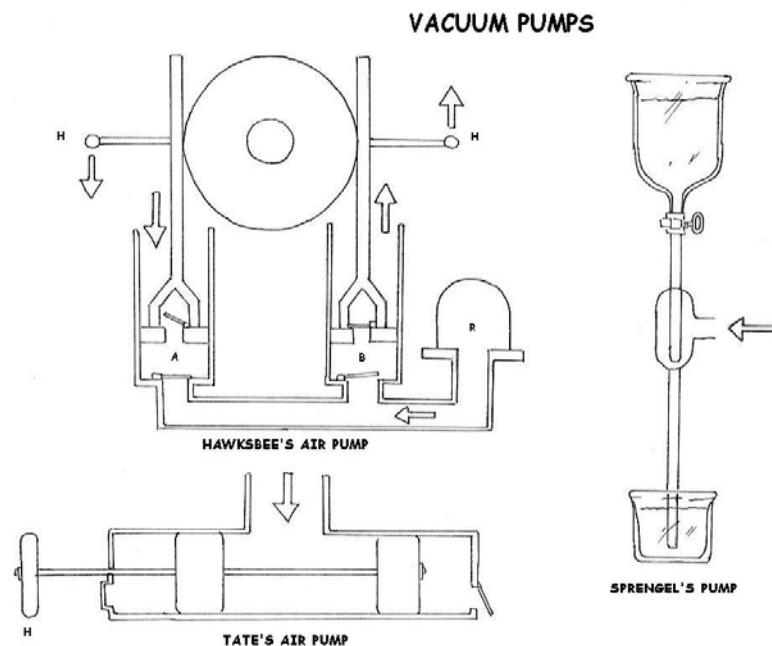
The first engine may have been erected in Cornwall in 1710, but the Dudley Castle engine of 1712 is much better known and thoroughly documented. The first pumps used in Cornwall were called bucket pumps, which we recognize as lift pumps, with the pistons somewhat misnamed buckets. They pumped on the up-stroke, when a clack in the bottom of the pipe opened and allowed water to enter beneath the piston. At the same time, the piston lifted the column of water above it, which could be of any length. The piston could only "suck" water 33 ft, or 28 ft more practically, of course, but this occurred at the bottom of the shaft, so this was only a limit on the piston stroke.

On the down stroke, a clack in the bucket opened, allowing it to sink through the water to the bottom, where it would be ready to make another lift. More satisfactory were the plunger pumps, also placed at the bottom of the shaft.

A plunger displaced volume in a chamber, forcing the water in it through a check valve up the shaft, when it descended. When it rose, water entered the pump chamber through a clack, as in the bucket pump.

Only the top of the plunger had to be packed; it was not necessary that it fit the cylinder accurately. In this case, the engine at the surface lifted the heavy pump rods on the up-stroke.

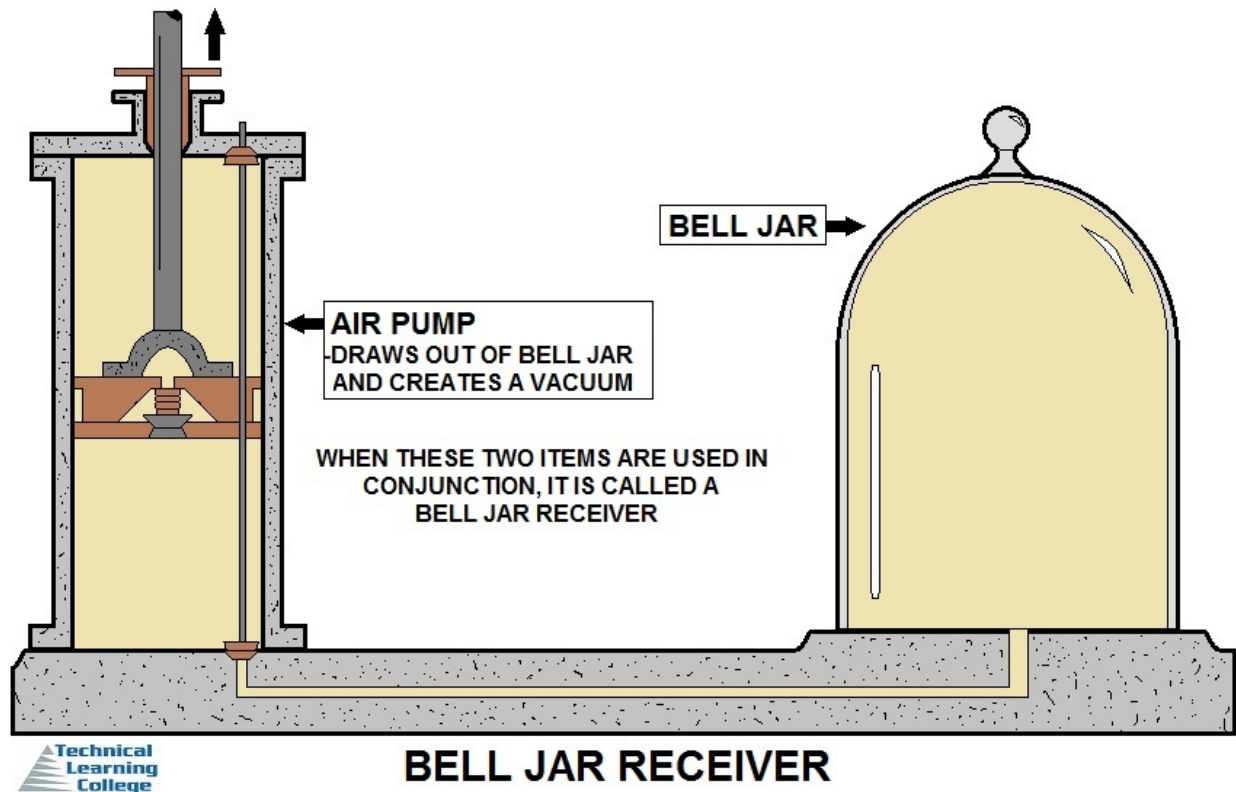
When the atmospheric engine piston returned, the heavy timber pump rods did the actual pumping, borne down by their weight. A special application for pumps is to produce a vacuum by exhausting a container, called the receiver.



Hawksbee's Dual Cylinder Pump

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

Bell-jar Receiver



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

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

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



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

It was used to pump brine for the Bavarian state salt industry. A search of the museum website did not reveal any evidence of it, but a good drawing of another brine pump with four cylinders and driven by a water wheel, also built by von Reichenbach, was found.

Solehebemaschine

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

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

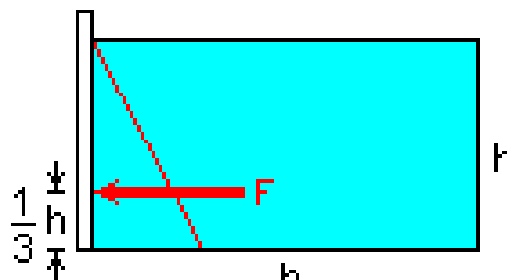
Von Reichenbach is said to have built this pipeline, for which he designed a water-wheel-driven, four-barrel pump. Maximilian I, King of Bavaria, commissioned von Reichenbach to bring brine from Berchtesgaden, elevation 530 m, to Reichenhall, elevation 470 m, over a summit 943 m high. Fresh water was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

Forces on Submerged Surfaces

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

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

By integration, we can find the total force F , and the depth at which it acts, $c = M / F$. If the surface is not symmetrical, the position of the total force in the transverse direction can be obtained from the integral of $dM' = \rho g x y \, dA$, the moment about some vertical line in the plane of the surface.



$$F = \rho g \frac{h}{2} \cdot hw$$

Force on a Surface

If there happens to be a pressure on the free surface of the water, then the forces due to this pressure can be evaluated separately and added to this result. We must add a force equal to the area of the surface times the additional pressure, and a moment equal to the product of this force and the distance to the centroid of the surface.

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

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

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

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

Consider a curious rectangular tank, with one side vertical but the opposite side inclined inwards or outwards. The horizontal forces exerted by the water on the two sides must be equal and opposite, or the tank would scoot off.

If the side is inclined outward, then there must be a downward vertical force equal to the weight of the water above it, and passing through the centroid of this water. If the side is inclined inward, there must be an upward vertical force equal to the weight of the 'missing' water above it. In both cases, the result is demanded by ordinary statics.

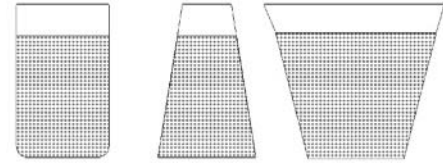
Hydrostatic Paradox

What we have here has been called the 'hydrostatic paradox.' It was conceived by the celebrated Flemish engineer Simon Stevin (1548-1620) of Brugge, the first modern scientist to investigate the statics of fluids and solids. Consider three tanks with bottoms of equal sizes and equal heights, filled with water. The pressures at the bottoms are equal, so the vertical force on the bottom of each tank is the same. But suppose that one tank has vertical sides, one has sides inclined inward, and third sides inclined outwards. The tanks do not contain the same weight of water, yet the forces on their bottoms are equal! I am sure that you can spot the resolution of this paradox.

Sometimes the forces are required on curved surfaces. The vertical and horizontal components can be found by considering the equilibrium of volumes with a plane surface equal to the projected area of the curved surface in that direction. The general result is usually a force plus a couple, since the horizontal and vertical forces are not necessarily in the same plane. Simple surfaces, such as cylinders, spheres and cones, may often be easy to solve.

In general, however, it is necessary to sum the forces and moments numerically on each element of area, and only in simple cases can this be done analytically.

Hydrostatic Paradox



If a volume of fluid is accelerated uniformly, the acceleration can be added to the acceleration of gravity. A free surface now becomes perpendicular to the total acceleration, and the pressure is proportional to the distance from this surface. The same can be done for a rotating fluid, where the centrifugal acceleration is the important quantity. The earth's atmosphere is an example. When air moves relative to the rotating system, the Coriolis force must also be taken into account. However, these are dynamic effects and are not strictly a part of hydrostatics.

Buoyancy

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

The weight was known, of course, and Archimedes cunningly measured its volume by the amount of water that ran off when it was immersed in a vessel filled to the brim. By comparing the results for the crown, and for pure gold, it was found that the crown displaced more water than an equal weight of gold, and had, therefore, been adulterated. This story, typical of the charming way science was made more interesting in classical times, may or may not actually have taken place, but whether it did or not, Archimedes taught that a body immersed in a fluid lost apparent weight equal to the weight of the fluid displaced, called Archimedes' Principle.

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

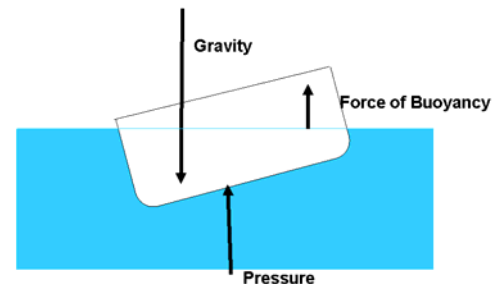
How Buoyancy Works

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

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

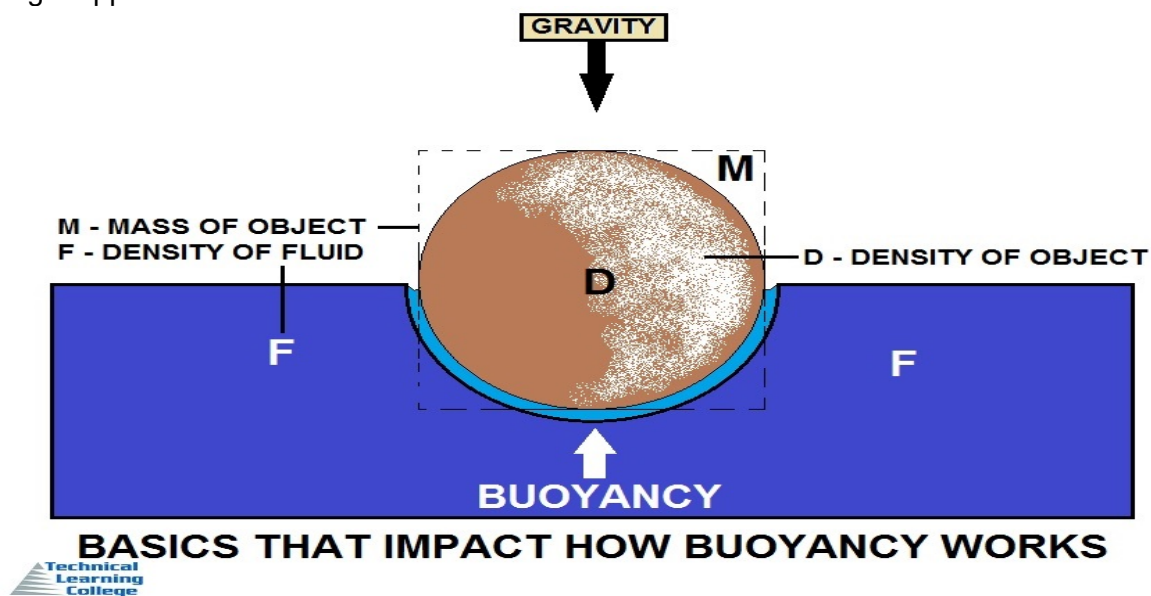
Consider a man in a rowboat on a lake, with a large rock in the boat. He throws the rock into the water. What is the effect on the water level of the lake? Suppose you make a drink of ice water with ice cubes floating in it. What happens to the water level in the glass when the ice has melted?

Change of Ship Stability



The force exerted by the water on the bottom of a boat acts through the center of gravity B of the displaced volume, while the force exerted by gravity on the boat acts through its own center of gravity A . This looks bad for the boat, since the boat's c.g. will naturally be higher than the c.g. of the displaced water, so the boat will tend to capsize. Well, a boat floats, and can tell us why. Should the boat start to rotate to one side, the displaced volume immediately moves to that side, and the buoyant force tends to correct the rotation.

A floating body will be stable provided the line of action of the buoyant force passes through a point M above the c.g. of the body, called the metacenter, so that there is a restoring couple when the boat heels. A ship with an improperly designed hull will not float. It is not as easy to make boats as it might appear.



Montgolfier Brothers' Hot Air Balloon

Archimedes' Principle can also be applied to balloons. The Montgolfier brothers' hot air balloon with a paper envelope ascended first in 1783 (the brothers got Pilâtre de Rozier and Chevalier d'Arlandes to go up in it). Such "fire balloons" were then replaced with hydrogen-filled balloons, and then with balloons filled with coal gas, which was easier to obtain and did not diffuse through the envelope quite as rapidly. Methane would be a good filler, with a density 0.55 that of air. Slack balloons, like most large ones, can be contrasted with taut balloons with an elastic envelope, such as weather balloons.

Slack balloons will not be filled full on the ground, and will plump up at altitude. Balloons are naturally stable, since the center of buoyancy is above the center of gravity in all practical balloons. Submarines are yet another application of buoyancy, with their own characteristic problems. Small neoprene or natural rubber balloons have been used for meteorological observations, with hydrogen filling. A 10g ceiling balloon was about 17" in diameter when inflated to have a free lift of 40g. It ascended 480ft the first minute, 670ft in a minute and a half, and 360ft per minute afterwards, to find cloud ceilings by timing, up to 2500ft, when it subtended about 2' of arc, easily seen in binoculars.

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

Weather Balloons

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

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

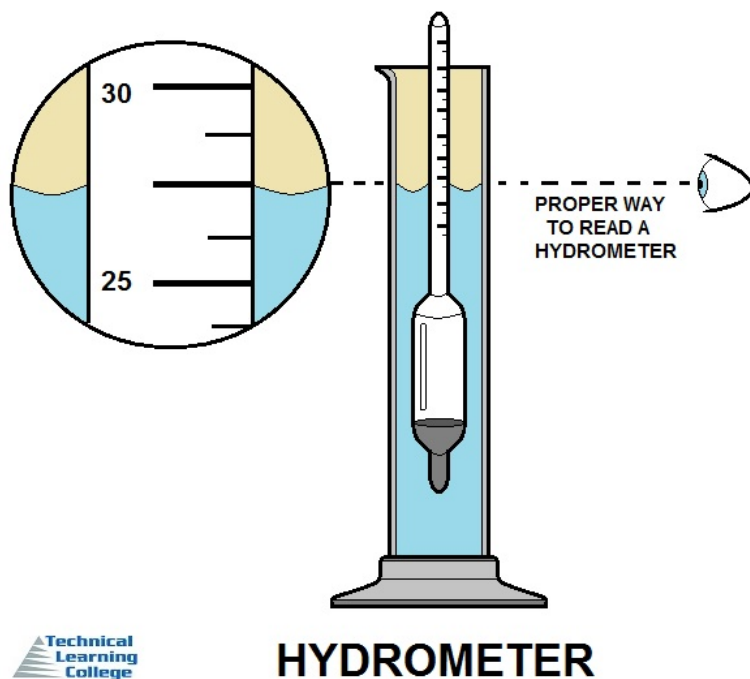
Electrolysis of water is an expensive source, since more energy is used than is recovered with the hydrogen.

Any enthusiasm for a "hydrogen economy" should be tempered by the fact that there are no

hydrogen wells, and all the hydrogen must be made with an input of energy usually greater than that available from the hydrogen, and often with the appearance of carbon.

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

Measurement of Specific Gravity



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

In English units, however, density, perhaps in lb/cu.ft or pcf, is numerically different from the specific gravity, since the weight of water is 62.5 lb/cu.ft.

Variations

Things are complicated by the variation of the density of water with temperature, and also by the confusion that gave us the distinction between cc and ml. The milliliter is the volume of 1.0 g of water at 4°C, by definition. The actual volume of 1.0 g of water at 4°C is 0.999973 cm³ by measurement. Since most densities are not known, or needed, to more than three significant figures, it is clear that this difference is of no practical importance, and the ml can be taken equal to the cc. The density of water at 0°C is 0.99987 g/ml, at 20° 0.99823, and at 100°C 0.95838. The temperature dependence of the density may have to be taken into consideration in accurate work. Mercury, while we are at it, has a density 13.5955 at 0°C, and 13.5461 at 20°C.

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

Pycnometer

A pycnometer is a flask with a close-fitting ground glass stopper with a fine hole through it, so a given volume can be accurately obtained. The name comes from the Greek word meaning "density." If the flask is weighed empty, full of water, and full of a liquid whose specific gravity is desired, the specific gravity of the liquid can easily be calculated.

A sample in the form of a powder, to which the usual method of weighing cannot be used, can be put into the pycnometer. The weight of the powder and the weight of the displaced water can be determined, and from them the specific gravity of the powder.

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

Hydrometer

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

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



DANIEL BERNOULLI (1700-1782)

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

Daniel was the son of Johann Bernoulli (one of the "early developers" of calculus), nephew of Jakob Bernoulli (who "was the first to discover the theory of probability"), and older brother of Johann II. Daniel Bernoulli was described by W. W. Rouse Ball as "by far the ablest of the younger Bernoullis". He is said to have had a bad relationship with his father, Johann. Upon both of them entering and tying for first place in a scientific contest at the University of Paris, Johann, unable to bear the "shame" of being compared as Daniel's equal, banned Daniel from his house. Johann Bernoulli also plagiarized some key ideas from Daniel's book *Hydrodynamica* in his own book *Hydraulica* which he backdated to before *Hydrodynamica*. Despite Daniel's attempts at reconciliation, his father carried the grudge until his death.

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



PASCAL BLAISE (1623-1662)

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

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

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

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

| 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

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.

Volume and Velocity of Flow

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

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

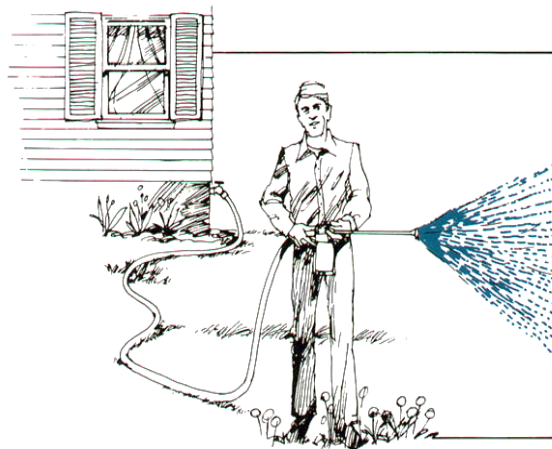
Bernoulli's Principle

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

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

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

Action of a spray atomizer

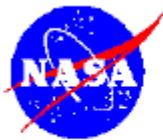


Bernoulli's principle also tells us why windows tend to explode, rather than implode in hurricanes: the very high speed of the air just outside the window causes the pressure just outside to be much less than the pressure inside, where the air is still.

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

Another example of Bernoulli's principle at work is in the lift of aircraft wings and the motion of "**curve balls**" in baseball. In both cases the design is such as to create a speed differential of the flowing air past the object on the top and the bottom - for aircraft wings this comes from the movement of the flaps, and for the baseball it is the presence of ridges.

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

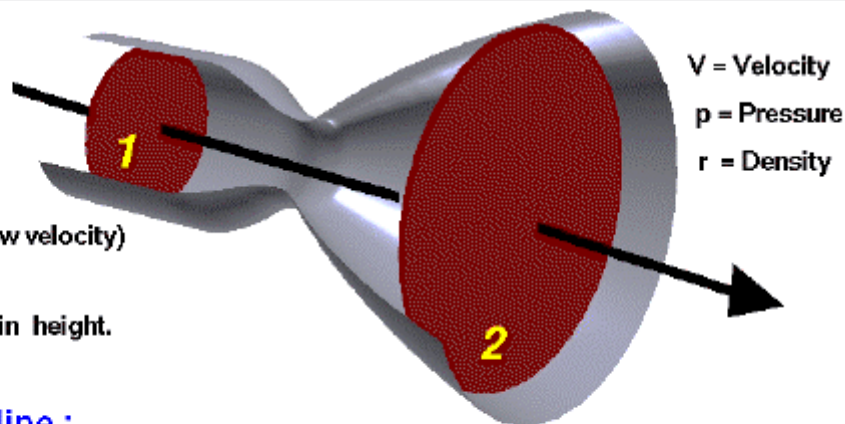


Bernoulli's Equation

Glenn
Research
Center

Restrictions :

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

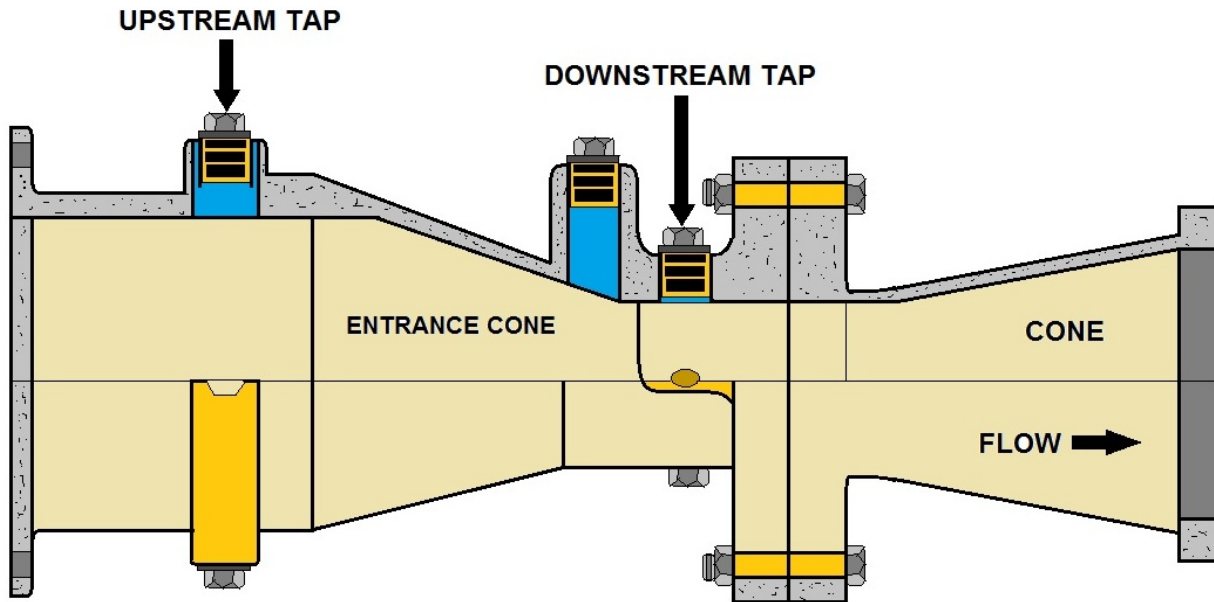


Along a streamline :

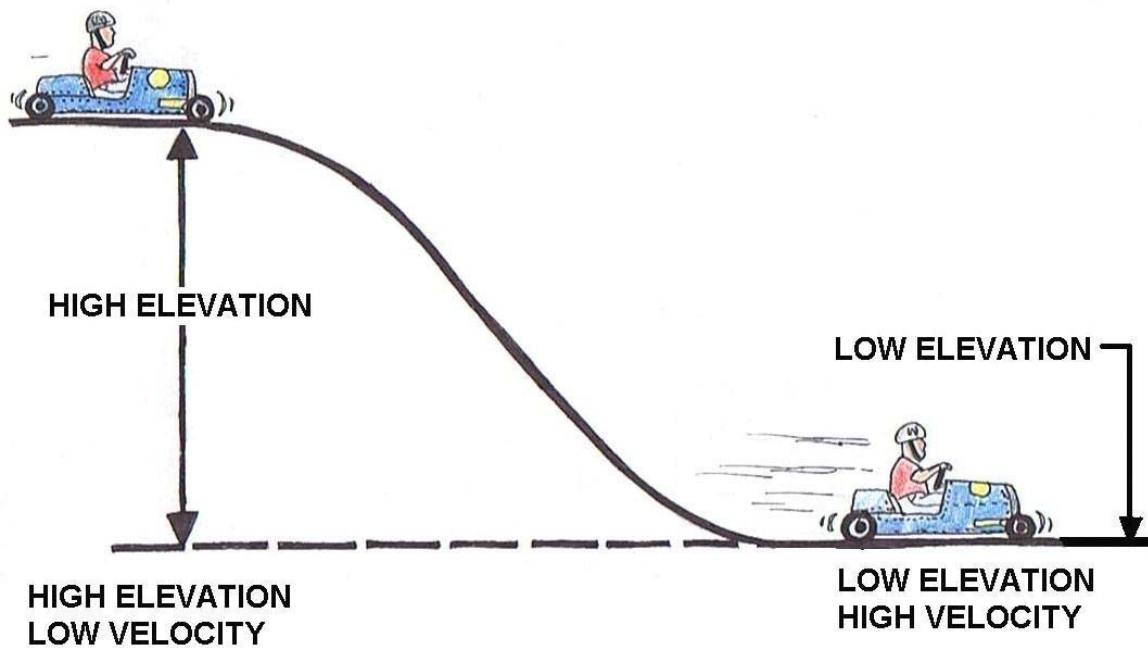
static pressure + dynamic pressure = total pressure

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

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



VENTURI TUBE





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.

Archimedes

| | |
|-----------------------------|--|
| Born | About 287 BC in Syracuse, Sicily. At the time, Syracuse was an independent Greek city-state with a 500-year history. |
| Died | 212 or 211 BC in Syracuse when it was being sacked by a Roman army. He was killed by a Roman soldier who did not know who he was. |
| Education | Probably studied in Alexandria, Egypt, under the followers of Euclid. |
| Family | His father was an astronomer named Phidias and he was probably related to Hieron II, the king of Syracuse. It is not known whether he was married or had any children. |
| Inventions | Many war machines used in the defense of Syracuse, compound pulley systems, planetarium, water screw (possibly), water organ (possibly), burning mirrors (very unlikely). |
| Fields of Science Initiated | Hydrostatics, static mechanics, pycnometry (the measurement of the volume or density of an object). He is called the "father of integral calculus" and also the "father of mathematical physics". |
| Major Writings | On plane equilibriums, Quadrature of the parabola, On the sphere and cylinder, On spirals, On conoids and spheroids, On floating bodies, Measurement of a circle, The Sandreckoner, On the method of mechanical problems. |
| Place in History | Generally regarded as the greatest mathematician and scientist of antiquity and one of the three greatest mathematicians of all time (together with Isaac Newton (English 1643-1727) and Carl Friedrich Gauss (German 1777-1855)). |

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

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

His works (that survived) include:

- Measurement of a Circle

- On the Sphere and Cylinder
- On Spirals
- The Sand Reckoner

The Roman's highest numeral was a myriad (10,000). Archimedes was not content to use that as the biggest number, so he decided to conduct an experiment using large numbers. The question: How many grains of sand there are in the universe? He made up a system to measure the sand. While solving this problem, Archimedes discovered something called powers. The answer to Archimedes' question was one with 62 zeros after it (1×10^{62}).

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

Some powers of two are:

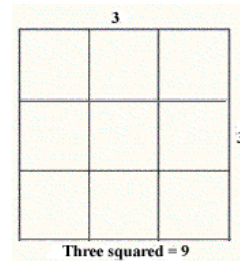
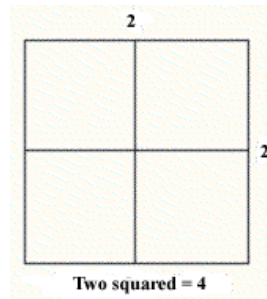
$$1 = 2^0 \text{ power}$$

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

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

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

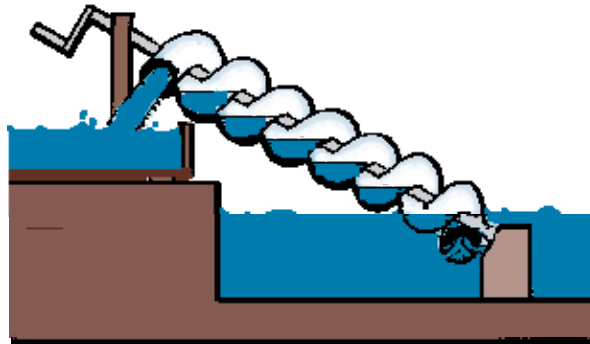
$$2 \times 2 \times 2 \times 2 = 2^4 \text{ power}$$



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

- On Plane Equilibriums
- On Floating Bodies

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



This pump is at least 2,000 years old.

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

References

J. T. Bottomley, *Hydrostatics* (London: William Collins, 1882). Found in a used-bookshop for 10p (\$0.20). For "school science," with no calculus but excellent, painstaking explanation and practical applications. 142pp.

S. L. Loney, *Elements of Hydrostatics* (Cambridge: Cambridge Univ. Press, 1956) 2nd ed. (1904). Also for schools, 253pp. Some calculus in an appendix.

R. L. Daugherty and J. B. Franzini, *Fluid Mechanics*, 6th ed. (New York: McGraw-Hill, 1965). Chapter 2. A typical engineering treatment in a classic text, of course with calculus.

The website of the Deutsches Museum is positively excellent. This is the best science museum in the world. It has not become mostly a medium of entertainment and advertising, as so many others have, but where you can still see original and unusual artifacts. The website contains actual information for others than children, and is well-illustrated. Unfortunately, it does not have illustrations of most of the exhibits, only selected ones, so it does not make it possible to visit the museum from where you are. Such a resource would be very welcome, and would rise above internet shallowness. Knowing German helps a lot, of course, but there is random English here and there.

A. Wolf, *A History of Science, Technology and Philosophy in the 16th and 17th Centuries*, 2nd ed., Vol. I (Gloucester, MA: Peter Smith, 1968). The index is in Vol II.

J. C. Poggendorff, *Geschichte der Physik*, (1878). Facsimile reprint by Zentral-Antiquariat der DDR, 1964.

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 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.



Actual Backflow Events

Paraquat

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

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

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

Mortuary

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

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

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

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

Recent Backflow Situations

Oregon 1993

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

California 1994

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

New York 1994

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

Nebraska 1994

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

California 1994

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

California 1994

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

Iowa 1994

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

Indiana 1994

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

Washington 1994

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

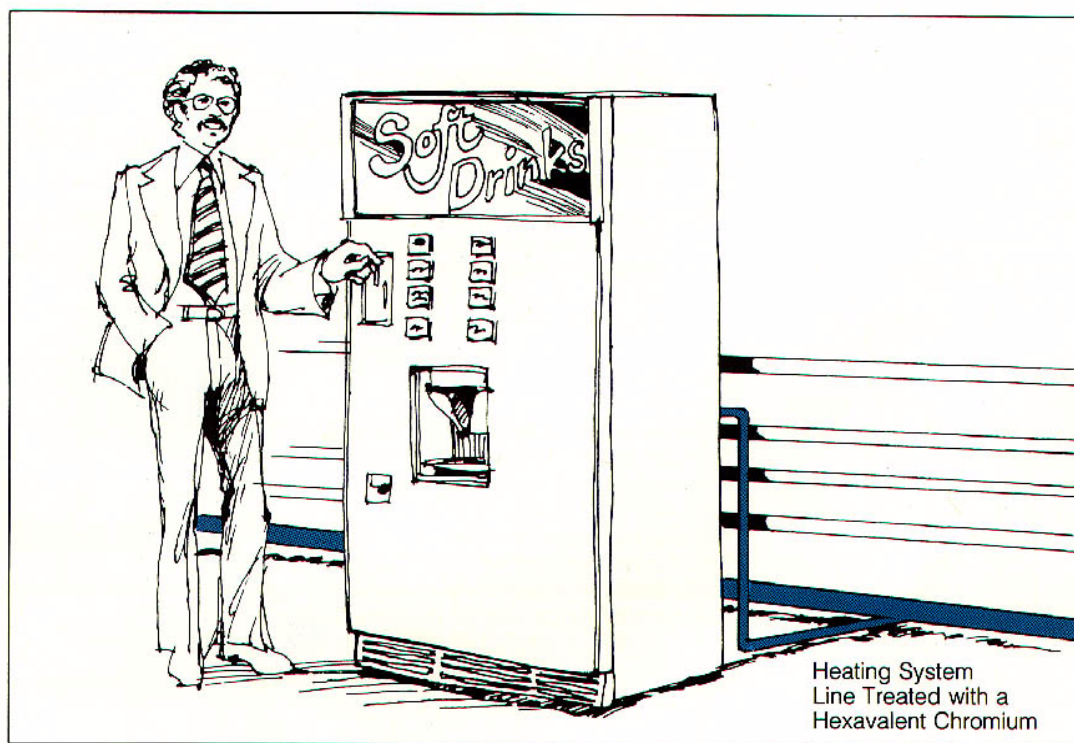
Ohio 1994

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

Cross-Connection Terms

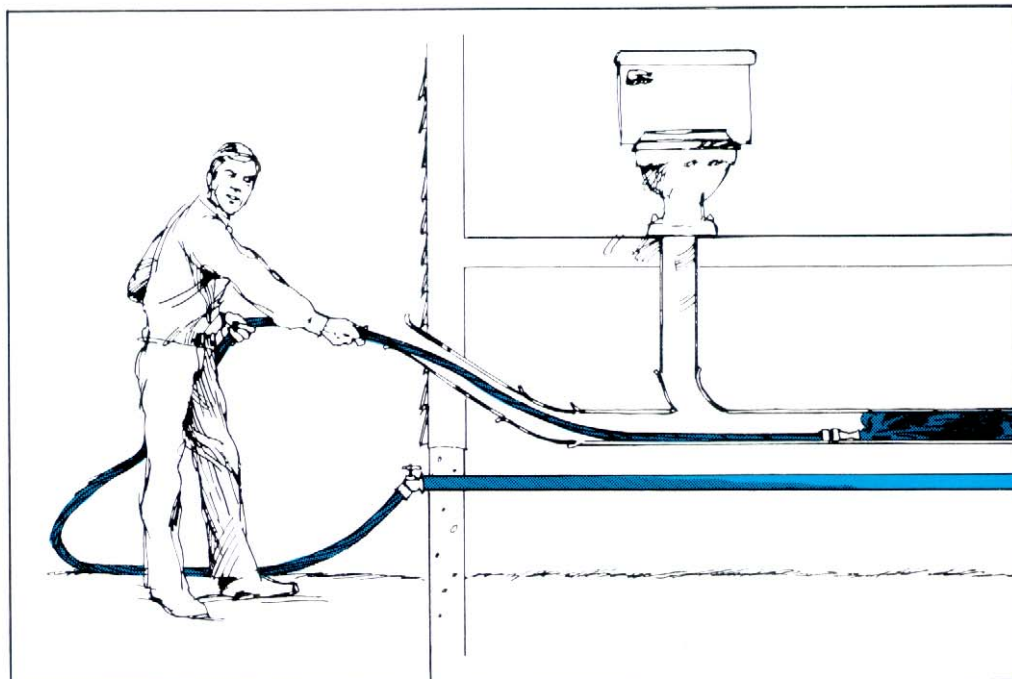
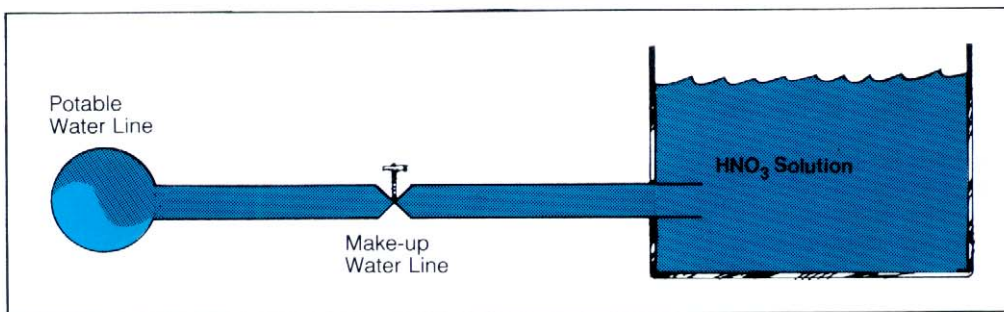
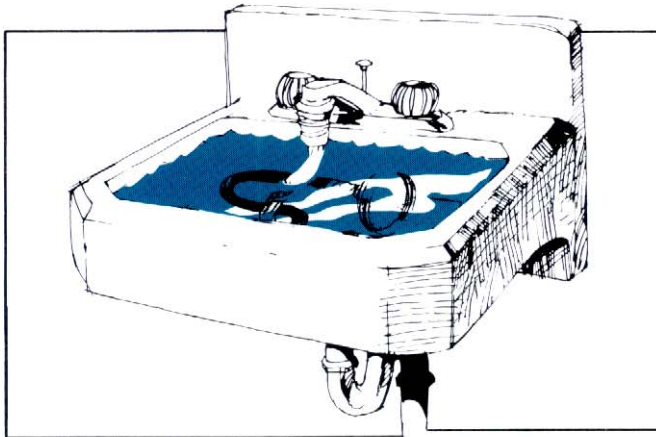
Cross-connection

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



Several cross-connection have been made to soda machines, the one to worry about is when you have a copper water line hooked to 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.

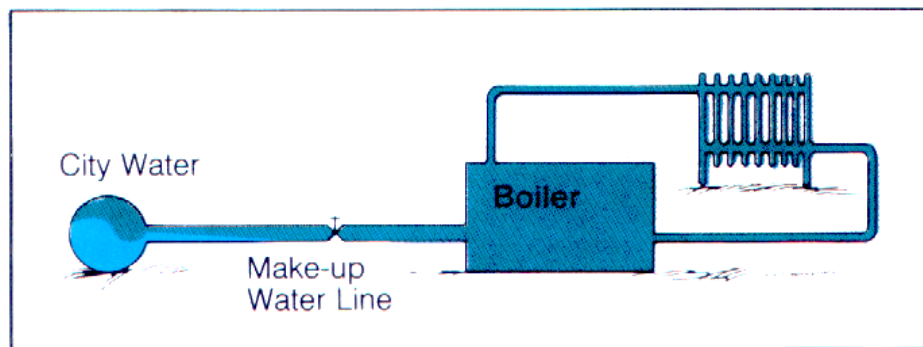
Common Cross-Connections



Backflow

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

Backsiphonage

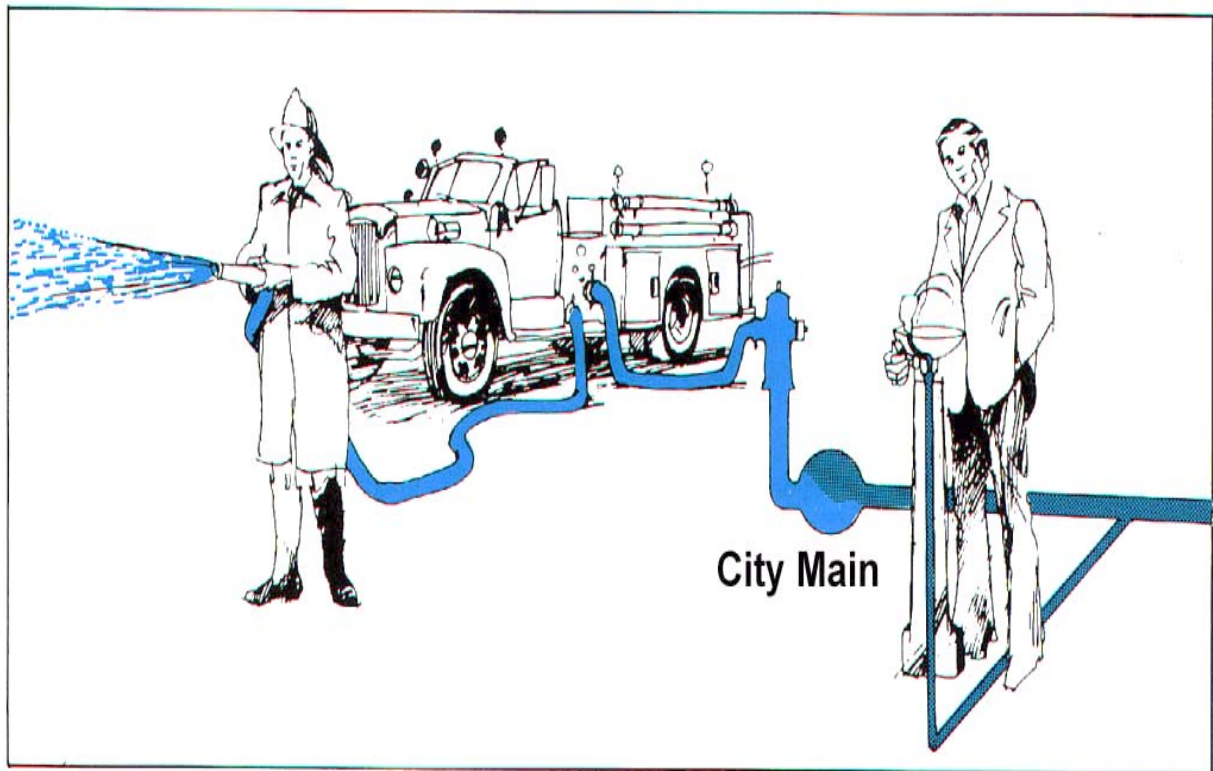


Backpressure caused by heat.

Backsiphonage

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

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



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

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

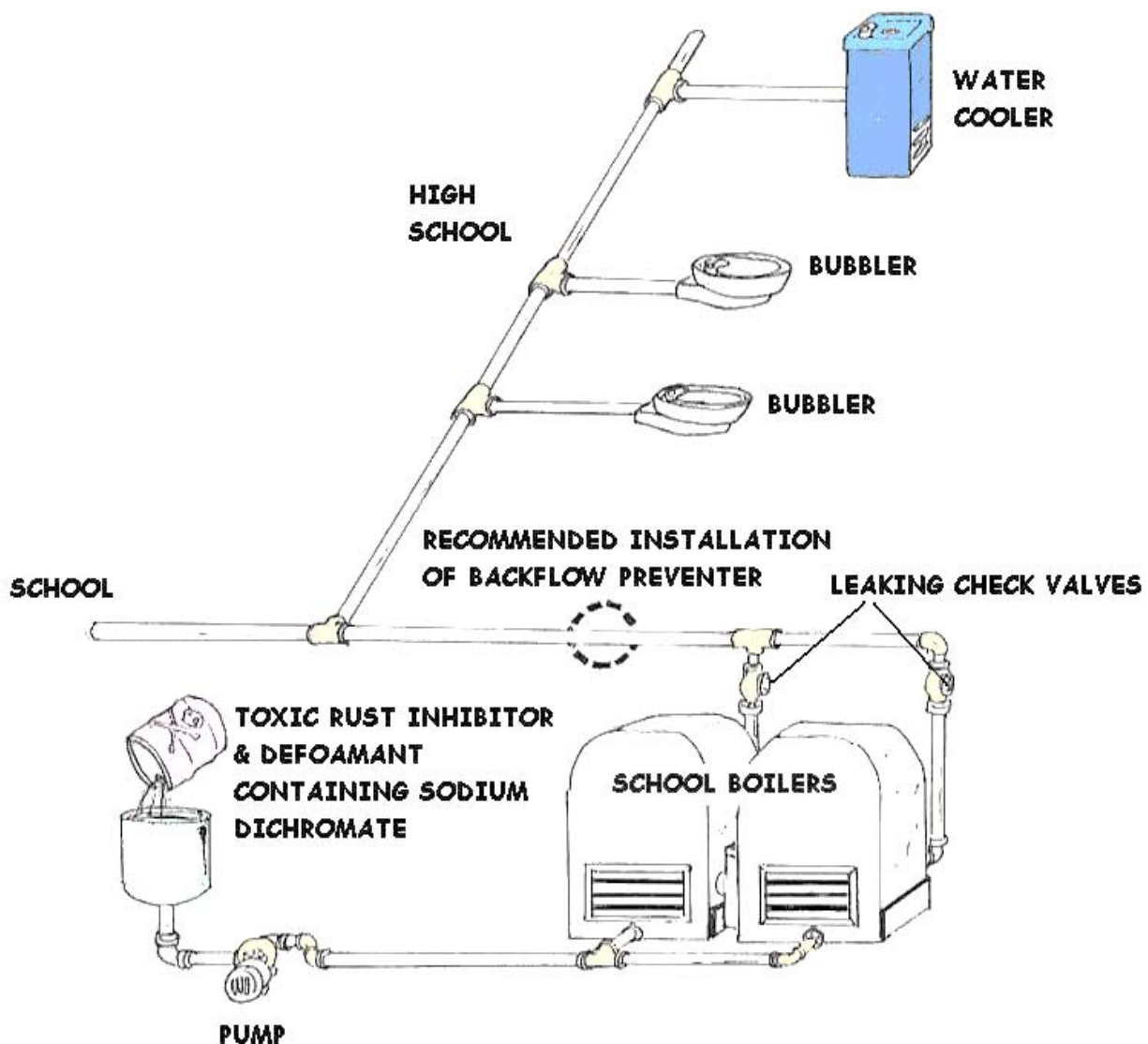
A good example is the pressure exerted by a building that is 100 feet tall is about 43 PSI; the water main feeding the building is at 35 PSI. The water will flow back to the water main.

Never drink water or coffee inside a funeral home, vet clinic or hospital.

Backpressure

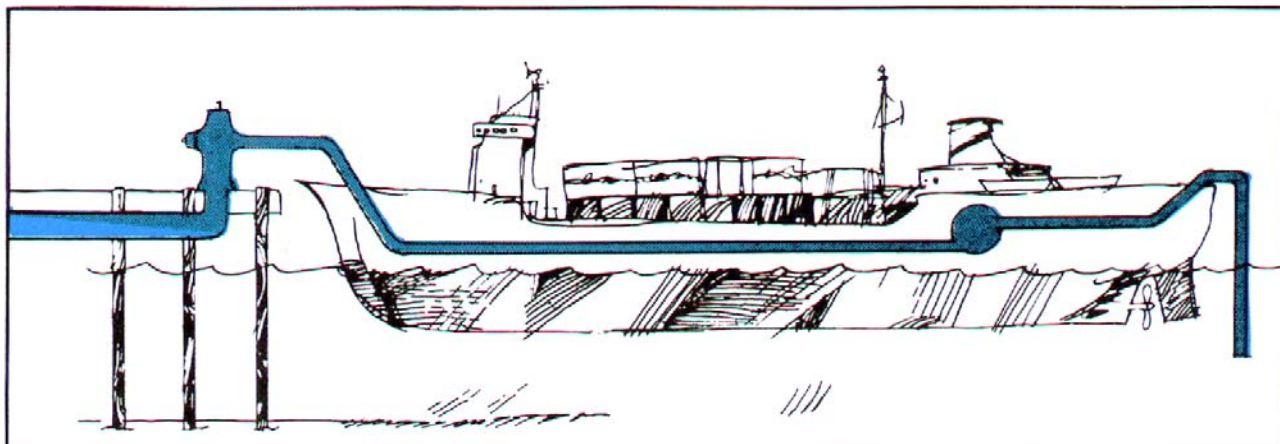
Backpressure backflow is backflow caused by a downstream pressure that is greater than the upstream or supply pressure in a public water system or consumer's potable water system. Backpressure (i.e., downstream pressure that is greater than the potable water supply pressure) can result from an increase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

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



Backpressure Examples

Booster pumps, pressure vessels, elevation, heat



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.

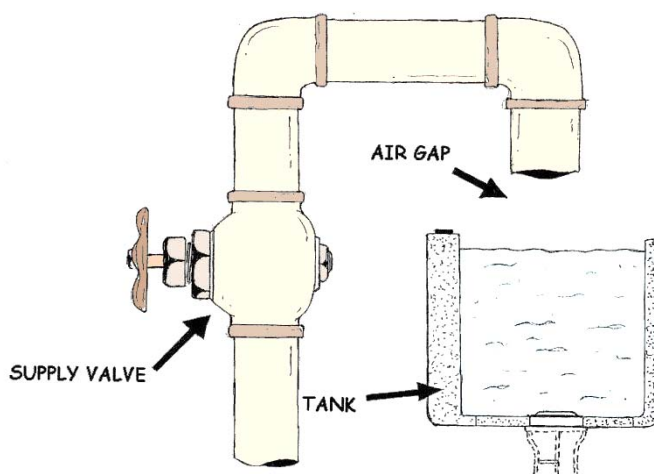
Second, the plumbing arrangement must be considered.

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.

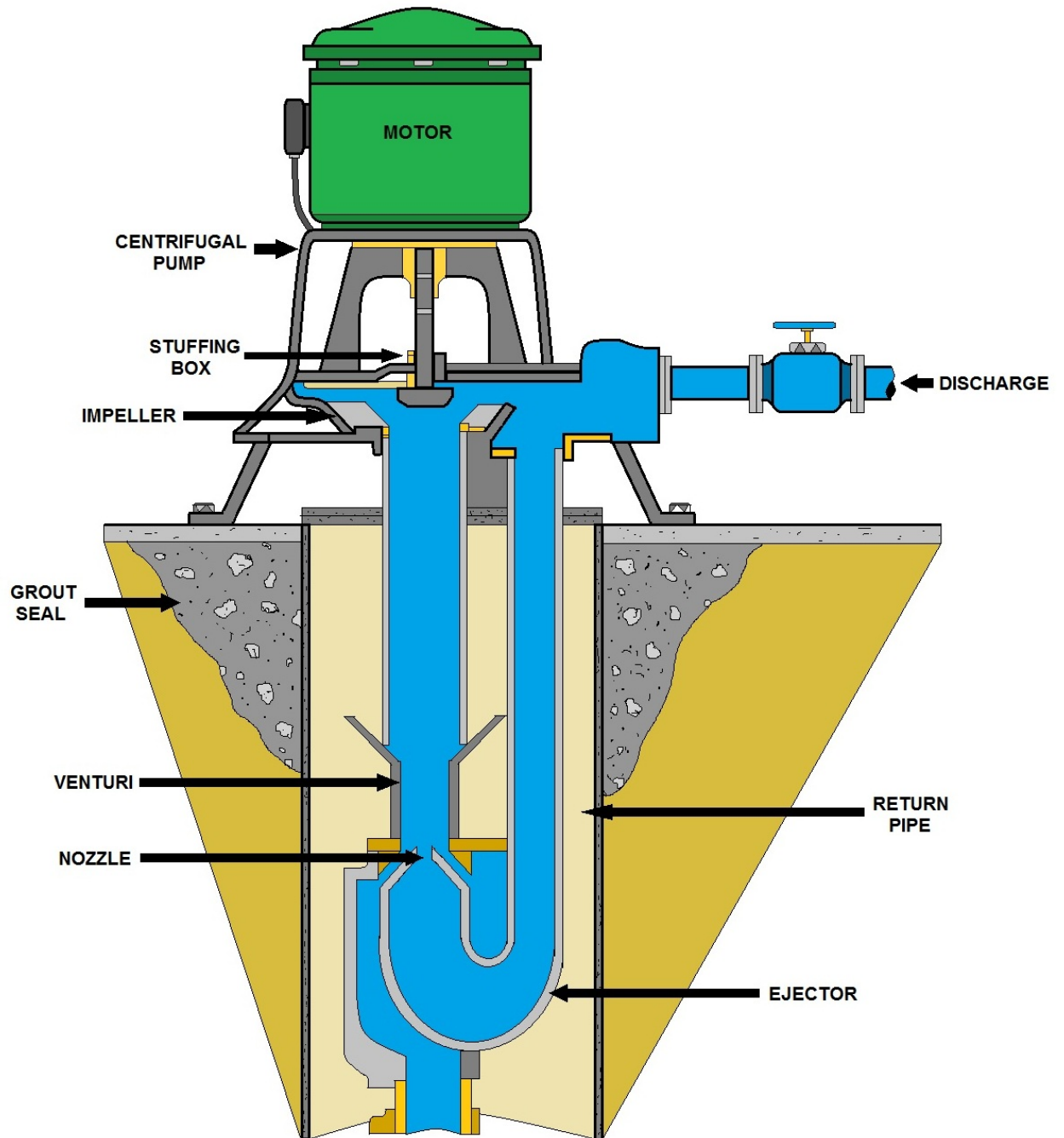


An obstruction around or near an air gap may restrict the flow of air into the outlet pipe and nullify the effectiveness of the air gap to prevent backsiphonage. When the air flow is restricted, such as the case of an air gap located near a wall, the air gap separation must be increased.

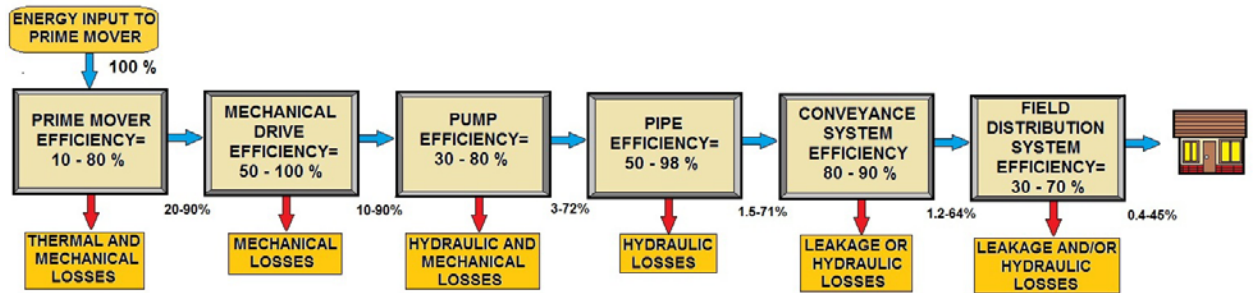
Also, within a building where the air pressure is artificially increased above atmospheric, such as a sports stadium with a flexible roof kept in place by air blowers, the air gap separation must be increased.

Operation of Pumps

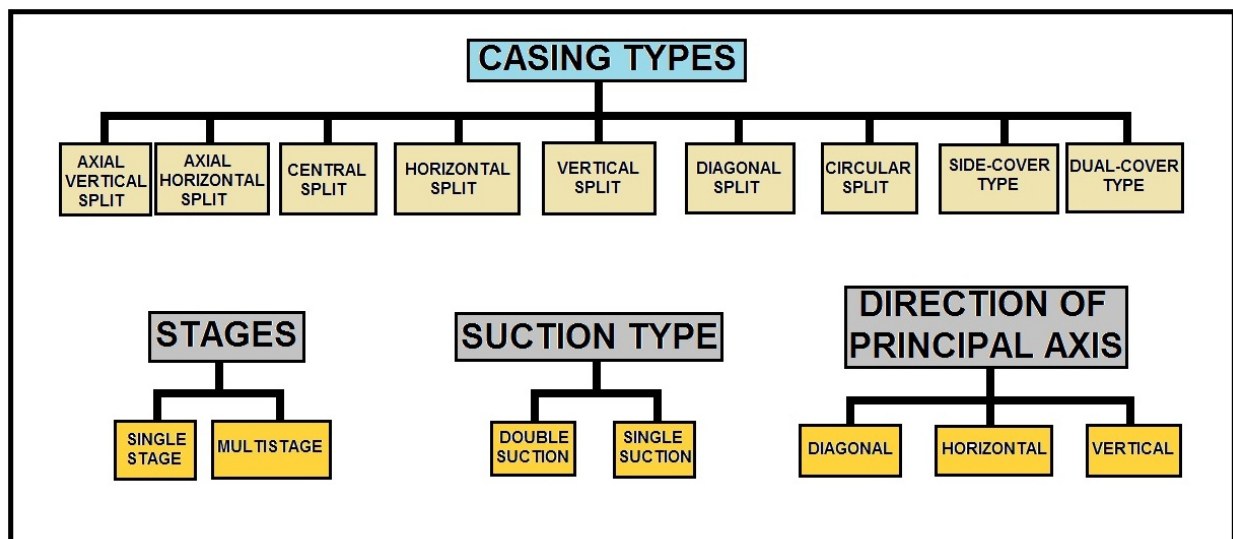
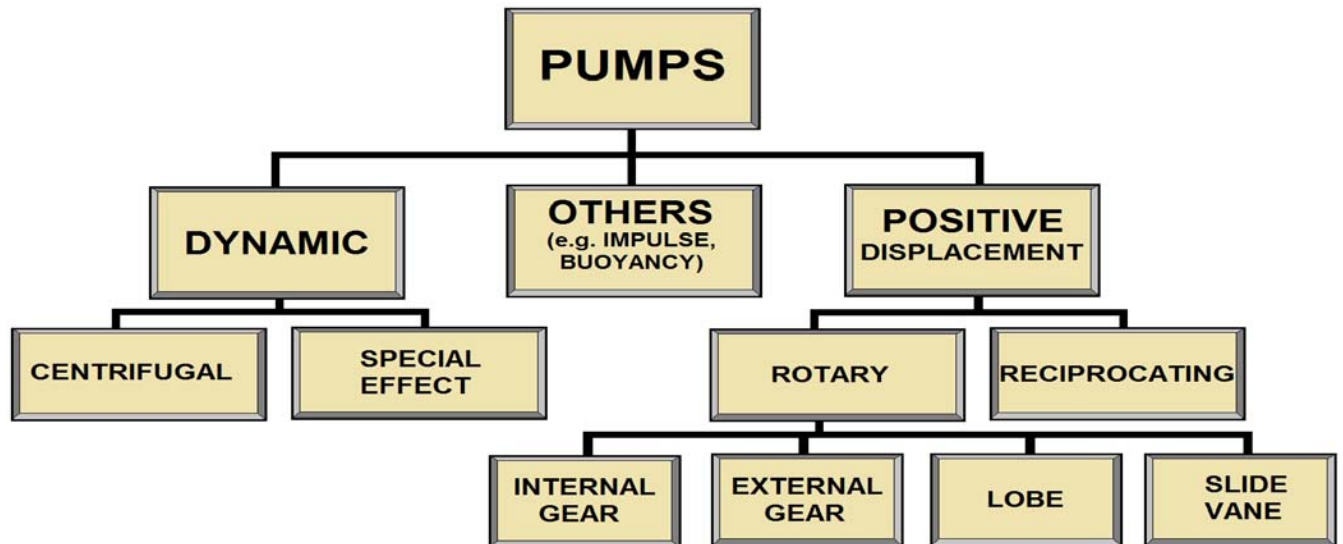
Chapter 2



VERTICAL TURBINE INSTALLATION DIAGRAM



PUMPING EFFICIENCY



PUMP CONFIGURATIONS

Pump Definitions *(Larger Glossary in the rear of this manual)*

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

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

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

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

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

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

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

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

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

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

Kinetic energy: Energy associated with motion.

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

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

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

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

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

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

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

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

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

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

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

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

Score: To cause lines, grooves or scratches.

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

Shaft sleeve: A replaceable tubular covering on the shaft.

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

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

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

Stages: Impellers in a multi-stage pump.

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

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

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

Suction: The place where fluid enters the pump.

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

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

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

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

Troubleshooting: Locating a problem.

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

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

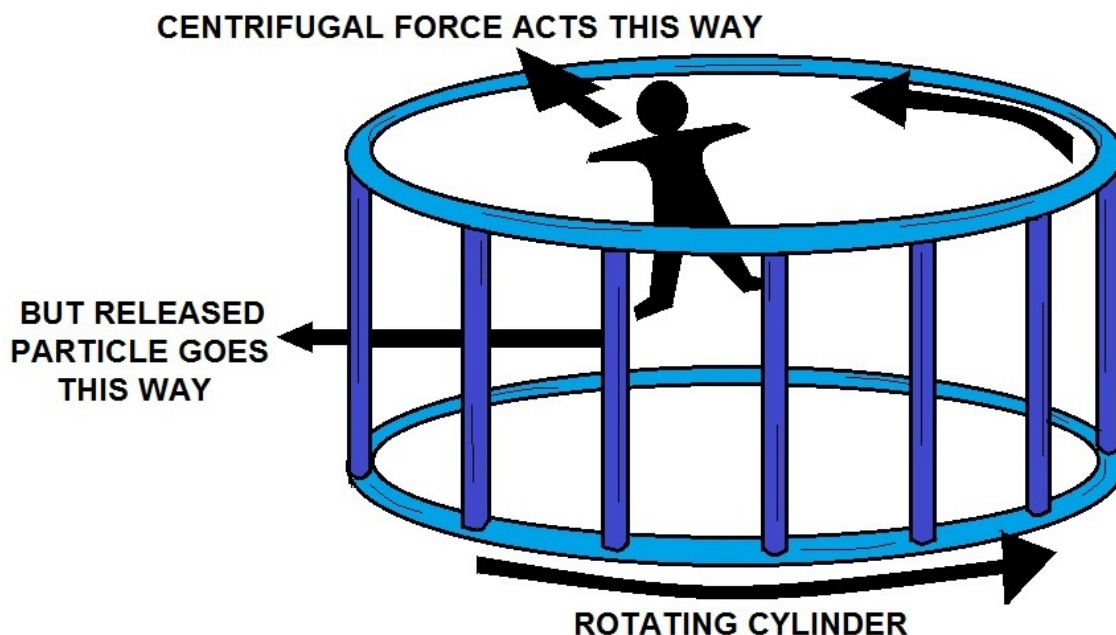
Volute: The part of the pump that changes the speed of the fluid into pressure.

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

Basic Water Pump

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

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



CENTRIFUGAL WATER EFFECTS

First, you can view the water between the impeller blades as an object traveling in a circle. Objects do not naturally travel in a circle--they need an inward force to cause them to accelerate inward as they spin. Without such an inward force, an object will travel in a straight line and will not complete the circle. In a centrifugal pump, that inward force is provided by high-pressure water near the outer edge of the pump housing. The water at the edge of the pump pushes inward on the water between the impeller blades and makes it possible for that water to travel in a circle. The water pressure at the edge of the turning impeller rises until it is able to keep water circling with the impeller blades.

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

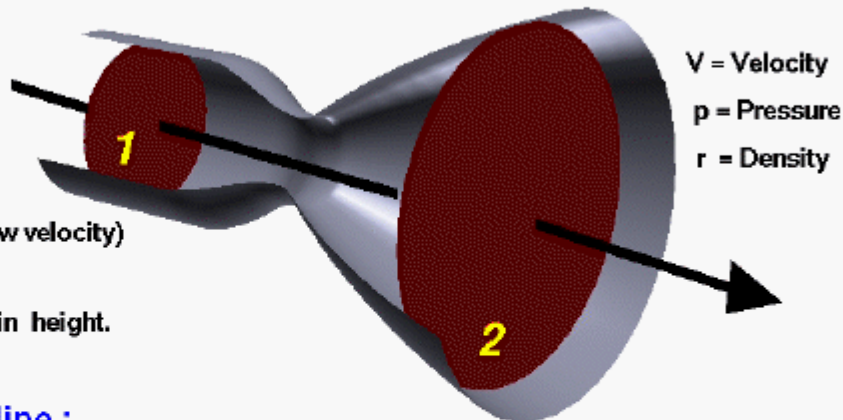


Bernoulli's Equation

Glenn
Research
Center

Restrictions :

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

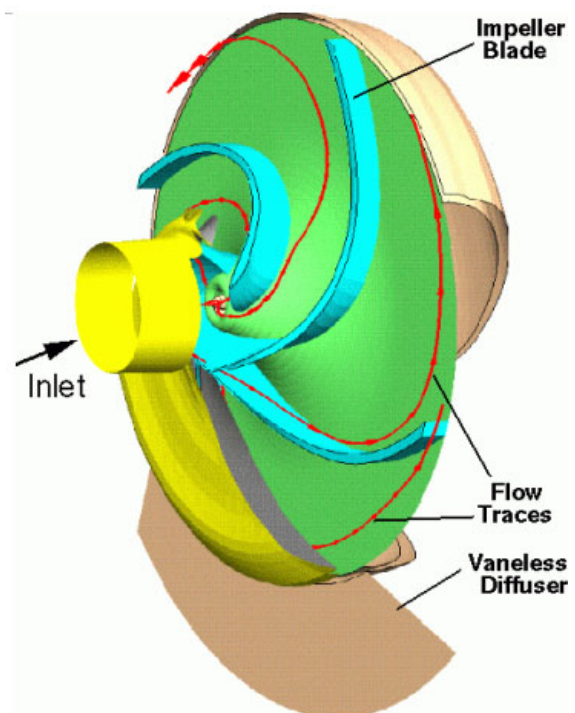


Along a streamline :

static pressure + dynamic pressure = total pressure

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

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



Types of Water Well Pumps

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

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

Vertical turbine pumps are commonly used in groundwater wells. These pumps are driven by a shaft rotated by a motor on the surface. The shaft turns the impellers within the pump housing while the water moves up the column.

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

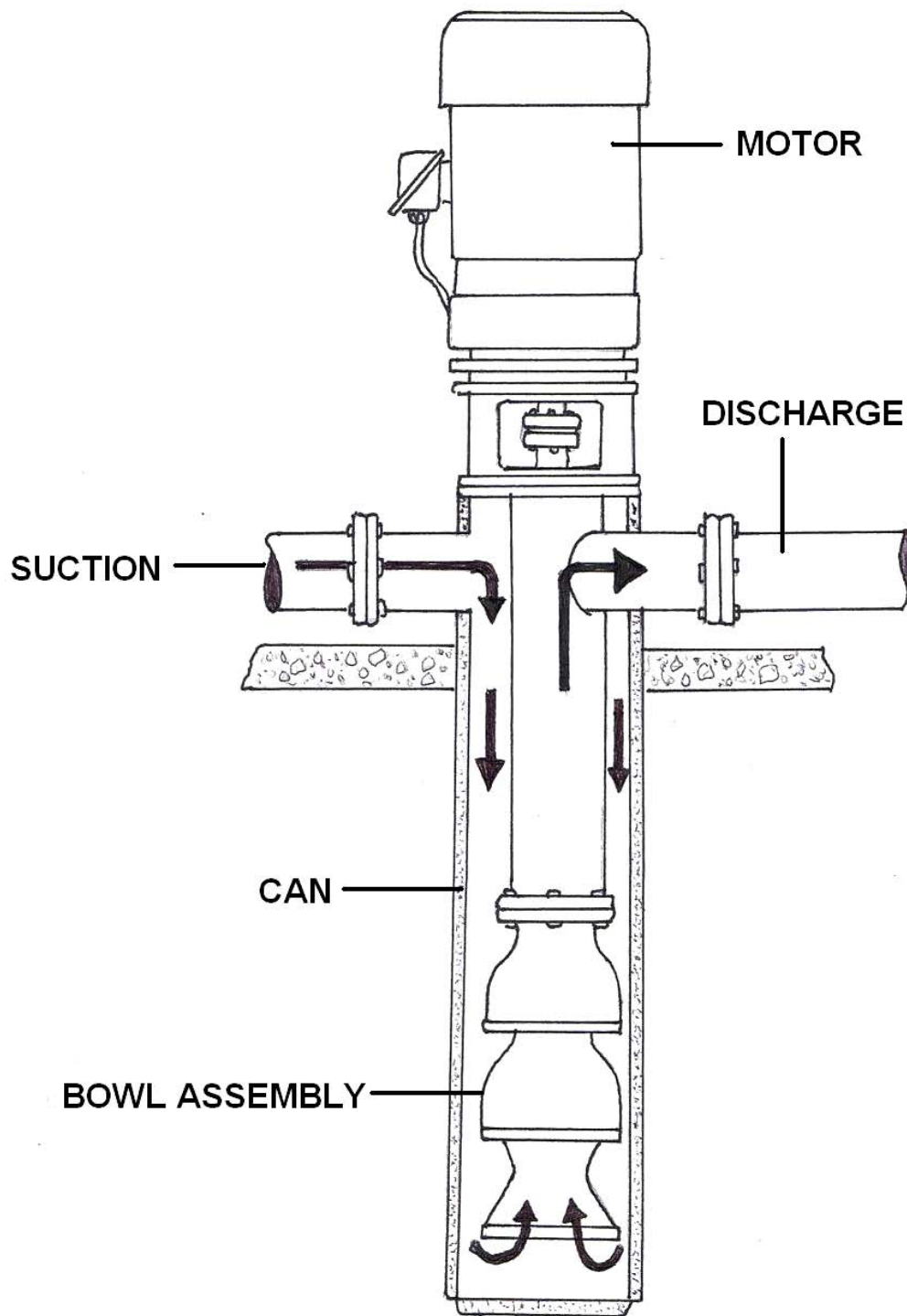
Column pipe sections can be threaded or coupled together while the drive shaft is coupled and suspended within the column by **spider bearings**. The spider bearings provide both a seal at the column pipe joints and keep the shaft aligned within the column. The water passing through the column pipe serves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

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

A small hole located at the top of the pump bow unit allows excess oil to enter the well. This results in the formation of an oil film on the water surface within oil-lubricated wells. Careful operation of oil lubricated turbines is needed to ensure that the pumping levels do not drop enough to allow oil to enter the pump.

Both water and oil lubricated turbine pumps units can be driven by an electric or fuel powered motors. Most installations use an electric motor that is connected to the drive shaft by a keyway and nut. However, where electricity is not readily available, fuel powered engines may be connected to the drive shaft by a right angle drive gear. Also, both oil and water lubricated systems will have a strainer attached to the intake to prevent sediment from entering the pump. When the line shaft turbine is turned off water will flow back down the column, turning the impellers in a reverse direction. A pump and shaft can easily be broken if the motor were to turn on during this process. This is why a **time delay** or **ratchet** assembly is often installed on these motors to either prevent the motor from turning on before reverse rotation stops or simply not allow it to reverse at all.

Common Elements of Vertical Turbines



TURBINE PUMP

Submersible Pumps

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

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

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

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

The shroud is a piece of pipe that attaches to the pump housing with an open end below the motor.

As with turbine pumps the size of the bowls and impellers, number of stages, and horsepower of the motor are adjusted to achieve the desired production rate within the limitations of the pumping head.



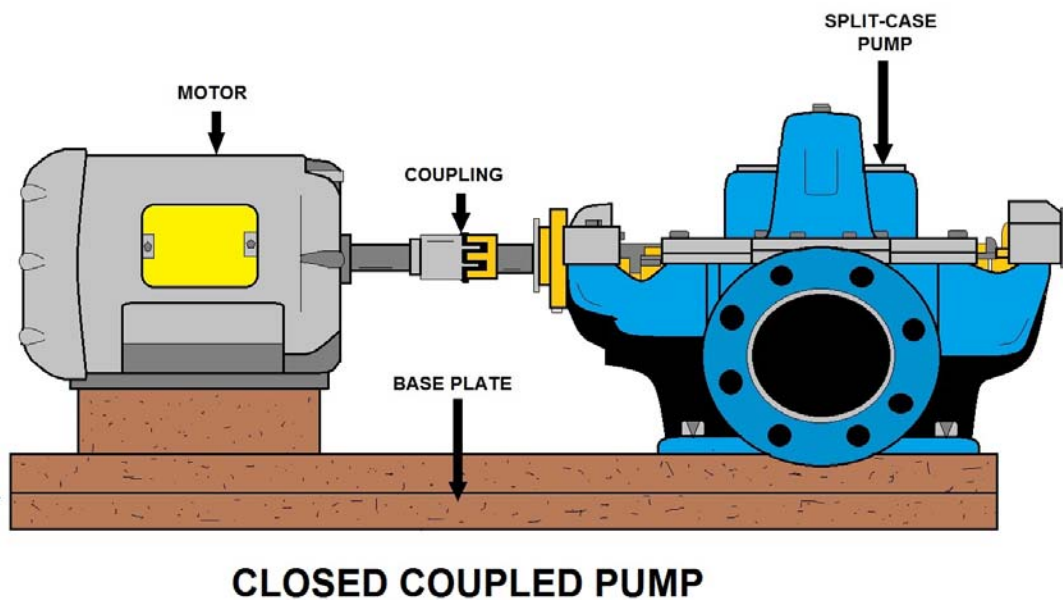
Insertion of motor spline into pump keyway

Cut away of a small submersible pump

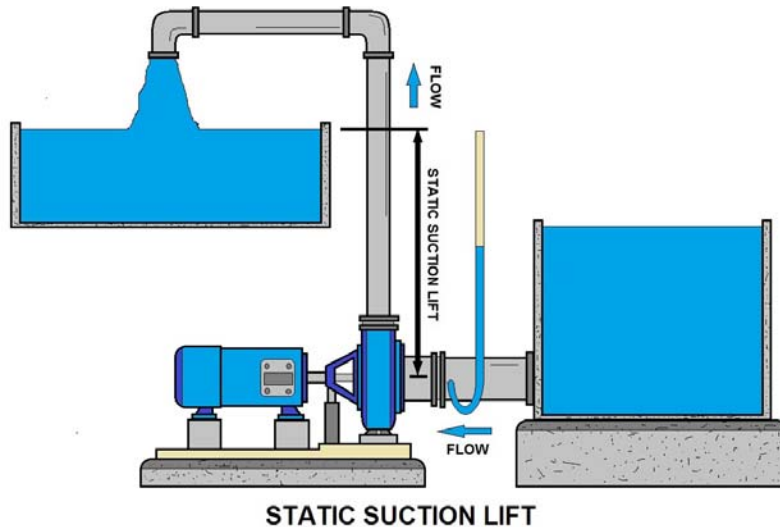


Pointing to a Lantern Ring. Two pieces of packing on the outside and two pieces on the inside. Always stagger the packing joints. The Lantern Ring allows air inside the stuffing box. Old School Technology.

The picture below illustrates the components that are common to all pump assemblies.



General Pumping Fundamentals



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

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

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

Points to Note are:

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



Vertical Turbine well with a mineral oil cooled seal. Mechanical seal bottom.



Motor, Coupling and Bearings Section

We will now refer to the motor, coupling, and bearings. The power source of the pump is usually an electric motor; which is connected by a coupling to the pump shaft. The purpose of the bearings are to hold the shaft firmly in place, yet allow it to rotate. The bearing house supports the bearings and provides a reservoir for the lubricant. An impeller is connected to the shaft. The pump assembly can be a vertical or horizontal set up. The components for both are basically the same.

Motors

The purpose of this discussion on pump motors is to identify and describe main types of motors, starters, enclosures and motor controls, as well as to provide you with some basic maintenance and troubleshooting information. Although pumps could be driven by diesel or gasoline engines, pumps driven by electric motors are commonly used in our industry.

There are two general categories of electric motors:

- ✱ D-C motors, or direct current
- ✱ A-C motors, or alternating current

You can expect most motors at facilities to be A-C type.

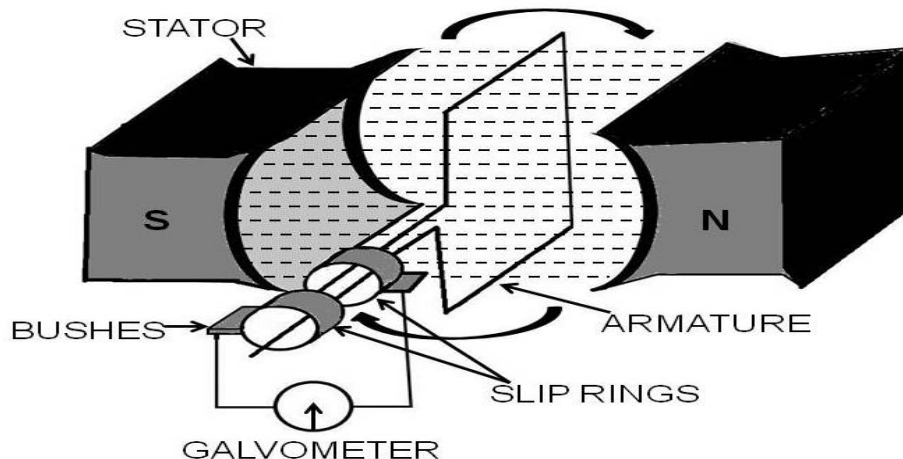
D-C Motors

The important characteristic of the D-C motor is that its speed will vary with the amount of current used. There are many different kinds of D-C motors, depending on how they are wound and on their speed/torque characteristics.



A-C Motors

There are a number of different types of alternating current motors, such as synchronous and induction; wound rotor and squirrel cage. The synchronous type of A-C motor requires complex control equipment, since they use a combination of A-C and D-C. This also means that the synchronous type of A-C motor is used in large horsepower sizes, usually above 250 HP. The induction type motor uses only alternating current. The squirrel cage motor provides a relatively constant speed and the wound rotor type could be used as a variable speed motor.



PRODUCTION OF AC CURRENT

Define the Following Terms:

Voltage:

EMF:

Power:

Current:

Resistance:

Conductor:

Phase:

Single Phase:

Three Phase:

Hertz:

Motor Starters

All electric motors, except very small ones such as chemical feed pumps, are equipped with starters, either full voltage or reduced voltage. This is because motors draw a much higher current when they are starting and gaining speed. The purpose of the reduced voltage starter is to prevent the load from coming on until the amperage is low enough.

How do you think keeping the discharge valve closed on a centrifugal pump could reduce the start up load?

Motor Enclosures

Depending on the application, motors may need special protection. Some motors are referred to as open motors. They allow air to pass through to remove heat generated when current passes through the windings. Other motors use specific enclosures for special environments or safety protection.

Can you think of any locations within your facility that require special enclosures?



Two Types of Totally Enclosed Motors Commonly Used are:

- ☞ **TENV**, or totally enclosed non-ventilated motor
- ☞ **TEFC**, or totally enclosed fan cooled motor

Totally enclosed motors include dust-proof, water-proof and explosion-proof motors. An explosion proof enclosure must be provided on any motor where dangerous gases might accumulate.

Motor Controls

All pump motors are provided with some method of control, typically a combination of manual and automatic. Manual pump controls can be located at the central control panel at the pump or at the suction or discharge points of the liquid being pumped.

There are a number of ways in which automatic control of a pump motor can be regulated:

- ☞ Pressure and vacuum sensors
- ☞ Preset time intervals
- ☞ Flow sensors
- ☞ Level sensors

Two typical level sensors are the float sensor and the bubble regulator. The float sensor is pear shaped and hangs in the wet well. As the height increases the float tilts and the mercury in the glass tube flows toward the end of the tube that has two wires attached to it. When the mercury covers the wires, it closes the circuit.



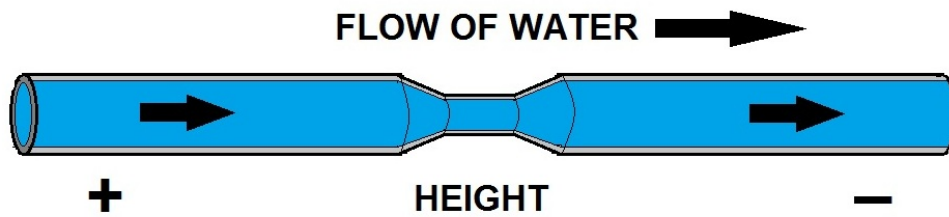
A low pressure air supply is allowed to escape from a bubbler pipe in the wet well. The back-pressure on the air supply will vary with the liquid level over the pipe. Sensitive air pressure switches will detect this change and use this information to control pump operation.

Motor Maintenance

Motors should be kept clean, free of moisture, and lubricated properly. Dirt, dust, and grime will plug the ventilating spaces and can actually form an insulating layer over the metal surface of the motor.

What condition would occur if the ventilation becomes blocked?

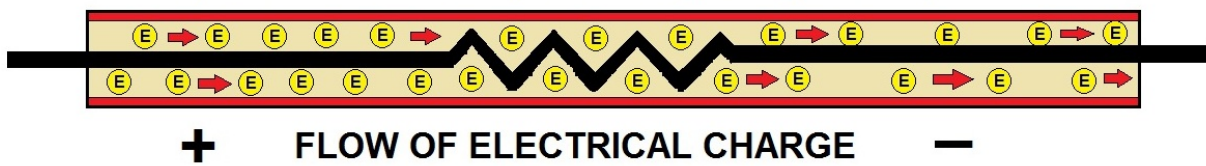




Electricity flow can be compared to flow of water:

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

(Flow of electrons (electricity) along a wire)



BASIC ELECTRICITY CONCEPT

Electrical Glossary

ALTERNATING CURRENT (AC) - A current which reverses in regularly recurring intervals of time and which has alternative positive and negative values, and occurring a specified number of times per second. The number is expressed in cycles per second or Hertz (Hz).

ALARM LIGHT - A light which is used to attract attention when a problem occurs in the system.

ALTERNATOR - A relay device designed for alternating the run cycle or duplexing action of two or more motors automatically. There are two basic types: One mechanically changes its contacts each time the operating coil is de-energized, the second is a solid state unit with an output relay. The alternator is used in the automatic control circuit to the motor starters to rotate the duty cycle of each motor.

AMBIENT TEMPERATURE - Temperature of the surroundings in which the equipment is used or operated.

AMMETER - Meter for measuring the current in an electrical circuit, measured in amperes.

AMPERE - The unit of electric current flow. One ampere will flow when one volt is applied across a resistance of one ohm.

AUDIBLE ALARM - Horn, siren, bell, or buzzer which is used to attract the attention of the operator when a problem occurs in the system.

AUXILIARY CONTACTS - Contacts of a switching device in addition to the main current contacts that operate with the movement of the latter. They can be normally open (NO) or normally closed (NC) and change state when operated.

CAPACITOR - A device which introduces capacitance into an electrical circuit. The capacitor, when connected in an alternating current circuit, causes the current to lead the voltage in time phase. The peak of the current wave is reached ahead of the peak of the voltage wave. This is the result of the successive storage and discharge of electric energy.

CIRCUIT BREAKER - A mechanical switching device capable of making, carrying, and breaking currents under normal conditions. Also making, carrying for a specific time, and automatically breaking currents under specified abnormal circuit conditions, such as those of short circuit. Circuit breakers have an ampere trip rating for normal overload protection and a maximum magnetic ampere interrupting capacity (AIC) for short circuit protection.

COMMERCIAL POWER - The term applied to power furnished by an electric power utility.

CONDENSATION HEATER - A device that warms the air within an enclosure and prevents condensation of moisture during shut-down periods. Also known as a space heater.

CONDUCTOR - A wire, cable or bus bar designed for the passage of electrical current.

CONTACTOR - An electro-mechanical device that is operated by an electric coil and allows automatic or remote operation to repeatedly establish or interrupt an electrical power circuit. A contactor provides no overload protection as required for motor loads. Sometimes called a power relay.

CONTACTS - Devices for making and breaking electrical circuits, which are a part of all electrical switching devices.

CURRENT - The amount of electricity measured in amperes which is flowing in a circuit.

CYCLE - A given length of time (See Alternating Current). In the U.S., most electric current is 60 cycle (60 Hz).

CYCLE TIMER - A timer that repeatedly opens and closes contacts according to pre-set time cycles.

DELTA CONNECTION - A common three phase connection shaped schematically like the Greek Delta. The end of one phase is connected to the beginning of the next phase, or vice versa.

DESIGN LETTER - A letter that is shown on the motor nameplate indicating NEMA's classification of that motor. Classification encompasses characteristics such as full-voltage starting, locked rotor torque, breakdown torque, and others that determine electrical type.

DISCONNECTING MEANS (DISCONNECT) - A device or group of devices, or other means whereby all the ungrounded conductors of a circuit can be disconnected simultaneously from their source of supply.

ELAPSED TIME METER - An instrument used to record the amount of time each pump runs. One elapsed time meter is used per pump.

ELECTRIC UTILITIES - All enterprises engaged in the production and/or distribution of electricity for use by the public.

EMERGENCY POWER (ALTERNATE SOURCE OF POWER) - An independent reserve source of electric power which, upon failure or outage of the normal power source, provides stand-by electric power.

ENCLOSURE - The cabinet or specially designed box in which electrical controls and apparatus are housed. It is required by the National Electrical Code (NEC) to protect persons from live electrical parts and limit access to authorized personnel. It also provides mechanical and environmental protection. An enclosure should be designed to provide the required protection and sized to provide good, safe wire access and replacement of components. It can be manufactured of steel, galvanized or stainless steel, aluminum, or suitable non-metallic materials including fiberglass.

EXPLOSION-PROOF MOTOR - A motor in a special enclosure. The purpose of the enclosure is twofold:

1) If an explosive vapor (gas) should explode inside the motor, the frame of the motor will not be affected.

2) The enclosure is so constructed that no such explosion will ignite vapors outside the motor.

FACTORY MUTUAL (FM) - Independent U.S. agency associated with the insurance industry which tests for safety.

FREQUENCY - The number of complete cycles of an alternating voltage or current per unit of time and usually expressed in cycles per second or Hertz (Hz).

FULL LOAD CURRENT - The greatest current that a motor or other device is designed to carry under specific conditions; any additional is an overload.

FULL LOAD AMPS (FULL LOAD CURRENT) - The current flowing through a line terminal of a winding when rated voltage is applied at rated frequency with rated horsepower.

FUSE - An over-current protective device which consists of a conductor that melts and breaks when current exceeds rated value beyond a predetermined time.

GENERAL PURPOSE RELAY - A relay that is adaptable to a wide variety of applications as opposed to a relay designed for a specific purpose or specific application.

GENERATOR - A machine for converting mechanical energy into electrical energy or power.

GENERATOR RECEPTACLE - A contact device installed for the connection of a plug and flexible cord to supply emergency power from a portable generator or other alternate source of power. Receptacles are rated in voltage, amps, number of wires, and by enclosure type.

GROUND - A connection, either intentional or accidental, between an electric circuit and the earth or some conducting body serving in place of the earth.

GROUND FAULT INTERRUPTION (GFI) - A unit or combination of units which provides protection against ground fault currents below the trip levels of the breakers of a circuit. The system must be carefully designed and installed to sense low magnitude insulation breakdowns and other faults that cause a fault ground current path. The GFI system must be capable of sensing the ground fault current and disconnecting the faulted circuit from the source voltage.

GROUNDING NEUTRAL - The common neutral conductor of an electrical system which is intentionally connected to ground to provide a current carrying path for the line to neutral load devices.

GROUNDING CONDUCTOR - The conductor that is used to establish a ground and that connects equipment, a device, a wiring system, or another conductor (usually the neutral conductor) with the grounding electrode.

HAND-OFF-AUTOMATIC (HOA) - Selector switch determining the mode of system operation. H is the hand mode only. O is system Off. A is automatic operation, normally with pump alternation.

HAZARDOUS LOCATIONS - Those areas as defined in the NEC where a potential for explosion and fire exist because of flammable gasses, vapors, or finely pulverized dusts in the atmosphere, or because of the presence of easily ignitable fibers or flyings.

HERTZ (Hz) - A unit of frequency equal to one cycle per second.

HIGH POTENTIAL TEST - A test which consists of the application of a voltage higher than the rated voltage between windings and frame, or between two or more windings, for the purpose of determining the adequacy of insulating materials and spacing against breakdown under normal conditions. It is not the test of the conductor insulation of any one winding.

HORSEPOWER - A method of rating motors whereby values are determined by factors including rotational speed and torque producing capability as well as other factors.

IN-RUSH CURRENT - See Locked Rotor Current.

INTERLOCK - Interrelates with other controllers. An auxiliary contact. A device connected in such a way that the motion of one part is held back by another part.

INTRINSICALLY SAFE - A term used to define a level of safety associated with the electrical controls used in some lift stations. Intrinsically safe equipment and wiring is incapable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a hazardous

atmospheric mixture - without the need for explosion-proof enclosures in the hazardous area. Any associated devices must be outside the hazardous area with an approved seal-off fitting used as an isolating barrier.

KILOWATT (KW) - A unit of measure of electrical power. One kilowatt equals 1000 watts. Used where larger units of electrical power are measured.

LOCKED ROTOR CURRENT - (See Starting Amps).

LOCKOUT - A mechanical device which may be set to prevent the operation of a push-button or other device.

MANUAL TRANSFER SWITCH - A switch designed so that it will disconnect the load from one power source and reconnect it to another source while at no time allowing both sources to be connected to the load simultaneously.

MEGGER OR MEGOHMMETER - A high resistance range ohmmeter utilizing a power source for measuring insulation resistance.

MEGOHM - A unit of resistance equal to one million ohms.

MOTOR CIRCUIT PROTECTOR - A molded case disconnect switch specifically designed for motor circuits. It has a trip unit that operates on the magnetic principle only, sensing current in each of the three poles with an adjustable trip point. It provides short circuit protection, required by the National Electrical Code (NEC). It differs from a standard breaker in that it does not have a thermal overload unit.

MOTOR EFFICIENCY - A measure of how effectively a motor converts electrical energy into mechanical energy. Motor efficiency is never 100 percent. It is a variable that depends on a given motor's performance. Tabulated at 100, 75 and 50 percent load, it is the ratio of power output to power input.

MOTOR, ELECTRIC - A rotating device which converts electrical power into mechanical power.

MOTOR HORSEPOWER RATING - The motor horsepower nameplate rating fully-loaded at the ambient temperature.

NEC - The National Electrical Code (NEC) is the standard of the National Board of Fire Underwriters for electric wiring and apparatus, as recommended by the National Fire Protection Association.

NEC CODE LETTER - Motors with 60 and 50 Hertz ratings shall be marked with a code letter designating the locked-rotor KVA per horsepower on 60 Hertz.

NEMA - National Electrical Manufacturers Association, a non-profit trade association supported by the manufacturers of electrical apparatus and supplies. NEMA promulgates standards to facilitate understanding between the manufacturers and users of electrical products.

NFPA - National Fire Protection Association. Sponsors and publishes the National Electrical Code (NEC).

NEUTRAL - The point common to all phases of a polyphase circuit, a conductor to that point, or the return conductor in a single phase circuit. The neutral in most systems is grounded at or near the point of service entrance only and becomes the grounded neutral.

NORMALLY OPEN and NORMALLY CLOSED - The terms "Normally Open" and "Normally Closed" when applied to a magnetically operated switching device - such as a contactor or relay, or to the contacts thereof - signify the position taken when the operating magnet is de-energized. These terms pertain to all switches.

OHM - Unit of electrical resistance. One volt will cause a current of one ampere to flow through a resistance of one ohm.

OHMMETER - A device for measuring electrical resistance expressed in ohms.

OVERLOAD PROTECTION - The effect of a device operative on excessive current, but not necessarily on short circuit, to cause and maintain the interruption of current flow to the device being governed. Re-set may be manual or automatic.

OVERLOAD RELAY - A relay that responds to electric load and operates at a pre-set value of overload. The unit senses the current in each line to the motor and is either bimetallic, melting alloy or solid state actuated. It may be of the non-compensated or ambient-compensated type, and of a standard or fast-trip design.

PHASE (THREE PHASE CIRCUIT) - A combination of circuits energized by alternating electromotive forces which differ in phase by one-third of a cycle (120 degrees). In practice, the phases may vary several degrees from the specified angle.

PHASE MONITOR - A device in the control circuit of motors which monitors the three phase voltage and protects against a phase loss (single phasing), under voltage (brown outs) and phase reversal (improper phase sequence). Most are adjustable to set the nominal voltage and some have a LED indicator to indicate acceptable voltage and phase conditions. The output contacts are used to control the motor

starters and provide signaling for telemetering.

PILOT LIGHT - A lamp available with various colored lenses designed to operate on a control voltage. They are each turned On and Off to provide the required indication for specific functions or alarm conditions. They are available in various sizes and voltage ratings. They are each designed for a specific bulb style and base configuration and some have an integral transformer to allow the use of low voltage bulbs. Full voltage incandescent bulbs are most common, but neon bulbs are also used.

POWER FACTOR - The ratio of the true power to the volt-amperes in an alternating current circuit. Power factor is expressed in a percent of unity either lagging for inductive loads or leading for capacitive loads. Resistive loads produce a unity power factor.

PUSHBUTTON - Part of an electrical device, consisting of a button that must be pressed to effect an operation.

RATED VOLTAGE - The voltage of electrical apparatus at which it is designed to operate.

REDUCED VOLTAGE AUTO-TRANSFORMER STARTER - A starter that includes an auto-transformer to furnish reduced voltage for starting an alternating current motor. It includes the necessary switching mechanism. This is the most widely used reduced voltage starter because of its efficiency and flexibility.

RELAY - An electric device that is designed to interpret input conditions in a prescribed manner and, after specified conditions are met, to respond and cause contact operation or similar abrupt changes in associated electric control circuits.

RELAY, ELECTROMAGNETIC - A relay controlled by electromagnetic means, to open and close electric contacts.

RELAY, SOLID STATE - A completely electronic switching device with no moving parts or contacts.

RPM - Revolutions per minute of the motor/pump rotating assembly.

REMOTE CONTROL - Control function initiation or change of electrical device from a remote point.

RESISTANCE - The non-reactive opposition which a device or material offers to the flow of direct or alternating current. Usually measured in ohms.

SAFETY SWITCH - An enclosed, manually-operated disconnecting switch, which is horsepower and current rated. Disconnects all power lines simultaneously.

SEAL FAILURE ALARM - The sensing and indication of the intrusion of water into the oil-filled seal chamber between the inner and outer shaft seal of a submersible pump.

SELECTOR SWITCH - A multi-position switch which can be set to the desired mode of operation.

SERVICE FACTOR - A safety factor designed and built into some motors which allows the motor, when necessary, to deliver greater than its rated horsepower.

SINGLE PHASE - A circuit that differs in phase by 180 degrees. Single phase circuits have two conductors, one of which may be a neutral, or three conductors, one of which is neutral.

STANDBY POWER SUPPLY - The power supply that is available to furnish electric power when the normal power supply is not available.

STAR CONNECTION - Same as a "Y" or "Wye" connection. This three-phase connection is so called because, schematically, the joint of the "Y" points looks like a star.

STARTER - A device used to control the electrical power to motors and provide overload protection as required by the NEC. The starter can be operated manually, electrically, or by automatic pilot devices. A starter has two basic parts - a contactor for power switching and an overload relay for protection.

STARTING AMPS (LOCKED ROTOR) - The maximum current drawn by the motor during the starting period.

STARTING RELAY - A relay - actuated by current, voltage or the combined effect of current and voltage - which is used to perform a circuit-changing function in the primary winding of single phase induction motor within a pre-determined range of speed as the motor accelerates; and to perform the reverse circuit-changing operation when the motor is disconnected from the supply line. One of the circuit changes that is usually performed is to open or disconnect the auxiliary winding (starting) circuit.

SUBMERSIBLE MOTOR - A motor whose housing and terminal box is so designed that the motor can run underwater - completely submerged at an allowable temperature.

SURGE ARRESTER - A protective device for limiting surge voltages on equipment by discharging or bypassing surge current; it prevents continued flow of follow current to ground, and is capable of repeating these functions as specified.

SWITCH - A device for making, breaking, or changing connections in a circuit.

TELEMETERING - The transmitting of alarm and control signals to and from remote lift station controls and a central monitoring location.

TERMINAL BLOCK - An insulating base equipped with terminals for connecting wires.

THERMAL OVERLOAD PROTECTOR - Device, either a bimetal element or electric circuit, which protects motor windings from excessive temperature by opening a set of contacts. This device may reach its' pre-set trip point as a result of ambient temperature, current, or both. May be automatic or manually set.

THREE PHASE CIRCUIT - A combination of circuits energized by alternating electromotive sources which differ in phase by one third of a cycle - that is, 120 degrees. A three phase circuit may be three wires or four wires with the fourth wire being connected to the neutral point of the circuit which may be grounded.

TIME CLOCK - A device used to schedule electrical On/Off cycling operations. The device may be solid state or mechanical designed using a synchronous motor. The cycling operation must be programmed manually. The time clocks may operate in any increments of days, weeks, minutes, or hours.

TIME DELAY RELAY (TDR) - A device with either mechanical or solid state output contacts that performs a timing function upon energization or control signal.

TRANSDUCER - A device to condition and transform an analog signal to a specific variable output electrical signal proportional to the input signal. Typical inputs include variable pressure, level, voltage or current. Some common outputs are 0 to 1ma, 4 to 20 ma, and various MVDC signals. A transducer must be specifically designed to be compatible with the input/output requirements of the total system.

TRANSFORMER - A static electric device consisting of a single winding, or two or more coupled windings, used to transfer power by electromagnetic induction between circuits at the same frequency, usually with changed values of voltage and current.

UNDERWRITERS LABORATORIES, INC. (UL) - An independent, non-profit U.S. organization that tests products for safety.

VFD - Variable frequency drive.

VOLTAGE (NOMINAL A) - A nominal value assigned to a circuit or system for the purpose of conveniently designating its voltage class (as 120/240, 480/240, 600, etc.). The actual voltage at which a circuit operates can vary from the nominal within a range that permits satisfactory operation of equipment.

VOLTMETER - An instrument for measuring voltage.

WATT - A unit of measure of electrical power.

WYE CONNECTION - See Star Connection.

Moisture

Moisture harms the insulation on the windings to the point where they may no longer provide the required insulation for the voltage applied to the motor. In addition, moisture on windings tends to absorb acid and alkali fumes, causing damage to both insulation and metals. To reduce problems caused by moisture, the most suitable motor enclosure for the existing environment will normally be used. It is recommended to run stand by motors to dry up any condensation which accumulates in the motor.

Motor Lubrication

Friction will cause wear in all moving parts, and lubrication is needed to reduce this friction. It is very important that all your manufacturer's recommended lubrication procedures are strictly followed. You have to be careful not to add too much grease or oil; this could cause more friction and generate heat.

To grease the motor bearings, this is the usual approach:

1. Remove the protective plugs and caps from the grease inlet and relief holes.
2. Pump grease in until fresh starts coming from the relief hole.

If fresh grease does not come out of the relief hole, this could mean that the grease has been pumped into the motor windings. The motor must then be taken apart and cleaned by a qualified service representative.

To change the oil in an oil lubricated motor, this is the usual approach:

1. Remove all plugs and let the oil drain.
2. Check for metal shearing.
3. Replace the oil drain.
4. Add new oil until it is up to the oil level plug.
5. Replace the oil level and filter plug.

Never mix oils, since the additives of different oils, when combined, can cause breakdown of the oil.

Couplings

The pump coupling serves two main purposes:

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

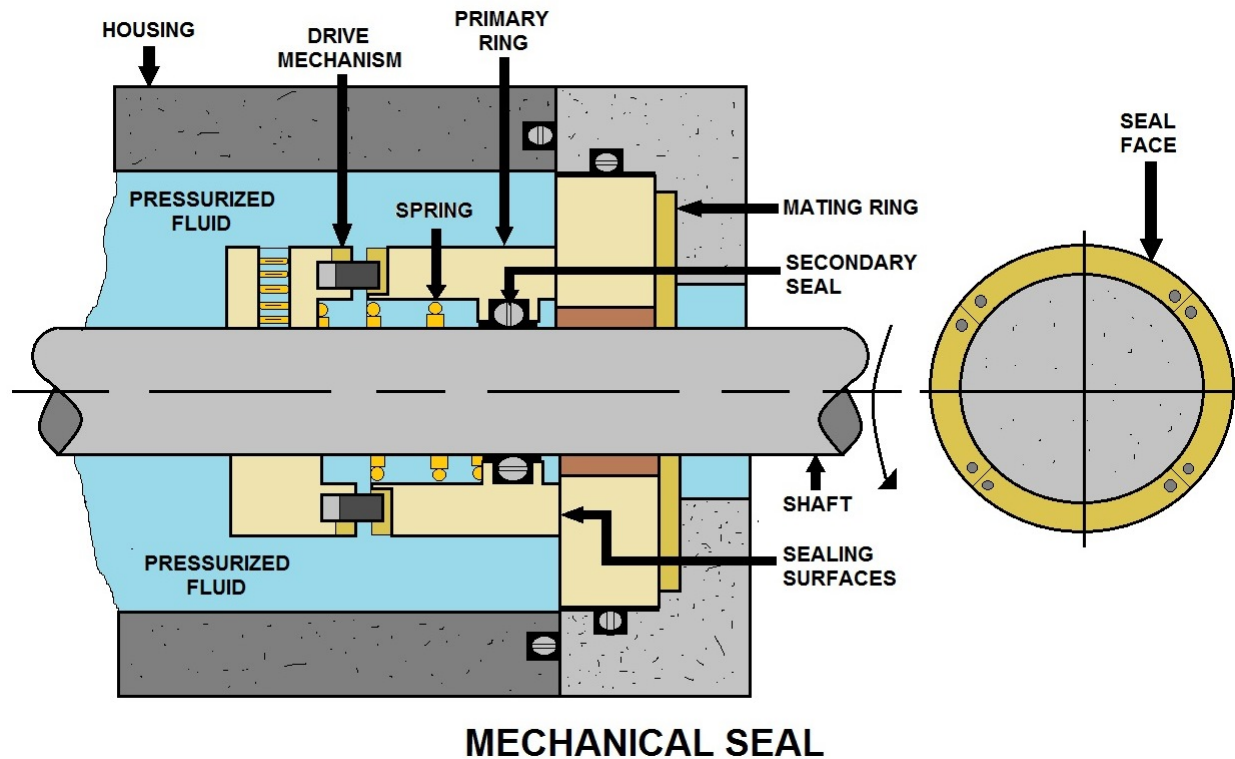
Remember that any coupling is a device in motion. If you have a 4-inch diameter coupling rotating at 1800 rpm's, its outer surface is traveling about 20 mph. With that in mind, can you think of safety considerations?

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

Rigid Coupling

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

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



Alignment of Flexible and Rigid Couplings

Both flexible and rigid couplings must be carefully aligned before they are connected. Misalignment will cause excessive heat and vibration, as well as bearing wear. Usually the noise from the coupling will warn you of shaft misalignment problems.

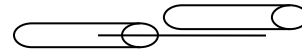
Three types of shaft alignment problems are shown in the pictures below:



ANGULAR MISALIGNMENT



ANGULAR AND PARALLEL



PARALLEL MISALIGNMENT

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

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

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

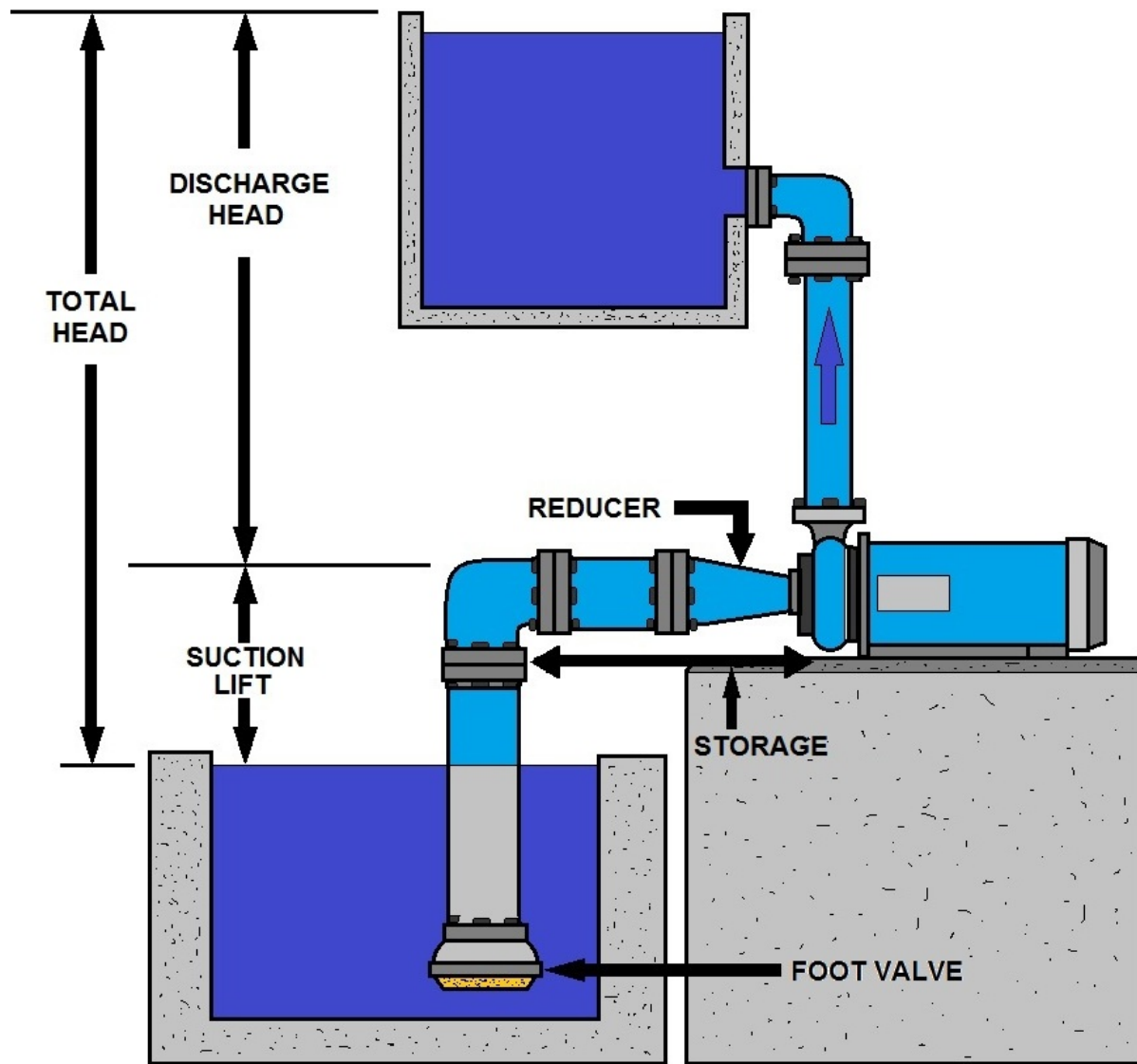
V-Belt Drive Couplings

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

Shaft Bearings

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

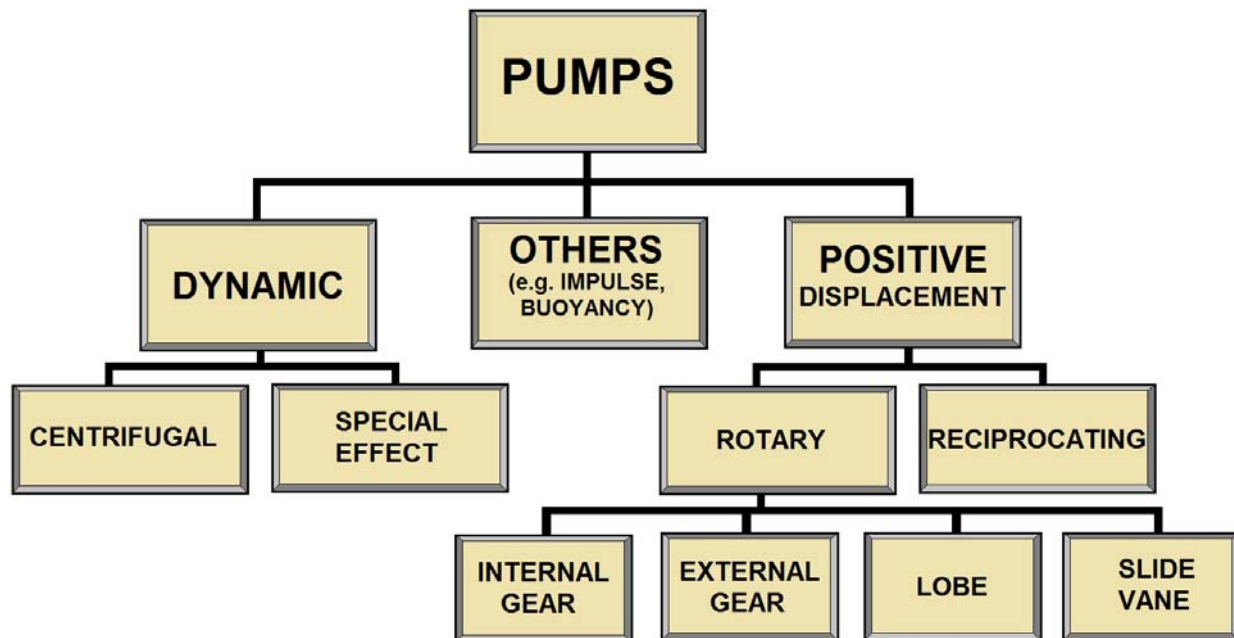
Bearings must be lubricated. Without proper lubrication, bearings will overheat and seize. Proper lubrication means using the correct type and the correct amount of lubrication. Similar to motor bearings, shaft bearings can be lubricated either by oil or by grease.



PUMPING FACTORS

Pump Categories

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



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



Multi-Stage Bowls

As a rule, each impeller acts separately, discharging to the suction of the next stage impeller. This arrangement is called series staging. Centrifugal pumps are also classified as **HORIZONTAL** or **VERTICAL**, depending upon the position of the pump shaft. The impellers used on centrifugal pumps may be classified as **SINGLE SUCTION** or **DOUBLE SUCTION**. The single-suction impeller allows liquid to enter the eye from one side only.

The double-suction impeller allows liquid to enter the eye from two directions. Impellers are also classified as **CLOSED** or **OPEN**.

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

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

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

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

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

Leakage

During pump operation, a certain amount of leakage around the shafts and casings normally takes place. This leakage must be controlled for two reasons: (1) to prevent excessive fluid loss from the pump, and (2) to prevent air from entering the area where the pump suction pressure is below atmospheric pressure. The amount of leakage that can occur without limiting pump efficiency determines the type of shaft sealing selected. Shaft sealing systems are found in every pump. They can vary from simple packing to complicated sealing systems.

Packing is the most common and oldest method of sealing. Leakage is checked by the compression of packing rings that causes the rings to deform and seal around the pump shaft and casing. The packing is lubricated by liquid moving through a lantern ring in the center of the packing. The sealing slows down the rate of leakage. It does not stop it completely, since a certain amount of leakage is necessary during operation. Mechanical seals are rapidly replacing conventional packing on centrifugal pumps.

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

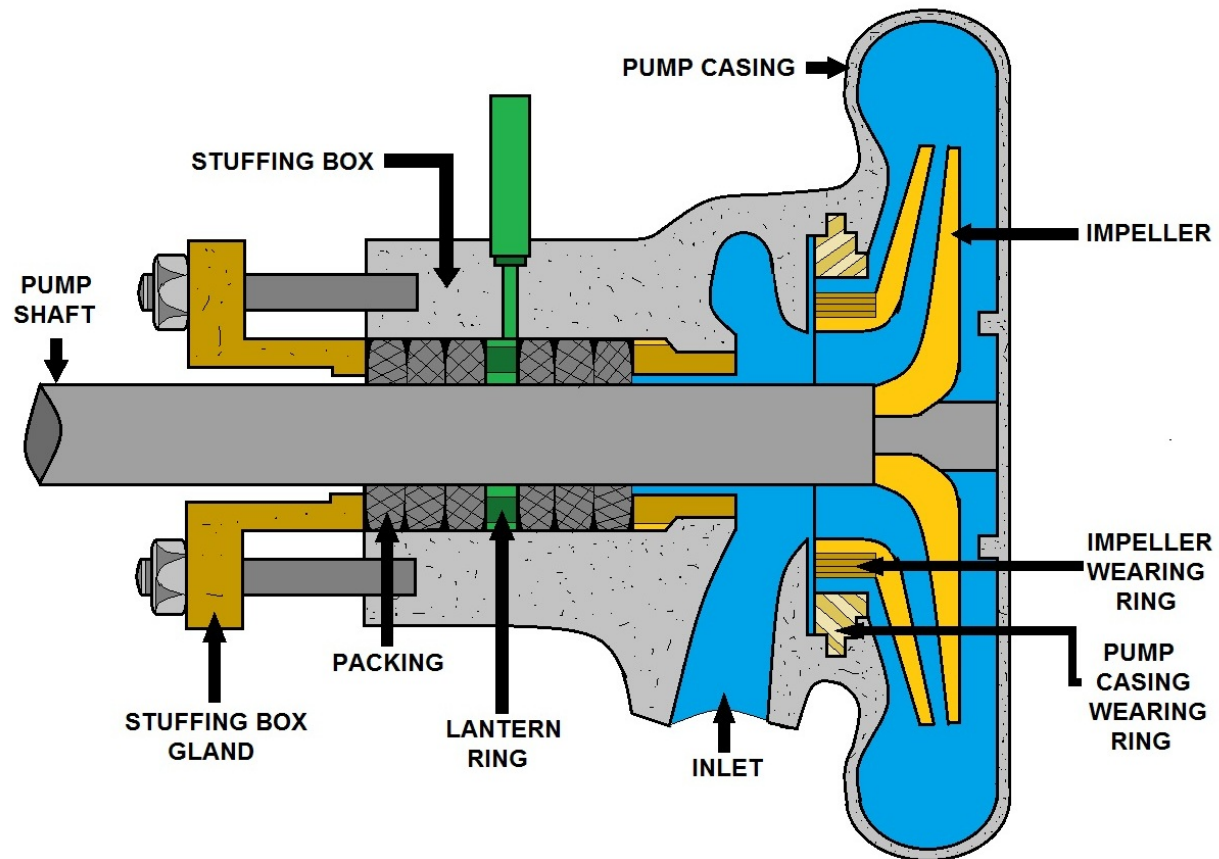
1. Leaking causes bearing failure by contaminating the oil with water. This is a major problem in engine-mounted water pumps.
2. Properly installed mechanical seals eliminate leakoff on idle (vertical) pumps. This design prevents the leak (water) from bypassing the water flinger and entering the lower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

Leakoff causes two types of seal leakage:

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

Centrifugal pumps are versatile and have many uses. This type of pump is commonly used to pump all types of water and wastewater flows including thin sludge.

We will look at the components of the centrifugal pump.



CENTRIFUGAL PUMP PARTS

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

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

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

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



Packing Seals

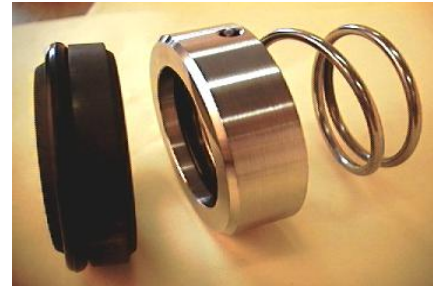
Should packing have leakage?

Lantern Rings

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

Mechanical Seals

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



What care should be taken when storing mechanical seals?



Mechanical Seals

Wear Rings

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

Pump Casing

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

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

Impeller

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

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

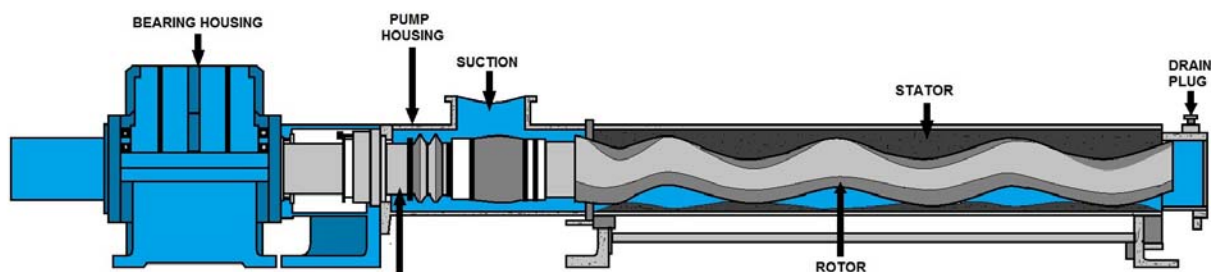
Impellers are designed in various ways. We will look at:

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

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

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

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

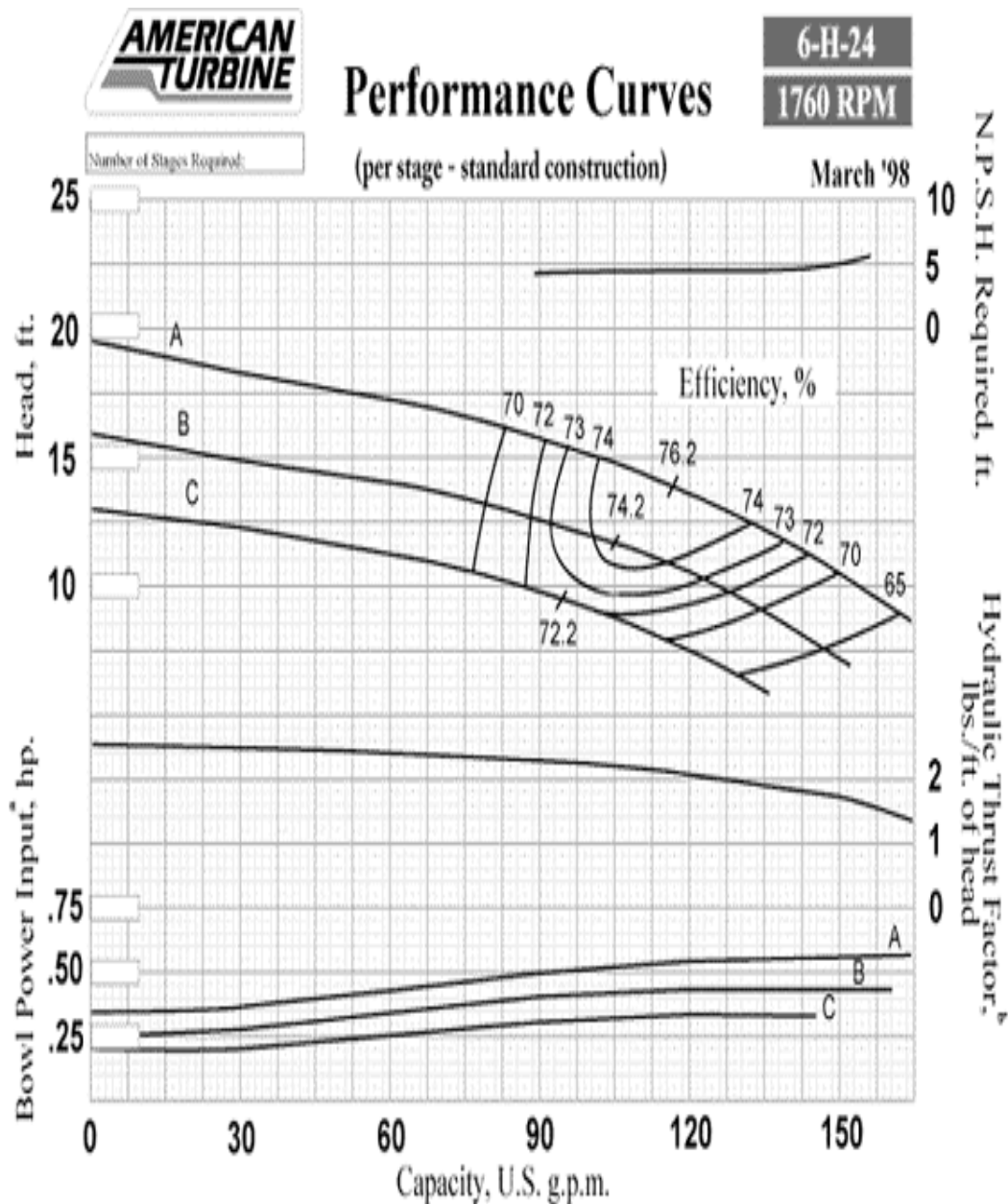


**POSITIVE DISPLACEMENT PUMP
PROGRESSIVE CAVITY TYPE**

Pump Performance and Curves

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

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



Positive Displacement Pumps

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

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

What kind of mechanical device do you think is used to provide this positive displacement in the:

Plunger pump?

Diaphragm pump?

In the same way, the progressing cavity, and the screw are two other types of mechanical action that can be used to provide movement of the liquid through the pump.

Plunger Pump

The plunger pump is a positive displacement pump that uses a plunger or piston to force liquid from the suction side to the discharge side of the pump. It is used for heavy sludge. The movement of the plunger or piston inside the pump creates pressure inside the pump, so you have to be careful that this kind of pump is never operated against any closed discharge valve.

All discharge valves must be open before the pump is started, to prevent any fast build-up of pressure that could damage the pump.

Diaphragm Pumps

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

There are three main types of diaphragm pumps available:

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

Progressing Cavity Pumps

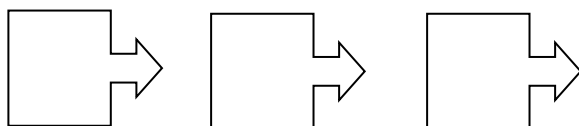
In this type of pump, components referred to as a rotor and an elastic stator provide the mechanical action used to force liquid from the suction side to the discharge side of the pump. Progressing cavity pumps are used to pump material very high in solids content. The progressive cavity pump must never be run dry, because the friction between the rotor and stator will quickly damage the pump.

Screw Pumps

In this type of pump, a large screw provides the mechanical action to move the liquid from the suction side to the discharge side of the pump. Here are some typical characteristics of screw pumps:

- ☞ Most screw pumps rotate in the 30 to 60 rpm range, although some screw pumps are faster.
- ☞ The slope of the screw is normally either 30° or 38°.
- ☞ The maximum lift for the larger diameter pumps is about 30 feet. The smaller diameter pumps have lower lift capabilities.

Motor and Pump Calculations



Motor hp

Brake hp

Water hp

Horsepower

Work involves the operation of force over a specific distance. The rate of doing work is called power. The rate in which a horse could work was determined to be about 550 ft-lbs/sec or 33,000 ft-lbs/min.

1 hp = 33,000 ft-lbs/min

Motor Horsepower (mhp)

1 hp = 746 watts or .746 Kilowatts

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

Brake Horsepower (bhp)

Water hp
Brake hp = -----
Pump Efficiency

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

Water Horsepower

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

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

Horsepower and Specific Gravity

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

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

MHP and Kilowatt requirements

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

Well Calculations

1. Well drawdown

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

2. Well yield

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

3. Specific yield

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

4. Deep well turbine pump calculations

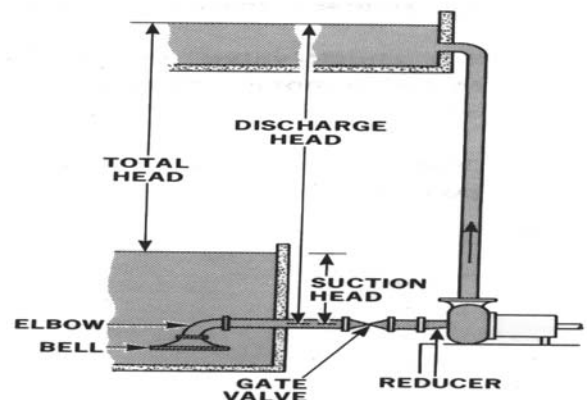
Discharge head, ft = (pressure measured) (2.31 ft/psi)

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

Bowl head, ft = field head + column friction

1 psi = 2.31 feet of head

1 foot of head = .433 psi



Example 1

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

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

Suction side:

Discharge side:

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

SSH:

SDH:

TSH:

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

6 psi:

48 psi:

110 psi:

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

20 ft:

205 ft:

185 ft:

Pump Troubleshooting Section

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

If a centrifugal pump **DOES NOT DELIVER ANY LIQUID**, the trouble may be caused by (1) insufficient priming; (2) insufficient speed of the pump; (3) excessive discharge pressure, such as might be caused by a partially closed valve or some other obstruction in the discharge line; (4) excessive suction lift; (5) clogged impeller passages; (6) the wrong direction of rotation (this may occur after motor overhaul); (7) clogged suction screen (if used); (8) ruptured suction line; or (9) loss of suction pressure.

If a centrifugal pump delivers some liquid but operates at **INSUFFICIENT CAPACITY**, the trouble may be caused by (1) air leakage into the suction line; (2) air leakage into the stuffing boxes in pumps operating at less than atmospheric pressure; (3) insufficient pump speed; (4) excessive suction lift; (5) insufficient liquid on the suction side; (6) clogged impeller passages; (7) excessive discharge pressure; or (8) mechanical defects, such as worn wearing rings, impellers, stuffing box packing, or sleeves.

If a pump **DOES NOT DEVELOP DESIGN DISCHARGE PRESSURE**, the trouble may be caused by (1) insufficient pump speed; (2) air or gas in the liquid being pumped; (3) mechanical defects, such as worn wearing rings, impellers, stuffing box packing, or sleeves; or (4) reversed rotation of the impeller (3-phase electric motor-driven pumps).

If a pump **WORKS FOR A WHILE AND THEN FAILS TO DELIVER LIQUID**, the trouble may be caused by (1) air leakage into the suction line; (2) air leakage in the stuffing boxes; (3) clogged water seal passages; (4) insufficient liquid on the suction side; or (5) excessive heat in the liquid being pumped. If a motor-driven centrifugal pump **DRAWS TOO MUCH POWER**, the trouble will probably be indicated by overheating of the motor. The basic causes may be (1) operation of the pump to excess capacity and insufficient discharge pressure; (2) too high viscosity or specific gravity of the liquid being pumped; or (3) misalignment, a bent shaft, excessively tight stuffing box packing, worn wearing rings, or other mechanical defects.

VIBRATION of a centrifugal pump is often caused by (1) misalignment; (2) a bent shaft; (3) a clogged, eroded, or otherwise unbalanced impeller; or (4) lack of rigidity in the foundation. Insufficient suction pressure may also cause vibration, as well as noisy operation and fluctuating discharge pressure, particularly in pumps that handle hot or volatile liquids. If the pump fails to build up pressure when the discharge valve is opened and the pump comes up to normal operating speed, proceed as follows:

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

Maintenance of Centrifugal Pumps

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



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

To ensure the longest possible service from pump packing, make certain the shaft or sleeve is smooth when the packing is removed from a gland. Rapid wear of the packing will be caused by roughness of the shaft sleeve (or shaft where no sleeve is installed). If the shaft is rough, it should be sent to the machine shop for a finishing cut to smooth the surface. If it is very rough, or has deep ridges in it, it will have to be renewed. It is absolutely necessary to use the correct packing. When replacing packing, be sure the packing fits uniformly around the stuffing box. If you have to flatten the packing with a hammer to make it fit, **YOU ARE NOT USING THE RIGHT SIZE**. Pack the box loosely, and set up the packing gland lightly. Allow a liberal leak-off for stuffing boxes that operate above atmospheric pressure. Next, start the pump. Let it operate for about 30 minutes before you adjust the packing gland for the desired amount of leak-off.

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

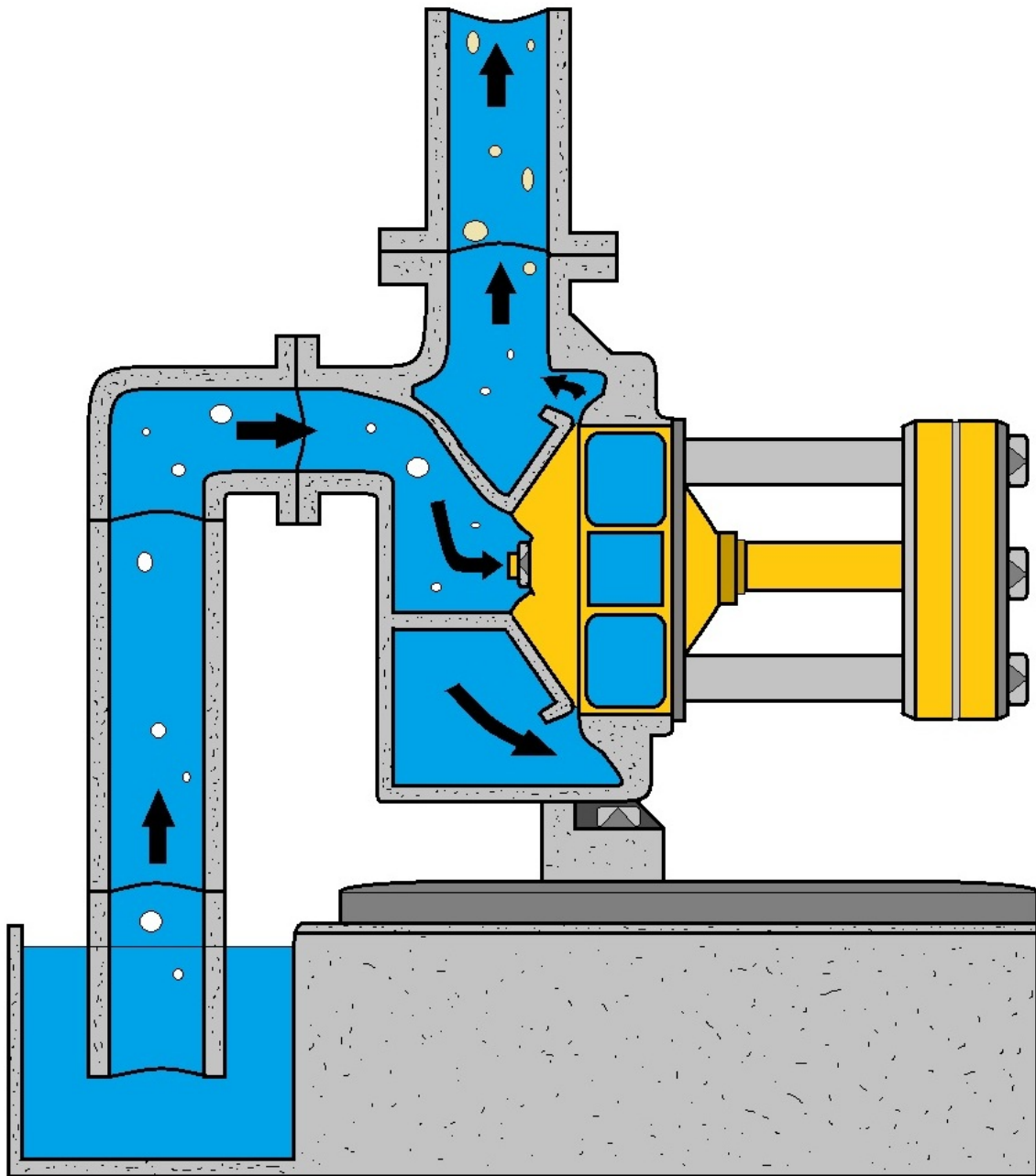
Mechanical Seals

Mechanical seals are rapidly replacing conventional packing as the means of controlling leakage on rotary and positive-displacement pumps. Mechanical seals eliminate the problem of excessive stuffing box leakage, which causes failure of pump and motor bearings and motor windings. Mechanical seals are ideal for pumps that operate in closed systems (such as fuel service and air-conditioning, chilled-water, and various cooling systems). They not only conserve the fluid being pumped but also improve system operation. The type of material used for the seal faces will depend upon the service of the pump. Most water service pumps use a carbon material for one of the seal faces and ceramic (tungsten carbide) for the other. When the seals wear out, they are simply replaced. You should replace a mechanical seal whenever the seal is removed from the shaft for any reason or whenever leakage causes undesirable effects on equipment or surrounding spaces. Do not touch a new seal on the sealing face because body acid and grease or dirt will cause the seal to pit prematurely and leak.



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

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



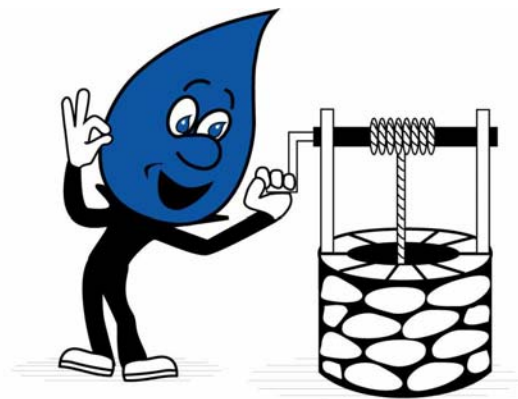
PUMP PRIMING

Troubleshooting Table for Well/Pump Problems

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

Possible Causes

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



Possible Solutions

- 1A. Reset breaker or manual overload relay.
- 1B. Check for cause and correct, replace fuse(s).
- 1C. Check incoming power supply. Contact power company.
- 1D. Check for shorts and correct, tighten terminals, replace broken wires.
- 1E. Check incoming line voltage. Contact power company if low.
- 1F. Contact electrical contractor.
- 1G. Check voltage of incoming electric supply with pressure switch closed. Contact power company if voltage low. Perform maintenance on switch if voltage normal.
- 2A. Check switch for proper operation. Replace switch.
- 2B. Adjust setting.
- 2C. Check and replace components or cable as needed.
- 3A. Adjust settings.
- 3B. Check for **backflow**. Contact well contractor.
- 3C. Check air volume. Add air if needed. If persistent, check air compressor, relief valve, air lines and connections, and repair if needed.
- 4A. Contact well contractor.
- 5A. Open valve, unclog discharge line.
- 5B. Check **static water level** and compare to past readings. If significantly lower, notify well contractor.
- 5C. Contact well contractor.
- 6A. Repair or replace check valve.
- 6B. Inspect and repair/replace as necessary.
- 7A. Test for iron and manganese at well. If levels exceed 0.3 mg/L iron or 0.005mg/L manganese, contact regulatory agency, TA provider or water treatment contractor.
- 7B. Check hot water heater and flush if needed.
- 8A. Check well for openings that allow surface water to enter. Check area for **sinkholes**, **fractures**, or other physical evidence of surface water **intrusion** Check water **turbidity**. Notify regulatory agency if >0.5 **NTU**. Check raw water for coliform **bacteria**. Notify regulatory agency immediately if positive.
- 9A. Check sampling technique, sampling container, and sampling location and tap.
- 9B. Notify regulatory agency immediately and re-sample for re-testing.



This brush is used to dislodge debris inside well casing.

Pump Section Summary and Review Statements

In general, any **Centrifugal** pump can be designed with a multistage configuration. Each stage requires an additional **Impeller** and casing chamber in order to develop increased pressure, which adds to the pressure developed by the preceding stage.

In all centrifugal pumps, there must be a flow restriction between the Impeller discharge and Suction areas that will prevent excessive circulation of water between the two parts.

When a pump operates under suction, the impeller inlet is actually operating in a vacuum. Air will enter the water stream along the shaft if the packing does not provide an effective seal. It may be impossible to tighten the packing sufficiently to prevent air from entering without causing excessive heat and wear on the packing and shaft or shaft sleeve. To solve this problem, a Lantern Ring is placed in the Stuffing Box.

A Centrifugal pump consists of an impeller fixed on a rotating shaft that is enclosed in a casing, and has an inlet and discharge connection. As the rotating impeller spins the liquid around, force builds up enough pressure to force the water through the discharge outlet.

The Foot Valve is a special type of check valve located at the bottom end of the suction side of a pump. This valve opens when the pump operates to allow water to enter the suction pipe, but closes when the pump shuts off to prevent water from flowing out of the suction pipe.

A pump engineer will design a system that uses multiple pumps for a parallel operation in the case of the following: To provide for a fluctuating demand, To provide an increased discharge head, To reduce the friction coefficient on a larger pump for greater efficiency.

The intent of a designer when multiple water pumps are installed for paralleled operation is to provide for a fluctuating demand/or for if one pump is out of service.

If the pump must operate under high suction head, the suction pressure itself will compress the packing rings regardless of the operator's care. Packing will then require frequent replacement. Most manufacturers recommend using Mechanical Seals for both high and low-suction head conditions as well.

The mechanical seal is designed so that it can be hydraulically balanced. The result is that the wearing force between the machined surfaces does not vary regardless of the suction head. Most seals have an operating life of 5,000 to 20,000 hours.

The axial-flow pump is often referred to as a Propeller Pump.

On most kilowatt meters, the current kilowatt load is indicated by disk revolutions.

If a single-phase motor is receiving adequate power and the run windings are operable, but the motor will not start, there is problem with the start winding. A single-phase motor will have a capacitor start motor which has a high starting torque and a high starting current.

As the wear ring inside a centrifugal pump loses tolerance between it and the impeller, the efficiency of the pump will decrease.

Multistage centrifugal pumps can discharge high-pressure water. The pressure increases with the number of stages, but what happens to the capacity/ flow of the pump? The flow will remain the same through each stage.

With remote manual control, the operator is also required to turn a switch or push a button to operate equipment. Control devices which actuate equipment by inducing a magnetic field in the device are commonly known as solenoids.

Mechanical seals consist of two machined and polished surfaces which must contact each other. This contact is maintained by spring pressure.

The speed at which the magnetic field rotates is called the motor's synchronous speed. It is expressed in revolutions per minute. For a motor that operates on an electric power system having a frequency of 60Hz, the maximum synchronous speed is 3,600 rpm, or 60 revolutions per second. In other words, because the electric current changes its flow direction 60 times a second, the rotor can rotate 60 times per second. This speed is achieved by a two-pole motor. A wound-rotor induction motor would be expected to have the lowest demand for starting current.

The purpose of a sump on a vertical turbine pump is used to maintain adequate liquid above the suction level.

Friction Loss is the term used to describe head pressure or energy lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls, and restriction by fittings.

Continuous leakage from a mechanical seal indicates an abnormal condition.



Wearing Rings

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.)

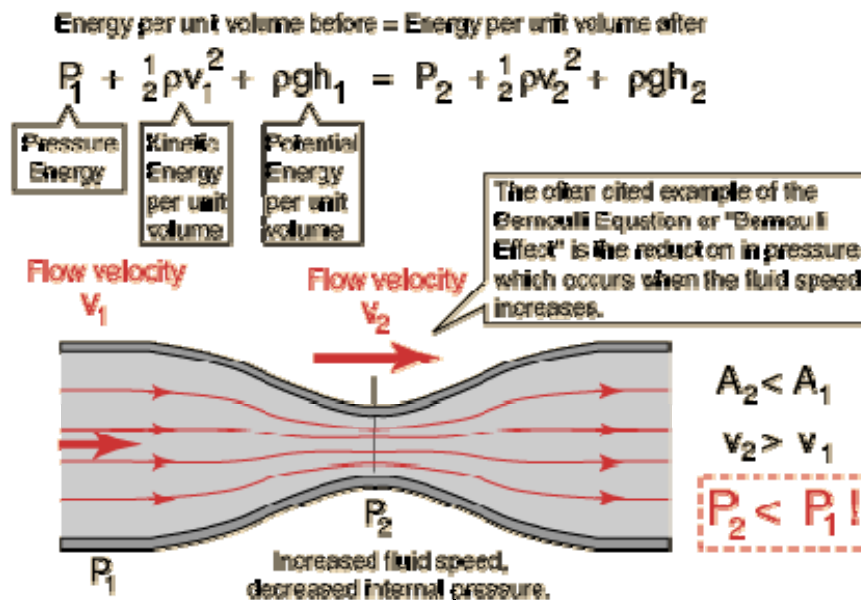
B

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

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

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

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

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

For steady state incompressible flow the Euler equation becomes (1). If we integrate (1) along the streamline it becomes (2). (2) can further be modified to (3) by dividing by gravity.

Head of Flow: Equation (3) is often referred to as the **head** because all elements have the unit of length.

Bernoulli's Equation Continued:

Dynamic Pressure

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

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

This phenomenon 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/in^2 (psi)

- $1 \text{ lb}_f/\text{in}^2 (\text{psi}) = 6.894 \times 10^3 \text{ N/m}^2 (\text{Pa})$

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) $\times 10^5$ | SI Units (Pa, N/m^2) $\times 10^9$ |
|----------------------|---|---|
| Carbon Tetrachloride | 1.91 | 1.31 |
| Ethyl Alcohol | 1.54 | 1.06 |
| Gasoline | 1.9 | 1.3 |
| Glycerin | 6.56 | 4.52 |
| Mercury | 4.14 | 2.85 |
| SAE 30 Oil | 2.2 | 1.5 |
| Seawater | 3.39 | 2.35 |
| Water | 3.12 | 2.15 |

C

Capillarity: (or capillary action) The ability of a narrow tube to draw a liquid upwards against the force of gravity.

The height of liquid in a tube due to capillarity can be expressed as

$$h = 2 \sigma \cos\theta / (\rho g r) \quad (1)$$

where

h = height of liquid (ft, m)

σ = surface tension (lb/ft , N/m)

θ = contact angle

ρ = density of liquid (lb/ft^3 , kg/m^3)

g = acceleration due to gravity (32.174 ft/s^2 , 9.81 m/s^2)

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/m^3)

v = flow velocity (m/s)

E = bulk modulus elasticity (N/m^2)

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

The Cauchy Number is the square root of the Mach Number

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

where

C = Mach Number

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

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

Avoiding Cavitation

Cavitation can in general be avoided by:

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

This can be done by:

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

Reengineering of Components Initiating High Speed Velocity and Low Static Pressure

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

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

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

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

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

Cavitation Continued: Reducing the Temperature of the Fluid

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

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

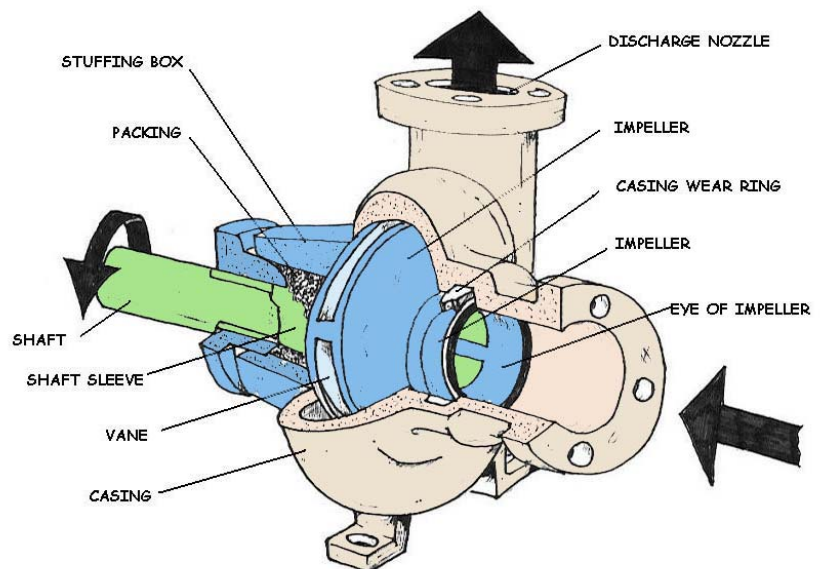
(Pa)

p_v = vapor pressure of the fluid (Pa)

ρ = density of the fluid (kg/m³)

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.

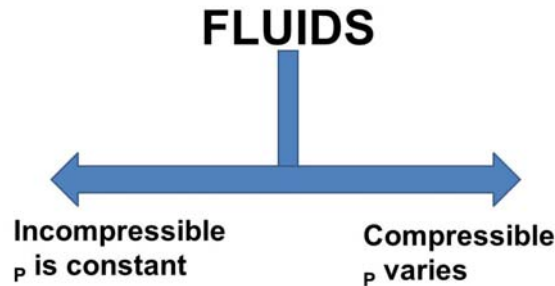
Compression and Expansion of Gases: If the compression or expansion takes place under constant temperature conditions - the process is called **isothermal**. The isothermal process can on the basis of the Ideal Gas Law be expressed as:

$$p / \rho = \text{constant (1)}$$

where

p = absolute pressure

ρ = density



Confined Space Entry: Entry into a confined space requires that all entrants wear a harness and safety line. If an operator is working inside a storage tank and suddenly faints or has a serious problem, there should be two people outside standing by to remove the injured operator.

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 or destroyed.

Contaminant: Any natural or man-made physical, chemical, biological, or radiological substance or matter in water, which is at a level that may have an adverse effect on public health, and which is known or anticipated to occur in public water systems.

Contamination: To make something bad; to pollute or infect something. To reduce the quality of the potable (drinking) water and create an actual hazard to the water supply by poisoning or through spread of diseases.

Corrosion: The removal of metal from copper, other metal surfaces and concrete surfaces in a destructive manner. Corrosion is caused by improperly balanced water or excessive water velocity through piping or heat exchangers.

Cross-Contamination: The mixing of two unlike qualities of water. For example, the mixing of good water with a polluting substance like a chemical.

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)

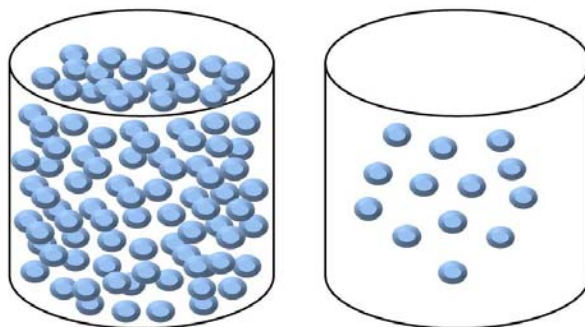
d_h = hydraulic diameter (m, ft)

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:

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

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:

$$F_d = c_d \frac{1}{2} \rho v^2 A \quad (1)$$

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

$$p_d = \frac{1}{2} \rho v^2 \quad (1)$$

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

- CentiPoises (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 is usually 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

$$ds = c_p \ln(T_2 / T_1) - R \ln(\rho_2 / \rho_1) \quad (2)$$

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:

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

where

m = mass flow rate (kg/s)

ρ = density (kg/m³)

v = speed (m/s)

A = area (m²)

With uniform density equation (1) can be modified to

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

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

$$\text{energy per unit mass (ft}^2/\text{s}^2 = \text{ft lb/slug or m}^2/\text{s}^2 = \text{N m/kg)}$$

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

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

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

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

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

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

The dimensions of equation (6) are

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

Head is the energy per unit weight.

h_{shaft} can also be expressed as:

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

where

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

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

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

Example - Pumping Water

Water is pumped from an open tank at level zero to an open tank at level 10 ft. The pump adds four horsepowers to the water when pumping 2 ft³/s.

Since $v_{in} = v_{out} = 0$, $p_{in} = p_{out} = 0$ and $h_{in} = 0$ - equation (6) can be modified to:

$$\begin{aligned}h_{shaft} &= h_{out} + h_{loss} \\ \text{or} \\ h_{loss} &= h_{shaft} - h_{out} \quad (8)\end{aligned}$$

Equation (7) gives:

- $h_{shaft} = W_{shaft} / \gamma Q = (4 \text{ hp})(550 \text{ ft.lb/s/hp}) / (62.4 \text{ lb/ft}^3)(2 \text{ ft}^3/\text{s}) = 17.6 \text{ ft}$
- specific weight of water 62.4 lb/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 m³/h = 0.0631 dm³(liter)/s = $2.228 \times 10^{-3} \text{ ft}^3/\text{s}$
= 0.1337 ft³/min = 0.8327 Imperial gal (UK)/min

Note! The Hazen-Williams formula gives accurate head loss due to friction for fluids with kinematic viscosity of approximately 1.1 cSt. More about fluids and kinematic viscosity.

The results for the formula are acceptable for cold water at 60° F (15.6° C) with kinematic viscosity 1.13 cSt. For hot water with a lower kinematic viscosity (0.55 cSt at 130° F (54.4° C)) the error will be significant. Since the Hazen Williams method is only valid for water flowing at ordinary temperatures between 40 to 75° F, the Darcy Weisbach method should be used for other liquids or gases.

Head: The height of a column or body of fluid above a given point expressed in linear units. Head is often used to indicate gauge pressure. Pressure is equal to the height times the density of the liquid. The measure of the pressure of water expressed in feet of height of water. 1 psi = 2.31 feet of water. There are various types of heads of water depending upon what is being measured. Static (water at rest) and Residual (water at flow conditions).

Hydraulics: Hydraulics is a branch of science and engineering concerned with the use of liquids to perform mechanical tasks.

Hydrodynamics: Hydrodynamics is the fluid dynamics applied to liquids, such as water, alcohol, and oil.

I

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

Isentropic Compression/Expansion Process: If the compression or expansion takes place under constant volume conditions - the process is called **isentropic**. The isentropic process on the basis of the Ideal Gas Law can be expressed as:

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

where

$k = c_p / c_v$ - the ratio of specific heats - the ratio of specific heat at constant pressure - c_p
- to the specific heat at constant volume - c_v

Irrigation: Water that is especially furnished to help provide and sustain the life of growing plants. It comes from ditches. It is sometimes treated with herbicides and pesticides to prevent the growth of weeds and the development of bugs in a lawn and a garden.

K

Kinematic Viscosity: The ratio of absolute or dynamic viscosity to density - a quantity in which no force is involved. Kinematic viscosity can be obtained by dividing the absolute viscosity of a fluid with its mass density as

$$\nu = \mu / \rho \quad (2)$$

where

ν = 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 impractical large unit, it is usual divided by 100 to give the unit called **Centistokes (cSt)** where

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

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

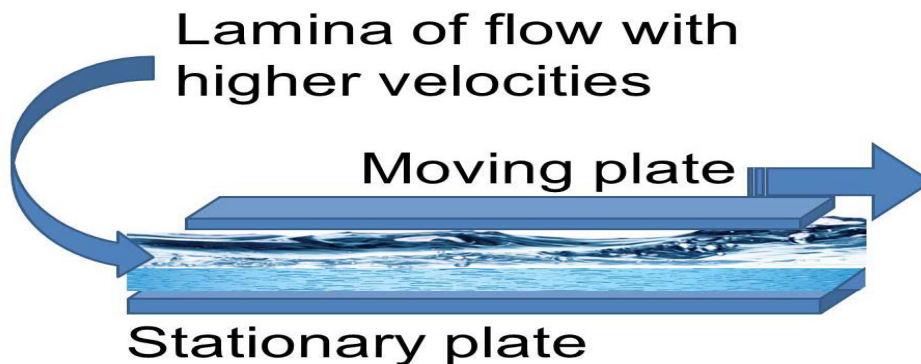
Since the specific gravity of water at 68.4°F (20.2°C) is almost one - 1, the kinematic viscosity of water at 68.4°F is for all practical purposes 1.0 cSt.

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 breaks 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

$$\nabla^2 \psi = 0, \quad (1)$$

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

$$\nabla^2 \psi + k^2 \psi = 0 \quad (2)$$

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

$$\nabla^2 \psi = -4 \pi \rho \quad (3)$$

with $\rho = 0$.

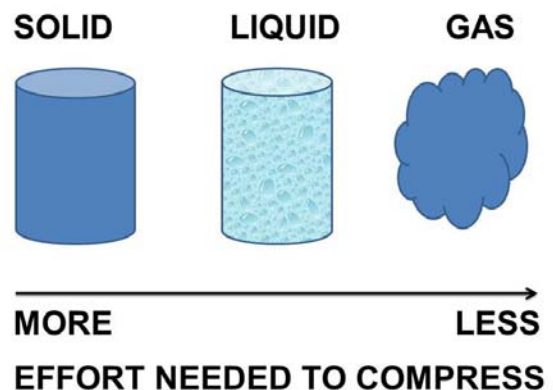
The vector Laplace's equation is given by

$$\nabla^2 \mathbf{F} = 0. \quad (4)$$

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), CentiPoises (cP), Saybolt Universal Seconds (SSU) and degree Engler.

Newton's Third Law: Newton's third law describes the forces acting on objects interacting with each other. Newton's third law can be expressed as

- *"If one object exerts a force F on another object, then the second object exerts an equal but opposite force F on the first object"*

Force is a convenient abstraction to represent mentally the pushing and pulling interaction between objects.

It is common to express forces as vectors with magnitude, direction and point of application. The net effect of two or more forces acting on the same point is the vector sum of the forces.

Non-Newtonian Fluid: Non-Newtonian fluid viscosity changes with the applied shear force.

O

Oxidizing: The process of breaking down organic wastes into simpler elemental forms or by products. Also used to separate combined chlorine and convert it into free chlorine.

P

Pascal's Law: A pressure applied to a confined fluid at rest is transmitted with equal intensity throughout the fluid.

Pathogens: Disease-causing pathogens; waterborne pathogens. A pathogen is a bacterium, virus or parasite that causes or is capable of causing disease. Pathogens may contaminate water and cause waterborne disease.

pCi/L- picocuries per liter: A curie is the amount of radiation released by a set amount of a certain compound. A picocurie is one quadrillionth of a curie.

pH: A measure of the acidity of water. The pH scale runs from 0 to 14 with 7 being the mid-point or neutral. A pH of less than 7 is on the acid side of the scale with 0 as the point of greatest acid activity. A pH of more than 7 is on the basic (alkaline) side of the scale with 14 as the point of greatest basic activity. pH (Power of Hydroxyl Ion Activity).

Pipeline Appurtenances: Pressure reducers, bends, valves, regulators (which are a type of valve), etc.

Peak Demand: The maximum momentary load placed on a water treatment plant, pumping station or distribution system is the Peak Demand.

Pipe Velocities: For calculating fluid pipe velocity.

Imperial units

A fluids flow velocity in pipes can be calculated with Imperial or American units as

$$v = 0.4085 q / d^2 \quad (1)$$

where

v = velocity (ft/s)

q = volume flow (US gal. /min)

d = pipe inside diameter (inches)

SI units

A fluids flow velocity in pipes can be calculated with SI units as

$$v = 1.274 q / d^2 \quad (2)$$

where

v = velocity (m/s)

q = volume flow (m^3/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.

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

Pressure Head: The height to which liquid can be raised by a given pressure.

Pressure Regulation Valves: Control water pressure and operate by restricting flows. They are used to deliver water from a high pressure to a low-pressure system. The pressure downstream from the valve regulates the amount of flow. Usually, these valves are of the globe design and have a spring-loaded diaphragm that sets the size of the opening.

Pressure Units: Since 1 Pa is a small pressure unit, the unit hectopascal (hPa) is widely used, especially in meteorology. The unit kilopascal (kPa) is commonly used designing technical applications like HVAC systems, piping systems and similar.

- $1 \text{ hectopascal} = 100 \text{ pascal} = 1 \text{ millibar}$
- $1 \text{ kilopascal} = 1000 \text{ pascal}$

Some Pressure Levels

- 10 Pa - The pressure at a depth of 1 mm of water
- 1 kPa - Approximately the pressure exerted by a 10 g mass on a 1 cm^2 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 bar - 100,000 Pa
- 1 millibar - 100 Pa
- 1 atmosphere - 101,325 Pa
- 1 mm Hg - 133 Pa
- 1 inch Hg - 3,386 Pa

A **torr** (torr) is named after Torricelli and is the pressure produced by a column of mercury 1 mm high equals to 1/760th of an atmosphere. 1 atm = 760 torr = 14.696 psi

Pounds per square inch (psi) was common in U.K. but has now been replaced in almost every country except in the U.S. by the SI units. The Normal atmospheric pressure is 14.696 psi, meaning that a column of air on one square inch in area rising from the Earth's atmosphere to space weighs 14.696 pounds.

The **bar** (bar) is common in the industry. One bar is 100,000 Pa, and for most practical purposes can be approximated to one atmosphere even if

$$1 \text{ Bar} = 0.9869 \text{ atm}$$

There are 1,000 **millibar** (mbar) in one bar, a unit common in meteorology.

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

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/m³)

ρ_{H_2O} = density of water (kg/m³)

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/m³, 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:

$$\begin{aligned} SG &= 7850 \text{ kg/m}^3 / 1000 \text{ kg/m}^3 \\ &= \underline{7.85} \\ &\text{(the density of water is } 1000 \text{ kg/m}^3\text{)} \end{aligned}$$

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

$$\gamma = \rho g \text{ (2)}$$

where

γ = specific weight (kN/m³)

g = acceleration of gravity (m/s²)

The SI-units of specific weight are kN/m³. The imperial units are lb/ft³. The local acceleration g is under normal conditions 9.807 m/s² in SI-units and 32.174 ft/s² 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

$$dp = - \gamma dz \text{ (1)}$$

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:

$$\gamma = \rho g \text{ (2)}$$

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:

$$p_2 - p_1 = - \gamma (z_2 - z_1) \text{ (3)}$$

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:

$$p_1 - p_2 = \gamma (z_2 - z_1) \text{ (4)}$$

or

$$p_1 - p_2 = \gamma h \text{ (5)}$$

where

$h = z_2 - z_1$ difference in elevation - the depth down from location z_2 .

or

$$p_1 = \gamma h + p_2 \text{ (6)}$$

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 expresses **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

$$5 \text{ (lbf/in}^2\text{)} \times 12 \text{ (in/ft)} \times 12 \text{ (in/ft)} / 62.4 \text{ (lb/ft}^3\text{)} = \underline{11.6 \text{ ft of water}}$$

$$5 \text{ (lbf/in}^2\text{)} \times 12 \text{ (in/ft)} \times 12 \text{ (in/ft)} / 847 \text{ (lb/ft}^3\text{)} = \underline{0.85 \text{ ft of mercury}}$$

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 submersed. 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

Telemetering Systems: The following are common pressure sensing devices: Helical Sensor, Bourdon Tube, and Bellows Sensor. The most frequent problem that affects a liquid pressure-sensing device is air accumulation at the sensor. A diaphragm element being used as a level sensor would be used in conjunction with a pressure sensor. Devices must often transmit more than one signal. You can use several types of systems including: Polling, Scanning and Multiplexing. Transmitting equipment requires installation where temperature will not exceed 130 degrees F.

Thixotropic Fluids: Shear Thinning Fluids or Thixotropic Fluids reduce their viscosity as agitation or pressure is increased at a constant temperature. Ketchup and mayonnaise are examples of thixotropic materials. They appear thick or viscous but are possible to pump quite easily.

Transonic: Flow with speed at velocities just below and above the speed of sound is said to be transonic.

Turbidity: A measure of the cloudiness of water caused by suspended particles.

U

U-Tube Manometer: Pressure measuring devices using liquid columns in vertical or inclined tubes are called manometers. One of the most common is the water filled u-tube manometer used to measure pressure difference in pitot or orifices located in the airflow in air handling or ventilation systems.

V

Valve: A device that opens and closes to regulate the flow of liquids. Faucets, hose bibs, and Ball are examples of valves.

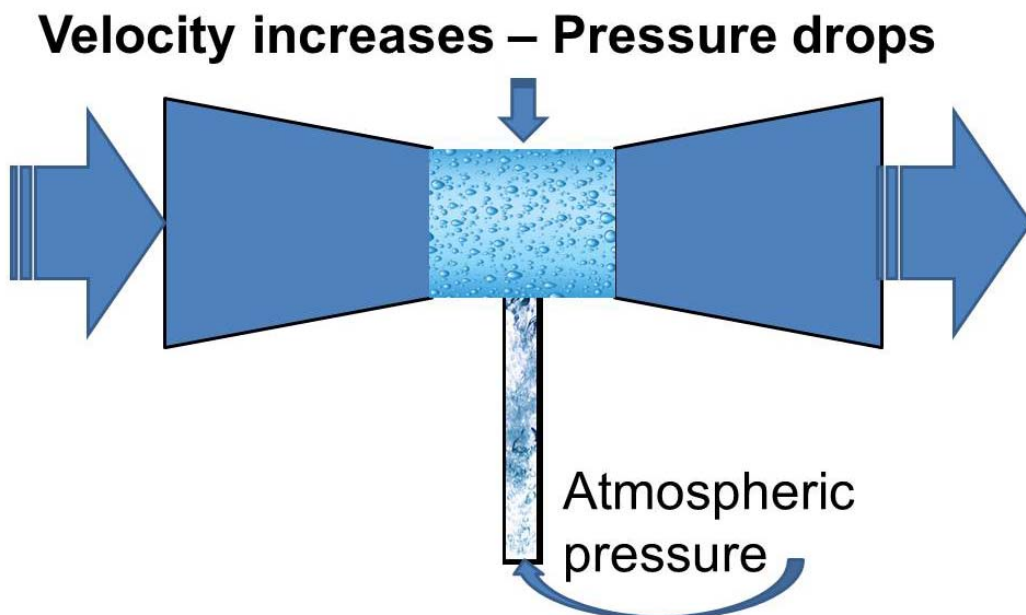
Vane: That portion of an impeller which throws the water toward the volute.

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

Velocity Head: The vertical distance a liquid must fall to acquire the velocity with which it flows through the piping system. For a given quantity of flow, the velocity head will vary indirectly as the pipe diameter varies.

Venturi: A system for speeding the flow of the fluid, by constricting it in a cone-shaped tube. Venturi are used to measure the speed of a fluid, by measuring the pressure changes from one point to another along the venture. A venturi can also be used to inject a liquid or a gas into another liquid. A pump forces the liquid flow through a tube connected to:

- A venturi to increase the speed of the fluid (restriction of the pipe diameter)
- A short piece of tube connected to the gas source
- A second venturi that decrease the speed of the fluid (the pipe diameter increase again)
- After the first venturi the pressure in the pipe is lower, so the gas is sucked in the pipe. Then the mixture enters the second venturi and slow down. At the end of the system a mixture of gas and liquid appears and the pressure rise again to its normal level in the pipe.
- This technique is used for ozone injection in water.



The newest injector design causes complete mixing of injected materials (air, ozone or chemicals), eliminating the need for other in-line mixers. Venturi injectors have no moving parts and are maintenance free. They operate effectively over a wide range of pressures (from 1 to 250 psi) and require only a minimum pressure difference to initiate the vacuum at the suction part. Venturis are often built in thermoplastics (PVC, PE, PVDF), stainless steel or other metals.

The cavitation effect at the injection chamber provides an instantaneous mixing, creating thousands of very tiny bubbles of gas in the liquid. The small bubbles provide and 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 [m^2/s], which has no special name. This unit is so large that it is rarely used. A more common unit of kinematic viscosity is the square centimeter per second [cm^2/s], which is given the name stoke [St] after the English scientist George Stoke. This unit is also a bit too large and so the most common unit is probably the square millimeter per second [mm^2/s] or centistoke [cSt].

Viscosity and Reference Temperatures: The viscosity of a fluid is highly temperature dependent and for either dynamic or kinematic viscosity to be meaningful, the **reference temperature** must be quoted. In ISO 8217 the reference temperature for a residual fluid is 100°C. For a distillate fluid the reference temperature is 40°C.

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

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

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

Vortex: A vortex is a whirlpool in the water.

W

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

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

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

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

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

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

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

Appendixes and Charts

Density of Common Liquids

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

| Liquid | Temperature - t - (°C) | Density - ρ - (kg/m ³) |
|----------------------|--------------------------------|---|
| Acetic Acid | 25 | 1049 |
| Acetone | 25 | 785 |
| Acetonitrile | 20 | 782 |
| Alcohol, ethyl | 25 | 785 |
| Alcohol, methyl | 25 | 787 |
| Alcohol, propyl | 25 | 780 |
| Ammonia (aqua) | 25 | 823 |
| Aniline | 25 | 1019 |
| Automobile oils | 15 | 880 - 940 |
| Beer (varies) | 10 | 1010 |
| Benzene | 25 | 874 |
| Benzyl | 15 | 1230 |
| Brine | 15 | 1230 |
| Bromine | 25 | 3120 |
| Butyric Acid | 20 | 959 |
| Butane | 25 | 599 |
| n-Butyl Acetate | 20 | 880 |
| n-Butyl Alcohol | 20 | 810 |
| n-Butylchloride | 20 | 886 |
| Caproic acid | 25 | 921 |
| Carbolic acid | 15 | 956 |
| Carbon disulfide | 25 | 1261 |
| Carbon tetrachloride | 25 | 1584 |
| Carene | 25 | 857 |
| Castor oil | 25 | 956 |
| Chloride | 25 | 1560 |
| Chlorobenzene | 20 | 1106 |
| Chloroform | 20 | 1489 |
| Chloroform | 25 | 1465 |
| Citric acid | 25 | 1660 |
| Coconut oil | 15 | 924 |
| Cotton seed oil | 15 | 926 |
| Cresol | 25 | 1024 |
| Creosote | 15 | 1067 |
| Crude oil, 48° API | 60°F | 790 |

| | | |
|-----------------------------|------|-------------|
| Crude oil, 40° API | 60°F | 825 |
| Crude oil, 35.6° API | 60°F | 847 |
| Crude oil, 32.6° API | 60°F | 862 |
| Crude oil, California | 60°F | 915 |
| Crude oil, Mexican | 60°F | 973 |
| Crude oil, Texas | 60°F | 873 |
| Cumene | 25 | 860 |
| Cyclohexane | 20 | 779 |
| Cyclopentane | 20 | 745 |
| Decane | 25 | 726 |
| Diesel fuel oil 20 to 60 | 15 | 820 - 950 |
| Diethyl ether | 20 | 714 |
| o-Dichlorobenzene | 20 | 1306 |
| Dichloromethane | 20 | 1326 |
| Diethylene glycol | 15 | 1120 |
| Dichloromethane | 20 | 1326 |
| Dimethyl Acetamide | 20 | 942 |
| N,N-Dimethylformamide | 20 | 949 |
| Dimethyl Sulfoxide | 20 | 1100 |
| Dodecane | 25 | 755 |
| Ethane | -89 | 570 |
| Ether | 25 | 73 |
| Ethylamine | 16 | 681 |
| Ethyl Acetate | 20 | 901 |
| Ethyl Alcohol | 20 | 789 |
| Ethyl Ether | 20 | 713 |
| Ethylene Dichloride | 20 | 1253 |
| Ethylene glycol | 25 | 1097 |
| Fluorine refrigerant R-12 | 25 | 1311 |
| Formaldehyde | 45 | 812 |
| Formic acid 10%oncentration | 20 | 1025 |
| Formic acid 80%oncentration | 20 | 1221 |
| Freon - 11 | 21 | 1490 |
| Freon - 21 | 21 | 1370 |
| Fuel oil | 60°F | 890 |
| Furan | 25 | 1416 |
| Furforol | 25 | 1155 |
| Gasoline, natural | 60°F | 711 |
| Gasoline, Vehicle | 60°F | 737 |
| Gas oils | 60°F | 890 |
| Glucose | 60°F | 1350 - 1440 |
| Glycerin | 25 | 1259 |

| | | |
|------------------------|------|-------------|
| Glycerol | 25 | 1126 |
| Heptane | 25 | 676 |
| Hexane | 25 | 655 |
| Hexanol | 25 | 811 |
| Hexene | 25 | 671 |
| Hydrazine | 25 | 795 |
| Iodine | 25 | 4927 |
| Ionene | 25 | 932 |
| Isobutyl Alcohol | 20 | 802 |
| Iso-Octane | 20 | 692 |
| Isopropyl Alcohol | 20 | 785 |
| Isopropyl Myristate | 20 | 853 |
| Kerosene | 60°F | 817 |
| Linolenic Acid | 25 | 897 |
| Linseed oil | 25 | 929 |
| Methane | -164 | 465 |
| Methanol | 20 | 791 |
| Methyl Isoamyl Ketone | 20 | 888 |
| Methyl Isobutyl Ketone | 20 | 801 |
| Methyl n-Propyl Ketone | 20 | 808 |
| Methyl t-Butyl Ether | 20 | 741 |
| N-Methylpyrrolidone | 20 | 1030 |
| Methyl Ethyl Ketone | 20 | 805 |
| Milk | 15 | 1020 - 1050 |
| Naphtha | 15 | 665 |
| Naphtha, wood | 25 | 960 |
| Napthalene | 25 | 820 |
| Ocimene | 25 | 798 |
| Octane | 15 | 918 |
| Olive oil | 20 | 800 - 920 |
| Oxygen (liquid) | -183 | 1140 |
| Palmitic Acid | 25 | 851 |
| Pentane | 20 | 626 |
| Pentane | 25 | 625 |
| Petroleum Ether | 20 | 640 |
| Petrol, natural | 60°F | 711 |
| Petrol, Vehicle | 60°F | 737 |
| Phenol | 25 | 1072 |
| Phosgene | 0 | 1378 |
| Phytadiene | 25 | 823 |
| Pinene | 25 | 857 |
| Propane | -40 | 583 |

| | | |
|---------------------------------|------|-----------|
| Propane, R-290 | 25 | 494 |
| Propanol | 25 | 804 |
| Propylenearbonate | 20 | 1201 |
| Propylene | 25 | 514 |
| Propylene glycol | 25 | 965 |
| Pyridine | 25 | 979 |
| Pyrrole | 25 | 966 |
| Rape seed oil | 20 | 920 |
| Resorcinol | 25 | 1269 |
| Rosin oil | 15 | 980 |
| Sea water | 25 | 1025 |
| Silane | 25 | 718 |
| Silicone oil | | 760 |
| Sodium Hydroxide (caustic soda) | 15 | 1250 |
| Sorbaldehyde | 25 | 895 |
| Soya bean oil | 15 | 924 - 928 |
| Stearic Acid | 25 | 891 |
| Sulphuric Acid 95%onc. | 20 | 1839 |
| Sugar solution 68 brix | 15 | 1338 |
| Sunflower oil | 20 | 920 |
| Styrene | 25 | 903 |
| Terpinene | 25 | 847 |
| Tetrahydrofuran | 20 | 888 |
| Toluene | 20 | 867 |
| Toluene | 25 | 862 |
| Triethylamine | 20 | 728 |
| Trifluoroacetic Acid | 20 | 1489 |
| Turpentine | 25 | 868 |
| Water - pure | 4 | 1000 |
| Water - sea | 77°F | 1022 |
| Whale oil | 15 | 925 |
| o-Xylene | 20 | 880 |

$1 \text{ kg/m}^3 = 0.001 \text{ g/cm}^3 = 0.0005780 \text{ oz/in}^3 = 0.16036 \text{ oz/gal (Imperial)} = 0.1335 \text{ oz/gal (U.S.)} = 0.0624 \text{ lb/ft}^3 = 0.000036127 \text{ lb/in}^3 = 1.6856 \text{ lb/yd}^3 = 0.010022 \text{ lb/gal (Imperial)} = 0.008345 \text{ lb/gal (U.S.)} = 0.0007525 \text{ ton/yd}^3$

Dynamic or Absolute Viscosity Units Converting Table

The table below can be used to convert between common dynamic or absolute viscosity units.

| Multiply by | Convert to | | | | |
|---|---------------------------------------|---|-------------------------------------|----------------------|------------------------------------|
| Convert from | Poiseuille (Pa s) | Poise (dyne s / cm ² = g / cm s) | centiPoise | kg / m h | kg _f s / m ² |
| Poiseuille (Pa s) | 1 | 10 | 10 ³ | 3.63 10 ³ | 0.102 |
| Poise (dyne s / cm ² = g / cm s) | 0.1 | 1 | 100 | 360 | 0.0102 |
| centiPoise | 0.001 | 0.01 | 1 | 3.6 | 0.00012 |
| kg / m h | 2.78 10 ⁻⁴ | 0.00278 | 0.0278 | 1 | 2.83 10 ⁻⁵ |
| kg _f s / m ² | 9.81 | 98.1 | 9.81 10 ³ | 3.53 10 ⁴ | 1 |
| lb _f s / inch ² | 6.89 10 ³ | 6.89 10 ⁴ | 6.89 10 ⁶ | 2.48 10 ⁷ | 703 |
| lb _f s / ft ² | 47.9 | 479 | 4.79 10 ⁴ | 1.72 10 ⁵ | 0.0488 |
| lb _f h / ft ² | 1.72 10 ⁵ | 1.72 10 ⁶ | 1.72 10 ⁸ | 6.21 10 ⁸ | 1.76 10 ⁴ |
| lb / ft s | 1.49 | 14.9 | 1.49 10 ³ | 5.36 10 ³ | 0.152 |
| lb / ft h | 4.13 10 ⁻⁴ | 0.00413 | 0.413 | 1.49 | 4.22 10 ⁻⁵ |
| Multiply by | Convert to | | | | |
| Convert from | lb _f s / inch ² | lb _f s / ft ² | lb _f h / ft ² | lb / ft s | lb / ft h |
| Poiseuille (Pa s) | 1.45 10 ⁻⁴ | 0.0209 | 5.8 10 ⁻⁶ | 0.672 | 2.42 10 ³ |
| Poise (dyne s / cm ² = g / cm s) | 1.45 10 ⁻⁵ | 0.00209 | 5.8 10 ⁻⁷ | 0.0672 | 242 |
| centiPoise | 1.45 10 ⁻⁷ | 2.9 10 ⁻⁵ | 5.8 10 ⁻⁹ | 0.000672 | 2.42 |
| kg / m h | 4.03 10 ⁻⁸ | 5.8 10 ⁻⁶ | 1.61 10 ⁻⁹ | 0.000187 | 0.672 |
| kg _f s / m ² | 0.00142 | 20.5 | 5.69 10 ⁻⁵ | 6.59 | 2.37 10 ⁴ |
| lb _f s / inch ² | 1 | 144 | 0.04 | 4.63 10 ³ | 1.67 10 ⁷ |
| lb _f s / ft ² | 0.00694 | 1 | 0.000278 | 32.2 | 1.16 10 ⁵ |
| lb _f h / ft ² | 25 | 3.6 10 ³ | 1 | 1.16 10 ⁵ | 4.17 10 ⁸ |
| lb / ft s | 0.000216 | 0.0311 | 8.63 10 ⁻⁶ | 1 | 3.6 10 ³ |
| lb / ft h | 6 10 ⁻⁸ | 1.16 10 ⁵ | 2.4 10 ⁻⁹ | 0.000278 | 1 |

Friction Loss Chart

The table below can be used to indicate the friction loss - feet of liquid per 100 feet of pipe - in standard schedule 40 steel pipes.

| Pipe Size (inches) | Flow Rate | | Kinematic Viscosity - SSU | | | | | |
|--------------------|-----------|-------|---------------------------|--------------|----------------------|-------------------|---------------------|--------------------|
| | (gpm) | (l/s) | 31 (Water) | 100 (~Cream) | 200 (~Vegetable oil) | 400 (~SAE 10 oil) | 800 (~Tomato juice) | 1500 (~SAE 30 oil) |
| 1/2 | 3 | 0.19 | 10.0 | 25.7 | 54.4 | 108.0 | 218.0 | 411.0 |
| 3/4 | 3 | 0.19 | 2.5 | 8.5 | 17.5 | 35.5 | 71.0 | 131.0 |
| | 5 | 0.32 | 6.3 | 14.1 | 29.3 | 59.0 | 117.0 | 219.0 |
| 1 | 3 | 0.19 | 0.8 | 3.2 | 6.6 | 13.4 | 26.6 | 50.0 |
| | 5 | 0.32 | 1.9 | 5.3 | 11.0 | 22.4 | 44.0 | 83.0 |
| | 10 | 0.63 | 6.9 | 11.2 | 22.4 | 45.0 | 89.0 | 165.0 |
| | 15 | 0.95 | 14.6 | 26.0 | 34.0 | 67.0 | 137.0 | |
| | 20 | 1.26 | 25.1 | 46 | 46.0 | 90.0 | 180.0 | |
| 1 1/4 | 5 | 0.32 | 0.5 | 1.8 | 3.7 | 7.6 | 14.8 | 26.0 |
| | 10 | 0.63 | 1.8 | 3.6 | 7.5 | 14.9 | 30.0 | 55.0 |
| | 15 | 0.95 | 3.7 | 6.4 | 11.3 | 22.4 | 45.0 | 84.0 |
| 1 1/2 | 10 | 0.63 | 0.8 | 1.9 | 4.2 | 8.1 | 16.5 | 31.0 |
| | 15 | 0.95 | 1.7 | 2.8 | 6.2 | 12.4 | 25.0 | 46.0 |
| | 20 | 1.26 | 2.9 | 5.3 | 8.1 | 16.2 | 33.0 | 61.0 |
| | 30 | 1.9 | 6.3 | 11.6 | 12.2 | 24.3 | 50.0 | 91.0 |
| | 40 | 2.5 | 10.8 | 19.6 | 20.8 | 32.0 | 65.0 | 121.0 |
| 2 | 20 | 1.26 | 0.9 | 1.5 | 3.0 | 6.0 | 11.9 | 22.4 |
| | 30 | 1.9 | 1.8 | 3.2 | 4.4 | 9.0 | 17.8 | 33.0 |
| | 40 | 2.5 | 3.1 | 5.8 | 5.8 | 11.8 | 24.0 | 44.0 |
| | 60 | 3.8 | 6.6 | 11.6 | 13.4 | 17.8 | 36.0 | 67.0 |
| | 80 | 5.0 | 1.6 | 3.0 | 3.2 | 4.8 | 9.7 | 18.3 |
| 2 1/2 | 30 | 1.9 | 0.8 | 1.4 | 2.2 | 4.4 | 8.8 | 16.6 |
| | 40 | 2.5 | 1.3 | 2.5 | 3.0 | 5.8 | 11.8 | 22.2 |
| | 60 | 3.8 | 2.7 | 5.1 | 5.5 | 8.8 | 17.8 | 34.0 |
| | 80 | 5.0 | 4.7 | 8.3 | 9.7 | 11.8 | 24.0 | 44.0 |
| | 100 | 6.3 | 7.1 | 12.2 | 14.1 | 14.8 | 29.0 | 55.0 |
| 3 | 60 | 3.8 | 0.9 | 1.8 | 1.8 | 3.7 | 7.3 | 13.8 |
| | 100 | 6.3 | 2.4 | 4.4 | 5.1 | 6.2 | 12.1 | 23.0 |
| | 125 | 7.9 | 3.6 | 6.5 | 7.8 | 8.1 | 15.3 | 29.0 |
| | 150 | 9.5 | 5.1 | 9.2 | 10.4 | 11.5 | 18.4 | 35.0 |
| | 175 | 11.0 | 6.9 | 11.7 | 13.8 | 15.8 | 21.4 | 40.0 |
| | 200 | 12.6 | 8.9 | 15.0 | 17.8 | 20.3 | 25.0 | 46.0 |
| 4 | 80 | 5.0 | 0.4 | 0.8 | 0.8 | 1.7 | 3.3 | 6.2 |
| | 100 | 6.3 | 0.6 | 1.2 | 1.3 | 2.1 | 4.1 | 7.8 |

| | | | | | | | | |
|----|-----|------|-----|-----|------|------|------|------|
| | 125 | 7.9 | 0.9 | 1.8 | 2.1 | 2.6 | 5.2 | 9.8 |
| | 150 | 9.5 | 1.3 | 2.4 | 2.9 | 3.1 | 6.2 | 11.5 |
| | 175 | 11.0 | 1.8 | 3.2 | 4.0 | 4.0 | 7.4 | 13.7 |
| | 200 | 12.6 | 2.3 | 4.2 | 5.1 | 5.1 | 8.3 | 15.5 |
| | 250 | 15.8 | 3.5 | 6.0 | 7.4 | 8.0 | 10.2 | 19.4 |
| 6 | 125 | 7.9 | 0.1 | 0.3 | 0.3 | 0.52 | 1.0 | 1.9 |
| | 150 | 9.5 | 0.2 | 0.3 | 0.4 | 0.6 | 1.2 | 2.3 |
| | 175 | 11.0 | 0.2 | 0.4 | 0.5 | 0.7 | 1.4 | 2.6 |
| | 200 | 12.6 | 0.3 | 0.6 | 0.7 | 0.8 | 1.6 | 3.0 |
| | 250 | 15.8 | 0.5 | 0.8 | 1.0 | 1.0 | 2.1 | 3.7 |
| | 300 | 18.9 | 1.1 | 8.5 | 10.0 | 11.6 | 12.4 | 23.0 |
| | 400 | 25.2 | 1.1 | 1.9 | 2.3 | 2.8 | 3.2 | 6.0 |
| 8 | 250 | 15.8 | 0.1 | 0.2 | 0.3 | 0.4 | 0.7 | 1.2 |
| | 300 | 18.9 | 0.3 | 1.2 | 1.4 | 1.5 | 2.5 | 4.6 |
| | 400 | 25.2 | 0.3 | 0.5 | 0.6 | 0.7 | 1.1 | 2.0 |
| 10 | 300 | 18.9 | 0.1 | 0.3 | 0.4 | 0.4 | 0.8 | 1.5 |
| | 400 | 25.2 | 0.1 | 0.2 | 0.2 | 0.2 | 0.4 | 0.8 |

Hazen-Williams Coefficients

Hazen-Williams factor for some common piping materials. Hazen-Williams coefficients are used in the Hazen-Williams equation for friction loss calculation in ducts and pipes. Coefficients for some common materials used in ducts and pipes can be found in the table below:

| Material | Hazen-Williams Coefficient - C - |
|---|-------------------------------------|
| Asbestos Cement | 140 |
| Brass | 130 - 140 |
| Brick sewer | 100 |
| Cast-Iron - new unlined (CIP) | 130 |
| Cast-Iron 10 years old | 107 - 113 |
| Cast-Iron 20 years old | 89 - 100 |
| Cast-Iron 30 years old | 75 - 90 |
| Cast-Iron 40 years old | 64-83 |
| Cast-Iron, asphalt coated | 100 |
| Cast-Iron, cement lined | 140 |
| Cast-Iron, bituminous lined | 140 |
| Cast-Iron, wrought plain | 100 |
| Concrete | 100 - 140 |
| Copper or Brass | 130 - 140 |
| Ductile Iron Pipe (DIP) | 140 |
| Fiber | 140 |
| Galvanized iron | 120 |
| Glass | 130 |
| Lead | 130 - 140 |
| Plastic | 130 - 150 |
| Polyethylene, PE, PEH | 150 |
| PVC, CPVC | 150 |
| Smooth Pipes | 140 |
| Steel new unlined | 140 - 150 |
| Steel | |
| Steel, welded and seamless | 100 |
| Steel, interior riveted, no projecting rivets | 100 |
| Steel, projecting girth rivets | 100 |
| Steel, vitrified, spiral-riveted | 90 - 100 |
| Steel, corrugated | 60 |
| Tin | 130 |
| Vitrified Clays | 110 |
| Wood Stave | 110 - 120 |

Pressure Head

A pressure difference of 5 psi (lbf/in²) is equivalent to

$$5 \text{ (lbf/in}^2\text{)} \times 12 \text{ (in/ft)} \times 12 \text{ (in/ft)} / 62.4 \text{ (lb/ft}^3\text{)} = \underline{11.6 \text{ ft of water}}$$

$$5 \text{ (lbf/in}^2\text{)} \times 12 \text{ (in/ft)} \times 12 \text{ (in/ft)} / 847 \text{ (lb/ft}^3\text{)} = \underline{0.85 \text{ ft of mercury}}$$

When specific weight of water is 62.4 (lb/ft³) and specific weight of mercury is 847 (lb/ft³).

Heads at different velocities can be taken from the table below:

| Velocity (ft/sec) | Head Water (ft) |
|----------------------|--------------------|
| 0.5 | 0.004 |
| 1.0 | 0.016 |
| 1.5 | 0.035 |
| 2.0 | 0.062 |
| 2.5 | 0.097 |
| 3.0 | 0.140 |
| 3.5 | 0.190 |
| 4.0 | 0.248 |
| 4.5 | 0.314 |
| 5.0 | 0.389 |
| 5.5 | 0.470 |
| 6.0 | 0.560 |
| 6.5 | 0.657 |
| 7.0 | 0.762 |
| 7.5 | 0.875 |
| 8.0 | 0.995 |
| 8.5 | 1.123 |
| 9.0 | 1.259 |
| 9.5 | 1.403 |
| 10.0 | 1.555 |
| 11.0 | 1.881 |
| 12.0 | 2.239 |
| 13.0 | 2.627 |
| 14.0 | 3.047 |
| 15.0 | 3.498 |
| 16.0 | 3.980 |
| 17.0 | 4.493 |
| 18.0 | 5.037 |
| 19.0 | 5.613 |
| 20.0 | 6.219 |
| 21.0 | 6.856 |
| 22.0 | 7.525 |

1 ft (foot) = 0.3048 m = 12 in = 0.3333 yd

Thermal Properties of Water

| Temperature - t - (°C) | Absolute pressure - p - (kN/m ²) | Density - ρ - (kg/m ³) | Specific volume - v - (m ³ /kgx10 ⁻³) | Specific Heat - c_p - (kJ/kgK) | Specific entropy - e - (kJ/kgK) |
|--------------------------------|---|---|---|--|--|
| 0 | 0.6 | 1000 | 100 | 4.217 | 0 |
| 5 | 0.9 | 1000 | 100 | 4.204 | 0.075 |
| 10 | 1.2 | 1000 | 100 | 4.193 | 0.150 |
| 15 | 1.7 | 999 | 100 | 4.186 | 0.223 |
| 20 | 2.3 | 998 | 100 | 4.182 | 0.296 |
| 25 | 3.2 | 997 | 100 | 4.181 | 0.367 |
| 30 | 4.3 | 996 | 100 | 4.179 | 0.438 |
| 35 | 5.6 | 994 | 101 | 4.178 | 0.505 |
| 40 | 7.7 | 991 | 101 | 4.179 | 0.581 |
| 45 | 9.6 | 990 | 101 | 4.181 | 0.637 |
| 50 | 12.5 | 988 | 101 | 4.182 | 0.707 |
| 55 | 15.7 | 986 | 101 | 4.183 | 0.767 |
| 60 | 20.0 | 980 | 102 | 4.185 | 0.832 |
| 65 | 25.0 | 979 | 102 | 4.188 | 0.893 |
| 70 | 31.3 | 978 | 102 | 4.190 | 0.966 |
| 75 | 38.6 | 975 | 103 | 4.194 | 1.016 |
| 80 | 47.5 | 971 | 103 | 4.197 | 1.076 |
| 85 | 57.8 | 969 | 103 | 4.203 | 1.134 |
| 90 | 70.0 | 962 | 104 | 4.205 | 1.192 |
| 95 | 84.5 | 962 | 104 | 4.213 | 1.250 |
| 100 | 101.33 | 962 | 104 | 4.216 | 1.307 |
| 105 | 121 | 955 | 105 | 4.226 | 1.382 |
| 110 | 143 | 951 | 105 | 4.233 | 1.418 |
| 115 | 169 | 947 | 106 | 4.240 | 1.473 |
| 120 | 199 | 943 | 106 | 4.240 | 1.527 |
| 125 | 228 | 939 | 106 | 4.254 | 1.565 |
| 130 | 270 | 935 | 107 | 4.270 | 1.635 |
| 135 | 313 | 931 | 107 | 4.280 | 1.687 |
| 140 | 361 | 926 | 108 | 4.290 | 1.739 |
| 145 | 416 | 922 | 108 | 4.300 | 1.790 |
| 150 | 477 | 918 | 109 | 4.310 | 1.842 |
| 155 | 543 | 912 | 110 | 4.335 | 1.892 |
| 160 | 618 | 907 | 110 | 4.350 | 1.942 |
| 165 | 701 | 902 | 111 | 4.364 | 1.992 |
| 170 | 792 | 897 | 111 | 4.380 | 2.041 |
| 175 | 890 | 893 | 112 | 4.389 | 2.090 |

| | | | | | |
|-----|-------|-----|-----|-------|-------|
| 180 | 1000 | 887 | 113 | 4.420 | 2.138 |
| 185 | 1120 | 882 | 113 | 4.444 | 2.187 |
| 190 | 1260 | 876 | 114 | 4.460 | 2.236 |
| 195 | 1400 | 870 | 115 | 4.404 | 2.282 |
| 200 | 1550 | 863 | 116 | 4.497 | 2.329 |
| 220 | | | | | |
| 225 | 2550 | 834 | 120 | 4.648 | 2.569 |
| 240 | | | | | |
| 250 | 3990 | 800 | 125 | 4.867 | 2.797 |
| 260 | | | | | |
| 275 | 5950 | 756 | 132 | 5.202 | 3.022 |
| 300 | 8600 | 714 | 140 | 5.769 | 3.256 |
| 325 | 12130 | 654 | 153 | 6.861 | 3.501 |
| 350 | 16540 | 575 | 174 | 10.10 | 3.781 |
| 360 | 18680 | 526 | 190 | 14.60 | 3.921 |

Viscosity Converting Chart

The viscosity of a fluid is its resistance to shear or flow, and is a measure of the fluid's adhesive/cohesive or frictional properties. This arises because of the internal molecular friction within the fluid producing the frictional drag effect. There are two related measures of fluid viscosity which are known as **dynamic** and **kinematic** viscosity.

Dynamic viscosity is also termed "**absolute viscosity**" and is the tangential force per unit area required to move one horizontal plane with respect to the other at unit velocity when maintained a unit distance apart by the fluid.

| Centipoise (CPS) Millipascal (mPas) | Poise (P) | Centistokes (cSt) | Stokes (S) | Saybolt Seconds Universal (SSU) |
|--|--------------|----------------------|---------------|--|
| 1 | 0.01 | 1 | 0.01 | 31 |
| 2 | 0.02 | 2 | 0.02 | 34 |
| 4 | 0.04 | 4 | 0.04 | 38 |
| 7 | 0.07 | 7 | 0.07 | 47 |
| 10 | 0.1 | 10 | 0.1 | 60 |
| 15 | 0.15 | 15 | 0.15 | 80 |
| 20 | 0.2 | 20 | 0.2 | 100 |
| 25 | 0.24 | 25 | 0.24 | 130 |
| 30 | 0.3 | 30 | 0.3 | 160 |
| 40 | 0.4 | 40 | 0.4 | 210 |
| 50 | 0.5 | 50 | 0.5 | 260 |
| 60 | 0.6 | 60 | 0.6 | 320 |
| 70 | 0.7 | 70 | 0.7 | 370 |
| 80 | 0.8 | 80 | 0.8 | 430 |
| 90 | 0.9 | 90 | 0.9 | 480 |
| 100 | 1 | 100 | 1 | 530 |
| 120 | 1.2 | 120 | 1.2 | 580 |
| 140 | 1.4 | 140 | 1.4 | 690 |
| 160 | 1.6 | 160 | 1.6 | 790 |
| 180 | 1.8 | 180 | 1.8 | 900 |
| 200 | 2 | 200 | 2 | 1000 |
| 220 | 2.2 | 220 | 2.2 | 1100 |
| 240 | 2.4 | 240 | 2.4 | 1200 |
| 260 | 2.6 | 260 | 2.6 | 1280 |
| 280 | 2.8 | 280 | 2.8 | 1380 |
| 300 | 3 | 300 | 3 | 1475 |
| 320 | 3.2 | 320 | 3.2 | 1530 |

| | | | | |
|------|-----|------|-----|-------|
| 340 | 3.4 | 340 | 3.4 | 1630 |
| 360 | 3.6 | 360 | 3.6 | 1730 |
| 380 | 3.8 | 380 | 3.8 | 1850 |
| 400 | 4 | 400 | 4 | 1950 |
| 420 | 4.2 | 420 | 4.2 | 2050 |
| 440 | 4.4 | 440 | 4.4 | 2160 |
| 460 | 4.6 | 460 | 4.6 | 2270 |
| 480 | 4.8 | 480 | 4.8 | 2380 |
| 500 | 5 | 500 | 5 | 2480 |
| 550 | 5.5 | 550 | 5.5 | 2660 |
| 600 | 6 | 600 | 6 | 2900 |
| 700 | 7 | 700 | 7 | 3380 |
| 800 | 8 | 800 | 8 | 3880 |
| 900 | 9 | 900 | 9 | 4300 |
| 1000 | 10 | 1000 | 10 | 4600 |
| 1100 | 11 | 1100 | 11 | 5200 |
| 1200 | 12 | 1200 | 12 | 5620 |
| 1300 | 13 | 1300 | 13 | 6100 |
| 1400 | 14 | 1400 | 14 | 6480 |
| 1500 | 15 | 1500 | 15 | 7000 |
| 1600 | 16 | 1600 | 16 | 7500 |
| 1700 | 17 | 1700 | 17 | 8000 |
| 1800 | 18 | 1800 | 18 | 8500 |
| 1900 | 19 | 1900 | 19 | 9000 |
| 2000 | 20 | 2000 | 20 | 9400 |
| 2100 | 21 | 2100 | 21 | 9850 |
| 2200 | 22 | 2200 | 22 | 10300 |
| 2300 | 23 | 2300 | 23 | 10750 |
| 2400 | 24 | 2400 | 24 | 11200 |

Various Flow Section Channels and their Geometric Relationships:

Area, wetted perimeter and hydraulic diameter for some common geometric sections like

- rectangular channels
- trapezoidal channels
- triangular channels
- circular channels.

Rectangular Channel

Flow Area

Flow area of a rectangular channel can be expressed as

$$A = b h \text{ (1)}$$

where

A = flow area (m^2 , in^2)

b = width of channel (m , in)

h = height of flow (m , in)

Wetted Perimeter

Wetted perimeter of a rectangular channel can be expressed as

$$P = b + 2 h \text{ (1b)}$$

where

P = wetted perimeter (m , in)

Hydraulic Radius

Hydraulic radius of a rectangular channel can be expressed as

$$R_h = b h / (b + 2 h) \text{ (1c)}$$

where

R_h = hydraulic radius (m , in)

Trapezoidal Channel

Flow Area

Flow area of a trapezoidal channel can be expressed as

$$A = (a + z h) h \text{ (2)}$$

where

z = see figure above (m , in)

Wetted Perimeter

Wetted perimeter of a trapezoidal channel can be expressed as

$$P = a + 2 h (1 + z^2)^{1/2} \text{ (2b)}$$

Hydraulic Radius

Hydraulic radius of a trapezoidal channel can be expressed as

$$R_h = (a + z h) h / a + 2 h (1 + z^2)^{1/2} \text{ (2c)}$$

Triangular Channel

Flow Area

Flow area of a triangular channel can be expressed as

$$A = z h^2 \quad (3)$$

where

z = see figure above (m, in)

Wetted Perimeter

Wetted perimeter of a triangular channel can be expressed as

$$P = 2 h (1 + z^2)^{1/2} \quad (3b)$$

Hydraulic Radius

Hydraulic radius of a triangular channel can be expressed as

$$R_h = z h / 2 (1 + z^2)^{1/2} \quad (3c)$$

Circular Channel

Flow Area

Flow area of a circular channel can be expressed as

$$A = D^2/4 (\alpha - \sin(2 \alpha)/2) \quad (4)$$

where

D = diameter of channel

$$\alpha = \cos^{-1}(1 - h/r)$$

Wetted Perimeter

Wetted perimeter of a circular channel can be expressed as

$$P = \alpha D \quad (4b)$$

Hydraulic Radius

Hydraulic radius of a circular channel can be expressed as

$$R_h = D/8 [1 - \sin(2 \alpha) / (2 \alpha)] \quad (4c)$$

Velocity Head: Velocity head can be expressed as

$$h = v^2/2g \quad (1)$$

where

v = velocity (ft, m)

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

Heads at different velocities can be taken from the table below:

| Velocity - v - (ft/sec) | Velocity Head - $v^2/2g$ - (ft Water) |
|---------------------------------|---|
| 0.5 | 0.004 |
| 1.0 | 0.016 |
| 1.5 | 0.035 |
| 2.0 | 0.062 |
| 2.5 | 0.097 |
| 3.0 | 0.140 |
| 3.5 | 0.190 |
| 4.0 | 0.248 |
| 4.5 | 0.314 |
| 5.0 | 0.389 |
| 5.5 | 0.470 |
| 6.0 | 0.560 |
| 6.5 | 0.657 |
| 7.0 | 0.762 |
| 7.5 | 0.875 |
| 8.0 | 0.995 |
| 8.5 | 1.123 |
| 9.0 | 1.259 |
| 9.5 | 1.403 |
| 10.0 | 1.555 |
| 11.0 | 1.881 |
| 12.0 | 2.239 |
| 13.0 | 2.627 |
| 14.0 | 3.047 |
| 15.0 | 3.498 |
| 16.0 | 3.980 |
| 17.0 | 4.493 |
| 18.0 | 5.037 |
| 19.0 | 5.613 |
| 20.0 | 6.219 |
| 21.0 | 6.856 |
| 22.0 | 7.525 |

Some Commonly used Thermal Properties for Water

- Density at 4 °C - 1,000 kg/m³, 62.43 Lbs./Cu.Ft, 8.33 Lbs./Gal., 0.1337 Cu.Ft./Gal.
 - Freezing temperature - 0 °C
 - Boiling temperature - 100 °C
 - Latent heat of melting - 334 kJ/kg
 - Latent heat of evaporation - 2,270 kJ/kg
 - Critical temperature - 380 - 386 °C
 - Critical pressure - 23.520 kN/m²
 - Specific heat capacity water - 4.187 kJ/kgK
 - Specific heat capacity ice - 2.108 kJ/kgK
 - Specific heat capacity water vapor - 1.996 kJ/kgK
 - Thermal expansion from 4 °C to 100 °C - 4.2×10^{-2}
- Bulk modulus elasticity - 2,068,500 kN/m²

Reynolds Number

Turbulent or laminar flow is determined by the dimensionless **Reynolds Number**.

The Reynolds number is important in analyzing any type of flow when there is substantial velocity gradient (i.e., shear.) It indicates the relative significance of the viscous effect compared to the inertia effect. The Reynolds number is proportional to inertial force divided by viscous force.

A definition of the Reynolds' Number:

The flow is

- **laminar** if $Re < 2300$
- **transient** if $2300 < Re < 4000$
- **turbulent** if $4000 < Re$

The table below shows Reynolds Number for one liter of water flowing through pipes of different dimensions:

| Pipe Size | | | | | | | | | | |
|---|------|-------|------|------|-----|-----|-----|-----|-----|-----|
| (inches) | 1 | 1 1/2 | 2 | 3 | 4 | 6 | 8 | 10 | 12 | 18 |
| (mm) | 25 | 40 | 50 | 75 | 100 | 150 | 200 | 250 | 300 | 450 |
| Reynolds number with one (1) liter/min | 835 | 550 | 420 | 280 | 210 | 140 | 105 | 85 | 70 | 46 |
| Reynolds number with one (1) gal/min | 3800 | 2500 | 1900 | 1270 | 950 | 630 | 475 | 380 | 320 | 210 |

Linear Motion Formulas

Velocity can be expressed as (velocity = constant):

$$v = s / t \text{ (1a)}$$

where

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

s = linear displacement (m, ft)

t = time (s)

Velocity can be expressed as (acceleration = constant):

$$v = V_0 + a t \text{ (1b)}$$

where

V₀ = linear velocity at time zero (m/s, ft/s)

Linear displacement can be expressed as (acceleration = constant):

$$s = V_0 t + 1/2 a t^2 \text{ (1c)}$$

Combining 1a and 1c to express velocity

$$v = (V_0^2 + 2 a s)^{1/2} \text{ (1d)}$$

Velocity can be expressed as (velocity variable)

$$v = ds / dt \text{ (1f)}$$

where

ds = change of displacement (m, ft)

dt = change in time (s)

Acceleration can be expressed as

$$a = dv / dt \text{ (1g)}$$

where

dv = change in velocity (m/s, ft/s)

Water - Dynamic and Kinematic Viscosity

Dynamic and Kinematic Viscosity of Water in Imperial Units (BG units):

| Temperature - t - ($^{\circ}F$) | Dynamic Viscosity - μ - $10^{-5} (lb.s/ft^2)$ | Kinematic Viscosity - ν - $10^{-5} (ft^2/s)$ |
|---|--|---|
| 32 | 3.732 | 1.924 |
| 40 | 3.228 | 1.664 |
| 50 | 2.730 | 1.407 |
| 60 | 2.344 | 1.210 |
| 70 | 2.034 | 1.052 |
| 80 | 1.791 | 0.926 |
| 90 | 1.500 | 0.823 |
| 100 | 1.423 | 0.738 |
| 120 | 1.164 | 0.607 |
| 140 | 0.974 | 0.511 |
| 160 | 0.832 | 0.439 |
| 180 | 0.721 | 0.383 |
| 200 | 0.634 | 0.339 |
| 212 | 0.589 | 0.317 |

Dynamic and Kinematic Viscosity of Water in SI Units:

| Temperature - t - ($^{\circ}C$) | Dynamic Viscosity - μ - $10^{-3} (N.s/m^2)$ | Kinematic Viscosity - ν - $10^{-6} (m^2/s)$ |
|---|---|--|
| 0 | 1.787 | 1.787 |
| 5 | 1.519 | 1.519 |
| 10 | 1.307 | 1.307 |
| 20 | 1.002 | 1.004 |
| 30 | 0.798 | 0.801 |
| 40 | 0.653 | 0.658 |
| 50 | 0.547 | 0.553 |
| 60 | 0.467 | 0.475 |
| 70 | 0.404 | 0.413 |
| 80 | 0.355 | 0.365 |
| 90 | 0.315 | 0.326 |
| 100 | 0.282 | 0.294 |

Water and Speed of Sound

Speed of sound in water at temperatures between 32 - 212°F (0-100°C) - imperial and SI units

Speed of Sound in Water - in imperial units (BG units)

| Temperature - <i>t</i> - (°F) | Speed of Sound - <i>c</i> - (ft/s) |
|-------------------------------------|--|
| 32 | 4,603 |
| 40 | 4,672 |
| 50 | 4,748 |
| 60 | 4,814 |
| 70 | 4,871 |
| 80 | 4,919 |
| 90 | 4,960 |
| 100 | 4,995 |
| 120 | 5,049 |
| 140 | 5,091 |
| 160 | 5,101 |
| 180 | 5,095 |
| 200 | 5,089 |
| 212 | 5,062 |

Speed of Sound in Water - in SI units

| Temperature - <i>t</i> - (°C) | Speed of Sound - <i>c</i> - (m/s) |
|-------------------------------------|---|
| 0 | 1,403 |
| 5 | 1,427 |
| 10 | 1,447 |
| 20 | 1,481 |
| 30 | 1,507 |
| 40 | 1,526 |
| 50 | 1,541 |
| 60 | 1,552 |
| 70 | 1,555 |
| 80 | 1,555 |
| 90 | 1,550 |
| 100 | 1,543 |

Math Conversion Factors and Practical Exercise Section

1 PSI = 2.31 Feet of Water
 1 Foot of Water = .433 PSI
 1.13 Feet of Water = 1 Inch of Mercury
 454 Grams = 1 Pound
 2.54 CM = Inch
 1 Gallon of Water = 8.34 Pounds
 1 mg/L = 1 PPM
 17.1 mg/L = 1 Grain/Gallon
 1% = 10,000 mg/L
 694 Gallons per Minute = MGD
 1.55 Cubic Feet per Second = 1 MGD
 60 Seconds = 1 Minute
 1440 Minutes = 1 Day
 .746 kW = 1 Horsepower

LENGTH

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

AREA

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

VOLUME

1000 Milliliters = 1 Liter
 3.785 Liters = 1 Gallon
 231 Cubic Inches = 1 Gallon
 7.48 Gallons = 1 Cubic Foot
 62.38 Pounds = 1 Cubic Foot

Dimensions

SQUARE: Area (sq.ft) = Length X Width
 Volume (cu.ft.) = Length (ft) X Width (ft) X Height (ft)

CIRCLE: Area (sq.ft) = 3.14 X Radius (ft) X Radius (ft)

CYLINDER: Volume (Cu. ft) = 3.14 X Radius (ft) X Radius (ft) X Depth (ft)

PIPE VOLUME: .785 X Diameter ² X Length = ? To obtain gallons multiply by 7.48

SPHERE: $\frac{(3.14) (\text{Diameter})^3}{(6)}$ Circumference = 3.14 X Diameter

General Conversions

Flowrate

| Multiply | → | to get |
|----------------------------|-------|--------------------|
| to get | ← | Divide |
| cc/min | 1 | mL/min |
| cfm (ft ³ /min) | 28.31 | L/min |
| cfm (ft ³ /min) | 1.699 | m ³ /hr |
| cfh (ft ³ /hr) | 472 | mL/min |
| cfh (ft ³ /hr) | 0.125 | GPM |
| GPH | 63.1 | mL/min |
| GPH | 0.134 | cfh |
| GPM | 0.227 | m ³ /hr |
| GPM | 3.785 | L/min |

POUNDS PER DAY= Concentration (mg/L) X Flow (MG) X 8.34

AKA Solids Applied Formula = Flow X Dose X 8.34

TEMPERATURE: $^{\circ}\text{F} = (^{\circ}\text{C} \times 9/5) + 32$ $9/5 = 1.8$
 $^{\circ}\text{C} = (^{\circ}\text{F} - 32) \times 5/9$ $5/9 = .555$

CONCENTRATION: Conc. (A) X Volume (A) = Conc. (B) X Volume (B)

FLOW RATE (Q): $Q = A \times V$ (**Quantity** = **Area** X **Velocity**)

FLOW RATE (gpm): Flow Rate (gpm) = $\frac{2.83 (\text{Diameter, in})^2 (\text{Distance, in})}{\text{Height, in}}$

VELOCITY = $\frac{\text{Distance (ft)}}{\text{Time (Sec)}}$

N = Manning's Coefficient of Roughness

R = Hydraulic Radius (ft.)

S = Slope of Sewer (ft/ft.)

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

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

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

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

Volume in Cubic Feet

Cube Formula

$$V = (L) (W) (D)$$

Volume = Length X Width X Depth

Cylinder Formula

$$V = (.785) (D^2) (d)$$

Build it, Fill it and Dose it.

1. Convert 10 cubic feet to gallons of water?

There is 7.48 gallons in one cubic foot.

2. A tank weighs 800 pounds, how many gallons are in the tank?

3. Convert a flow rate of 953 gallons per minute to million gallons per day.

There is 1440 minutes in a day.

4. Convert a flow rate of 610 gallons per minute to million of gallons per day.

5. Convert a flow of 550 gallons per minute to gallons per second?

6. Now, convert this number to liters per second.

7. A tank is 6' X 15' x 7' and can hold a maximum of _____ gallons of water.

$$V = (L) (W) (D) \times 7.48 =$$

8. A tank is 25' X 75' X 10' what is the volume of water in gallons?

$$V = (L) (W) (D) \times 7.48 =$$

9. In Liters?

$$V = (L) (W) (D) \times 7.48 = \underline{\hspace{2cm}} \times 3.785$$

10. A tank holds 67,320 gallons of water. The length is 60' and the width is 15'. How deep is the tank?

$$\text{Gallons } \underline{\hspace{2cm}} \div 7.48 = \underline{\hspace{2cm}} \quad 60 \times 15 =$$

11. The diameter of a tank is 60' and the depth is 25'. How many gallons does it hold?

Cylinder Formula

$$V = (.785) (D^2) (d)$$

$$.785 \times 60' \times 60' \times 25' \times 7.48 =$$

Cubic Feet Information

There is no universally agreed symbol but the following are used:

cubic feet, cubic foot, cubic ft

cu ft, cu feet, cu foot

ft³, feet³, foot³

feet³, foot³, ft³

feet/-3, foot/-3, ft/-3

Water Treatment Production Math Numbering System

In water treatment, we express our production numbers in Million Gallon numbers. Example 2,000,000 or 2 million gallons would be expressed as 2 MG or 2 MGD.

Hints. A million has six zeros, you can always divide your final number by 1,000,000 or move the decimal point to the left six places. Example 528,462 would be expressed .56 MGD.

12. The diameter of a tank is 15 Centimeters or cm and the depth is 25 cm, what is the volume in liters?

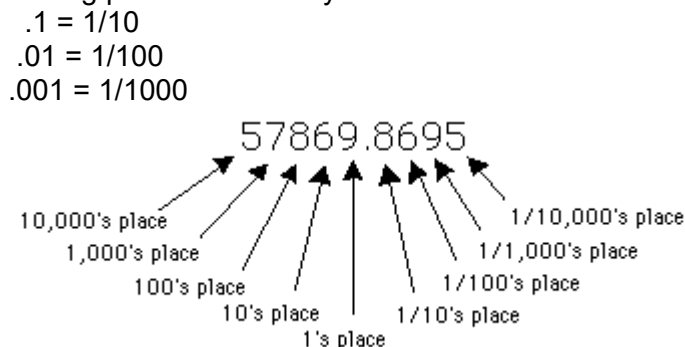
$$2.54\text{cm} = 1 \text{ inch}, 12 \text{ inches} = 1 \text{ foot}$$

$$15 \text{ cm} \div 2.54 \text{ cm} \div 12 \text{ inches} = .492 \text{ feet}$$

$$.785 \times .492' \times .492' \times \underline{\hspace{1cm}}' = \underline{\hspace{1cm}} \times 7.48 = \underline{\hspace{1cm}} \times 3.785 \text{ L} =$$

Percentage and Fractions

Let's look again at the sequence of numbers 1000, 100, 10, 1, and continue the pattern to get new terms by dividing previous terms by 10:



So just as the digits to the left of the decimal represent 1's, 10's, 100's, and so forth, digits to the right of the decimal point represent 1/10's, 1/100's, 1/1000's, and so forth.

Let's express 5% as a decimal. $5 \div 100 = 0.05$ or you can move the decimal point to the left two places.

Changing a fraction to a decimal:

Divide the numerator by the denominator

A. $5/10$ (five tenths) = five divided by ten:

$$\begin{array}{r} .5 \\ \text{----} \\ 10 \overline{) 5.0} \\ \underline{5 \ 0} \\ \text{----} \end{array}$$

So $5/10$ (five tenths) = $.5$ (five tenths).

B. How about $1/2$ (one half) or 1 divided by 2 ?

$$\begin{array}{r} .5 \\ \text{----} \\ 2 \overline{) 1.0} \\ \underline{1 \ 0} \\ \text{----} \end{array}$$

So $1/2$ (one half) = $.5$ (five tenths)

Notice that equivalent fractions convert to the same decimal representation.

$8/12$ is a good example. $8 \div 12 = .66666666$ or rounded off to $.667$

How about $6/12$ or 6 inches? $.5$ or half a foot

Flow and Velocity

This depends on measuring the average velocity of flow and the cross-sectional area of the channel and calculating the flow from:

$$Q(\text{m}^3/\text{s}) = A(\text{m}^2) \times V(\text{m/s})$$

Or

$$Q = A \times V$$

Q CFM = Cubic Ft, Inches, Yards of time, Sec, Min, Hrs, Days

A = Area, squared Length X Width

V f/m = Inch, Ft, Yards, Per Time, Sec, Min, Ft or Speed

13. A channel is 3 feet wide and has water flowing to a depth of 2.5 feet. If the velocity through the channel is 2 fps or feet per second, what is the cfs flow rate through the channel?

$$Q = A \times V$$

$$Q = 7.5 \text{ sq. ft.} \times 2 \text{ fps} \text{ What is } Q?$$

$$A = 3' \times 2.5' = 7.5$$

$$V = 2 \text{ fps}$$

14. A channel is 40 inches wide and has water flowing to a depth of 1.5 ft. If the velocity of the water is 2.3 fps, what is the cfs flow in the channel? $Q = A \times V$

First we must convert 40 inches to feet.

$$40 \div 12" = 3.333 \text{ feet}$$

$$A = 3.333' \times 1.5' = 4.999 \text{ or round up to } 5$$

$$V = 2.3 \text{ fps}$$

We can round this answer up.

15. The flow through a 6 inch diameter pipe is moving at a velocity of 3 ft/sec. What is the cfs flow rate through the pipeline?

$$Q =$$

$$A = .785 \times .5' \times .5' =$$

$$V = 3 \text{ fps}$$

16. An 8 inch diameter pipe has water flowing at a velocity of 3.4 fps. What is the gpm flow rate through the pipe?

$$Q = \text{_____ cfs} \times 60 \text{ sec/min} \times 7.48 = \text{_____ gpm}$$

$$A = .785 \times .667' \times .667'$$

$$V = 3.4 \text{ fps}$$

17. A 6 inch diameter pipe delivers 280 gpm. What is the velocity of flow in the pipe in ft/sec?

$$\text{Take the water out of the pipe. } 280 \text{ gpm} \div 7.48 \div 60 \text{ sec/min} = \text{_____ cfs}$$

$$Q =$$

$$A = .785 \times .5' \times .5' =$$

$$V =$$

18. A new section of 12 inch diameter pipe is to be disinfected before it is placed in service. If the length is 2000 feet, how many gallons of 5% NaOCl will be need for a dosage of 200 mg/L?

Cylinder Formula

$$V = (.785) (D^2) (d)$$

$$.785 \times 1' \times 1' \times 2000' = \text{_____ cuft} \times 7.48 = \text{_____} \div 1,000,000 = \text{_____ MG}$$

Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal if 100% concentrate. If not, divide the lbs/day by the given %

$$0.0117436 \text{ MG} \times 200 \text{ mg/L} \times 8.34 = \text{_____ lbs/day} \div .05 =$$

19. A section of 6 inch diameter pipe is to be filled with water. The length of the pipe is 1320 feet long. How many kilograms of chlorine will be needed for a chlorine dose of 3 mg/L?

$$.785 \times .5' \times .5' \times 1320' \times 7.48 = \text{_____} \text{ Make it MGD}$$

$$\text{Pounds per day formula} = \text{Flow} \times \text{Dose} \times 8.34 \times 45.4 \text{ Grams per pound}$$

20. Determine the chlorinator setting in pounds per 24 hour period to treat a flow of 3.4 MGD with a chlorine dose of 3.35 mg/L?

Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal

21. To correct an odor problem, you use chlorine continuously at a dosage of 15 mg/L and a flow rate of 85 GPM. Approximately how much will odor control cost annually if chlorine is \$0.17 per pound?

85 gpm X 1440 min/day = _____ gpd ÷ 1,000,000 = _____ MGD

_____ MGD X 15 mg/L X 8.34 lbs/gal X \$0.17 per pound X 365 days/year =

22. A wet well measures 8 feet by 10 feet and 3 feet in depth between the high and low levels. A pump empties the wet well between the high and low levels 9 times per hour, 24 hours a day. Neglecting inflow during the pumping cycle, calculate the flow into the pump station in million of gallons per day (MGD).

Build it, fill it and do what it says, hint: X 9 X 24

Metric Section

The metric system is known for its simplicity. All units of measurement in the metric system are based on decimals—that is, units that increase or decrease by multiples of ten. A series of Greek decimal prefixes is used to express units of ten or greater; a similar series of Latin decimal prefixes is used to express fractions. For example, *deca* equals ten, *hecto* equals one hundred, *kilo* equals one thousand, *mega* equals one million, *giga* equals one billion, and *tera* equals one trillion. For units below one, *deci* equals one-tenth, *centi* equals one-hundredth, *milli* equals one-thousandth, *micro* equals one-millionth, *nano* equals one-billionth, and *pico* equals one-trillionth.

23. How many grams equal 3,500 mg?

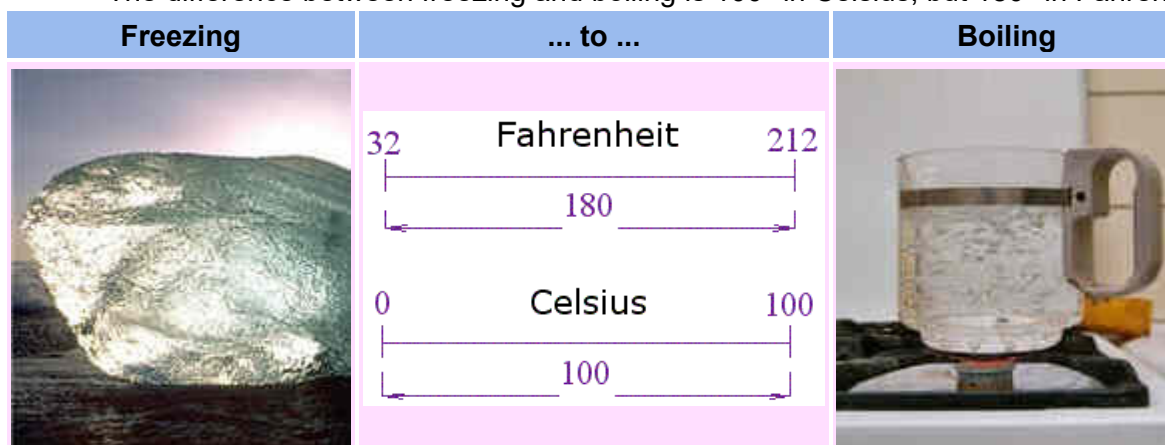
Just simply divide by 1,000.

Temperature

There are two main temperature scales. The **Fahrenheit Scale** (used in the US), and the **Celsius Scale** (part of the Metric System, used in most other Countries)

They both measure the same thing (temperature!), just using different numbers.

- If you freeze water, it measures 0° in Celsius, but 32° in Fahrenheit
- If you boil water, it measures 100° in Celsius, but 212° in Fahrenheit
- The difference between freezing and boiling is 100° in Celsius, but 180° in Fahrenheit.



Conversion Method

Looking at the diagram, notice:

- The scales start at a different number (32 vs 0), so we will need to add or subtract 32
- The scales rise at a different rate (180 vs 100), so we will also need to multiply

And this is how it works out:

To convert from Celsius to Fahrenheit, first multiply by 180/100, then add 32

To convert from Fahrenheit to Celsius, first subtract 32, then multiply by 100/180

Note: 180/100 can be simplified to **9/5**, and likewise 100/180=**5/9**.

$$^{\circ}\text{F} = (^{\circ}\text{C} \times 9/5) + 32 \quad 9/5 = 1.8$$

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) \times 5/9 \quad 5/9 = .555$$

24. Convert 20 degrees Celsius to degrees Fahrenheit.

$$20^{\circ} \times 1.8 + 32 = \text{F}$$

25. Convert 4 degrees Celsius to degrees Fahrenheit.

Water Treatment Filters

26. A 19 foot wide by 31 foot long rapid sand filter treats a flow of 2,050 gallons per minute. Calculate the filtration rate in gallons per minute per square foot of filter area.

$$\text{GPM} \div \text{Square Feet}$$

27. A 26 foot wide by 36 foot wide long rapid sand filter treats a flow of 2,500 gallons per minute. Calculate the filtration rate in gallons per minute per square foot of filter area.

Chemical Dose

28. A pond has a surface area of 51,500 square feet and the desired dose of a chemical is 6.5 lbs per acre. How many pounds of the chemical will be needed?

43,560 Square feet in an acre

$$51,500 \div 43,560 = \underline{\hspace{2cm}} \times 6.5 =$$

29. A pond having a volume of 6.85 acre feet equals how many millions of gallons?

Q=AV Review

30. An 8 inch diameter pipe has water flowing at a velocity of 3.4 fps. What is the GPM flow rate through the pipe?

$$Q = 1.18 \text{ CFS} \times 60 \text{ Seconds} \times 7.48 \text{ GAL/CU.FT} = 532 \text{ GPM}$$

$$A = .785 \times .667 \times .667 \times 1 = .349 \text{ Sq. Ft.}$$

$$V = 3.4 \text{ Feet per second}$$

31. An 6 inch diameter pipe delivers 280 GPM. What is the velocity of flow in the pipe in Ft/Sec?

$$280 \text{ GPM} \div 60 \text{ seconds in a minute} \div 7.48 \text{ gallons in a cu. ft.} = .623 \text{ CFS}$$

$$Q = .623$$

$$A = .785 \times .5 \times .5 = .196 \text{ Sq. Ft.}$$

$$V = 3.17 \text{ Ft/Second}$$

32. Calculate the total dosage in pounds of a chemical. Assume the sewer is completely filled with the concentration. Pipe diameter: 18 inches, Pipe length: 420 feet, Dose: 120 mg/L.

Figure out the volume first.

$$.785 \times 1.5' \times 1.5' \times 420' \times 7.48 = \underline{\hspace{2cm}} \text{ convert to MG}$$

$$\text{Pounds per day formula} = \text{Flow (MGD)} \times \text{Dose (mg/L)} \times 8.34 \text{ lbs/gal}$$

**“I hope you’ve enjoyed this course”, Professor Melissa Durbin.
I always welcome comments and digital pictures of pumps and water related activities.**

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