

# HYDRAULIC PRINCIPLES

## CONTINUING EDUCATION PROFESSIONAL DEVELOPMENT COURSE

*8 PDHs, 8 T.U.s, 8 CEHs, or .8 CEUs upon completion*





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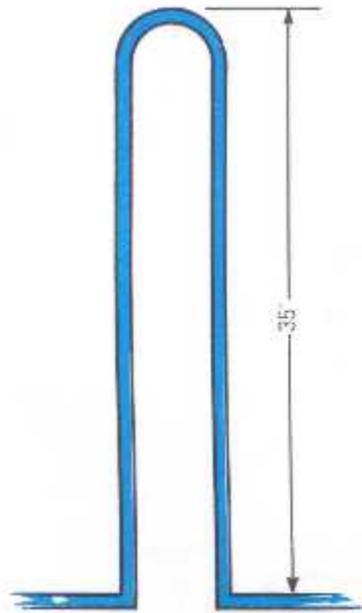
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## Barometric Loop



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.

There are students that will argue against this principle until they are blue in the face. If you can prove otherwise, send us a photograph and we will teach it, until then, this is principle is law. *Believe it or not.*

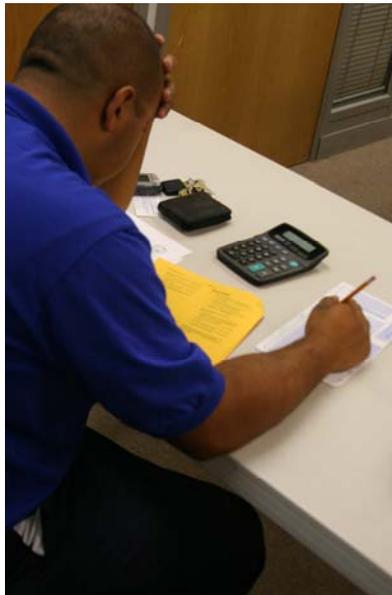
## Important Information about this Manual

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

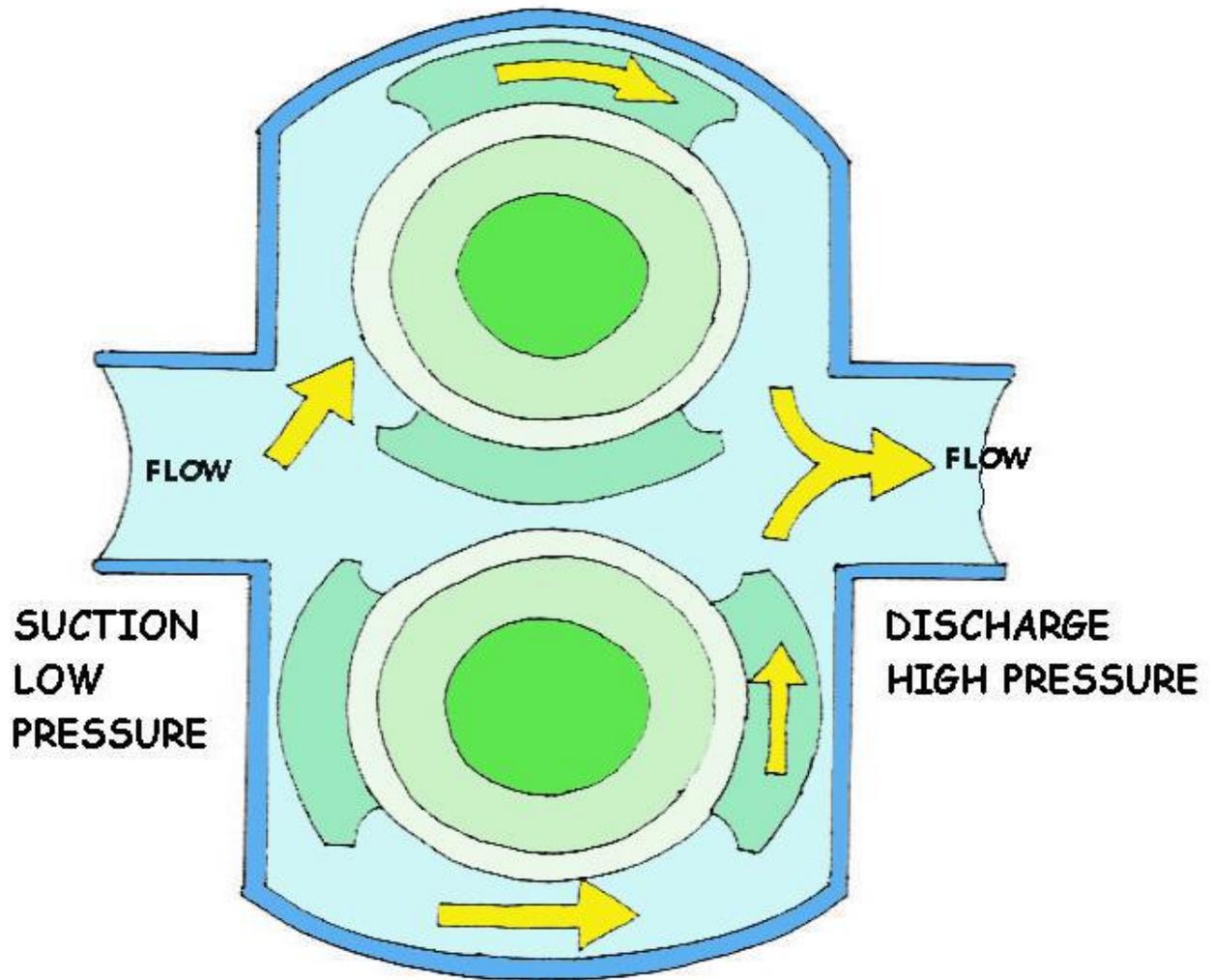
This manual should not be used as a guidance document for employees who are involved with cross-connection control. It is not designed to meet the requirements of the United States Environmental Protection Agency (**EPA**), the Department of Labor-Occupational Safety and Health Administration (**OSHA**),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

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

In this course, you will learn the various and interesting physic laws and the long exciting history related to hydraulic power as well as hydraulic terms and mathematics commonly used throughout the water related industry. This is a universal course that can be utilized by all classifications and positions. The reason this course is universal is because we examine how water works. Here are some examples: Industrial Inspector that needs to know how to figure a water flow. A Plumbing or Customer Inspector who needs to figure flow restriction in a water line. This course will cover several unique and interesting water related facts that most of us have forgotten or haven't recognized.



**Print the manual out or complete the CEU assignment online in a Word document. We are here to answer your calls or e-mails.**



## **Technical Learning College's Scope and Function**

Technical Learning College (**TLC**) offers affordable continuing education for today's working professionals who need to maintain licenses or certifications. TLC holds approximately eighty different governmental 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. Most of TLC's distance based or independent study courses are offered in a print based format and you are welcome to examine this material on your computer with no obligation. 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 assignments.

Most CEU courses allow students to submit lessons using e-mail or fax; however some courses require students to submit lessons by postal mail. (See the course description for more information.) Students have direct contact with their instructor—primarily by e-mail. 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 exams depending upon your state requirements.

### **Flexible Learning**

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

We will beat any other training competitor's price for the same CEU material or classroom training. Student satisfaction is guaranteed.

### **Course Structure**

TLC's online courses combine the best of online delivery and traditional university textbooks. Online you will find the course syllabus, course content, assignments, and online open book exams. This student friendly course design allows you the most flexibility in choosing when and where you will study.

### **Classroom of One**

TLC Online 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 are assigned at the beginning of each course providing the academic support you need to successfully complete each course.

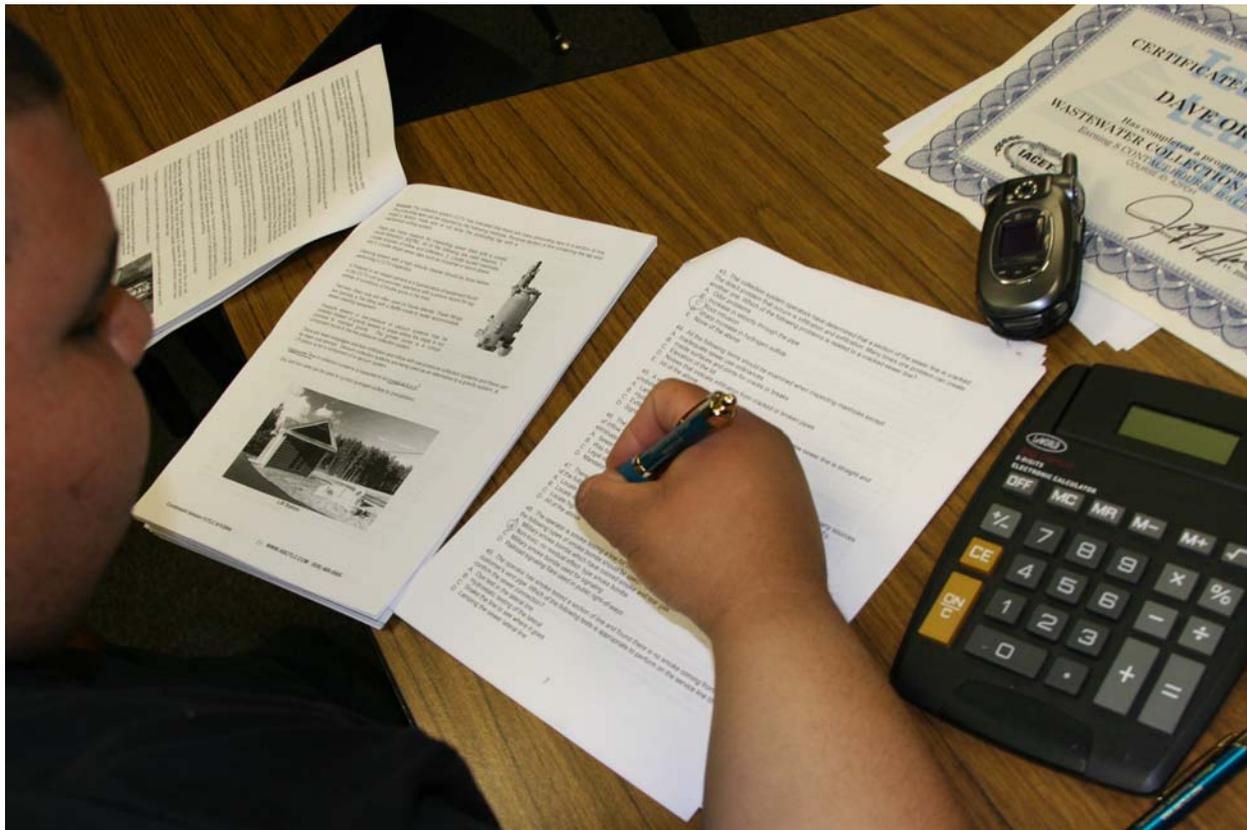
### **Satisfaction Guaranteed**

Our Iron-Clad, Risk-Free Guarantee ensures you will be another satisfied TLC student. 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 10,000 students.

Our administrative staff is trained to provide the best customer service in town. Part of that training is knowing how to solve most problems on the spot with an exchange or refund.

### **TLC Continuing Education Course Material Development**

Technical Learning College's (TLC's) continuing education course material development was based upon several factors; extensive academic research, advice from subject matter experts, data analysis, task analysis and training needs assessment process information gathered from other states.



**We invite you to utilize the electronic version of the assignment. You can complete the assignment in Word or simply print it out and fax or e-mail the completed assignment to us. Allow 2 weeks for course grading. If you need your assignment graded and mailed back to you within 48-hours, prepare to pay an additional rush process service charge.**

# CEU Course Description

## Hydraulic Principles CEU Training Course

This short CEU course will review of hydraulic fundamentals and principles--from taking this CEU course, the student will develop an understanding of the engineering science pertaining to liquid pressure and flow. This course will cover the basics of hydraulic fundamentals commonly related to the study of the mechanical properties of water. This course will also examine hydrostatics or fluid mechanics as well as the history and development of pumps, hydraulics and the science of fluids. This training course will present several familiar topics in hydraulics and hydrostatics which often appear in most educational expositions of introductory science, and which are also of historical interest that can enliven a student's educational experience. ***You will not need any other materials for this course.***

**Water Distribution, Well Drillers, Pump Installers, Water Treatment Operators, Wastewater Treatment Operators, Wastewater Collection Operators, Industrial Wastewater Operators, Customer Service Professionals and General Backflow Assembly**

**Testers**--the target audience for this course is the person interested in working in a water or wastewater treatment or distribution/collection facility and/or wishing to maintain CEUs for certification license or to learn how to do the job safely and effectively, and/or to meet education needs for promotion.

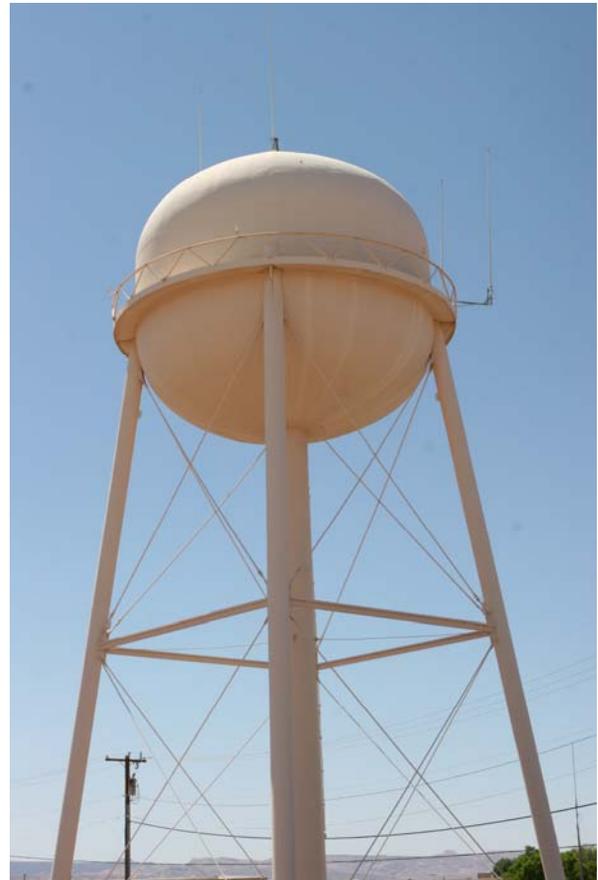
### What is Hydraulics?

The term hydraulics 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. 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.

### What is Hydrostatics?

Hydrostatics is about the pressures exerted by a fluid at rest. Any fluid is meant, not just water. It is usually relegated to Fluid Mechanics texts, since its results are widely used in that study. The study 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. It 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.



### **Final Examination for Credit**

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

**Prerequisites:** None

### **Course Procedures for Registration and Support**

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

When a student registers for a distance or correspondence course, he/she is assigned a start date and an end date. It is the student's responsibility to note dates for assignments and keep up with the course work. If a student falls behind, he/she must contact TLC and request an end date extension in order to complete the course. It is the prerogative of TLC to decide whether to grant the request. All students will be tracked by their social security number or a unique number will be assigned to the student.

### **Instructions for Assignment**

The Hydraulic Principles CEU training course uses a multiple choice type answer key. You can find a copy of the answer key in the back of this course manual or 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.

### **Feedback Mechanism (examination procedures)**

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

### **Security and Integrity**

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

### **Grading Criteria**

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

### **Required Texts**

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

### **Recordkeeping and Reporting Practices**

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

### **ADA Compliance**

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



You will have 90 days from receipt of this manual to complete it in order to receive your Continuing Education Units (**CEUs**) or Professional Development Hours (**PDHs**). A score of 70% or better is necessary to pass this course. If you should need any assistance, please email all concerns and the final test to: [info@tlch2o.com](mailto:info@tlch2o.com).

### **Educational Mission**

**The educational mission of TLC is:**

*To provide TLC students with comprehensive and ongoing training in the theory and skills needed for the environmental education field,*

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

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

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

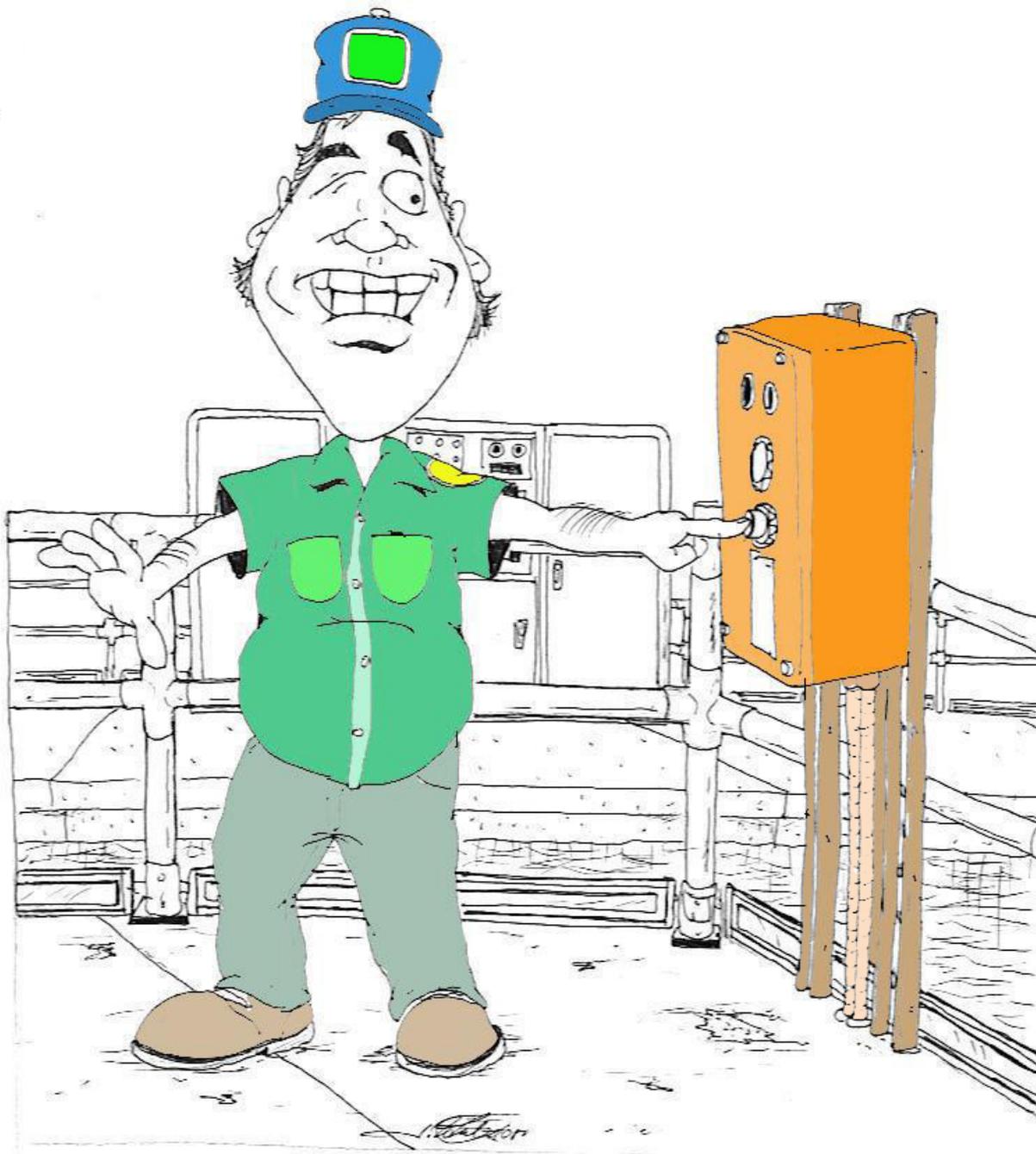
*To provide a forum for the collection and dissemination of current information related to environmental education, and to maintain an environment that nurtures academic and personal growth.*



**Here is one of our Instructors working with a student in the hands-on hydraulic class. Please call one of the Instructors if you need any assistance with this course or assignment.**

**Toll Free (866) 557-1746**





## INDEX

Hydraulic Principles	15
Atmospheric Pressure	16
Geometric Arguments	20
Vacuum	21
Archimedes	25
Development of Hydraulics	31
Pascal's Law	34
Bernoulli's Principles	35
Hydraulic Levels	37
Dudley Castle Engine	39
Hydrostatic Paradox	42
How Buoyancy Works	43
Hydrometer	45
Backflow Introduction	47
Actual Events	48
Cross-Connections	51
Glossary	121
Appendixes	161
Math Exercise	183



**Right photograph: Why do you think that this hose on this pump is never longer than about 25 feet long? Remember the principle of water not being able to be sucked more than 33.9 feet high.**

**Most pumps that are deeper or have a longer hose will push the water up and not suck or pull it up.**

## Common Hydraulic Terms

### ***Head***

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

### ***Head, Friction***

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

### ***Head, Static***

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

### ***Hydraulics***

Engineering science pertaining to liquid pressure and flow.

### ***Hydrokinetics***

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

### ***Pascal's Law***

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

### ***Pressure***

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

### ***Pressure, Absolute***

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

### ***Pressure, Atmospheric***

Pressure 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. Let's start our study with the principles of our atmosphere.

## 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.

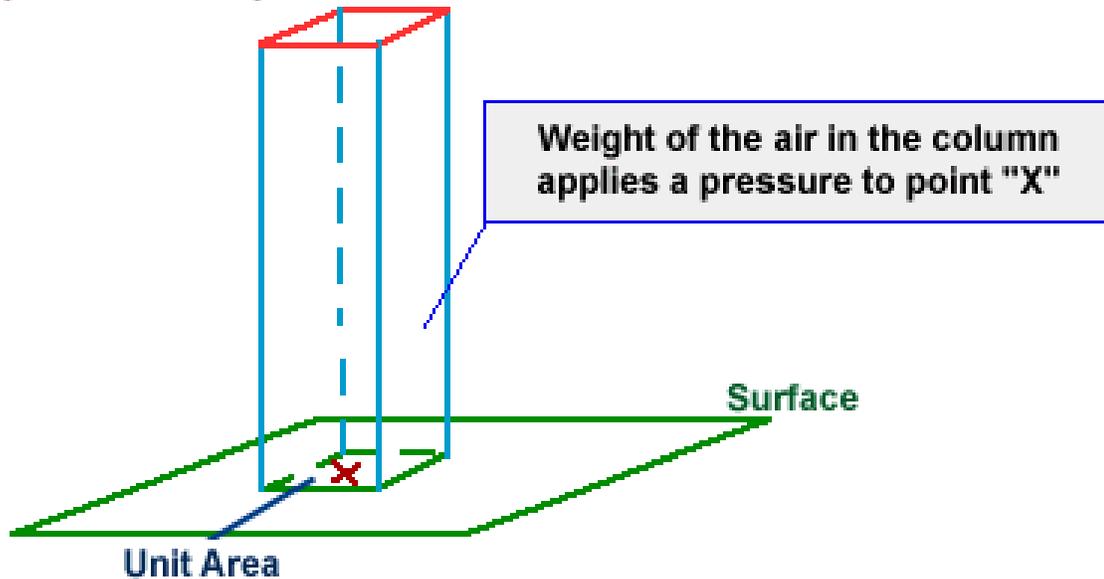
As one ascends, the atmospheric pressure decreases by approximately 1.0 psi for every 2,343 feet. However, below sea level, in excavations and depressions, atmospheric pressure increases. Pressures under water differ from those under air only because the weight of the water must be added to the pressure 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 on the following page, the pressure at point "**X**" increases as the weight of the air above it increases. The same can be said about decreasing pressure, where the pressure at point "**X**" decreases if the weight of the air above it also decreases.

## Top of the Atmosphere



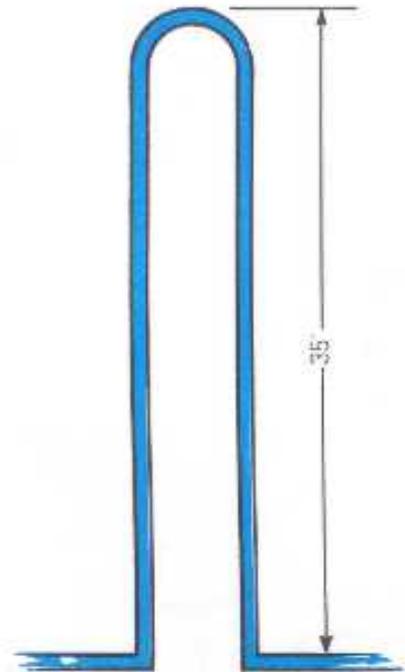
### Barometric Loop

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

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

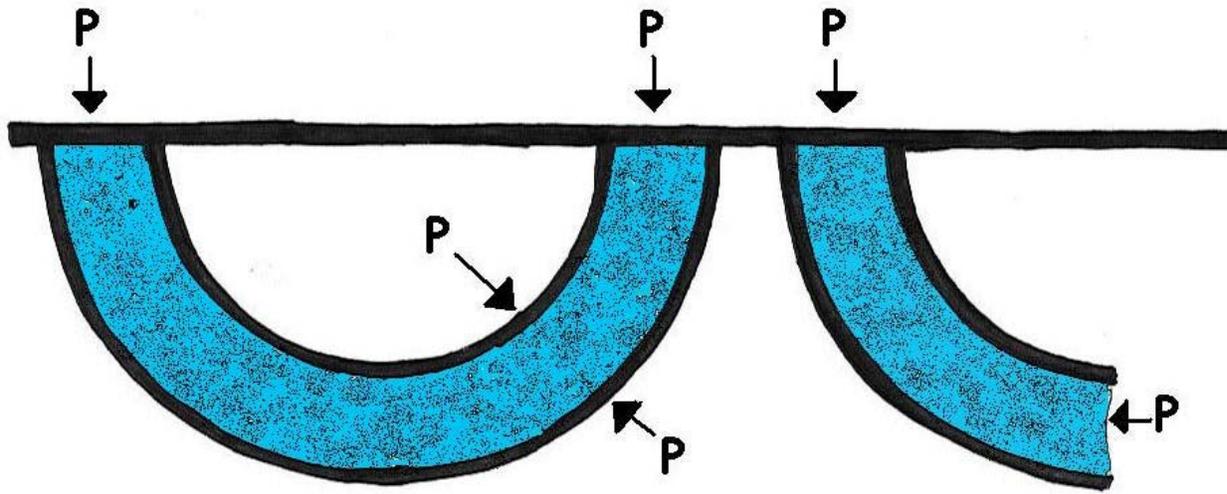
Pressure may be referred to using an absolute scale, pounds per square inch absolute (**psia**), or gauge scale, (**psiag**). Absolute pressure and gauge pressure are related. Absolute pressure is equal to gauge pressure plus the atmospheric pressure. At sea level, the atmospheric pressure is 14.7 psia.

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



## 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.

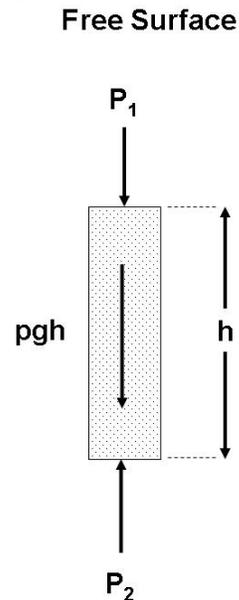
Therefore, in this case the pressure will be the same throughout the fluid, and the same in any direction at a point (Pascal's Principle). Pressure is expressed in units of force per unit area such as  $\text{dyne/cm}^2$ ,  $\text{N/cm}^2$  (pascal),  $\text{pounds/in}^2$  (psi) or  $\text{pounds/ft}^2$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

On earth, fluids are also subject to the force of gravity, which acts vertically downward, and has a magnitude  $\gamma = \rho g$  per unit volume, where  $g$  is the acceleration of gravity, approximately  $981 \text{ cm/s}^2$  or  $32.15 \text{ ft/s}^2$ ,  $\rho$  is the density, the mass per unit volume, expressed in  $\text{g/cm}^3$ ,  $\text{kg/m}^3$ , or  $\text{slug/ft}^3$ , and  $\gamma$  is the specific weight, measured in  $\text{lb/in}^3$ , or  $\text{lb/ft}^3$  (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  $p = \rho gh + p_0$ .

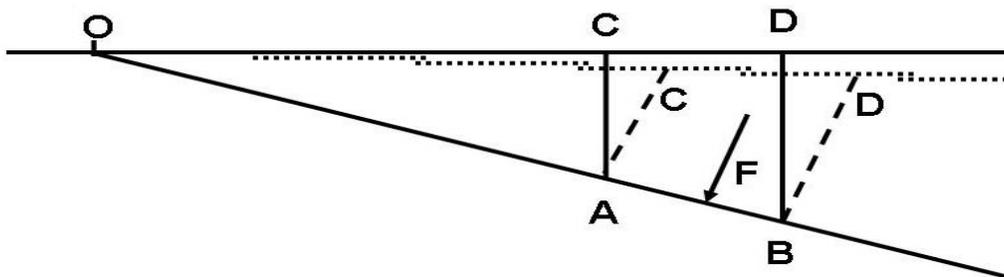
The density of water is about  $1 \text{ g/cm}^3$ , or its specific weight is  $62.4 \text{ pcf}$ . We may ask what depth of water gives the normal sea-level atmospheric pressure of  $14.7 \text{ psi}$ , or  $2117 \text{ psf}$ .

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

The forces exerted on the curved surfaces have no component along the normal to a plane section, so the pressures at any two points of a plane must be equal, since the fluid represented by the curtain ring was in equilibrium. The right-hand part of the diagram illustrates the equality of pressures in orthogonal directions. 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's Principle that the buoyant force is equal to the weight of the displaced fluid, and passes through the center of mass of this displaced fluid.

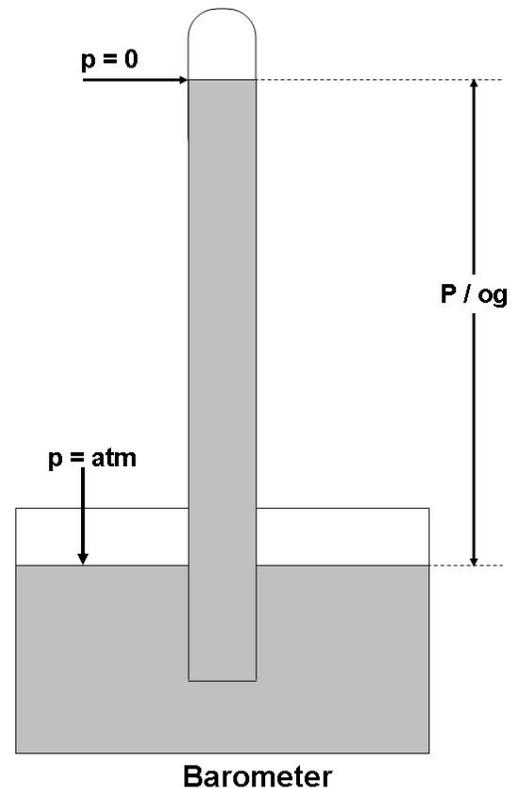
## Geometric Arguments

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

## 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.

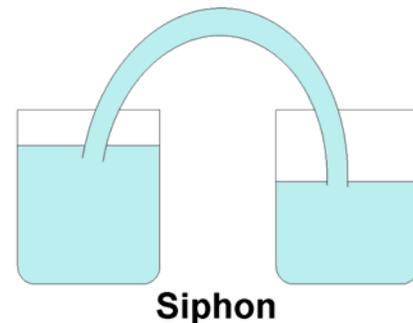
Now start the pump. When it has sucked all the air out above the water, the pressure on the surface of the water inside the pipe is zero, and the pressure at the level of the water on the outside of the pipe is still the atmospheric pressure. Of course, there is the vapor pressure of the water to worry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

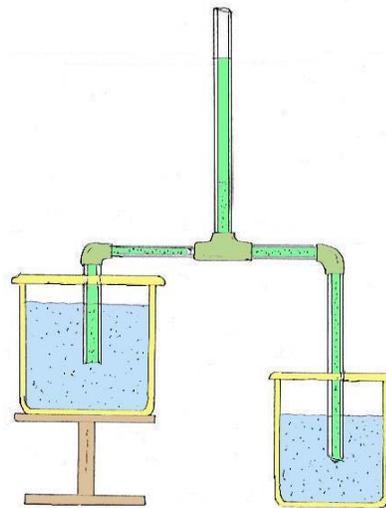
## Water Pressure

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 0.866 psig or two times the original pressure.

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

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

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



**PASCAL'S SIPHON**

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

## Liquids at Rest

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

### Pressure and Force

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

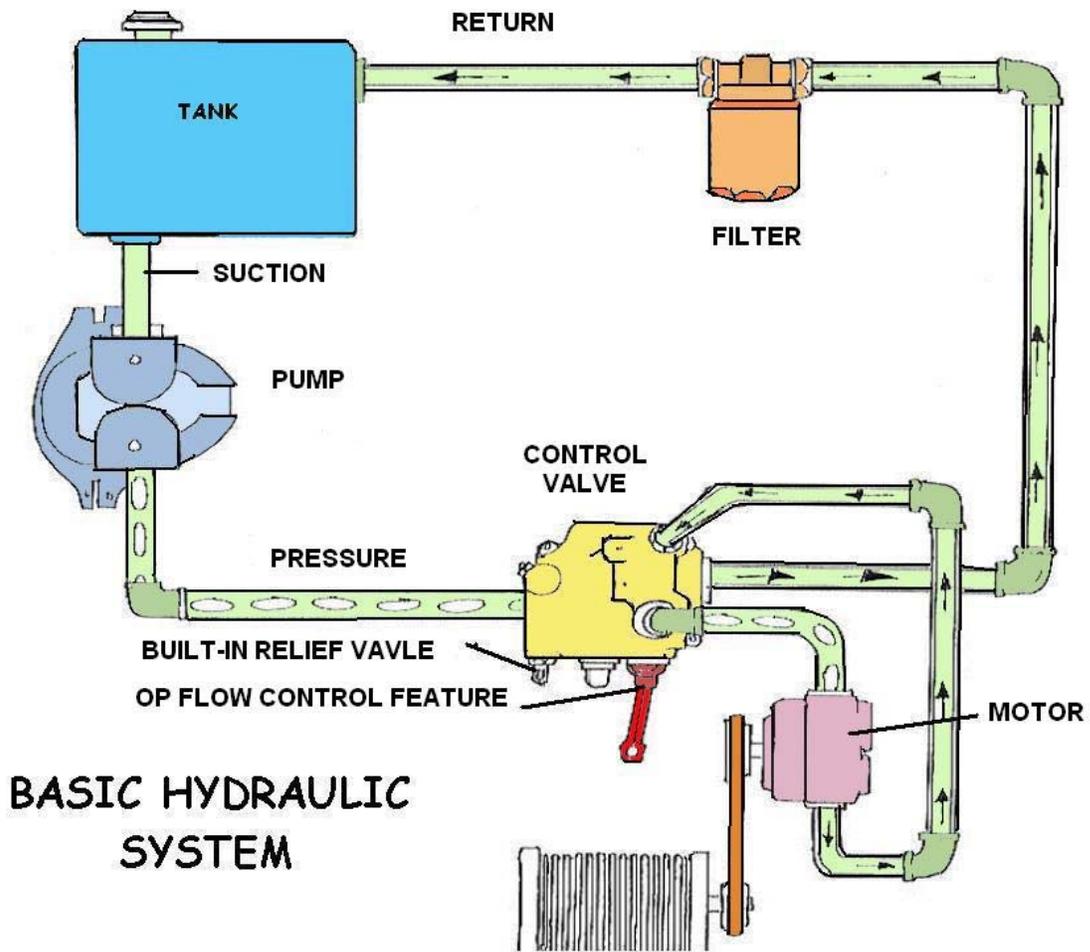
The terms **force** and **pressure** are used extensively in the study of fluid power. It is essential that we distinguish between the terms.

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

### Computing Force, Pressure, and Area

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





## Archimedes



**ARCHIMEDES**

## 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 ( $1 \times 10^{62}$ ).

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

Some powers of two are:

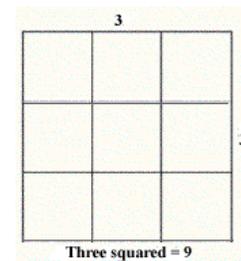
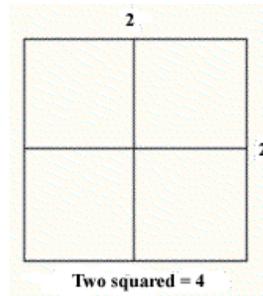
$$1 = 2^0 \text{ power} = 2^0$$

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

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

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

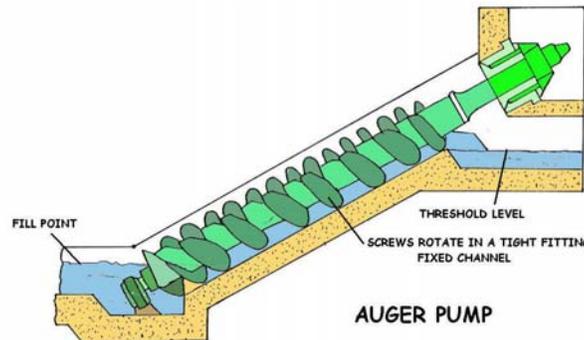
$$2 \times 2 \times 2 \times 2 = 2^4 \text{ power} = 2^4$$



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

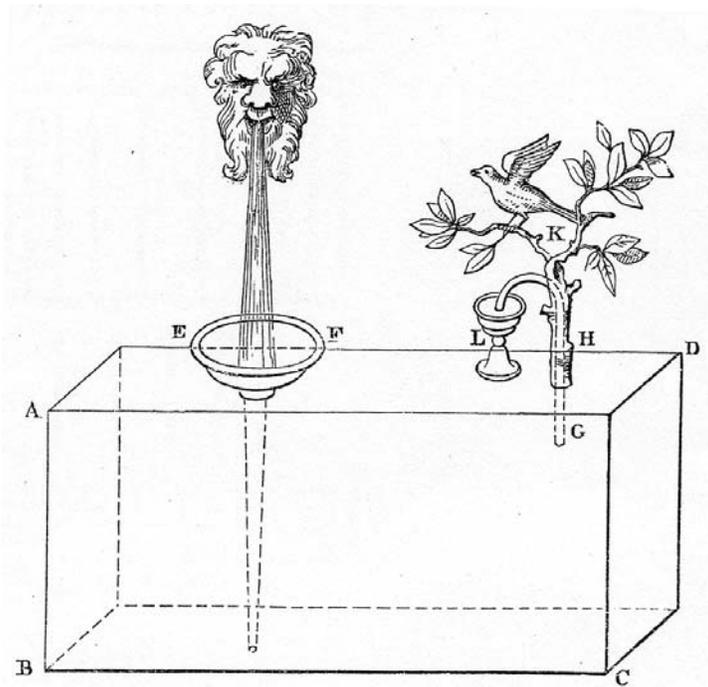
- On Plane Equilibriums
- On Floating Bodies

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



**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.



Inventions of Heron of Alexandria, above picture. The flow of water into a sealed container forces air out through a small bent tube. The air, bubbling into a cup of water, sounds like a bird singing. (The Pneumatics of Hero of Alexandria, page 29)



When the human figure is turned toward the dragon, a valve between the two sealed chambers under the figure closes. However if the human figure is rotated to the side, the valve connecting the two chambers opens, water flows from the top to the bottom chamber, and suction is created in the pipe leading from the upper chamber to the dragon's mouth. Because of this suction, the dragon appears to drink if a cup of water is held up to its mouth. (Buch von Luft-Und Wasser-Kunsten, page 3)

## Heron of Alexandria

Heron, or Hiero, was a scientist and inventor in Alexandria. Heron wrote many books on mathematics, physics, geometry, and mechanics. The '*Pneumatica*' describes mechanical devices operated by compressed air, water or steam, such as a fire engine, a water organ, and the aeolipile, which is the first steam-powered engine. His device consisted of a sphere mounted on a boiler by an axial shaft and having two canted nozzles to produce a rotary motion from the escaping steam. The later steam engines of the 18th century were partly based on this design. He was a Greek mathematician who was mainly interested in practical studies in mechanics and engineering. He dealt with a number of such problems in his work Dioptra. He is best known today for Proposition 1.8 of his Metrica, which is now known as Heron's formula.

The manuscript had been lost for centuries until a fragment was discovered in 1894, followed by a complete copy in 1896. The aeolipile (known as Hero's engine) was a rocket-like reaction engine and the first recorded steam engine. It was created almost two millennia before the industrial revolution. Hero's steam engine was used to open temple doors, and as a toy, but the principles behind it were not well understood, and its full potential was not realized for well over a millennium.

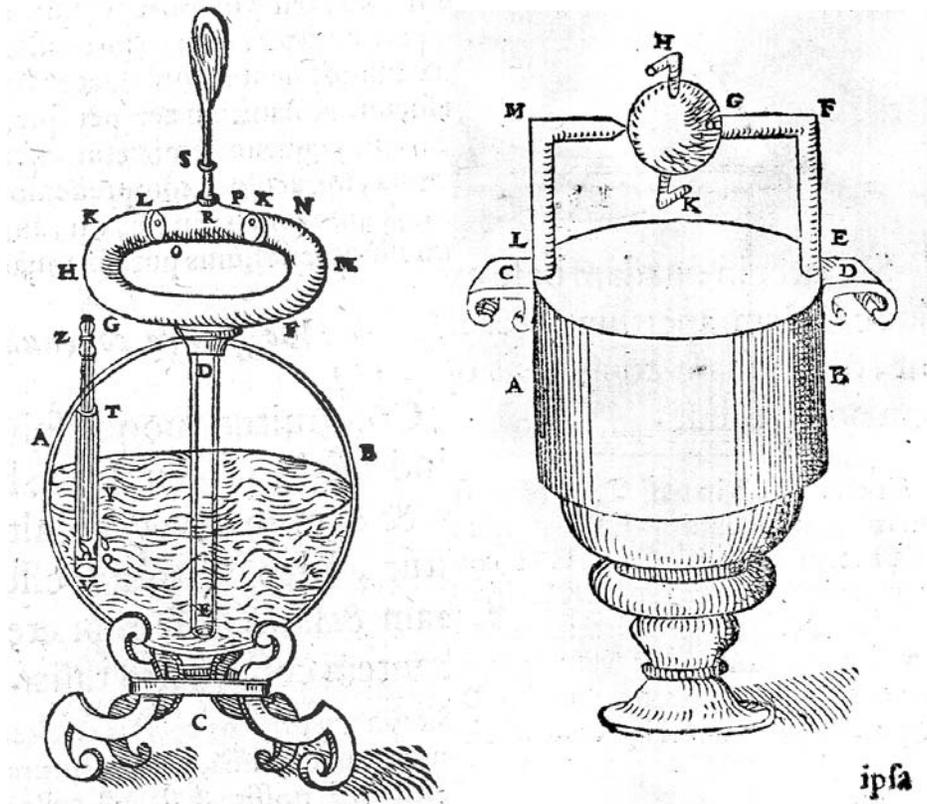
The first vending machine was also one of his constructions, when a coin was introduced via a slot on the top of the machine, a set amount of Holy Water was dispensed. This was included in his list of inventions in his book, "Mechanics and Optics". When the coin was deposited, it fell upon a pan attached to a lever. The lever opened up a valve which let some water flow out. The pan continued to tilt with the weight of the coin until it fell off, at which point a counter-weight would snap the lever back up and turn off the valve. A windwheel operating an organ, marking probably the first instance of wind powering a machine in history.

Hero also invented many mechanisms for the Greek theater, including an entirely mechanical play almost ten minutes in length, powered by a binary-like system of ropes, knots, and simple machines operated by a rotating cylindrical cogwheel. The sound of thunder was produced by the mechanically-timed dropping of metal balls onto a hidden drum.

In Optics, Hero formulated the Principle of the Shortest Path of Light: If a ray of light propagates from point A to point B within the same medium, the path-length followed is the shortest possible. It was nearly 1000 years later that Ibn al-Haytham expanded the principle to both reflection and refraction, and the principle was not stated in this form until Pierre de Fermat did so in 1662; the most modern form is that the path is at an extremum.

A standalone fountain that operates under self-contained hydrostatic energy. (Heron's fountain)  
Mathematics

Heron described a method of iteratively computing the square root. It is also called the Babylonian method, because the Babylonians also probably knew of it before Heron wrote it down.



On the left hand side, a water jet produced by mechanically compressed air. (Pneumatics, page 23, OR *Spiritualium Liber*, page 19.)

On the right hand side, steam, produced in a heated pot, is fed into a ball that is held on 2 pivots, which spins when the steam exits via bent tubes. This device is one of the earliest suggestions of the steam engine. (*Spiritualium Liber*, page 52)

**Hero in the History of Hydraulics Collection:**

- \* *Spiritualium Liber*, Latin translation of Hero's *Pneumatics*, published 1575, Urbino, Italy. (Call number QC 142 H54)
- \* *De Gli Automati, Overo Machine Se Moventi* (Italian translation of Hero's *Mechanics*, published 1601 in Venice, Italy) (Call number: TJ215 H4)
- \* *Buch von Lufft-Und Wasser-Kunsten* (German translation of Hero's *Pneumatics*, published 1688, Frankfurt) (Call number: Q147 H4)
- \* *The Pneumatics of Hero of Alexandria* (English translation, published London, 1851) (Call number: QC 142 H52)

## Development of Hydraulics

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

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

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

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

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

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

### Evangelista Torricelli

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

Pascal had a barometer carried up the 1465 m high Puy de Dôme, an extinct volcano in the Auvergne just west of his home of Clermont-Ferrand in 1648 by Périer, his brother-in-law. Pascal's experimentum crucis is one of the triumphs of early modern science. The Puy de Dôme is not the highest peak in the Massif Central--the Puy de Sancy, at 1866 m is, but it was the closest. Clermont is now the centre 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 right). He also showed that air had weight, and how much force it required to separate evacuated hemispheres. Then, in England, Robert Hooke (1635-1703) made a vacuum pump for Robert Boyle (1627-1691). Christian Huygens (1629-1695) became interested in a visit to London in 1661 and had a vacuum pump built for him. By this time, Torricelli's doctrine had triumphed over the Church's support for horror vacui. This was one of the first victories for rational physics over the illusions of experience, and is well worth consideration.



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

## Torr

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

The weight of a sphere of air as small as 10 cm in diameter is 0.68 g, easily measurable with a chemical balance. The pressure of the atmosphere is also considerable, like being 34 ft under water, but we do not notice it. A bar is  $10^6 \text{ dyne/cm}^2$ , very close to a standard atmosphere, which is 1.01325 bar. In meteorology, the millibar, mb, is used.  $1 \text{ mb} = 1.333 \text{ mmHg} = 100 \text{ Pa} = 1000 \text{ dyne/cm}^2$ .

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

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

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

This is a little harder to integrate than before, but the result is  $\ln p = -Mgh/RT + C$ , or  $\ln(p/p_0) = -Mgh/RT$ , or finally  $p = p_0 \exp(-Mgh/RT)$ . In an isothermal atmosphere, the pressure decreases exponentially. The quantity  $H = RT/Mg$  is called the "height of the homogeneous atmosphere" or the scale height, and is about 8 km at  $T = 273K$ .

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



## Pascal's Law

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

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

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

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

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

## 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.

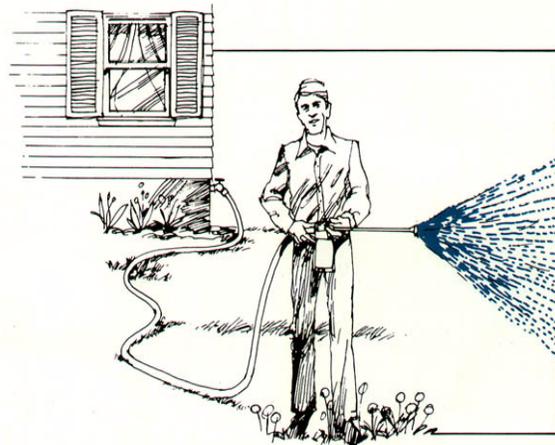
Volume and velocity of flow are often considered together. With other conditions unaltered—that is, with volume of input unchanged—the velocity of flow increases as the cross section or size of the pipe decreases, and the velocity of flow decreases as the cross section increases. For example, the velocity 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.



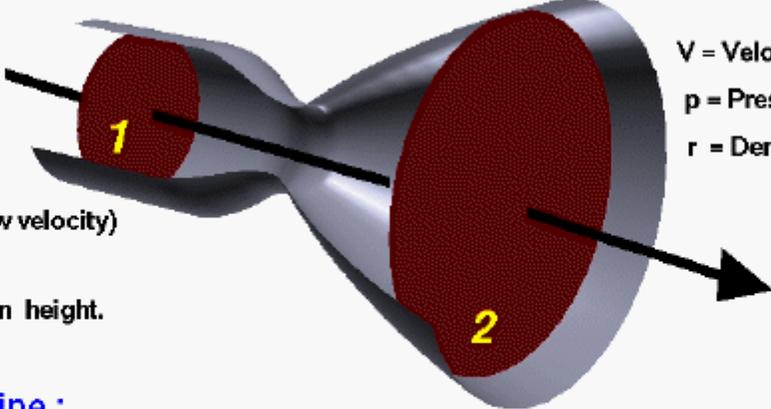
## Bernoulli's Equation

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**Restrictions :**

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



V = Velocity  
p = Pressure  
r = Density

**Along a streamline :**

static pressure + dynamic pressure = total pressure

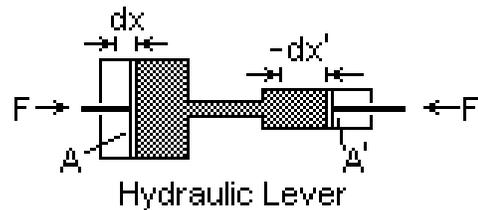
$$p_s + \frac{rV^2}{2} = p_t$$

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

## The Hydraulic Lever

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

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



The work done by the fluid in this displacement is  $dW = F dx = pA dx = p dV$ . If the movement is slow enough that inertia and viscosity forces are negligible, then hydrostatics will still be valid.

A process for which this is true is called quasi-static. Now consider two cylinders, possibly of different areas  $A$  and  $A'$ , connected with each other and filled with fluid. For simplicity, suppose that there are no gravitational forces.

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

## Bramah Hydraulic Press

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

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

In the presence of gravity,  $p' = p + pgh$ , where  $h$  is the difference in elevation of the two cylinders. Now,  $p' dV' = -dV (p + pgh) = -p dV - (\rho dV)gh$ , 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.

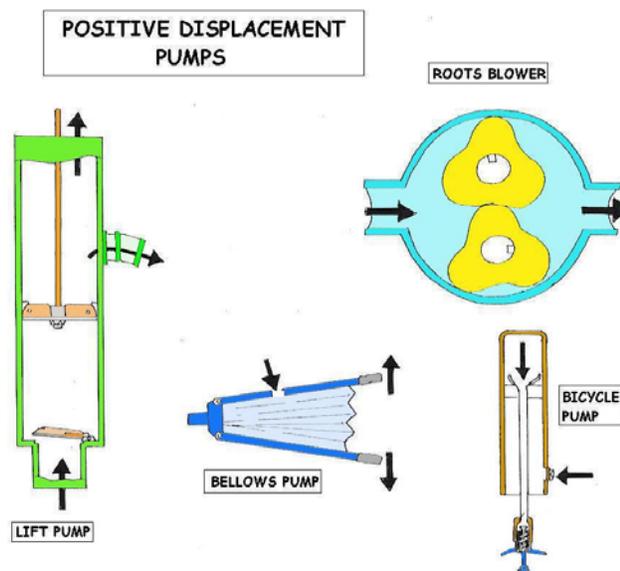
## Pumps

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 on right. 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 fire fighting. 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 miscalled buckets. They pumped on the up-stroke, when a clack in the bottom of the pipe opened and allowed water to enter beneath the piston. At the same time, the piston lifted the column of water above it, which could be of any length. The piston could only "suck" water 33 ft, or 28 ft more practically, of course, but this occurred at the bottom of the shaft, so this was only a limit on the piston stroke. On the down stroke, a clack in the bucket opened, allowing it to sink through the water to the bottom, where it would be ready to make another lift.

More satisfactory were the plunger pumps, also placed at the bottom of the shaft. A plunger displaced volume in a chamber, forcing the water in it through a check valve up the shaft, when it descended. When it rose, water entered the pump chamber through a clack, as in the bucket pump.

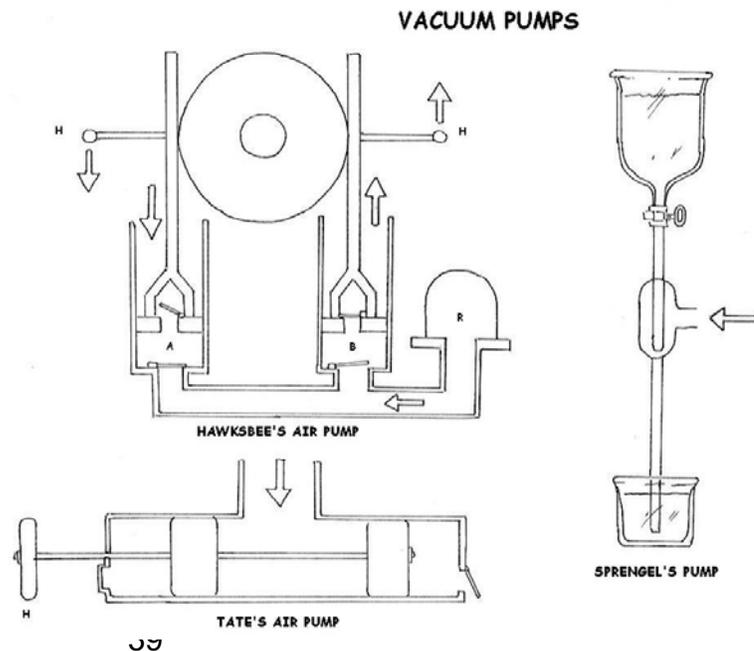
Only the top of the plunger had to be packed; it was not necessary that it fit the cylinder accurately. In this case, the engine at the surface lifted the heavy pump rods on the up-stroke. When the atmospheric engine piston returned, the heavy timber pump rods did the actual pumping, borne down by their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

## Hawksbee's Dual Cylinder Pump

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

## Bell-jar Receiver

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



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

Theoretically, a vacuum of about 1  $\mu\text{m}$  can be obtained with a Sprengel pump, but it is very slow and can only evacuate small volumes. Later, Langmuir's mercury diffusion pump, which was much faster, replaced Sprengel pumps, and led to oil diffusion pumps that can reach very high vacua.

The column of water or hydrostatic engine is the inverse of the force pump, used to turn a large head (pressure) of water into rotary motion. It looks like a steam engine, with valves operated by valve gear, but of course is not a heat engine and can be of high efficiency.

However, it is not of as high efficiency as a turbine, and is much more complicated, but has the advantage that it can be operated at variable speeds, as for lifting.

A few very impressive column of water engines were made in the 19th century, but they were never popular and remained rare. Richard Trevithick, famous for high pressure steam engines, also built hydrostatic engines in Cornwall. The photograph at the right shows a column-of-water engine built by Georg von Reichenbach, and placed in service in 1917. This engine was exhibited in the Deutsches Museum in München as late as 1977.



It was used to pump brine for the Bavarian state salt industry. 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.

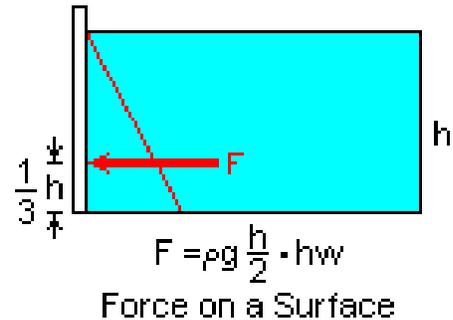
The pump shown in the photograph pumped brine over this line, entering service in 1816. Fresh water was also allowed to flow down to the salt beds, and the brine was then pumped to the surface. This was a much easier way to mine salt than underground mining. The salt industry of Bad Reichenhall still operates, but it is now Japanese-owned.

## Forces on Submerged Surfaces

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

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

By integration, we can find the total force  $F$ , and the depth at which it acts,  $c = M / F$ . If the surface is not symmetrical, the position of the total force in the transverse direction can be obtained from the integral of  $dM' = \rho g x y dA$ , the moment about some vertical line in the plane of the surface. If there happens to be a pressure on the free surface of the water, then the forces due to this pressure can be evaluated separately and added to this result. We must add a force equal to the area of the surface times the additional pressure, and a moment equal to the product of this force and the distance to the centroid of the surface.



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

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

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

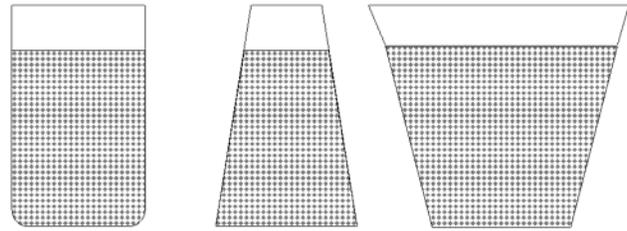
## Hydrostatic Paradox

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 a 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. 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.

## Hydrostatic Paradox



## 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  $\rho gh$ , so the difference in total force on top and bottom of the brick is simply  $(\rho gh)(wl) = \rho gV$ , where  $V$  is the volume of the brick.

The forces on the sides have no vertical components, so they do not matter. The net upward force is the weight of a volume  $V$  of the fluid of density  $\rho$ . Any body 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.

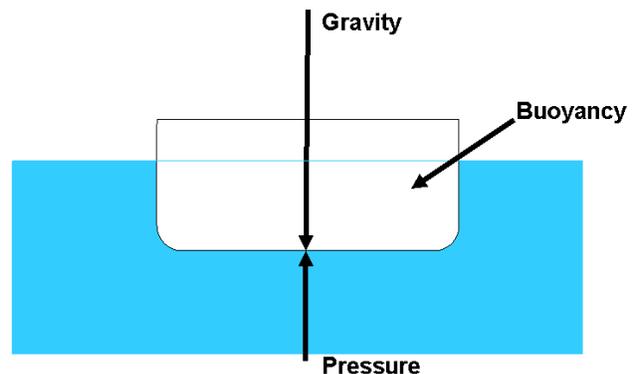
Consider a man in a rowboat on a lake, with a large rock in the boat. He throws the rock into the water. What is the effect on the water level of the lake?

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?

The force exerted by the water on the bottom of a boat acts through the centre of gravity  $B$  of the displaced volume, while the force exerted by gravity on the boat acts through its own centre 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 metacentre, 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.

## Ship Stability



## Montgolfier Brothers' Hot Air Balloon

Archimedes's Principle can also be applied to balloons. The Montgolfier brothers' hot air balloon with a paper envelope ascended first in 1783 (the brothers got Pilâtre de Rozier and Chevalier d'Arlandes to go up in it). Such "fire balloons" were then replaced with hydrogen-filled balloons, and then with balloons filled with coal gas, which was easier to obtain and did not diffuse through the envelope quite as rapidly. Methane would be a good filler, with a density 0.55 that of air. Slack balloons, like most large ones, can be contrasted with taut balloons with an elastic envelope, such as weather balloons. Slack balloons will not be filled full on the ground, and will plump up at altitude. Balloons are naturally stable, since the center of buoyancy is above the center of gravity in all practical balloons. Submarines are yet another application of buoyancy, with their own characteristic problems. Small neoprene or natural rubber balloons have been used for meteorological observations, with hydrogen filling.

A 10g ceiling balloon was about 17" in diameter when inflated to have a free lift of 40g. It ascended 480ft the first minute, 670ft in a minute and a half, and 360ft per minute afterwards, to find cloud ceilings by timing, up to 2500ft, when it subtended about 2' of arc, easily seen in binoculars.

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

## Weather Balloons

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

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

Electrolysis of water is an expensive source, since more energy is used than is recovered with the hydrogen. Any enthusiasm for a "hydrogen economy" should be tempered by the fact that there are no hydrogen wells, and all the hydrogen must be made with an input of energy usually greater than 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/cuft or pcf, is numerically different from the specific gravity, since the weight of water is 62.5 lb/cuft.

## Variations

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

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

## Pycnometer

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

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

## Hydrometer

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

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

## 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.

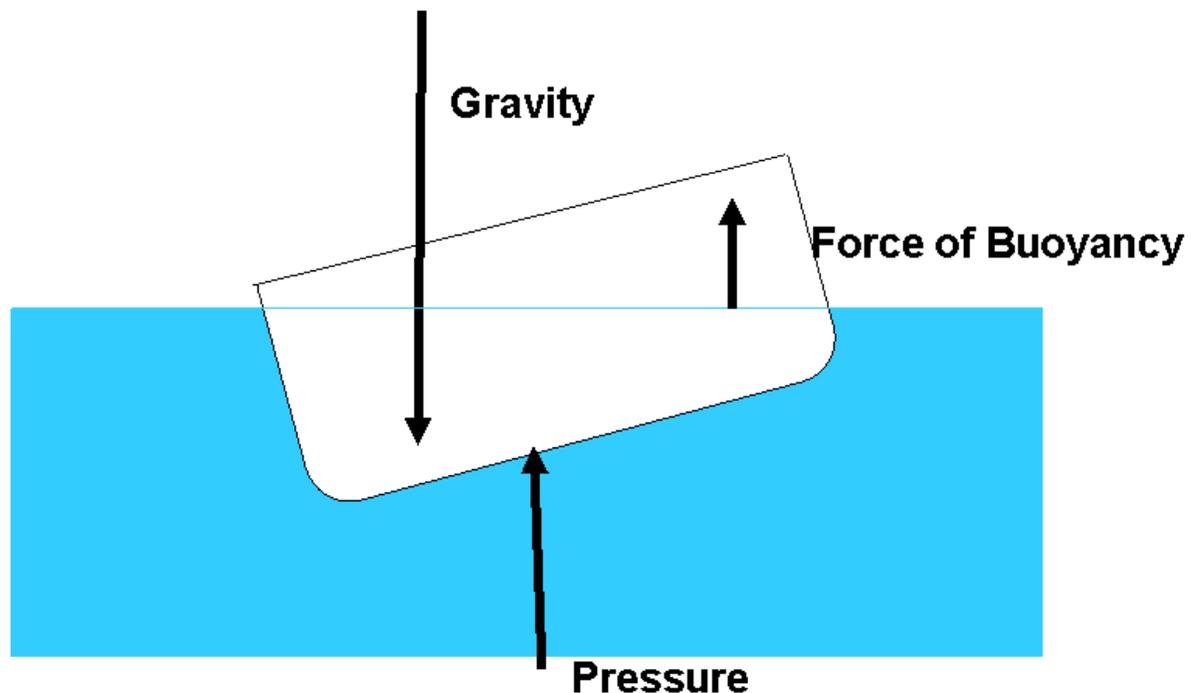
R. L. Daugherty and J. B. Franzini, *Fluid Mechanics*, 6th ed. (New York: McGraw-Hill, 1965). Chapter 2. A typical engineering treatment in a classic text, of course with calculus.

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.

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# Change of Ship Stability



## 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.

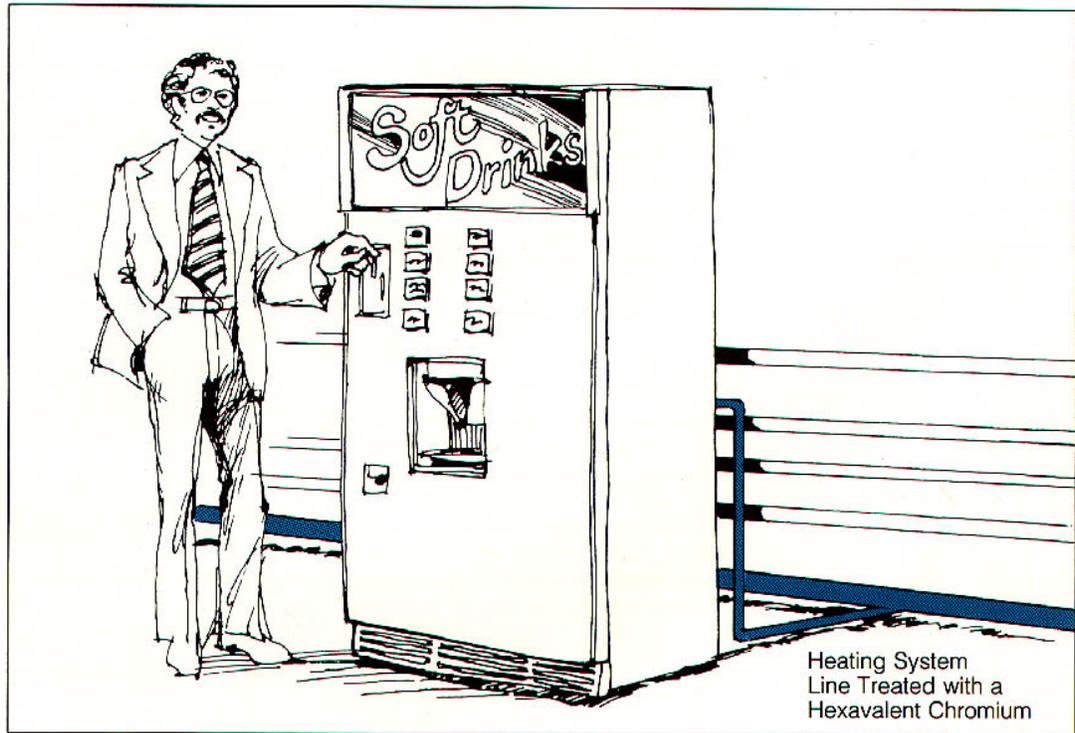
### **Ohio 1994**

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

## Cross-Connection Terms

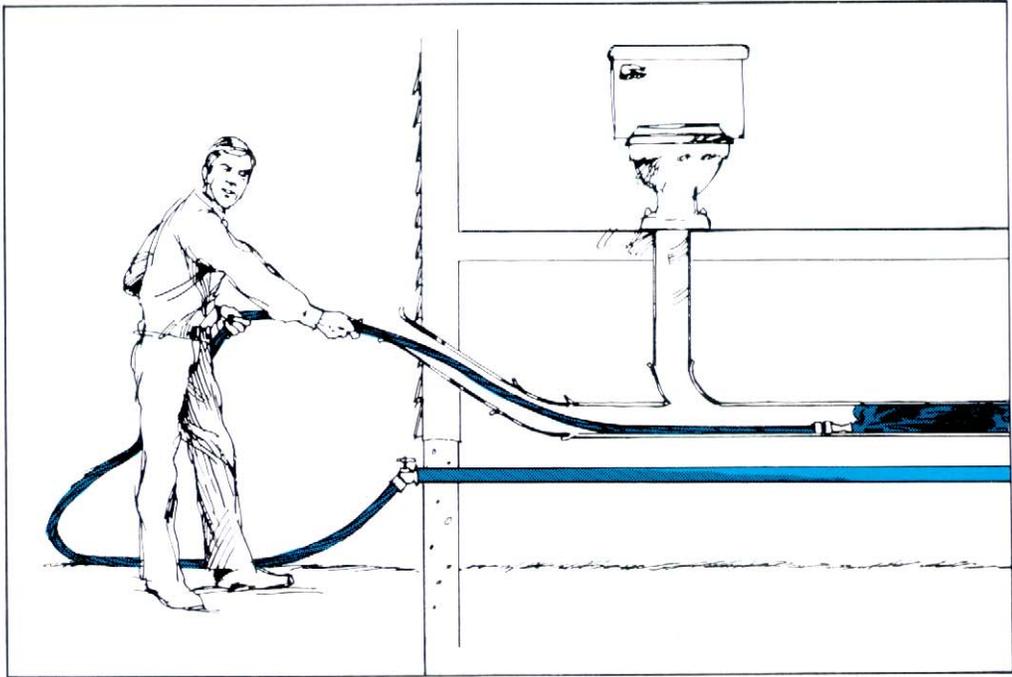
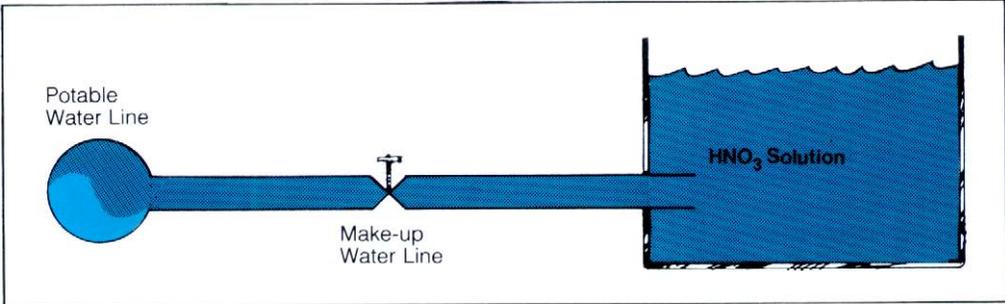
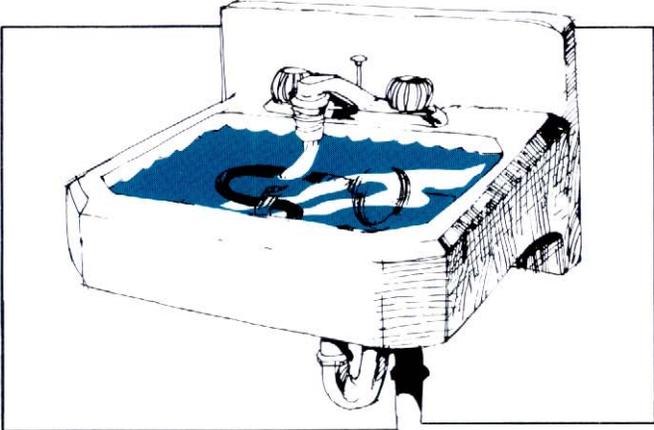
### Cross-connection

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 CO<sub>2</sub> without a backflow preventer. The reason is that the CO<sub>2</sub> will mix in the water and create copper carbonic acid, which is 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**



## Possible Bad Connection



Direct connection from hydrant to pump.



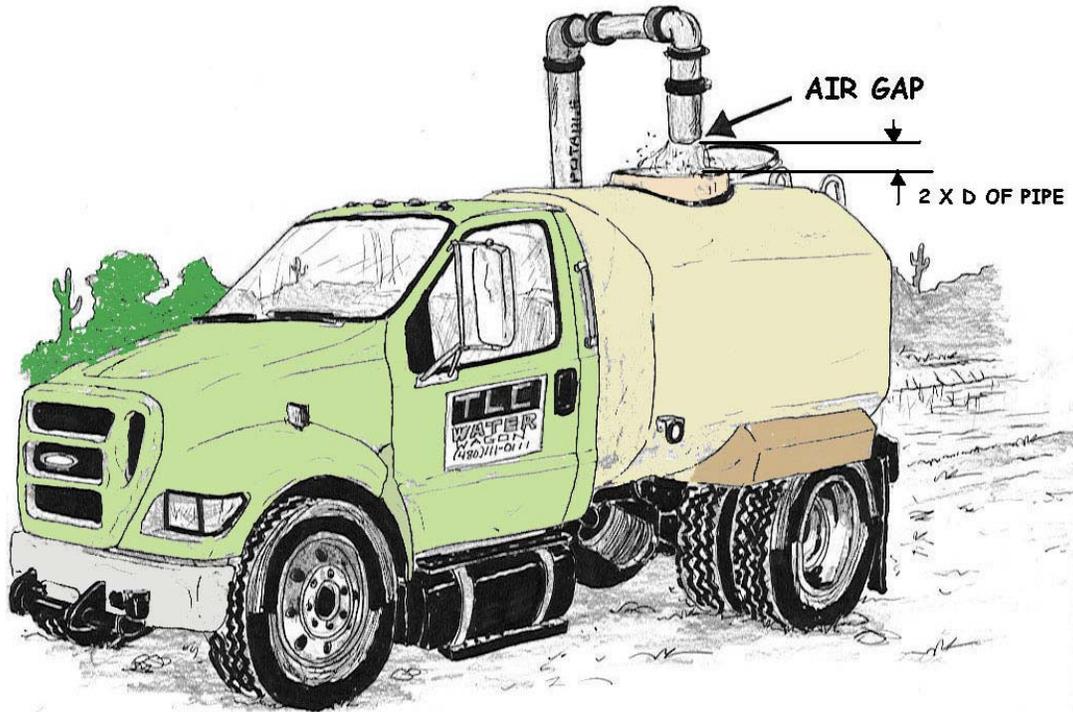
Air Gap



Fitting at hydrant

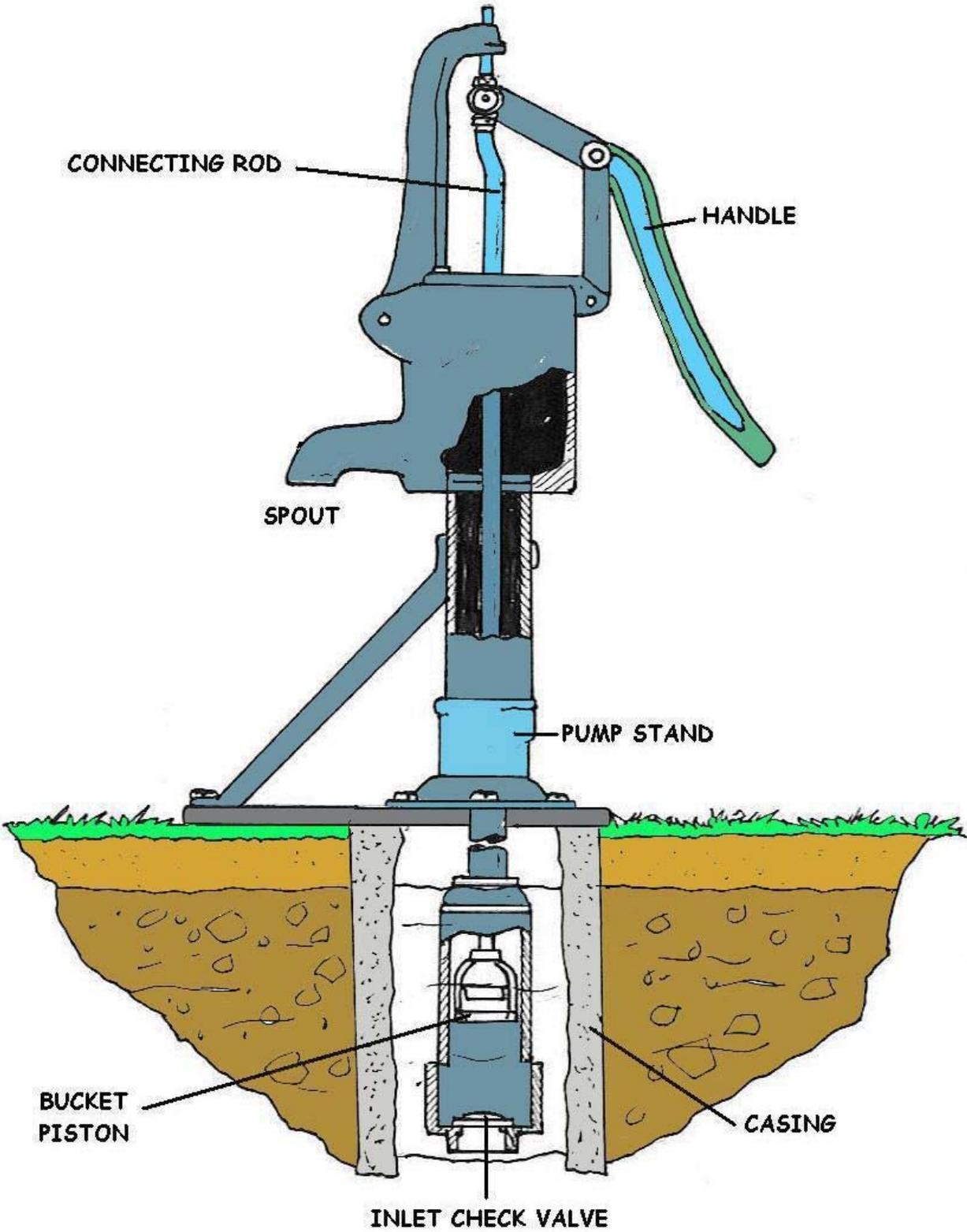


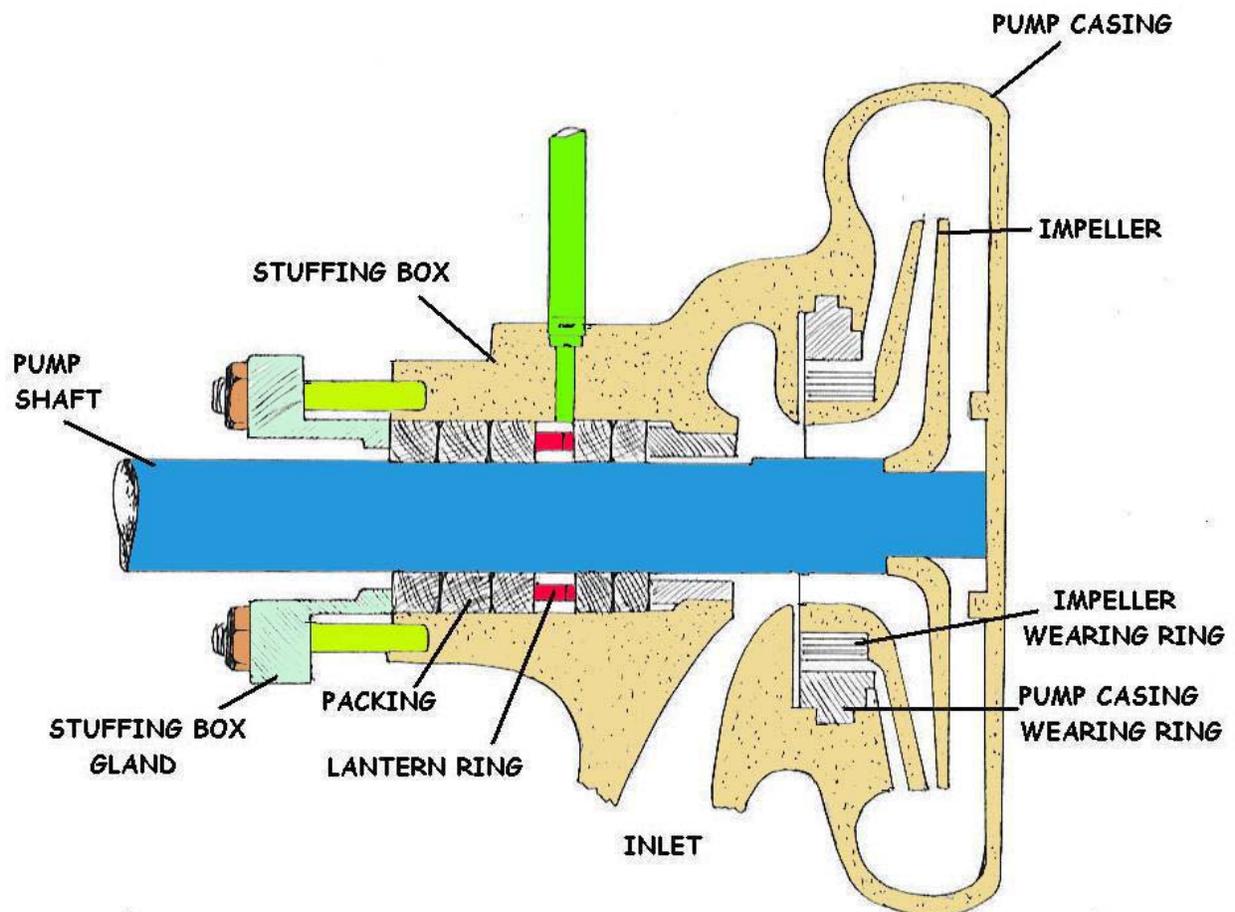
Lines cut but it had been connected to a chemical barrel earlier.



EXAMPLE OF AN AIR GAP

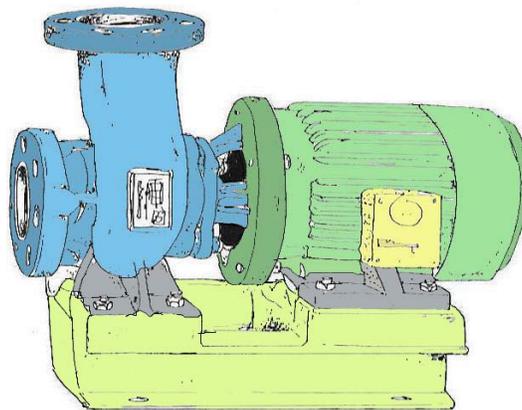
# Pump and Motor Section





A centrifugal pump has two main components:

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



**END SUCTION CENTRIFUGAL PUMP**

## General Pumping Fundamentals

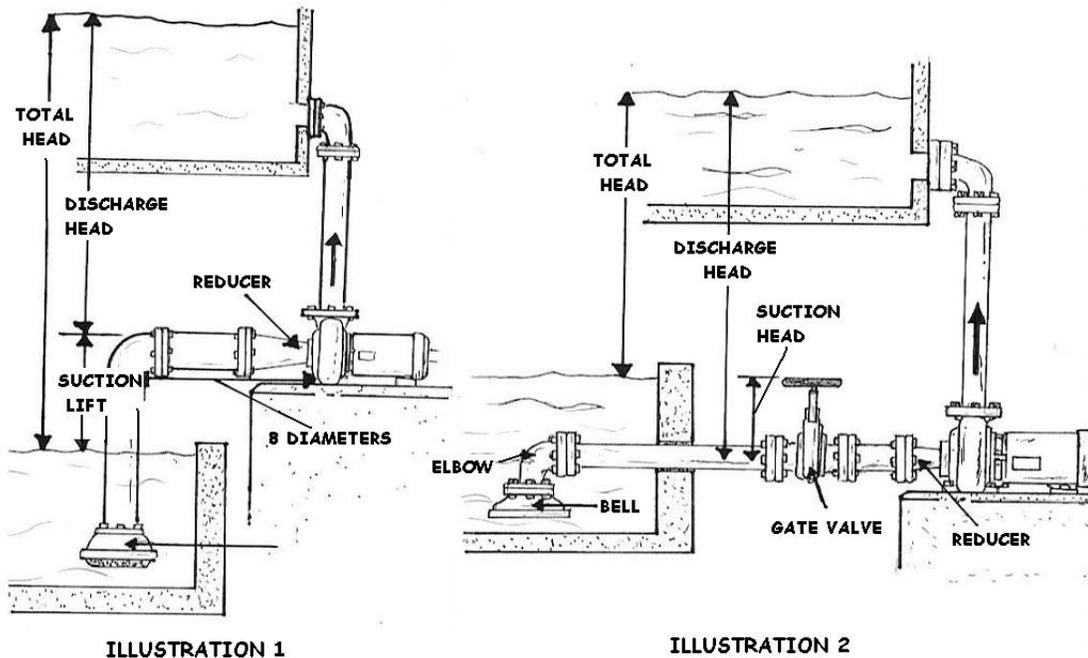


ILLUSTRATION 1

ILLUSTRATION 2

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

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

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

### Points to Note are:

If an elbow and bell are used, they should be at least one pipe diameter from the tank bottom and side. This type of suction piping must have a gate valve which can be used to prevent the reverse flow when the pump has to be removed. In the 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.**



## **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 included between the bearing housing and the impeller.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Troubleshooting:** Locating a problem.

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

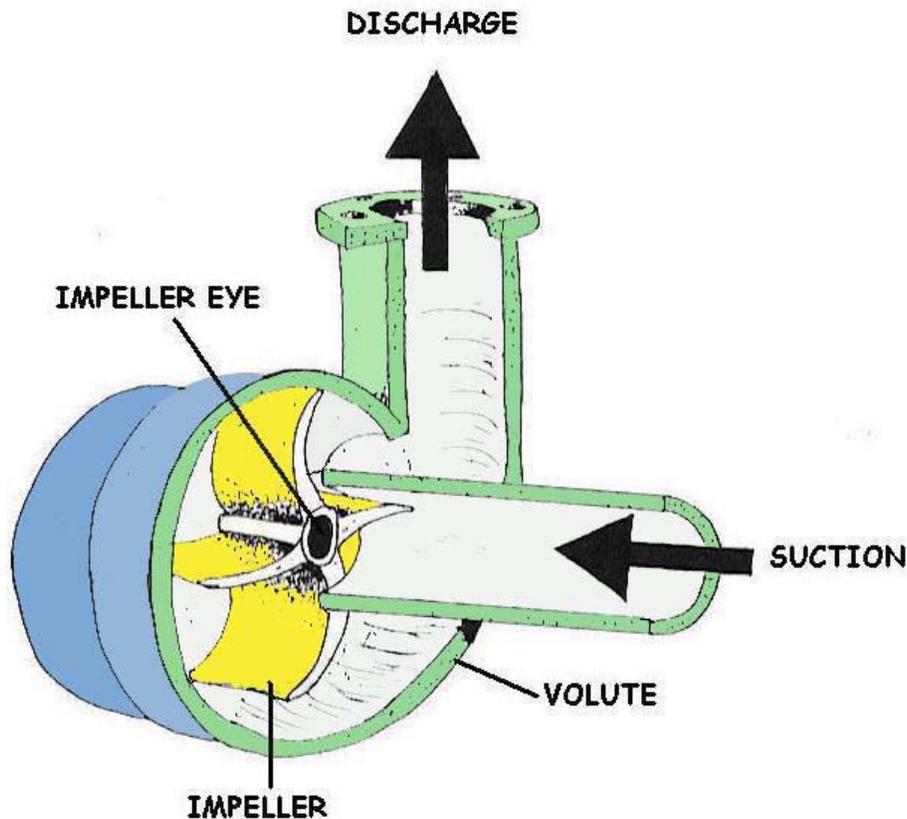
**Vertical pumps:** Pumps in which the center line of the shaft runs vertically.

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

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

## Pumps

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.

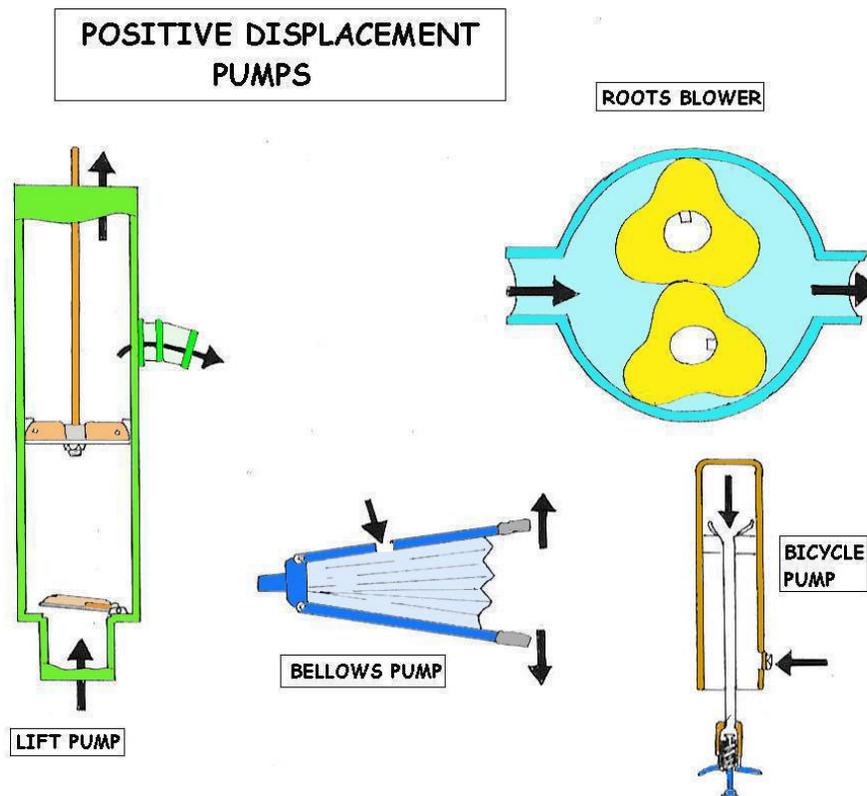
The lift pump has a supply valve and a valve in the piston that allows the liquid to pass around it when the volume of the cylinder is reduced. The delivery in this case is from the upper part of the cylinder, which the piston does not enter.

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 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 fire fighting. Fire fighting force pumps usually have two cylinders feeding one receiver alternately. The air space in the receiver helps to make the water pressure uniform.

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



## Types of Pumps

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

### Dynamic Pumps (Centrifugal Pump)

**Centrifugal pumps are classified into three general categories:**

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

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

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

### Positive Displacement Pumps

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

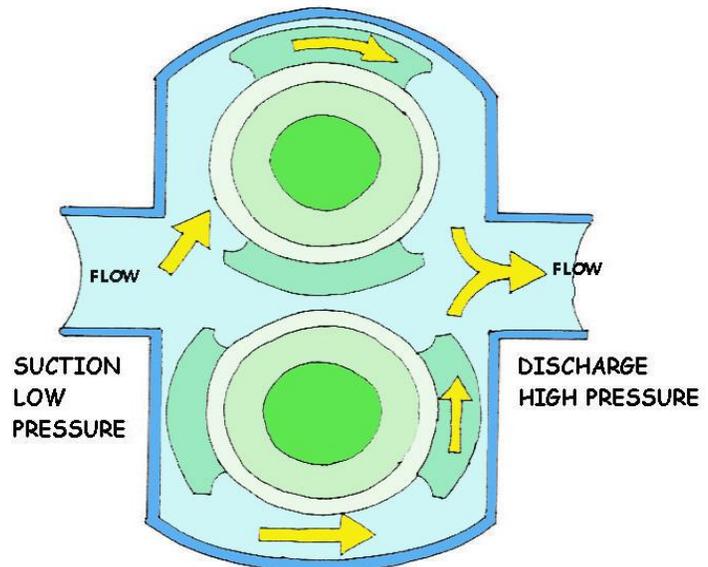
A Positive Displacement Pump, unlike a Centrifugal Pump, will produce the same flow at a given RPM no matter what the discharge pressure is. A Positive Displacement Pump cannot be operated against a closed valve on the discharge side of the pump, i.e. it does not have a shut-off head like a Centrifugal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

#### Types of Positive Displacement Pumps

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

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

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



## Single Rotator

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

## Multiple Rotator

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

***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.

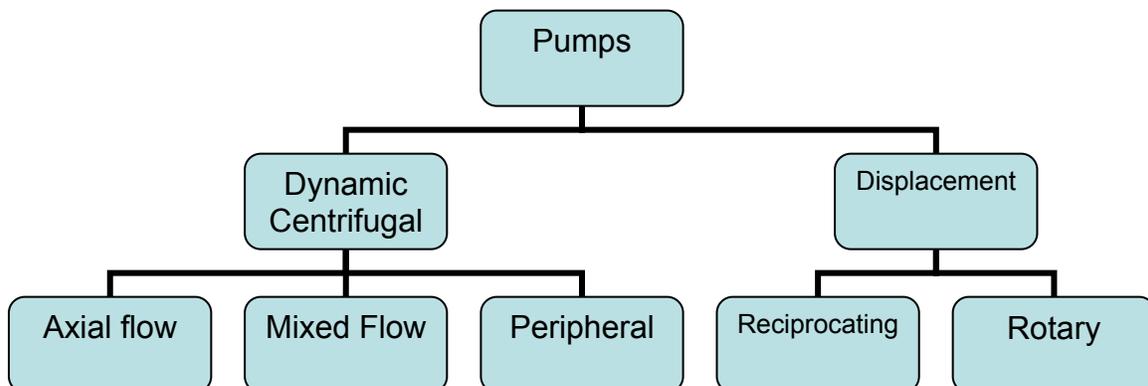
**There are three main types of diaphragm pumps available:**

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

## Pump Categories

Let's cover the essentials first. The key to the whole operation is, of course, the *pump*. And regardless of what type it is (reciprocating piston, centrifugal, turbine or jet-ejector, for either shallow or deep well applications), its purpose is to move water and generate the delivery force we call pressure. Sometimes — with centrifugal pumps in particular — pressure is not referred to in pounds per square inch but rather as the equivalent in elevation, called head. No matter; head in feet divided by 2.31 equals pressure, so it's simple enough to establish a common figure.

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





**Split-Case centrifugal pump.**

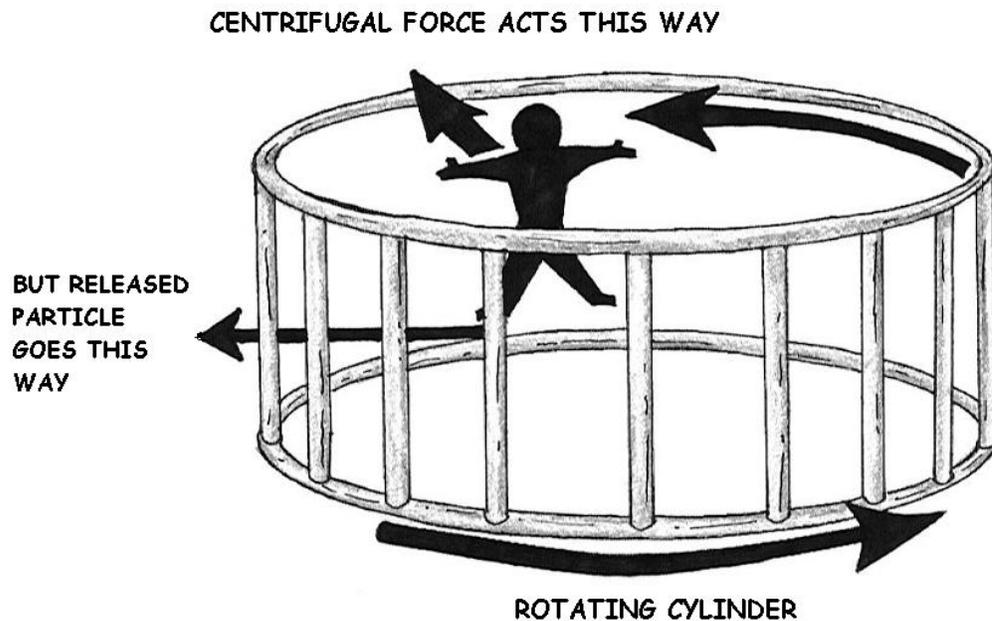


**BFP – 12 inch diameter multi-bowl vertical turbine well pump.**

## Basic Water Pump

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

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



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.

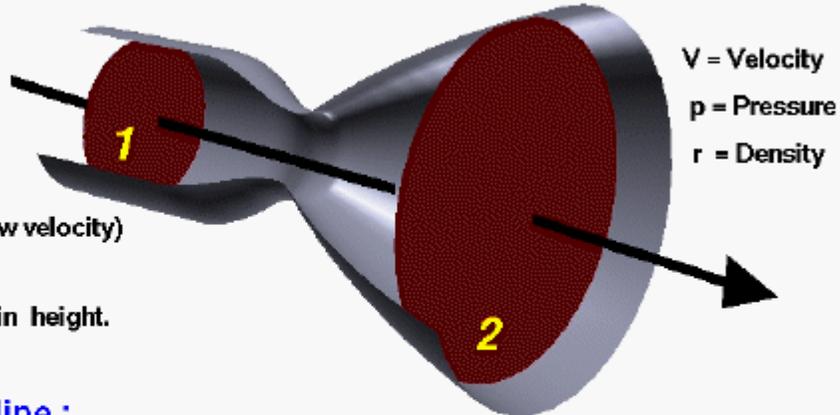


# Bernoulli's Equation

Glenn  
Research  
Center

## Restrictions :

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



## Along a streamline :

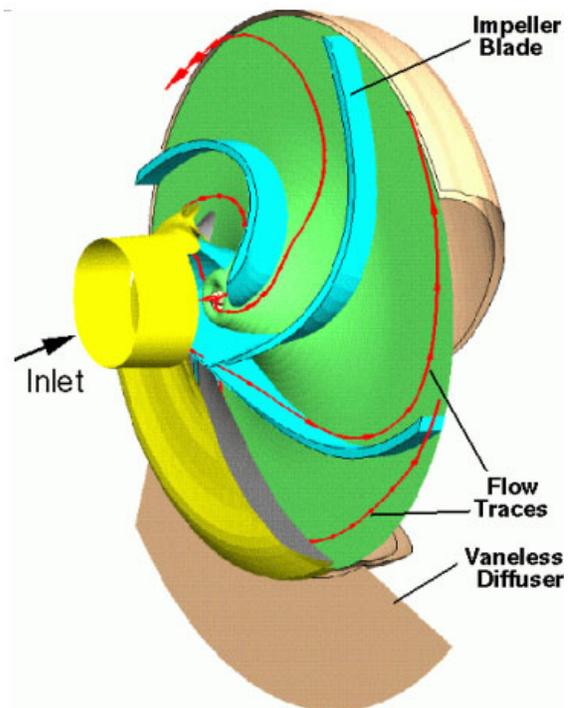
static pressure + dynamic pressure = total pressure

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

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

Her

e 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 Pumps

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

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

**There are three main types of diaphragm pumps:**

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

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

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

**Cavitation**

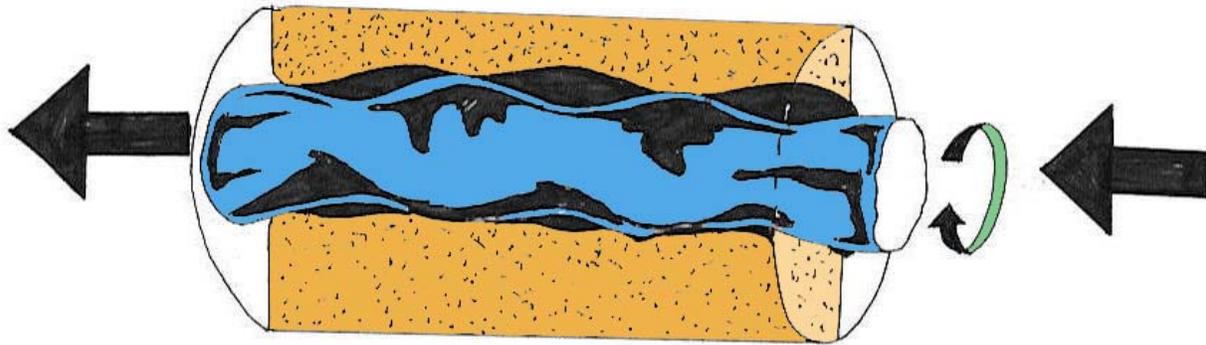
Cavitation is defined as the phenomenon of formation of vapor bubbles of a flowing liquid in a region where the pressure of the liquid falls below its vapor pressure. Cavitation is usually divided into two classes of behavior: inertial (or transient) cavitation and non-inertial cavitation. Inertial cavitation is the process where a void or bubble in a liquid rapidly collapses, producing a shock wave. Such cavitation often occurs in pumps, propellers, impellers, and in the vascular tissues of plants. Non-inertial cavitation is the process in which a bubble in a fluid is forced to oscillate in size or shape due to some form of energy input, such as an acoustic field. Such cavitation is often employed in ultrasonic cleaning baths and can also be observed in pumps, propellers etc.

Cavitation is, in many cases, an undesirable occurrence. In devices such as propellers and pumps, cavitation causes a great deal of noise, damage to components, vibrations, and a loss of efficiency. When the cavitation bubbles collapse, they force liquid energy into very small volumes, thereby creating spots of high temperature and emitting shock waves, the latter of which are a source of noise. The noise created by cavitation is a particular problem for military submarines, as it increases the chances of being detected by passive sonar. Although the collapse of a cavity is a relatively low-energy event, highly localized collapses can erode metals, such as steel, over time. The pitting caused by the collapse of cavities produces great wear on components and can dramatically shorten a propeller's or pump's lifetime. After a surface is initially affected by cavitation, it tends to erode at an accelerating pace. The cavitation pits increase the turbulence of the fluid flow and create crevasses that act as nucleation sites for additional cavitation bubbles. The pits also increase the component's surface area and leave behind residual stresses. This makes the surface more prone to stress corrosion.

**Impeller**

An impeller is a rotating component of a centrifugal pump, usually made of iron, steel, aluminum or plastic, which transfers energy from the motor that drives the pump to the fluid being pumped by accelerating the fluid outwards from the center of rotation. The velocity achieved by the impeller transfers into pressure when the outward movement of the fluid is confined by the pump casing. Impellers are usually short cylinders with an open inlet (called an eye) to accept incoming fluid, vanes to push the fluid radially, and a splined center to accept a driveshaft.

## Progressing Cavity Pump



### PROGRESSIVE CAVITY PUMP

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. As the rotor turns within the stator, cavities are formed which progress from the suction to the discharge end of the pump, conveying the pumped material. The continuous seal between the rotor and the stator helices keeps the fluid moving steadily at a fixed flow rate proportional to the pump's rotational speed. 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.

#### More on the Progressive Cavity Pump

A progressive cavity pump is also known as a progressing cavity pump, eccentric screw pump, or even just cavity pump, and as is common in engineering generally, these pumps can often be referred to by using a generalized trademark. Hence, names can vary from industry to industry and even regionally; examples include: Mono pump, Moyno pump, Mohno pump, and Nemo pump.

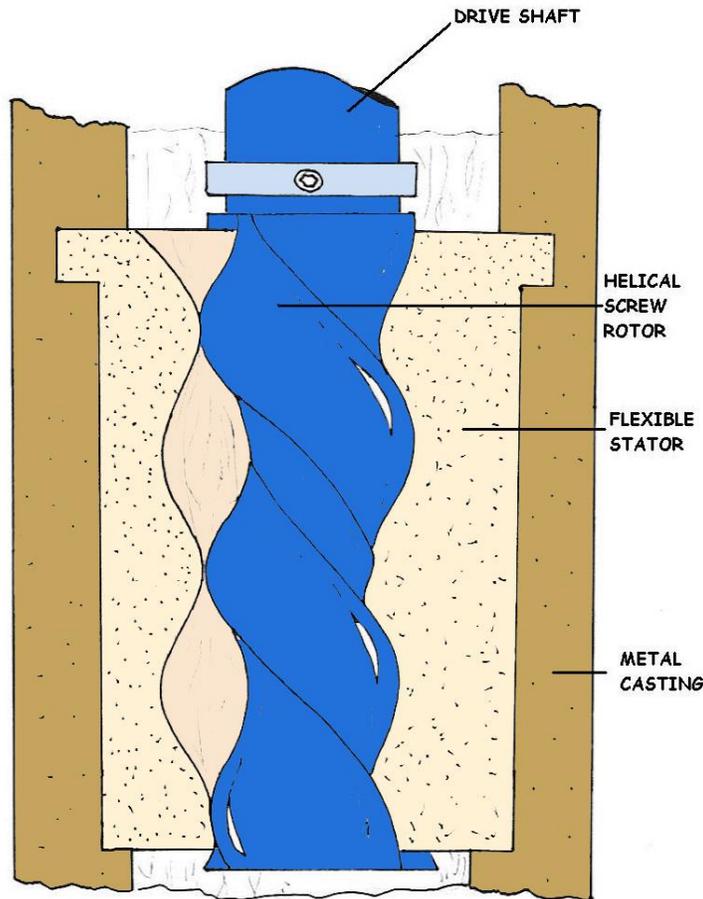
This type of pump transfers fluid by means of the progress, through the pump, of a sequence of small, fixed shape, discrete cavities, as its rotor is turned. This leads to the volumetric flow rate being proportional to the rotation rate (bi-directionally) and to low levels of shearing being applied to the pumped fluid. Hence these pumps have application in fluid metering and pumping of viscous or shear sensitive materials. It should be noted that the cavities taper down toward their ends and overlap with their neighbors, so that, in general, no flow pulsing is caused by the arrival of cavities at the outlet, other than caused by compression of the fluid or pump components.

The principle of this pumping technique is frequently misunderstood; often it is believed to occur due to a dynamic effect caused by drag, or friction against the moving teeth of the screw rotor. However, in reality it is due to sealed cavities, like a piston pump, and so has similar operational characteristics, such as being able to pump at extremely low rates, even to high pressure, revealing the effect to be purely positive displacement.

The mechanical layout that causes the cavities to, uniquely, be of fixed dimensions as they move through the pump, is hard to visualize (its essentially 3D nature renders diagrams quite ineffective for explanation), but it is accomplished by the preservation in shape of the gap formed between a helical shaft and a two start, twice the wavelength and double the diameter, helical hole, as the shaft is "**rolled**" around the inside surface of the hole. The motion of the rotor being the same as the smaller gears of a planetary gears system. This form of motion gives rise to the curves called Hypocycloids.

In order to produce a seal between cavities, the rotor requires a circular cross-section and the stator an oval one. The rotor so takes a form similar to a corkscrew, and this, combined with the off-center rotary motion, leads to the name; **Eccentric screw pump**.

Different rotor shapes and rotor/stator pitch ratios exist, but are specialized in that they don't generally allow complete sealing, so reducing low speed pressure and flow rate linearity, but improving actual flow rates, for a given pump size, and/or the pump's solids handling ability.



### PROGRESSIVE CAVITY PUMP

At a high enough pressure the sliding seals between cavities will leak some fluid rather than pumping it, so when pumping against high pressures a longer pump with more cavities is more effective, since each seal has only to deal with the pressure difference between adjacent cavities. Pumps with between two and a dozen or so cavities exist.

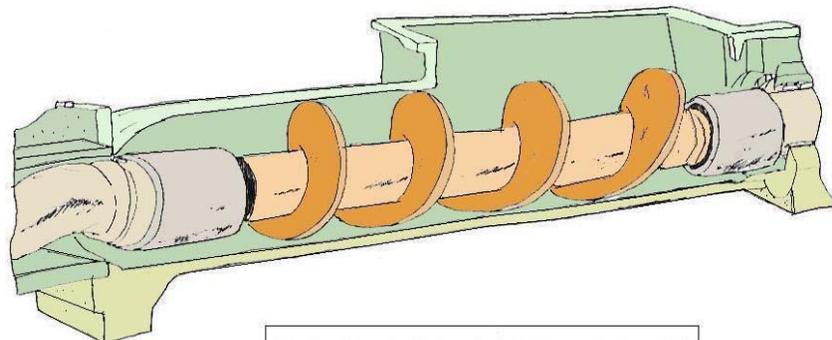
In operation, progressive cavity pumps are fundamentally fixed flow rate pumps, like piston pumps and peristaltic pumps. This type of pump needs a fundamentally different understanding to the types of pumps to which people are more commonly first introduced, namely ones that can be thought of as generating a pressure. This can lead to the mistaken assumption that all pumps can have their flow rates adjusted by using a valve attached to their outlet, but with this type of pump this assumption is a problem, since such a valve will have practically no effect on the flow rate and completely closing it will involve very high, probably damaging, pressures being generated. In order to prevent this, pumps are often fitted with cut-off pressure switches, burst disks (deliberately weak and easily replaced points), or a bypass pipe that allows a variable amount of a fluid to return to the inlet. With a bypass fitted, a fixed flow rate pump is effectively converted to a fixed pressure one.

At the points where the rotor touches the stator, the surfaces are generally traveling transversely, so small areas of sliding contact occur, these areas need to be lubricated by the fluid being pumped (Hydrodynamic lubrication), this can mean that more torque is required for starting, and if allowed to operate without fluid, called '**run dry**', rapid deterioration of the stator can result.

While progressive cavity pumps offer long life and reliable service transporting thick or lumpy fluids, abrasive fluids will significantly shorten the life of the stator. However, slurries (particulates in a medium) can be pumped reliably as long as the medium is viscous enough to maintain a lubrication layer around the particles and so provide protection to the stator.

Specific designs involve the rotor of the pump being made of a steel, coated in a smooth hard surface, normally chromium, with the body (the stator) made of a molded elastomer inside a metal tube body. The Elastomer core of the stator forms the required complex cavities. The rotor is held against the inside surface of the stator by angled link arms, bearings (which have to be within the fluid) allowing it to roll around the inner surface (un-driven). Elastomer is used for the stator to simplify the creation of the complex internal shape, created by means of casting, and also improves the quality and longevity of the seals by progressively swelling due to absorption of water and/or other common constituents of pumped fluids. Elastomer/pumped fluid compatibility will thus need to be taken into account.

Two common designs of stator are the "**Equal-walled**" and the "**Unequal walled**". The latter, having greater elastomer wall thickness at the peaks, allows larger-sized solids to pass through because of its increased ability to distort under pressure.



**PROGRESSIVE CAVITY PUMP**

## Key Pump Words

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

**S.G. :** Specific gravity. The weight of liquid in comparison to water at approx 20 deg c (SG = 1).

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

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

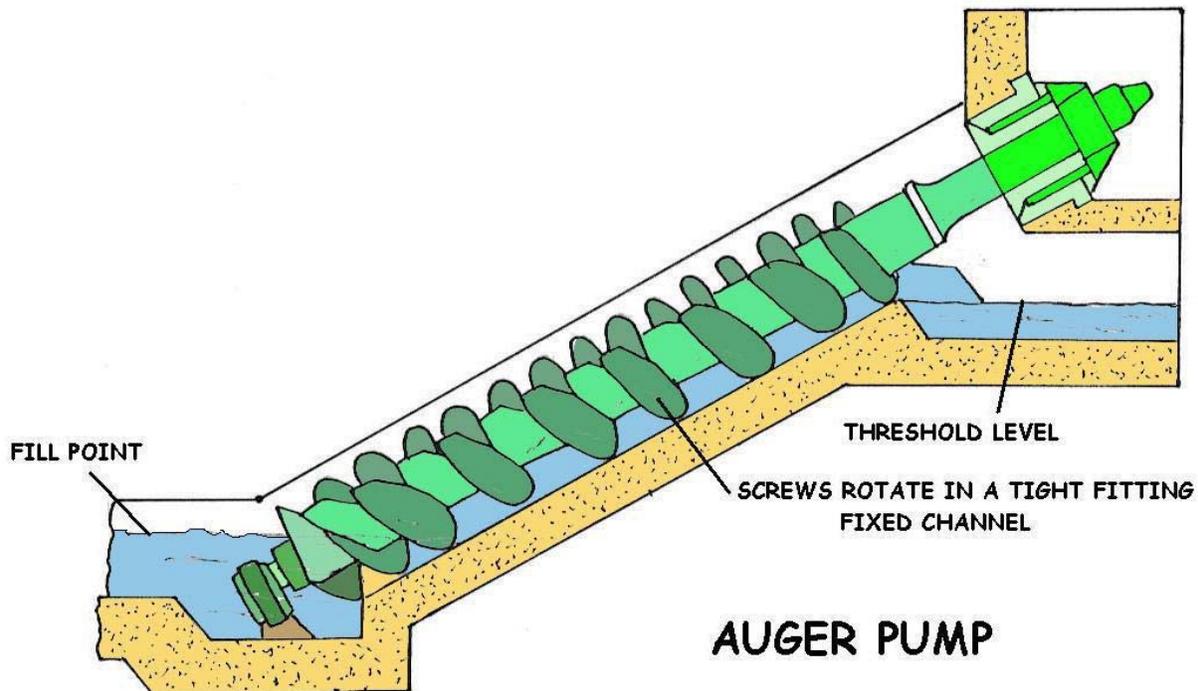
**Viscosity:** A measure of a liquid's resistance to flow. i.e.: how thick it is. The viscosity determines the type of pump used, the speed it can run at, and with gear pumps, the internal clearances required.

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



## Screw or Auger Pump

The Archimedes' screw, Archimedean screw, or screw pump is a machine historically used for transferring water from a low-lying body of water into irrigation ditches. It was one of several inventions and discoveries traditionally attributed to Archimedes in the 3rd century BC.



The machine consists of a screw inside a hollow pipe. Some attribute its invention to Archimedes in the 3rd century BC, while others attribute it to Nebuchadnezzar II in the 7th century BC. A screw can be thought of as an inclined plane (another simple machine) wrapped around a cylinder.

The screw is turned (usually by a windmill or by manual labor). As the bottom end of the tube turns, it scoops up a volume of water. This amount of water will slide up in the spiral tube as the shaft is turned, until it finally pours out from the top of the tube and feeds the irrigation system.

The contact surface between the screw and the pipe does not need to be perfectly water-tight because of the relatively large amount of water being scooped at each turn with respect to the angular speed of the screw. Also, water leaking from the top section of the screw leaks into the previous one and so on. So a sort of equilibrium is achieved while using the machine, thus preventing a decrease in efficiency.

The "**screw**" does not necessarily need to turn inside the casing, but can be allowed to turn with it in one piece. A screw could be sealed with pitch or some other adhesive to its casing, or, cast as a single piece in bronze, as some researchers have postulated as being the devices used to irrigate Nebuchadnezzar II's Hanging Gardens of Babylon. Depictions of Greek and Roman water screws show the screws being powered by a human treading on the outer casing to turn the entire apparatus as one piece, which would require that the casing be rigidly attached to the screw.

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.



## 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's intake is located between the motor and the pump and is normally screened to prevent sediment from entering the pump and damaging the impellers.

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

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

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



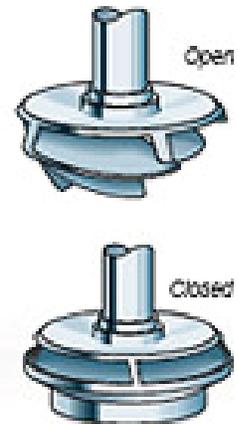
**Insertion of motor spline into the pump keyway.**

**Cut away of a small submersible pump.**

## Understanding the Operation of a Vertical Turbine Pump

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

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



### Bowl Assembly

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

### Drivers

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

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

### Discharge Head Assembly

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

### Column Assembly

The shaft and column assembly provides a connection between the head and pump bowls. The line shaft transfers the power from the motor to the impellers and the column carries the water to the surface. The line shaft on a turbine pump may be either water lubricated or oil lubricated. The oil-lubricated pump has an enclosed shaft into which oil drips, lubricating the bearings. The water-lubricated pump has an open shaft. The bearings are lubricated by the pumped water.

If there is a possibility of fine sand being pumped, select the oil lubricated pump because it will keep the sand out of the bearings. If the water is for domestic or livestock use, it must be free of oil and a water-lubricated pump must be used.

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

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

Impellers used in turbine pumps may be either semi-open or enclosed. The vanes on semi-open impellers are open on the bottom and they rotate with a close tolerance to the bottom of the pump bowl. The tolerance is critical and must be adjusted when the pump is new. During the initial break-in period the line shaft couplings will tighten, therefore, after about 100 hours of operation, the impeller adjustments should be checked. After break-in, the tolerance must be checked and adjusted every three to five years or more often if pumping sand.

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

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

**Column assembly will consist of:**

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

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

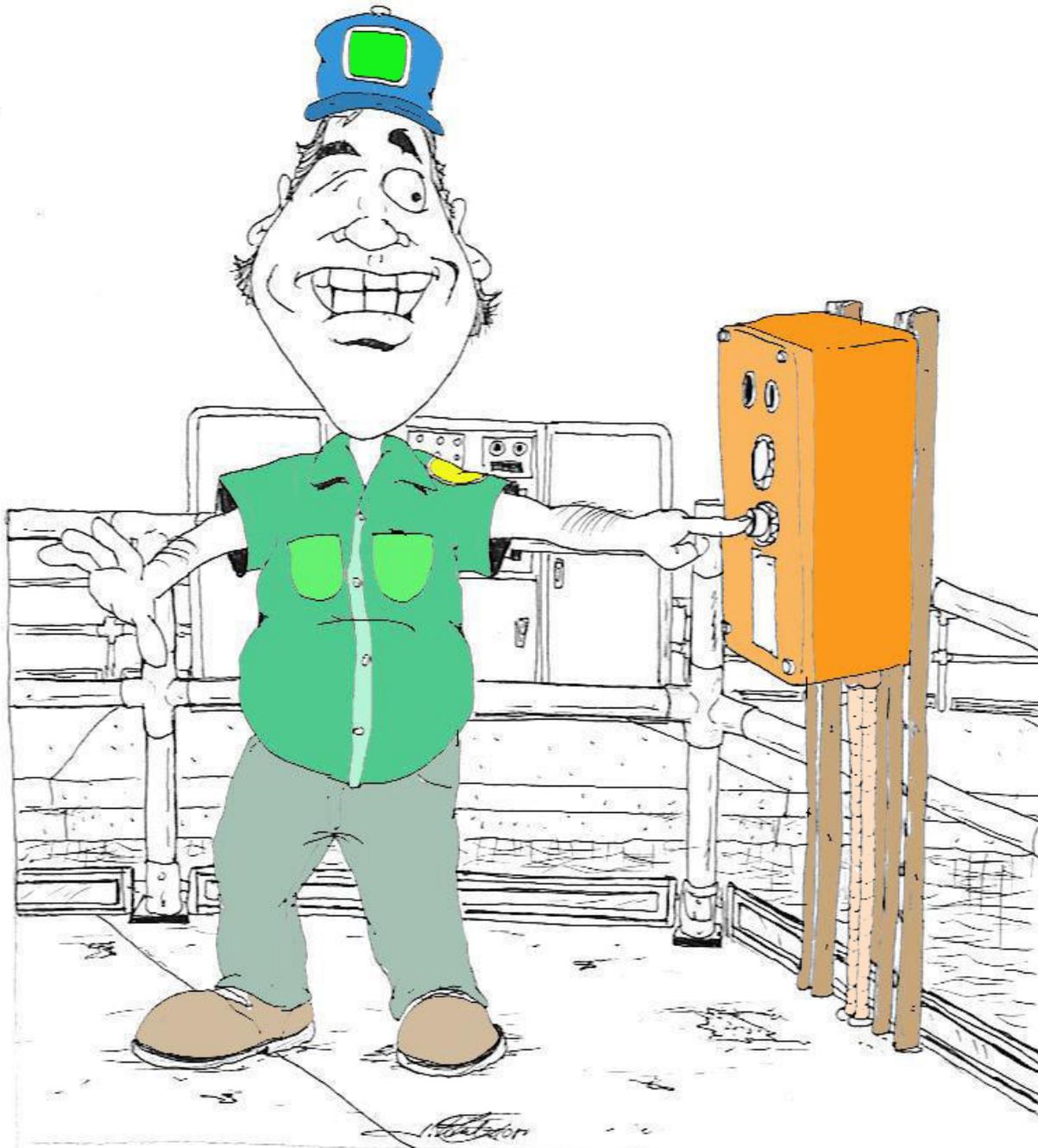
**Bowl Assemblies**

The bowl consists of:

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

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

Impeller adjustments are made by tightening or loosening a nut on the top of the head assembly. Impeller adjustments are normally made by lowering the impellers to the bottom of the bowls and adjusting them upward. The amount of upward adjustment is determined by how much the line shaft will stretch during pumping. The adjustment must be made based on the lowest possible pumping level in the well. The proper adjustment procedure is often provided by the pump manufacturer.



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

## Basic Operation of a Vertical Turbine

### Pre-start

Before starting the pump, the following checks should be made:

1. Rotate the pump shaft by hand to make sure the pump is free and the impellers are correctly positioned.
2. Is the head shaft adjusting nut properly locked into position?
3. Has the driver been properly lubricated in accordance with the instructions furnished with the driver?
4. Has the driver been checked for proper rotation? If not, the pump must be disconnected from the driver before checking. The driver must rotate **COUNTER CLOCKWISE** when looking down at the top of the driver.
5. Check all connections to the driver and control equipment.
6. Check that all piping connections are tight.
7. Check all anchor bolts for tightness.
8. Check all bolting and tubing connections for tightness (driver mounting bolts, flanged coupling bolts, glad plate bolts, seal piping, etc.).
9. On pumps equipped with stuffing box, make sure the gland nuts are only finger tight — **DO NOT TIGHTEN** packing gland before starting.
10. On pumps equipped with mechanical seals, clean fluid should be put into the seal chamber. With pumps under suction pressure this can be accomplished by bleeding all air and vapor out of the seal chamber and allowing the fluid to enter. With pumps not under suction pressure, the seal chamber should be flushed liberally with clean fluid to provide initial lubrication. Make sure the mechanical seal is properly adjusted and locked into place.

**NOTE: After initial start-up, pre-lubrication of the mechanical seal will usually not be required, as enough liquid will remain in the seal chamber for subsequent start-up lubrication.**

11. On pumps equipped with enclosed lineshaft, lubricating liquid must be available and should be allowed to run into the enclosing tube in sufficient quantity to thoroughly lubricate all lineshaft bearings.

### Initial Start-Up

1. If the discharge line has a valve in it, it should be partially open for initial starting — Min. 10%.
2. Start lubrication liquid flow on enclosed lineshaft units.
3. Start the pump and observe the operation. If there is any difficulty, excess noise or vibration, stop the pump immediately.
4. Open the discharge valve as desired.
5. Check complete pump and driver for leaks, loose connections, or improper operation.
6. If possible, the pump should be left running for approximately ½ hour on the initial start-up. This will allow the bearings, packing or seals, and other parts to “run-in” and reduce the possibility of trouble on future starts.

**NOTE: If abrasives or debris are present upon startup, the pump should be allowed to run until the pumpage is clean. Stopping the pump when handling large amounts of abrasives (as sometimes present on initial starting) may lock the pump and cause more damage than if the pump is allowed to continue operation.**

**CAUTION: Every effort should be made to keep abrasives out of lines, sumps, etc. so that abrasives will not enter the pump.**

### **Stuffing Box Adjustment**

On the initial starting it is very important that the packing gland not be tightened too much. New packing must be “run in” properly to prevent damage to the shaft and shortening of the packing life. The stuffing box must be allowed to leak for proper operation. The proper amount of leakage can be determined by checking the temperature of the leakage; this should be cool or just lukewarm — **NOT HOT**. When adjusting the packing gland, bring both nuts down evenly and in small steps until the leakage is reduced as required. The nuts should only be tightened about ½ turn at a time at 20 to 30 minute intervals to allow the packing to “run in”. Under proper operation, a set of packing will last a long time. Occasionally a new ring of packing will need to be added to keep the box full. After adding two or three rings of packing, or when proper adjustment cannot be achieved, the stuffing box should be cleaned completely of all old packing and re-packed.

### **Lineshaft Lubrication**

Open lineshaft bearings are lubricated by the pumped fluid and on close coupled units (less than 30' long), will usually not require pre or post lubrication. Enclosed lineshaft bearings are lubricated by extraneous liquid (usually oil or clean water), which is fed to the tension nut by either a gravity flow system or pressure injection system. The gravity flow system utilizing oil is the most common arrangement. The oil reservoir must be kept filled with a good quality light turbine oil (about 150 SSU at operating temperature) and adjusted to feed 10 to 12 drops per minute plus one (1) drop per 100' of setting. Injection systems are designed for each installation — injection pressure and quantity of lubricating liquid will vary. Refer to packing slip or separate instruction sheet for requirements when unit is designed for injection lubrication.

### **General Maintenance Section**

A periodic inspection is recommended as the best means of preventing breakdown and keeping maintenance costs to a minimum. Maintenance personnel should look over the whole installation with a critical eye each time the pump is inspected — a change in noise level, amplitude or vibration, or performance can be an indication of impending trouble. Any deviation in performance or operation from what is expected can be traced to some specific cause. Determination of the cause of any misperformance or improper operation is essential to the correction of the trouble — whether the correction is done by the user, the dealer or reported back to the factory. Variances from initial performance will indicate changing system conditions or wear or impending breakdown of unit.

Deep well turbine pumps must have correct alignment between the pump and the power unit. Correct alignment is made easy by using a head assembly that matches the motor and column/pump assembly. It is very important that the well is straight and plumb. The pump column assembly must be vertically aligned so that no part touches the well casing. Spacers are usually attached to the pump column to prevent the pump assembly from touching the well casing. If the pump column does touch the well casing, vibration will wear holes in the casing. A pump column out of vertical alignment may also cause excessive bearing wear.

The head assembly must be mounted on a good foundation at least 12 inches above the ground surface. A foundation of concrete (Figure 7) provides a permanent and trouble-free installation. The foundation must be large enough to allow the head assembly to be securely fastened. The foundation should have at least 12 inches of bearing surface on all sides of the well. In the case of a gravel-packed well, the 12-inch clearance is measured from the outside edge of the gravel packing.

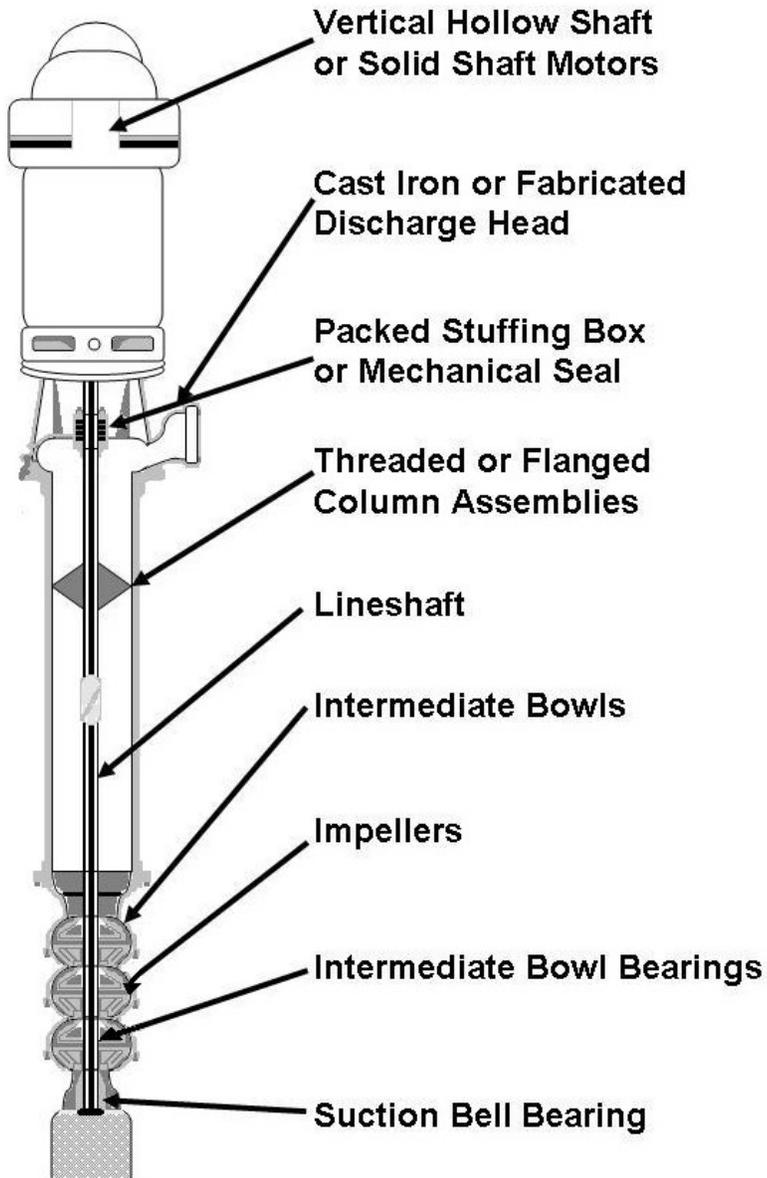
## Vertical Turbine Pump



**Large Diameter Submersible Pump, Motor, and Column Pipe**

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

## Common Elements of Vertical Turbines



Above, Vertical Turbine Pump Being Removed (notice line shaft)

Below  
Closed Pump Impeller

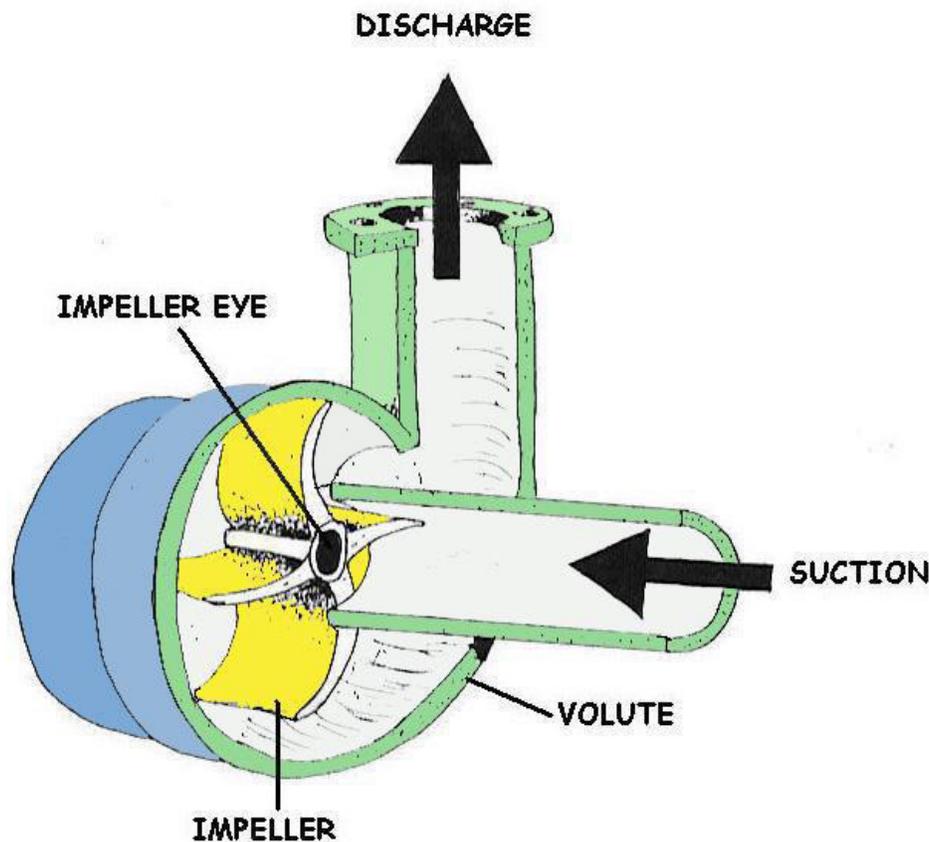


## Centrifugal Pump

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

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

In operation, a centrifugal pump “slings” liquid out of the impeller via centrifugal force. One fact that must always be remembered: A pump does not create pressure, it only provides flow. Pressure is a just an indication of the amount of resistance to flow. Centrifugal pumps may be classified in several ways. For example, they may be either **SINGLE STAGE** or **MULTI-STAGE**. A single-stage pump has only one impeller. A multi-stage pump has two or more impellers housed together in one casing.



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.

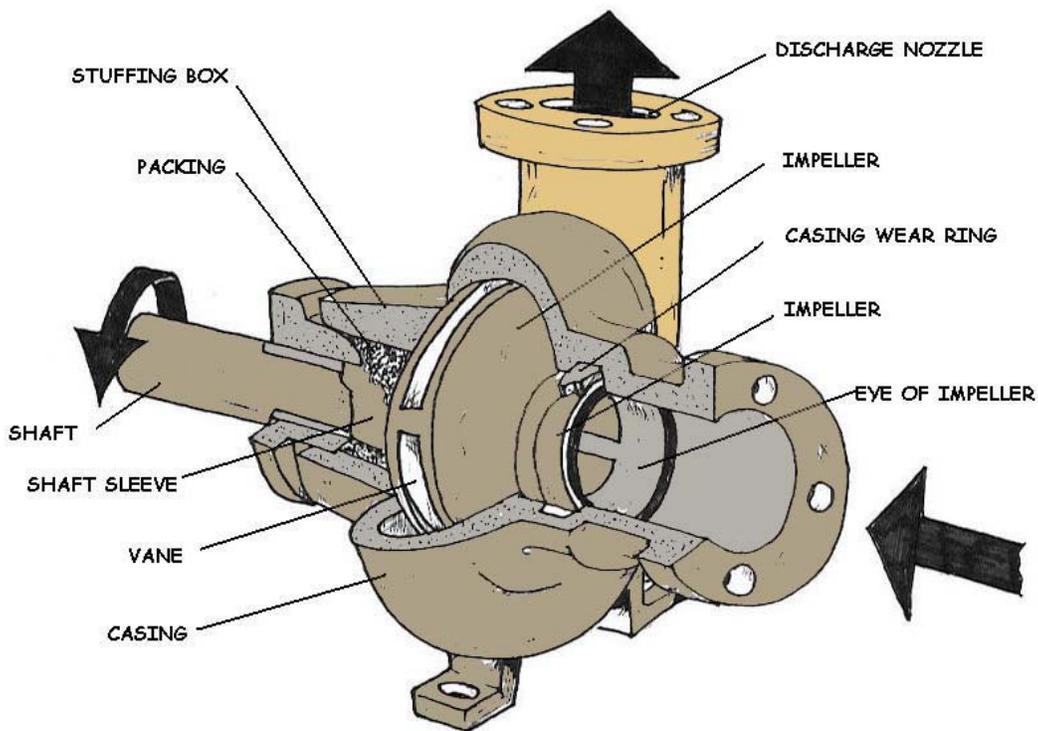
Recirculation lines are installed on some centrifugal pumps to prevent the pumps from overheating and becoming vapor bound, in case the discharge is entirely shut off or the flow of fluid is stopped for extended periods.

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).

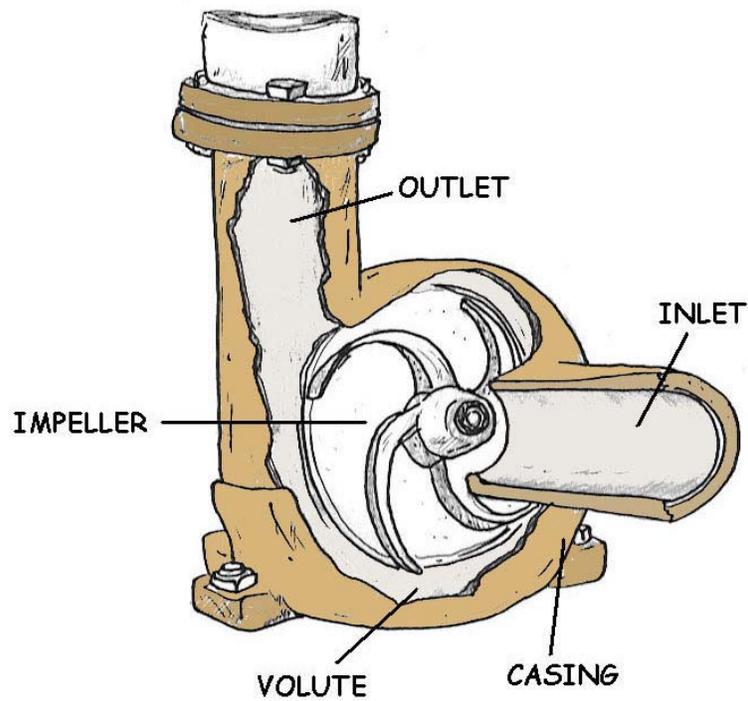
Water flinger rings are fitted on the shaft between the packing gland and the pump bearing housing. These flingers prevent water in the stuffing box from flowing along the shaft and entering the bearing housing.

**Let's look at the components of the centrifugal pump.**

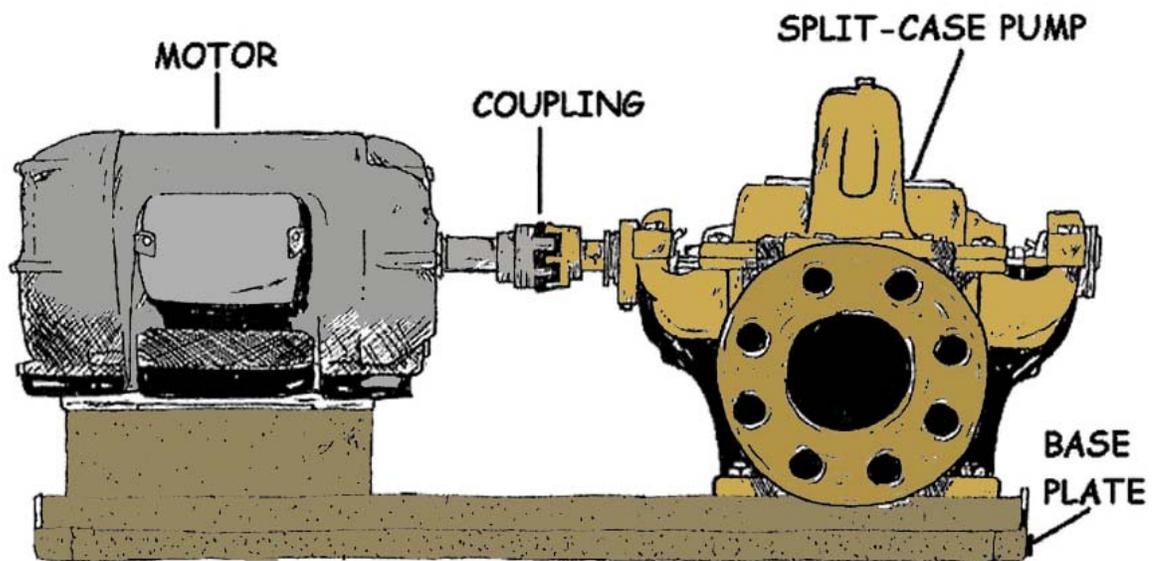


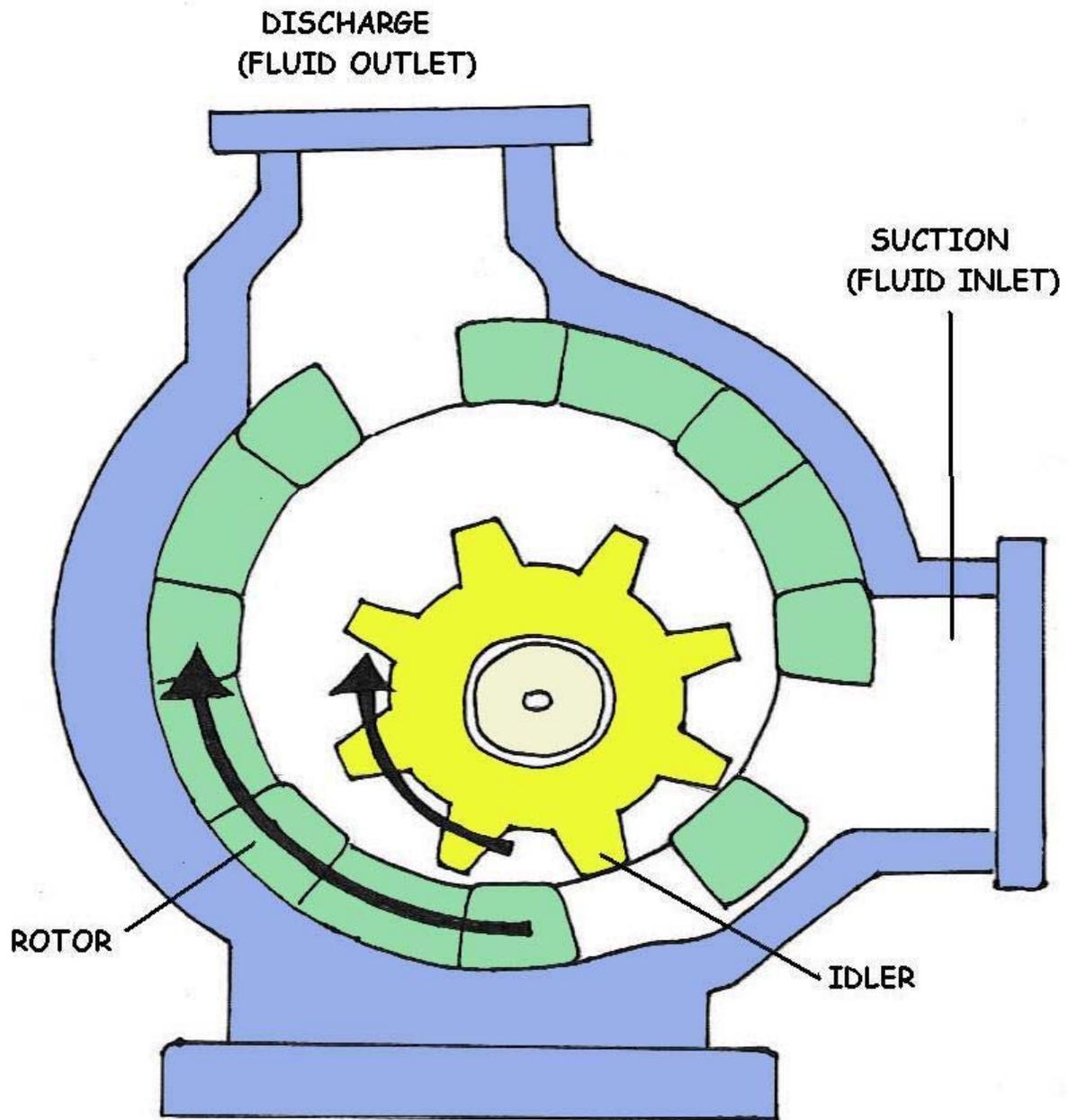
**Centrifugal Pump**

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.



*These pictures illustrate the components that are common to most pump assemblies.*





**GEAR PUMP**

## NPSH - Net Positive Suction Head

If you accept that a pump creates a partial vacuum and atmospheric pressure forces water into the suction of the pump, then you will find NPSH a simple concept.

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

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

Where:

'p'= atmospheric pressure,

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

'v'= liquid vapor pressure

'f'= friction loss

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

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

NPSH(r) is the Net Positive Suction Head Required by the pump, which is read from the pump performance curve. (Think of NPSH(r) as friction loss caused by the entry to the pump suction.)

## Affinity Laws

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

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

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

If, for example, the pump speed were doubled:

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

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

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

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

From the laws of Affinity:

1) Capacity varies directly or:

$$1.14 \times 210 \text{ GPM} = 240 \text{ GPM}$$

2) Head varies as the square or:

$$1.14 \times 1.14 \times 75 = 97.5' \text{ TDH}$$

3) BHP varies as the cube or:

$$1.14 \times 1.14 \times 1.14 \times 5.2 = 7.72 \text{ BHP}$$

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

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

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

## Suction Lift

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

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

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

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

For Water it is:

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

Thus, 34 feet is the theoretical maximum suction lift for a pump pumping cold water at sea level. No pump can attain a suction lift of 34 ft; however, well designed ones can reach 25 ft quite easily. You will note, from the equation above, that specific gravity can have a major effect on suction lift. For example, the theoretical maximum lift for brine (Specific Gravity = 1.2) at sea level is 28 ft.. The realistic maximum is around 20ft. Remember to always factor in specific gravity if the liquid being pumped is anything but clear, cold (68 degrees F) water.

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

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

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

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

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

A. NPSH (r) EXCEEDS NPSH (a)

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

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

## **Affinity Laws - Centrifugal Pumps**

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

### **Affinity laws**

a. The flow changes proportionally to speed

i.e.: double the speed / double the flow

b. The pressure changes by the square of the difference

i.e.: double the speed / multiply the pressure by 4

c. The power changes by the cube of the difference

i.e.: double the speed / multiply the power by 8

### **Notes:**

1. These laws apply to operating points at the same efficiency.

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

## Pump 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 discharged valve closed for a **SHORT** period of time. Remember the motor sends energy along the shaft, and if the water is in the volute too long it will heat up and create steam. Not good!

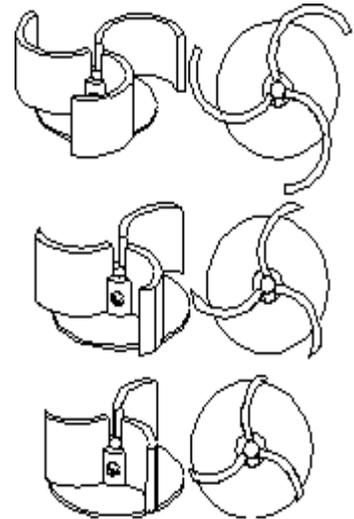
**Impellers are designed in various ways. We will look at:**

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

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.

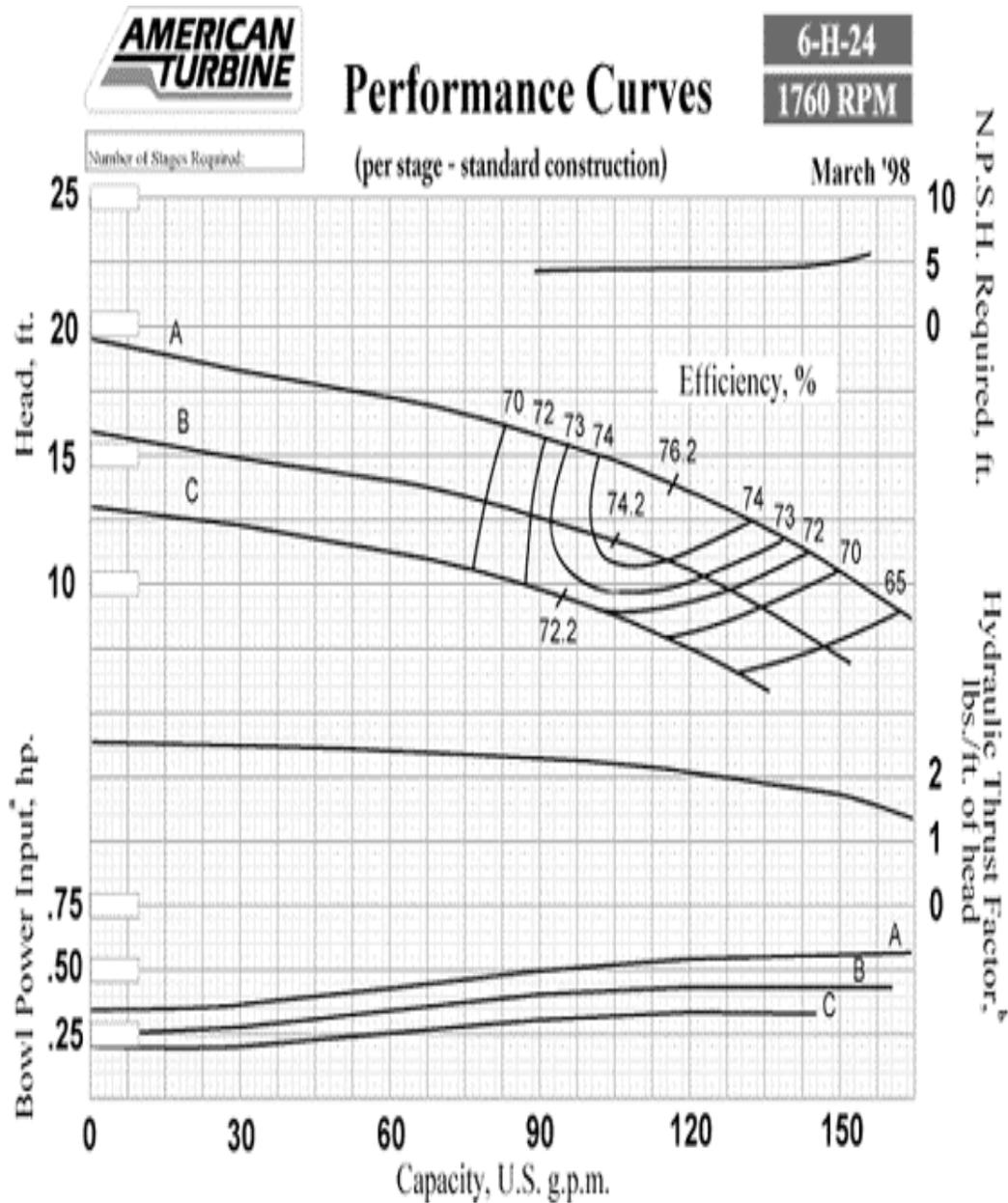


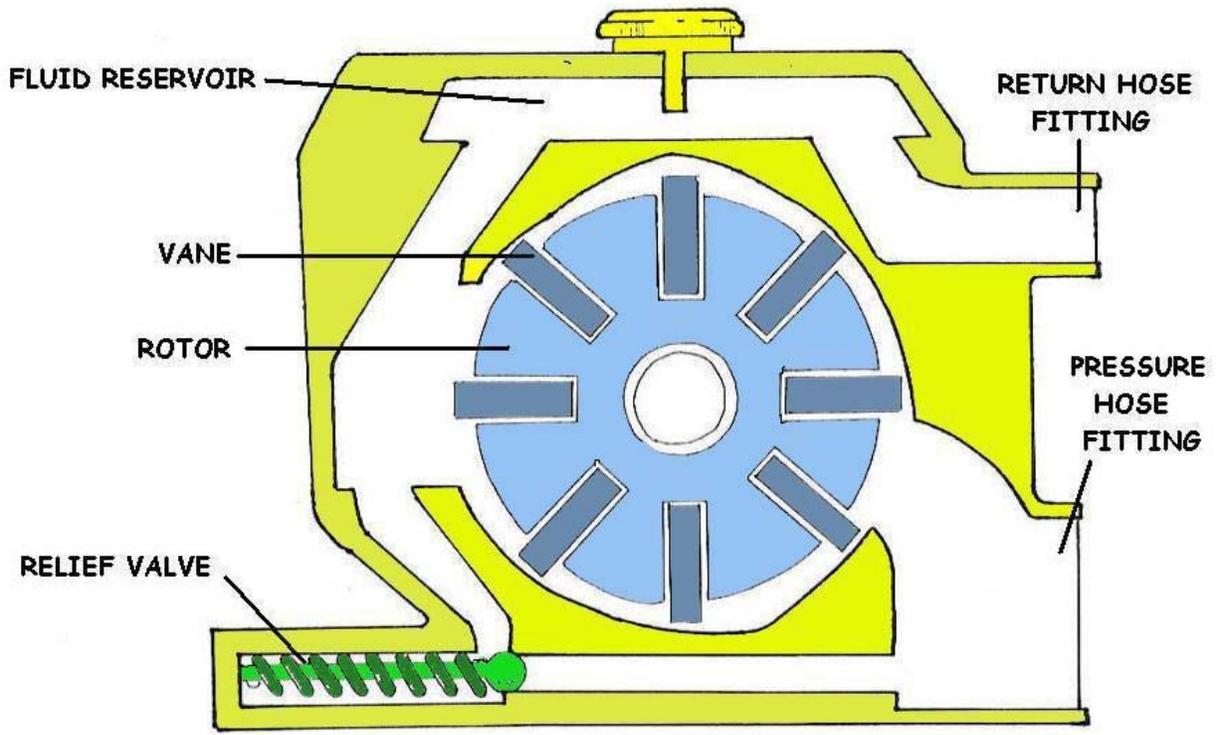
**PNEUMATIC SUBMERSIBLE  
PUMP**

## Pump Performance and Curves

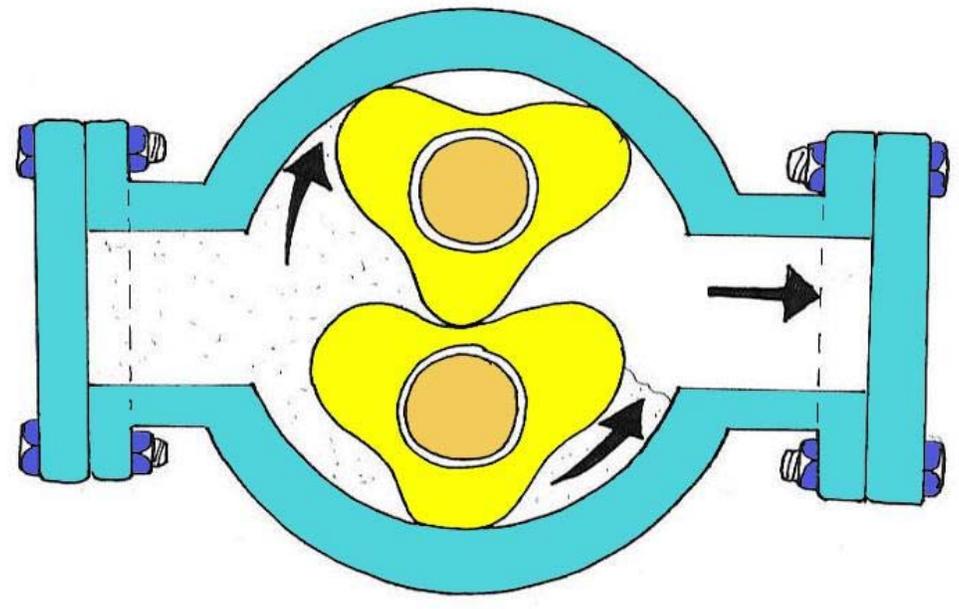
Lets looks at the big picture. Before you make that purchase of the pump and motor you need to know the basics such as:

- 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





**FLEX VANE PUMP**



**LOBE PUMP**

## Motor and Pump Calculations

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

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

**Suction head is measured the same way.**

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

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

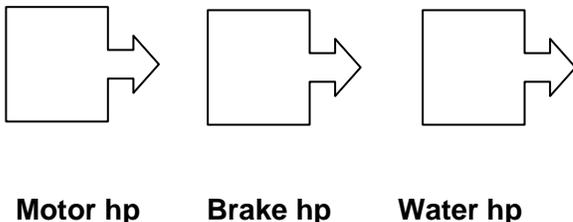
**TDH = Static Lift + Static Height + Friction Loss**

where:

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

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

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



## Horsepower

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

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

## Motor Horsepower (mhp)

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

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

## Brake Horsepower (bhp)

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

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

## Water Horsepower

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

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

## Horsepower and Specific Gravity

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

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

## MHP and Kilowatt requirements

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

## Well Calculations

### 1. Well drawdown

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

### 2. Well yield

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

### 3. Specific yield

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

### 4. Deep well turbine pump calculations.

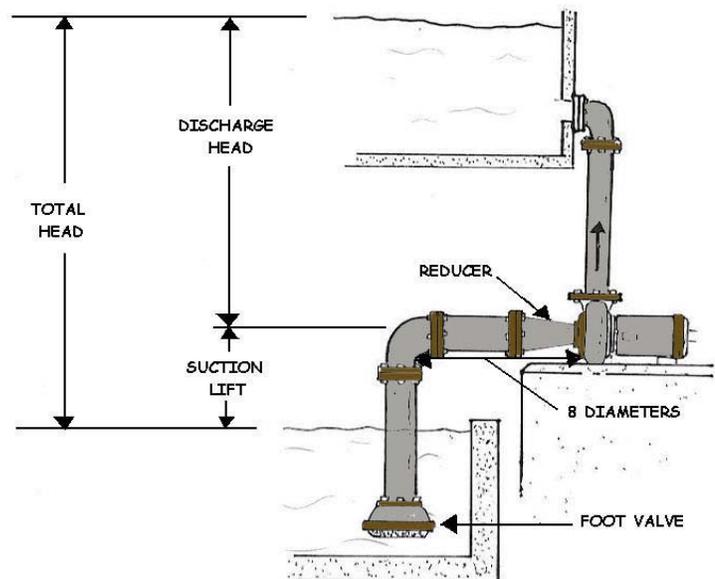
Discharge head, ft = (pressure measured) ( 2.31 ft/psi)

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

Bowl head, ft = field head + column friction

1 psi = 2.31 feet of head

1 foot of head = .433 psi



### Example 1

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

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

Suction side:

Discharge side:

2. How can you tell if this is a suction head condition?

3. Calculate the following head measurements:

SSH:

SDH:

TSH:

4. Convert the pressure gauge readings to feet:

6 psi:

48 psi:

110 psi:

5. Calculate the following head in feet to psi:

20 ft:

205 ft:

185 ft:

## Motor, Coupling and Bearing Section

We will now refer to the motor, coupling, and bearings. The power source of the pump is usually an electric motor. The motor is connected by a coupling to the pump shaft. The purpose of the bearings is 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 the 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

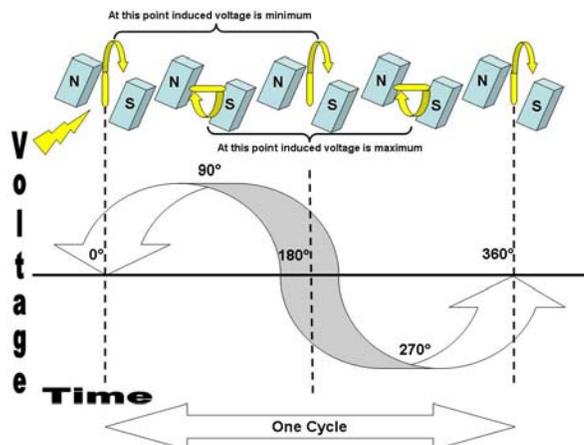
You can expect most motors at facilities to be A-C type.

### 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 their speed/torque characteristics.

### A-C Motors

There are a number of different types of alternating current motors, such as Synchronous, 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. The wound rotor type could be used as a variable speed motor.



**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 requires 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?**



## 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 tend 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, as 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.

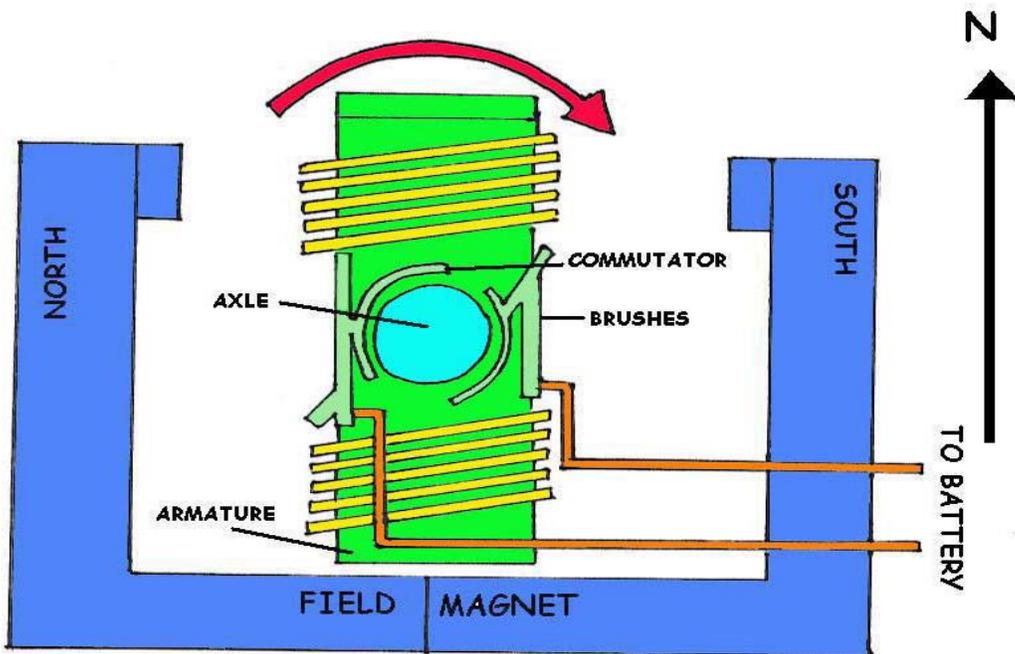
### **To change the oil in an oil lubricated motor, this is the usual approach:**

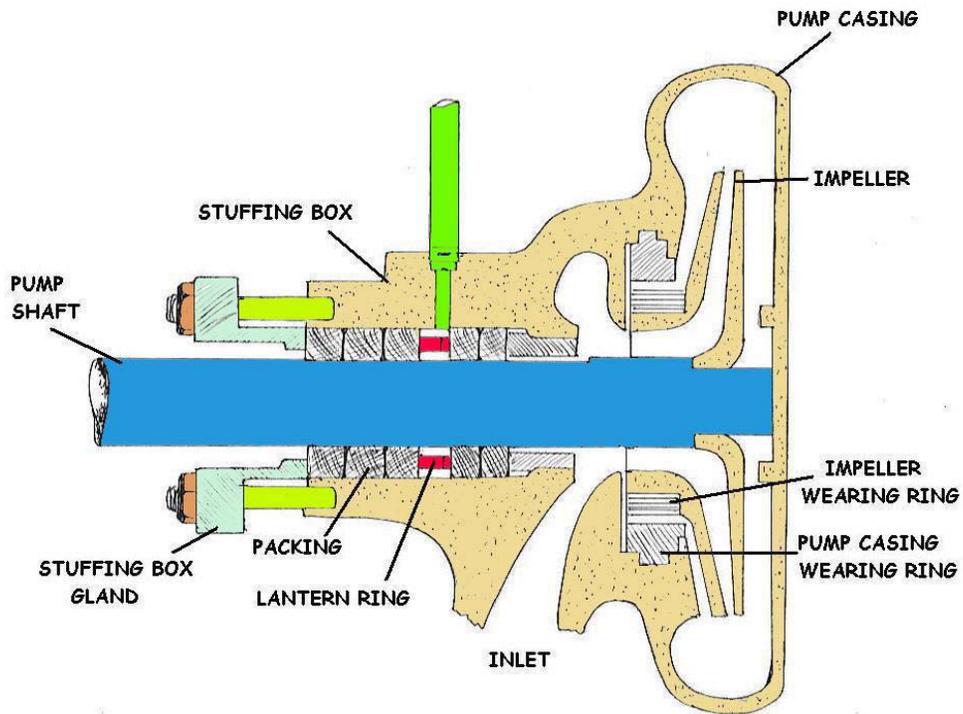
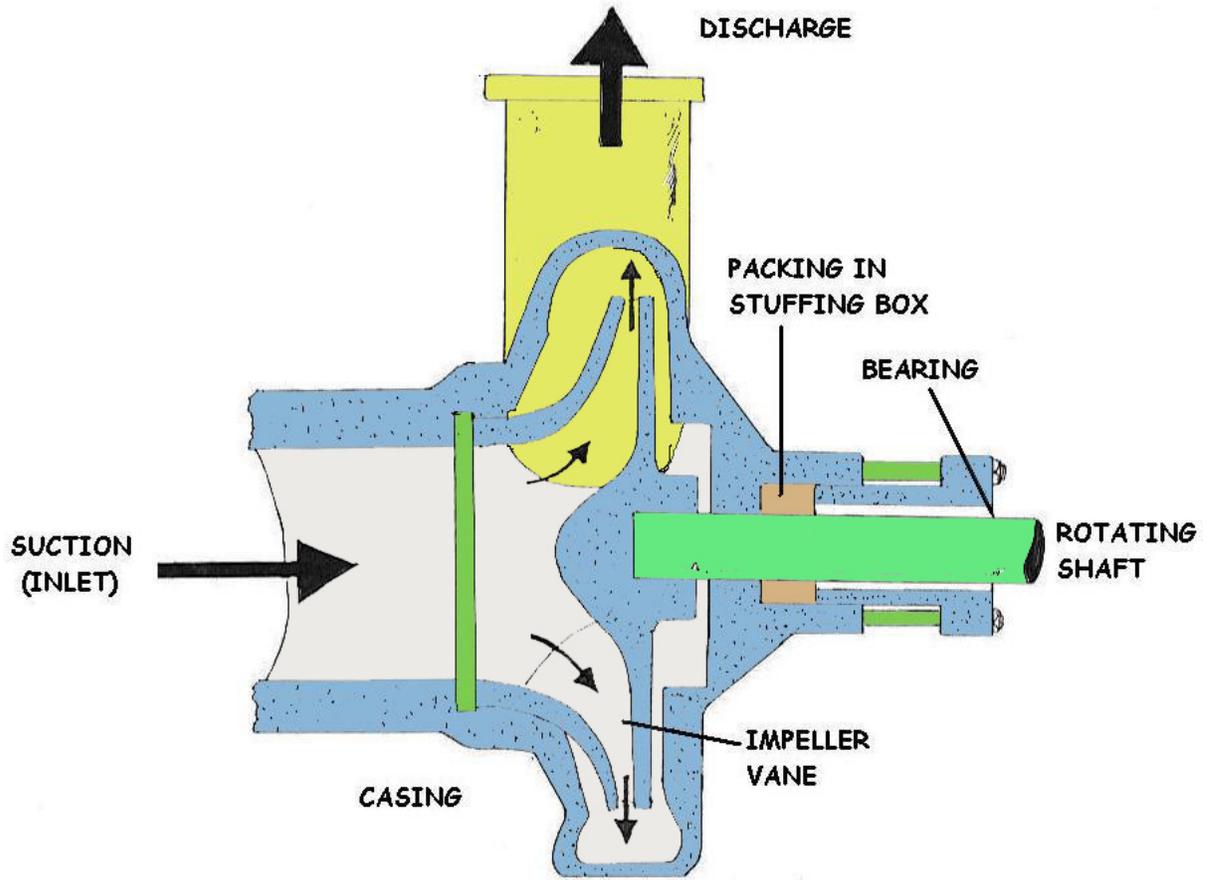
1. Remove all plugs and let the oil drain.
2. Check for metal shearing.
3. Replace the oil drain.
4. Add new oil until it is up to the oil level plug.
5. Replace the oil level and filter plug.

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

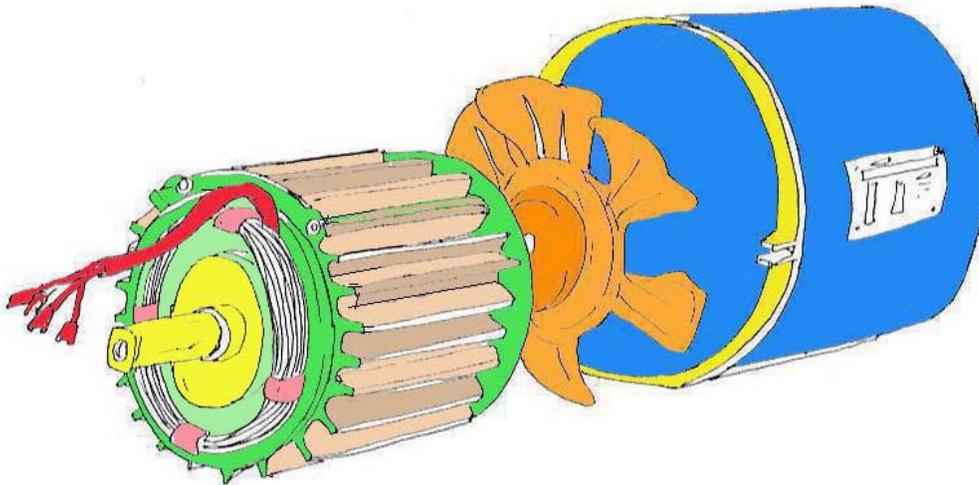


Finger is shown pointing to a Lantern Ring. This old school method of sealing a pump is still out there. Notice the packing on both sides of the ring. The packing joints need to be staggered and the purpose of this device is to allow air to the Stuffing Box.





## More Detailed Information on Motors



The classic division of electric motors has been that of Direct Current (**DC**) types vs. Alternating Current (**AC**) types. This is more a de facto convention, rather than a rigid distinction. For example, many classic DC motors run happily on AC power.

The ongoing trend toward electronic control further muddles the distinction, as modern drivers have moved the commutator out of the motor shell. For this new breed of motor, driver circuits are relied upon to generate sinusoidal AC drive currents, or some approximation of. The two best examples are: the brushless DC motor and the stepping motor, both being polyphase AC motors requiring external electronic control.

There is a clearer distinction between a synchronous motor and asynchronous types. In the synchronous types, the rotor rotates in synchrony with the oscillating field or current (e.g. permanent magnet motors). In contrast, an asynchronous motor is designed to slip; the most ubiquitous example being the common AC induction motor which must slip in order to generate torque.

A DC motor is designed to run on DC electric power. Two examples of pure DC designs are Michael Faraday's homopolar motor (which is uncommon), and the ball bearing motor, which is (so far) a novelty. By far the most common DC motor types are the brushed and brushless types, which use internal and external commutation respectively to create an oscillating AC current from the DC source -- so they are not purely DC machines in a strict sense.

### **Brushed DC Motors**

The classic DC motor design generates an oscillating current in a wound rotor with a split ring commutator, and either a wound or permanent magnet stator. A rotor consists of a coil wound around a rotor which is then powered by any type of battery. Many of the limitations of the classic commutator DC motor are due to the need for brushes to press against the commutator. This creates friction. At higher speeds, brushes have increasing difficulty in maintaining contact. Brushes may bounce off the irregularities in the commutator surface, creating sparks. This limits the maximum speed of the machine.

The current density per unit area of the brushes limits the output of the motor. The imperfect electric contact also causes electrical noise. Brushes eventually wear out and require replacement, and the commutator itself is subject to wear and maintenance. The commutator assembly on a large machine is a costly element, requiring precision assembly of many parts.

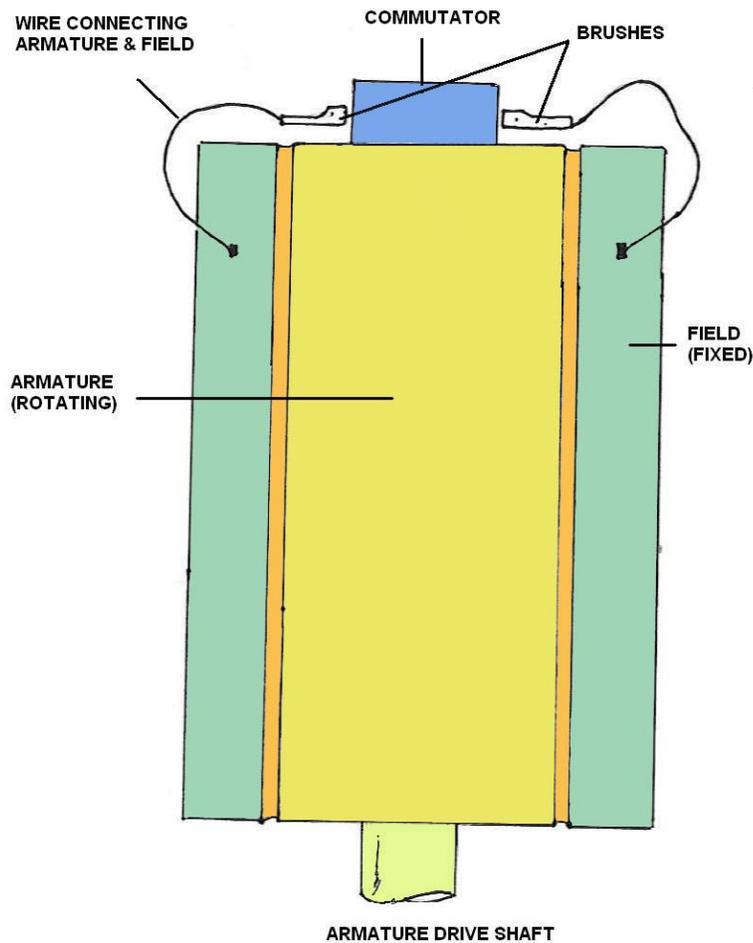


DIAGRAM SHOWING MECHANICAL CONSTRUCTION OF A DC SERIES WOUND MOTOR

### Brushless DC Motors

Some of the problems of the brushed DC motor are eliminated in the brushless design. In this motor, the mechanical "rotating switch" or commutator/brush gear assembly is replaced by an external electronic switch synchronized to the rotor's position. Brushless motors are typically 85-90% efficient, whereas DC motors with brush gear are typically 75-80% efficient.

Midway between ordinary DC motors and stepper motors lies the realm of the brushless DC motor. Built in a fashion very similar to stepper motors, these often use a permanent magnet external rotor, three phases of driving coils, one or more Hall effect sensors to sense the position of the rotor, and the associated drive electronics.

The coils are activated one phase after the other by the drive electronics, as cued by the signals from the Hall effect sensors. In effect, they act as three-phase synchronous motors containing their own variable-frequency drive electronics. A specialized class of brushless DC motor controllers utilize EMF feedback through the main phase connections instead of Hall effect sensors to determine position and velocity. These motors are used extensively in electric radio-controlled vehicles. When configured with the magnets on the outside, these are referred to by modelists as outrunner motors.

Brushless DC motors are commonly used where precise speed control is necessary, as in computer disk drives or in video cassette recorders, the spindles within CD, CD-ROM (etc.) drives, and mechanisms within office products such as fans, laser printers, and photocopiers.

**They have several advantages over conventional motors:**

- \* Compared to AC fans using shaded-pole motors, they are very efficient, running much cooler than the equivalent AC motors. This cool operation leads to much-improved life of the fan's bearings.
- \* Without a commutator to wear out, the life of a DC brushless motor can be significantly longer compared to a DC motor using brushes and a commutator. Commutation also tends to cause a great deal of electrical and RF noise; without a commutator or brushes, a brushless motor may be used in electrically sensitive devices like audio equipment or computers.
- \* The same Hall effect sensors that provide the commutation can also provide a convenient tachometer signal for closed-loop control (servo-controlled) applications. In fans, the tachometer signal can be used to derive a "fan OK" signal.
- \* The motor can be easily synchronized to an internal or external clock, leading to precise speed control.
- \* Brushless motors have no chance of sparking, unlike brushed motors, making them better suited to environments with volatile chemicals and fuels.
- \* Brushless motors are usually used in small equipment such as computers, and are generally used to get rid of unwanted heat.
- \* They are also very quiet motors, which is an advantage if being used in equipment that is affected by vibrations.

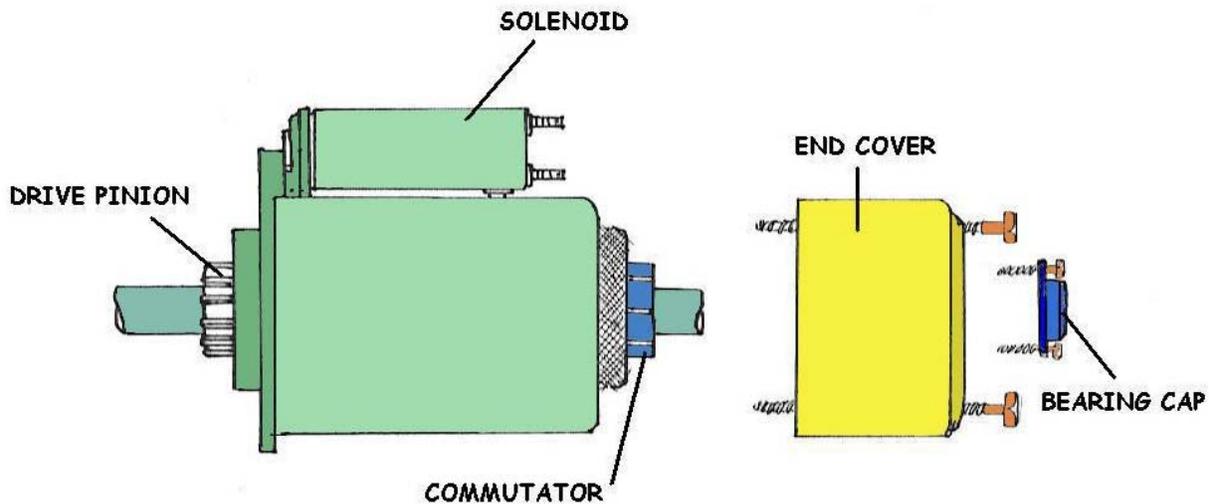
Modern DC brushless motors range in power from a fraction of a watt to many kilowatts. Larger brushless motors up to about 100 kW rating are used in electric vehicles. They also find significant use in high-performance electric model aircraft.

**Coreless DC Motors**

Nothing in the design of any of the motors described above requires that the iron (steel) portions of the rotor actually rotate; torque is exerted only on the windings of the electromagnets. Taking advantage of this fact is the coreless DC motor, a specialized form of a brush or brushless DC motor. Optimized for rapid acceleration, these motors have a rotor that is constructed without any iron core. The rotor can take the form of a winding-filled cylinder inside the stator magnets, a basket surrounding the stator magnets, or a flat pancake (possibly formed on a printed wiring board) running between upper and lower stator magnets. The windings are typically stabilized by being impregnated with electrical epoxy potting systems. Filled epoxies that have moderate mixed viscosity and a long gel time. These systems are highlighted by low shrinkage and low exotherm.

Because the rotor is much lighter in weight (mass) than a conventional rotor formed from copper windings on steel laminations, the rotor can accelerate much more rapidly, often achieving a mechanical time constant under 1 ms. This is especially true if the windings use aluminum rather than the heavier copper. But because there is no metal mass in the rotor to act as a heat sink, even small coreless motors must often be cooled by forced air.

These motors were commonly used to drive the capstan(s) of magnetic tape drives and are still widely used in high-performance servo-controlled systems, like radio-controlled vehicles/aircraft, humanoid robotic systems, industrial automation, medical devices, etc.



## STARTER MOTOR

### Universal Motors

A variant of the wound field DC motor is the universal motor. The name derives from the fact that it may use AC or DC supply current, although in practice they are nearly always used with AC supplies. The principle is that in a wound field DC motor the current in both the field and the armature (and hence the resultant magnetic fields) will alternate (reverse polarity) at the same time, and hence the mechanical force generated is always in the same direction. In practice, the motor must be specially designed to cope with the AC current (impedance must be taken into account, as must the pulsating force), and the resultant motor is generally less efficient than an equivalent pure DC motor. Operating at normal power line frequencies, the maximum output of universal motors is limited and motors exceeding one kilowatt are rare. But universal motors also form the basis of the traditional railway traction motor in electric railways. In this application, to keep their electrical efficiency high, they were operated from very low frequency AC supplies, with 25 Hz and 16 2/3 hertz operation being common. Because they are universal motors, locomotives using this design were also commonly capable of operating from a third rail powered by DC.

The advantage of the universal motor is that AC supplies may be used on motors which have the typical characteristics of DC motors, specifically high starting torque and very compact design if high running speeds are used. The negative aspect is the maintenance and short life problems caused by the commutator. As a result, such motors are usually used in AC devices such as food mixers and power tools, which are used only intermittently. Continuous speed control of a universal motor running on AC is very easily accomplished using a thyristor circuit, while stepped speed control can be accomplished using multiple taps on the field coil. Household blenders that advertise many speeds frequently combine a field coil with several taps and a diode that can be inserted in series with the motor (causing the motor to run on half-wave rectified AC).

Universal motors can rotate at relatively high revolutions per minute (rpm). This makes them useful for appliances such as blenders, vacuum cleaners, and hair dryers where high-speed operation is desired. Many vacuum cleaner and weed trimmer motors exceed 10,000 rpm; Dremel and other similar miniature grinders will often exceed 30,000 rpm. Motor damage may occur due to overspeed (rpm in excess of design specifications) if the unit is operated with no significant load. On larger motors, sudden loss of load is to be avoided, and the possibility of such an occurrence is incorporated into the motor's protection and control schemes. Often, a small fan blade attached to the armature acts as an artificial load to limit the motor speed to a safe value, as well as provide cooling airflow to the armature and field windings. With the very low cost of semiconductor rectifiers, some applications that would have previously used a universal motor now use a pure DC motor, sometimes with a permanent magnet field.

### **AC Motors**

In 1882, Nicola Tesla identified the rotating magnetic field principle, and pioneered the use of a rotary field of force to operate machines. He exploited the principle to design a unique two-phase induction motor in 1883. In 1885, Galileo Ferraris independently researched the concept. In 1888, Ferraris published his research in a paper to the Royal Academy of Sciences in Turin.

Introduction of Tesla's motor from 1888 onwards initiated what is sometimes referred to as the Second Industrial Revolution, making possible the efficient generation and long distance distribution of electrical energy using the alternating current transmission system, also of Tesla's invention (1888). Before the invention of the rotating magnetic field, motors operated by continually passing a conductor through a stationary magnetic field (as in homopolar motors). Tesla had suggested that the commutators from a machine could be removed and the device could operate on a rotary field of force. Professor Poeschel, his teacher, stated that would be akin to building a perpetual motion machine.

### **Components**

**A typical AC motor consists of two parts:**

1. An outside stationary stator having coils supplied with AC current to produce a rotating magnetic field, and;
2. An inside rotor attached to the output shaft that is given a torque by the rotating field.

### **Torque Motors**

A torque motor is a specialized form of induction motor which is capable of operating indefinitely at stall (with the rotor blocked from turning) without damage. In this mode, the motor will apply a steady stall torque to the load (hence the name). A common application of a torque motor would be the supply- and take-up reel motors in a tape drive. In this application, driven from a low voltage, the characteristics of these motors allow a relatively-constant light tension to be applied to the tape whether or not the capstan is feeding tape past the tape heads. Driven from a higher voltage, (and so delivering a higher torque), the torque motors can also achieve fast-forward and rewind operation without requiring any additional mechanics such as gears or clutches. In the computer world, torque motors are used with force feedback steering wheels.

## Slip Ring

The slip ring or wound rotor motor is an induction machine where the rotor comprises a set of coils that are terminated in slip rings to which external impedances can be connected. The stator is the same as is used with a standard squirrel cage motor. By changing the impedance connected to the rotor circuit, the speed/current and speed/torque curves can be altered.

The slip ring motor is used primarily to start a high inertia load or a load that requires a very high starting torque across the full speed range. By correctly selecting the resistors used in the secondary resistance or slip ring starter, the motor is able to produce maximum torque at a relatively low current from zero speed to full speed. A secondary use of the slip ring motor is to provide a means of speed control.

Because the torque curve of the motor is effectively modified by the resistance connected to the rotor circuit, the speed of the motor can be altered. Increasing the value of resistance on the rotor circuit will move the speed of maximum torque down. If the resistance connected to the rotor is increased beyond the point where the maximum torque occurs at zero speed, the torque will be further reduced. When used with a load that has a torque curve that increases with speed, the motor will operate at the speed where the torque developed by the motor is equal to the load torque. Reducing the load will cause the motor to speed up, and increasing the load will cause the motor to slow down until the load and motor torque are equal. Operated in this manner, the slip losses are dissipated in the secondary resistors and can be very significant. The speed regulation is also very poor.

### Stepper Motors

Closely related in design to three-phase AC synchronous motors are stepper motors, where an internal rotor containing permanent magnets or a large iron core with salient poles is controlled by a set of external magnets that are switched electronically. A stepper motor may also be thought of as a cross between a DC electric motor and a solenoid. As each coil is energized in turn, the rotor aligns itself with the magnetic field produced by the energized field winding. Unlike a synchronous motor, in its application, the motor may not rotate continuously; instead, it "steps" from one position to the next as field windings are energized and de-energized in sequence. Depending on the sequence, the rotor may turn forwards or backwards.

Simple stepper motor drivers entirely energize or entirely de-energize the field windings, leading the rotor to "cog" to a limited number of positions; more sophisticated drivers can proportionally control the power to the field windings, allowing the rotors to position between the cog points and thereby rotate extremely smoothly. Computer controlled stepper motors are one of the most versatile forms of positioning systems, particularly when part of a digital servo-controlled system.

Stepper motors can be rotated to a specific angle with ease, and hence stepper motors are used in pre-gigabyte era computer disk drives, where the precision they offered was adequate for the correct positioning of the read/write head of a hard disk drive. As drive density increased, the precision limitations of stepper motors made them obsolete for hard drives, thus newer hard disk drives use read/write head control systems based on voice coils. Stepper motors were upscaled to be used in electric vehicles under the term SRM (switched reluctance machine).

## Coupling Section

The pump coupling serves two main purposes:

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

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

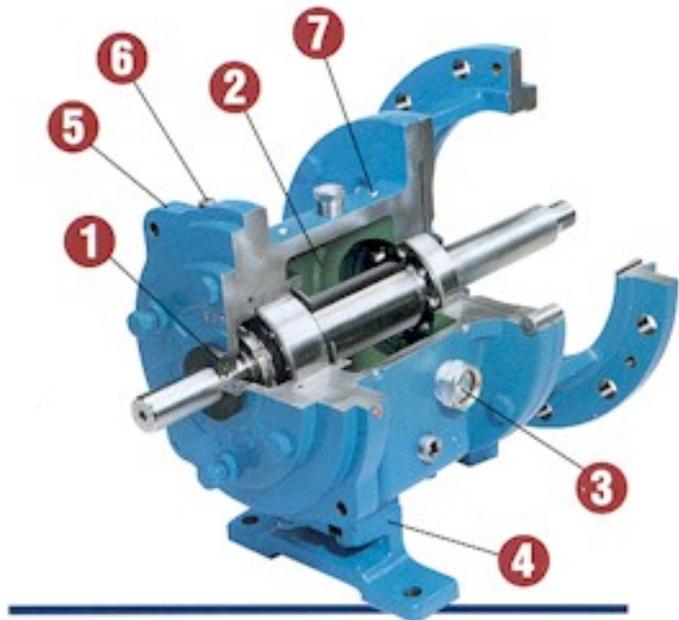
There are three commonly used types of couplings: **Rigid, Flexible and V-belts.**

### Rigid Coupling

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

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

1. Oil Seals
2. Large Oil Sump
3. Bulls Eye Sight Glass
4. Rigid Frame Foot
5. C-Face Mounting Flange
6. Lubrication Flexibility
7. Condition Monitoring Sites



## 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:**



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.

## 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?

### 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.



## Lantern Rings

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

## Mechanical Seals

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



**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 of different alloys. The wear ring on the head side is usually a harder alloy.

It's called a "**WEAR RING**" and what would be the purpose?

## Mechanical Seals

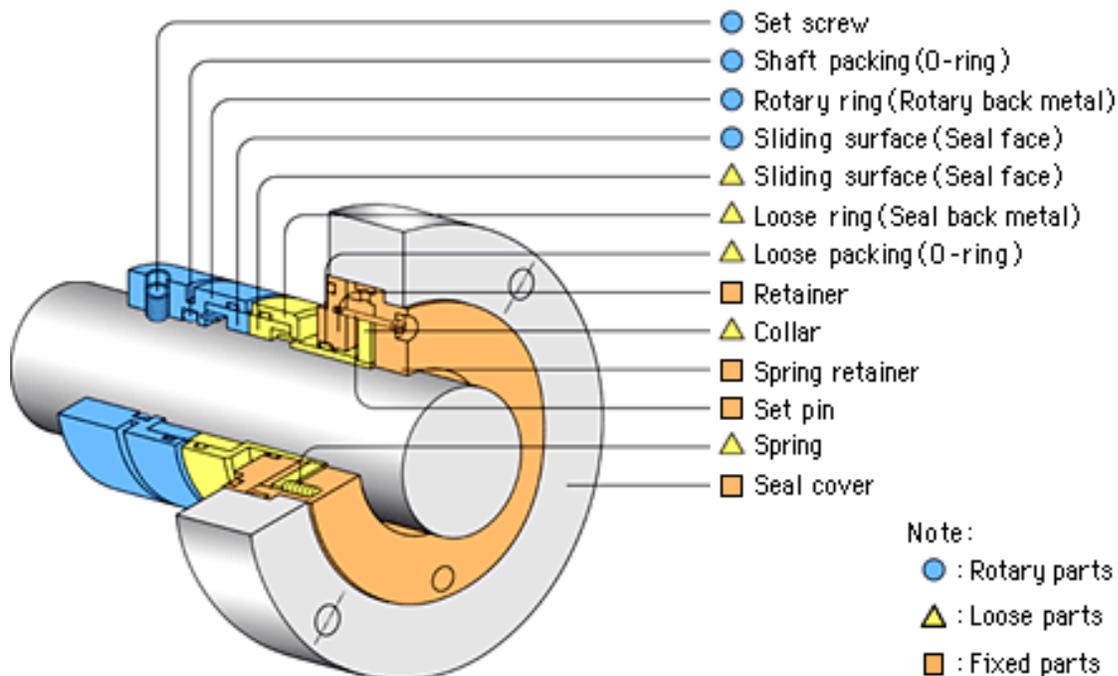
Mechanical seals are rapidly replacing conventional packing as the means of controlling leakage on rotary and positive-displacement pumps. Mechanical seals eliminate the problem of excessive stuffing box leakage, which causes failure of pump and motor bearings and motor windings.

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



## Pump Troubleshooting Section

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

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

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

If a pump **DOES NOT DEVELOP DESIGN DISCHARGE PRESSURE**, the trouble may be caused by (1) insufficient pump speed; (2) air or gas in the liquid being pumped; (3) mechanical defects, such as worn wearing rings, impellers, stuffing box packing, or sleeves; or (4) reversed rotation of the impeller (3-phase electric motor-driven pumps). If a pump **WORKS FOR A WHILE AND THEN FAILS TO DELIVER LIQUID**, the trouble may be caused by (1) air leakage into the suction line; (2) air leakage in the stuffing boxes; (3) clogged water seal passages; (4) insufficient liquid on the suction side; or (5) excessive heat in the liquid being pumped.

If a motor-driven centrifugal pump **DRAWS TOO MUCH POWER**, the trouble will probably be indicated by overheating of the motor. The basic causes may be (1) operation of the pump to excess capacity and insufficient discharge pressure; (2) too high viscosity or specific gravity of the liquid being pumped; or (3) misalignment, a bent shaft, excessively tight stuffing box packing, worn wearing rings, or other mechanical defects.

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

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

## 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 are discussed in the following sections.

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



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

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

### Mechanical Seals

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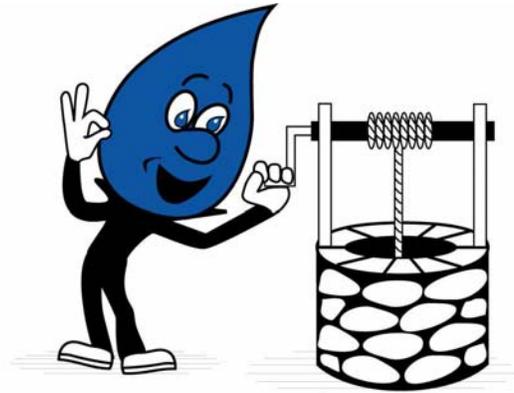


## Troubleshooting Table for Well/Pump Problems

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 hydro-pneumatic tank.
- 4A. Problems with well screen or gravel envelope.
- 5A. Valve on discharge partially closed or line clogged.
- 5B. Well is over-pumped.
- 5C. Well screen clogged.
- 6A. **Check valve** not operating properly.
- 6B. Leakage occurring in discharge piping or valves.
- 7A. Water contains excessive **iron** (red brown) and/or **manganese** (black water).
- 7B. Complainant's hot water needs maintenance.
- 8A. Surface water entering or **influencing** well.
- 9A. Sample is invalid.
- 9B. **Sanitary protection** of well has been **breached**.



### Possible Solutions

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

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



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

# SCADA

## What is SCADA?

SCADA stands for Supervisory Control and Data Acquisition. As the name indicates, it is not a full control system, but rather focuses on the supervisory level. As such, it is a purely software package that is positioned on top of hardware to which it is interfaced, in general via Programmable Logic Controllers (**PLCs**), or other commercial hardware modules. Contemporary SCADA systems exhibit predominantly open-loop control characteristics and utilize predominantly long distance communications, although some elements of closed-loop control and/or short distance communications may also be present. Systems similar to SCADA systems are routinely seen in treatment plants and distribution systems. These are often referred to as Distributed Control Systems (**DCS**). They have similar functions to SCADA systems, but the field data gathering or control units are usually located within a more confined area. Communications may be via a local area network (**LAN**), and will normally be reliable and high speed. A DCS system usually employs significant amounts of closed loop control.

## What is Data Acquisition?

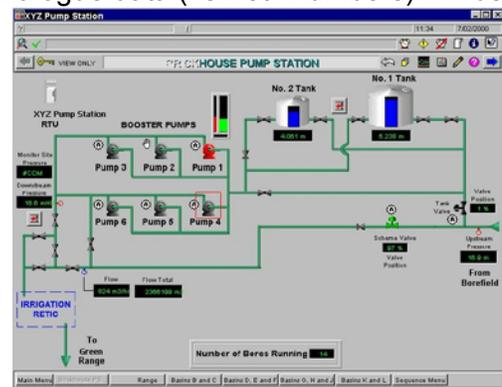
Data acquisition refers to the method used to access and control information or data from the equipment being controlled and monitored. The data accessed are then forwarded onto a telemetry system ready for transfer to the different sites. They can be analog and digital information gathered by sensors, such as flowmeter, ammeter, etc. It can also be data to control equipment such as actuators, relays, valves, motors, etc.

## So Why or Where Would You Use SCADA?

SCADA can be used to monitor and control plant or equipment. The control may be automatic, or initiated by operator commands. The data acquisition is accomplished firstly by the RTU's (remote Terminal Units) scanning the field inputs connected to the RTU (**RTU** may also be called a PLC - programmable logic controller). This is usually at a fast rate. The central host will scan the RTU's (usually at a slower rate.)

The data is processed to detect alarm conditions, and if an alarm is present, it will be displayed on special alarm lists. Data can be of three main types. Analogue data (i.e. real numbers) will be trended (i.e. placed in graphs). Digital data (on/off) may have alarms attached to one state or the other. Pulse data (e.g. counting revolutions of a meter) is normally accumulated or counted.

The primary interface to the operator is a graphical display (mimic) usually via a PC Screen which shows a representation of the plant or equipment in graphical form. Live data is shown as graphical shapes (foreground) over a static background. As the data changes in the field, the foreground is updated. A valve may be shown as open or closed. Analog data can be shown either as a number, or graphically. The system may have many such displays, and the operator can select from the relevant ones at any time.





# 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.

**Angular Motion Formulas:** Angular velocity can be expressed as (angular velocity = constant):

$$\omega = \theta / t \text{ (2a)}$$

where

$\omega$  = angular velocity (rad/s)

$\theta$  = angular displacement (rad)

$t$  = time (s)

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

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

where

$\omega_o$  = angular velocity at time zero (rad/s)

$\alpha$  = angular acceleration (rad/s<sup>2</sup>)

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

$$\theta = \omega_o t + 1/2 \alpha t^2 \text{ (2c)}$$

Combining 2a and 2c:

$$\omega = (\omega_o^2 + 2 \alpha \theta)^{1/2}$$

Angular acceleration can be expressed as:

$$\alpha = d\omega / dt = d^2\theta / dt^2 \text{ (2d)}$$

where

$d\theta$  = change of angular displacement (rad)

$dt$  = change in time (s)

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

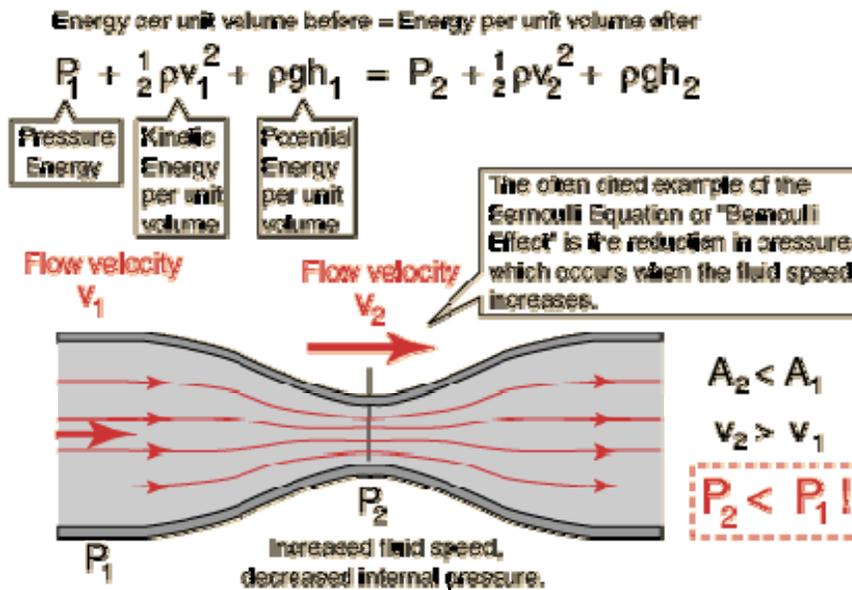
## B

**Backflow Prevention:** To stop or prevent the occurrence of, the unnatural act of reversing the normal direction of the flow of liquid, gases, or solid substances back in to the public potable (drinking) water supply. See Cross-connection control.

**Backflow:** To reverse the natural and normal directional flow of a liquid, gases, or solid substances back in to the public potable (drinking) water supply. This is normally an undesirable effect.

**Backsiphonage:** A liquid substance that is carried over a higher point. It is the method by which the liquid substance may be forced by excess pressure over or into a higher point.

**Bernoulli's Equation:** Describes the behavior of moving fluids along a streamline. The Bernoulli Equation can be considered to be a statement of the conservation of energy principle appropriate for flowing fluids. The qualitative behavior that is usually labeled with the term "**Bernoulli effect**" is the lowering of fluid pressure in regions where the flow velocity is increased. This lowering of pressure in a constriction of a flow path may seem counterintuitive, but seems less so when you consider pressure to be energy density. In the high velocity flow through the constriction, kinetic energy must increase at the expense of pressure energy.



A special form of the Euler's equation derived along a fluid flow streamline is often called the **Bernoulli Equation**.

$$\frac{\partial}{\partial s} \left( \frac{v^2}{2} + \frac{p}{\rho} + g \cdot h \right) = 0 \quad (1)$$

where

$v$  = flow speed

$p$  = pressure

$\rho$  = density

$g$  = gravity

$h$  = height

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

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

where

$\gamma = \rho \cdot g$

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

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

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

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

### ***Bernoulli's Equation Continued:***

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

### ***Bernoulli's Equation Continued:***

#### **Dynamic Pressure**

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

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

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

### ***Bernoulli's Equation Continued:***

#### **Pressurized Tank**

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

The velocity out from the tank 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

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

### ***Bernoulli's Equation Continued:***

#### **Coefficient of Discharge - Friction Coefficient**

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

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

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

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

The Bulk Modulus Elasticity can be expressed as

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

where

$E$  = bulk modulus elasticity

$dp$  = differential change in pressure on the object

$dV$  = differential change in volume of the object

$V$  = initial volume of the object

The Bulk Modulus Elasticity can be alternatively expressed as

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

where

$dp$  = differential change in density of the object

$\rho$  = initial density of the object

An increase in the pressure will decrease the volume (1). A decrease in the volume will increase the density (2).

- The SI unit of the bulk modulus elasticity is  $\text{N/m}^2$  (Pa)

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

A large Bulk Modulus indicates a relatively incompressible fluid.

Bulk Modulus for some common fluids can be found in the table below:

Bulk Modulus - $E$	Imperial Units - BG (psi, $\text{lb}_f/\text{in}^2$ ) $\times 10^5$	SI Units (Pa, $\text{N/m}^2$ ) $\times 10^9$
Carbon Tetrachloride	1.91	1.31
Ethyl Alcohol	1.54	1.06
Gasoline	1.9	1.3
Glycerin	6.56	4.52
Mercury	4.14	2.85
SAE 30 Oil	2.2	1.5
Seawater	3.39	2.35
Water	3.12	2.15

## C

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

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

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

where

$h$  = height of liquid (ft, m)

$\sigma$  = surface tension (lb/ft, N/m)

$\theta$  = contact angle

$\rho$  = density of liquid (lb/ft<sup>3</sup>, kg/m<sup>3</sup>)

$g$  = acceleration due to gravity (32.174 ft/s<sup>2</sup>, 9.81 m/s<sup>2</sup>)

$r$  = radius of tube (ft, m)

**Cauchy Number:** A dimensionless value useful for analyzing fluid flow dynamics problems where compressibility is a significant factor.

The Cauchy Number is the ratio between inertial and the compressibility force in a flow and can be expressed as

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

where

$\rho$  = density (kg/m<sup>3</sup>)

$v$  = flow velocity (m/s)

$E$  = bulk modulus elasticity (N/m<sup>2</sup>)

The bulk modulus elasticity has the dimension pressure and is commonly used to characterize

the compressibility of a fluid.

The Cauchy Number is the square root of the Mach Number

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

where

$C$  = Mach Number

**Cavitation:** Under the wrong condition, cavitation will reduce the component's lifetime 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

### **Cavitation Continued: 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 of the fluid temperature. Water, our most common fluid, is an example:

Temperature (°C)	Vapor Pressure (kN/m <sup>2</sup> )
0	0.6
5	0.9
10	1.2
15	1.7
20	2.3
25	3.2
30	4.3
35	5.6
40	7.7
45	9.6
50	12.5
55	15.7
60	20
65	25
70	32.1
75	38.6
80	47.5
85	57.8
90	70
95	84.5
100	101.33

As we can see - the possibility of evaporation and cavitation increases dramatically with the

water temperature.

Cavitation can be avoided by locating the components in the coldest part of the system. For example, it is common to locate the pumps in heating systems at the "cold" return lines. The situation is the same for control valves. Where it is possible, they should be located on the cold side of heat exchangers.

**Cavitations Number:** A "special edition" of the dimensionless Euler Number.

The Cavitations Number is useful for analyzing fluid flow dynamics problems where cavitations may occur.

The Cavitations Number can be expressed as

$$Ca = (p_r - p_v) / 1/2 \rho v^2 \quad (1)$$

where

$Ca$  = Cavitations number

$p_r$  = reference pressure (Pa)

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

$\rho$  = density of the fluid ( $\text{kg/m}^3$ )

$v$  = velocity of fluid (m/s)

**Centrifugal Pump:** A pump consisting of an impeller fixed on a rotating shaft and enclosed in a casing, having an inlet and a discharge connection. The rotating impeller creates pressure in the liquid by the velocity derived from centrifugal force.

**Chezy Formula:** Conduits flow and mean velocity. The Chezy formula can be used to calculate mean flow velocity in conduits and is expressed as

$$v = c (R S)^{1/2} \quad (1)$$

where

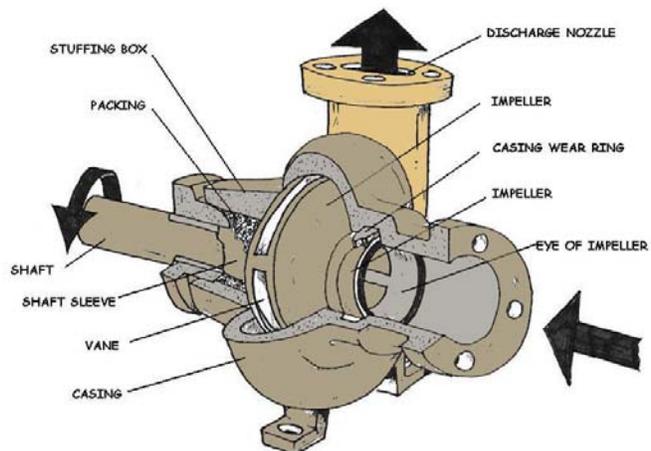
$v$  = mean velocity (m/s, ft/s)

$c$  = the Chezy roughness and conduit coefficient

$R$  = hydraulic radius of the conduit (m, ft)

$S$  = slope of the conduit (m/m, ft/ft)

In general the Chezy coefficient -  $c$  - is a function of the flow Reynolds Number -  $Re$  - and the relative roughness -  $\epsilon/R$  - of the channel.  $\epsilon$  is the characteristic height of the roughness elements on the channel boundary.



**Coanda Effect:** The tendency of a stream of fluid to stay attached to a convex surface, rather than follow a straight line in its original direction.

**Colebrook Equation:** The friction coefficients used to calculate pressure loss (or major loss) in ducts, tubes and pipes can be calculated with the Colebrook equation.

$$1 / \lambda^{1/2} = -2 \log ( (2.51 / (Re \lambda^{1/2})) + (k / d_h) / 3.72 ) \quad (1)$$

where

$\lambda$  = D'Arcy-Weisbach friction coefficient

Re = Reynolds Number

k = roughness of duct, pipe or tube surface (m, ft)

$d_h$  = hydraulic diameter (m, ft)

The Colebrook equation is only valid at turbulent flow conditions.

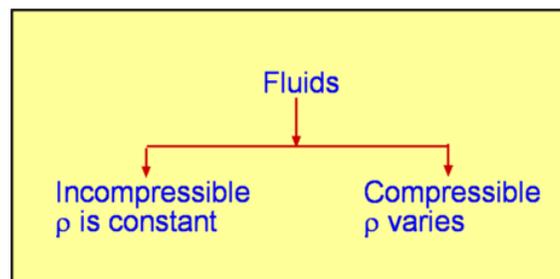
Note that the friction coefficient is involved on both sides of the equation and that the equation must be solved by iteration.

The Colebrook equation is generic and can be used to calculate the friction coefficients in different kinds of fluid flows - air ventilation ducts, pipes and tubes with water or oil, compressed air and much more.

**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

$\rho$  = density

**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

$\Delta p$  = pressure loss (Pa, N/m<sup>2</sup>, lb<sub>f</sub>/ft<sup>2</sup>)

$\lambda$  = D'Arcy-Weisbach friction coefficient

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

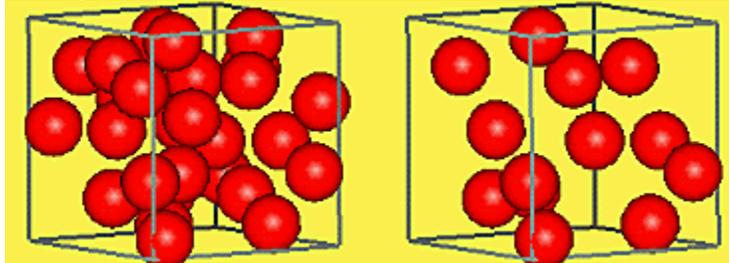
$d_h$  = hydraulic diameter (m, ft)

$\rho$  = density (kg/m<sup>3</sup>, lb/ft<sup>3</sup>)

**Note!** Be aware that there are two alternative friction coefficients present in the literature. One is 1/4 of the other and (1) must be multiplied with four to achieve the correct result. This is important to verify when selecting friction coefficients from Moody diagrams.

**Density:** Is a physical property of matter, as each element and compound has a unique density associated with it.

Density defined in a qualitative manner as the measure of the relative "heaviness" of objects with a constant volume. For example: A rock is obviously more dense than a crumpled piece of paper of the same size. A Styrofoam cup is less dense than a ceramic cup. Density may also refer to how closely "packed" or "crowded" the material appears to be - again refer to the Styrofoam vs. ceramic cup. Take a look at the two boxes below.



Each box has the same volume. ***If each ball has the same mass, which box would weigh more? Why?***

The box that has more balls has more mass per unit of volume. This property of matter is called density. The density of a material helps to distinguish it from other materials. Since mass is usually expressed in grams and volume in cubic centimeters, density is expressed in grams/cubic centimeter. We can calculate density using the formula:

**Density= Mass/Volume**

The density can be expressed as

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

where

$\rho$  = density (kg/m<sup>3</sup>)

$m$  = mass (kg)

$V$  = volume (m<sup>3</sup>)

$v_g$  = specific volume (m<sup>3</sup>/kg)

The SI units for density are kg/m<sup>3</sup>. The imperial (BG) units are lb/ft<sup>3</sup> (slugs/ft<sup>3</sup>). While people often use pounds per cubic foot as a measure of density in the U.S., pounds are really a measure of force, not mass. Slugs are the correct measure of mass. You can multiply slugs by 32.2 for a rough value in pounds.

The higher the density, the tighter the particles are packed inside the substance. Density is a physical property constant at a given temperature and density can help to identify a substance.

***Example - Use the Density to Identify the Material:***

An unknown liquid substance has a mass of 18.5 g and occupies a volume of 23.4 ml. (milliliter).

The density can be calculated as

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

If we look up densities of some common substances, we can find that ethyl alcohol, or ethanol, has a density of 790 kg/m<sup>3</sup>. Our unknown liquid may likely be ethyl alcohol!

**Example - Use Density to Calculate the Mass of a Volume**

The density of titanium is 4507 kg/m<sup>3</sup>. Calculate the mass of 0.17 m<sup>3</sup> titanium!

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

**Dilatant Fluids:** Shear Thickening Fluids or Dilatant Fluids increase their viscosity with agitation. Some of these liquids can become almost solid within a pump or pipe line. With agitation, cream becomes butter and Candy compounds, clay slurries and similar heavily filled liquids do the same thing.

**Disinfect:** To kill and inhibit growth of harmful bacterial and viruses in drinking water.

**Disinfection:** The treatment of water to inactivate, destroy, and/or remove pathogenic bacteria, viruses, protozoa, and other parasites.

**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:

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

where

$F_d$  = drag force (N)

$c_d$  = drag coefficient

$\rho$  = density of fluid

$v$  = flow velocity

$A$  = characteristic frontal area of the body

The drag coefficient is a function of several parameters as shape of the body, Reynolds Number for the flow, Froude number, Mach Number and Roughness of the Surface.

The characteristic frontal area -  $A$  - depends on the body.

**Dynamic or Absolute Viscosity:** The viscosity of a fluid is an important property in the analysis of liquid behavior and fluid motion near solid boundaries. The viscosity of a fluid is its resistance to shear or flow and is a measure of the adhesive/cohesive or frictional properties of a fluid. The resistance is caused by intermolecular friction exerted when layers of fluids attempts to slide by another.

**Dynamic Pressure:** Dynamic pressure is the component of fluid pressure that represents a fluid's kinetic energy. The dynamic pressure is a defined property of a moving flow of gas or liquid and can be expressed as

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

where

$p_d$  = dynamic pressure (Pa)

$\rho$  = density of fluid ( $\text{kg/m}^3$ )

$v$  = 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's 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 attempt to slide by another.

Viscosity is a measure of a fluid's resistance to flow.

The knowledge of viscosity is needed for proper design of required temperatures for storage, pumping or injection of fluids.

Common used units for viscosity are

- CentiPois (cp) = CentiStokes (cSt)  $\times$  Density
  - SSU<sup>1</sup> = Centistokes (cSt)  $\times$  4.55
  - Degree Engler<sup>1</sup>  $\times$  7.45 = Centistokes (cSt)
  - Seconds Redwood<sup>1</sup>  $\times$  0.2469 = Centistokes (cSt)
- <sup>1</sup>centistokes greater than 50

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

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

The dynamic or absolute viscosity can be expressed like

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

where

$\tau$  = shearing stress

$\mu$  = dynamic viscosity

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

In the SI system the dynamic viscosity units are **N s/m<sup>2</sup>**, **Pa s** or **kg/m s** where

- $1 \text{ Pa s} = 1 \text{ N s/m}^2 = 1 \text{ kg/m s}$

The dynamic viscosity is also often expressed in the metric CGS (centimeter-gram-second) system as **g/cm.s, dyne.s/cm<sup>2</sup>** or **poise (p)** where

- $1 \text{ poise} = \text{dyne s/cm}^2 = \text{g/cm s} = 1/10 \text{ Pa s}$

For practical use the Poise is too large and it's 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 viscous, incompressible flow the total energy remains constant along a stream line as expressed through the Bernoulli

**Equation:**

$$p + 1/2 \rho v^2 + \gamma h = \text{constant along a streamline (1)}$$

where

$p$  = static pressure (relative to the moving fluid)

$\rho$  = density

$\gamma$  = specific weight

$v$  = flow velocity

$g$  = acceleration of gravity

$h$  = elevation height

Each term of this equation has the dimension *force per unit area* - psi, lb/ft<sup>2</sup> or N/m<sup>2</sup>.

**Energy and Hydraulic Grade Line Continued:**

**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.

***Energy and Hydraulic Grade Line Continued:***

**The Total Head**

(2) states that the sum of **pressure head** -  $p / \gamma$  -, **velocity head** -  $v^2 / 2 g$  - and **elevation head** -  $h$  - is constant along the stream line. This constant can be called **the total head** -  $H$  -.

The total head in a flow can be measured by the stagnation pressure using a pitot tube.

***Energy and Hydraulic Grade Line Continued:***

**The Piezometric Head**

The sum of pressure head -  $p / \gamma$  - and elevation head -  $h$  - is called **the piezometric head**. The piezometric head in a flow can be measured through an flat opening parallel to the flow.

***Energy and Hydraulic Grade Line Continued:***

**The Energy Line**

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

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

*where*

*EL = Energy Line*

For a fluid flow without any losses due to friction (major losses) or components (minor losses), the energy line would be at a constant level. In the practical world, the energy line decreases along the flow due to the losses.

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

**The Hydraulic Grade Line**

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

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

*where*

*HGL = Hydraulic Grade Line*

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

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

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

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

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

$\rho$  = density of gas

$p$  = absolute pressure

**Equation of Continuity:** The Law of Conservation of Mass states that mass can be neither created nor destroyed. Using the Mass Conservation Law on a **steady flow** process - flow where the flow rate doesn't change over time - through a control volume where the stored mass in the control volume doesn't change - implements that inflow equals outflow.

This statement is called **the Equation of Continuity**. Common application where **the Equation of Continuity** can be used are pipes, tubes and ducts with flowing fluids and gases, rivers, overall processes as power plants, dairies, logistics in general, roads, computer networks and semiconductor technology and more.

The Equation of Continuity and can be expressed as:

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

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

where

$m$  = mass flow rate (kg/s)

$\rho$  = density (kg/m<sup>3</sup>)

$v$  = speed (m/s)

$A$  = area (m<sup>2</sup>)

With uniform density equation (1) can be modified to

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

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

where

$q$  = flow rate (m<sup>3</sup>/s)

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

### Example - Equation of Continuity

10 m<sup>3</sup>/h of water flows through a pipe of 100 mm inside diameter. The pipe is reduced to an inside dimension of 80 mm. Using equation (2) the velocity in the 100 mm pipe can be calculated as

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

or

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

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

Using equation (2) the velocity in the 80 mm pipe can be calculated

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

or

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

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

**Equation of Mechanical Energy:** The Energy Equation is a statement of the first law of thermodynamics. The energy equation involves energy, heat transfer and work. With certain limitations, the mechanical energy equation can be compared to the Bernoulli Equation and transferred to the Mechanical Energy Equation in Terms of Energy per Unit Mass.

The mechanical energy equation for a **pump or a fan** can be written in terms of **energy per unit mass**:

$$p_{in} / \rho + v_{in}^2 / 2 + g h_{in} + w_{shaft} = p_{out} / \rho + v_{out}^2 / 2 + g h_{out} + w_{loss} \quad (1)$$

where

$p$  = static pressure

$\rho$  = density

$v$  = flow velocity

$g$  = acceleration of gravity

$h$  = elevation height

$w_{shaft}$  = net shaft energy inn per unit mass for a pump, fan or similar

$w_{loss}$  = loss due to friction

The energy equation is often used for incompressible flow problems and is called **the Mechanical Energy Equation** or **the Extended Bernoulli Equation**.

The mechanical energy equation for a **turbine** can be written as:

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

where

$w_{shaft}$  = net shaft energy out per unit mass for a turbine or similar

Equation (1) and (2) dimensions are

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

### Efficiency

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

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

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

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

### The Mechanical Energy Equation in Terms of Energy per Unit Volume

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

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

where

$\gamma = \rho g$  = specific weight

The dimensions of equation (5) are

energy per unit volume ( $ft \cdot lb/ft^3 = lb/ft^2$  or  $N \cdot m/m^3 = N/m^2$ )

### The Mechanical Energy Equation in Terms of Energy per Unit Weight involves Heads

The mechanical energy equation for a **pump or a fan** (1) can also be written in terms of **energy per unit weight** by dividing with gravity -  $g$ :

$$p_{in} / \gamma + v_{in}^2 / 2 g + h_{in} + h_{shaft} = p_{out} / \gamma + v_{out}^2 / 2 g + h_{out} + h_{loss} \quad (6)$$

where

$\gamma = \rho g$  = specific weight

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

$h_{loss} = w_{loss} / g$  = loss head due to friction

The dimensions of equation (6) are

energy per unit weight ( $ft \cdot lb/lb = ft$  or  $N \cdot m/N = m$ )

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

$W_{shaft}$  = shaft power

$m$  = mass flow rate

$Q$  = volume flow rate

### Example - Pumping Water

Water is pumped from an open tank at level zero to an open tank at level 10 ft. The pump adds four horsepowers to the water when pumping 2 ft<sup>3</sup>/s.

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

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

or

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

Equation (7) gives:

$$h_{shaft} = W_{shaft} / \gamma Q = (4 \text{ hp})(550 \text{ ft.lb/s/hp}) / (62.4 \text{ lb/ft}^3)(2 \text{ ft}^3/\text{s}) = 17.6 \text{ ft}$$

- specific weight of water 62.4 lb/ft<sup>3</sup>
- 1 hp (English horse power) = 550 ft. lb/s

Combined with (8):

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

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

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

## H

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

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

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

Friction head loss (ft H<sub>2</sub>O per 100 ft pipe) in water pipes can be obtained by using the empirical Hazen-Williams equation. The Darcy-Weisbach equation with the Moody diagram are considered to be the most accurate model for estimating frictional head loss in steady pipe flow. Since the approach requires a not so efficient trial and error solution, an alternative empirical head loss calculation that does not require the trial and error solutions, as the Hazen-Williams equation, may be preferred:

$$f = 0.2083 (100/c)^{1.852} q^{1.852} / d_h^{4.8655} \quad (1)$$

where

$f$  = friction head loss in feet of water per 100 feet of pipe (ft<sub>H<sub>2</sub>O</sub>/100 ft pipe)

$c$  = Hazen-Williams roughness constant

$q$  = volume flow (gal/min)

$d_h$  = inside hydraulic diameter (inches)

Note that the Hazen-Williams formula is empirical and lacks physical basis. Be aware that the roughness constants are based on "normal" condition with approximately 1 m/s (3 ft/sec).

The Hazen-Williams formula is not the only empirical formula available. Manning's formula is common for gravity driven flows in open channels.

The flow velocity may be calculated as:

$$v = 0.4087 q / d_h^2$$

where

$v$  = flow velocity (ft/s)

The Hazen-Williams formula can be assumed to be relatively accurate for piping systems where the Reynolds Number is above  $10^5$  (turbulent flow).

- 1 ft (foot) = 0.3048 m
- 1 in (inch) = 25.4 mm
- 1 gal (US)/min =  $6.30888 \times 10^{-5} \text{ m}^3/\text{s}$  =  $0.0227 \text{ m}^3/\text{h}$  =  $0.0631 \text{ dm}^3(\text{liter})/\text{s}$  =  $2.228 \times 10^{-3} \text{ ft}^3/\text{s}$   
=  $0.1337 \text{ ft}^3/\text{min}$  =  $0.8327 \text{ Imperial gal (UK)/min}$

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

The results for the formula are acceptable for cold water at 60 °F (15.6 °C) with kinematic viscosity 1.13 cSt. For hot water with a lower kinematic viscosity (0.55 cSt at 130 °F (54.4 °C)) the error will be significant.

Since the Hazen Williams method is only valid for water flowing at ordinary temperatures between 40 to 75 °F, the Darcy Weisbach method should be used for other liquids or gases.

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

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

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

**I**

**Ideal Gas:** The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law.

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

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

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

where

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

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

## J

## K

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

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

where

$v$  = kinematic viscosity

$\mu$  = absolute or dynamic viscosity

$\rho$  = density

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

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

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

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

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

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

**Kinetic Energy:** The ability of an object to do work by virtue of its motion. The energy terms that are used to describe the operation of a pump are pressure and head.

**Knudsen Number:** Used by modelers who wish to non dimensionless speed

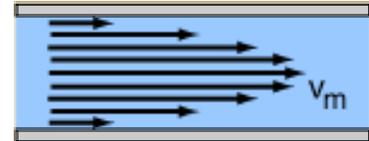
## L

**Laminar Flow:** The resistance to flow in a liquid can be characterized in terms of the viscosity of the fluid if the flow is smooth. In the case of a moving plate in a liquid, it is found that there is a layer or lamina which moves with the plate, and a layer which is essentially stationary if it is next to a stationary plate.



There is a gradient of velocity as you move from the stationary to the moving plate, and the liquid tends to move in layers with successively higher speed. This is called laminar flow, or sometimes "streamlined" flow. Viscous resistance to flow can be modeled for laminar flow, but if the lamina break up into turbulence, it is very difficult to characterize the fluid flow.

The common application of laminar flow would be in the smooth flow of a viscous liquid through a tube or pipe. In that case, the velocity of flow varies from zero at the walls to a maximum along the centerline of the vessel. The flow profile of laminar flow in a tube can be calculated by dividing the flow into thin cylindrical elements and applying the viscous force to them. Laminar, Transitional or Turbulent Flow? - It is important to know if the fluid flow is laminar, transitional or turbulent when calculating heat transfer or pressure and head loss.



**Laplace's Equation:** Describes the behavior of gravitational, electric, and fluid potentials.

The scalar form of Laplace's equation is the partial differential equation

$$\nabla^2 \psi = 0, \tag{1}$$

where  $\nabla^2$  is the Laplacian.

Note that the operator  $\nabla^2$  is commonly written as  $\Delta$  by mathematicians (Krantz 1999, p. 16).

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

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

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

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

with  $\rho = 0$ .

The vector Laplace's equation is given by

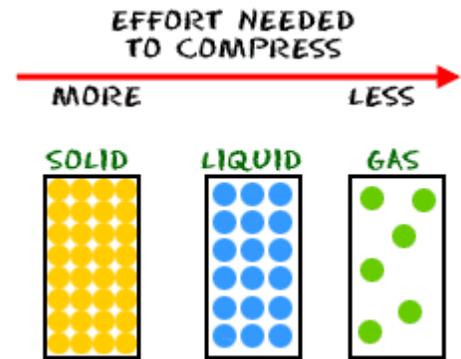
$$\nabla^2 \mathbf{F} = \mathbf{0}, \tag{4}$$

A function  $\psi$  which satisfies Laplace's equation is said to be harmonic. A solution to Laplace's equation has the property that the average value over a spherical surface is equal to the value at the center of the sphere (Gauss's harmonic function theorem). Solutions have no local maxima or minima. Because Laplace's equation is linear, the superposition of any two solutions is also a solution.

**Lift (Force):** Lift consists of the sum of all the aerodynamic forces normal to the direction of the external airflow.

**Liquids:** An in-between state of matter. They can be found in-between the solid and gas states. They don't have to be made up of the same compounds. If you have a variety of materials in a liquid, it is called a solution.

One characteristic of a liquid is that it will fill up the shape of a container. If you pour some water in a cup, it will fill up the bottom of the cup first and then fill the rest. The water will also take the shape of the cup. It fills the bottom first because of **gravity**. The top part of a liquid will usually have a flat surface. That flat surface is because of gravity too. Putting an ice cube (solid) into a cup will leave you with a cube in the middle of the cup; the shape won't change until the ice becomes a liquid.



Another trait of liquids is that they are difficult to compress. When you compress something, you take a certain amount and force it into a smaller space. Solids are very difficult to compress and gases are very easy. Liquids are in the middle but tend to be difficult. When you compress something, you force the atoms closer together. When pressure goes up, substances are compressed. Liquids already have their atoms close together, so they are hard to compress. Many shock absorbers in cars compress liquids in tubes.

A special force keeps liquids together. Solids are stuck together and you have to force them apart. Gases bounce everywhere and they try to spread themselves out. Liquids actually want to stick together. There will always be the occasional evaporation where extra energy gets a molecule excited and the molecule leaves the system. Overall, liquids have **cohesive** (sticky) forces at work that hold the molecules together. Related Liquid Information: Equations in Fluid Mechanics - Continuity, Euler, Bernoulli, Dynamic and Total Pressure

## M

**Mach Number:** When an object travels through a medium, then its Mach number is the ratio of the object's speed to the speed of sound in that medium.

**Manning Formula for Gravity Flow:** Manning's equation can be used to calculate cross-sectional average velocity flow in open channels

$$v = k_n/n R^{2/3} S^{1/2} \quad (1)$$

where

$v$  = cross-sectional average velocity (ft/s, m/s)

$k_n = 1.486$  for English units and  $k_n = 1.0$  for SI units

$A$  = cross sectional area of flow (ft<sup>2</sup>, m<sup>2</sup>)

$n$  = Manning coefficient of roughness

$R$  = hydraulic radius (ft, m)

$S$  = slope of pipe (ft/ft, m/m)

The volume flow in the channel can be calculated as

$$q = A v = A k_n/n R^{2/3} S^{1/2} \quad (2)$$

where

$q$  = volume flow (ft<sup>3</sup>/s, m<sup>3</sup>/s)

$A$  = cross-sectional area of flow (ft<sup>2</sup>, m<sup>2</sup>)

**Maximum Contamination Levels or (MCLs):** The maximum allowable level of a contaminant that federal or state regulations allow in a public water system. If the MCL is exceeded, the water system must treat the water so that it meets the MCL. Or provide adequate backflow protection.

**Mechanical Seal:** A mechanical device used to control leakage from the stuffing box of a pump. Usually made of two flat surfaces, one of which rotates on the shaft. The two flat surfaces are of such tolerances as to prevent the passage of water between them.

**Mg/L:** milligrams per liter

**Microbe, Microbial:** Any minute, simple, single-celled form of life, especially one that causes disease.

**Microbial Contaminants:** Microscopic organisms present in untreated water that can cause waterborne diseases.

**ML:** milliliter

## N

**Navier-Stokes Equations:** The motion of a non-turbulent, Newtonian fluid is governed by the Navier-Stokes equation. The equation can be used to model turbulent flow, where the fluid parameters are interpreted as time-averaged values.

**Newtonian Fluid:** Newtonian fluid (named for Isaac Newton) is a fluid that flows like water—its shear stress is linearly proportional to the velocity gradient in the direction perpendicular to the plane of shear. The constant of proportionality is known as the viscosity. Water is Newtonian, because it continues to exemplify fluid properties no matter how fast it is stirred or mixed.

Contrast this with a non-Newtonian fluid, in which stirring can leave a "hole" behind (that gradually fills up over time - this behavior is seen in materials such as pudding, or to a less rigorous extent, sand), or cause the fluid to become thinner, the drop in viscosity causing it to flow more (this is seen in non-drip paints). For a Newtonian fluid, the viscosity, by definition, depends only on temperature and pressure (and also the chemical composition of the fluid if the fluid is not a pure substance), not on the forces acting upon it. If the fluid is incompressible and viscosity is constant across the fluid, the equation governing the shear stress. Related Newtonian Information: A Fluid is Newtonian if viscosity is constant applied to shear force. Dynamic, Absolute and Kinematic Viscosity - An introduction to dynamic, absolute and kinematic viscosity and how to convert between CentiStokes (cSt), CentiPoises (cP), Saybolt Universal Seconds (SSU) and degree Engler.

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

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

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

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

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

## O

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

## P

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

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

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

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

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

**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)

$q = \text{volume flow (m}^3/\text{s)}$   
 $d = \text{pipe inside diameter (m)}$

**Potable:** Good water which is safe for drinking or cooking purposes. **Non-Potable:** A liquid or water that is not approved for drinking.

**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.

**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

$Pr = \text{Prandtl's number}$

$\nu = \text{kinematic viscosity (Pa s)}$

$\alpha = \text{thermal diffusivity (W/m K)}$

The Prandtl number can alternatively be expressed as

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

where

$\mu = \text{absolute or dynamic viscosity (kg/m s, cP)}$

$c_p = \text{specific heat capacity (J/kg K, Btu/(lb }^\circ\text{F))}$

$k = \text{thermal conductivity (W/m K, Btu/(h ft}^2 \text{ }^\circ\text{F/ft))}$

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 a imaginary or real plane surface in a fluid or a gas"*

The equation for pressure can expressed as:

$$p = F / A \quad (1)$$

where

$p = \text{pressure [lb/in}^2 \text{ (psi) or lb/ft}^2 \text{ (psf), N/m}^2 \text{ or kg/ms}^2 \text{ (Pa)]}$

$F = \text{force [}^1\text{, N]}$

$A = \text{area [in}^2 \text{ or ft}^2 \text{, m}^2\text{]}$

<sup>1)</sup> In the English Engineering System special care must be taken for the force unit. The basic unit for mass is the pound mass (lb<sub>m</sub>) and the unit for the force is the pound (lb) or pound force (lb<sub>f</sub>).

## Absolute Pressure

The **absolute pressure** -  $p_a$  - is measured relative to the *absolute zero pressure* - the pressure that would occur at absolute vacuum.

## Gauge Pressure

A **gauge** is often used to measure the pressure difference between a system and the surrounding atmosphere. This pressure is often called the **gauge pressure** and can be expressed as

$$p_g = p_a - p_o \quad (2)$$

where

$p_g$  = gauge pressure

$p_o$  = atmospheric pressure

## Atmospheric Pressure

The atmospheric pressure is the pressure in the surrounding air. It varies with temperature and altitude above sea level.

### Standard Atmospheric Pressure

The **Standard Atmospheric Pressure** (atm) is used as a reference for gas densities and volumes. The Standard Atmospheric Pressure is defined at sea-level at 273°K (0°C) and is **1.01325 bar** or 101325 Pa (absolute). The temperature of 293°K (20°C) is also used.

In imperial units the Standard Atmospheric Pressure is 14.696 psi.

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

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

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

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

### Some Pressure Levels

- 10 Pa - The pressure at a depth of 1 mm of water
- 1 kPa - Approximately the pressure exerted by a 10 g mass on a 1 cm<sup>2</sup> area
- 10 kPa - The pressure at a depth of 1 m of water, or the drop in air pressure when going from sea level to 1000 m elevation
- 10 MPa - A "high pressure" washer forces the water out of the nozzles at this pressure
- 10 GPa - This pressure forms diamonds

### Some Alternative Units of Pressure

- $1 \text{ bar} = 100,000 \text{ Pa}$
- $1 \text{ millibar} = 100 \text{ Pa}$
- $1 \text{ atmosphere} = 101,325 \text{ Pa}$
- $1 \text{ mm Hg} = 133 \text{ Pa}$
- $1 \text{ inch Hg} = 3,386 \text{ Pa}$

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

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

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

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

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

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

## Q

## R

**Residual Disinfection/Protection:** A required level of disinfectant that remains in treated water to ensure disinfection protection and prevent recontamination throughout the distribution system (i.e., pipes).

**Reynolds Number:** The Reynolds number is used to determine whether a flow is laminar or turbulent. The Reynolds Number is a nondimensional parameter defined by the ratio of dynamic pressure ( $\rho u^2$ ) and shearing stress ( $\mu u / L$ ) - and can be expressed as

$$\begin{aligned} Re &= (\rho u^2) / (\mu u / L) \\ &= \rho u L / \mu \\ &= u L / \nu \quad (1) \end{aligned}$$

where

$Re$  = Reynolds Number (non-dimensional)

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

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

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

$L$  = characteristic length (m, ft)

$\nu$  = kinematic viscosity ( $\text{m}^2/\text{s}$ ,  $\text{ft}^2/\text{s}$ )

**Richardson Number:** A dimensionless number that expresses the ratio of potential to kinetic energy.

## S

**Sanitizer:** A chemical which disinfects (kills bacteria), kills algae and oxidizes organic matter.

**Saybolt Universal Seconds (or SUS, SSU):** Saybolt Universal Seconds (or SUS) is used to measure viscosity. The efflux time is Saybolt Universal Seconds (SUS) required for 60 milliliters of a petroleum product to flow through the calibrated orifice of a Saybolt Universal viscometer, under carefully controlled temperature and as prescribed by test method ASTM D 88. This method has largely been replaced by the kinematic viscosity method. Saybolt Universal Seconds is also called the SSU number (Seconds Saybolt Universal) or SSF number (Saybolt Seconds Furol).

Kinematic viscosity versus dynamic or absolute viscosity can be expressed as

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

where

$v$  = kinematic viscosity (SSU)

$\mu$  = dynamic or absolute viscosity (cP)

**Scale:** Crust of calcium carbonate, the result of unbalanced pool water. Hard insoluble minerals deposited (usually calcium bicarbonate) which forms on pool and spa surfaces and clog filters, heaters and pumps. Scale is caused by high calcium hardness and/or high pH. You will often find major scale deposits inside a backflow prevention assembly.

**Shock:** Also known as superchlorination or break point chlorination. Ridding a pool of organic waste through oxidization by the addition of significant quantities of a halogen.

**Shock Wave:** A shock wave is a strong pressure wave produced by explosions or other phenomena that create violent changes in pressure.

**Solder:** A fusible alloy used to join metallic parts. Solder for potable water pipes shall be lead-free.

**Sound Barrier:** The sound barrier is the apparent physical boundary stopping large objects from becoming supersonic.

**Specific Gravity:** The Specific Gravity - SG - is a dimensionless unit defined as the ratio of density of the material to the density of water at a specified temperature. Specific Gravity can be expressed as

$$SG = \rho / \rho_{H_2O} \quad (3)$$

where

$SG$  = specific gravity

$\rho$  = density of fluid or substance ( $kg/m^3$ )

$\rho_{H_2O}$  = density of water ( $kg/m^3$ )

It is common to use the density of water at 4 °C (39°F) as a reference - at this point the density of water is at the highest. Since Specific Weight is dimensionless it has the same value in the metric SI system as in the imperial English system (BG). At the reference point the Specific Gravity has same numerically value as density.

#### **Example - Specific Gravity**

If the density of iron is  $7850 \text{ kg/m}^3$ , 7.85 grams per cubic millimeter, 7.85 kilograms per liter, or 7.85 metric tons per cubic meter - the specific gravity of iron is:

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

$$= 7.85$$

(the density of water is  $1000 \text{ kg/m}^3$ )

**Specific Weight:** Specific Weight is defined as weight per unit volume. Weight is a **force**.

- Mass and Weight - the difference! - What is weight and what is mass? An explanation of the difference between weight and mass.

Specific Weight can be expressed as

$$\gamma = \rho g \quad (2)$$

where

$\gamma$  = specific weight (kN/m<sup>3</sup>)

$g$  = acceleration of gravity (m/s<sup>2</sup>)

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

**Example - Specific Weight Water**

Specific weight for water at 60 °F is 62.4 lb/ft<sup>3</sup> in imperial units and 9.80 kN/m<sup>3</sup> in SI-units.

**Example - Specific Weight Some other Materials**

Product	Specific Weight - $\gamma$	
	Imperial Units (lb/ft <sup>3</sup> )	SI Units (kN/m <sup>3</sup> )
Ethyl Alcohol	49.3	7.74
Gasoline	42.5	6.67
Glycerin	78.6	12.4
Mercury	847	133
SAE 20 Oil	57	8.95
Seawater	64	10.1
Water	62.4	9.80

**Static Head:** The height of a column or body of fluid above a given point

**Static Pressure:** The pressure in a fluid at rest.

**Static Pressure and Pressure Head in Fluids:** The pressure indicates the normal force per unit area at a given point acting on a given plane. Since there is no shearing stresses present in a fluid at rest - the pressure in a fluid is independent of direction.

For fluids - liquids or gases - at rest the pressure gradient in the vertical direction depends only on the specific weight of the fluid.

How pressure changes with elevation can be expressed as

$$dp = - \gamma dz \quad (1)$$

where

$dp$  = change in pressure

$dz$  = change in height

$\gamma$  = specific weight

The pressure gradient in vertical direction is negative - the pressure decrease upwards.

**Static Pressure and Pressure Head in Fluids Continued:**

**Specific Weight:** Specific Weight can be expressed as:

$$\gamma = \rho g \quad (2)$$

where

$\gamma$  = specific weight

$g$  = acceleration of gravity

In general the specific weight -  $\gamma$  - is constant for fluids. For gases the specific weight -  $\gamma$  - varies with the elevation.

**Static Pressure and Pressure Head in Fluids Continued:**

**Static Pressure in a Fluid:** For an incompressible fluid - as a liquid - the pressure difference between two elevations can be expressed as:

$$p_2 - p_1 = -\gamma (z_2 - z_1) \quad (3)$$

where

$p_2$  = pressure at level 2

$p_1$  = pressure at level 1

$z_2$  = level 2

$z_1$  = level 1

(3) can be transformed to:

$$p_1 - p_2 = \gamma (z_2 - z_1) \quad (4)$$

or

$$p_1 - p_2 = \gamma h \quad (5)$$

where

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

or

$$p_1 = \gamma h + p_2 \quad (6)$$

**Static Pressure and Pressure Head in Fluids Continued:**

**The Pressure Head**

(6) can be transformed to:

$$h = (p_2 - p_1) / \gamma \quad (6)$$

$h$  express **the pressure head** - the height of a column of fluid of specific weight -  $\gamma$  - required to give a pressure difference of  $(p_2 - p_1)$ .

**Example - Pressure Head**

A pressure difference of 5 psi (lbf/in<sup>2</sup>) is equivalent to

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

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

when specific weight of water is 62.4 (lb/ft<sup>3</sup>) and specific weight of mercury is 847 (lb/ft<sup>3</sup>).

**Streamline - Stream Function:** A streamline is the path that an imaginary particle would follow if it was embedded in the flow.

**Strouhal Number:** A quantity describing oscillating flow mechanisms. The Strouhal Number is a dimensionless value useful for analyzing oscillating, unsteady fluid flow dynamics problems.

The Strouhal Number can be expressed as

$$St = \omega l / v \quad (1)$$

where

$St$  = Strouhal Number

$\omega$  = oscillation frequency

$l$  = characteristic length

$v$  = flow velocity

The Strouhal Number represents a measure of the ratio of inertial forces due to the unsteadiness of the flow or local acceleration to the inertial forces due to changes in velocity from one point to another in the flow field.

The vortices observed behind a stone in a river, or measured behind the obstruction in a vortex flow meter, illustrate these principles.

**Stuffing Box:** That portion of the pump which houses the packing or mechanical seal.

**Submerged:** To cover with water or liquid substance.

**Supersonic Flow:** Flow with speed above the speed of sound, 1,225 km/h at sea level, is said to be supersonic.

**Surface Tension:** Surface tension is a force within the surface layer of a liquid that causes the layer to behave as an elastic sheet. The cohesive forces between liquid molecules are responsible for the phenomenon known as surface tension. The molecules at the surface do not have other like molecules on all sides of them and consequently they cohere more strongly to those directly associated with them on the surface. This forms a surface "film" which makes it more difficult to move an object through the surface than to move it when it is completely submerged. Surface tension is typically measured in dynes/cm, the force in dynes required to break a film of length 1 cm. Equivalently, it can be stated as surface energy in ergs per square centimeter. Water at 20°C has a surface tension of 72.8 dynes/cm compared to 22.3 for ethyl alcohol and 465 for mercury.

Surface tension is typically measured in *dynes/cm* or *N/m*.

Liquid	Surface Tension	
	N/m	dynes/cm
Ethyl Alcohol	0.0223	22.3
Mercury	0.465	465
Water 20°C	0.0728	72.75
Water 100°C	0.0599	58.9

Surface tension is the energy required to stretch a unit change of a surface area. Surface tension will form a drop of liquid to a sphere since the sphere offers the smallest area for a

definite volume.

Surface tension can be defined as

$$\sigma = F_s / l \quad (1)$$

where

$\sigma$  = surface tension (N/m)

$F_s$  = stretching force (N)

$l$  = unit length (m)

### Alternative Units

Alternatively, surface tension is typically measured in dynes/cm, which is

- the force in dynes required to break a film of length 1 cm
- or as surface energy J/m<sup>2</sup> or alternatively ergs per square centimeter.
- 1 dynes/cm = 0.001 N/m = 0.0000685 lb<sub>f</sub>/ft = 0.571 10<sup>-5</sup> lb<sub>f</sub>/in = 0.0022 poundal/ft = 0.00018 poundal/in = 1.0 mN/m = 0.001 J/m<sup>2</sup> = 1.0 erg/cm<sup>2</sup> = 0.00010197 kg<sub>f</sub>/m

Common Imperial units used are lb/ft and lb/in.

Water surface tension at different temperatures can be taken from the table below:

Temperature (°C)	Surface Tension - $\sigma$ - (N/m)
0	0.0757
10	0.0742
20	0.0728
30	0.0712
40	0.0696
50	0.0679
60	0.0662
70	0.0644
80	0.0626
90	0.0608
100	0.0588

### Surface Tension of some common Fluids

- benzene : 0.0289 (N/m)
- diethyl ether : 0.0728 (N/m)
- carbon tetrachloride : 0.027 (N/m)
- chloroform : 0.0271 (N/m)
- ethanol : 0.0221 (N/m)
- ethylene glycol : 0.0477 (N/m)
- glycerol : 0.064 (N/m)
- mercury : 0.425 (N/m)

- methanol : 0.0227 (N/m)
- propanol : 0.0237 (N/m)
- toluene : 0.0284 (N/m)
- water at 20°C : 0.0729 (N/m)

## T

**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.

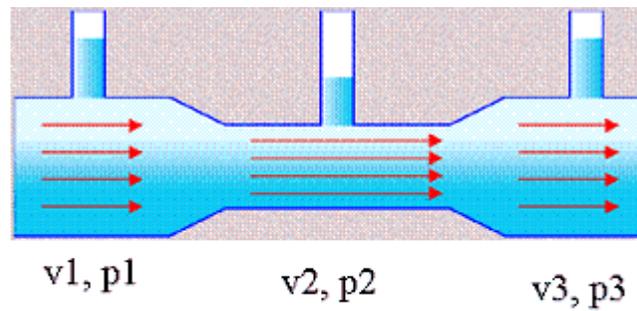
**Vane:** That portion of an impeller which throws the water toward the volute.

**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 Venturi is 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:

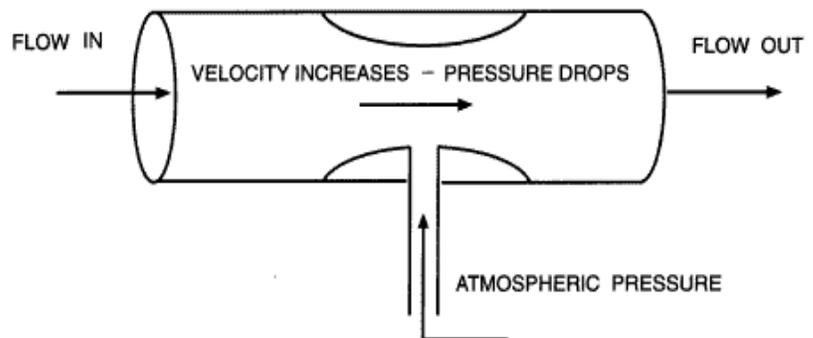
- A venturi to increase the speed of the fluid (restriction of the pipe diameter)
- A short piece of tube connected to the gas source
- A second venturi that decrease the speed of the fluid (the pipe diameter increase again)



$$v_1 < v_2 \qquad v_2 > v_3$$

$$p_1 > p_2 \qquad p_2 < p_3$$

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 thousand of very tiny bubbles of gas in the liquid. The small bubbles provide an increased gas exposure to the liquid surface area, increasing the effectiveness of the process (i.e. ozonation).



(represented by the symbol  $\nu$ ) 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 [ $\text{m}^2/\text{s}$ ], which has no special name. This unit is so large that it is rarely used. A more common unit of kinematic viscosity is the square centimeter per second [ $\text{cm}^2/\text{s}$ ], which is given the name stoke [St] after the English scientist George Stoke. This unit is also a bit too large and so the most common unit is probably the square millimeter per second [ $\text{mm}^2/\text{s}$ ] or centistoke [cSt].

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

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

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

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

## W

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

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

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

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

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

## Appendixes and Charts

### Density of Common Liquids

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

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

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

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

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

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

## Dynamic or Absolute Viscosity Units Converting Table

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

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

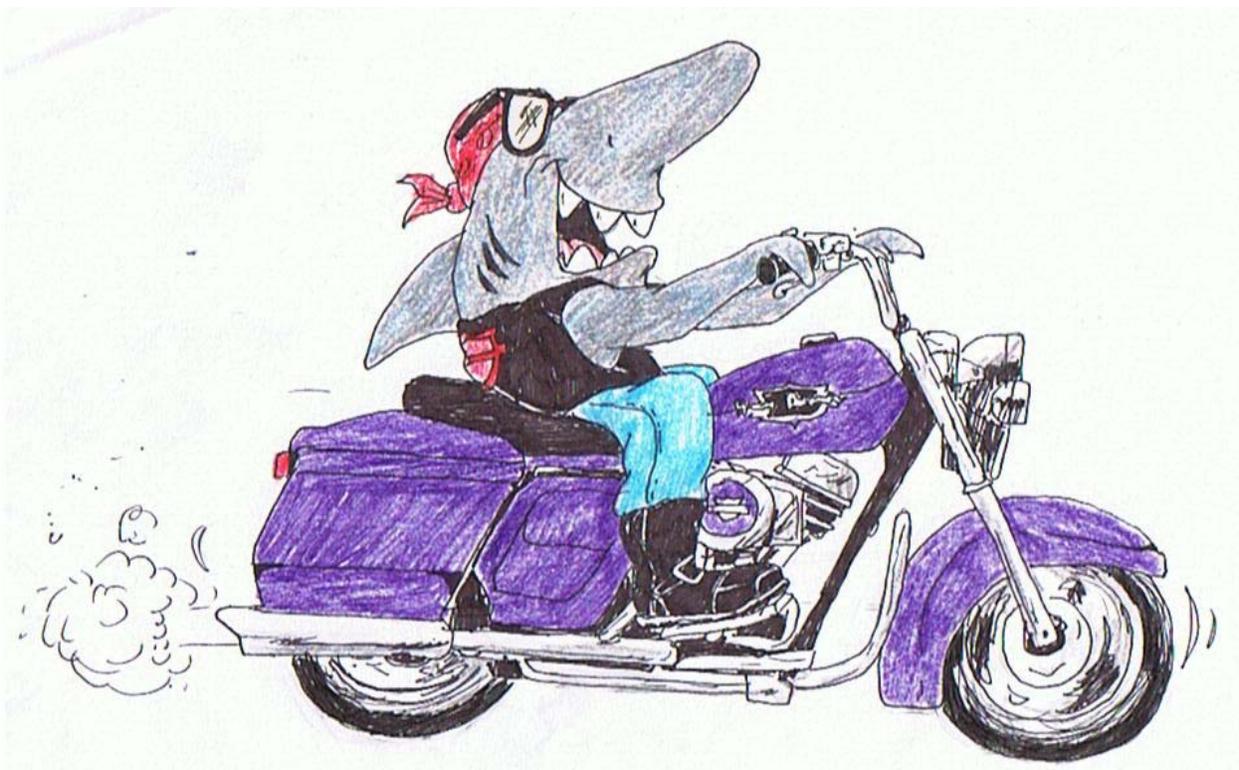


## Friction Loss Chart

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

Pipe Size (inches)	Flow Rate		Kinematic Viscosity - SSU					
	(gpm)	(l/s)	31 (Water)	100 (~Cream)	200 (~Vegetable oil)	400 (~SAE 10 oil)	800 (~Tomato juice)	1500 (~SAE 30 oil)
1/2	3	0.19	10.0	25.7	54.4	108.0	218.0	411.0
3/4	3	0.19	2.5	8.5	17.5	35.5	71.0	131.0
	5	0.32	6.3	14.1	29.3	59.0	117.0	219.0
1	3	0.19	0.8	3.2	6.6	13.4	26.6	50.0
	5	0.32	1.9	5.3	11.0	22.4	44.0	83.0
	10	0.63	6.9	11.2	22.4	45.0	89.0	165.0
	15	0.95	14.6	26.0	34.0	67.0	137.0	
1 1/4	20	1.26	25.1	46	46.0	90.0	180.0	
	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
1 1/2	15	0.95	3.7	6.4	11.3	22.4	45.0	84.0
	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
2	40	2.5	10.8	19.6	20.8	32.0	65.0	121.0
	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
2 1/2	80	5.0	1.6	3.0	3.2	4.8	9.7	18.3
	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
3	100	6.3	7.1	12.2	14.1	14.8	29.0	55.0
	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
4	200	12.6	8.9	15.0	17.8	20.3	25.0	46.0
	80	5.0	0.4	0.8	0.8	1.7	3.3	6.2
	100	6.3	0.6	1.2	1.3	2.1	4.1	7.8

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



## Hazen-Williams Coefficients

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

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

## Pressure Head

A pressure difference of 5 psi (lbf/in<sup>2</sup>) is equivalent to

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

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

When specific weight of water is 62.4 (lb/ft<sup>3</sup>) and specific weight of mercury is 847 (lb/ft<sup>3</sup>).

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

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

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

## Thermal Properties of Water

Temperature - <i>t</i> - (°C)	Absolute pressure - <i>p</i> - (kN/m <sup>2</sup> )	Density - <i>ρ</i> - (kg/m <sup>3</sup> )	Specific volume - <i>v</i> - (m <sup>3</sup> /kgx10 <sup>-3</sup> )	Specific Heat - <i>c<sub>p</sub></i> - (kJ/kgK)	Specific entropy - <i>e</i> - (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



**See a cross-connection?**

## Viscosity Converting Chart

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

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

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

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

## Various Flow Section Channels and their Geometric Relationships:

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

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

### Rectangular Channel

#### **Flow Area**

Flow area of a rectangular channel can be expressed as

$$A = b h \quad (1)$$

where

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

$b$  = width of channel ( $m$ ,  $in$ )

$h$  = height of flow ( $m$ ,  $in$ )

#### **Wetted Perimeter**

Wetted perimeter of a rectangular channel can be expressed as

$$P = b + 2 h \quad (1b)$$

where

$P$  = wetted perimeter ( $m$ ,  $in$ )

#### **Hydraulic Radius**

Hydraulic radius of a rectangular channel can be expressed as

$$R_h = b h / (b + 2 h) \quad (1c)$$

where

$R_h$  = hydraulic radius ( $m$ ,  $in$ )

### Trapezoidal Channel

#### **Flow Area**

Flow area of a trapezoidal channel can be expressed as

$$A = (a + z h) h \quad (2)$$

where

$z$  = see figure above ( $m$ ,  $in$ )

#### **Wetted Perimeter**

Wetted perimeter of a trapezoidal channel can be expressed as

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

#### **Hydraulic Radius**

Hydraulic radius of a trapezoidal channel can be expressed as

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

## **Triangular Channel**

### **Flow Area**

Flow area of a triangular channel can be expressed as

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

where

$z$  = see figure above (m, in)

### **Wetted Perimeter**

Wetted perimeter of a triangular channel can be expressed as

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

### **Hydraulic Radius**

Hydraulic radius of a triangular channel can be expressed as

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

## **Circular Channel**

### **Flow Area**

Flow area of a circular channel can be expressed as

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

where

$D$  = diameter of channel

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

### **Wetted Perimeter**

Wetted perimeter of a circular channel can be expressed as

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

### **Hydraulic Radius**

Hydraulic radius of a circular channel can be expressed as

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

**Velocity Head:** Velocity head can be expressed as

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

where

$v$  = velocity (ft, m)

$g$  = acceleration of gravity (32.174 ft/s<sup>2</sup>, 9.81 m/s<sup>2</sup>)

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

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

## Some Commonly used Thermal Properties for Water

- Density at 4 °C - 1,000 kg/m<sup>3</sup>, 62.43 Lbs./Cu.Ft, 8.33 Lbs./Gal., 0.1337 Cu.Ft./Gal.
  - Freezing temperature - 0 °C
  - Boiling temperature - 100 °C
  - Latent heat of melting - 334 kJ/kg
  - Latent heat of evaporation - 2,270 kJ/kg
  - Critical temperature - 380 - 386 °C
  - Critical pressure - 23.520 kN/m<sup>2</sup>
  - Specific heat capacity water - 4.187 kJ/kgK
  - Specific heat capacity ice - 2.108 kJ/kgK
  - Specific heat capacity water vapor - 1.996 kJ/kgK
  - Thermal expansion from 4 °C to 100 °C -  $4.2 \times 10^{-2}$
- Bulk modulus elasticity - 2,068,500 kN/m<sup>2</sup>



## Reynolds Number

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

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

A definition of the Reynolds' Number.

The flow is

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

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

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

## Linear Motion Formulas

Velocity can be expressed as (velocity = constant):

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

*where*

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

*s = linear displacement (m, ft)*

*t = time (s)*

Velocity can be expressed as (acceleration = constant):

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

*where*

*V<sub>0</sub> = linear velocity at time zero (m/s, ft/s)*

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

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

Combining 1a and 1c to express velocity

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

Velocity can be expressed as (velocity variable)

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

*where*

*ds = change of displacement (m, ft)*

*dt = change in time (s)*

Acceleration can be expressed as

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

*where*

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

## Water - Dynamic and Kinematic Viscosity

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

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

Dynamic and Kinematic Viscosity of Water in SI Units:

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

## Water and Speed of Sound

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

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

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

Speed of Sound in Water - in SI units

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

## Math Conversion Factors 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  
 5,280 Feet = 1 Mile

### AREA

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

### VOLUME

1000 Milliliters = 1 Liter  
 3.785 Liters = 1 Gallon  
 231 Cubic Inches = 1 Gallon  
 7.48 Gallons = 1 Cubic foot of water  
 62.38 Pounds = 1 Cubic foot of water

### Dimensions

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

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

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

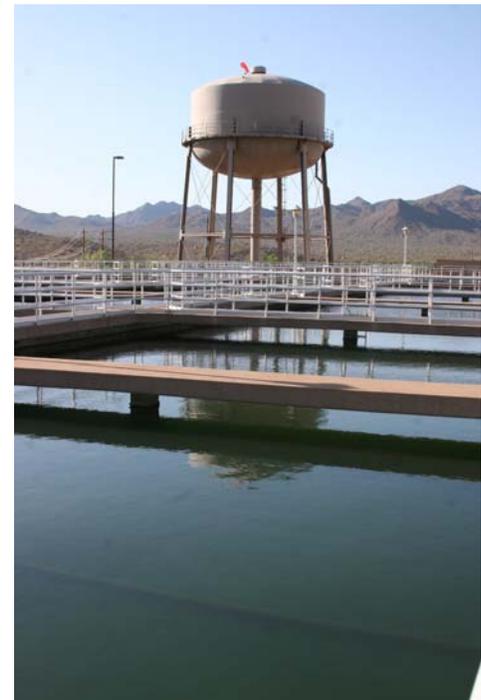
**PIPE VOLUME:** .785 X Diameter<sup>2</sup> X Length = ? To obtain gallons multiply by 7.48

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

### General Conversions

#### Flowrate

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



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

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

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

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

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

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

**N** = Manning's Coefficient of Roughness

**R** = Hydraulic Radius (ft.)

**S** = Slope of Sewer (ft./ft.)

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

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

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

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



## 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

ft<sup>3</sup>, feet<sup>3</sup>, foot<sup>3</sup>

feet<sup>3</sup>, foot<sup>3</sup>, ft<sup>3</sup>

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

### Water Treatment Production Math Numbering System

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

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

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

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

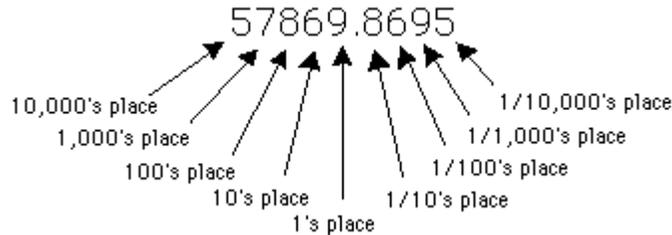
$$15 \text{ cm} \div 2.54 \text{ cm} \div 12 \text{ inches} = .492 \text{ feet}$$

$$.785 \times .492' \times .492' \times \underline{\hspace{1cm}}' = \underline{\hspace{1cm}} \times 7.48 = \underline{\hspace{1cm}} \times 3.785 \text{ L} =$$

### 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:

$$\begin{aligned} .1 &= 1/10 \\ .01 &= 1/100 \\ .001 &= 1/1000 \end{aligned}$$



So just as the digits to the left of the decimal represent 1's, 10's, 100's, and so forth, digits to the right of the decimal point represent 1/10's, 1/100's, 1/1000's, and so forth.

Let's express 5% as a decimal.  $5 \div 100 = 0.05$  or you can move the decimal point to the left two places.

### Changing a fraction to a decimal:

**Divide the numerator by the denominator**

**A.**  $5/10$  (five tenths) = five divided by ten:

$$\begin{array}{r} .5 \\ \text{----} \\ 10 \overline{) 5.0} \\ \underline{50} \\ \text{----} \end{array}$$

So  $5/10$  (five tenths) =  $.5$  (five tenths).

**B.** How about  $1/2$  (one half) or 1 divided by 2 ?

$$\begin{array}{r} .5 \\ \text{----} \\ 2 \overline{) 1.0} \\ \underline{10} \\ \text{----} \end{array}$$

So  $1/2$  (one half) =  $.5$  (five tenths)

*Notice that equivalent fractions convert to the same decimal representation.*

$8/12$  is a good example.  $8 \div 12 = .66666666$  or rounded off to  $.667$

How about  $6/12$  or 6 inches?  $.5$  or half a foot

## Flow and Velocity

This depends on measuring the average velocity of flow and the cross-sectional area of the channel and calculating the flow from:

$$Q(\text{m}^3/\text{s}) = A(\text{m}^2) \times V(\text{m}/\text{s})$$

Or

$$Q = A \times V$$

Q CFM = Cubic Ft, Inches, Yards of time, Sec, Min, Hrs, Days

A = Area, squared Length X Width

V f/m = Inch, Ft, Yards, Per Time, Sec, Min, Ft or Speed

**13. A channel is 3 feet wide and has water flowing to a depth of 2.5 feet. If the velocity through the channel is 2 fps or feet per second, what is the cfs flow rate through the channel?**

$$Q = A \times V$$

Q = 7.5 sq. ft. X 2 fps What is Q?

$$A = 3' \times 2.5' = 7.5$$

$$V = 2 \text{ fps}$$

**14. A channel is 40 inches wide and has water flowing to a depth of 1.5 ft. If the velocity of the water is 2.3 fps, what is the cfs flow in the channel?  $Q = A \times V$**

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?

$$Q = \underline{\hspace{2cm}} \text{ cfs} \times 60 \text{ sec/min} \times 7.48 = \underline{\hspace{2cm}} \text{ gpm}$$

$$A = .785 \times .667' \times .667'$$

$$V = 3.4 \text{ fps}$$

17. A 6 inch diameter pipe delivers 280 gpm. What is the velocity of flow in the pipe in ft/sec?

$$\text{Take the water out of the pipe. } 280 \text{ gpm} \div 7.48 \div 60 \text{ sec/min} = \underline{\hspace{2cm}} \text{ cfs}$$

$$Q =$$

$$A = .785 \times .5' \times .5' =$$

$$V =$$

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

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

$$.785 \times 1' \times 1' \times 2000' = \underline{\hspace{2cm}} \text{ cuft} \times 7.48 = \underline{\hspace{2cm}} \div 1,000,000 = \underline{\hspace{2cm}} \text{ MG}$$

**Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal if 100% concentrate. If not, divide the lbs/day by the given %**

$$0.0117436 \text{ MG} \times 200 \text{ mg/L} \times 8.34 = \underline{\hspace{2cm}} \text{ lbs/day} \div .05 =$$

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?

$$.785 \times .5' \times .5' \times 1320' \times 7.48 = \underline{\hspace{2cm}} \text{ Make it MGD}$$

$$\text{Pounds per day formula} = \text{Flow} \times \text{Dose} \times 8.34 \times 45.4 \text{ Grams per pound}$$

**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



$$^{\circ}\text{F} = (^{\circ}\text{C} \times 9/5) + 32 \quad 9/5 = 1.8$$

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

**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. A 6 inch diameter pipe delivers 280 GPM. What is the velocity of flow in the pipe in Ft/Sec?**

$$280 \text{ GPM} \div 60 \text{ seconds in a minute} \div 7.48 \text{ gallons in a cu. ft.} = .623 \text{ CFS}$$

$$Q = .623$$

$$A = .785 \times .5 \times .5 = .196 \text{ Sq. Ft.}$$

$$V = 3.17 \text{ Ft/Second}$$

**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.

$$.785 \times 1.5' \times 1.5' \times 420' \times 7.48 = \underline{\hspace{2cm}} \text{ convert to MG}$$

**Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal**

*I hope you've enjoyed this course. Professor Melissa Durbin.*



**We welcome you to complete the assignment in Microsoft Word. You can easily find the assignment at [www.abctlc.com](http://www.abctlc.com). Once complete, just simply fax or e-mail the answer key along with the registration page to us and allow two weeks for grading. Once we grade it, we will mail a certificate of completion to you. Call us if you need any help. If you need your certificate back within 48 hours, you may be asked to pay a rush service fee.**

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