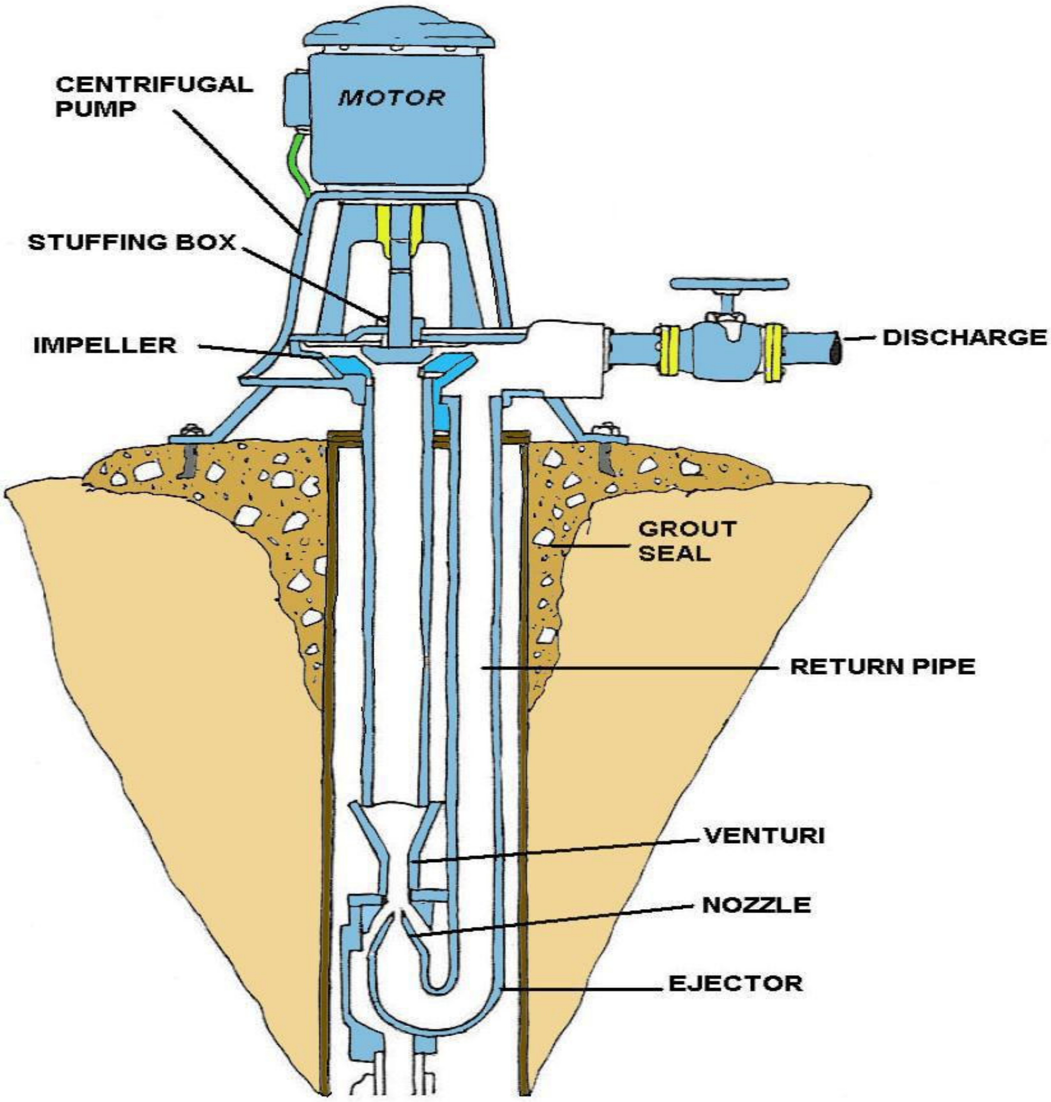
PUMP PRIMER II

CONTINUING EDUCATION
PROFESSIONAL DEVELOPMENT COURSE



Technical Learning College

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

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

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

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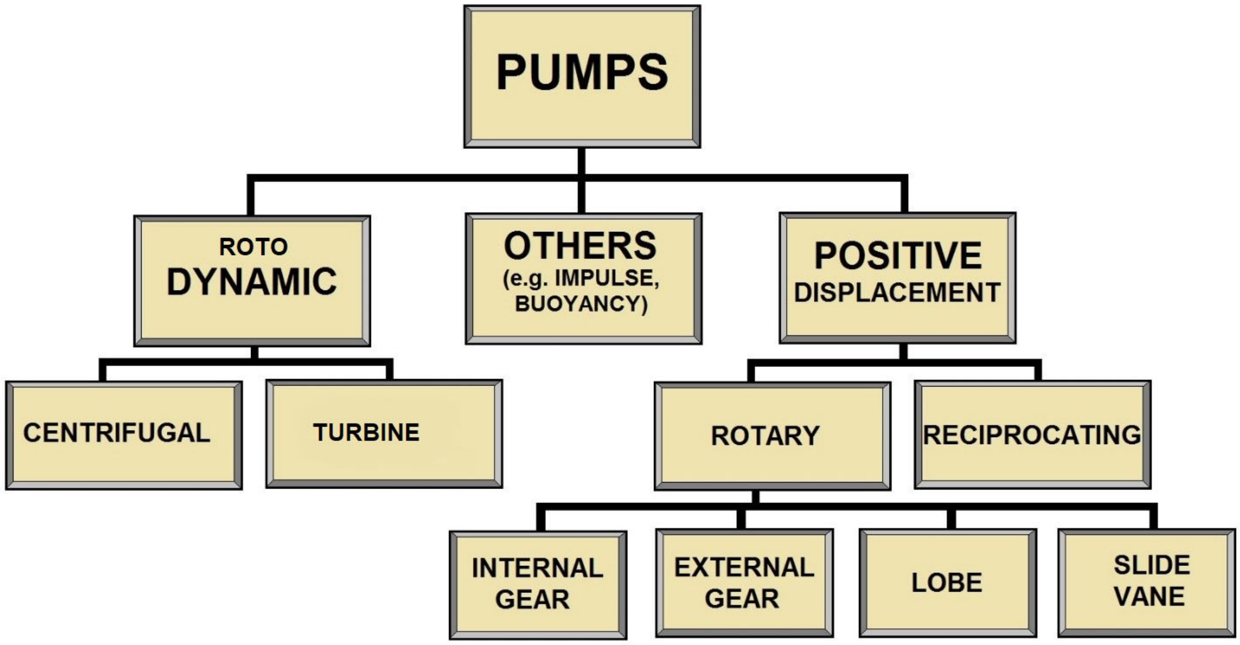


Important Information about this Manual

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

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

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

Technical Learning College's Scope and Function

Welcome to the Program,

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

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

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

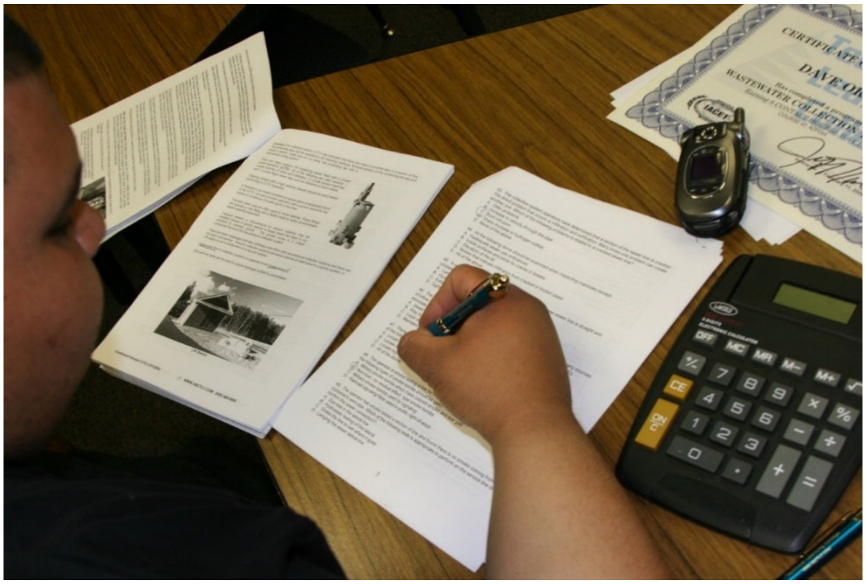
Students have direct contact with their instructor—primarily by e-mail or telephone. TLC's CEU courses may use such technologies as the World Wide Web, e-mail, CD-ROMs, videotapes and hard copies. (See the course description.) Make sure you have access to the necessary equipment before enrolling; i.e.,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

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

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

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

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



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

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

Course Description

Pump Primer II CEU Training Course

This short CEU course will review various hydraulic principles and basic pumping foundations to properly understand the operation and function of primary water/wastewater related pumps and equipment. ***You will not need any other materials for this course.***

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

Final Examination for Credit
Opportunity to pass the final comprehensive examination is limited to three attempts per course enrollment.

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

When a student registers for a distance or correspondence course, he/she is assigned a start date and an end date. It is the student's responsibility to note dates for assignments and keep up with the course work.

If a student falls behind, he/she must contact TLC and request an end date extension in order to complete the course. It is the prerogative of TLC to decide whether to grant the request.

Instructions for Assignment
The Pump Primer II - 0.8 CEU training course training course uses a multiple choice type answer key. You can find a copy of the answer key r 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 Pump Primer II - 0.8 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.

When the Student finishes this course…
At the conclusion of this course:
At the finish of this course, the student should be able to explain and describe the various hydraulic principles, pumping devices, and pumping methods, identify various hydraulic and horsepower principles that are commonly employed in moving fluids. Upon completion of this course, the student will obtain 8 hours of continuing education relating to pump, pumping and hydraulic principles.

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.

Table of Contents

Topic Legend

This CEU course covers several educational topics/functions/purposes/objectives of hydraulic and pumping principles including groundwater production, engineering, physic laws, hydraulic theories and pump operation.

Educational topic (objectives assessment) categories were determined by beta-testing.

The topic categories listed below are to assist in determining which educational objective or goal to be covered in a specific topic area:

CROSS-CONNECTION (CC): Having to do with cross-connection control and backflow prevention. Simple hydraulic principles. This may be considered O&M training for many operators.

ELECTRICAL (SPARK): This section has to do with electrical principles and difficult math calculations. Maybe good for credit for those who hold an electrician or instrumentation certification. This may be considered O&M training for many operators.

FLUID MECHANICS (FM): Having to do with hydraulic or fluid mechanics. A highly technical and specialized engineering field. This may be considered O&M training for many operators or credit for pump engineers or well drillers.

GROUNDWATER MINING OR PRODUCTION (GP): This may be considered O&M training for many operators or credit for pump engineers or well drillers.

MOTOR: Having to do with the electrical-mechanical portion of moving water. This may be considered O&M training for many operators. Maybe good for credit for those who hold an electrician or instrumentation certification.

OPERATIONS AND MAINTENANCE O&M: This area is for normal operation and/or maintenance of the distribution system. Part of O&M training requirement for many operators.

PUMP ENGINEERING (PE): The technical science of pumping and pump performance principles. May be a law or theory or calculation related to pumping. Information that a pump engineer or well operator may need.

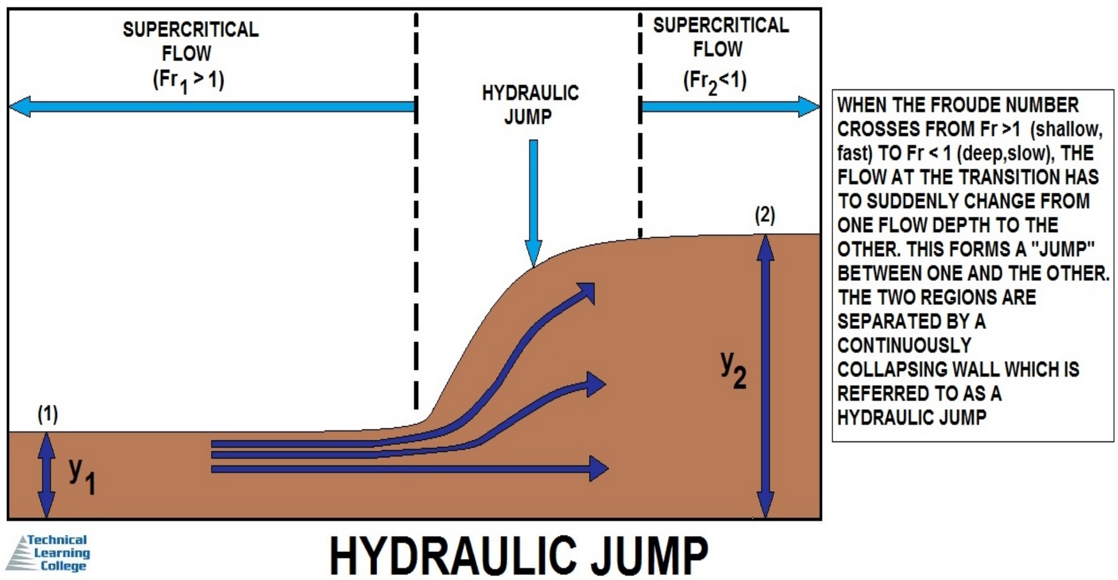
SCIENCE (SCI): Having to do with scientific principles, laws or theories. A principle that can be observed or repeated in the Laborotory. May be good for laboratory or engineering credit.

TECHNICAL (TECH): The engineering or administrative, mechanical or physical pumping related process/component. The applications, engineering, history or theory that is critical to the pump operation or composition of water (pH). May include advanced groundwater treatment methods or centrifugal pump operation. This may be considered O&M training for many operators or credit for pump engineers or well drillers.

Section 1- Fluid Mechanics and Hydraulic Principles

Section Focus: You will learn the basics of fluid mechanics and hydraulic principles. At the end of this section, you the student will be able to describe primary water mechanics and hydraulic principles. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In order to design flow rates, pumping system, calculate pump flows, we need to master this area of engineering.



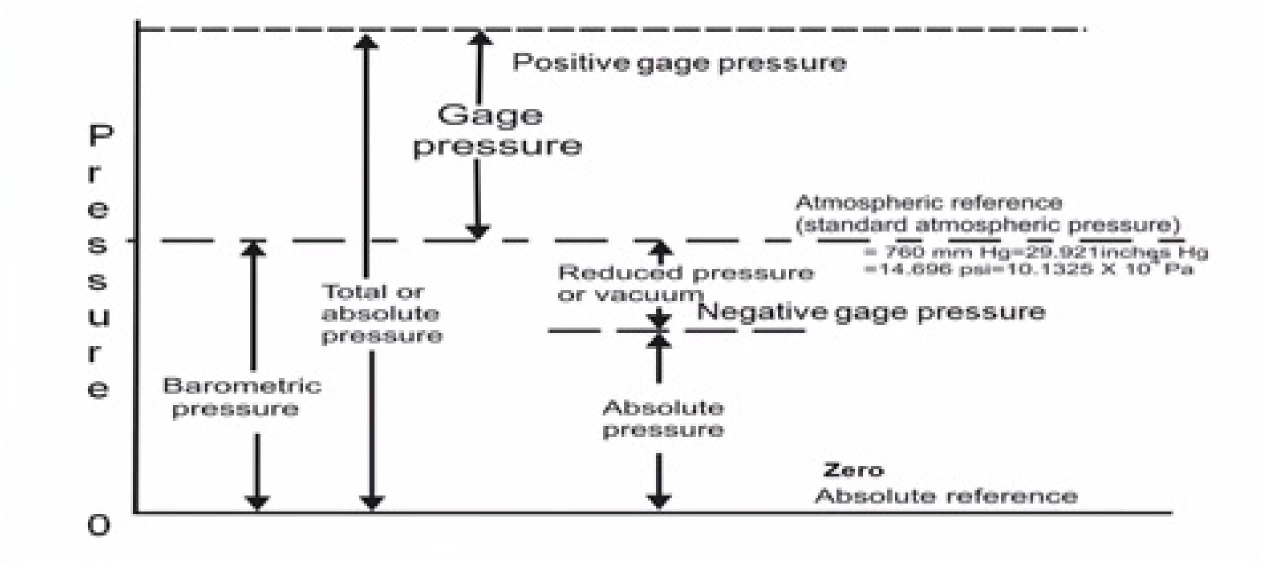
A hydraulic jump is a phenomenon in the science of hydraulics which is frequently observed in open channel flow such as rivers and spillways. When liquid at high velocity discharges into a zone of lower velocity, a rather abrupt rise occurs in the liquid surface. Hydraulic jump is the jump or standing wave formed when the depth of flow of water changes from supercritical to subcritical state.

Applicable Equations
Froude Number: $Fr = V/\sqrt{(gL)}$
Where: Fr = Froude number V = Velocity g = gravity L = depth of flow

Critical Flow Depth: $yc = (y_1/2)(\sqrt{(1+8Fr_1^2)}-1)$
Where: yc = critical flow depth y_1 = upstream measured depth Fr = Froude number

Upstream Energy Level: $E_1 = y_1 + (V_1^2/2g)$
Where: E_1 = upstream energy level V_1 = Velocity upstream y_1 = upstream measured depth g = gravity

Head Loss: $hL = (y_2-y_1)^8/(4y_1y_2)$
Where: hL = head loss in the hydraulic jump y_1 = upstream measured depth y_2 = downstream measured depth



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

Technical Learning College

DIFFERENT UNITS OF PRESSURE

Fluid Mechanics and Hydraulic Principles Key Terms

Fluid Dynamics
In physics, fluid dynamics is a sub-discipline of fluid mechanics that deals with fluid flow—the natural science of fluids (liquids and gases) in motion. It has several sub-disciplines itself, including aerodynamics (the study of air and other gases in motion) and hydrodynamics (the study of liquids in motion).

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

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

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

Pressure, Static
The pressure in a fluid at rest.

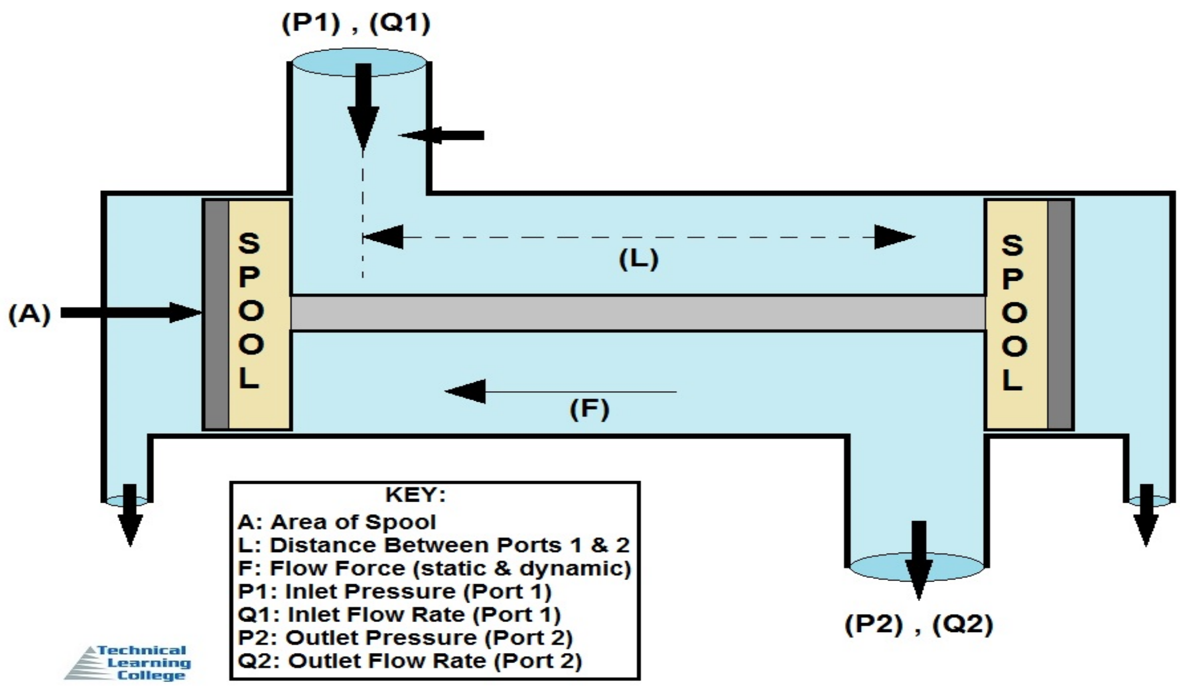
Fluid Fiction

We need to think about complicated piping arrangements and the fiction loses that are created that restrict water flows.

The concepts of fluid friction vary depending on whether the motion is taking place in a liquid or gas. One item that both media share is that the resistance to motion contributes to an object reaching its terminal velocity. This occurs when the resistance from a gas or fluid is equal to the weight of the object, and it remains constant until another force is introduced.

For motion in a liquid, viscous resistance caused by a drag force is proportional to the velocity of the object at slow speeds. This drag force is based on the object's geometry and the viscosity of the liquid, which can vary between fluids.

For motion through air, friction at slow speeds is proportional to the velocity. At higher speeds, the drag force depends on the cross-sectional area of an object, the object's density and the drag coefficient. This drag force has a negative value, as the resistance is always opposite the direction of velocity.



BASIC HYDRAULIC PRINCIPAL

Hydraulic Systems - Closed or Open Systems

A closed loop system is one where the inlet of the pump is supplied by the oil leaving outlet of the actuator (usually a motor) the pump is driving, hence the closed loop.

An open loop system is one where the outlet of the actuator will return to the tank via a directional valve, with the pump inlet drawing fluid from the same common tank.

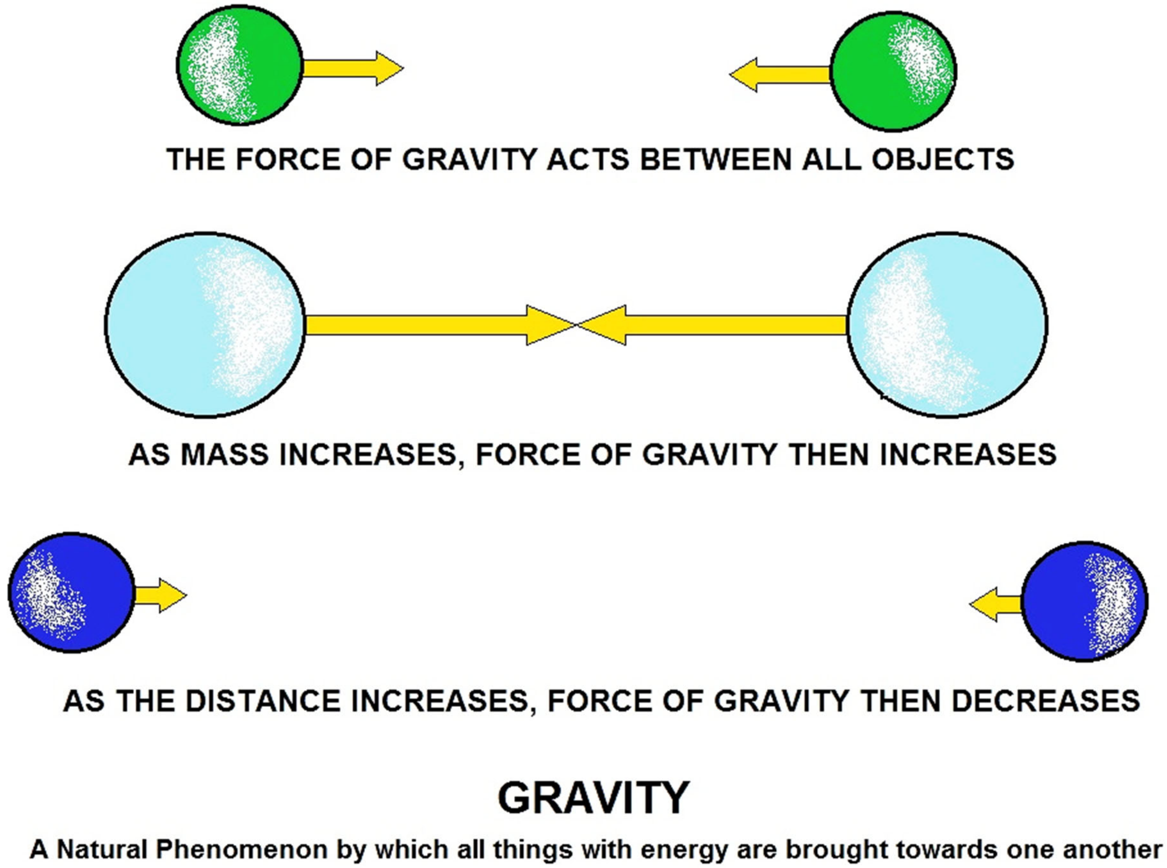
The open loop system relatively speaking has no pressurized connection between actuator outlet and pump inlet and is the most common type used in industrial hydraulics as it can perform multiple tasks and therefore multiple sequences.

The closed loop with its pressurized connection is most commonly found hydro-static transmissions in mobile applications.

Fluid Mechanics Review

Fluid mechanics provides the theoretical foundation for hydraulics, which focuses on the applied engineering using the properties of fluids. In its fluid power applications, hydraulics is used for the generation, control, and transmission of power by the use of pressurized liquids.

Hydraulic topics range through some parts of science and most of engineering modules, and cover concepts such as pipe flow, dam design, fluidics and fluid control circuitry. The principles of hydraulics are in use naturally in the human body within the vascular system and erectile tissue. Free surface hydraulics is the branch of hydraulics dealing with free surface flow, such as occurring in rivers, canals, lakes, estuaries and seas. Its sub-field open-channel flow studies the flow in open channels.



Specific Gravity Introduction

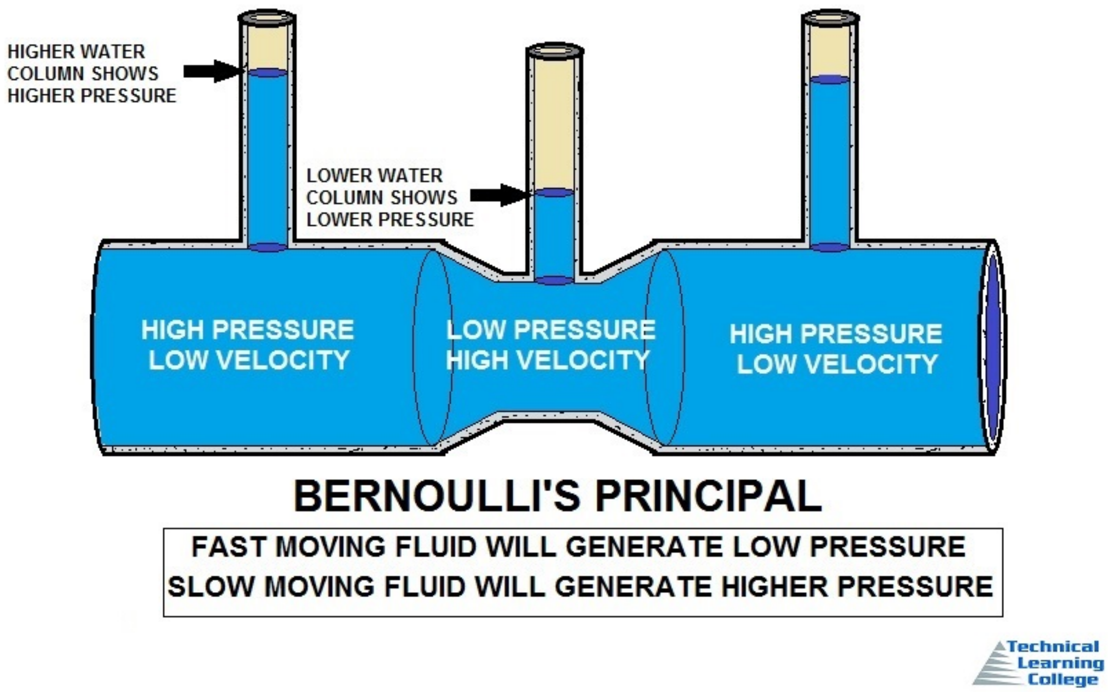
When you put something in water, gravity can pull the object down through the water only if an equal volume of water is allowed to go up against the force of gravity; this is called displacement. In effect, gravity has to choose which it will pull down, the water or the immersed object. What we call buoyancy is, in effect, forcing gravity to make this choice.

Faced with this choice, gravity will act more strongly on whichever has more mass (thus, more weight) per given volume. So if the thing you immerse is denser than water it will sink, but its apparent weight is reduced by the volume of water that gets displaced upward. If instead the water is denser, the immersed object will float up to the point where the displaced volume of water matches the whole object's mass. Then the net weight is zero

Specific gravity is the ratio of the density of a substance to the density of a reference substance; equivalently, it is the ratio of the mass of a substance to the mass of a reference substance for the same given volume. *Apparent* specific gravity is the ratio of the weight of a volume of the substance to the weight of an equal volume of the reference substance.

The reference substance for liquids is nearly always water at its densest (at 4 °C or 39.2 °F); for gases it is air at room temperature (20 °C or 68 °F). Nonetheless, the temperature and pressure must be specified for both the sample and the reference. Pressure is nearly always 1 atm (101.325 kPa).

Fluid Mechanics and Hydraulic Principles- Introduction



Hydraulics

The Engineering science pertaining to liquid pressure and flow.

Hydraulics is a branch of engineering concerned mainly with moving liquids. This 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 separated into two areas, hydrostatics and hydrokinetics.

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

Hydrostatics is the study 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 hydrostatics' basic principles.

Hydrodynamics is the study of liquids in motion, is concerned with such matters as friction and turbulence generated by flowing liquids inside pipes, the flow of water over weirs and through nozzles, and the use of hydraulic pressure in machinery.

Hydrostatics

Hydrostatics is the study 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, thus, such as forces on dams, buoyancy and hydraulic actuation, and is well worth studying for such practical reasons.

Hydrostatics is a superb 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 and converted, 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 thought.

Generally, 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.

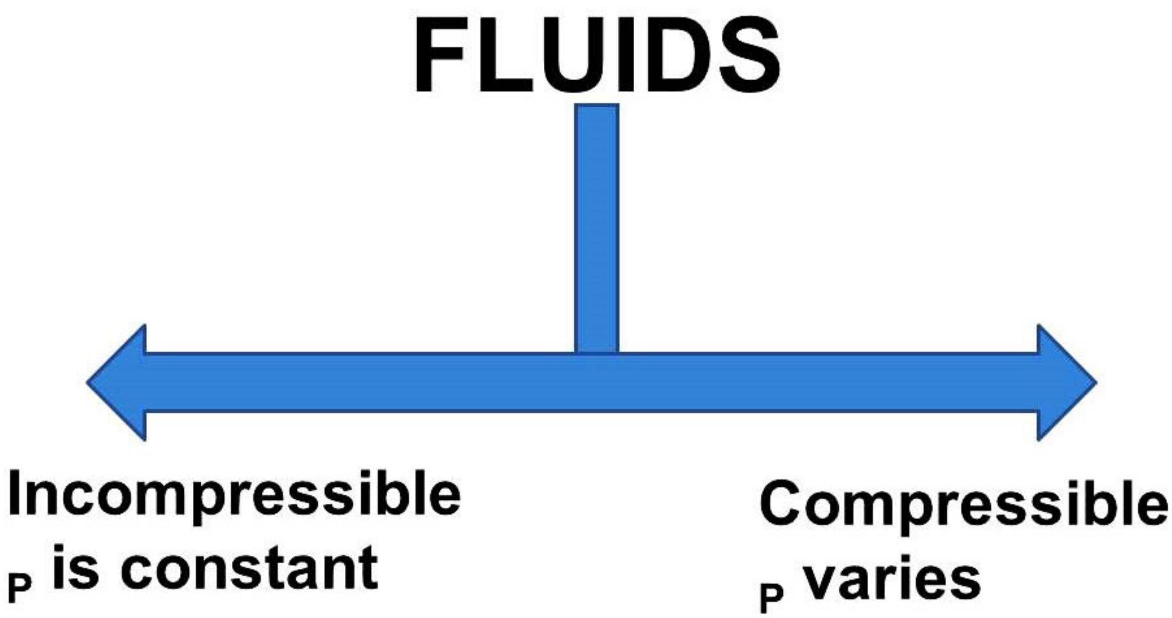
The study of geology has now shown us that there are substances which can resist shearing forces over short time intervals, and appear to be typical solids, but which flow like liquids over long time intervals. Such materials include wax and pitch, ice, and even rock.

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.

Fluid Mechanics-Introduction



What is Fluid Mechanics?

Fluid mechanics is a science concerned with the response of fluids to forces exerted upon them. It is a branch of classical physics with applications of great importance in hydraulic and aeronautical engineering, chemical engineering, meteorology, and zoology.

Fluid mechanics research and history goes back at least to the days of ancient Greece, when Archimedes investigated fluid statics and buoyancy and formulated his famous law known now as the Archimedes' principle, which was published in his work On Floating Bodies – generally considered to be the first major work on fluid mechanics. Rapid advancement in fluid mechanics began with Leonardo da Vinci (observations and experiments), Evangelista Torricelli (invented the barometer), Isaac Newton (investigated viscosity) and Blaise Pascal (researched hydrostatics, formulated Pascal's law), and was continued by Daniel Bernoulli with the introduction of mathematical fluid dynamics in Hydrodynamica (1739).

Inviscid flow was further analyzed by various mathematicians (Leonhard Euler, Jean le Rond d'Alembert, Joseph Louis Lagrange, Pierre-Simon Laplace, Siméon Denis Poisson) and viscous flow was explored by a multitude of engineers including Jean Léonard Marie Poiseuille and Gotthilf Hagen.

Further mathematical justification was provided by Claude-Louis Navier and George Gabriel Stokes in the Navier–Stokes equations, and boundary layers were investigated (Ludwig Prandtl, Theodore von Kármán), while various scientists such as Osborne Reynolds, Andrey Kolmogorov, and Geoffrey Ingram Taylor advanced the understanding of fluid viscosity and turbulence. We will examine these scientists and their laws/theories/concepts in detail.

Archimedes
Archimedes instituted the study of hydrostatics in about 250 B.C. when, according to legend, he leapt out of his bath and ran naked through the streets of Syracuse crying “Eureka!”; it has undergone rather little development since.

The foundations of hydrodynamics, on the other hand, were not laid until the 18th century when mathematicians such as Leonhard Euler and Daniel Bernoulli began to explore the consequences, for a virtually continuous medium like water, of the dynamic principles that Newton had enunciated for systems composed of discrete particles. Their work was continued in the 19th century by several mathematicians and physicists of the first rank, notably G.G. Stokes and William Thomson.

By the end of the century, explanations had been found for a host of intriguing phenomena having to do with the flow of water through tubes and orifices, the waves that ships moving through water leave behind them, raindrops on windowpanes, and the like. There was still no proper understanding, thus, of problems as fundamental as that of water flowing past a fixed obstacle and exerting a drag force upon it; the theory of potential flow, which worked so well in other contexts, yielded results that at relatively high flow rates were grossly at variance with experiment.

Ludwig Prandtl
This problem was not properly comprehended until 1904, when the German physicist Ludwig Prandtl introduced the concept of the boundary layer. Prandtl’s career continued into the period in which the first manned aircraft were developed. Since that time, the flow of air has been of as much interest to physicists and engineers as the flow of water, and hydrodynamics has, as an after-affect , become fluid dynamics. The term fluid mechanics, as used here, embraces both fluid dynamics and the subject still generally referred to as hydrostatics.

Geoffrey Taylor
One other representative of the 20th century who deserves reference here besides Prandtl is Geoffrey Taylor of England. Taylor remained a classical physicist while most of his contemporaries were turning their attention to the problems of atomic structure and quantum mechanics, and he made several unexpected and important discoveries in the field of fluid mechanics.

The value of fluid mechanics is due in large part to a term in the basic equation of the motion of fluids which is nonlinear—*i.e.,* one that involves the fluid velocity twice over. It is characteristic of systems described by nonlinear equations that under certain conditions they become unstable and begin behaving in ways that seem at first sight to be totally chaotic. In the case of fluids, chaotic behavior is very common and is called turbulence.

Mathematicians have now begun to recognize patterns in chaos that can be analyzed fruitfully, and this development suggests that fluid mechanics will remain a field of active research well into the 21st century.

Fluid mechanics is a subject with almost endless results, and the account that follows is necessarily incomplete. Some knowledge of the basic properties of fluids will be needed; a survey of the most relevant properties will be given in the next section.

Properties of Fluids

Fluids are not strictly continuous media in the way that all the successors of Euler and Bernoulli have assumed, for fluids are composed of discrete molecules. The molecules, though, are so small and, except in gases at very low pressures, the number of molecules per milliliter is so enormous that they need not be viewed as individual entities.

There are a few liquids, known as liquid crystals, in which the molecules are packed together in such a way as to make the properties of the medium locally anisotropic, but the vast majority of fluids -including air and water- are isotropic.

In fluid mechanics, the state of an isotropic fluid may be completely described by defining its mean mass per unit volume, or density (ρ), its temperature (T), and its velocity (v) at every point in space, and just what the connection is between these macroscopic properties and the positions and velocities of individual molecules is of no direct relevance.

Isotropic Fluid or Newtonian Fluid
If the fluid is also isotropic (that is, its mechanical properties are the same along any direction), the viscosity tensor reduces to two real coefficients, describing the fluid's resistance to continuous shear deformation and continuous compression or expansion, respectively.

Fluid Statics
Fluid statics or hydrostatics is the branch of fluid mechanics that studies fluids at rest. It embraces the study of the conditions under which fluids are at rest in stable equilibrium; and is contrasted with fluid dynamics, the study of fluids in motion.

Hydrostatics offers physical explanations for many wonders of everyday life, such as why atmospheric pressure changes with altitude, why wood and oil float on water, and why the surface of water is always flat and horizontal whatever the shape of its container.

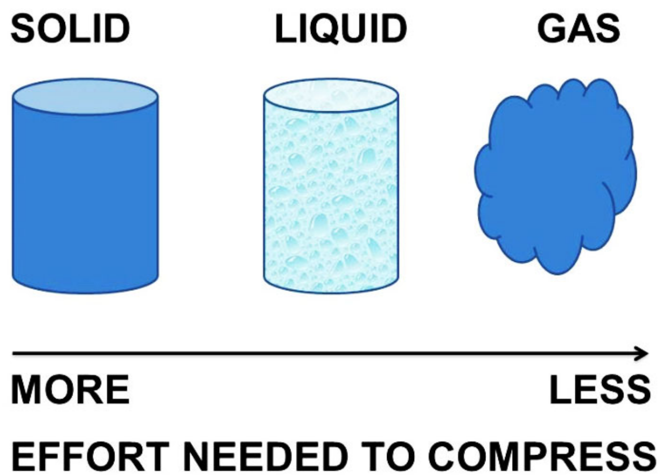
Hydrostatics is fundamental to hydraulics, the engineering of equipment for storing, transporting and using fluids. It is also relevant to some aspect of geophysics and astrophysics (i.e., in understanding plate tectonics and anomalies in the Earth's gravitational field), to meteorology, to medicine (with the context of blood pressure), and many other fields.

Fluid Dynamics
Fluid dynamics is a sub-discipline of fluid mechanics that deals with fluid flow—the science of liquids and gases in motion. Fluid dynamics offers a systematic structure—which underlies these practical disciplines—that embraces empirical and semi-empirical laws derived from flow measurement and used to solve practical problems.

The solution to a fluid dynamics problem typically involves calculating various properties of the fluid, such as velocity, pressure, density, and temperature, as functions of space and time.

It has several sub-disciplines itself, including aerodynamics (the study of air and other gases in motion) and hydrodynamics (the study of liquids in motion).

Fluid dynamics has a wide range of applications, including calculating forces and moments on aircraft, determining the mass flow rate of petroleum through pipelines, predicting evolving weather patterns, even understanding nebulae in interstellar space and modeling explosions.



Gases and Liquids

A word is needed about the difference between gases and liquids, though the difference is easier to perceive than to describe.

In gases, the molecules are sufficiently far apart to move almost independently of one another, and gases tend to expand to fill any volume available to them.

In liquids, the molecules are more or less in contact, and the short-range attractive forces between them make them cohere; the molecules are moving too fast to settle down into the ordered arrays that are characteristic of solids, but not so fast that they can fly apart.

Thus, samples of liquid can exist as drops or as jets with free surfaces, or they can sit in beakers constrained only by gravity, in a way that samples of gas cannot.

Such samples may evaporate in time, as molecules one by one pick up enough speed to escape across the free surface and are not replaced. The lifetime of liquid drops and jets, yet, is normally long enough for evaporation to be ignored.

Properties of Fluids Key Terms

The term fluid includes both liquid and gases. The main difference between a liquid and a gas is that the volume of a liquid remains definite because it takes the shape of the surface on or in which it comes into contact, whereas a gas occupies the complete space available in the container in which it is kept. In hydraulics in civil engineering, the fluid for consideration is liquid, so, we will examine some terms and properties of the liquids

1. DENSITY OR MASS DENSITY
Density or mass density of a fluid is defined as the ratio of the mass of a fluid to its volume. Thus mass per unit volume of a fluid is called density.

It is denoted by the symbol ρ (rho). The unit of mass density in SI unit is kg per cubic meter. The density of liquids may be considered as constant while that of gases changes with the variation of pressure and temperature.

$$\rho = \frac{\text{Mass of fluid}}{\text{Volume of fluid}}$$

The value of density of water is 1gm per cubic centimeter or 1000 kg per cubic meter.

2. SPECIFIC WEIGHT AND WEIGHT DENSITY
Specific weight or weight density of a fluid is the ratio between the weight of a fluid to its volume. Thus weight per unit volume of a fluid is called weight density and it is denoted by the symbol

w .

$$w = \frac{\text{Weight of fluid}}{\text{Volume of fluid}} = \frac{(\text{Mass of fluid}) \times \text{Acceleration due to gravity}}{\text{Volume of fluid}}$$

$$= \frac{\text{Mass of fluid} \times g}{\text{Volume of fluid}} = \rho \times g$$

$$=> w = \rho g$$

The value of specific weight of specific density (w) of water is $9.81 \times 1000 \text{ Newton/m}^3$

3. SPECIFIC VOLUME
Specific volume of a fluid is defined as the volume of a fluid occupied by a unit mass or volume per unit mass of a fluid.

Specific volume = $$\frac{\text{Volume of fluid}}{\text{Mass of fluid}} = \frac{1}{\frac{\text{Mass of fluid}}{\text{Volume of fluid}}} = \frac{1}{\rho}$$

Thus, specific volume is the reciprocal of mass density. It is expressed as m^3/kg. It is commonly applied to gases.

4. SPECIFIC GRAVITY

Specific gravity is defined as the ratio of the weight density (or density) of a fluid to the weight density (or density) of a standard fluid. For liquids, the standard fluid is taken as water and for gases, the standard fluid is taken as air.

Specific gravity is also called relative density. It is a dimensionless quantity and is denoted by the symbol S.

$$S \text{ (for liquids)} = \frac{\text{Weight density of liquid}}{\text{Weight density of water}}$$

$$S \text{ (for gases)} = \frac{\text{Weight density of gas}}{\text{Weight density of air}}$$

Thus, weight density of a liquid = S x weight density of water = S x $9.81 \times 1000 \text{ Newton/m}^3$

The density of liquid = S x Density of water = S x 1000 kg/m^3.

If the specific gravity of a fluid is known, then the density of the liquid will be equal to specific gravity of fluid multiplied by the density of water. For example, the specific gravity of mercury is 13.6. Hence density of mercury = 13.6 x 1000 kg/m^3.

5. VISCOSITY OF LIQUID:

Viscosity is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of fluid. When two layers of a fluid, a distance apart move over one other at different velocities, the viscosity together with relative velocity causes a shear stress acting between the fluid layers.

The top layer causes a shear stress on the adjacent layer while the lower layer causes a shear stress on the top layer. This shear stress is proportional to the rate of change of velocity. It is denoted by the symbol τ.

$$\tau \propto \frac{du}{dy}$$

$$\tau = \mu \frac{du}{dy}$$

Where μ (mu) is the constant of proportionality and is known as the coefficient of dynamic viscosity or only viscosity, $\frac{du}{dy}$ represents the rate of shear strain or rate of shear deformation or velocity gradient.

$$=> \mu = \frac{\tau}{\frac{du}{dy}}$$

The viscosity is also defined as the shear stress required to produce unit rate of shear strain.

Units of Viscosity

In MKS system, unit of viscosity = $\frac{kgf \cdot cm}{m^2}$

CGS unit of viscosity (also called Poise) = $\frac{dyne \cdot \sec}{cm^2}$

SI unit of viscosity = Ns / m^2 =Pa-s

Unit Conversion

Conversion between MKS and CGS system

$$\frac{1\,\text{kgf-sec}}{m^2} = \frac{9.81\,\text{N-sec}}{m^2}$$

$$dyne = gm \times \frac{cm}{\sec^2}$$

1 N = 1000 x 100 dyne

$$\frac{1\,\text{kgf-sec}}{m^2} = \frac{9.81\,\text{N-sec}}{m^2} = 98.1\,poise$$

$$1\,poise = \frac{1}{10}\frac{Ns}{m^2}$$

$$1\ \text{centipoise} = \frac{1}{100}\,poise$$

KINEMATIC VISCOSITY

It is defined as the ratio between the dynamic viscosity and density of fluid. It is denoted by the Greek symbol (υ) called nu. Thus,

$$\upsilon = \frac{\text{Viscosity}}{\text{Density}} = \frac{\mu}{\rho}$$

In MKS and SI, the unit of kinematic viscosity is $\text{m}^2 / \sec$ while in CGS units, it is written as cm^2/s. In CGS system, kinematic viscosity is also known as stoke.

One stoke =1 cm^2/s

Newton's Law of Viscosity:
It states that the shear stress (τ) on a fluid element layer is directly proportional to the rate of change of shear strain. The constant of proportionality is called the co-efficient of viscosity.

$$\tau \propto \frac{du}{dy}$$

$$\tau = \mu \frac{du}{dy}$$

Fluids which obey the above relation are known as Newtonian fluids and the fluids which do not obey the above relation are called Non-Newtonian fluids.

Variation of Viscosity with temperature:
The viscosity of liquids decreases with the increase in temperature, while the viscosity of gases increases with the increase in temperature.

(i) For liquids:

$$\mu = \mu_0 \left(\frac{1}{1 + \alpha t + \beta t^2} \right)$$

Where, μ = viscosity of liquid at $t^\circ C$ in poise

μ_0 = viscosity of liquid at $0^\circ C$ in poise

α, β are constants for the liquid.

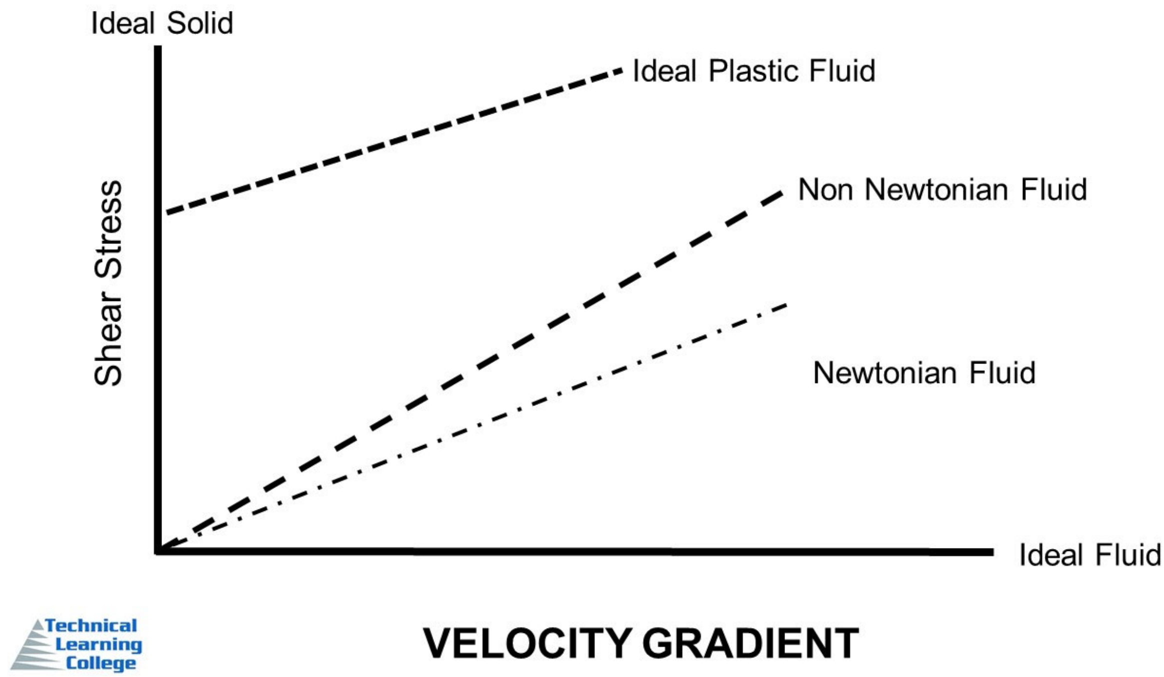
For water, $\mu_0 = 1.79 \times 10^{-3}$ poise, $\alpha = 0.03368$ and $\beta = 0.000221$

(ii) For Gases

$$\mu = \mu_0 + \alpha t - \beta t^2$$

For air, $\mu_0 = 000017$, $\alpha = 0.000000056$ and $\beta = 0.1189 \times 10^{-9}$

TYPES OF FLUIDS BASED ON VISCOSITY
The fluids may be classified into following five types:
1. Ideal fluid
2. Real fluid
3. Newtonian fluid
4. Non-Newtonian fluid
5. Ideal plastic fluid



Type of Fluids

1. Ideal Fluid
A fluid which is incompressible and is having no viscosity, is known as ideal fluid. Ideal fluid is only an imaginary fluid as all the fluids which exists have some viscosity.

2. Real Fluids
A fluid which possesses viscosity is known as real fluid. All the fluids in actual practice are real fluids.

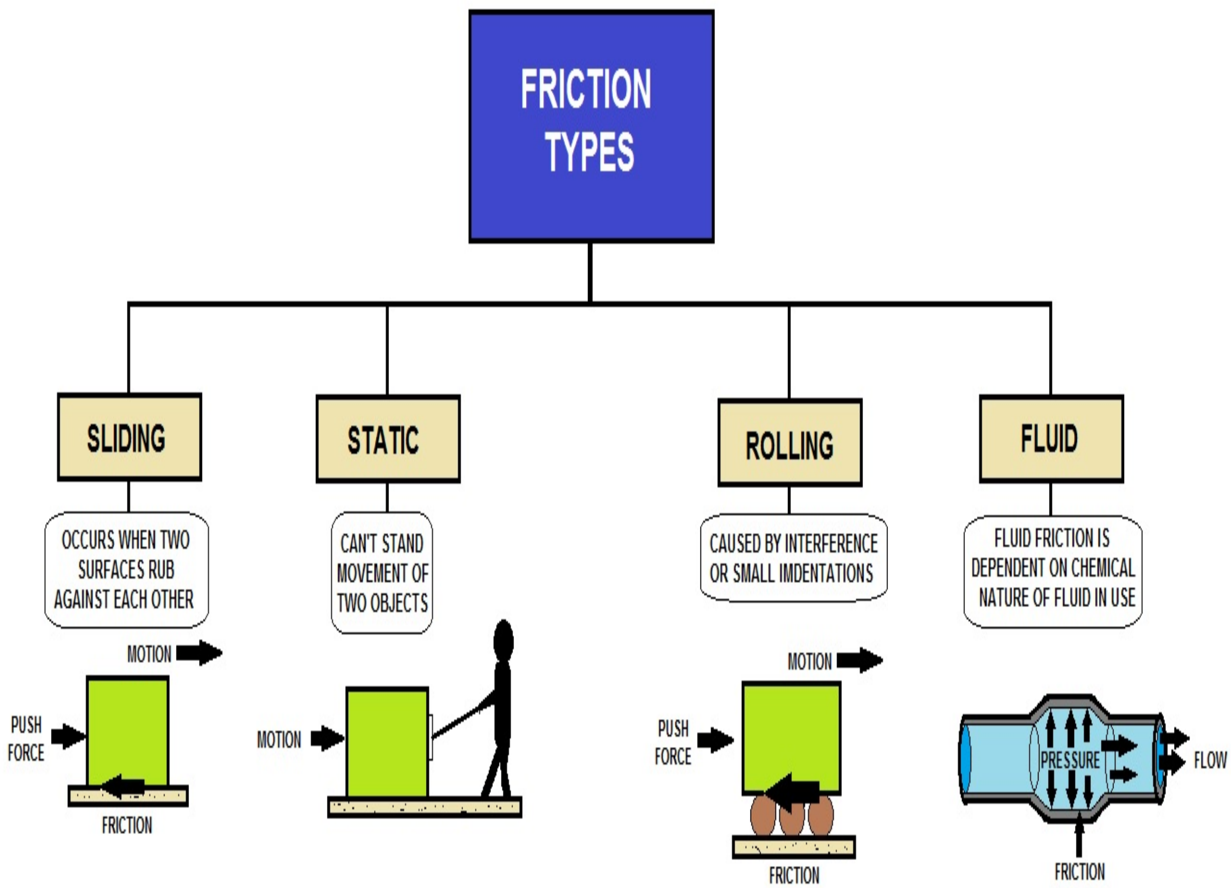
3. Newtonian Fluids
A real fluid in which the shear stress is directly proportional to rate of shear strain (or velocity gradient).

4. Non-Newtonian Fluid
A real fluid in which the shear stress is not proportional to the rate of shear strain.

5. Ideal Plastic Fluid
A fluid in which shear stress is more than the yield value and shear stress is proportional to the rate of shear strain (or velocity gradient).

UNITS OF PRESSURE

	Pascal	Bar	Technical atmosphere	Standard atmosphere	Torr	Pounds per square inch
	(Pa)	(bar)	(at)	(atm)	(Torr)	(lbf/in^2)
1 Pa	≡ 1 N/m^2	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	0.000 145 037 737 730
1 bar	10^5	≡ 100 kPa ≡ 10^6 dyn/cm^2	1.0197	0.986 92	750.06	14.503 773 773 022
1 at	98 066.5	0.980 665	≡ 1 kgf/cm^2	0.967 841 105 354 1	735.559 240 1	14.223 343 307 120 3
1 atm	101 325	1.013 25	1.0332	1	760	14.695 948 775 514 2
1 Torr	133.322 368 421	0.001 333 224	0.001 359 51	$\frac{1}{760}$ ≈ 0.001 315 789	1 Torr ≈ 1 mmHg	0.019 336 775
1 lbf/in^2	6894.757 293 168	0.068 947 573	0.070 306 958	0.068 045 964	51.714 932 572	≡ 1 lbf/in^2



FRICTION TYPE EXAMPLES

Stresses and Pressure

There are two sorts of stress that may exist in any solid or fluid medium, and the difference between them may be demonstrated by holding a brick held between two hands. If the holder moves his hands toward each other, he exerts pressure on the brick; if he moves one hand toward his body and the other away from it, then he exerts what is called a shear stress.

A solid substance such as a brick can withstand stresses of both types, but fluids, by definition, yield to shear stresses no matter how small these stresses may be. They do so at a rate determined by the fluid's viscosity.

This property, about which more will be said later, is a measure of the friction that arises when adjacent layers of fluid slip over one another. It follows that the shear stresses are everywhere zero in a fluid at rest and in equilibrium, and from this it follows that the pressure (that is, force per unit area) acting perpendicular to all planes in the fluid is the same irrespective of their orientation (Pascal's law).

For an isotropic fluid in equilibrium there is only one value of the local pressure (*p*) consistent with the stated values for ρ and *T*. These three quantities are linked together by what is called the equation of state for the fluid.

For gases at low pressures the equation of state is simple and well known. It is

$$p = \left(\frac{RT}{M}\right)\rho \qquad (118)$$

where *R* is the universal gas constant (8.3 joules per degree Celsius per mole) and *M* is the molar mass, or an average molar mass if the gas is a mixture; for air, the appropriate average is about 29×10^{-3} kilogram per mole.

For other fluids, knowledge of the equation of state is often incomplete. Except under very extreme conditions, however, all one needs to know is how the density changes when the pressure is changed by a small amount, and this is described by the compressibility of the fluid—either the isothermal compressibility, β_T, or the adiabatic compressibility, β_S, according to circumstance. When an element of fluid is compressed, the work done on it tends to heat it up.
If the heat has time to dissipate away to the surroundings and the temperature of the fluid remains essentially unchanged throughout, then β_T is the relevant quantity.

If virtually none of the heat escapes, as is more commonly the case in flow problems because the thermal conductivity of most fluids is poor, then the flow is said to be adiabatic, and β_S is needed instead.

(The *S* refers to entropy, which remains constant in an adiabatic process provided that it takes place slowly enough to be treated as "reversible" in the thermodynamic sense.)

For gases that obey equation (118), it is evident that *p* and ρ are proportional to one another in an isothermal process, and

$$\beta_T = \rho^{-1}\left(\frac{\partial\rho}{\partial P}\right)_T = p^{-1} \quad (119)$$

Reversible Adiabatic Processes
In reversible adiabatic processes for such gases, however, the temperature rises on compression at a rate such that

$$T \propto p^{(y-1)},\ \mathrm{p} \propto p^{y} \quad (120)$$

and

$$\beta_S = \rho^{-1}\left(\frac{\partial\rho}{\partial P}\right)_S = (yp)^{-1} = \frac{\beta T}{\gamma} \quad (121)$$

where γ is about 1.4 for air and takes similar values for other common gases. For liquids the ratio between the isothermal and adiabatic compressibilities is much closer to unity. For liquids, however, both compressibilities are normally much less than p^{-1}, and the simplifying assumption that they are zero is often justified.

The factor γ is not only the ratio between two compressibilities; it is also the ratio between two principal specific heats.

The molar specific heat is the amount of heat required to raise the temperature of one mole through one degree. This is greater if the substance is allowed to expand as it is heated, and therefore to do work, than if its volume is fixed.

The principal molar specific heats, C_P and C_V, refer to heating at constant pressure and constant volume, respectively, and

$$\gamma = \left(\frac{Cp}{C_V}\right) \quad (122)$$

For air, C_P is about 3.5 *R*.

Solids

Solids can be stretched without breaking, and liquids, though not gases, can withstand stretching, too. Therefore, if the pressure is steadily reduced in a specimen of very pure water, bubbles will ultimately appear, but they may not do so until the pressure is negative and well below -10^7 newton per square meter; this is 100 times greater in magnitude than the (positive) pressure exerted by the Earth's atmosphere.

Water owes its high ideal strength to the fact that rupture involves breaking links of attraction between molecules on either side of the plane on which rupture occurs; work must be done to break these links.

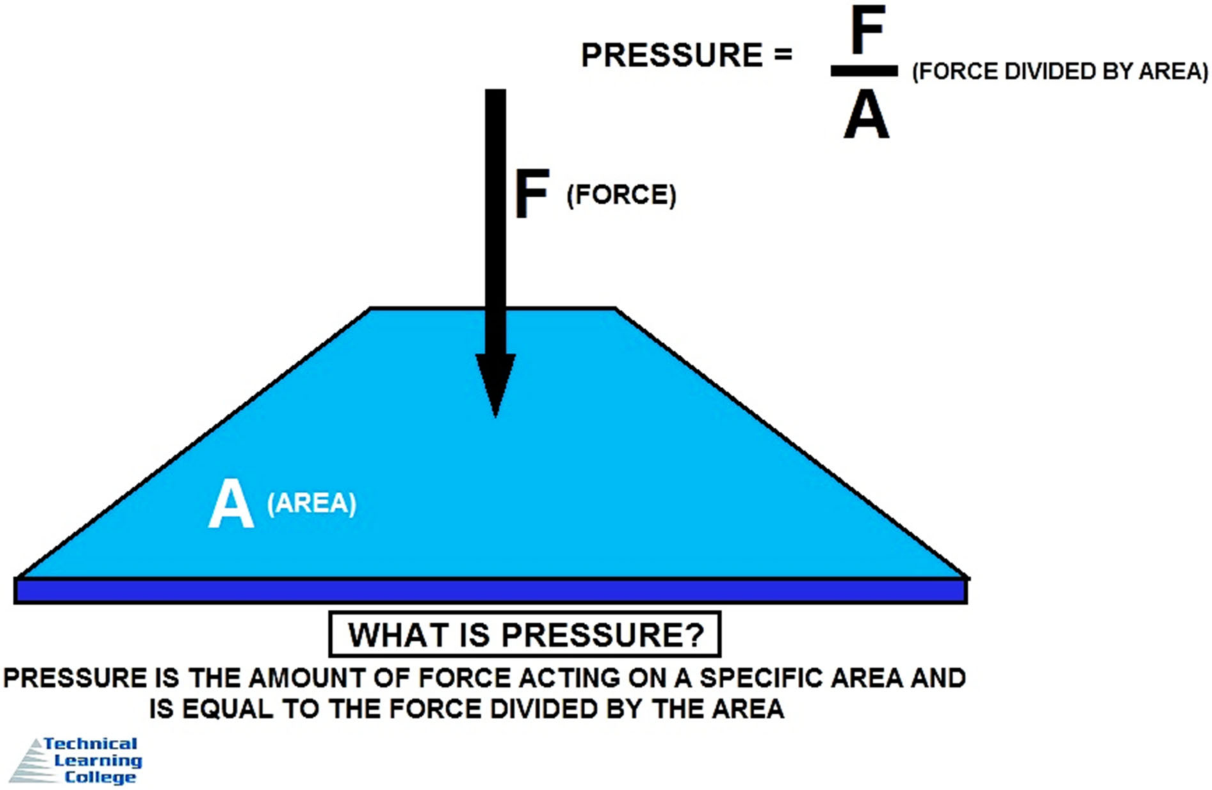
Yet, its strength is drastically reduced by anything that provides a nucleus at which the process known as cavitation (formation of vapor- or gas-filled cavities) can begin, and a liquid containing suspended dust particles or dissolved gases is liable to cavitate quite easily.

Surface Tension

Work also must be done if a free liquid drop of spherical shape is to be drawn out into a long thin cylinder or deformed in any other way that increases its surface area. Here again work is needed to break intermolecular links.

The surface of a liquid behaves as if it were an elastic membrane under tension, except that the tension exerted by an elastic membrane increases when the membrane is stretched in a way that the tension exerted by a liquid surface does not.

Surface tension is what causes liquids to rise up capillary tubes, what supports hanging liquid drops, what limits the formation of ripples on the surface of liquids, and so on.


PRESSURE = F / A (FORCE DIVIDED BY AREA)
F (FORCE)
A (AREA)
WHAT IS PRESSURE?
PRESSURE IS THE AMOUNT OF FORCE ACTING ON A SPECIFIC AREA AND IS EQUAL TO THE FORCE DIVIDED BY THE AREA
Technical Learning College

Fluid Mechanics and Hydraulic Principles Post Quiz

Link to Assignment…

http://www.abctlc.com/downloads/PDF/PumpPrimer2Ass.pdf

Hydraulics

1. Hydraulics can be divided into two areas, hydrostatics and?

Hydrostatics

2. Which term may be the physical property that varies over the largest numerical range, competing with electrical resistivity?

Fluid Statics

3. The solution to a fluid dynamics problem typically involves calculating various properties of the fluid, such as velocity, pressure, density, and temperature, as functions of?

Gases and Liquids

4. In liquids the molecules are more or less in contact, and the short-range attractive forces between them make them cohere; the molecules are moving too _____________into the ordered arrays that are characteristic of solids, but not so fast that they can fly apart.

Solids

5. Water owes its high ideal strength to the fact that rupture involves breaking links of attraction between molecules on either side of the plane on which ____________occurs; work must be done to break these links.

Surface Tension

6. The surface of a liquid behaves, in fact, as if it were an elastic membrane under tension, except that the tension exerted by ______________increases when the membrane is stretched in a way that the tension exerted by a liquid surface does not.

Friction

7. Which term is a force that opposes the relative lateral motion of two solid surfaces in contact?

Kinetic Energy

8. Kinetic energy is converted to thermal energy whenever ______________occurs, for example when a viscous fluid is stirred.

Fluid Friction (Drag)

9. Fluid friction is affected by increased_______________, and the modern streamline design of airplanes and automobiles is the result of engineers' efforts to minimize fluid friction while retaining speed and protecting structure.

Drag Force

10. Drag force is proportional to the velocity for a ________________and the squared velocity for a turbulent flow.

Answers 1. Hydrokinetics, 2. Viscosity, 3. Space and time, 4. Fast to settle down, 5. Rupture, 6. An elastic membrane, 7. Dry friction, 8. Motion with friction, 9. Velocities, 10. Laminar flow

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Section 2 - Hydraulic Foundations and Theories

Section Focus: You will learn the foundations of fluid mechanics and hydraulic principle theories. At the end of this section, you the student will be able to describe early hydraulic scientists who founded hydraulic ideas. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In order to design water systems or calculate pumping rates or flow rates, we need to master this area of engineering.

Blaise Pascal

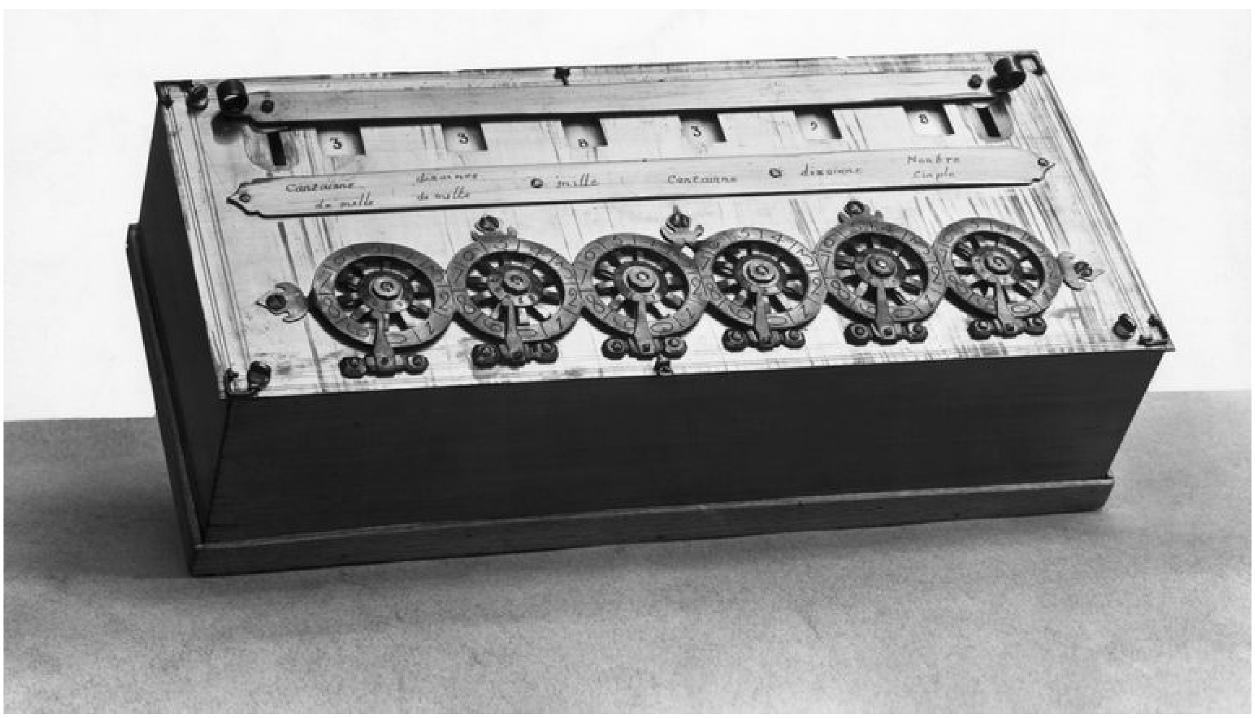
Blaise Pascal 19 June 1623 – 19 August 1662) was a French mathematician, physicist, inventor, writer and Christian philosopher. He was a child prodigy who was educated by his father, who was a tax collector in Rouen. Pascal's earliest work was in the natural and applied sciences where he made important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

In 1642, while still a teenager, he started some pioneering work on calculating machines. After three years of effort and fifty prototypes, he invented the mechanical calculator. He built 20 of these machines, called Pascal’s calculator and later pascaline in the following ten years.

Pascal was an important mathematician, helping create two major new areas of research: he wrote a significant treatise on the subject of projective geometry at the age of 16, and later corresponded with Pierre de Fermat on probability theory, strongly influencing the development of modern economics and social science.
Following Galileo and Torricelli, in 1646 he refuted Aristotle's followers who insisted that nature abhors a vacuum. Pascal's results caused many disputes before being accepted.

Between 1658 and 1659 he wrote on the cycloid and its use in calculating the volume of solids. Pascal had poor health especially after his 18th year and his death came just two months after his 39th birthday.

Pascal's inventions and discoveries have been instrumental to developments in the fields of geometry, physics and computer science, influencing 17th-century visionaries like Gottfried Wilhelm Leibniz and Isaac Newton. During the 20th century, the Pascal (Pa) unit was named after the thinker in honor of his contributions to the understanding of atmospheric pressure and how it could be estimated in terms of weight.



In the late 1960s, Swiss computer scientist Nicklaus Wirth invented a computer language and insisted on naming it after Pascal. This was Wirth's way of memorializing Pascal's invention of the Pascaline, one of the earliest forms of the modern computer.

Hydraulic Foundations and Theories Key Terms

English Units
English units of measurement, principal system of weights and measures weights and measures**,** units and standards for expressing the amount of some quantity, such as length, capacity, or weight; the science of measurement standards and methods is known as metrology.

Floating Bodies
On Floating Bodies, which is thought to have been written around 250 BC, survives only partly in Greek, the rest in medieval Latin translation from the Greek. It is the first known work on hydrostatics, of which Archimedes is recognized as the founder.

Horror vacui
In physics, horror vacui, or plenism, is commonly stated as "Nature abhors a vacuum." It is a postulate attributed to Aristotle, who articulated a belief, later criticized by the atomism of Epicurus and Lucretius, that nature contains no vacuums because the denser surrounding material continuum would immediately fill the rarity of an incipient void. He also argued against the void in a more abstract sense (as "separable"), for example, that by definition a void, itself, is nothing, and following Plato, nothing cannot rightly be said to exist. Furthermore, in so far as it would be featureless, it could neither be encountered by the senses, nor could its supposition lend additional explanatory power. Hero of Alexandria challenged the theory in the first century AD, but his attempts to create an artificial vacuum failed. The theory was debated in the context of 17th-century fluid mechanics, by Thomas Hobbes and Robert Boyle, among others, and through the early 18th century by Sir Isaac Newton and Gottfried Leibniz.

Hydrodynamica
Hydrodynamica (Latin for *Hydrodynamics*) is a book published by Daniel Bernoulli in 1738. The title of this book eventually christened the field of fluid mechanics as hydrodynamics. The book deals with fluid mechanics and is organized around the idea of conservation of energy, as received from Christiaan Huygens's formulation of this principle. The book describes the theory of water flowing through a tube and of water flowing from a hole in a container. In doing so, Bernoulli explained the nature of hydrodynamic pressure and discovered the role of loss of *vis viva* in fluid flow, which would later be known as the Bernoulli principle. The book also discusses hydraulic machines and introduces the notion of work and efficiency of a machine. In the tenth chapter, Bernoulli discussed the first model of the kinetic theory of gases. Assuming that heat increases the velocity of the gas particles, he demonstrated that the pressure of air is proportional to kinetic energy of gas particles, thus making the temperature of gas proportional to this kinetic energy as well.

Isothermal
An isothermal process is a change of a *system*, in which the temperature remains constant: $\Delta T = 0$. This typically occurs when a system is in contact with an outside thermal reservoir (heat bath), and the change will occur slowly enough to allow the system to continually adjust to the temperature of the reservoir through heat exchange. In contrast, an *adiabatic process* is where a system exchanges no heat with its surroundings ($Q = 0$). In other words, in an isothermal process, the value $\Delta T = 0$ and therefore $\Delta U = 0$ (only for an ideal gas) but $Q \neq 0$, while in an adiabatic process, $\Delta T \neq 0$ but $Q = 0$

Liquid
A liquid is a nearly incompressible fluid that conforms to the shape of its container but retains a (nearly) constant volume independent of pressure. As such, it is one of the four fundamental states of matter (the others being solid, gas, and plasma), and is the only state with a definite volume but no fixed shape.

Measurement of the Circle
The area of a **circle** is to the square on its diameter as 11 to 14. The ratio of the circumference of any **circle** to its diameter is greater than but less than. Measurement of a Circle (Greek: Κύκλου μέτρησις, Kuklou metrēsis) is a treatise that consists of three propositions by Archimedes.

Mercury
Mercury is a chemical element with symbol Hg and atomic number 80. It is commonly known as quicksilver and was formerly named hydrargyrum. A heavy, silvery d-block element, mercury is the only metallic element that is liquid at standard conditions for temperature and pressure; the only other element that is liquid under these conditions is bromine, though metals such as Caesium, gallium, and rubidium melt just above room temperature.

Plane Equilibrium
On the Equilibrium of Planes (or Centers of Gravity of Planes; in two books) is mainly concerned with establishing the centers of gravity of various rectilinear plane figures and segments of the parabola and the paraboloid.

Torr
The **torr** (symbol: Torr) is a unit of pressure based on an absolute scale, now defined as exactly 1/760 of a standard atmosphere. Thus one torr is exactly 101325/760 pascals (~133.3 Pa). Historically, one torr was intended to be the same as one "millimeter of mercury".

However, subsequent redefinitions of the two units made them slightly different (by less than 0.000015%). The torr is not part of the International System of Units (SI), but it is often combined with the metric prefix milli to name one **millitorr** (mTorr) or 0.001 Torr. The unit was named after Evangelista Torricelli, an Italian physicist and mathematician who discovered the principle of the barometer in 1644.

Hydraulic Foundations and Theories - Introduction

Section Focus
We will explain various scientists and their theories relating to fluid mechanics including the history and development of Pascal's Law.

Archimedes - *The King of Hydraulics*

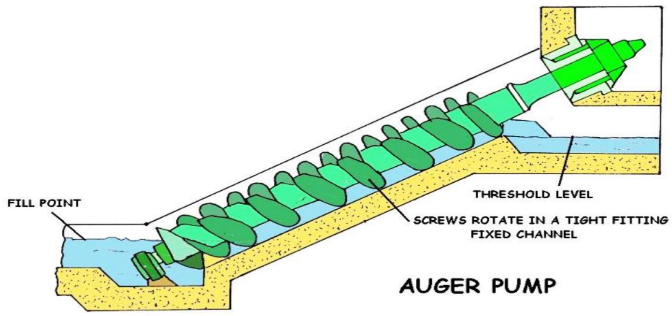
Archimedes

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 10/71 and 3 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.



This pump is at least 2,000 years old.

Archimedes Screw

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, while rarely! The helix revolves inside a tube and the water rises accordingly. Whether or not it was actually invented by Archimedes is certainly debatable, though his overall brilliance is not.

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 x 10^{62}).

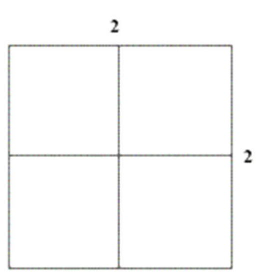
When numbers are multiplied by themselves, they are called powers.

Some powers of two are:

1 = 0 power=2^0

2 = 1^{st} power=2^1

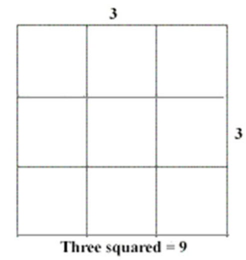
2 x 2 = 2^{nd} power (squared) =2^2



Two squared = 4

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

$2 \times 2 \times 2 \times 2 = 4^{th}$ 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*.

Other Archimedes’ Inventions

Iron Hand
The iron hand, also called the Archimedes claw, was a weapon designed by Archimedes to defend Syracuse from attack from the Roman Empire’s fleet in 213 B.C. It consisted of a huge lever. At one end was a grappling hook, or the claw. The claw was maneuvered to grasp the bow of an approaching ship, lift the ship out of the water, then drop it onto the water or onto nearby rocks. The ship's stern would be flooded and the unfortunate crew would be thrown out of the vessel in many directions.

Integral Calculus
Integral calculus -- a mathematical theory that derives the areas and volumes of spaces and the relationships between variables such as speed, distance and time -- remains one of Archimedes greatest accomplishments. He calculated areas of figures by breaking them up into a number of tiny rectangles and adding them up together to give a total. Today, this process is called integration and forms the basis of advanced mathematics.

DANIEL BERNOULLI (1700-1782)

Daniel Bernoulli

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

Daniel was the son of Johann Bernoulli (one of the "early developers" of calculus), nephew of Jakob Bernoulli (who "was the first to discover the theory of probability"), and older brother of Johann II. Daniel Bernoulli was described by W. W. Rouse Ball as "by far the ablest of the younger Bernoullis". He is said to have had a troubled relationship with his father, Johann.

Upon both of them entering and tying for first place in a scientific contest at the University of Paris, Johann, unable to bear the "shame" of being compared as Daniel's equal, and banned Daniel from his house. Johann Bernoulli also plagiarized some key ideas from Daniel's book *Hydrodynamica* in his own book *Hydraulica* which he backdated to before *Hydrodynamica*. Despite Daniel's attempts at reconciliation, his father carried the grudge until his death.

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

Daniel Bernoulli's Other Inventions

Blood Pressure Measurements
After developing his first mathematical principles, Bernoulli realized that the flow of fluids would also be adaptable to the idea of energy conservation. To investigate his theory, Bernoulli punctured the wall of a pipe and stuck in a small straw. He realized that the height the fluid rose within the straw was reflective of how much pressure was being generated. Being a physician as well, Bernoulli realized this would also work to measure the blood pressure of patients if a small tube was stuck in an artery. This was the preferred method of checking blood pressure for almost 200 years and this method is still used today to measure aircraft speeds.

Risk Measurements
Economic theory is all about measuring risks and rewards. Sometimes you want to avert risk and sometimes the right risks can pay off with a premium amount. In 1738, Bernoulli wrote a piece where the St. Petersburg paradox, an idea that relates probability and decision theory, as a means of being able to measure risk within an economic environment. He also attempted to analyze statistics involving censored data to measure the efficacy of vaccines within the general population.

Euler-Bernoulli Beam Equation
Theories about beams and their elasticity had been being developed for some time before Bernoulli began working on it. This equation shores up the elasticity of a beam, or how flexible it can be, yet still be considered a rigid beam. By knowing this information, it is possible to understand the tolerances of the beam, how much weight it is able to bear, and how functional the beam can be over an extended period of time. This equation is critical to the development of proper aerodynamics and you can see this equation applied every day on vehicles, airplanes, and anything else that moves with some version of improved velocity.

Quotes

It would be better for the true physics if there were no mathematicians on earth.

There is no philosophy which is not founded upon knowledge of the phenomena, but to get any profit from this knowledge it is absolutely necessary to be a mathematician.

Early Development of Hydraulics

The Egyptians and the ancient people of Persia, India, and China transferred water along channels for irrigation and domestic purposes, using dams and sluice gates to control the flow. The ancient Cretans and Romans had intricate plumbing system. Archimedes studied the laws of floating and submerged bodies.

The Romans constructed aqueducts to carry water to their cities. Although the modern development of hydraulics is comparatively recent, the ancients were conversant with many hydraulic principles and their applications.

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.

Pascal Law-Introduction

During the same period, Blaise Pascal, a French scientist, discovered the basic 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.

Burgomeister of Magdeburg

The noteworthy 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. Notably, he evacuated a sphere consisting of two well-fitting hemispheres about a foot in diameter, and showed that 16 horses, 8 on each side, could not pull them apart.

An original vacuum pump and hemispheres from 1663 are shown at the right (photo edited from the Deutsches Museum; see on right).

He also showed that air had weight, and how much force it did require to separate evacuated hemispheres. Later, 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 Catholic 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.

Evangelista Torricelli

Evangelista Torricelli (1608-1647) was an Italian physicist and mathematician, best known for his invention of the barometer, but is also known for his advances in optics and work on the method of indivisibles. Evangelista Torricelli incredibly was one of Galileo's student and secretary and a member of the Florentine Academy of Experiments, invented the mercury barometer in 1643, and brought the weight of the atmosphere to light.

The mercury column was held up by the pressure of the atmosphere, not by horror vacui as Aristotle had supposed. Torricelli's early death was a blow to science, but his ideas were furthered by Blaise Pascal (1623-1662).

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

Torricelli's law
Torricelli also discovered Torricelli's law, regarding the speed of a fluid flowing out of an opening, which was later shown to be a particular case of Bernoulli's principle. "Evangelista Torricelli found that water leaks out a small hole in the bottom of a container at a rate proportional to the square root of the depth of the water.

The Study of projectiles
Torricelli studied projectiles and how they traveled through the air. "Perhaps his most notable achievement in the field of projectiles was to establish for the first time the idea of an envelope: projectiles sent out at [...] the same speed in all directions trace out parabolas which are all tangent to a common paraboloid. This envelope became known as the *parabola di sicurezza* (safety parabola)."

Cause of Wind
Torricelli gave the first scientific description of the cause of wind:
... winds are produced by differences of air temperature, and hence density, between two regions of the ear

Torr

The mm of mercury is sometimes called a torr after Torricelli, and Pascal also has been honored by a unit of pressure, a newton per square meter or 10 dyne/cm2. A cubic centimeter of air weighs 1.293 mg under standard conditions, and a cubic meter 1.293 kg, so air is by no means even approximately weightless, though it seems so.

The weight of a sphere of air as small as 10 cm in diameter is 0.68 g, easily measurable with a chemical balance. The pressure of the atmosphere is also considerable, like being 34 ft. under water, but we do not notice it. A bar is 106 dyne/cm2, very close to a standard atmosphere, which is 1.01325 bar. In meteorology, the millibar, mb, is used. 1 mb = 1.333 mmHg = 100 Pa = 1000 dyne/cm2.

A kilogram-force per square centimeter is 981,000 dyne/cm2, also close to one atmosphere. In Europe, it has been considered approximately 1 atm, as in tire pressures and other engineering applications.

As we have seen, in English units the atmosphere is about 14.7 psi, and this figure can be used to find other approximate equivalents. For example, 1 psi = 51.7 mmHg. In Britain, tons per square inch has been used for large pressures. The ton in this case is 2240 lb, not the American short ton. 1 tsi = 2240 psi, 1 tsf = 15.5 psi (about an atmosphere!).

The fluid in question here is air, which is by no means incompressible. As we rise in the atmosphere and the pressure decreases, the air also expands.

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

This is a little harder to integrate than before, but the result is $\ln p = -Mgh/RT + C$, or $\ln (p/p0) = -Mgh/RT$, or finally $p = p0\exp(-Mgh/RT)$.

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°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.

Hydraulic Foundations and Theories Post Quiz

Link to Assignment…
http://www.abctlc.com/downloads/PDF/PumpPrimer2Ass.pdf

Archimedes
1. 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 __________which was "invented" 2,000 years later by Sir Isaac Newton and Gottfried Wilhelm von Leibniz.

2. 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?

Daniel Bernoulli
3. Daniel was the son of Johann Bernoulli (one of the "early developers" of calculus), nephew of Jakob Bernoulli (who "was the first to discover the ___________"), and older brother of Johann II.

4. Daniel Bernoulli was described by W. W. Rouse Ball as "by far the ablest of the younger Bernoullis". He is said to have had a bad relationship with his father, Johann. Upon both of them entering and tying for first place in a scientific contest at the University of Paris, Johann, unable to bear the "shame" of being compared as Daniel's equal, banned?

Blaise Pascal
5. Pascal's earliest work was in the natural and applied sciences where he made important contributions to the study of fluids, and clarified the concepts of pressure and vacuum by generalizing the work of?

6. In 1642, while still a teenager, he started some pioneering work on calculating machines. After three years of effort and fifty prototypes, he invented the?

7. Between 1658 and 1659 he wrote on the ___________ and its use in calculating the volume of solids. Pascal had poor health especially after his 18th year and his death came just two months after his 39th birthday.

Evangelista Torricelli
8. Evangelista Torricelli (1608-1647), ___________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.

Burgomeister of Magdeburg

9. Famously, he evacuated a sphere consisting of two well-fitting hemispheres about a foot in diameter, and showed that____________, could not pull them apart.

10. Pascal demonstrated that the siphon worked by atmospheric pressure, not by?

Answers 1. Calculus, 2. Tomb, 3. Theory of probability, 4. Daniel from his house, 5. Evangelista Torricelli, 6. Mechanical calculator, 7. Cycloid, 8. Galileo's, 9. 16 horses, 8 on each side, 10. Horror vacui

Hydraulic Foundations and Theories References

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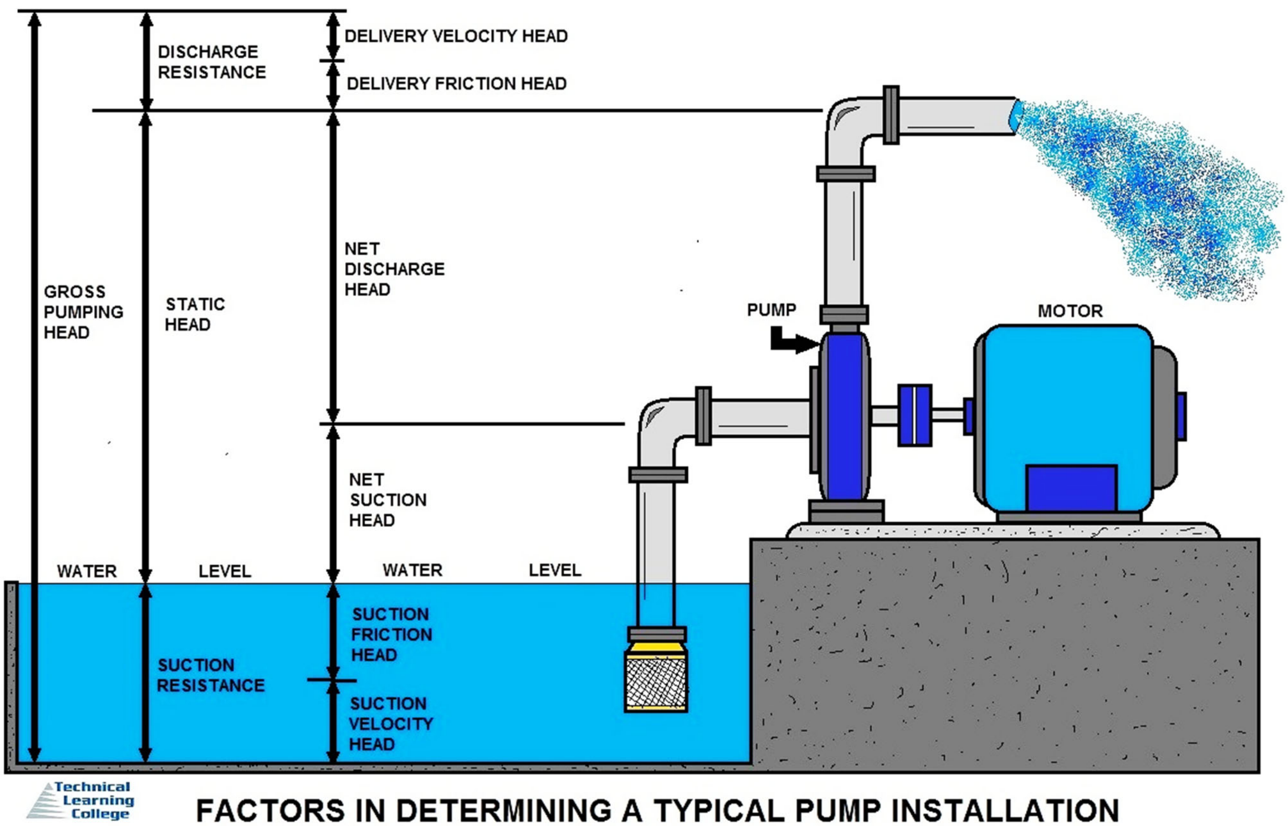
Section 3 –Pumps and Pumping Water

Section Focus: You will learn the basics of various pumps. At the end of this section, you the student will be able to describe water pumps and the associated hydraulic principles. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: The main purpose of this section is to provide understanding of various water lifting procedures, basic pump fundamentals, hydraulic principles, theory, and maintenance.

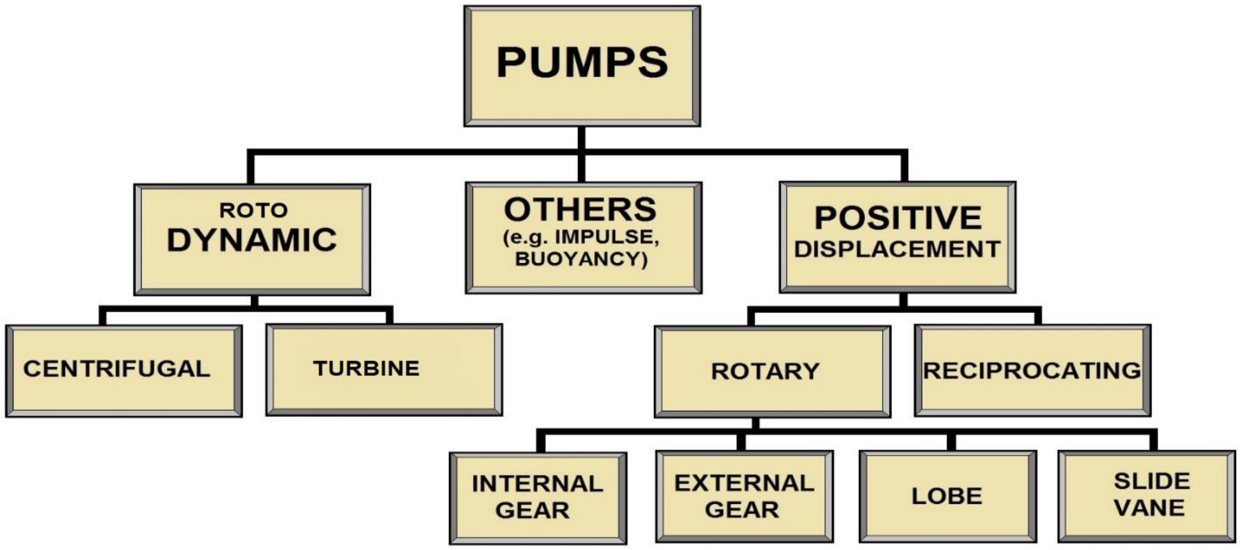


FACTORS IN DETERMINING A TYPICAL PUMP INSTALLATION

Pump Introduction

Moving fluids plays a major role in the process of a plant. Liquid can only move on its own power from top to bottom or from a high pressure to a lower pressure system. This means that energy to the liquid must be added to move the liquid from a low to a higher level.

To add the required energy to liquids, pumps are used. There are many different definitions of a pump but it can be described as: A machine used for the purpose of transferring quantities of liquids, gases and even solids from one location to another.



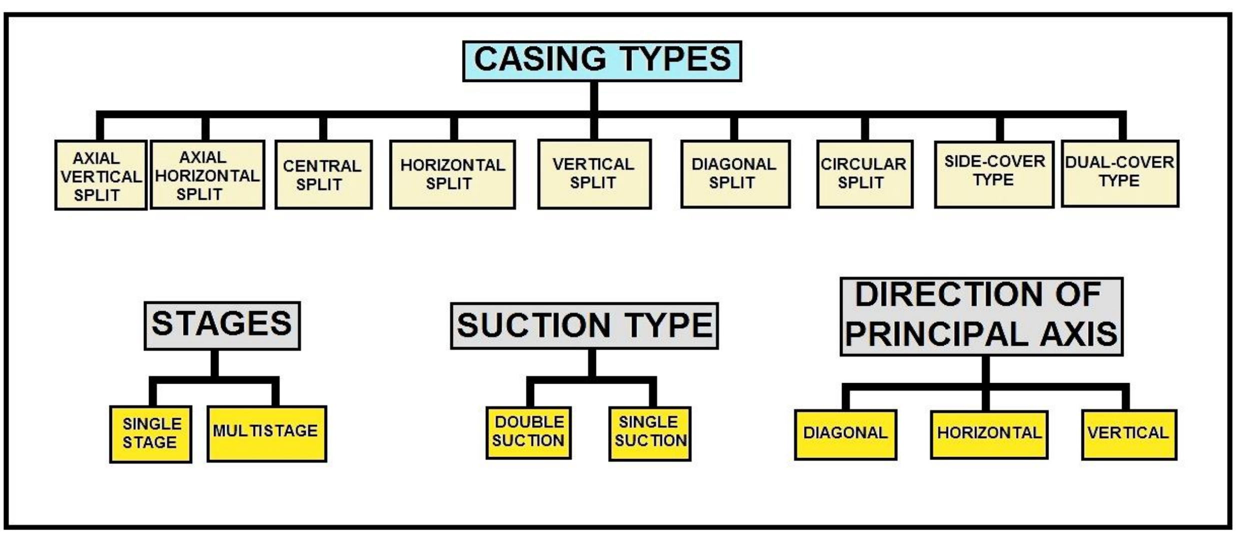
PUMP CATEGORIES

Types of Pumps

Pump types generally fall into two main categories - Rotodynamic and Positive Displacement, of which there are many forms.

The Rotodynamic pump transfers rotating mechanical energy into kinetic energy in the form of fluid velocity and pressure. The Centrifugal and Liquid Ring pumps are types of rotodynamic pump, which utilize centrifugal force to transfer the fluid being pumped.

The Rotary Lobe pump is a type of positive displacement pump, which directly displaces the pumped fluid from pump inlet to outlet in discrete volumes.



PUMP CONFIGUARATIONS

Pumps and Pumping Water - Introduction
General Pumping Fundamentals

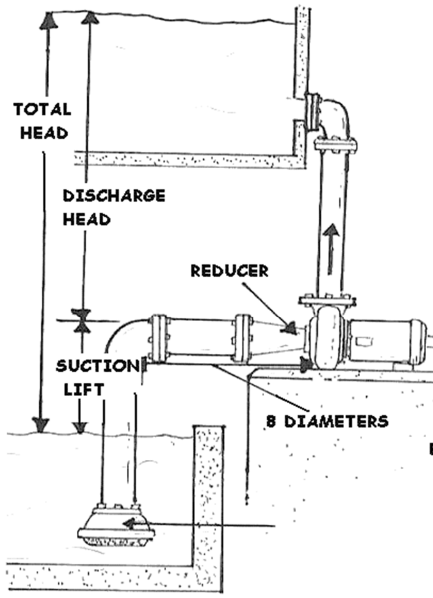


ILLUSTRATION 1

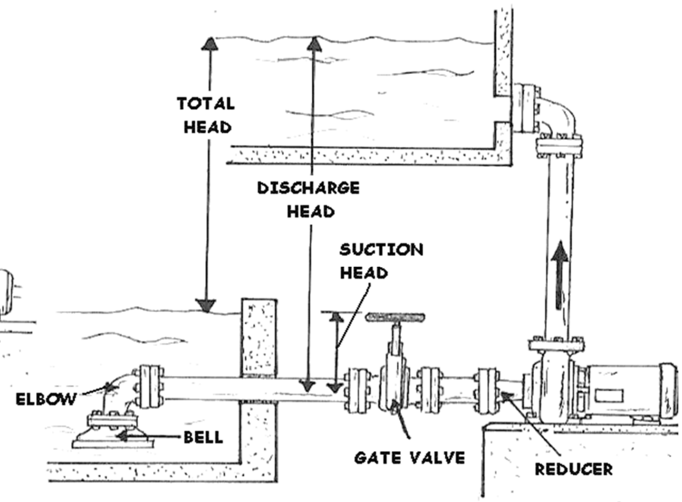


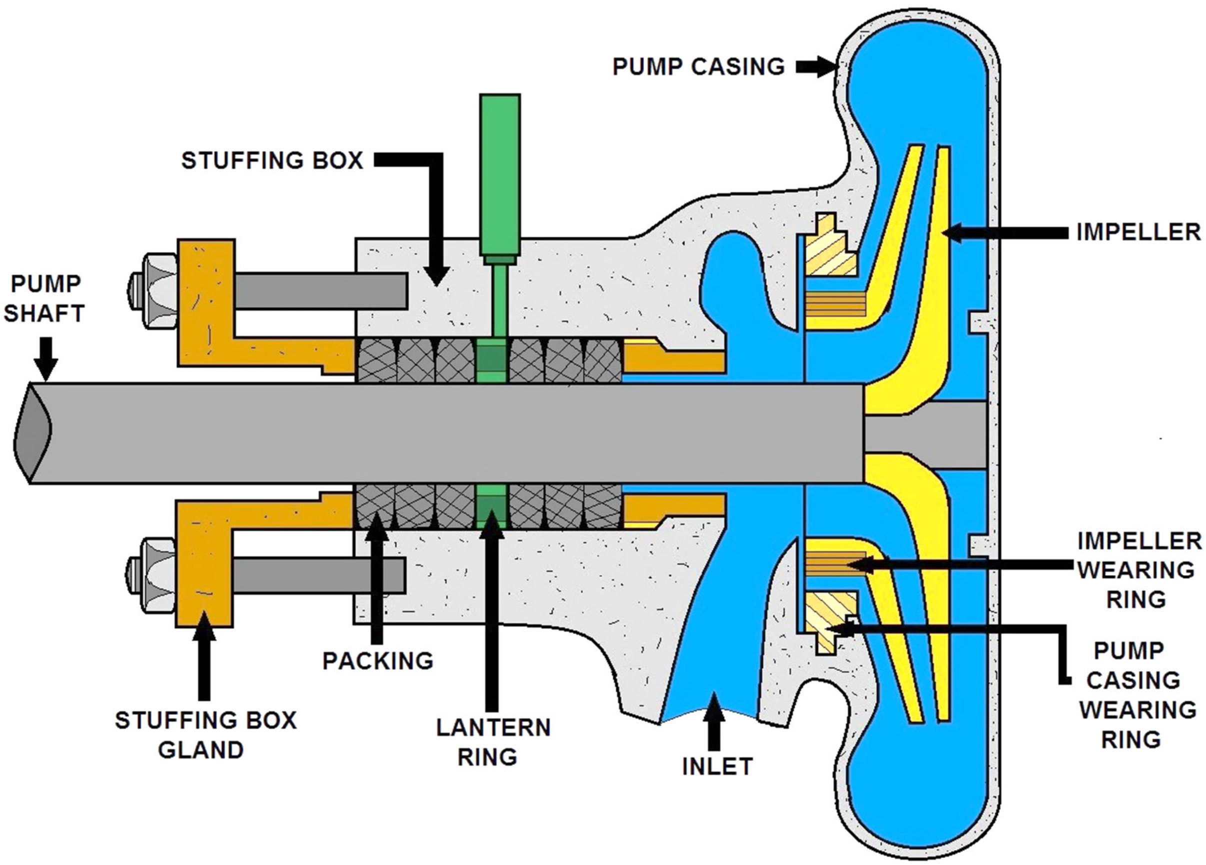
ILLUSTRATION 2

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 by the atmosphere on the liquid around the outside of the straw, causing the liquid in the straw to move up. By sucking on the straw, this allows atmospheric pressure to move the liquid.
- Look at the diagram illustrated as "**1**". The foot valve is located at the end of the suction pipe of a pump. It opens to allow water to enter the suction side, but closes to prevent water from passing back out of the bottom end.
- The suction side of pipe should be one diameter larger than the pump inlet. The required eccentric reducer should be turned so that the top is flat and the bottom tapered.

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

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



CENTRIFUGAL PUMP BREAKDOWN

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.

We will cover this pump and other complicated pumps in detail in the next section.

Common Types of Water Pumps

The most common type of water pumps used for municipal and domestic water supplies are *variable displacement* pumps another term for dynamic 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 but also in many other applications. These pumps are driven by a shaft rotated by a motor that is usually found on the surface. The shaft turns the impellers within the pump housing while the water moves up the column.

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

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

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

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

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

When the line shaft turbine is turned off, water will flow back down the column, turning the impellers in a reverse direction. A pump and shaft can easily be broken if the motor were to turn on during this process.

This is why a *time delay* or *ratchet* assembly is often installed on these motors to either prevent the motor from turning on before reverse rotation stops or simply not allow it to reverse at all.

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

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.

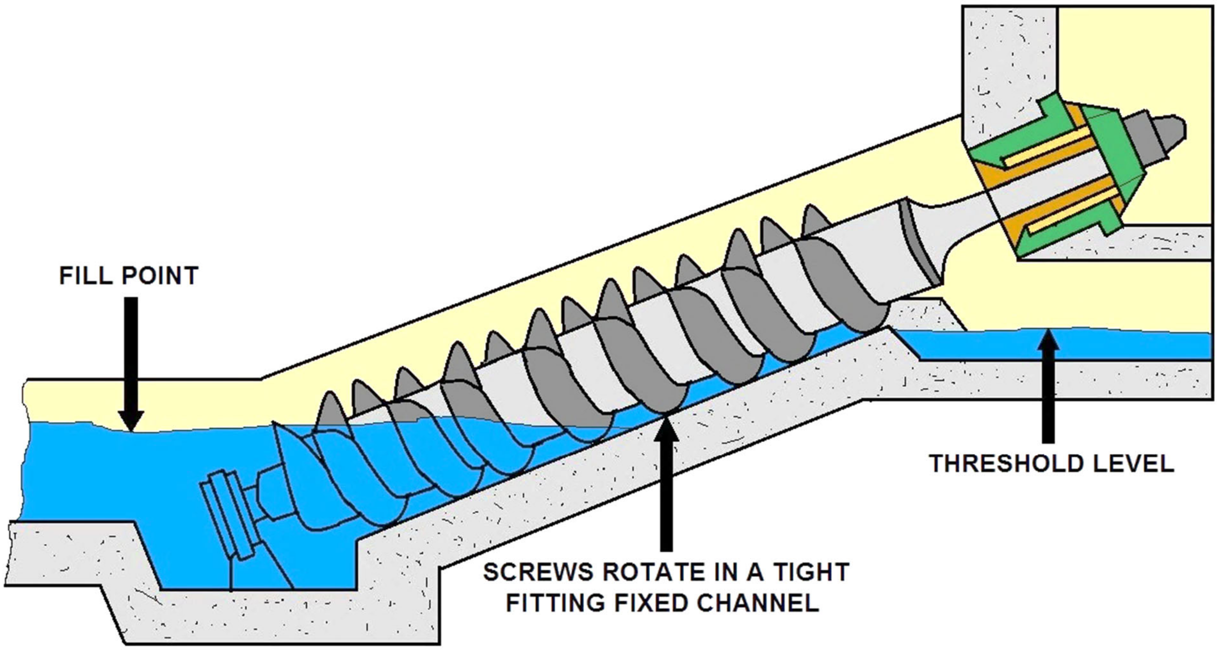
Cavitation is, in many cases, an undesirable occurrence. In devices such as propellers and pumps, cavitation causes a great deal of noise, damage to components, vibrations, and a loss of efficiency. When the cavitation bubbles collapse, they force liquid energy into very small volumes, thereby creating spots of high temperature and emitting shock waves, the latter of which are the source of rattling noise. The noise created by cavitation is a particular problem for military submarines, as it increases the chances of being detected by passive sonar.

Although the collapse of a cavity is a relatively low-energy event, highly localized collapses can erode metals, such as steel, over time. The pitting caused by the collapse of cavities produces great wear on components and can dramatically shorten a propeller's or pump's lifetime.

Simple Pumps Sub-Section

Screw or Auger Pump

The Archimedes' screw, Archimedean screw, or screwpump 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.



AUGER PUMP DIAGRAM

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.

In addition, 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.

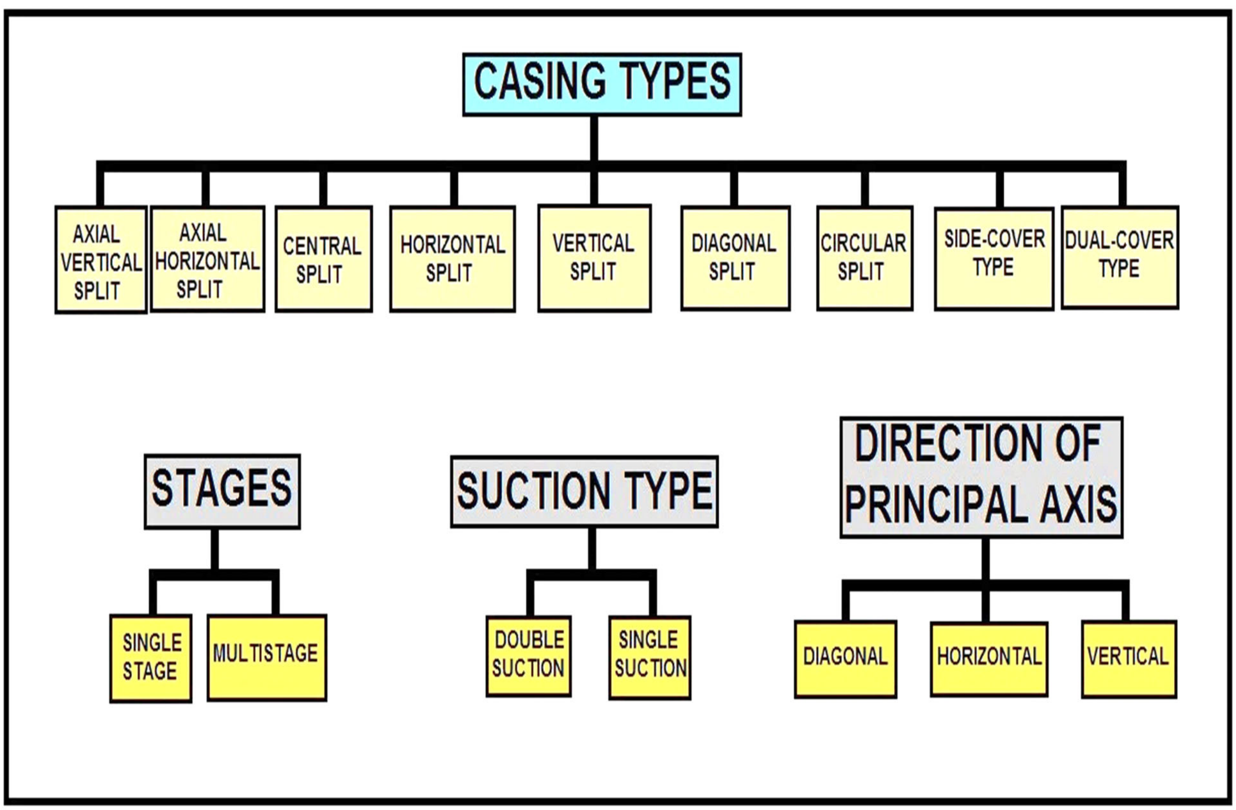
A screw could be sealed with pitch or some other adhesive to its casing, or, cast as a single piece in bronze, as some researchers have postulated as being the devices used to irrigate Nebuchadnezzar II's Hanging Gardens of Babylon.

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:

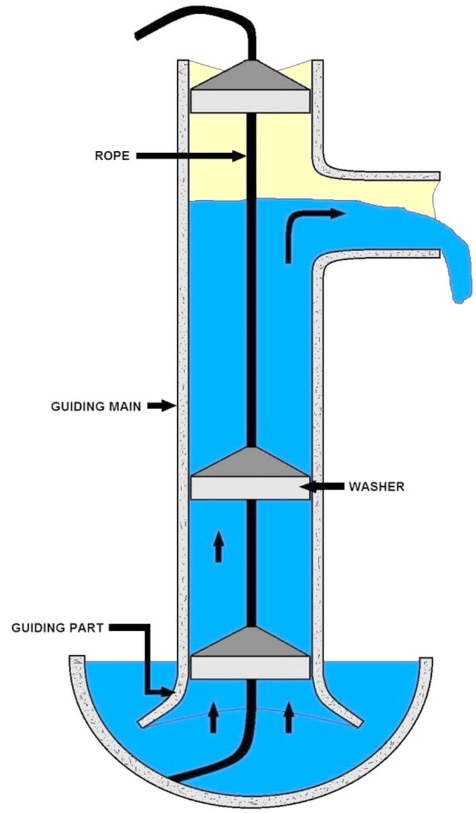
- Most screw pumps rotate in the 30 to 60 rpm range, although some screw pumps are faster.
- The slope of the screw is normally either 30° or 38°.

The maximum lift for the larger diameter pumps is about 30 feet. The smaller diameter pumps have lower lift capabilities.



PUMP CONFIGURATION DIAGRAM

Rope Pump Sub-Section



ROPE PUMP DESIGN

Devised in China as chain pumps over 1000 years ago, these pumps can be made from very simple materials: A rope, a wheel and a PVC pipe are sufficient to make a simple rope pump. For this reason, they have become extremely popular around the world since the 1980s. Rope pump efficiency has been studied by grass roots organizations and the techniques for making and running them has been continuously improved.

The pumping elements of the rope pump are the pistons and the endless rope, which pull the water to the surface through the pumping pipe made of PVC or plastic. The rotation of the wheel, moved by the handle, pulls the rope and the pistons. The pistons, made of polypropylene or polyethylene injected into molds, are of high precision to prevent hydraulic losses.

The structure is basically made out of angle iron, piping and concrete steel. The pulley wheel is made out of the two internal rings cut out of truck tires and joined by staples and spokes, which must be strong for intensive use. A guide box at the bottom of the well leads the rope into the pumping pipe. The guide box is made out of concrete with an internal glazed ceramic piece to prevent any wear. The rope pump can be operated by the whole family and is also used at the community level, for small agriculture production or cattle watering. It is also a high efficiency and low cost technology, but includes some pieces of high precision and high quality.

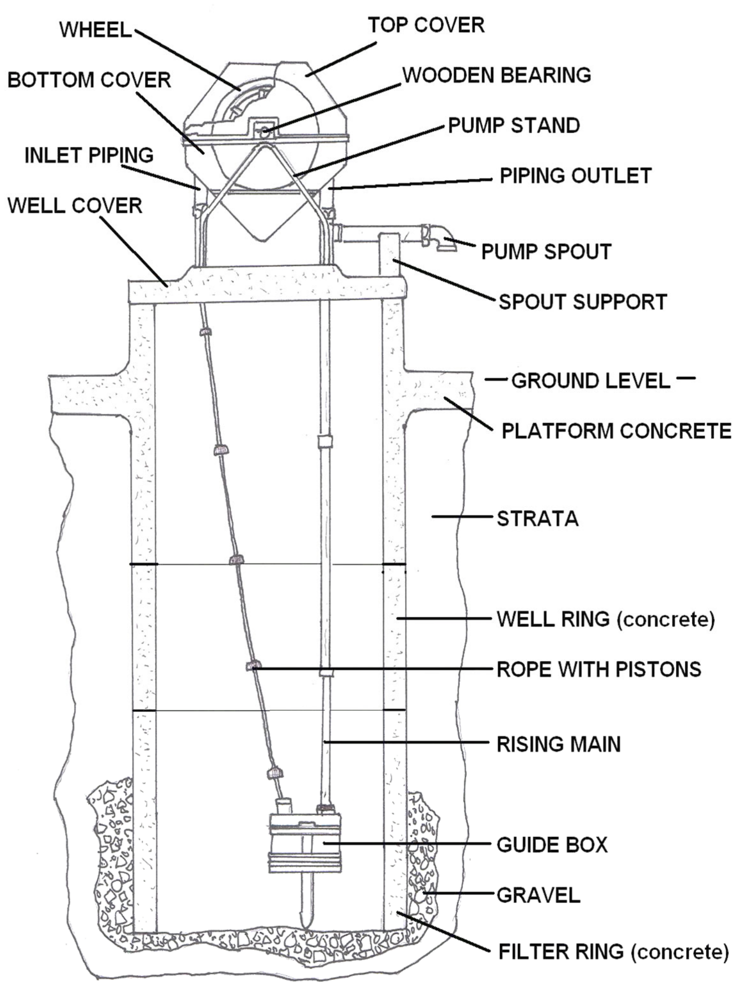
The Guide
The guide is installed at the bottom of the well and is where the pumping process is initiated. Its function consists of guiding the rope with pistons attached so that it enters into the pumping pipe from below, as well as maintaining the pipes taught (plumbed) with the appropriate tension. Therefore, the guide has various functions integrated into one piece. It serves as well as a counterweight to tauten the rope in order to avoid sliding on the wheel.

The guide is a concrete box with a base piece, an entry pipe, a pumping pipe and support pipe, and a ceramic piece inside.

These parts of the guide must be made in such a way that the rope never touches the concrete, which would cause wear to it as well as to the pistons. In the production are no iron parts involved and therefore, the rope pump is not susceptible to rust problems and can be used in very corrosive water. The entry and pumping pipes on the guide have a wide mouth to facilitate the entry of the rope and pistons.

The water enters the guide through the base piece (2" PVC pipe) located at about five centimeters from the bottom of the guide. The guide itself is placed on the bottom of the well. This allows practically all of the water to be drained from the well. This is important when a well has very little water, as water can still be extracted, which would not be the case with a bucket and rope.

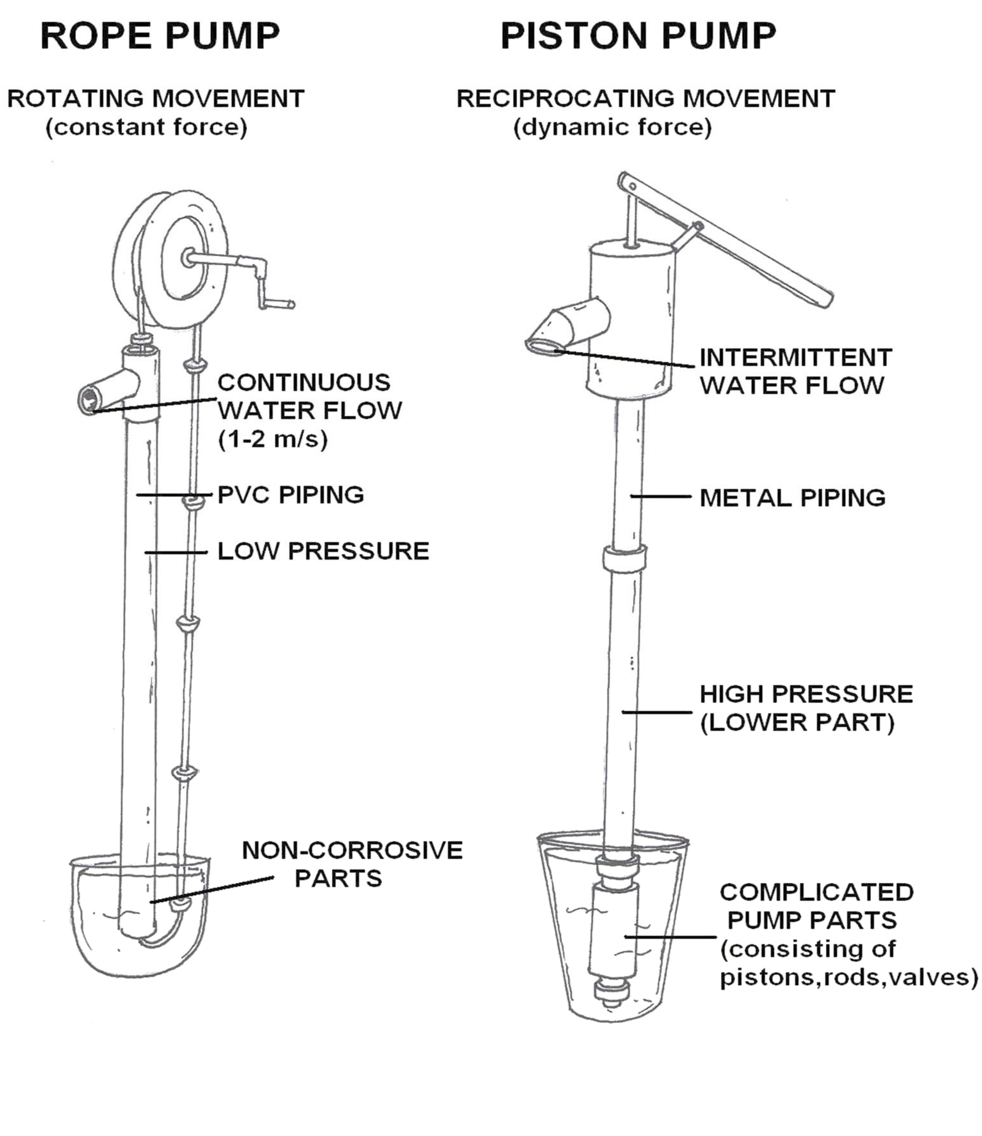
The Ceramic Piece
The ceramic piece in the center of the guide has a design that was developed based on practical work and corresponds to various needs at the moment of assembly. The ceramic piece is shaped like a horse saddle to stop the rope from leaving the canal formed by the saddle. The ceramic piece is made of refractory clay similar to white porcelain. Its vitrification temperature is between 1250^{o} C and 1300^{o} C. The ceramic piece has a coat of enamel, which makes it completely smooth there where it touches the rope. This enamel does not wear.



ROPE PUMP

Wheel
The function of the rope pump structure is to support the efforts of the axle, wheel, and crank, as well as fix the pumping pipe, both entry and exit sections. It is the esthetic part (Visible) of the pump and is installed on the well cover. The types of materials and their diameters depend on the use given to the equipment. The structure is basically made out of pipes, iron rods, iron strip and angle iron. The pulley wheel is made out of the two internal rings cut out of truck tires and joined by clamps and spokes, which must be strong for intensive use. The 20" inch truck tires are used, but for wells deeper than 29 meters 16 " inch tires are used.

Pistons
The pistons are one of the most sensitive parts of the pump. Together with the rope they form an endless chain. When the rope rotates it leads the piston through the pumping pipe, pushing the water inside upwards.



The piston is a cone shaped part with a hole on its top and must meet the following norms:

- ✓ Exact dimensions.
- ✓ Cone shape to reduce friction.
- ✓ Strong and water-resistant material.
- ✓ The piston diameters vary with depth as do the pumping pipe.
- ✓ Piston diameter is determined by the type of pipe to be used and the well's depth. Pistons should be made of injected polypropylene or polyethylene. Neither rubber nor wood are recommended.
- ✓ The rope's length, diameter and amount of pistons are determined by the well's depth.
- ✓ Two-inch (0 - 3.5 meters depth) and 1 ½" inch (3.5 - 5 meters depth) pistons are used in wells which are not too deep or when motor driven rope pumps are used.
- ✓ A perfect fit is required between the pistons and the pumping pipe. The space between piston and inner wall of the pipe is only 0.15 mm for the 1/2-inch pipe and up to 0.40 mm for the 1-inch pipe. The production of the molds thus requires high precision.

Piston production requires a small plastic injection machine, and different-size molds. The pistons are made of high-density polypropylene or polyethylene. Polyethylene is poured in the injection machine hopper. As the plastic passes through the heated hopper bottom, it becomes fluid and is injected into the mold. As it cools, the plastic adopts the mold's form.

Pipes

The pumping pipes are a fundamental part of the rope pump. The recommended pipe should meet ASTM D-2241 standards. All piping is the pressure type used for potable water. In Nicaragua, measurements are in inches, whereas other countries use millimeter measurements, requiring adaptation. Several countries have changed from PVC to plastic pipes, these equally can be used in rope pump production.

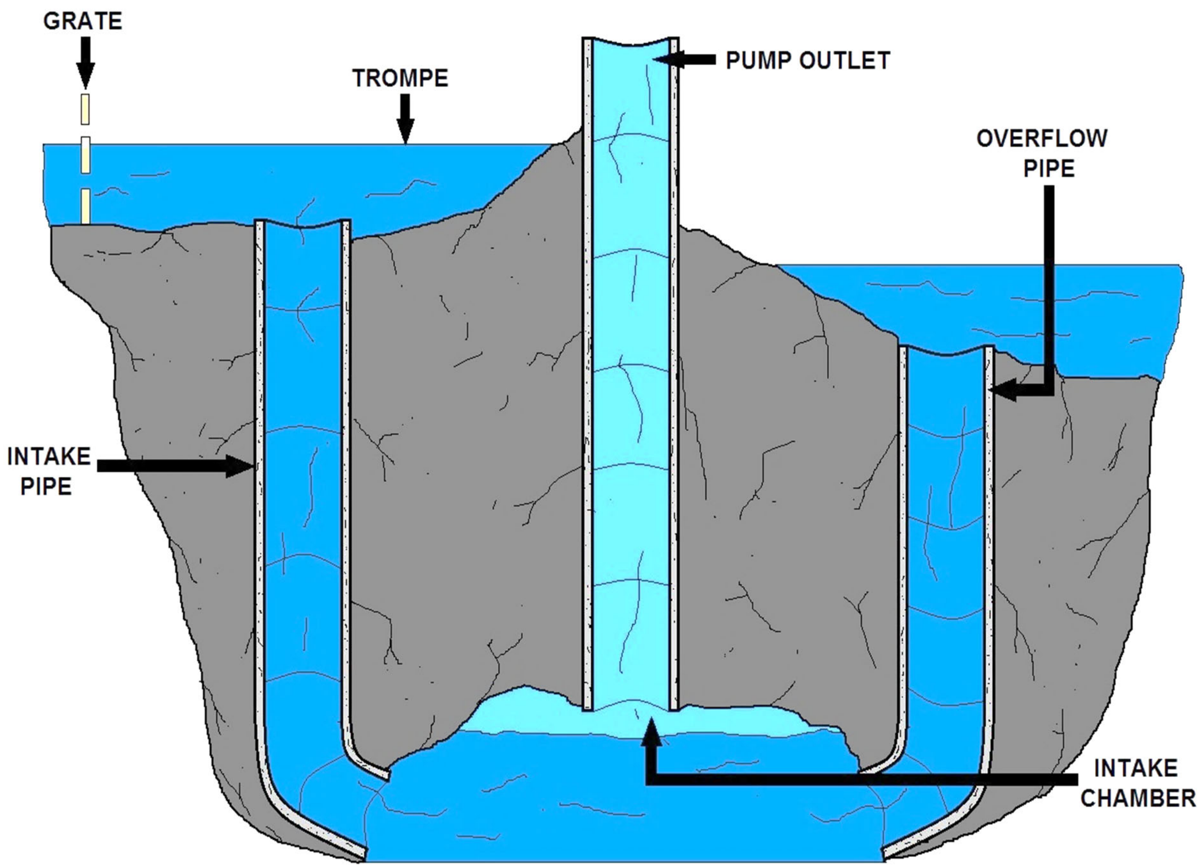
A fundamental difference with the traditional piston pumps is that the weight of the water column is distributed over the pistons and is thus hanging on the rope. The inside pressure on the pipe wall is minimum and as high as the water column between two pistons.

The pumping process is a continuous process and not an intermittent up and down movement, therefor there is no fatiguing breakage. Only the pumping pipes plus the guide box are hanging on the upper pumping pipe.

Pumping pipes vary according to the depth of the well. The deeper the well, the smaller the diameter of the pipe. The maximum weight of the water in the pipes is 10 kilograms and should not be exceeded. Therefore, if pipes with different measurements are used, the maximum depth should be adapted to the maximum weight of 10 kilograms. The diameter of the pipes is determined by the depth from wellhead to water level. Deficiencies have been encountered in the pipes depending on their origin of production.

Impulse Pump

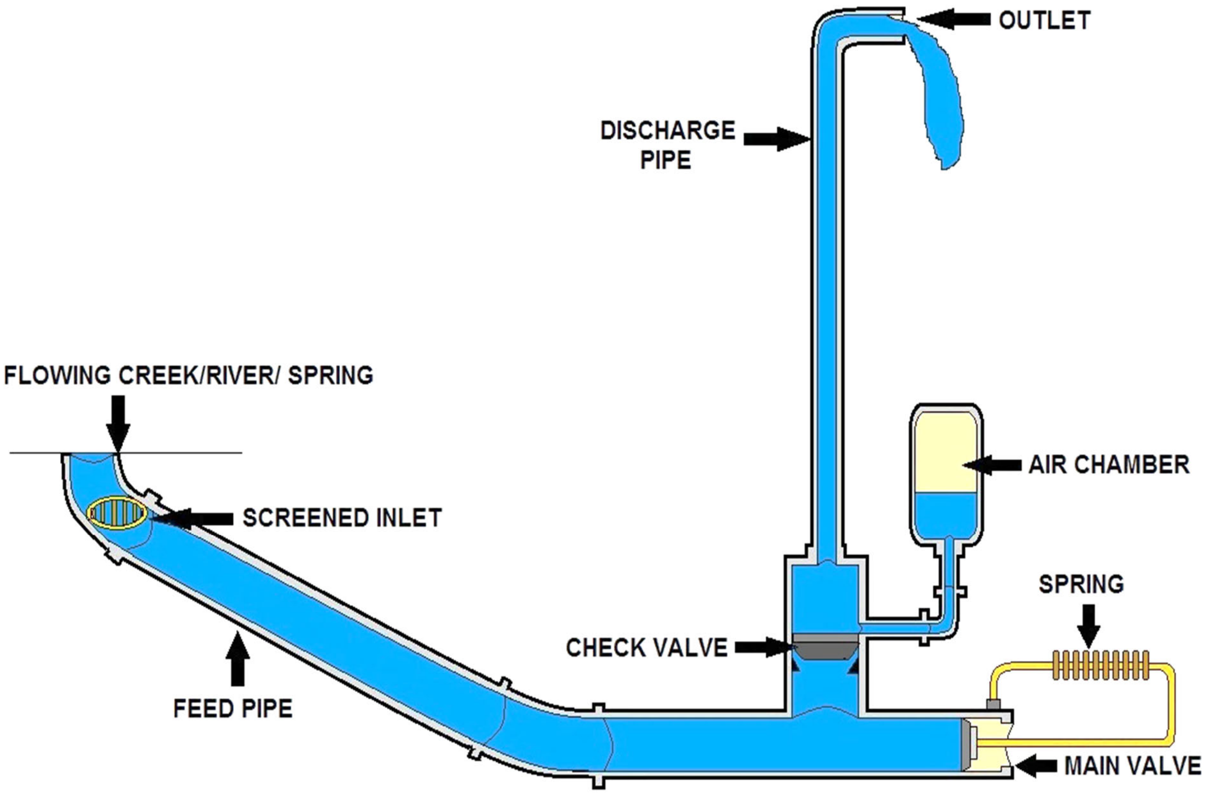
Impulse pumps use pressure created by gas (usually air). In some impulse pumps the gas trapped in the liquid (usually water), is released and accumulated somewhere in the pump, creating a pressure that can push part of the liquid upwards.



PULSER PUMP DIAGRAM

Impulse pumps include:

- ✓ Hydraulic ram pumps - uses pressure built up internally from released gas in liquid flow.
- ✓ Pulser pumps - run with natural resources, by kinetic energy only.
- ✓ Airlift pumps - run on air inserted into pipe, pushing up the water, when bubbles move upward, or on pressure inside pipe pushing water up.



HYDRAULIC RAM PUMP DIAGRAM

Hydraulic Ram Pumps

A hydraulic ram is a water pump powered by hydropower. It functions as a hydraulic transformer that takes in water at one "hydraulic head" (pressure) and flow-rate, and outputs water at a higher hydraulic-head and lower flow-rate. The device uses the water hammer effect to develop pressure that allows a portion of the input water that powers the pump to be lifted to a point higher than where the water originally started.

The hydraulic ram is sometimes used in remote areas, where there is both a source of low-head hydropower, and a need for pumping water to a destination higher in elevation than the source. In this situation, the ram is often useful, since it requires no outside source of power other than the kinetic energy of flowing water.

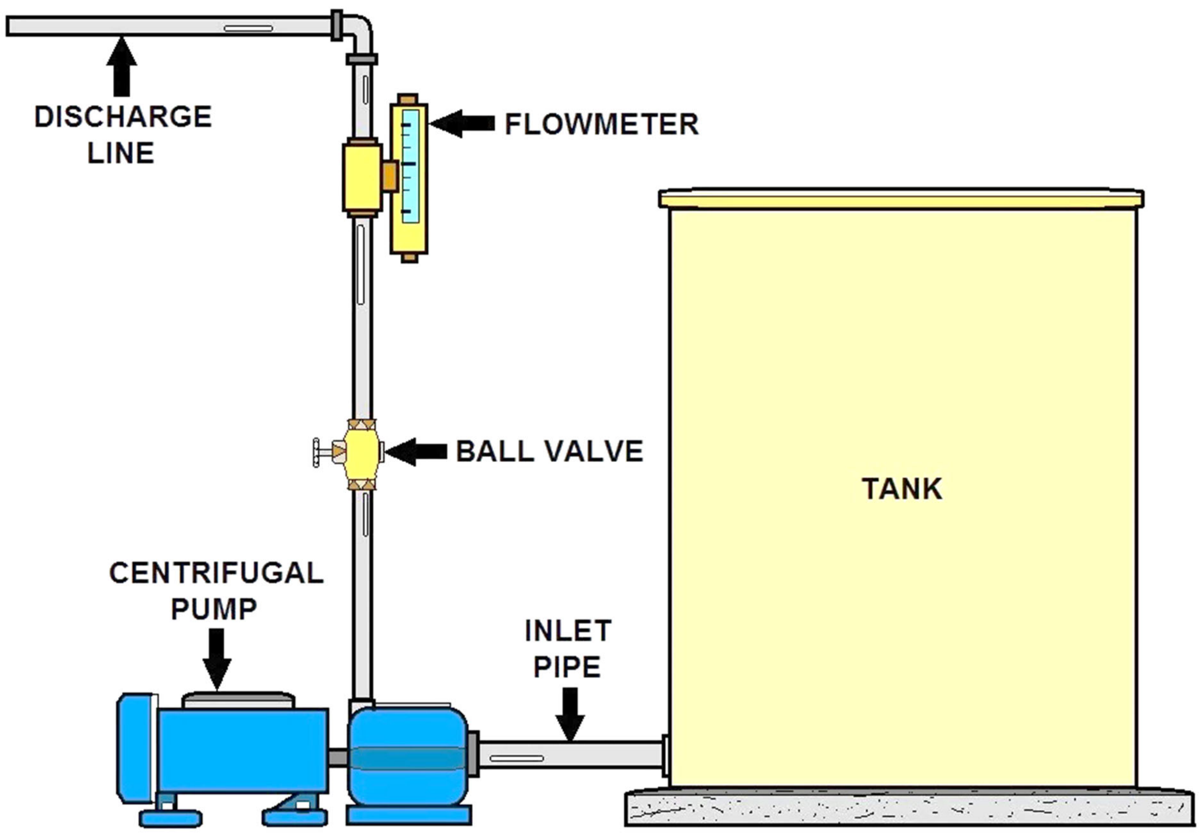
Velocity Pumps

Rotodynamic pumps (or dynamic pumps) are a type of velocity pump in which kinetic energy is added to the fluid by increasing the flow velocity. This increase in energy is converted to a gain in potential energy (pressure) when the velocity is reduced prior to or as the flow exits the pump into the discharge pipe. This conversion of kinetic energy to pressure can be explained by the First law of thermodynamics or more specifically by Bernoulli's principle. Dynamic pumps can be further subdivided according to the means in which the velocity gain is achieved.

These types of pumps have a number of characteristics:
1. Continuous energy
2. Conversion of added energy to increase in kinetic energy (increase in velocity)
3. Conversion of increased velocity (kinetic energy) to an increase in pressure head

One practical difference between dynamic and positive displacement pumps is their ability to operate under closed valve conditions. Positive displacement pumps physically displace the fluid; hence closing a valve downstream of a positive displacement pump will result in a continual build up in pressure resulting in mechanical failure of either pipeline or pump.

Dynamic pumps differ in that they can be safely operated under closed valve conditions (for short periods of time).



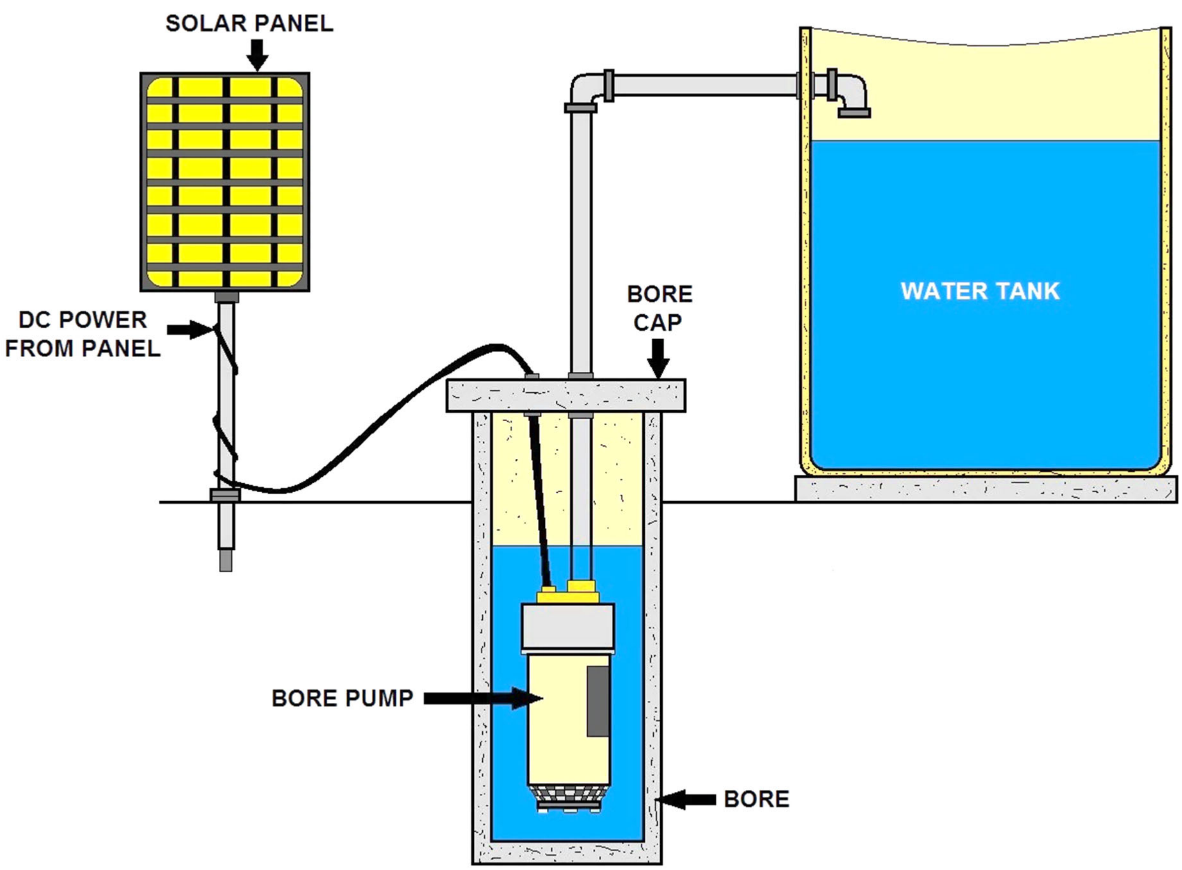
GRAVITY FEED SYSTEM DIAGRAM

Gravity Pumps

Gravity pumps include the syphon and Heron's fountain – and there also important qanat or foggara systems which simply use downhill flow to take water from far-underground aquifers in high areas to consumers at lower elevations. The hydraulic ram is also sometimes referred to as a gravity pump.

Gravity Pump Sub-Section

The ability of water to flow from higher to lower elevations makes a gravity system the one to utilize whenever possible. With no moving parts or energy inputs, these systems can provide dependable, low-maintenance service. To allow for flow resistance in the pipe, a minimum delivery pipe diameter 1 1/4 in. should be used where the grade is over l%. For grades between 0.5% and 1.0%, a 1 1/2 in. minimum size is recommended. Grades less than 0.2% are not recommended for gravity systems. Lay the delivery pipe on a uniform grade to prevent airlocks from forming. Water tank volume should reflect livestock numbers and water demand. If necessary, add gravel to ensure the tank area is stable to withstand herd traffic. A float at the water tank or an overflow outlet would control these conditions. Put a shade canopy over the tank to control seasonal algae growth.



SOLAR WATER PUMP

Solar Power

Photovoltaic (PV) or solar panels can be used to power pumping systems for a wide range of output requirements. Solar systems can be very reliable and low in maintenance, but are expensive and require good design for practical service. Two system designs can be used depending upon the application.

Both systems involve storing energy to compensate for variances in solar radiation intensity. Systems that use energy storage in the form of pumped water held in an elevated reservoir have the advantage of design simplicity.

Solar panels supply power to the water pump through a maximum power point device to deliver water to the reservoir only during periods of bright sunlight. Water from the reservoir is gravity fed to the stock trough and controlled by a float valve. Battery systems also store energy for use during periods of low sunlight intensity. Through a sequencing device, solar panels charge the batteries that power the water pump.

Pump operation is controlled by an electric float switch to allow flow on demand to the stock trough. Proper design of a solar system is critical to meet the specific needs of the user. Consider a suntracker if you are concerned about space for sufficient number of panels. A tracker follows the sun as the day progresses and maximizes panel exposure to the sun.

Heissler Pump
This pump was designed by Paul Heissler of Frankford, Ontario. It is an inexpensive system and can be built from materials around the farm. It has a 12-volt submersible pump sitting in shallow water driven by a tractor battery. A 45-gallon drum acts as a reservoir with a float to control water level. A small trough is attached. Water flows into the trough by gravity as the livestock drink it down. The pump will deliver 22 gallons per minute. The battery is covered to protect it from the weather. This unit sits on top of the reservoir.

The height and distance water is pumped limits the use of the Heissler pump. The more energy required for pumping water the more often the battery needs recharging. The battery charge has lasted 24 days, drawing water up 10 ft and providing water to 44 head of cattle.

Hydraulic Rams
Hydraulic ram pumps have been used since the 1700s. New designs with the same principles are being used today. Falling water is required to operate a hydraulic ram pump. If installed correctly the pump moves water as high as 10 times the fall. The weight of falling water drives a lesser amount to an elevation above the source of supply. The pump operates on the basis of the falling water opening and closing 2 valves with air pressure forcing the water to its destination.

The volume of water a ram pumps depends on the size of the pump, the fall between the source of supply and the ram, the height to which the water is to be raised and the quantity of water available. Output ranges from 700 to 3,000 gallons per day depending on these factors. A small stream is an excellent source to water livestock.

Water needs to flow into the pump at 1 to 5 gallons per minute. A fall of 2 ft. or more is sufficient to drive a ram capable of pumping water to a stock trough at considerable elevation and distance. As the pumping rate is constant but generally slow, a storage reservoir may be necessary to accommodate high demand periods.

Hydraulic ram pumps are a time-tested technology that uses the energy of a large amount of water falling a small height to lift a small amount of that water to a much greater height. In this way, water from a spring or stream in a valley can be pumped to a village or irrigation scheme on the hillside.

Depending on the difference in heights between the inlet pipe and the outlet pipe, these water pumps will lift 1-20 percent of the water that flows into it. In general, a ram can pump approximately one tenth of the received water volume to a height ten times greater than the intake. A hydraulic ram pump is useful where the water source flows constantly and the usable fall from the water source to the pump location is at least 91 cm (3 ft).

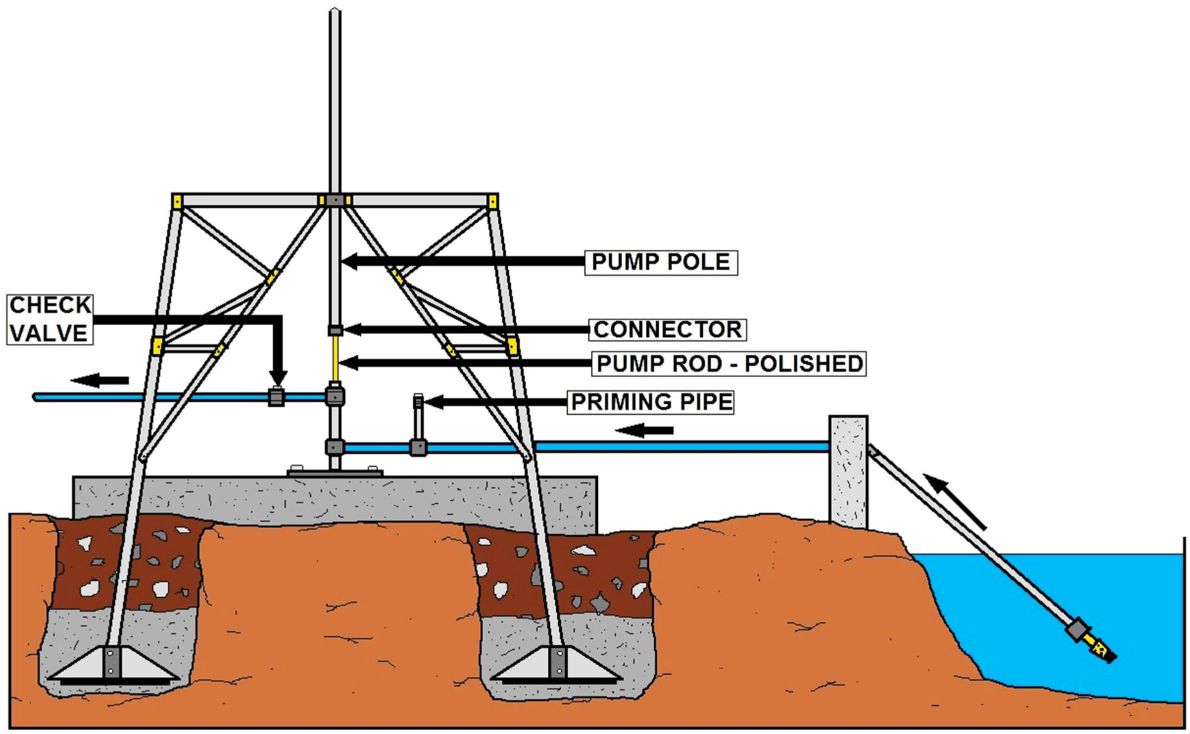
Since ram pumps can only be used in situations where falling water is available, their use is restricted to three main applications:

- ✓ lifting drinking water from springs to settlements on higher ground.
- ✓ pumping drinking water from streams that have significant slope.
- ✓ lifting irrigation water from streams or raised irrigation channels.

Ram Pump Advantages include:

1. Inexpensive
2. Very simple construction and easy to install yourself.
3. Does not consume petrol, diesel or electricity.
4. Minimum maintenance.
5. Pollution free.
6. Quiet pumping 24 hours per day.

Wind Mills



WINDMILL DRIVEN WATER PUMP

Wind Mills

In the past, windmills have been a proven part of the farm enterprise and could find greater use for livestock water purposes today. Though now a fairly expensive technology, currently manufactured windmills are reliable and need little maintenance, equal to their antique counterparts.

Old windmills can be successfully rebuilt and may offer a practical alternative to the expense of new equipment. Modern windmills will operate in a stream, pond or shallow well. The pump sits on the surface or in the water. An airline connects the pump to the windmill. Air pressure generated by the windmill activates the pump. Water is pumped when there is wind. The windmill can be located up to 300 ft. from the water source and at the best location to catch the wind. It can lift water up to 20 ft. and pump 5 gallons per minute. As wind is a variable energy source, use a storage reservoir to provide a supply for periods of low wind velocity. Locate the storage reservoir within 1,000 ft. of the water source.

Pasture (Nose) Pumps

Using a simple pumping mechanism to draw water to a bowl, the nose pump is a good alternative to in stream watering. Installation is quick and easy - easy enough to use as portable system for rotation pastures. Animals push a plunger with their nose to move water with a diaphragm pump into a bowl. The pump is a rubber diaphragm and 2 check valves.

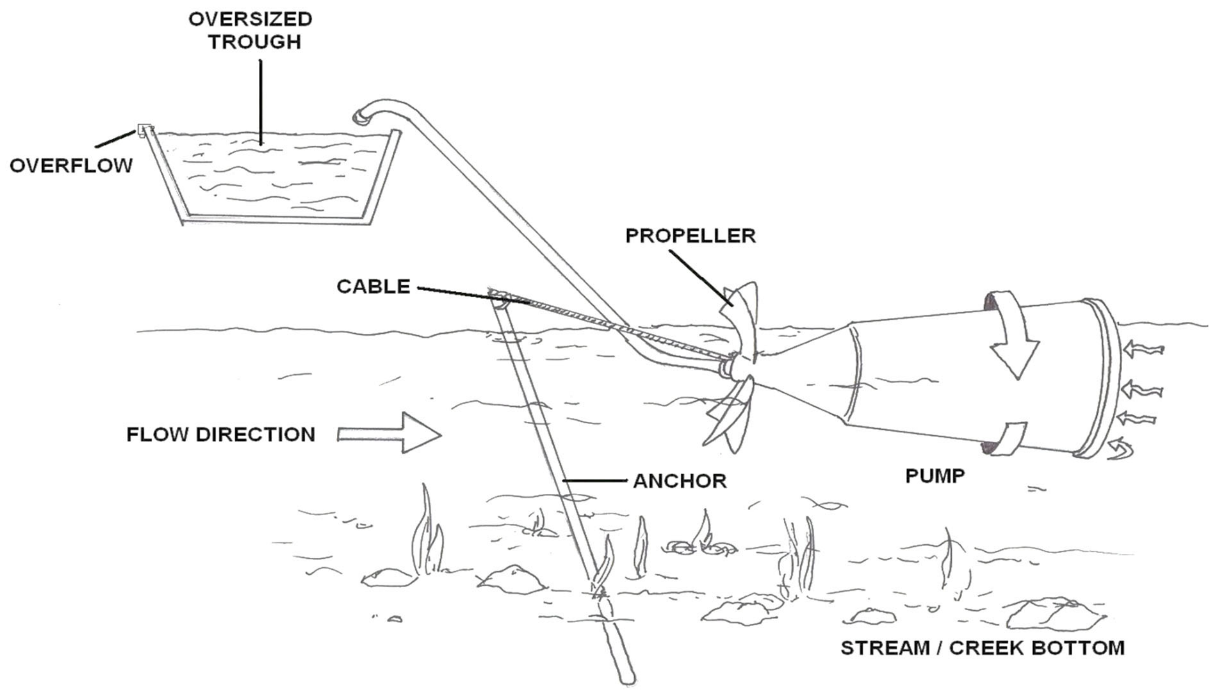
One push of the plunger brings water in on the forward stroke and again as it is released. The intake line incorporates a foot valve and strainer for reliable operation.
The water source may be a nearby stream, pond or well of suitable quality. A disadvantage of the nose pump is that stock must water individually, limiting practical use to about 25 animals per unit. Maximum lift from the water source is 25 ft. Where there is very little lift required nose pumps can draw water from 200 to 3,000 ft, depending on the pump size. Nose pumps are relatively low in cost and installation expense is minimal. Animals must be trained to use them. Young calves may have difficulty at the beginning.

- Nose pumps are generally not the least cost or the most desirable watering facility option unless the site is too distant from farmstead facilities, water lines, springs, etc. to make conventional pipeline and water tubs impracticable or cost prohibitive.
- The livestock watering system shall have capacity to meet the water requirements of the livestock.
- Due to the water requirements of dairy milkers, nose pumps may not be a viable option unless the number of animals being served is very low.
- The site should be well drained, or if not, drainage measures will be provided. Areas adjacent to the nose pump that will be trampled by livestock shall be graveled, or otherwise treated to provide firm footing and to reduce erosion.
- Design and install watering facilities to prevent overturning by wind and animals.
- Nose pump sites must be chosen that have a low risk on contaminating surface or ground water.
- Water intake pipes shall be protected to prevent damage by livestock.
- Nose pump(s) will be protected from freezing by draining and storing under cover.

The following O&M activities will be planned and applied as needed:

- Repair damaged components as necessary.
- Install and maintain fences as needed to prevent livestock damage to the system and appurtenances.
- Maintain the area adjacent to the nose pump(s) in a stable, well-drained condition to prevent rutting, ponding and erosion from livestock use. Maintain surface treatment for livestock footing.
- During winter months, the nose pump and hose must be removed and placed under cover, drained of water, and stored out of reach of children.

Priming a Pump
Liquid and slurry pumps can lose prime and this will require the pump to be primed by adding liquid to the pump and inlet pipes to get the pump started. Loss of "prime" is usually due to ingestion of air into the pump. The clearances and displacement ratios in pumps used for liquids and other more viscous fluids cannot displace the air due to its lower density.



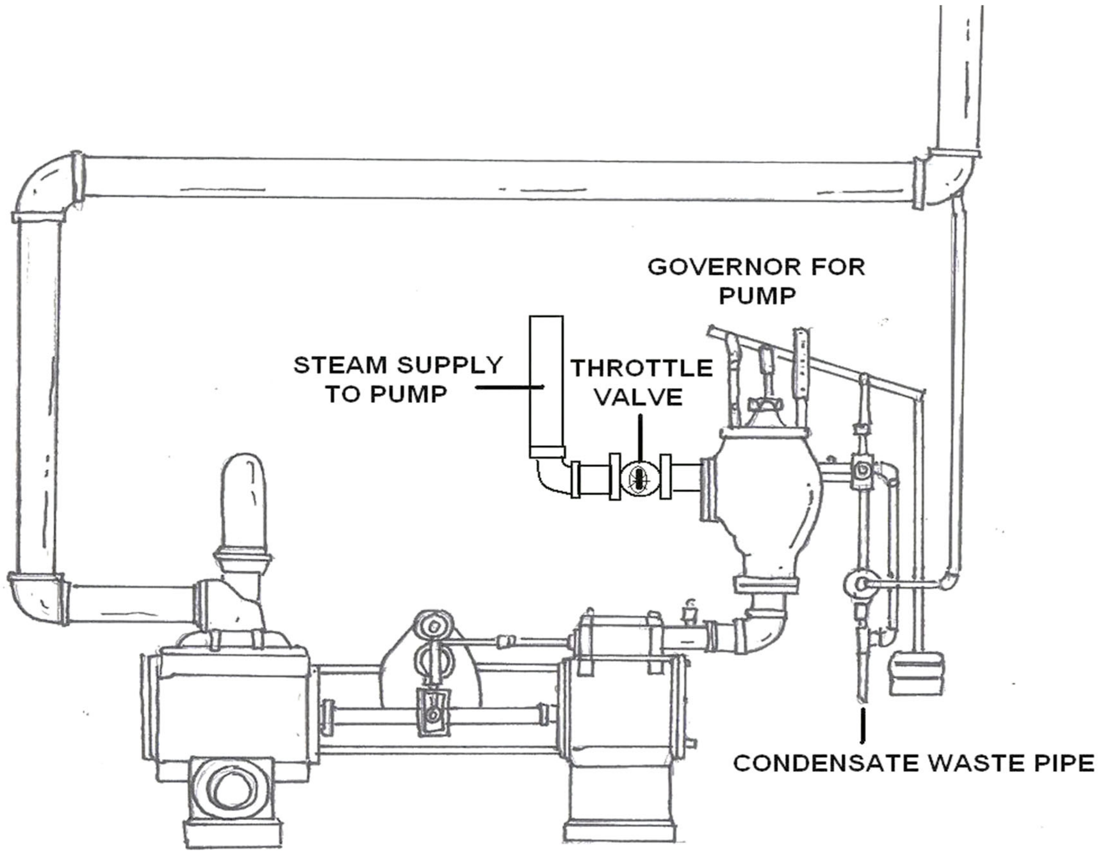
SLINGPUMP

Sling Pump

A sling pump is powered by flowing water or wind. It floats on top of the water and is anchored in the water. A water powered pump is driven by water flowing past the pump. This rotates the propellers and will pump 24 hr/day. A water flow velocity of 2 ft/sec is necessary. A wind powered sling pump is often used where there is little water flow such as in a pond. It sits on 2 pontoons for floatation, but is anchored. Power is moved from the propellers to a belt that rotates the pump. A holding is used to store water for use in low wind periods. The minimum depth of water required is 16 in. It will pump from 800 to 3,300 Imperial gallons per day. Floating debris such as leaves and branches can hinder the operation of a sling pump. Silt or sand can also plug water hoses.

The Sling Pump, with only one moving part, is a modern application of an Archimedes Snail Pump. A helical intake coil is wrapped around and around the inside surface of a cone. The coil is connected to an output tube via a water-lubricated swivel coupling at the extreme upstream side of the pump and is open at the downstream (fat) end. The downstream end of the cone has slats to let water in but keep debris out. A rope or pair of ropes holds it in place.

The pump floats partially submerged, being largely of plastic, with aluminum propeller blades and buoyant Styrofoam in the nose. With each revolution of the cone, the coil picks up air during the top portion of the cycle and water during the bottom portion. This causes a pulsed output, and also means the output water is highly oxygenated. The Rife Hydraulic Engine Mfg. Co., Inc. claims some models of their Sling Pumps (inset) can raise water over 80 feet high or move it a mile horizontally, from a stream moving at just 1.5 feet per second. (Head doesn't change with speed, only volume.) The unit weighs about 44 lbs. and uses a 1/2" hose.



STEAM PUMP DIAGRAM

Steam Pumps

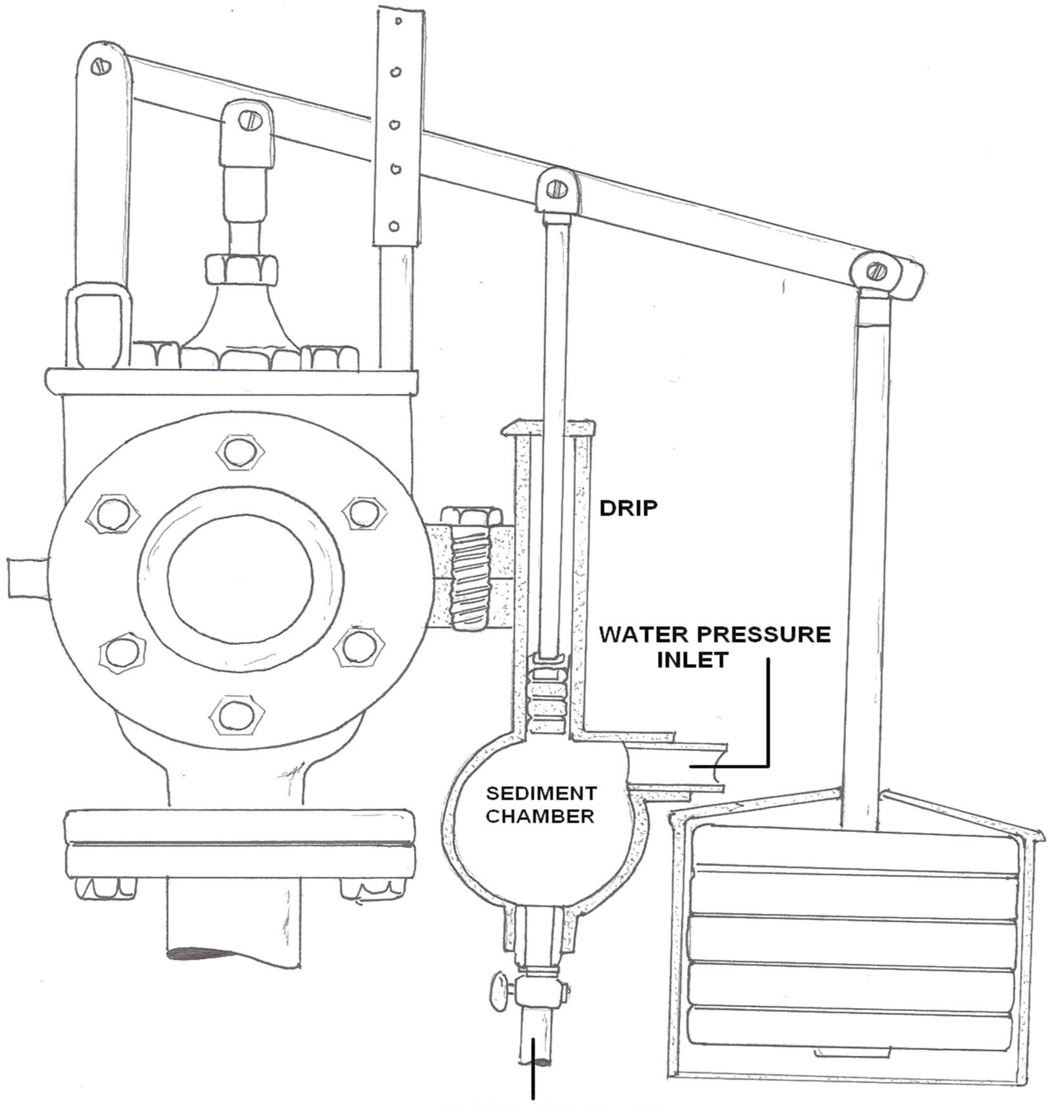
Steam pumps have been for a long time mainly of historical interest. They include any type of pump powered by a steam engine and also pistonless pumps such as Thomas Savery's, the Pulsometer steam pump or the Steam injection pump.

This extremely simple pump was made of cast iron, and had no pistons, rods, cylinders, cranks, or flywheels. It operated by the direct action of steam on water. The mechanism consisted of two chambers. As the steam condensed in one chamber, it acted as a suction pump, while in the other chamber, steam was introduced under pressure and so it acted as a force pump.

At the end of every stroke, a ball valve consisting of a small rubber ball moved slightly, causing the two chambers to swap functions from suction-pump to force-pump and vice versa. The result was that the water was first suction pumped and then force pumped. The pump ran automatically without attendance.

It was praised for its "extreme simplicity of construction, operation, compact form, high efficiency, economy, durability, and adaptability". Later designs were improved upon to enhance efficiency and to make the machine more accessible for inspection and repairs, thus reducing maintenance costs.

Recently there has been a resurgence of interest in low power solar steam pumps for use in smallholder irrigation in developing countries. Previously small steam engines have not been viable because of escalating inefficiencies as vapor engines decrease in size. However, the use of modern engineering materials coupled with alternative engine configurations has meant that these types of system are now a cost effective opportunity.



STEAM PUMP REGULATOR

Pump Definitions

Hyperlink to the Glossary and Appendix
http://www.abctlc.com/downloads/PDF/PumpGlossary.pdf

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

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

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

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

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

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

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

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

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

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

Kinetic energy: Energy associated with motion.

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

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

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

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

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

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

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

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

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

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

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

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

Score: To cause lines, grooves, or scratches.

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

Shaft sleeve: A replaceable tubular covering on the shaft.

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

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

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

Stages: Impellers in a multi-stage pump.

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

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

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

Suction: The place where fluid enters the pump.

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

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

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

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

Troubleshooting: Locating a problem.

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

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

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

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

Pumps and Pumping Water Section Post Quiz

Pump Definitions

1. What definition represents is a mechanical device that seals the pump stuffing box?

2. What definition represents is the energy associated with motion?

3. What definition represents is the fluid that leaks from the stuffing box?

Hydraulic Terms

4. Which of the following definitions is the engineering science pertaining to liquid pressure and flow?

5. Which of the following definitions is the engineering science pertaining to the energy of liquid flow and pressure?

6. Which of the following definitions is the pressure applied to a confined fluid at rest is transmitted with equal intensity throughout the fluid?

7. What definition represents is often used to indicate gauge pressure?

Pump Introduction

8. The key to understanding a pumps operation is that a pump is to move water and generate the ___________ we call pressure.

9. Pump operation like with a centrifugal pump — pressure is not referred to in pounds per square inch but rather as the equivalent in elevation, called?

10. According to the text, pumps may be classified on the basis of the application they serve.

A. True B. False

11. According to the text, all pumps may be divided into two major categories: (1) dynamic and (2)?

Understanding the Basic Water Pump

12. According to the text, the centrifugal pumps work by spinning water around in a circle inside a?

13. The pump makes the water spin by pulling it with an impeller.
A. True B. False

14. The blades of this impeller project inward from an axle like the arms of a turnstile and, as the impeller spins, the water moves through it.
A. True B. False

15. In a centrifugal pump, the water pressure at the edge of the turning impeller rises until it is able to keep water circling with the?

16. In a centrifugal pump, as water drifts outward between the ________________ of the pump, it must move faster and faster because its circular path is getting larger and larger.

17. As the water slows down and its kinetic energy decreases, that water's pressure potential energy increases.
A. True B. False

18. As the water spins, the pressure near the outer edge of the pump housing becomes much lower than near the center of the impeller.
A. True B. False

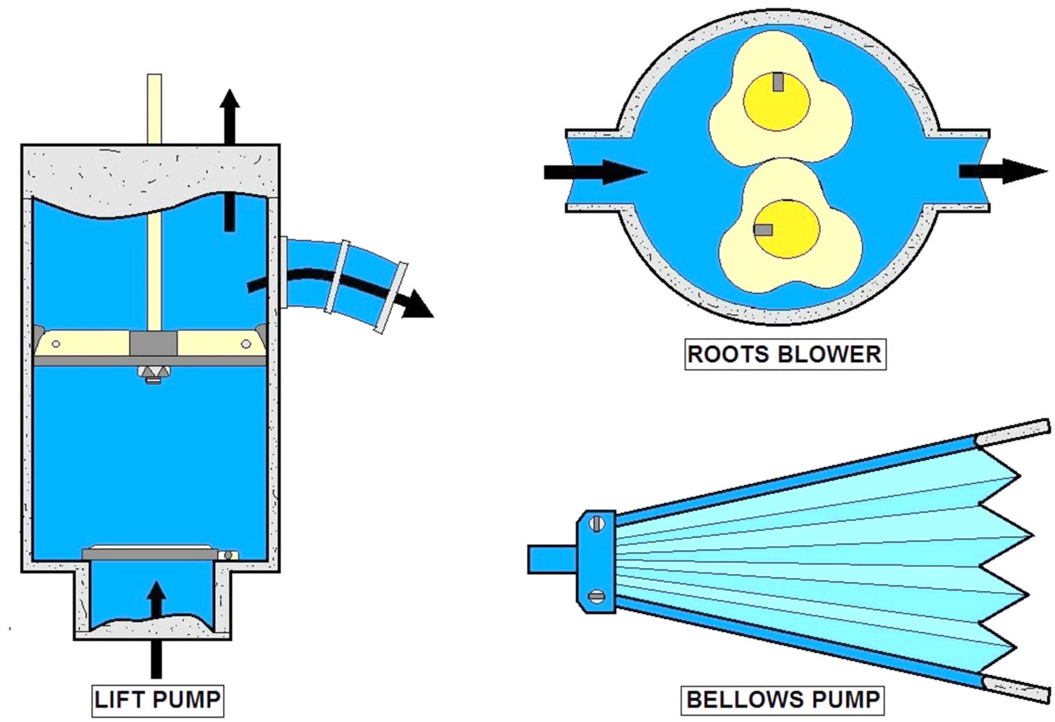
19. The impeller blades cause the water to move faster and faster.
A. True B. False

References are found in the nest section.
Answers: 1. Mechanical seal, 2. Kinetic energy, 3. Leak-off, 4. Hydraulics, 5. Hydrokinetics, 6. Pascal's Law, 7. Head, 8. Delivery force, 9. Head, 10. True, 11. Displacement, 12. Cylindrical pump housing, 13. False, 14. False, 15. Impeller blade(s), 16. Impeller blade(s), 17. True, 18. False, 19. True

Section 4 - Complicated Pump Section

Section Focus: You will learn the more about pumps, specifically, the complicated pumps. At the end of this section, you the student will be able to describe types of complicated based on application and capabilities with a focus upon the two major groups of pumps are dynamic and positive displacement. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: Pump engineers, well drillers and many water operators work daily on various complicated water, or sludge pumps. This section is a continuation of the prior section.



TYPES OF POSITIVE DISPLACEMENT PUMPS

The pump is a machine or mechanical equipment which is required to lift liquid from low level to high level or to flow liquid from low pressure area to high pressure area or as a booster in a piping network system.

Principally, pump converts mechanical energy of motor into fluid flow energy.

Pumps are used in process operations that requires a high hydraulic pressure. This can be seen in heavy duty equipment's. Often heavy duty equipment's requires a high discharge pressure and a low suction pressure. Due to low pressure at suction side of pump, fluid will lift from certain depth, whereas due to high pressure at discharge side of pump, it will push fluid to lift until reach desired height.

Classification of Pumps
Pump types generally fall into two main categories –

1. Dynamic (Centrifugal) Pumps
2. Positive Displacement 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.

Differences between the Dynamic and Positive Displacement Pumps

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

Hyperlink to the Glossary and Appendix
http://www.abctlc.com/downloads/PDF/PumpGlossary.pdf

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.

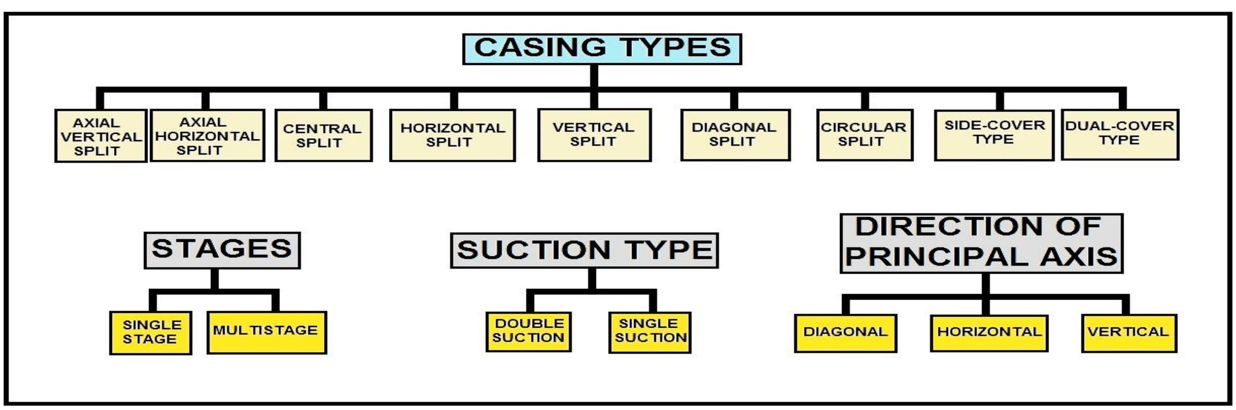
Plunger Pump
The plunger pump is a positive displacement pump that uses a plunger or piston to force liquid from the suction side to the discharge side of the pump. It is used for heavy sludge. The movement of the plunger or piston inside the pump creates pressure inside the pump, so you have to be careful 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 CONFIGURATIONS

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.

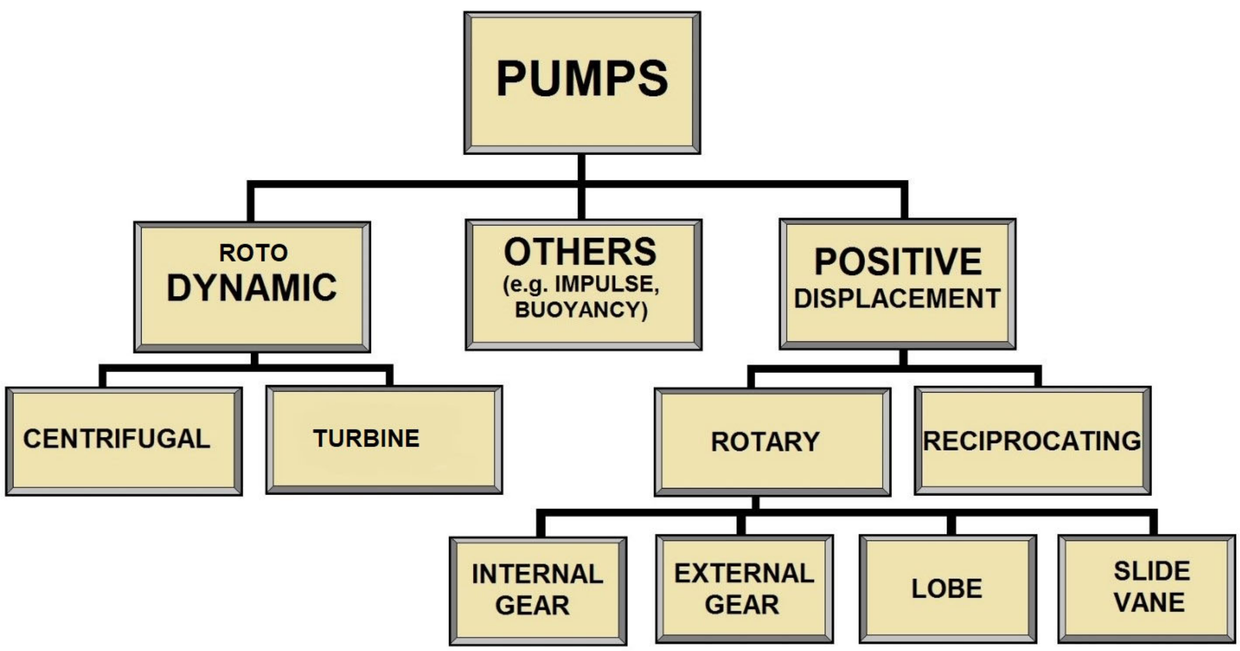
From time to time— with centrifugal pumps in particular — pressure is not referred to in pounds per square inch but rather as the equivalent in elevation, called "head".

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.



PUMP CATEGORIES

Complicated Pumps - Introduction

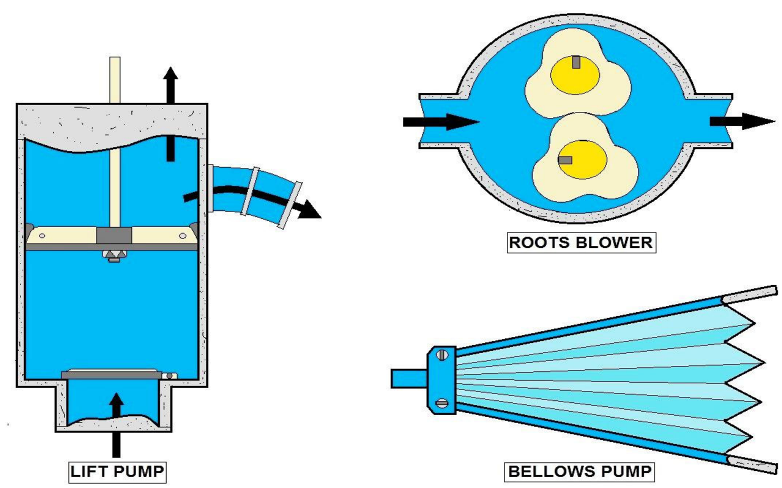
More complicated pumps have valves allowing them to work repetitively. These are usually check valves that open to allow passage in one direction, and close automatically to prevent reverse flow. There are many kinds of valves, and they are usually the most trouble-prone and complicated part of a pump. 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 firefighting. Fire fighting force pumps usually have two cylinders feeding one receiver alternately. The air space in the receiver helps to make the water pressure uniform.



POSITIVE DISPLACEMENT PUMP TYPES

The three pumps above 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 (Rotary Lobe) 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.

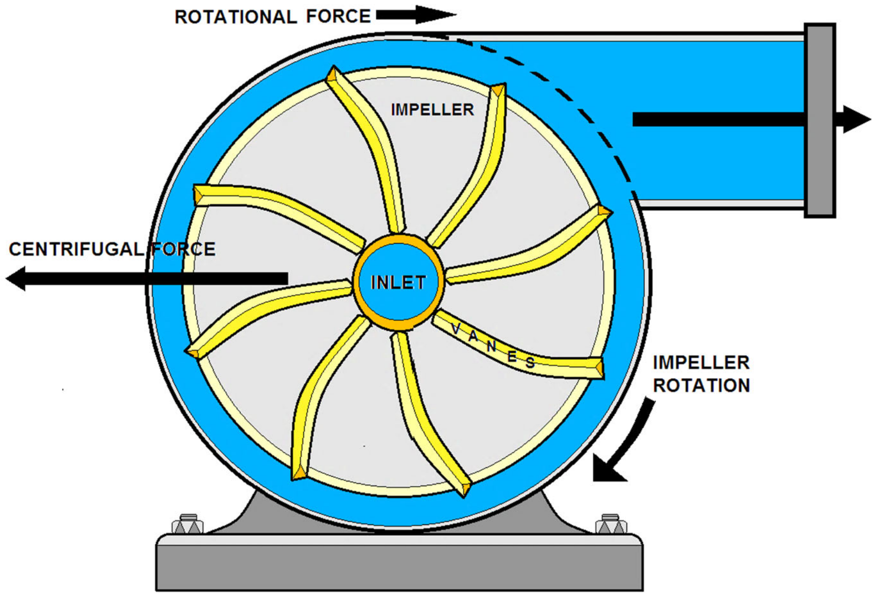
Fluid Properties
The properties of the fluids being pumped can significantly affect the choice of pump.

Key considerations include:
• **Acidity/alkalinity (pH) and chemical composition.** Corrosive and acidic fluids can degrade pumps, and should be considered when selecting pump materials.
• **Operating temperature.** Pump materials and expansion, mechanical seal components, and packing materials need to be considered with pumped fluids that are hotter than 200°F.
• **Solids concentrations/particle sizes.** When pumping abrasive liquids such as industrial slurries, selecting a pump that will not clog or fail prematurely depends on particle size, hardness, and the volumetric percentage of solids.
• **Specific gravity.** The fluid specific gravity is the ratio of the fluid density to that of water under specified conditions. Specific gravity affects the energy required to lift and move the fluid, and must be considered when determining pump power requirements.
• **Vapor pressure.** A fluid’s vapor pressure is the force per unit area that a fluid exerts in an effort to change phase from a liquid to a vapor, and depends on the fluid’s chemical and physical properties. Proper consideration of the fluid’s vapor pressure will help to minimize the risk of cavitation.
• **Viscosity.** The viscosity of a fluid is a measure of its resistance to motion. Since kinematic viscosity normally varies directly with temperature, the pumping system designer must know the viscosity of the fluid at the lowest anticipated pumping temperature. High viscosity fluids result in reduced centrifugal pump performance and increased power requirements. It is particularly important to consider pump suction-side line losses when pumping viscous fluids.

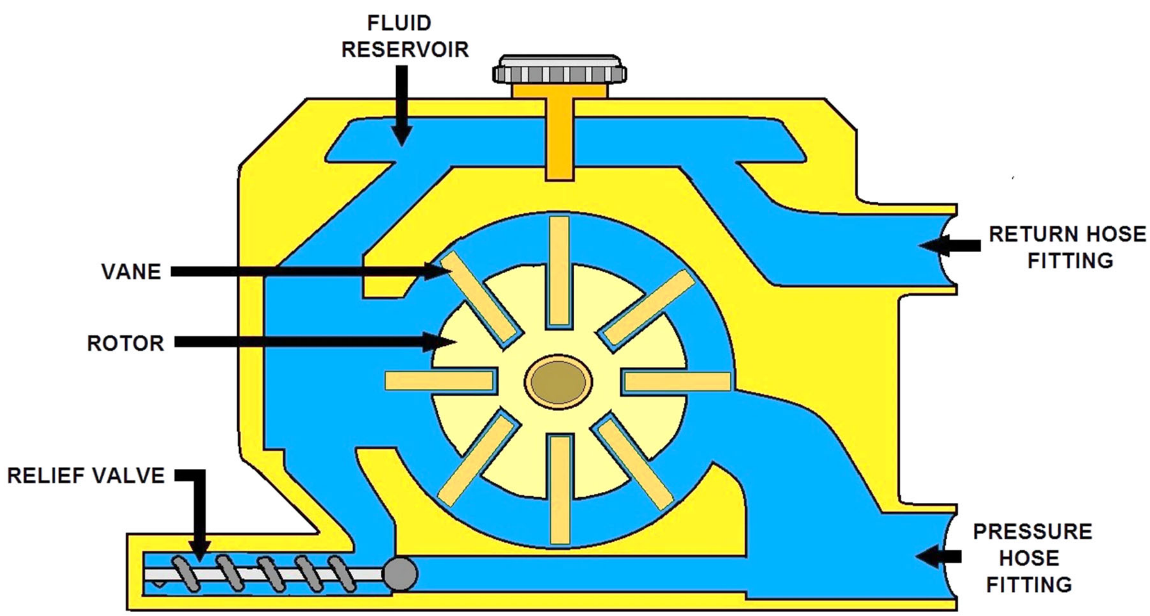
Environmental Considerations
Important environmental considerations include ambient temperature and humidity, elevation above sea level, and whether the pump is to be installed indoors or outdoors.

Software Tools
Most pump manufacturers have developed software or Web-based tools to assist in the pump selection process. Pump purchasers enter their fluid properties and system requirements to obtain a listing of suitable pumps. Software tools that allow you to evaluate and compare operating costs are available from private vendors.

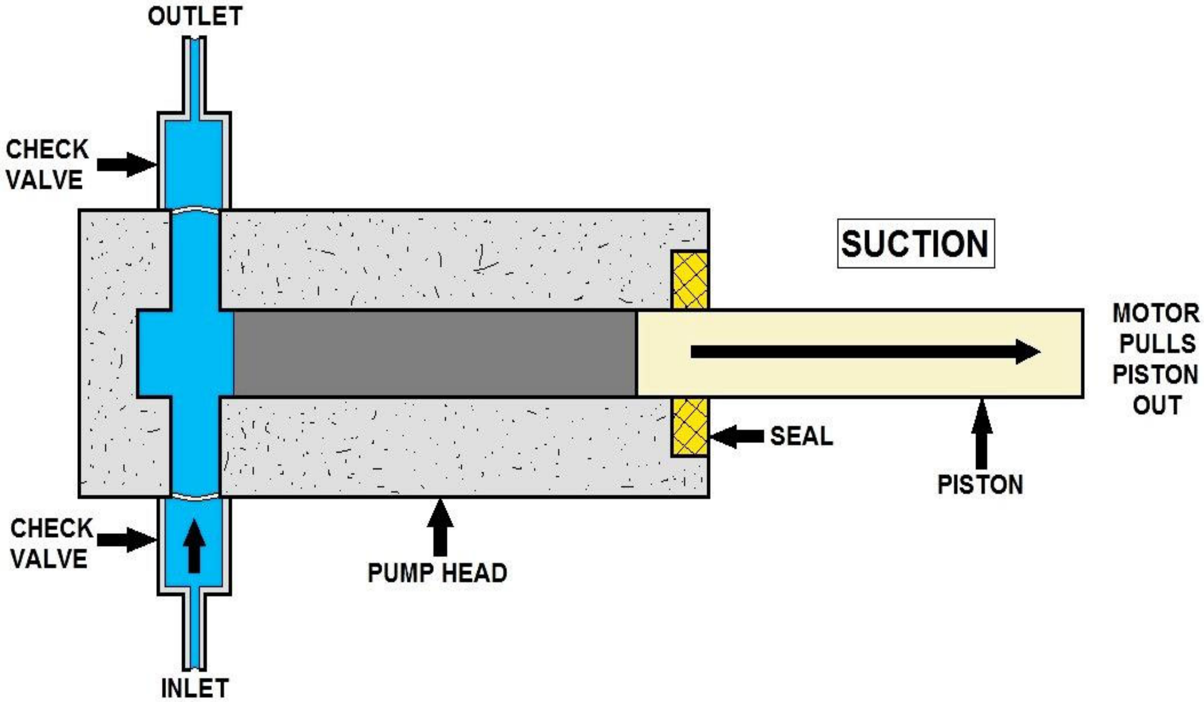
Complicated Pump Diagrams

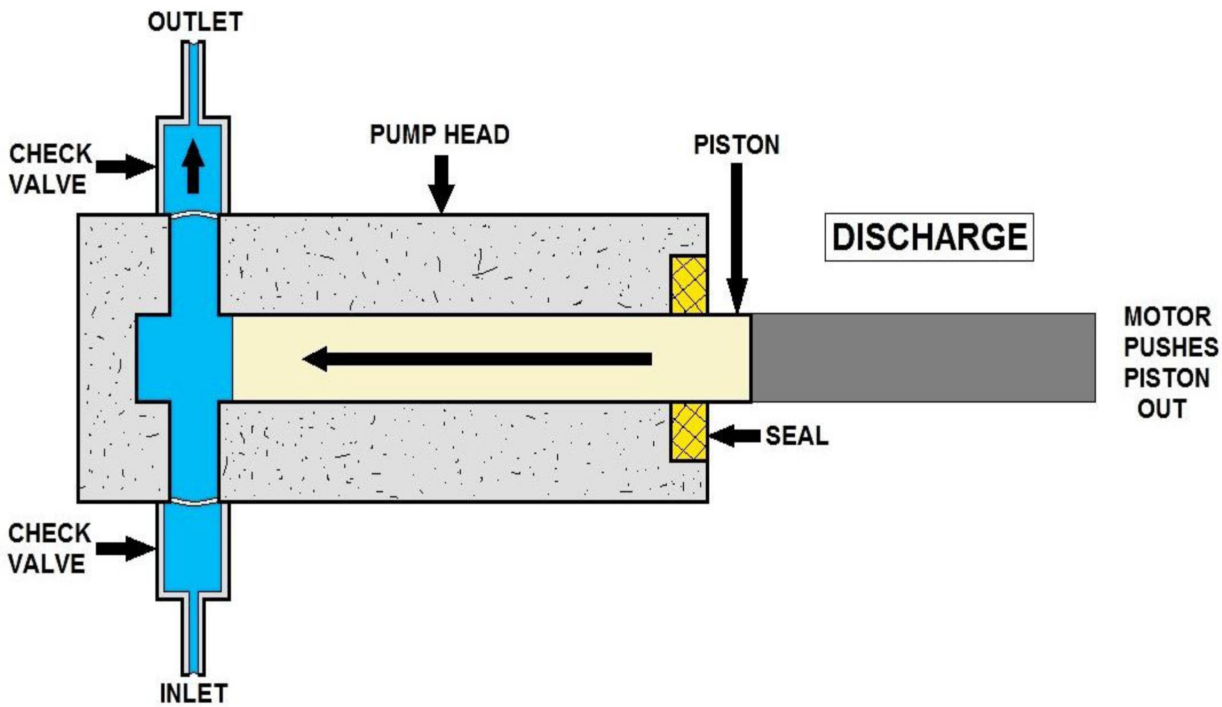


BASIC PUMP IMPELLER DIAGRAM

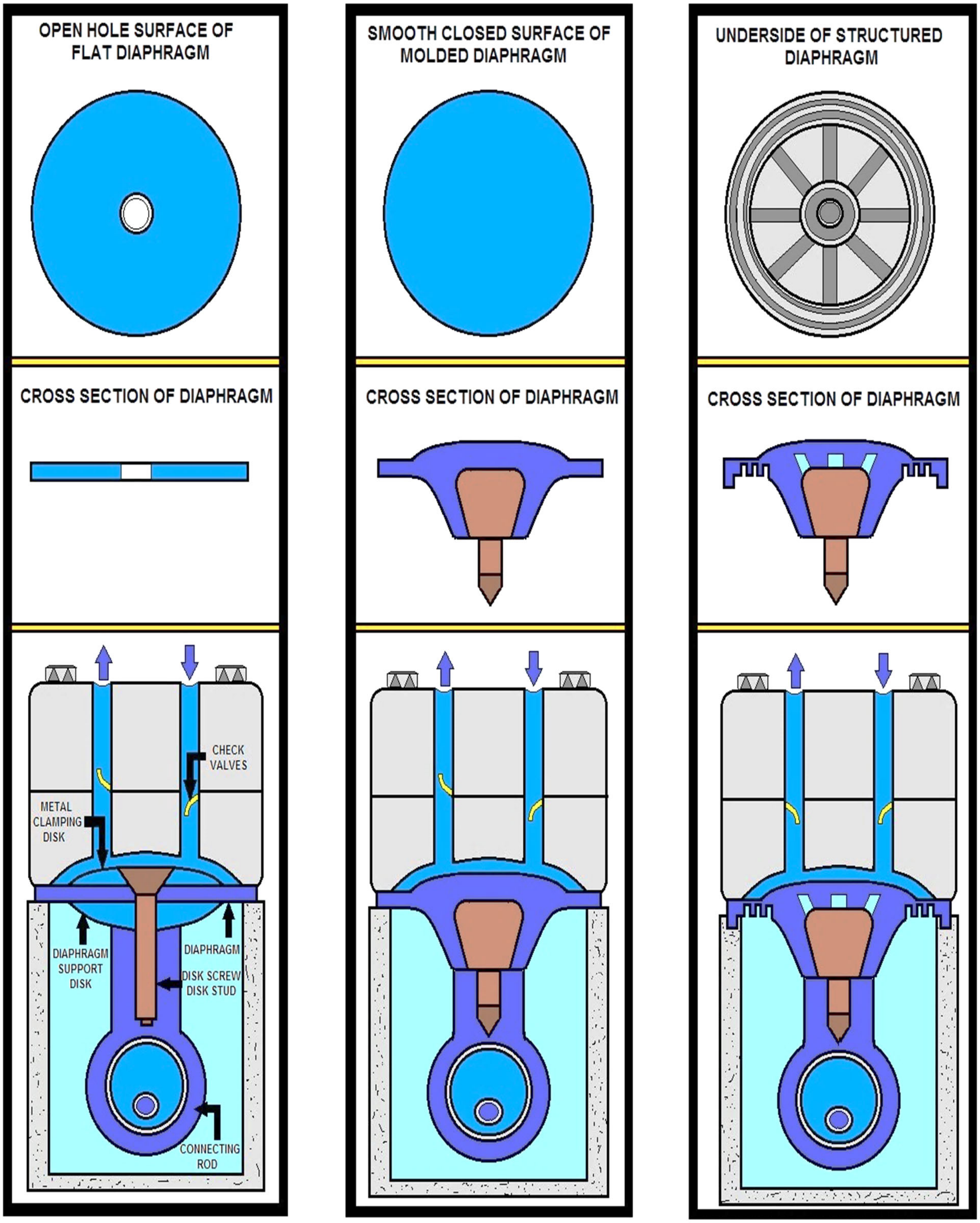


FLEX VANE PUMP DIAGRAM

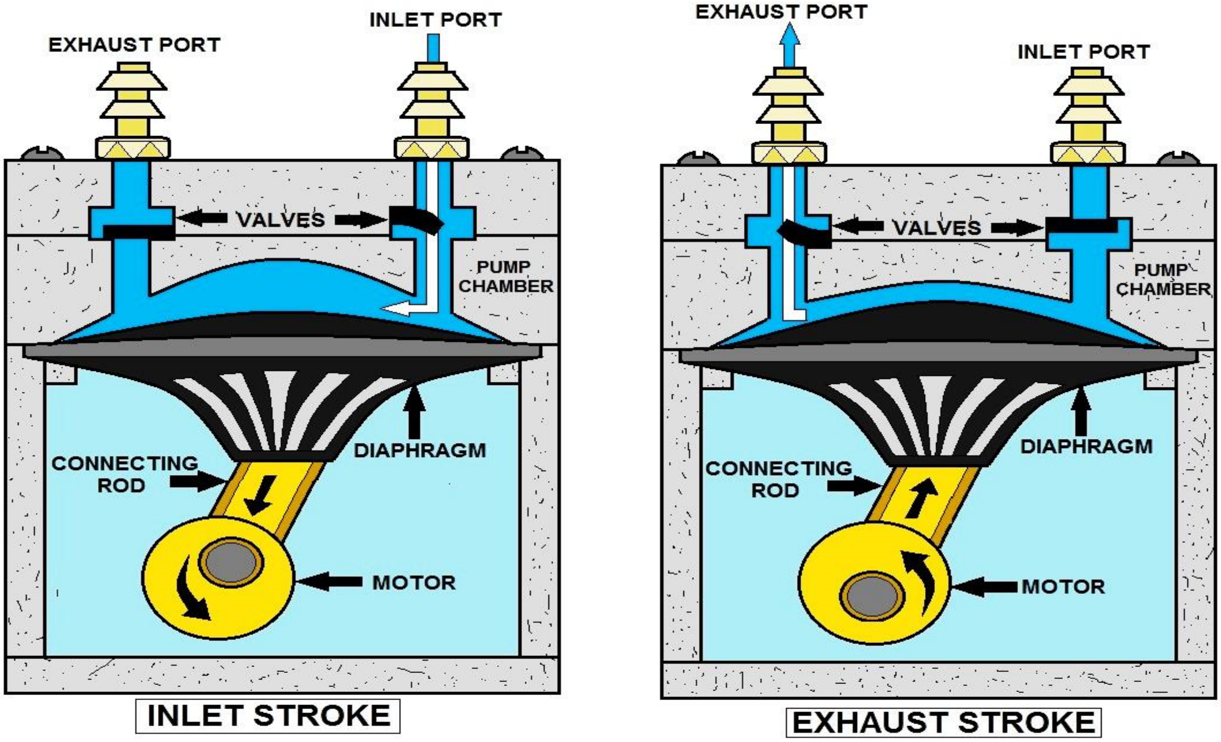




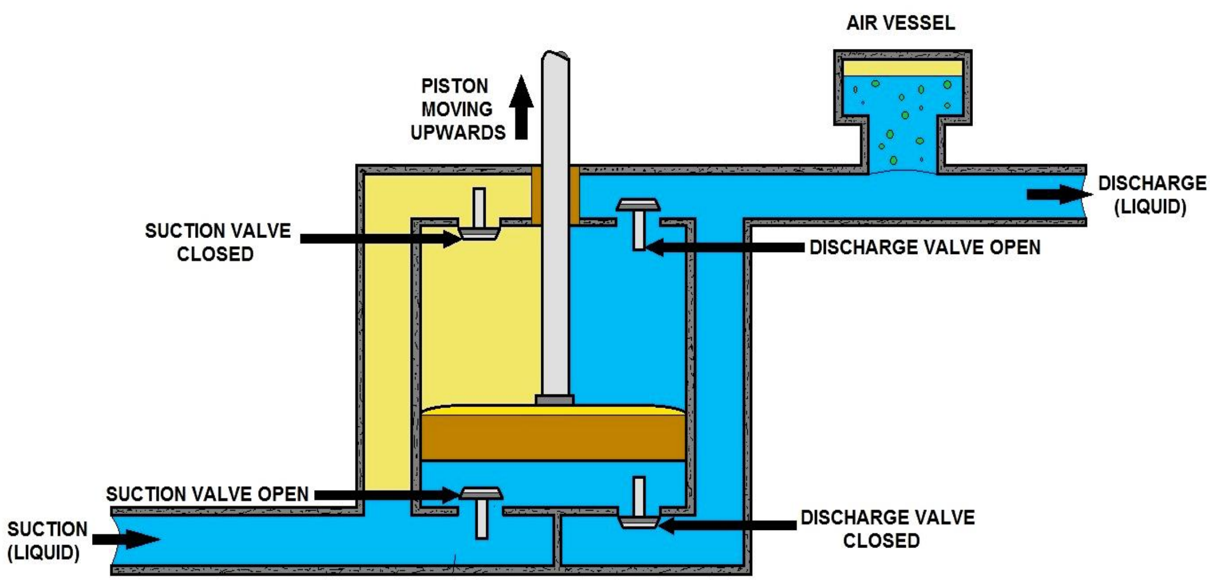
**POSITIVE DISPLACEMENT PUMP DIAGRAM
RECIPROCATING TYPE**



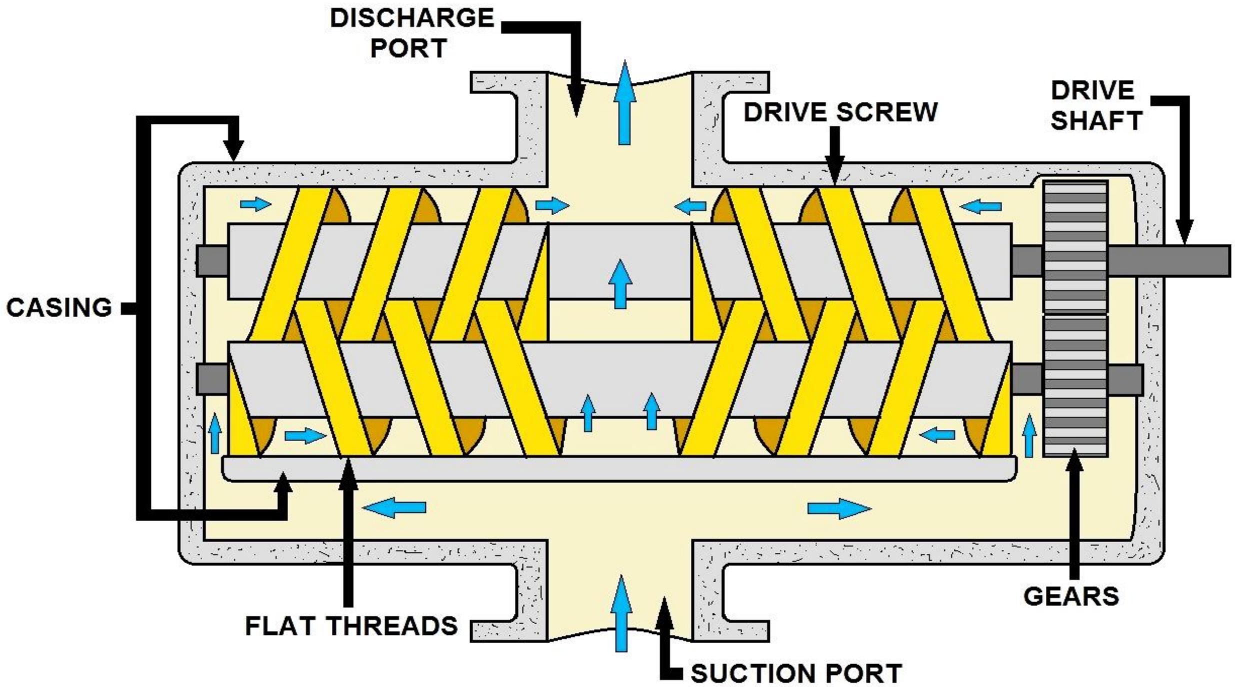
TYPES OF DIAPHRAGM PUMPS



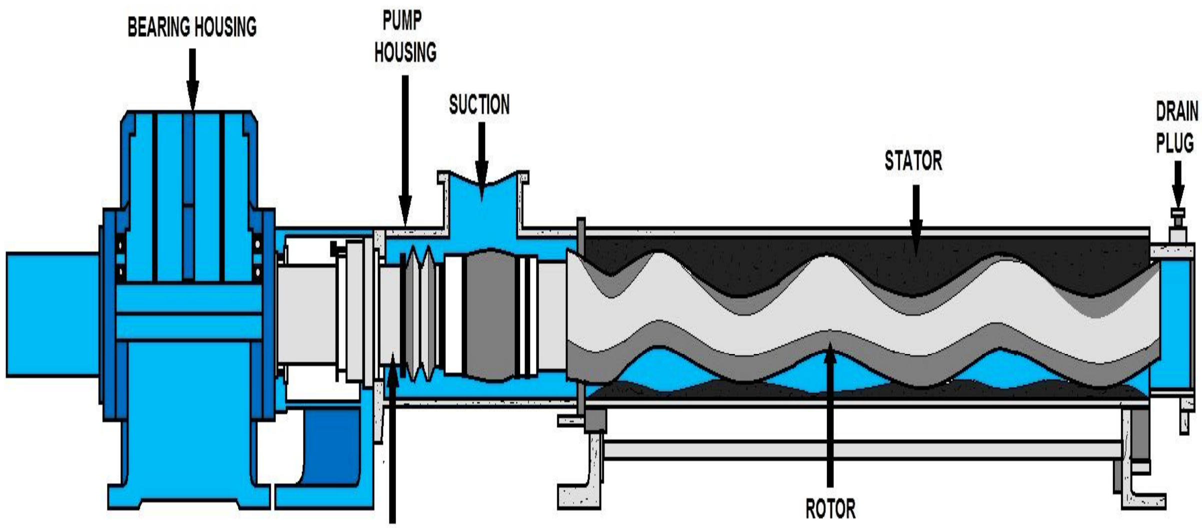
HOW A FLUID HANDLING DIAPHRAGM PUMP WORKS



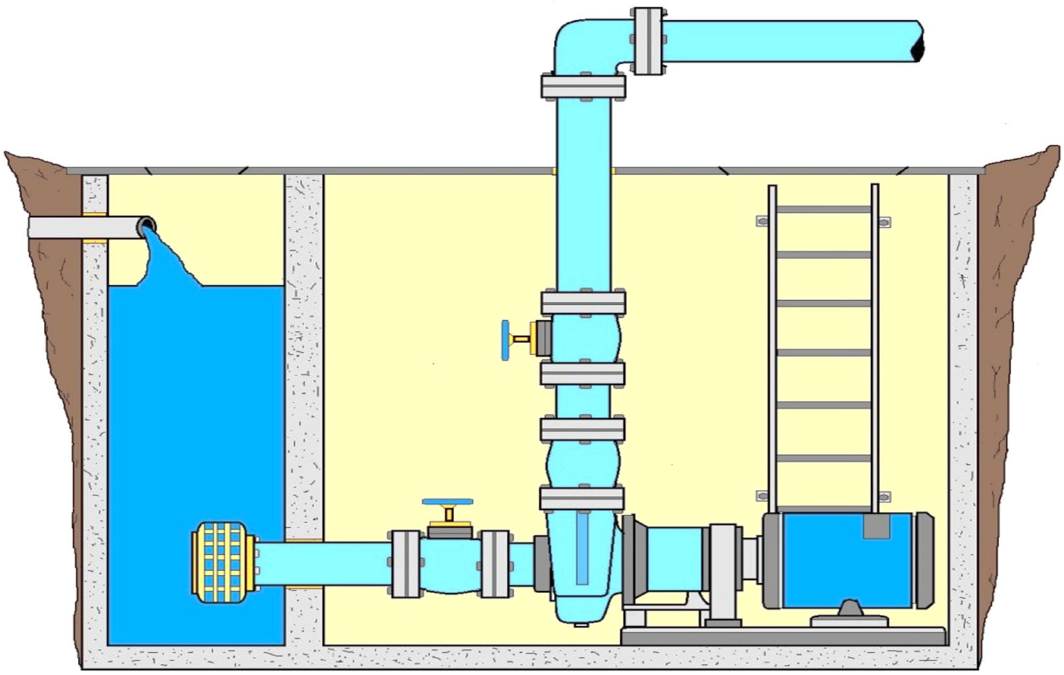
POSITIVE DISPLACEMENT PUMP
RECIPROCATING PISTON TYPE



POSITIVE DISPLACEMENT PUMP
SCREW TYPE

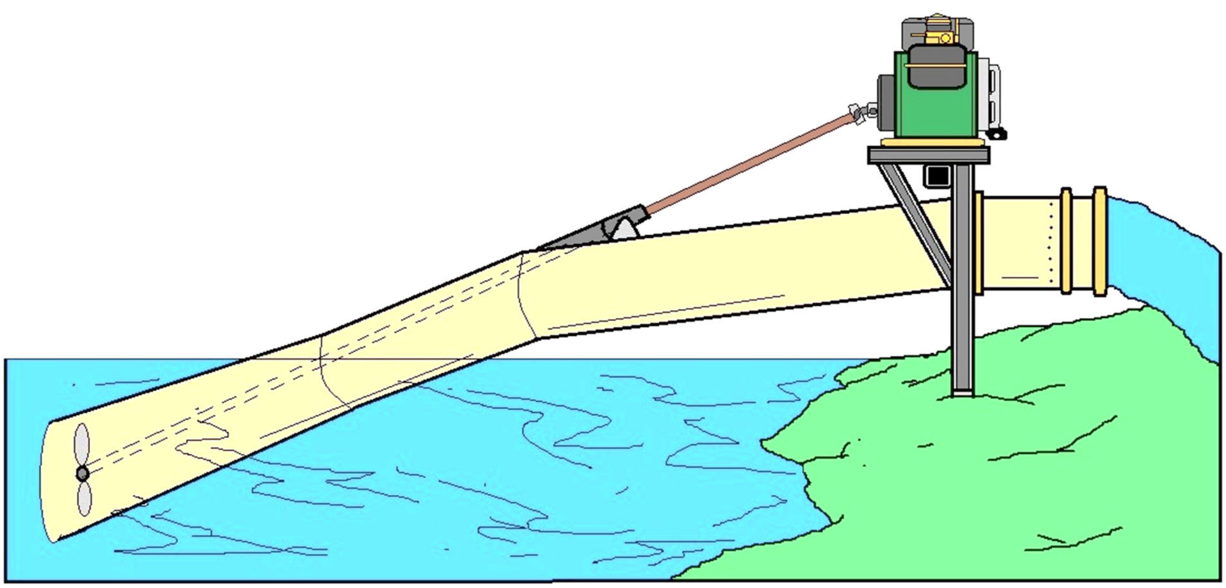


POSITIVE DISPLACEMENT PUMP
PROGRESSIVE CAVITY TYPE



CLOSED COUPLED CENTRIFUGAL PUMP

Viscous Drag Pump
A pump whose impeller has no vanes but relies on fluid contact with a flat rotating plate turning at high speed to move the liquid.

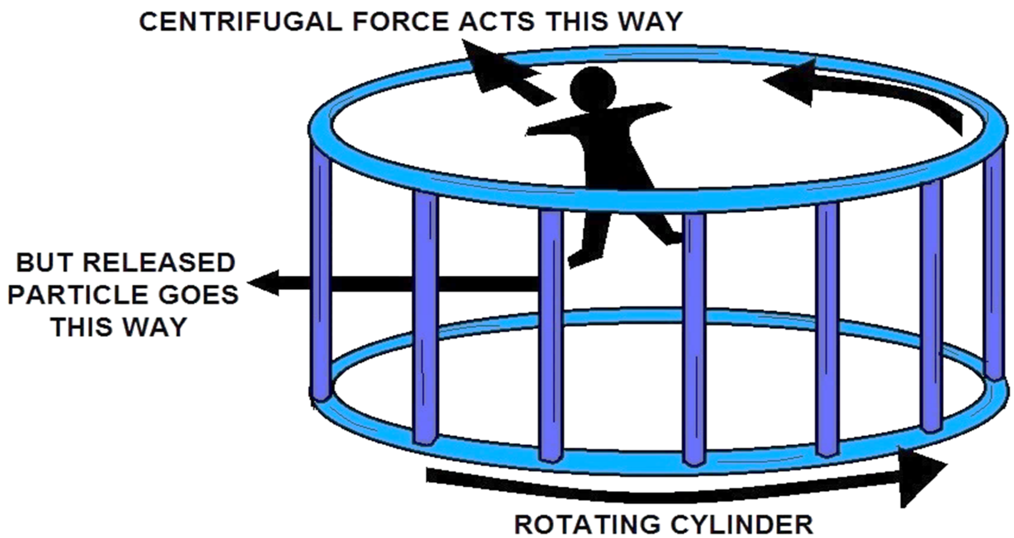


SIMPLE PROPELLER PUMP

The Basic Water Pump –Pump Operation

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

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



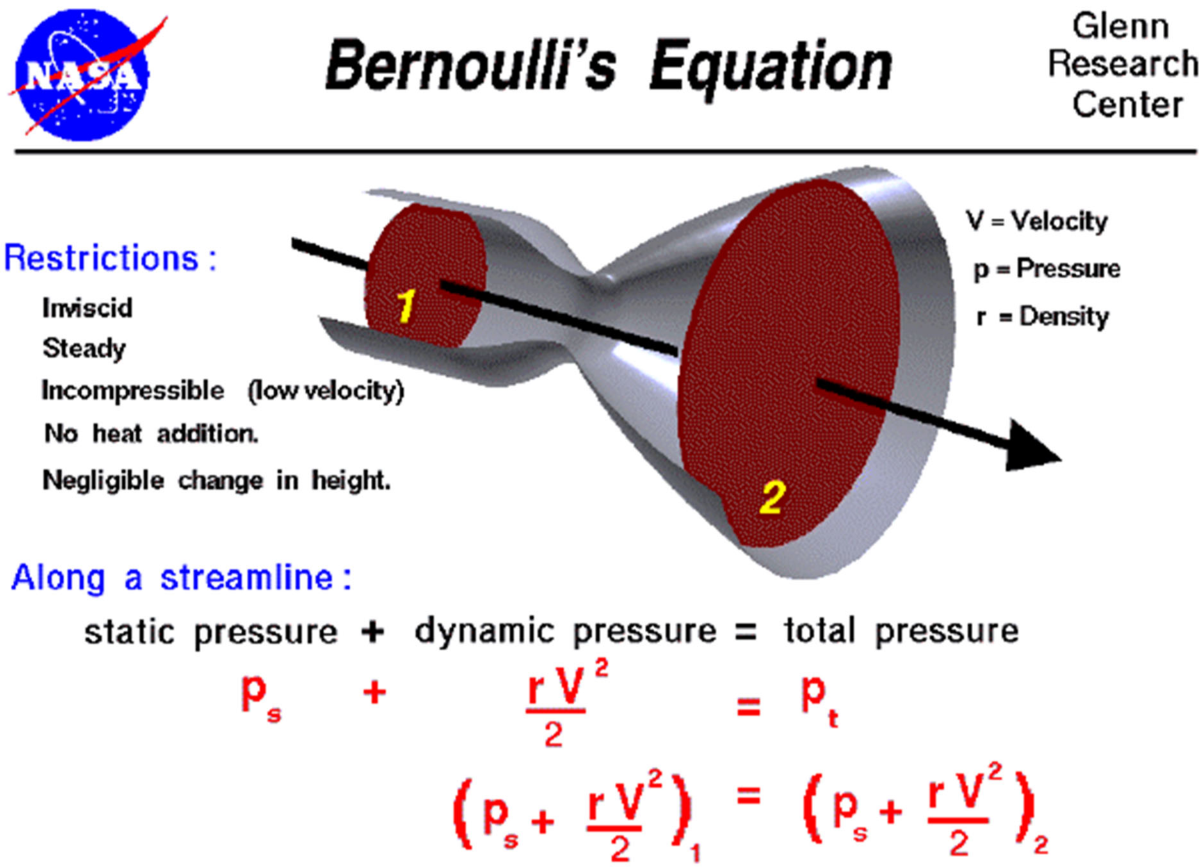
CENTRIFUGAL PUMPING ACTION – WATER EFFECTS

First, you can view the water between the impeller blades as an object traveling in a circle. Objects do not naturally travel in a circle--they need an inward force to cause them to accelerate inward as they spin.

Without such an inward force, an object will travel in a straight line and will not complete the circle. In a centrifugal pump, that inward force is provided by high-pressure water near the outer edge of the pump housing. The water at the edge of the pump pushes inward on the water between the impeller blades and makes it possible for that water to travel in a circle. The water pressure at the edge of the turning impeller rises until it is able to keep water circling with the impeller blades.

You can also view the water as an incompressible fluid, one that obeys Bernoulli's equation in the appropriate contexts. As water drifts outward between the impeller blades of the pump, it must move faster and faster because its circular path is getting larger and larger. The impeller blades cause the water to move faster and faster.

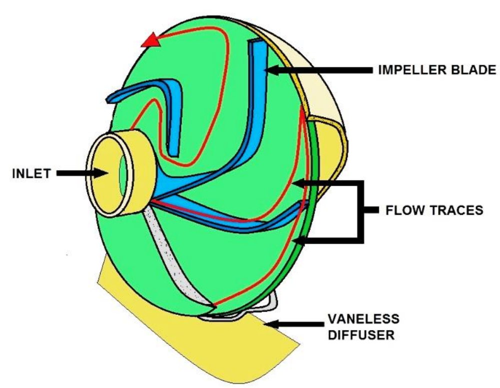
By the time the water has reached the outer edge of the impeller, it is moving quite fast. However, when the water leaves the impeller and arrives at the outer edge of the cylindrical pump housing, it slows down.



Here is where Bernoulli's equation figures in. As the water slows down and its kinetic energy decreases, that water's pressure potential energy increases (***to conserve energy***). Thus, the slowing is accompanied by a pressure rise.

That is why the water pressure at the outer edge of the pump housing is higher than the water pressure near the center of the impeller.

When water is actively flowing through the pump, arriving through a hole near the center of the impeller and leaving through a hole near the outer edge of the pump housing, the pressure rise between center and edge of the pump is not as large.



COMMON PUMP IMPELLER

Key Pump Words

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

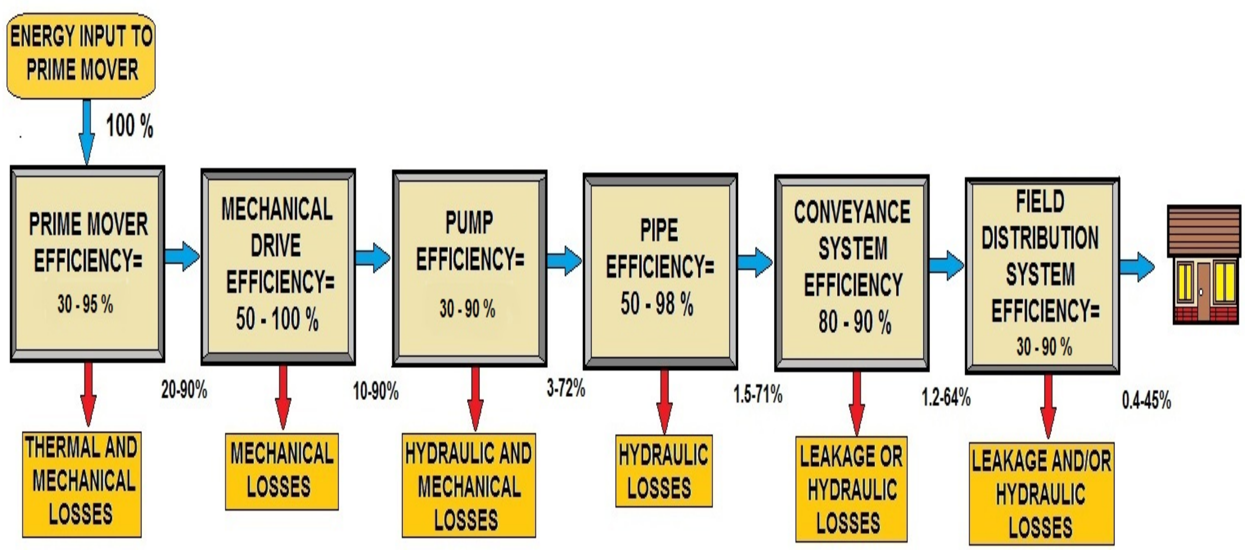
S.G.: Specific gravity. The weight of liquid in comparison to water at approx. 20 degrees C (SG = 1).

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

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

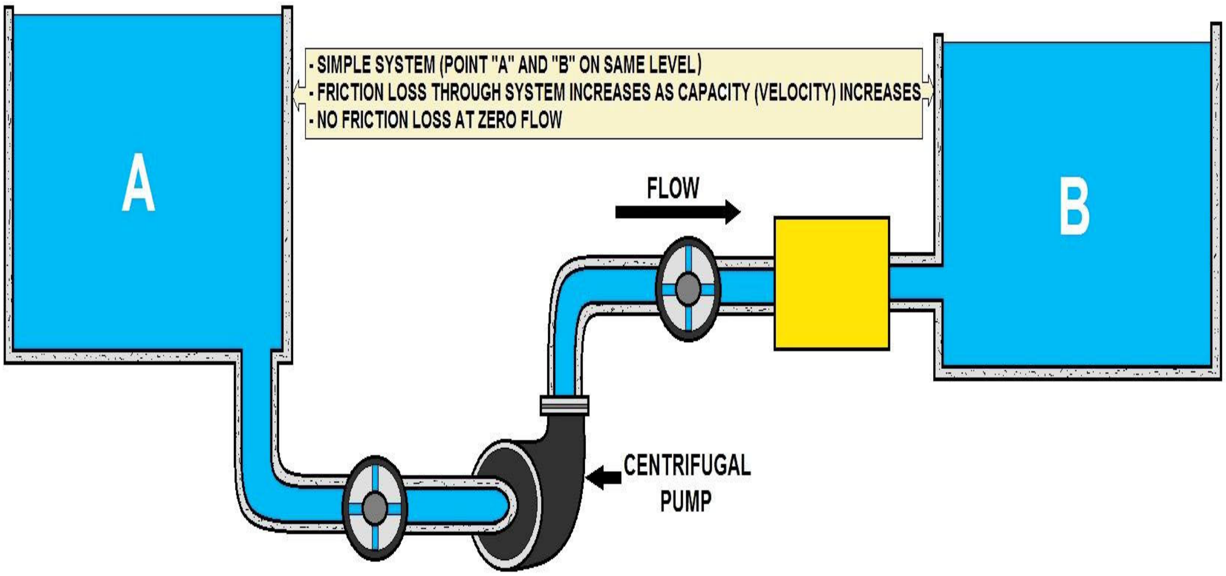
Viscosity: A measure of a liquid's resistance to flow. i.e.: how thick it is. The viscosity determines the type of pump used, the speed it can run at, and with gear pumps, the internal clearances required.

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

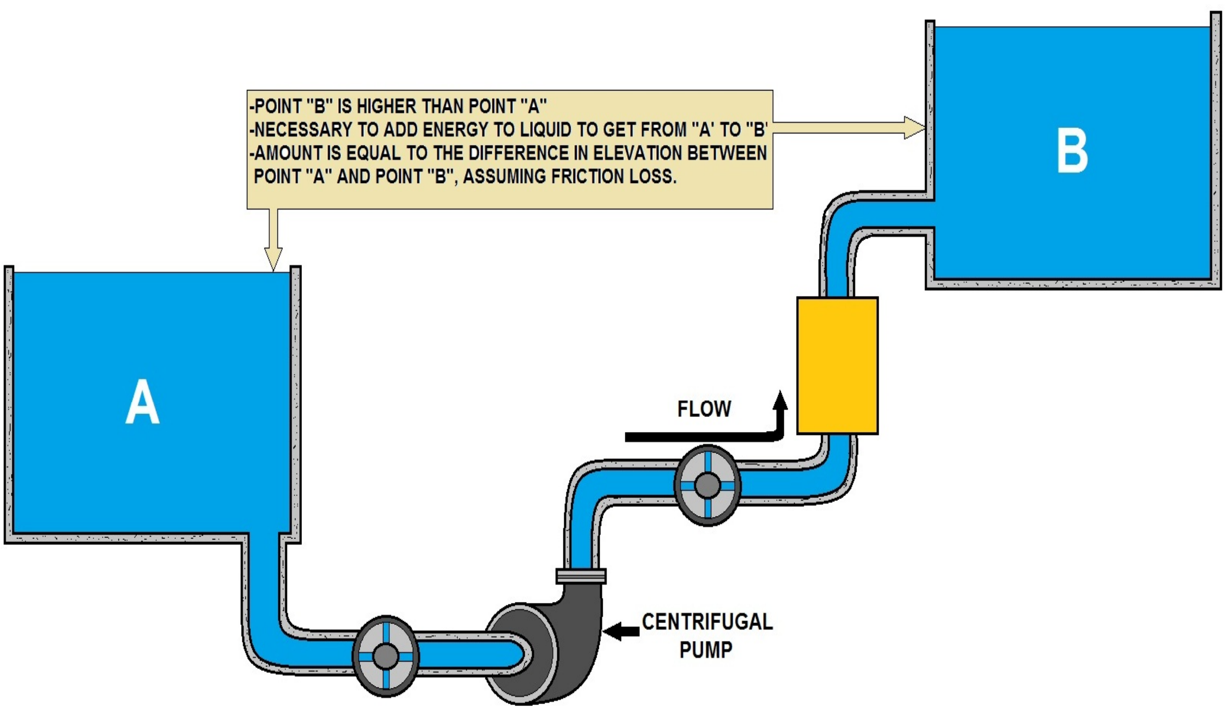


SYSTEM ENERGY EFFICIENCY LOSSES DIAGRAM

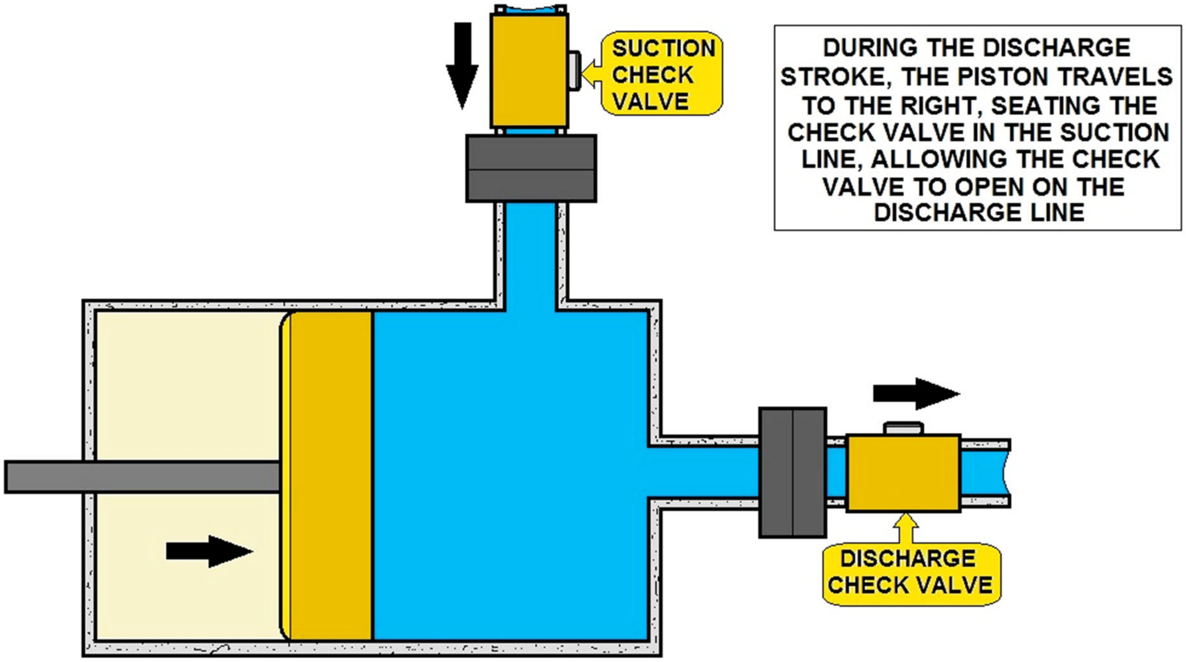
Hyperlink to the Glossary and Appendix
http://www.abctlc.com/downloads/PDF/PumpGlossary.pdf



CENTRIFUGAL PUMP CURVE CHARACTERISITICS



CENTRIFUGAL PUMP CURVE CHARACTERISITICS



PISTON TYPE –POSITIVE DISPLACEMENT PUMP

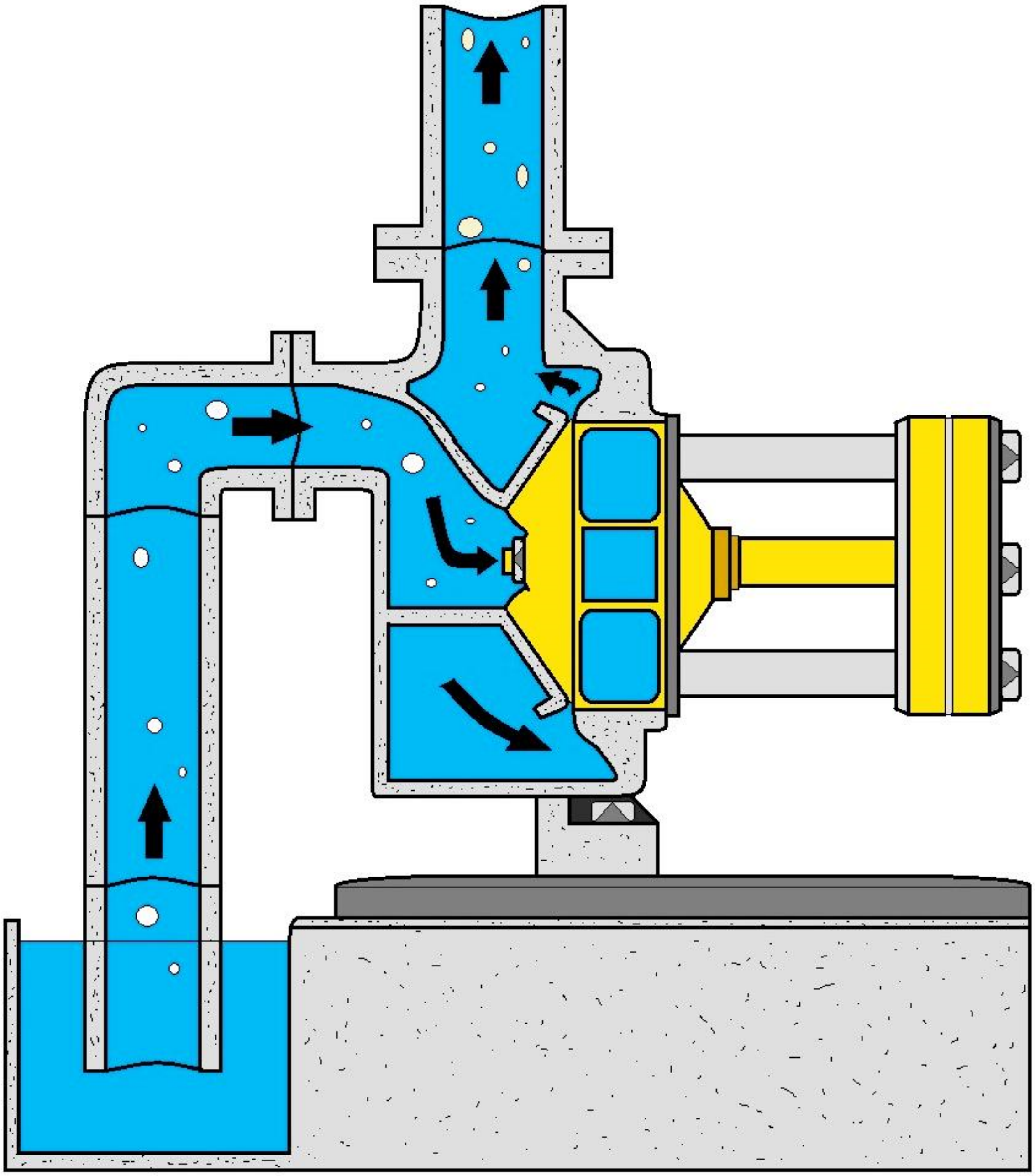
Pumping Operation

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.



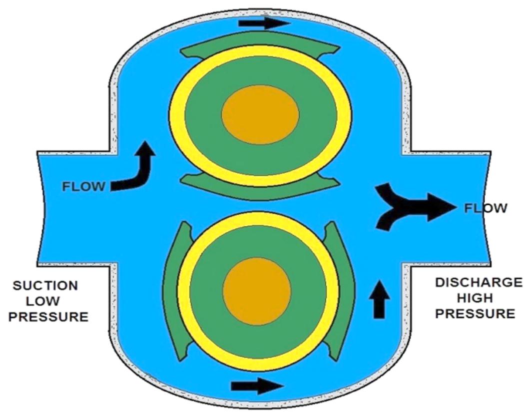
PUMP PRIMING DIAGRAM

Self-Priming Pump
A pump that does not require priming or initial filling with liquid. The pump casing carries a reserve of water that helps create a vacuum that will lift the fluid from a low source.

Positive Displacement Pump Sub-Section

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

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



POSITIVE DISPLACEMENT PUMP WITH ROTATING LOBES

Types of Positive Displacement Pumps

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

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

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

Single Rotator Positive Displacement Pump

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

Multiple Rotator

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

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

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

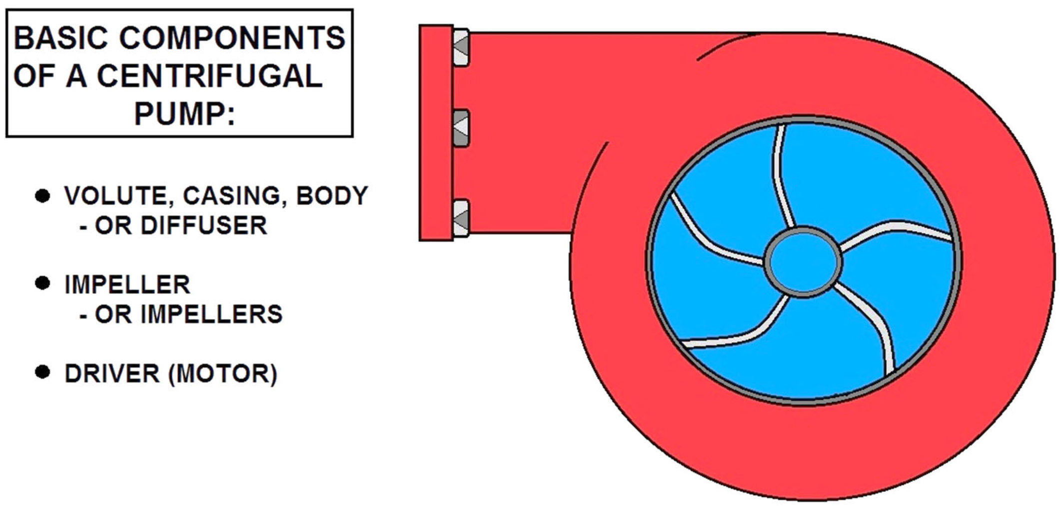
There are three main types of diaphragm pumps available:
1. Diaphragm sludge pump
2. Chemical metering or proportional pump
3. Air-powered double-diaphragm pump

Centrifugal Pump Sub-Section

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



BASICS OF A CENTRIFUGAL PUMP

As a standard, 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 opened or closed. 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.

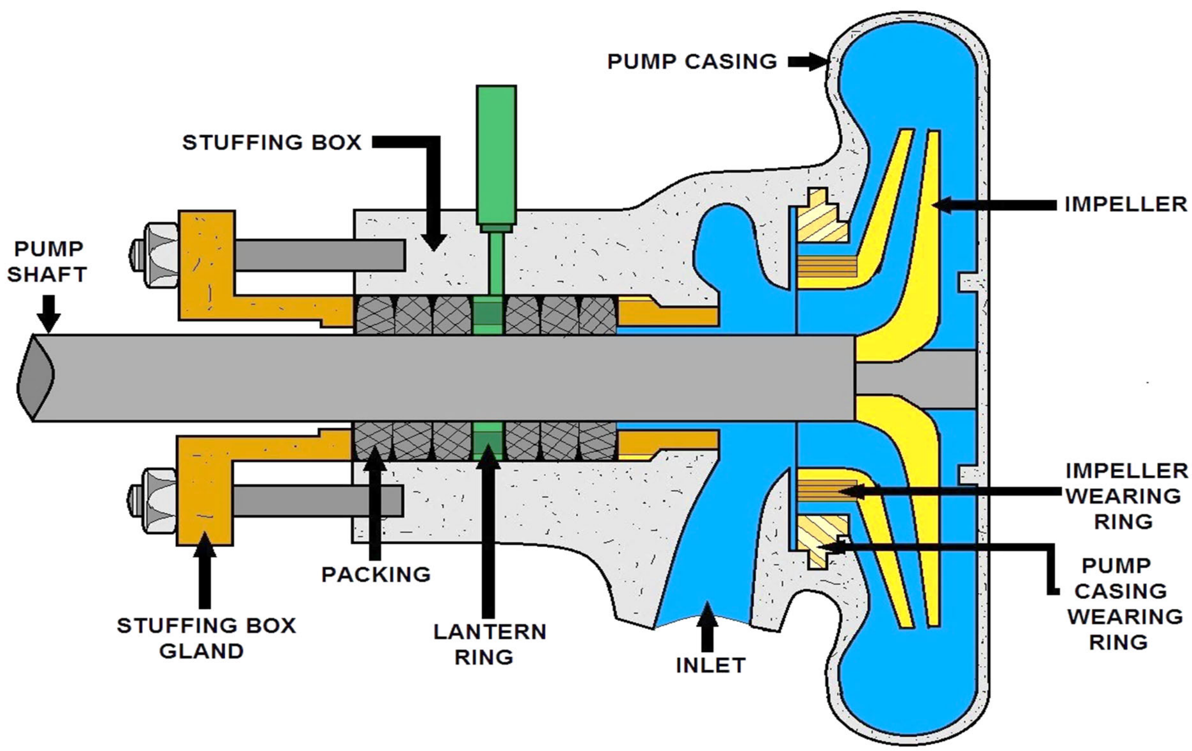
Recirculation lines are installed on some centrifugal pumps to prevent the pumps from overheating and becoming vapor bound, in case the discharge is entirely shut off or the flow of fluid is stopped for extended periods.

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).

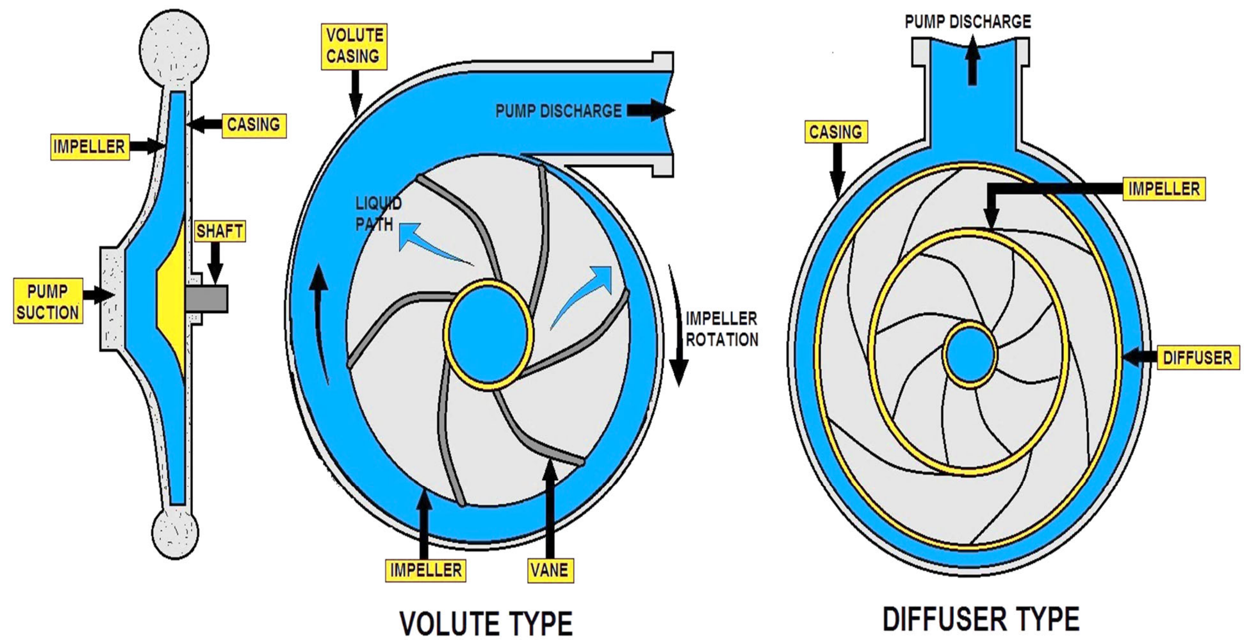
Water flinger rings may be fitted on the shaft between the packing gland and the pump bearing housing. These flingers prevent water in the stuffing box from flowing along the shaft and entering the bearing housing.

Let's Look at the Components of the Centrifugal Pump...

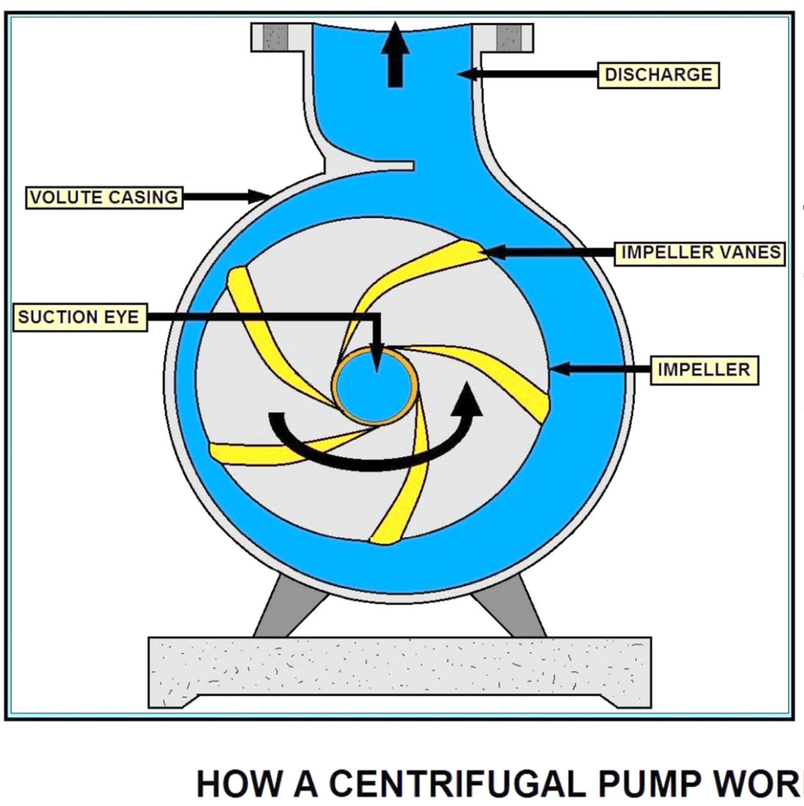


CENTRIFUGAL PUMP CUT-AWAY DIAGRAM #1

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



TYPES OF CENTRIFUGAL PUMPS



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

HOW A CENTRIFUGAL PUMP WORKS

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!

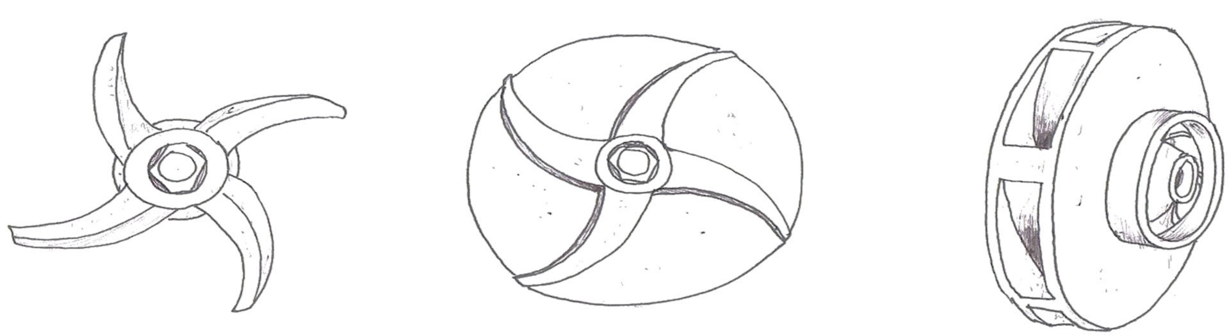
Impellers are designed in various ways. We will look at:

- 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.



OPEN SEMI-OPEN CLOSED

More on Centrifugal or Roto-Dynamic Pump

The centrifugal or roto-dynamic pump produce a head and a flow by increasing the velocity of the liquid through the machine with the help of a rotating vane impeller. Centrifugal pumps include radial, axial and mixed flow units.

Centrifugal Pumps Can Further be Classified As...

- ✓ end suction pumps
- ✓ in-line pumps
- ✓ double suction pumps
- ✓ vertical multistage pumps
- ✓ horizontal multistage pumps
- ✓ submersible pumps
- ✓ self-priming pumps
- ✓ axial-flow pumps
- ✓ regenerative pumps

The fact of the matter is that there are three types of problems mostly encountered with centrifugal pumps:

- ✓ design errors
- ✓ poor operation
- ✓ poor maintenance practices

Working Mechanism of a Centrifugal Pump

A centrifugal pump is one of the simplest pieces of equipment in any process plant. Its purpose is to convert energy of a prime mover (an electric motor or turbine) first into velocity or kinetic energy and then into pressure energy of a fluid that is being pumped.

The energy changes occur by virtue of two main parts of the pump, the impeller and the volute or diffuser. The impeller is the rotating part that converts driver energy into the kinetic energy. The volute or diffuser is the stationary part that converts the kinetic energy into pressure energy.

Note: All of the forms of energy involved in a liquid flow system are expressed in terms of feet of liquid i.e. head.

Generation of Centrifugal Force

The process liquid enters the suction nozzle and then into eye (center) of a revolving device known as an impeller. When the impeller rotates, it spins the liquid sitting in the cavities between the vanes outward and provides centrifugal acceleration.

As liquid leaves the eye of the impeller a low-pressure area is created causing more liquid to flow toward the inlet. Because the impeller blades are curved, the fluid is pushed in a tangential and radial direction by the centrifugal force. This force acting inside the pump is the same one that keeps water inside a bucket that is rotating at the end of a string.

Selecting between Centrifugal or Positive Displacement Pumps

Selecting between a Centrifugal Pump or a Positive Displacement Pump is not always straight forward.

Flow Rate and Pressure Head
The two types of pumps behave very differently regarding pressure head and flow rate: The centrifugal pump has varying flow depending on the system pressure or head. The positive displacement pump has more or less a constant flow regardless of the system pressure or head. positive displacement pumps generally gives more pressure than centrifugal pumps. Depending on how the measurement is taken suction lift and head may also be referred to as static or dynamic. Static indicates the measurement does not take into account the friction caused by water moving through the hose or pipes. Dynamic indicates that losses due to friction are factored into the performance. The following terms are usually used when referring to lift or head.

Static Suction Lift - The vertical distance from the water line to the centerline of the impeller.

Static Discharge Head - The vertical distance from the discharge outlet to the point of discharge or liquid level when discharging into the bottom of a water tank.

Dynamic Suction Head - The Static Suction Lift plus the friction in the suction line. Also referred to as a Total Suction Head.

Dynamic Discharge Head - The Static Discharge Head plus the friction in the discharge line. Also referred to as Total Discharge Head.

Total Dynamic Head - The Dynamic Suction Head plus the Dynamic Discharge Head. Also referred to as Total Head.

Capacity and Viscosity
Another major difference between the pump types is the effect of viscosity on the capacity:
- ✓ In the centrifugal pump the flow is reduced when the viscosity is increased.
- ✓ In the positive displacement pump the flow is increased when viscosity is increased

Liquids with high viscosity fills the clearances of a positive displacement pump causing a higher volumetric efficiency and a positive displacement pump is better suited for high viscosity applications.

A centrifugal pump becomes very inefficient at even modest viscosity.

Mechanical Efficiency
The pumps behaves different considering mechanical efficiency as well.
- ✓ Changing the system pressure or head has little or no effect on the flow rate in the positive displacement pump.
- ✓ Changing the system pressure or head has a dramatic effect on the flow rate in the centrifugal pump.

Net Positive Suction Head - NPSH
Another consideration is the Net Positive Suction Head NPSH.
- ✓ In a centrifugal pump, NPSH varies as a function of flow determined by pressure.
- ✓ In a positive displacement pump, NPSH varies as a function of flow determined by speed. Reducing the speed of the positive displacement pump reduces the NPSH.

Darcy-Weisbach Formula

Flow of Fluid Through a Pipe
The flow of liquid through a pipe is resisted by viscous shear stresses within the liquid and the turbulence that occurs along the internal walls of the pipe, created by the roughness of the pipe material. This resistance is usually known as pipe friction and is measured is feet or meters head of the fluid, thus the term head loss is also used to express the resistance to flow.

Many factors affect the head loss in pipes, the viscosity of the fluid being handled, the size of the pipes, the roughness of the internal surface of the pipes, the changes in elevations within the system and the length of travel of the fluid.

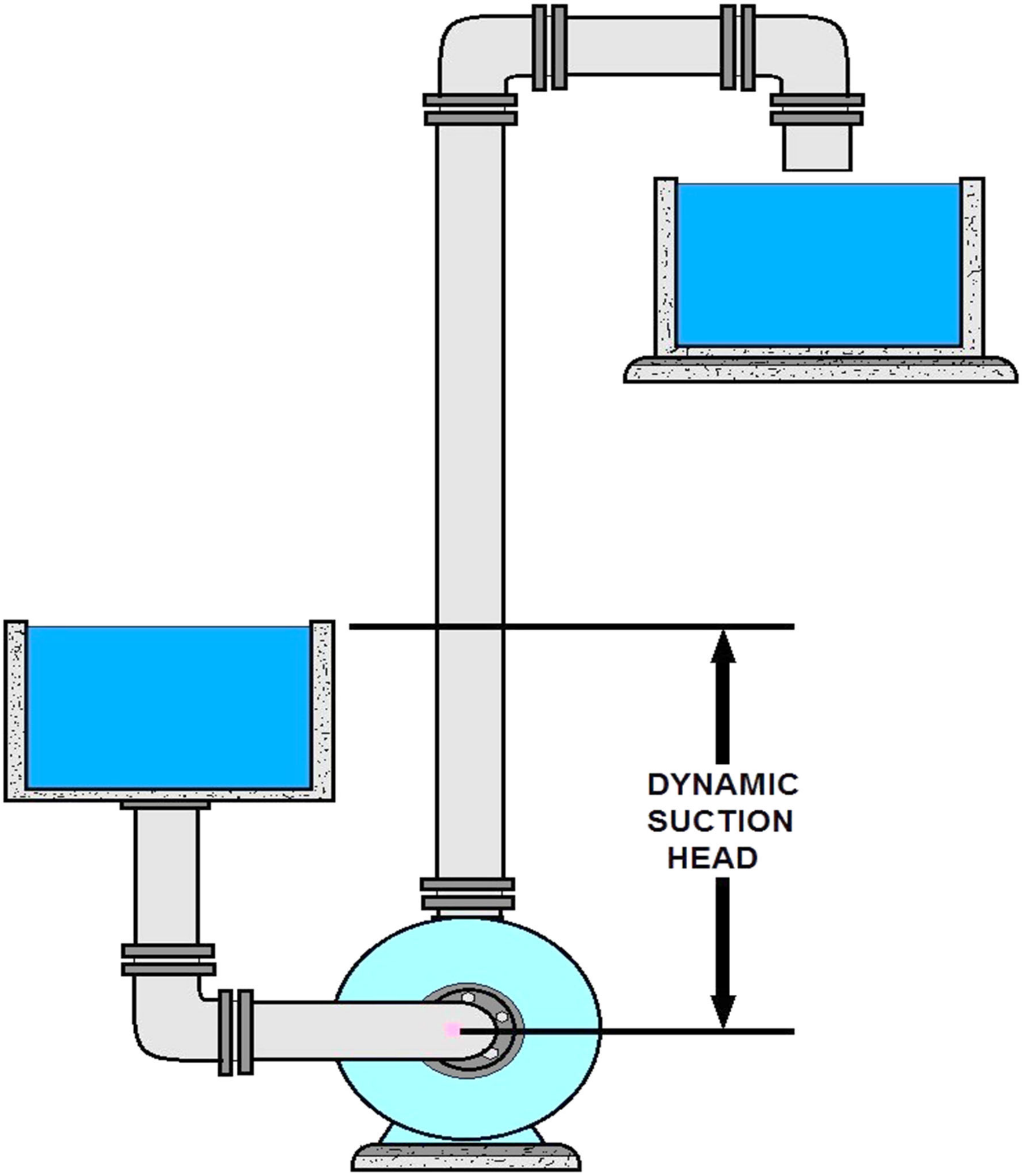
The resistance through various valves and fittings will also contribute to the overall head loss. A method to model the resistances for valves and fittings is described elsewhere. In a well-designed system the resistance through valves and fittings will be of minor significance to the overall head loss, many designers choose to ignore the head loss for valves and fittings at least in the initial stages of a design.

Much research has been carried out over many years and various formulas to calculate head loss have been developed based on experimental data. Among these is the Chézy formula which dealt with water flow in open channels. Using the concept of 'wetted perimeter' and the internal diameter of a pipe the Chézy formula could be adapted to estimate the head loss in a pipe, although the constant 'C' had to be determined experimentally.

The Darcy-Weisbach Equation
Weisbach first proposed the equation we now know as the Darcy-Weisbach formula or Darcy-Weisbach equation:

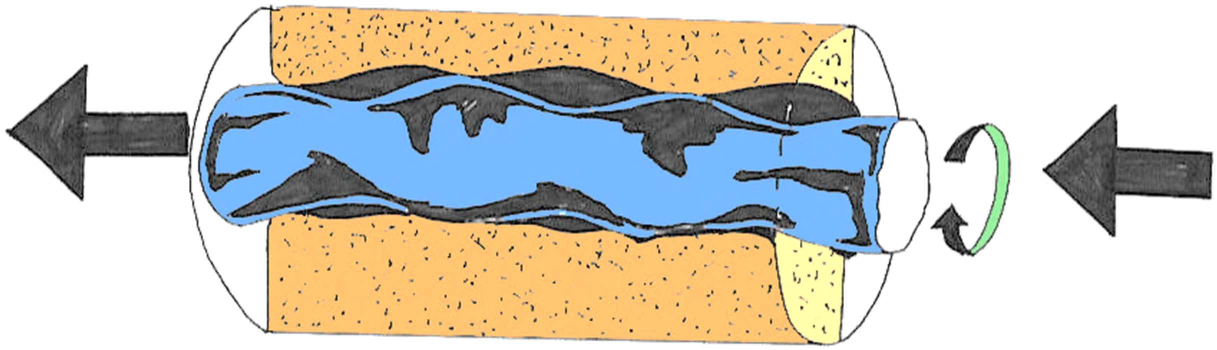
hf = f (L/D) x (v2/2g)

where:
hf = head loss (m)
f = friction factor
L = length of pipe work (m)
d = inner diameter of pipe work (m)
v = velocity of fluid (m/s)
g = acceleration due to gravity (m/s^2)
or:
hf = head loss (ft)
f = friction factor
L = length of pipe work (ft)
d = inner diameter of pipe work (ft)
v = velocity of fluid (ft/s)
g = acceleration due to gravity (ft/s^2)



DYNAMIC SUCTION HEAD DIAGRAM
THE SUCTION LIFT PLUS FRICTION IN SUCTION LINE

Progressing Cavity Pump Sub-Section



PROGRESSING CAVITY ACTION

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.

Therefore, 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 that caused by compression of the fluid or pump components.

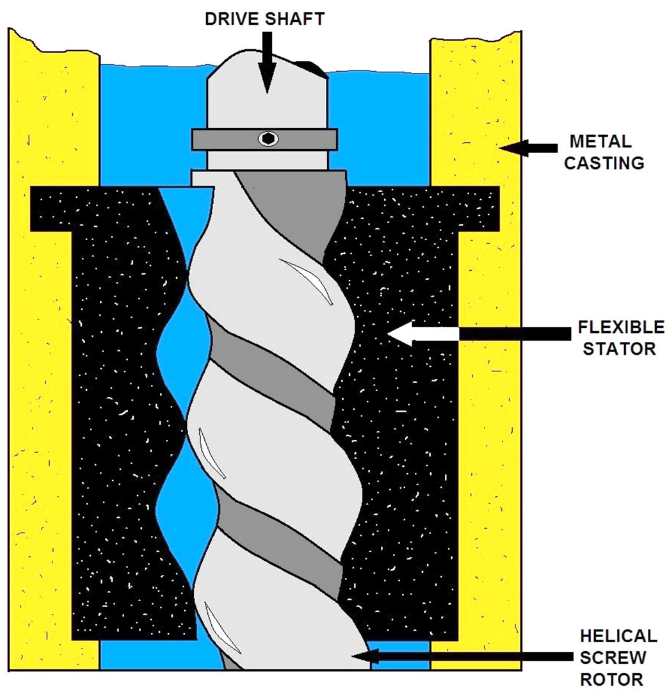
The principle of this pumping technique is frequently misunderstood; often it is believed to occur due to a dynamic effect caused by drag, or friction against the moving teeth of the screw rotor.

Nevertheless, 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 (it's 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.

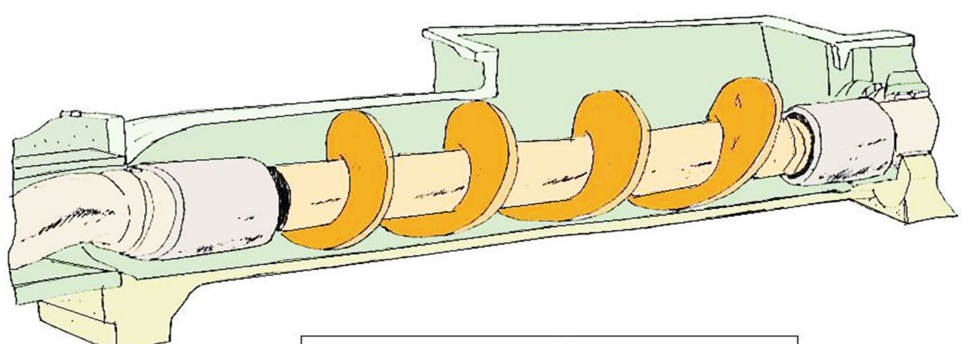
While progressive cavity pumps offer long life and reliable service transporting thick or lumpy fluids, abrasive fluids will significantly shorten the life of the stator. However, slurries (particulates in a medium) can be pumped reliably, as long as the medium is viscous enough to maintain a lubrication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

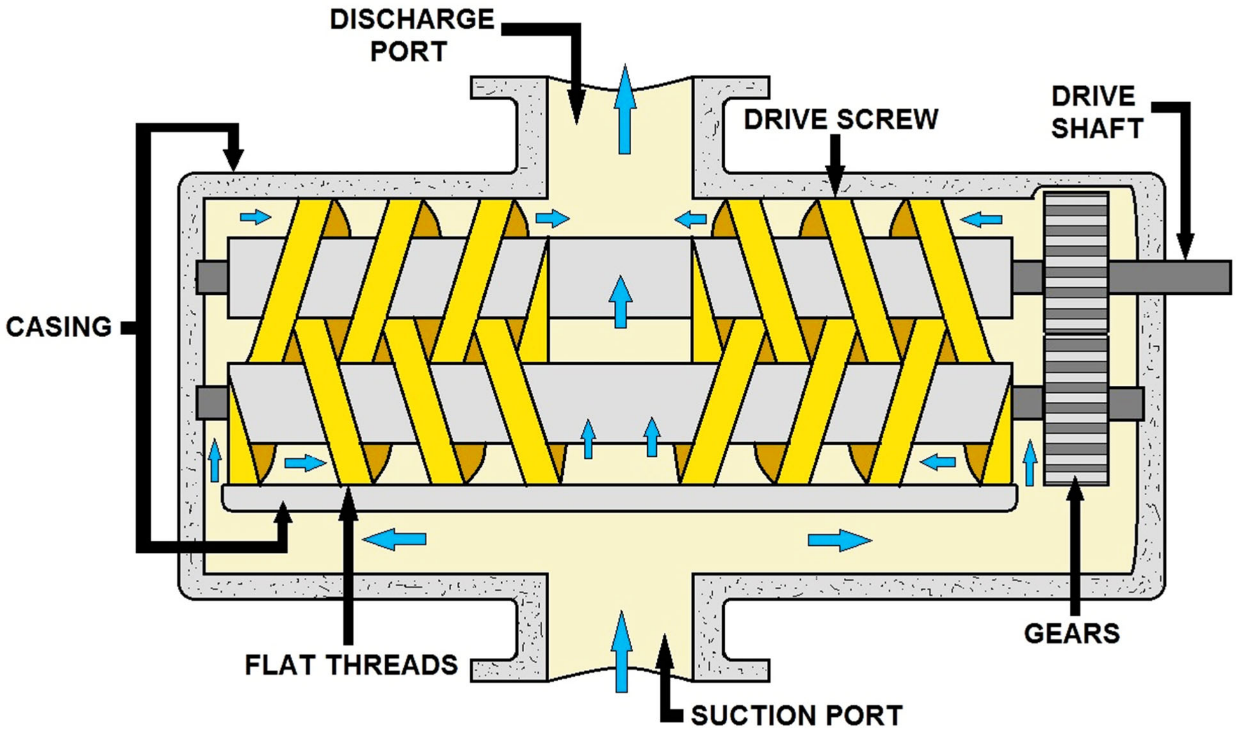
The rotor is held against the inside surface of the stator by angled link arms, bearings (which have to be within the fluid) allowing it to roll around the inner surface (un-driven).

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



POSITIVE DISPLACEMENT PUMP SCREW TYPE

Peristaltic Pump Sub-Section

A peristaltic pump is a type of positive displacement pump used for pumping a variety of fluids. The fluid is contained within a flexible tube fitted inside a circular pump casing (though linear peristaltic pumps have been made). A rotor with a number of "rollers", "shoes" or "wipers" attached to the external circumference compresses the flexible tube.

As the rotor turns, the part of the tube under compression closes (or "occludes") thus forcing the fluid to be pumped to move through the tube. Additionally, as the tube opens to its natural state after the passing of the cam ("restitution") fluid flow is induced to the pump. This process is called peristalsis and is used in many biological systems such as the gastrointestinal tract.

Priming a Pump
Liquid and slurry pumps can lose prime and this will require the pump to be primed by adding liquid to the pump and inlet pipes to get the pump started. Loss of "prime" is usually due to ingestion of air into the pump. The clearances and displacement ratios in pumps used for liquids and other more viscous fluids cannot displace the air due to its lower density.

Plunger Pumps
Plunger pumps are reciprocating positive displacement pumps. They consist of a cylinder with a reciprocating plunger in them. The suction and discharge valves are mounted in the head of the cylinder. In the suction stroke the plunger retracts and the suction valves open causing suction of fluid into the cylinder. In the forward stroke the plunger pushes the liquid out of the discharge valve.

Efficiency and Common Problems
With only one cylinder in plunger pumps, the fluid flow varies between maximum flow when the plunger moves through the middle positions and zero flow when the plunger is at the end positions. A lot of energy is wasted when the fluid is accelerated in the piping system. Vibration and "water hammer" may be a serious problem. In general, the problems are compensated for by using two or more cylinders not working in phase with each other.

Priming a Pump
Liquid and slurry pumps can lose prime and this will require the pump to be primed by adding liquid to the pump and inlet pipes to get the pump started.

Loss of "prime" is usually due to ingestion of air into the pump. The clearances and displacement ratios in pumps used for liquids and other more viscous fluids cannot displace the air due to its lower density.

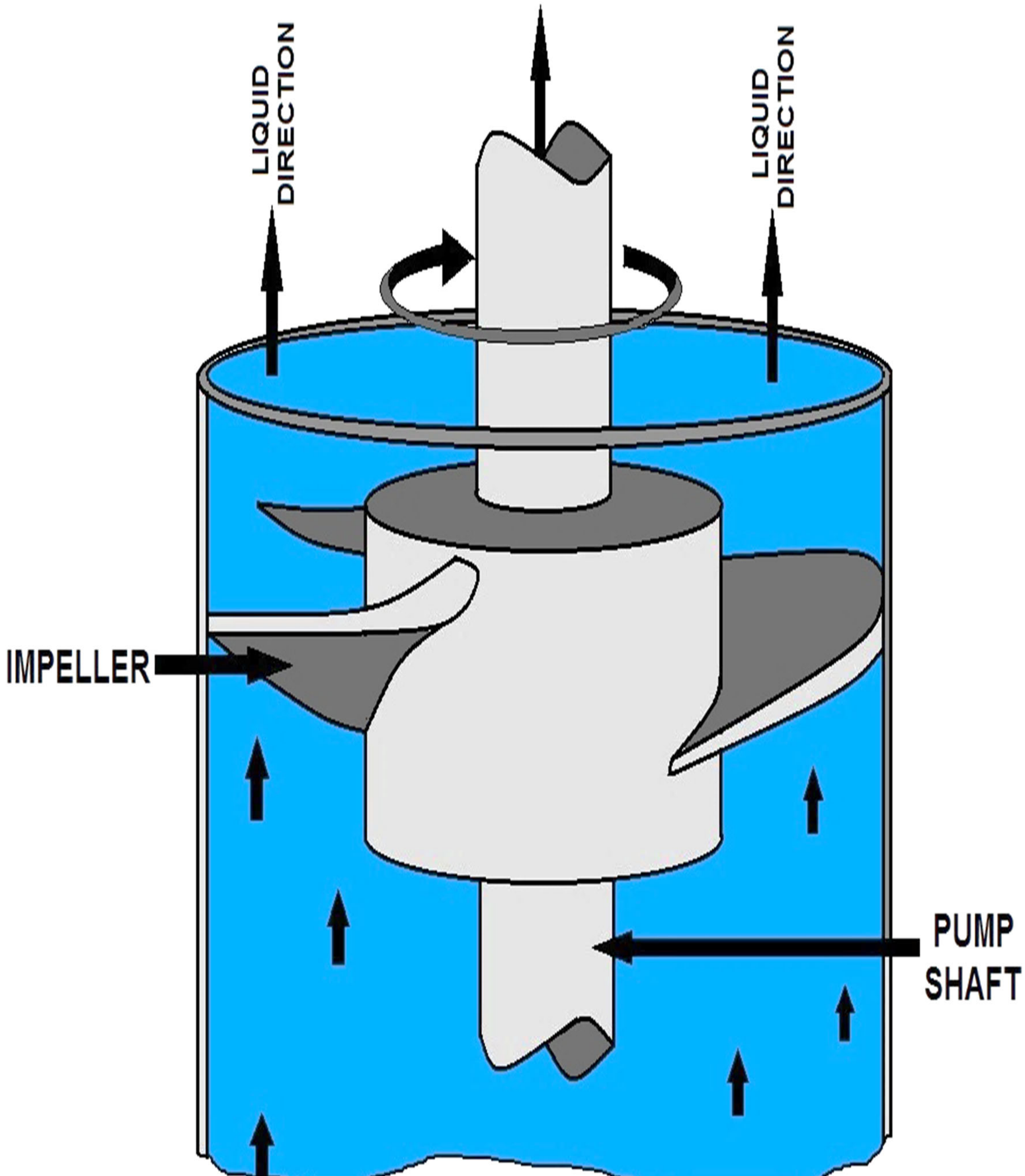
Compressed-Air-Powered Double-Diaphragm Pumps
One modern application of positive displacement diaphragm pumps is compressed-air-powered double-diaphragm pumps.

Run on compressed air these pumps are intrinsically safe by design, although all manufacturers offer ATEX certified models to comply with industry regulation.

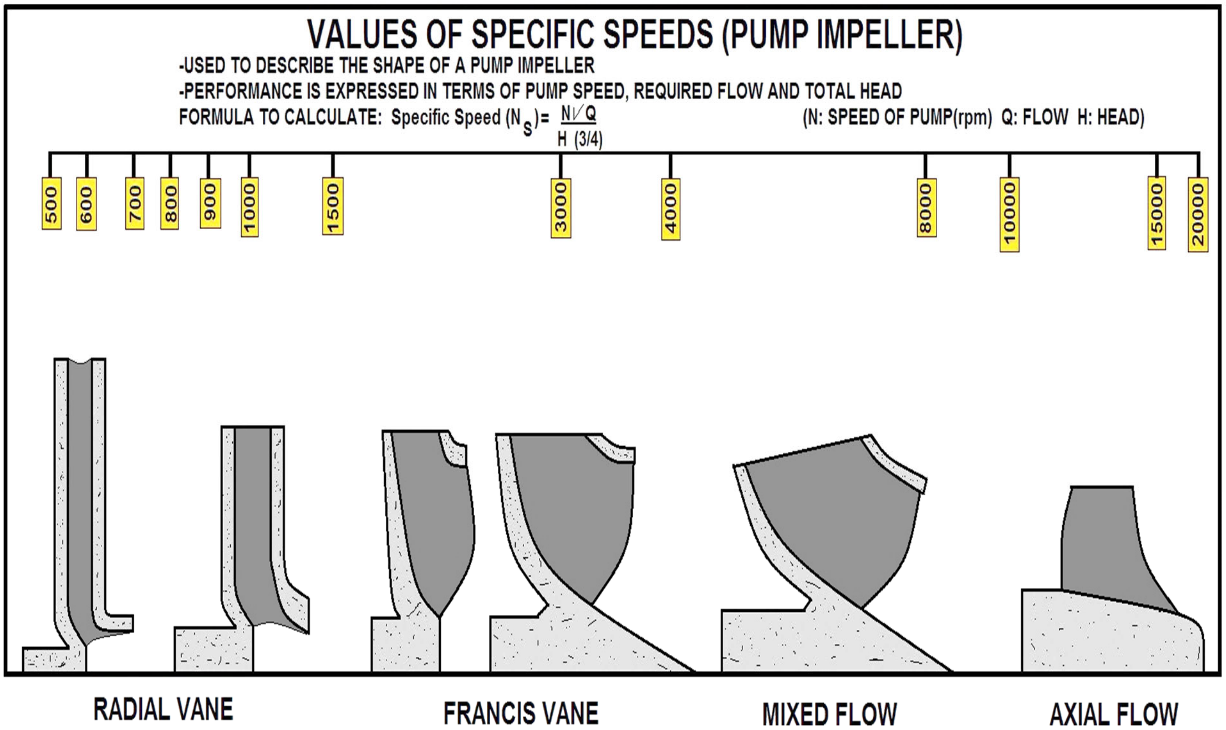
Commonly seen in all areas of industry from shipping to processing, Wilden Pumps, Graco, SandPiper or ARO are generally the larger of the brands.

They are relatively inexpensive and can be used for almost any duty from pumping water out of bunds, to pumping hydrochloric acid from secure storage (dependent on how the pump is manufactured – elastomers / body construction).

Lift is normally limited to roughly 18 feet (6m) although heads can reach almost 200 Psi.



AXIAL FLOW PUMPING PRINCIPAL
IMPELLER FORCES LIQUID IN DIRECTION PARALLEL TO SHAFT



VANE SPEED VALUE DIAGRAM

Understanding Progressing Cavity Pump Theory

Progressing cavity pumps (PCPs) are a special type of rotary positive displacement pump where the produced fluid is displaced axially at a constant rate. This characteristic enables progressing cavity pumps to produce viscous, abrasive, multiphase and gaseous fluids and slurries over a wide range of flow rates and differential pressures. Progressing cavity pumps are comprised of two helicoidal gears (rotor and stator), where the rotor is positioned inside the stator. The combination of rotational movement and geometry of the rotor inside the stator results in the formation of cavities that move axially from pump suction to pump discharge.

Rotors are typically machined from high-strength steel and then coated with a wear resistant material to resist abrasion and reduce stator/rotor friction. Stators consist of steel tubular with an elastomer core bonded to the steel. The elastomer is molded into the shape of an internal helix to match the rotor.

Progressive cavity pumps are fundamentally fixed flow rate pumps, like piston pumps and peristaltic pumps, and 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 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 pressures being generated.

To prevent this, pumps are often fitted with cut-off pressure switches, burst disks (deliberately weak and easily replaced), or a bypass pipe that allows a variable amount 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. Progressive cavity pumps offer long life and reliable service transporting thick or lumpy substances.

Helical Rotor and a Twin Helix
The progressive cavity pump consists of a helical rotor and a twin helix, twice the wavelength and double the diameter helical hole in a rubber stator. The rotor seals tightly against the rubber stator as it rotates, forming a set of fixed-size cavities in between. The cavities move when the rotor is rotated but their shape or volume does not change. The pumped material is moved inside the cavities.

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. In reality, it is due to the 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.

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.

When the rotor is rotated, it rolls around the inside surface of the hole. The motion of the rotor is the same as the smaller gears of a planetary gears system. As the rotor simultaneously rotates and moves around, the combined motion of the eccentrically mounted drive shaft is in the form of a hypocycloid. In the typical case of single-helix rotor and double-helix stator, the hypocycloid is just a straight line. The rotor must be driven through a set of universal joints or other mechanisms to allow for the movement.

The rotor takes a form similar to a corkscrew, and this, combined with the off-center rotary motion, leads to the alternative 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

Specific designs involve the rotor of the pump being made of a steel, coated with 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 (immersed in the fluid) allowing it to roll around the inner surface (un-driven).

Elastomer

Elastomer is used for the stator to simplify the creation of the complex internal shape, created by means of casting, which 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.

The former have a constant elastomer wall thickness and therefore exceed in most other aspects such as pressure per stage, precision, heat transfer, wear and weight. They are more expensive due to the complex shape of the outer tube.

Cavities are created by the geometry of the rotor and stator where the stator has one more lobe than the rotor. The cavities are moved axially along the pump by the rotating motion of the rotor. The motion of the rotor is a combination of a clockwise rotation of the rotor along its own axis and a counterclockwise rotation of the rotor eccentrically about the axis of the stator. Because the volume of each cavity remains constant throughout the process, the pump delivers a uniform non-pulsating flow. The total pressure capability of the pump is determined by the maximum pressure that can be generated within each cavity times the total number of cavities.

PC pumps are manufactured with a variety of stator/rotor tooth combinations. Typically, artificial lift applications use a two-tooth stator and a single tooth rotor pump referred to as single-lobe pump. Higher stator/rotor tooth combinations, such as 3/2, are used to achieve higher volumetric and lift capacity although with higher torque requirements.

Understanding Pump NPSH
NPSH is an initialism for Net Positive Suction Head. In any cross-section of a generic hydraulic circuit, the NPSH parameter shows the difference between the actual pressure of a liquid in a pipeline and the liquid's vapor pressure at a given temperature. NPSH is an important parameter to take into account when designing a circuit: whenever the liquid pressure drops below the vapor pressure, liquid boiling occurs, and the final effect will be cavitation: vapor bubbles may reduce or stop the liquid flow, as well as damage the system.

Centrifugal pumps are particularly vulnerable especially when pumping heated solution near the vapor pressure, whereas positive displacement pumps are less affected by cavitation, as they are better able to pump two-phase flow (the mixture of gas and liquid), however, the resultant flow rate of the pump will be diminished because of the gas volumetrically displacing a disproportion of liquid. Careful design is required to pump high temperature liquids with a centrifugal pump when the liquid is near its boiling point.

The violent collapse of the cavitation bubble creates a shock wave that can literally carve material from internal pump components (usually the leading edge of the impeller) and creates noise often described as "pumping gravel". Additionally, the inevitable increase in vibration can cause other mechanical faults in the pump and associated equipment.

A somewhat simpler informal way to understand NPSH…
Fluid can be pushed down a pipe with a great deal of force. The only limit is the ability of the pipe to withstand the pressure. However, a liquid cannot be pulled up a pipe with much force because bubbles are created as the liquid evaporates into a gas. The greater the vacuum created, the larger the bubble, so no more liquid will flow into the pump.

Rather than thinking in terms of the pump's ability to pull the fluid, the flow is limited by the ability of gravity and air pressure to push the fluid into the pump. The atmosphere pushes down on the fluid, and if the pump is below the tank, the weight of the fluid from gravity above the pump inlet also helps. Until the fluid reaches the pump, those are the only two forces providing the push. Friction loss and vapor pressure must also be considered.

Friction loss limits the ability of gravity and air pressure to push the water toward the pump at high speed. Vapor pressure refers to the point at which bubbles form in the liquid. NPSH is a measure of how much spare pull you have before the bubbles form.

Some helpful information regarding atmospheric pressure; Atmospheric pressure is always naturally occurring and is always around us. At sea level, it equates to 101.325 kPa or approximately 14 Psi OR 10 meters of liquid pressure head. As we move higher up mountains, the air gets thinner and the atmospheric pressure reduces.

This should be taken into account when designing pumping systems. The reason there is atmospheric pressure is simply due to earth's gravity and its position in our solar system. It is a natural phenomenon and we are very lucky to have it as water wells and bores with shallow aquifers allow us to use this atmospheric pressure to our advantage.

We all know that pressure gauges exist on pumping systems and other machines to give us an indication of what performances are being achieved. We also use known pressures versus known performance in order to create a reference for system designs.

An example would be an experienced pump technician or plumber knowing that a pressure of between 300 kPa and 500 kPa will provide adequate and comfortable pressure for household use.

A typical pressure gauge reads what is known as 'Gauge Pressure,' or pressure relative to atmospheric pressure. An 'Absolute Pressure' gauge displays atmospheric pressure (typically 100 kPa or 14 psi or 10 meters of liquid pressure head) before any system had been connected. Manufacturers set typical gage pressure gauges to read ZERO at sea level as a standard, assuming designers will make allowances for the atmospheric pressure calculations themselves. Knowing this simple fact can make NPSH easier to understand.

If we now know that there is 100 kPa or 10 meters of head pressure, plus or minus whatever the gage pressure gauge shows, then we can safely see that this gives us an instant advantage of 10 meters of head pressure at sea level.

This means we can borrow against this and drop a maximum of 10 meters into or under the ground (or below sea level) reducing the gauge to zero and still get natural 'push' into our pump. Great for wells and bores with shallow aquifers within this depth! It is important to note that to get to exactly 10 meters may be difficult, but with the correct pipework and system design, it is possible to get very close.

Once NPSH is fully understood, sizing and controlling pumps and pumping machines is a much simpler task.

NPSH is the liquid suction force at the intake of a pump. In other words, the force of a liquid naturally “pushing” into a pump from gravity pressure plus liquid head pressure only - into a single pump intake.

This means;
NPSH = the net (left over) positive pressure of suction force into a pump intake after friction loss has occurred. Liquid head height or liquid head pressure + gravity pressure, minus friction loss, leaves a net head pressure of force into the pump. If we want to pump some amount of liquid, we have to ensure that this liquid can reach the center line of the suction point of the pump. NPSH represents the head (pressure and gravity head) of liquid in the suction line of the pump that will overcome the friction along the suction line.

NPSHR is the amount of liquid pressure required at the intake port of a pre-designed and manufactured pump. This is known as NPSHR (Net Positive Suction Head Required). The pump manufacturer will usually clearly have a NPSH curve to assist you in the correct installation.

NPSHA is the amount (A = available) to the pump intake after pipe friction losses and head pressures have been taken into account.

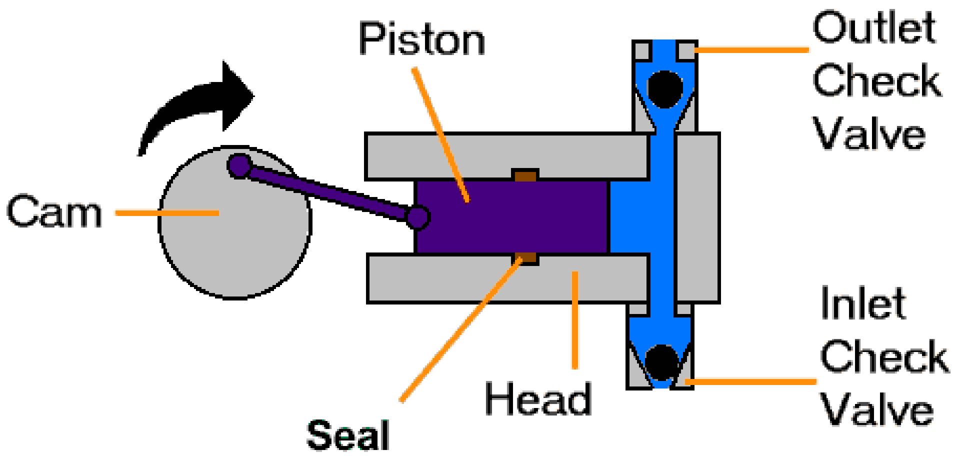
The Reason for This Requirement?
When the pump is receiving liquid at intake port and the impeller is pushing the liquid out the discharge port, they are effectively trying to tear each other apart because the pump is changing the liquid movement by a pressure increase at the impeller vanes, (general pump installations). Insufficient NPSHR will cause a low or near-vacuum pressure (negative NPSHA) to exist at the pump intake.

This will cause the liquid to boil and cause cavitation, and the pump will not receive the liquid fast enough because it will be attempting to pump vapor. Cavitation will lower pump performance and damage pump internals. At low temperatures the liquid can "hold together" (remain fluid) relatively easily, hence a lower NPSH requirement. However, at higher temperatures, the higher vapor pressure starts the boiling process much quicker, hence a high NPSH requirement.

- ✓ Water will boil at lower temperatures under lower pressures. Conversely its boiling point is higher at higher pressures.
- ✓ Water boils at 100 degrees Celsius at sea level and an atmospheric pressure of 1 bar.
- ✓ Vapor Pressure is the pressure of a gas in equilibrium with its liquid phase at a given temperature. If the vapor pressure at a given temperature is greater than the pressure of the atmosphere above the liquid, then the liquid will boil. (This is why water boils at a lower temperature high in the mountains).
- ✓ At normal atmospheric pressure minus 5 psi (or -0.35 bar) water will boil at 89 degrees Celsius.
- ✓ At normal atmospheric pressure minus 10 psi (or -0.7 bar) water will boil at 69 degrees Celsius.
- ✓ At a positive pressure of +12 psi or +0.82 bar above atmospheric, water will boil at 118 degrees Celsius.
- ✓ Liquid temperature greatly affects NPSH and must be taken into account when expensive installations are being designed.
- ✓ A pump designed with a NPSHR suitable for cold water may cavitate when pumping hot water

Hyperlink to the Glossary and Appendix
http://www.abctlc.com/downloads/PDF/PumpGlossary.pdf

Reciprocating Pump Sub-Section



Typical reciprocating pumps are

- Plunger pumps
- Diaphragm pumps

A plunger pump consists of a cylinder with a reciprocating plunger in it. The suction and discharge valves are mounted in the head of the cylinder. In the suction stroke the plunger retracts and the suction valves open causing suction of fluid into the cylinder. In the forward stroke the plunger pushes the liquid out of the discharge valve.

With only one cylinder the fluid flow varies between maximum flow when the plunger moves through the middle positions and zero flow when the plunger is at the end positions. A lot of energy is wasted when the fluid is accelerated in the piping system. Vibration and "water hammer" may be a serious problem. In general, the problems are compensated for by using two or more cylinders not working in phase with each other.

In diaphragm pumps, the plunger pressurizes hydraulic oil which is used to flex a diaphragm in the pumping cylinder. Diaphragm valves are used to pump hazardous and toxic fluids. An example of the piston displacement pump is the common hand soap pump.

Gear Pump
This uses two meshed gears rotating in a closely fitted casing. Fluid is pumped around the outer periphery by being trapped in the tooth spaces. It does not travel back on the meshed part, since the teeth mesh closely in the center. Widely used on car engine oil pumps. It is also used in various hydraulic power packs.

Progressing Cavity Pump
Widely used for pumping difficult materials such as sewage sludge contaminated with large particles, this pump consists of a helical shaped rotor, about ten times as long as its width. This can be visualized as a central core of diameter x, with typically a curved spiral wound around of thickness half x, although of course in reality it is made from one casting. This shaft fits inside a heavy duty rubber sleeve, of wall thickness typically x also. As the shaft rotates, fluid is gradually forced up the rubber sleeve. Such pumps can develop very high pressure at quite low volumes.

Diaphragm Pumps

A diaphragm pump is a positive displacement pump that uses a combination of the reciprocating action of a rubber, thermoplastic or Teflon diaphragm and suitable non-return check valves to pump a fluid. Sometimes this type of pump is also called a membrane pump. Diaphragm Pumps are used extensively in many industries and can handle a very wide variety of liquids.

Diaphragm Pumps are in the category of "positive displacement" pumps because their flowrates do not vary much with the discharge "head" (or pressure) the pump is working against (for a given pump speed).

Diaphragm pumps can transfer liquids with low, medium or high viscosities and also liquids with a large solids content. They can also handle many aggressive chemicals such as acids because they can be constructed with a wide variety of body materials and diaphragms.

There are three main types of diaphragm pumps:

- ✓ Those in which 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 prevent reverse flow of the fluid.
- ✓ Those employing volumetric positive displacement where the prime mover of the diaphragm 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.
- ✓ Those employing 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. The most popular type of diaphragm pump is the Air-Operated Diaphragm Pump.

These pumps use compressed air as their power supply. They also include two chambers with a diaphragm, inlet check valve and outlet check valve in each chamber.

The air supply is shifted from one chamber to another with an air spool valve that is built into the pump. This continual shifting of air from one chamber to another (to the backside of the diaphragm) forces liquid out of one chamber and into the discharge piping while the other chamber is being filled with liquid.

There is some pulsation of discharge flow in Air-Operated Diaphragm Pumps. This pulsating flow can be reduced somewhat by using pulsation dampeners in the discharge piping.

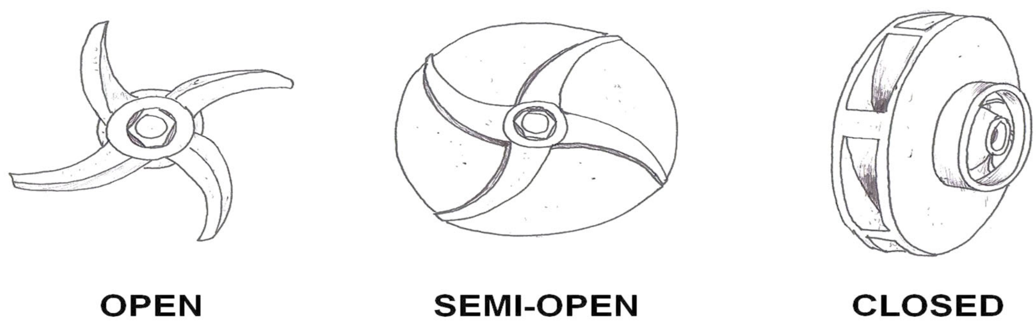
Characteristics
Diaphragm Pumps

- ✓ have good suction lift characteristics, some are low pressure pumps with low flow rates; others are capable of higher flow rates, dependent on the effective working diameter of the diaphragm and its stroke length. They can handle sludges and slurries with a relatively high amount of grit and solid content.
- ✓ suitable for discharge pressure up to 1,200 bar.
- ✓ have good dry running characteristics.
- ✓ can be used to make artificial hearts.
- ✓ are used to make air pumps for the filters on small fish tanks.
- ✓ can be up to 97% efficient.
- ✓ have good self-priming capabilities.
- ✓ can handle highly viscous liquids.
- ✓ are available for industrial, chemical and hygienic applications.
- ✓ cause a pulsating flow that may cause water hammer.

Vapor Pressure and Cavitation Sub-Section

Cavitation is the formation and then immediate implosion of cavities in a liquid – i.e. small liquid-free zones ("bubbles") – that are the consequence of forces acting upon the liquid. It usually occurs when a liquid is subjected to rapid changes of pressure that cause the formation of cavities where the pressure is relatively low.

Cavitation is a significant cause of wear in some engineering contexts. When entering high pressure areas, cavitation bubbles that implode on a metal surface cause cyclic stress. These results in surface fatigue of the metal causing a type of wear also called "cavitation". The most common examples of this kind of wear are pump impellers and bends when a sudden change in the direction of liquid occurs. Cavitation is usually divided into two classes of behavior: inertial (or transient) cavitation and non-inertial cavitation.



COMMONLY FOUND IMPELLER TYPES

Inertial Cavitation
Inertial cavitation is the process where a void or bubble in a liquid rapidly collapses, producing a shock wave. Inertial cavitation occurs in nature in the strikes of mantis shrimps and pistol shrimps, as well as in the vascular tissues of plants. In man-made objects, it can occur in control valves, pumps, propellers and impellers.

Non-Inertial Cavitation
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. Since the shock waves formed by cavitation are strong enough to significantly damage moving parts, cavitation is usually an undesirable phenomenon. It is specifically avoided in the design of machines such as turbines or propellers, and eliminating cavitation is a major field in the study of fluid dynamics.

To understand Cavitation, you must first understand vapor pressure. Vapor pressure is the pressure required to boil a liquid at a given temperature. Soda water is a good example of a high vapor pressure liquid. Even at room temperature the carbon dioxide entrained in the soda is released. In a closed container, the soda is pressurized, keeping the vapor entrained.

Temperature Affects Vapor Pressure
Temperature affects vapor pressure as well, raises the water's temperature to 212°F and the vapors are released because at that increased temperature the vapor pressure is greater than the atmospheric pressure.
Pump cavitation occurs when the pressure in the pump inlet drops below the vapor pressure of the liquid. Vapor bubbles form at the inlet of the pump and are moved to the discharge of the pump where they collapse, often taking small pieces of the pump with them. Cavitation is often characterized by:

- ✓ Loud noise often described as a grinding or "marbles" in the pump.
- ✓ Loss of capacity (bubbles are now taking up space where liquid should be).
- ✓ Pitting damage to parts as material is removed by the collapsing bubbles.

Noise is a nuisance and lower flows will slow your process, but pitting damage will ultimately decrease the life of the pump.

In general, cavitation performance is related to some "critical" value:
NPSHA (=available) > NPSHc or NPSHR (=critical or required)
Typical "critical" characteristics identified for centrifugal pumps:
• Incipient cavitation (NPSHi)
• Developed cavitation causing 3% head drop (NPSH3%)
• Developed cavitation causing complete head breakdown (vapor lock).

Choice of NPSHR is rather arbitrary, but usually NPSHR=NPSH3%
Alternative choices:
• NPSHR=NPSH1% or NPSHR=NPSH5%
• NPSHR=NPSHi (cavitation free operation)

Cavitation causes or may cause:
• Performance loss (head drop)
• Material damage (cavitation erosion)
• Vibrations
• Noise
• Vapor lock (if suction pressure drops below break-off value)

The definition of NPSHA is simple: Static head + surface pressure head - the vapor pressure of your product - the friction losses in the piping, valves and fittings.

But to really understand it, you first have to understand a couple of other concepts:

- ✓ Cavitation is what net positive suction head (NPSH) is all about, so you need to know a little about cavitation.
- ✓ Vapor Pressure is another term we will be using. The product's vapor pressure varies with the fluid's temperature.
- ✓ Specific gravity plays an important part in all calculations involving liquid. You have to be familiar with the term.
- ✓ You have to be able to read a pump curve to learn the N.P.S.H. required for your pump.
- ✓ You need to understand how the liquid's velocity affects its pressure or head.
- ✓ It is important to understand why we use the term Head instead of Pressure when we make our calculations.
- ✓ Head loss is an awkward term, but you will need to understand it.

You will have to be able to calculate the head loss through piping, valves and fittings.

- ✓ You must know the difference between gage pressure and absolute pressure.
- ✓ Vacuum is often a part of the calculations, so you are going to have to be familiar with the terms we use to describe vacuum.

Let's look at each of these concepts in a little more detail

- ✓ Cavitation means cavities or holes in liquid. Another name for a hole in a liquid is a bubble, so cavitation is all about bubbles forming and collapsing.
- ✓ Bubbles take up space so the capacity of our pump drops.
- ✓ Collapsing bubbles can damage the impeller and volute. This makes cavitation a problem for both the pump and the mechanical seal.
- ✓ Vapor pressure is about liquids boiling. If I asked you, "at what temperature does water boil?" You could say 212° F. or 100° C., but that is only true at atmospheric pressure. Every product will boil (make bubbles) at some combination of pressure and temperature. If you know the temperature of your product you need to know its vapor pressure to prevent boiling and the formation of bubbles. In the charts section of this web site you will find a vapor pressure chart for several common liquids.
- ✓ Specific gravity is about the weight of the fluid. Using 4°C (39° F) as our temperature standard we assign fresh water a value of one. If the fluid floats on this fresh water it has a specific gravity is less than one. If the fluid sinks in this water the specific gravity of the fluid is greater than one.
- ✓ Look at any pump curve and make sure you can locate the values for head, capacity, best efficiency point (B.E.P.), efficiency, net positive suction head (NPSH), and horse power required. If you cannot do this, have someone show you where they are located.
- ✓ Liquid velocity is another important concept. As a liquid's velocity increases, its pressure (90° to the flow) decreases. If the velocity decreases the pressure increases. The rule is: velocity times pressure must remain a constant.
- ✓ "Head" is the term we use instead of pressure. The pump will pump any liquid to a given height or head depending upon the diameter and speed of the impeller. The amount of pressure you get depends upon the weight (specific gravity) of the liquid. The pump manufacturer does not know what liquid the pump will be pumping so he gives you only the head that the pump will generate. You have to figure out the pressure using a formula described later on in this paper.
- ✓ Head (feet) is a convenient term because when combined with capacity (gallons or pounds per minute) you come up with the conversion for horsepower (foot pounds per minute).
- ✓ "Head loss through the piping, valves and fittings" is another term we will be using. Pressure drop is a more comfortable term for most people, but the term "pressure" is not used in most pump calculations so you could substitute the term "head drop" or "loss of head" in the system. To calculate this loss, you will need to be able to read charts like those you will find in the "charts you can use" section in the home page of this web site. They are labeled Friction loss for water and Resistance coefficients for valves and fittings.
- ✓ Gage and absolute pressure. Add atmospheric pressure to the gage pressure and you get absolute pressure.
- ✓ Vacuum is a pressure less than atmospheric. At sea level atmospheric pressure is 14.7 psi. (760 mm of Mercury). Vacuum gages are normally calibrated in inches or millimeters of mercury.

To calculate the net positive suction head (NPSH) of your pump and determine if you are going to have a cavitation problem, you will need access to several additional pieces of information:

- ✓ The curve for your pump. This pump curve is supplied by the pump manufacturer. Someone in your plant should have a copy. The curve is going to show you the Net Positive Suction Head (NPSH) required for your pump at a given capacity. Each pump is different so make sure you have the correct pump curve and use the numbers for the impeller diameter on your pump. Keep in mind that this NPSH required was for cold, fresh water.
- ✓ A chart or some type of publication that will give you the vapor pressure of the fluid you are pumping.
- ✓ If you would like to be a little more exact, you can use a chart to show the possible reduction in NPSH required if you are pumping hot water or light hydrocarbons.
- ✓ You need to know the specific gravity of your fluid. Keep in mind that the number is temperature sensitive. You can get this number from a published chart, ask some knowledgeable person at your plant, or take a reading on the fluid using a hydrometer.
- ✓ Charts showing the head loss through the size of piping you are using between the source and the suction eye of your pump. You will also need charts to calculate the loss in any fittings, valves, or other hardware that might have been installed in the suction piping.
- ✓ Is the tank you are pumping from at atmospheric pressure or is it pressurized in some manner? Maybe it is under a vacuum?
- ✓ You need to know the atmospheric pressure at the time you are making your calculation. We all know atmospheric pressure changes throughout the day, but you have to start somewhere.

The formulas for converting pressure to head and head back to pressure in the imperial system are as follows:

- o sg. = specific gravity
- o pressure = pounds per square inch
- o head = feet

You also need to know the formulas that show you how to convert vacuum readings to feet of head. Here are a few of them:

To convert surface pressure to feet of liquid; use one of the following formulas:

- ✓ Inches of mercury x 1.133 / specific gravity = feet of liquid
- ✓ Pounds per square inch x 2.31 / specific gravity = feet of liquid
- ✓ Millimeters of mercury / (22.4 x specific gravity) = feet of liquid

There are different ways to think about net positive suction head (NPSH) but they all have two terms in common.

- ✓ NPSHA (net positive suction head available)
- ✓ NPSHR (net positive suction head required)

Submersible Pump Sub-Section

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

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

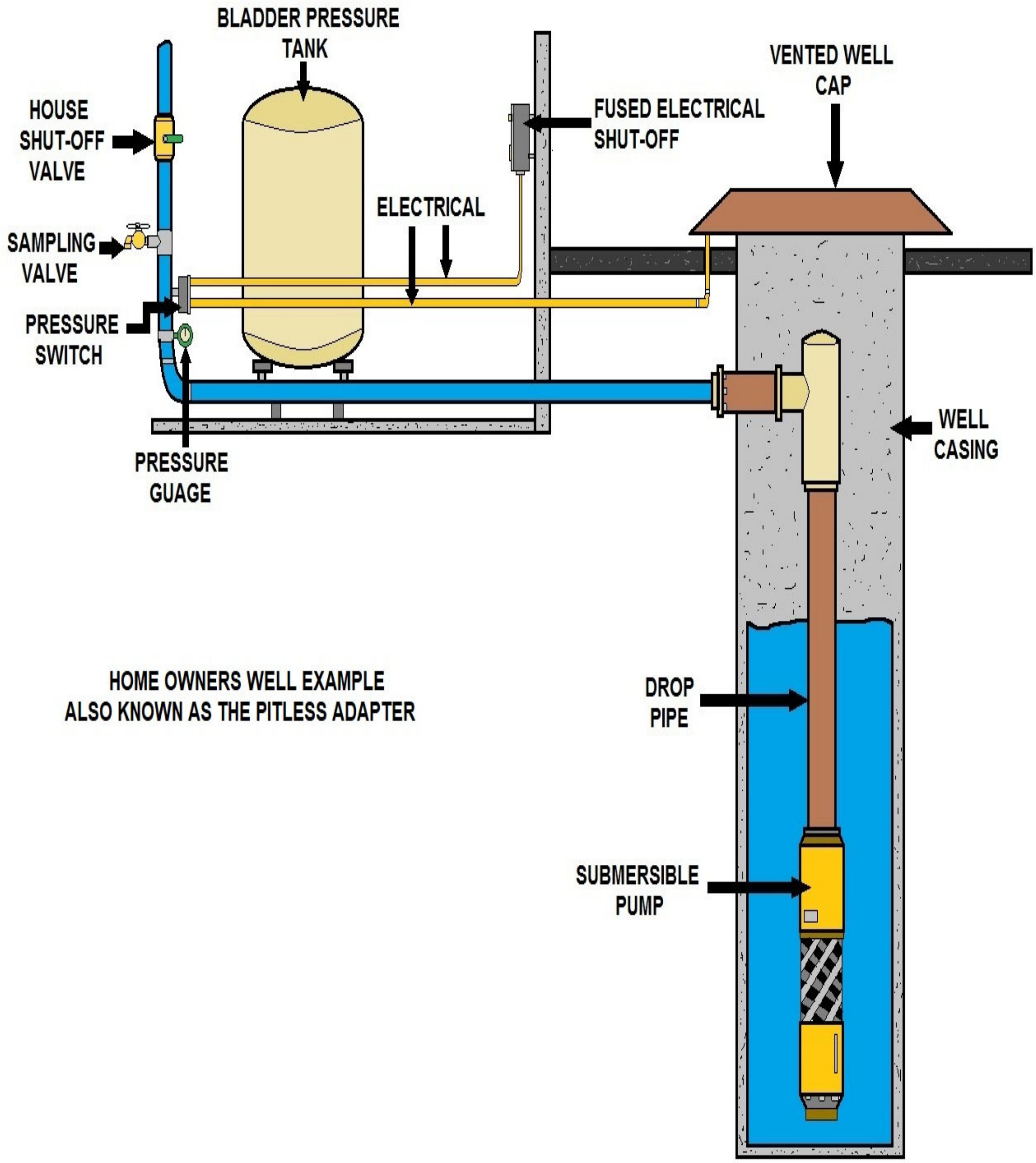
The efficient cooling of submersible motors is very important, so these types of pumps are often installed such that flow through the well screen can occur upwards past the motor and into the intake. If the motor end is inserted below the screened interval or below all productive portions of the aquifer,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

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

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

Insertion of motor spline into the pump keyway.

Cut away of a small submersible (turbine) pump without a motor.


BLADDER PRESSURE
TANK
HOUSE
SHUT-OFF
VALVE
SAMPLING
VALVE
PRESSURE
SWITCH
PRESSURE
GUAGE
ELECTRICAL
FUSED ELECTRICAL
SHUT-OFF
VENTED WELL
CAP
WELL
CASING
DROP
PIPE
SUBMERSIBLE
PUMP
HOME OWNERS WELL EXAMPLE
ALSO KNOWN AS THE PITLESS ADAPTER

Pulling a Small Submersible Well Pump

Well cap removed, looking at pvc pipe and electrical wire

Attachment that screws into well pipe to be pulled. Metal disk supports couplings on wellhead while being pulled.

Each pipe section is 20 feet long. Here the attachment that screws into the pipe is being disconnected from the well rig.

While pulling the PVC, care is taken not to damage electrical wiring. Next to the casing is conduit that runs from the electrical panel to the well.

The wire gauge used is determined by volts, amps and the run. Care is taken not to tangle the wire while pulling the well and re-installing.

Small well assemblies will use industrial tape to secure the wiring to the pump shaft and the centering device keeps the pump assembly centered in the casing.

The submersible pump is about to be pulled out. Above, is the discharge side of the pump.

This pump has 16 stages and a 4 inch impeller. Rule of thumb, if you take the diameter of the impeller squared (4 x 4) and times it by the stages you will get the lift in feet. For example 4 x 4 x 16 = 256 ft of lift.

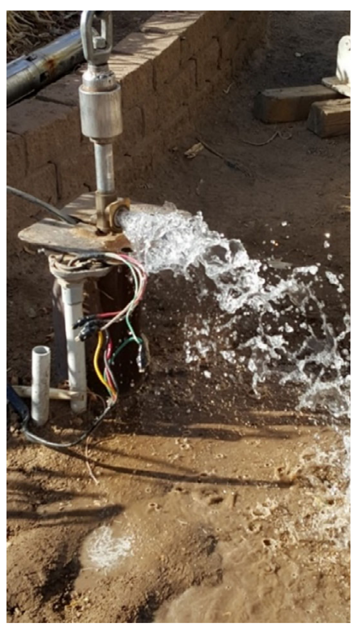
The PVC pipe id threaded into the pump assembly. The PVC is special pre-threaded pipe.

Looking at the discharge side of the pump where the pipe is screwed in and you can see the foot valve on the inside.

Pump and motor connection.


It is recommended to install a check valve every 100 feet of piping. Sometimes the valve becomes defective and causes pumping issues. When installing the the check valve, the correct direction of the check valve is important.

Installing new submersible pump, securing wire and connecting pump wiring.



Checking to make sure new pump is working properly.

The discharge side of the pipe has a tee that seats on a saddle down below ground to prevent freezing.

Submersible Pump Troubleshooting

A submersible pump (or electric submersible pump (ESP)) is a device which has a hermetically sealed motor close-coupled to the pump body. The whole assembly is submerged in the fluid to be pumped. The main advantage of this type of pump is that it prevents pump cavitation, a problem associated with a high elevation difference between pump and the fluid surface. Submersible pumps push fluid to the surface as opposed to jet pumps having to pull fluids. Submersibles are more efficient than jet pumps.

The submersible pumps used in ESP installations are multistage centrifugal pumps operating in a vertical position. Although their constructional and operational features underwent a continuous evolution over the years, their basic operational principle remained the same. Produced liquids, after being subjected to great centrifugal forces caused by the high rotational speed of the impeller, lose their kinetic energy in the diffuser where a conversion of kinetic to pressure energy takes place. This is the main operational mechanism of radial and mixed flow pumps.

The pump shaft is connected to the gas separator or the protector by a mechanical coupling at the bottom of the pump. Well fluids enter the pump through an intake screen and are lifted by the pump stages. Other parts include the radial bearings (bushings) distributed along the length of the shaft providing radial support to the pump shaft turning at high rotational speeds. An optional thrust bearing takes up part of the axial forces arising in the pump but most of those forces are absorbed by the protector’s thrust bearing.

Understanding the Operation of a Vertical Turbine Pump
The basic components of the pump are the driver, discharge head assembly, column assembly (when used) and bowl assembly. The driver, coupling strainer (when used) are generally shipped unassembled to prevent damage.

Installation Check List
The following checks should be made before starting actual installation to assure proper installation and prevent delays:
1. With motor driven units, be sure the voltage and frequency on the motor nameplate agree with the service available. Also make sure the horsepower and voltage rating of the control box or starter agrees with the horsepower and voltage rating of the motor
2. Check the depth of the sump or caisson against the pump length to be sure there will be no interference.
3. Check the proposed liquid level in the sump against the pump length - the bottom stage of the pump must be submerged at all times.
4. Clean the sump and piping system before installing the pump.
5. Check the installation equipment to be sure it will safely handle the equipment.
6. Check all pump connections (bolts, nuts, etc.) for tightness. These have been properly tightened before leaving the factory, however, some connections may have worked loose in transit.
7. Check the coupling on the driver to make sure the shaft will fit properly.
8. Proper installation is necessary to provide maximum service from the pump. To insure proper alignment three items are very important during installation.

    A. All machined mating surfaces (such as the mating flanges of the pump and motor) must be clean and free of burrs and nicks. These surfaces should be cleaned thoroughly with a scraper, wire brush and emery cloth if necessary and any nicks or burrs removed with a fine file.

B. Exterior strain must not be transmitted to the pump. The most common cause of trouble in this respect is forcing the piping to mate with the pump. It is recommended that flexible connectors be installed in the piping adjacent to the pump.

C. All threads should be checked for damage and repaired if necessary. If filing is necessary, remove the part from the pump if possible, or arrange a rag to catch all the filings so they do not fall into other parts of the pump. Clean all threads with a wire brush and cleaning solvent. Ends of the shafts must be cleaned and any burrs removed since alignment depends on the shaft ends butting squarely. Lubricate all screwed connections with a suitable thread lubricant (an anti-galling compound such as "Anti-Seize" should be used on stainless mating threads). The end faces of the pump shafts must be centered in the coupling and aligned with the relief hole drilled into the side of the coupling. To verify that the end of the shaft is centered in the coupling and aligned with the relief hole, insert a small wire (a paper clip works well) into the hole to feel where the shaft ends. Remove the wire before tightening the coupling and shafts. Excess thread lubricant will purge out of the relief hole when properly aligned.

Foundation

The foundation may consist of any materials that will afford permanent, rigid support to the discharge head and will absorb expected stresses that may be encountered in service. Verify the foundation is flat and level.

Installation Process

Equipment and Tools

No installation should be attempted without equipment adequate for the job. The following list covers the principal items required for an installation.

1. Mobile crane capable of hoisting and lowering the entire weight of the pump and motor.
2. (2) Two steel clamps or elevators with bails or cable.
3. (2) Two sets of chain tongs.
4. Cable sling for attaching to the pump and motor lifting eyes.
5. Steel pipe clamp for lifting bowl assembly and column pipe.
6. Approximately 15 feet of 3/4" rope for tying shaft during installation.
7. Ordinary hand tools - pipe wrenches, end wrenches, socket set, screw drivers, Allen wrenches, etc.
8. Wire brush, scraper, fine file, and fine emery cloth.
9. Thread compound designed for type of connection and light machinery oil.

Assembling and Installing Pump

1. Position adequate lifting equipment so it will center over the foundation opening.

2. Bowl Assembly

A. Check and measure for axial clearance or end play. While bowls are in a horizontal position you should be able to push or pull the pump shaft indicating axial clearance. Check all bolts for tightness. Do not lift or handle the bowl assembly by the pump shaft.

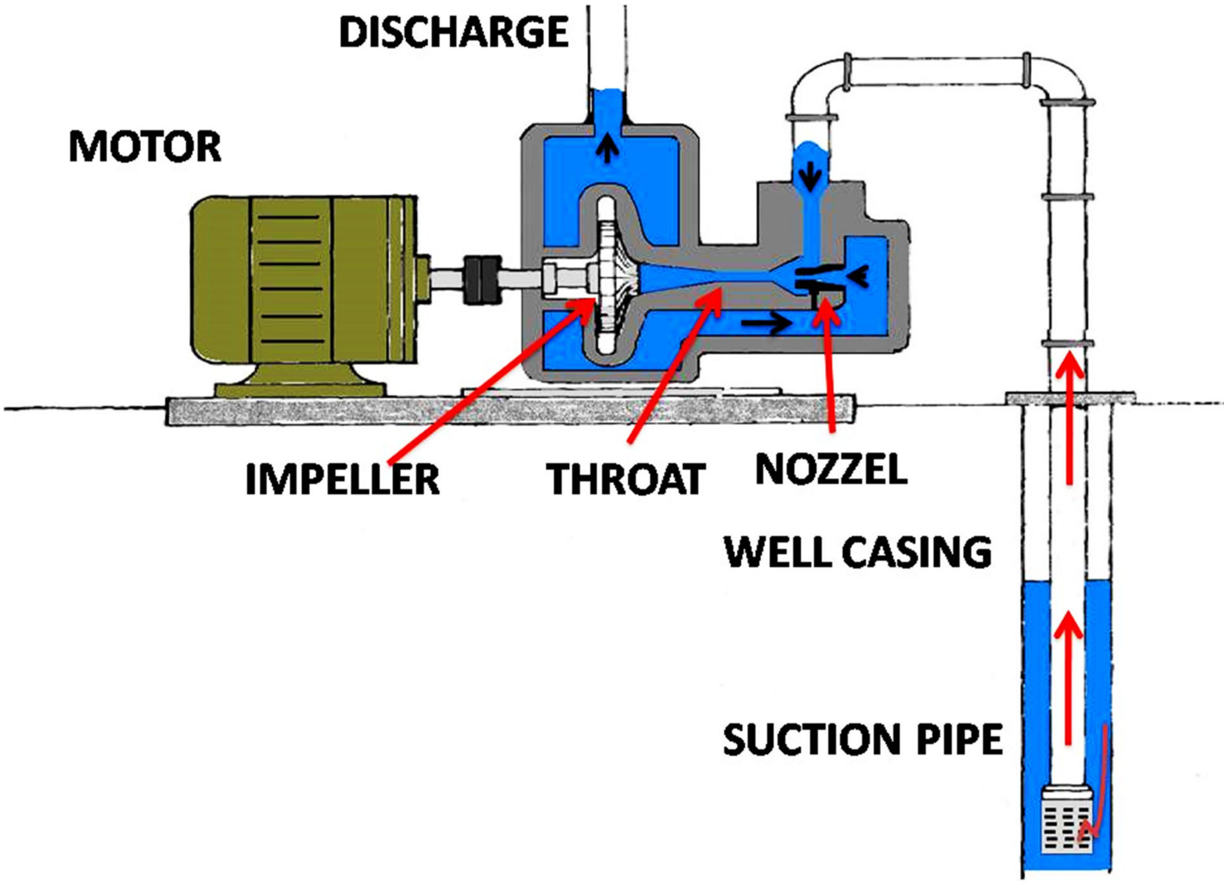
B. Carefully lift the bowl assembly and suction with a bail or clamp.

When installing a very long 6" or 8" bowl assembly, leave the bowl securely fastened to the wooden skid that is attached for shipping until the bowl assembly is raised to a vertical position. This will help prevent breaking the bowls or bending the shaft.

C. If a strainer is to be used, attach to the bowl assembly using the fasteners provided. If a threaded strainer is to be used, attach to the bowl assembly by threading them together.
D. Lower the bowl assembly into the well or sump. Set the clamp or holding device that is attached to the bowls on a flat surface. This is to stabilize the bowl assembly and reduce possibility of cross threading shaft.

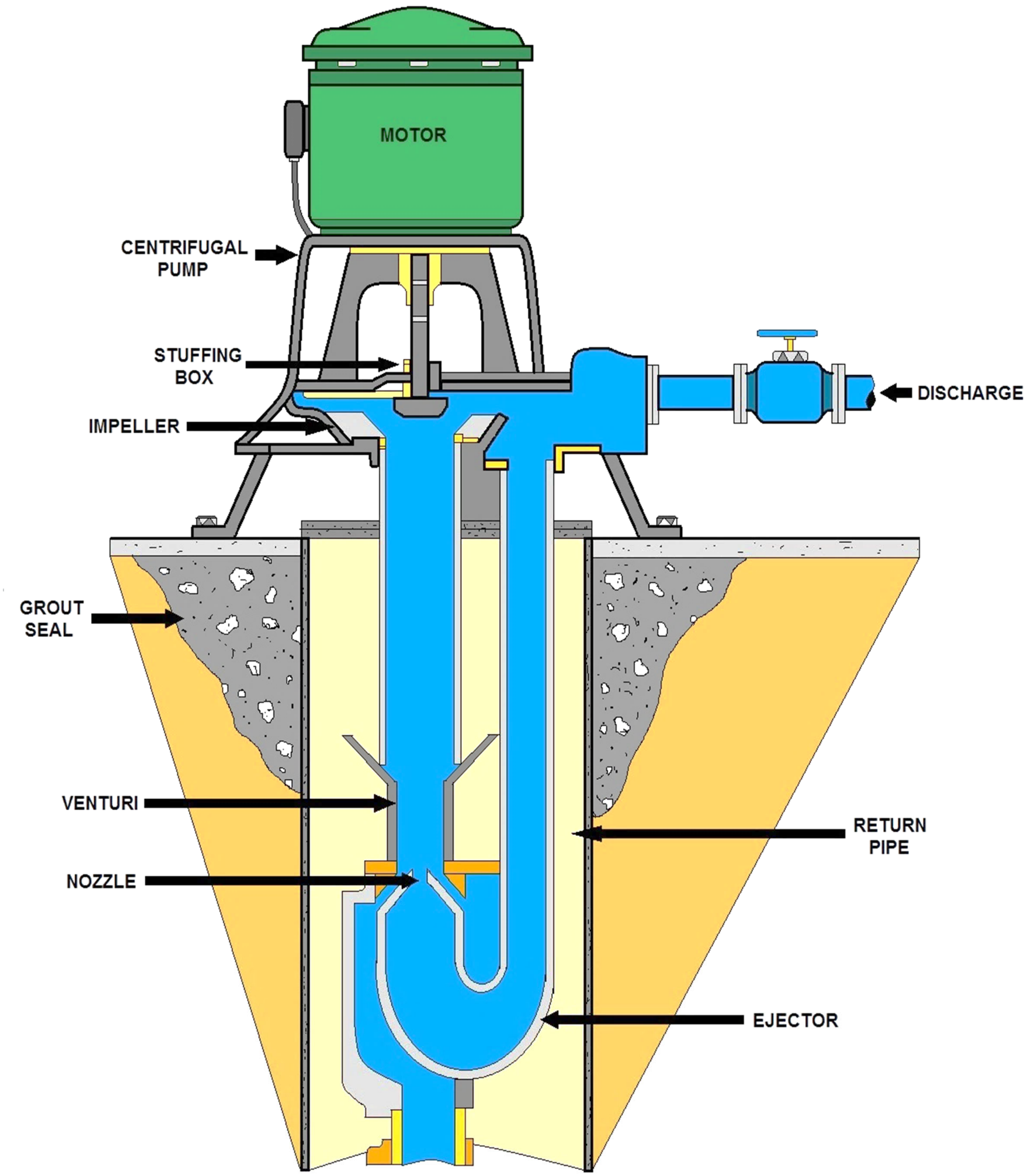
3. Column Assembly

A. Plan the assembly by process before proceeding to assure proper placement of pump components. Match each lineshaft, line shaft sleeve, bearing/retainer assembly and bolting set to the appropriate column pipe.
B. Slide the shaft into the column pipe being careful not to damage any threads or to get dirt into the column pipe.
C. Thread shaft coupling onto bottom end of shaft (left hand threads). Shaft coupling must be centered so the air relief hole is located at the end of the shaft. The end faces of the pump shafts must be centered in the coupling and aligned with the relief hole drilled into the side of the coupling. To verify that the end of the shaft is centered in the coupling and aligned with the relief hole, insert a small wire (a paper clip works well) into the hole to feel where the shaft ends. Remove the wire before tightening the coupling and shafts. Excess thread lubricant will purge out of the relief hole when properly aligned.
D. Attach hoist to the first section of column pipe. Using rope, tie the shaft and column pipe together so that the shaft does not slip out of the column pipe. Raise the column and shaft to a vertical position over the bowl assembly.
Do not allow the shaft to drag or bump while it is being raised. When handling the shaft horizontally, always support in at least three places - never two.
E. Make sure the shafting faces, threads and couplings are clean. Holding lineshaft with pipe wrench, lower lineshaft. Align lineshaft with pump shaft to prevent cross threading and thread shaft into coupling (left hand threads). All shaft faces must butt inside coupling or damage will result on start-up.
F. Lower the column pipe to engage with the fit circle or threads (right hand threads) on bowl assembly. If flanged, tighten the column pipe bolts attaching the upper part of the bowl assembly to column pipe. If threaded with pipe thongs, thread the column pipe onto the bowl so the end of the pipe butts to the bowl.
G. Lift to allow removal of clamp holding bowl assembly in place. Carefully lower this section into well or sump so that it rests on upper clamp.
H. Slide the bearing retainer with bushing over the shaft and insert into column coupling. Make certain the bearing retainer ring is butted against the top end of the column pipe.
I. If threaded construction, thread the top column flange to the top column. No bearing retainer, bearing or sleeve is included on this connection.
J. Bolt the top column flange with an O-ring or gasket to the bottom of the discharge head.
K. Repeat this procedure for each column section. Add lineshaft bearings and retainer at each pipe joint. If the pump is equipped with shaft sleeves, orient the shaft sleeve with the drive hub and set screws on top. Slide the sleeve down the pump shaft until the shaft sleeve is centered along the length of the bearing. Remove the set screws and apply thread locking compound such as Loctite. Tighten the set screws securely against the shaft.



SUBMERSIBLE PUMP WITH BOOSTER DIAGRAM #2

Vertical Turbine Pump Sub-Section



VERTICAL TURBINE INSTALLATION DIAGRAM AKA JET PUMP

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

Deep well turbine pumps are adapted for use in cased wells or where the water surface is below the practical limits of a centrifugal pump. Turbine pumps are also used with surface water systems. Since the intake for the turbine pump is continuously under water, priming is not a concern. Turbine pump efficiencies are comparable to or greater than most centrifugal pumps. They are usually more expensive than centrifugal pumps and more difficult to inspect and repair.

The turbine pump has three main parts: (1) the head assembly, (2) the shaft and column assembly and (3) the pump bowl assembly. The head is normally cast iron and designed to be installed on a foundation. It supports the column, shaft, and bowl assemblies, and provides a discharge for the water. It also will support 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.

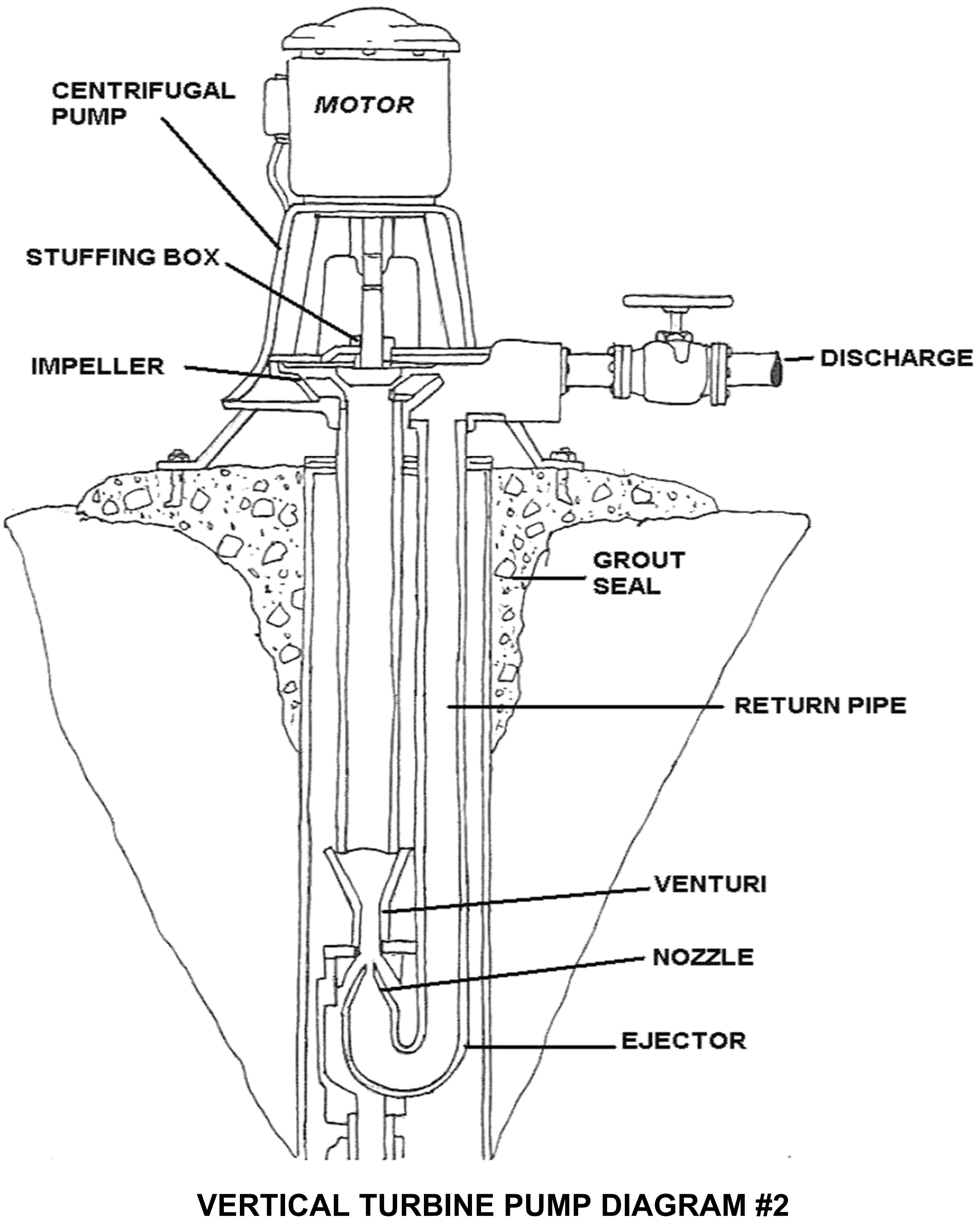
Column assembly is of two basic types, either of which may be used:
1. Open lineshaft construction utilizes the fluid being pumped to lubricate the lineshaft bearings.
2. Enclosed lineshaft construction has an enclosing tube around the lineshaft and utilizes oil, grease, or injected liquid (usually clean 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 if often provided by the pump manufacturer.



VERTICAL TURBINE PUMP DIAGRAM #2

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.

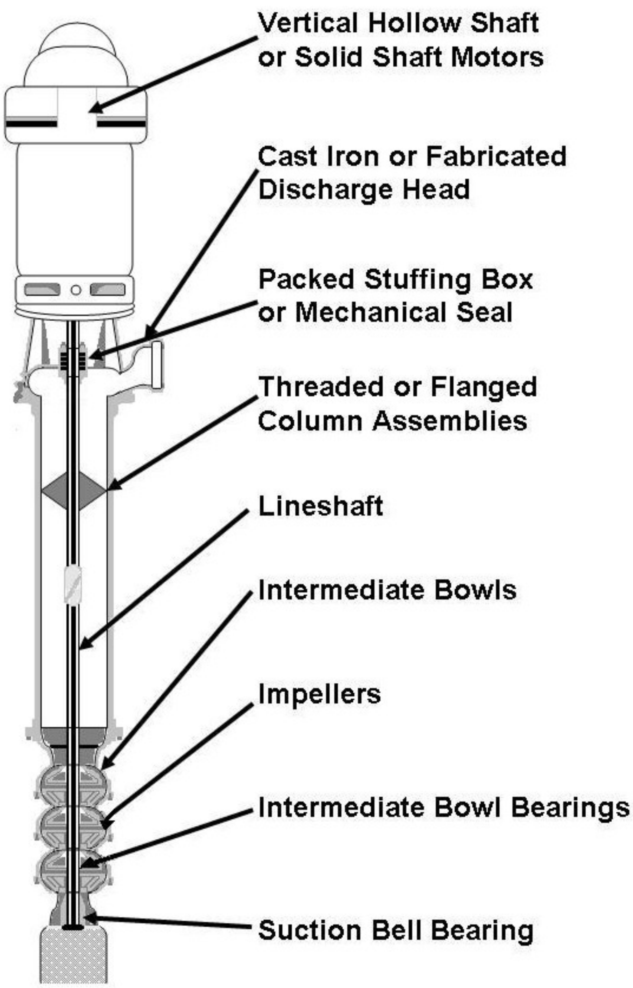
General Maintenance Section
A periodic inspection is recommended as the best means of preventing breakdown and keeping maintenance costs to a minimum. Maintenance personnel should look over the whole installation with a critical eye each time the pump is inspected — a change in noise level, amplitude 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.

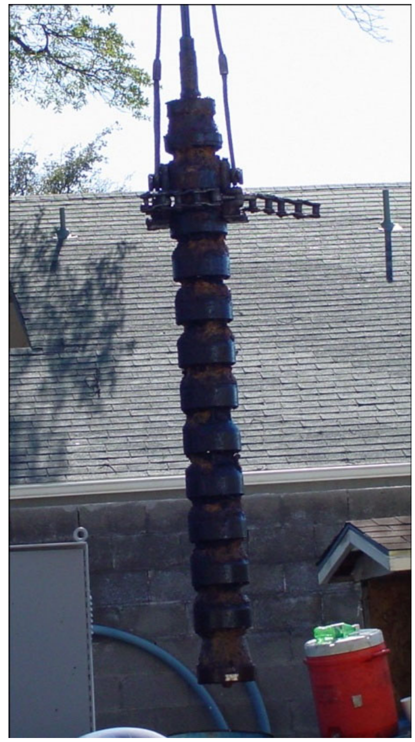
Determination of the cause of any misperformance or improper operation is essential to the correction of the trouble — whether the correction is done by the user, the dealer or reported back to the factory. Variances from initial performance will indicate changing system conditions or wear or impending 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 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.

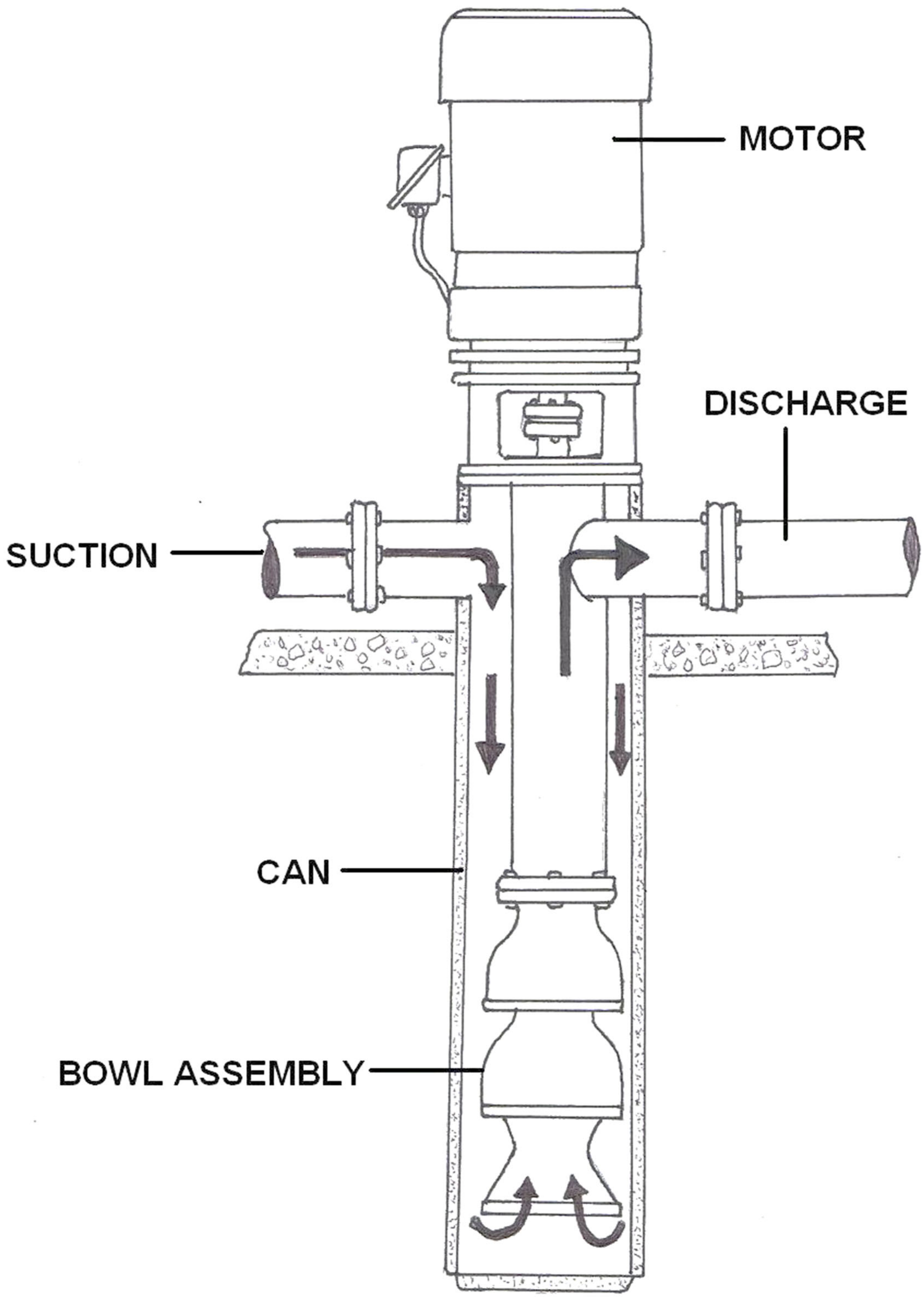
Common Elements of Vertical Turbines





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

Closed Pump Impeller



VERTICAL TURBINE PUMP DIAGRAM #3

Maintenance of a Vertical Turbine Pump

Periodic Inspection
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 of 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 impending breakdown of the unit.

Monthly Inspection
A periodic monthly inspection is suggested for all units. During this inspection the pump and driver should be checked for performance, change in noise or vibration level, loose bolts or piping, dirt and corrosion. Clean and re-paint all areas that are rusted or corroded.

Impeller Re-Adjustment
Ordinarily impellers will not require readjustment if properly set at initial installation. Almost no change in performance can be obtained by minor adjustment of enclosed impellers. All adjustments of the impellers will change the mechanical seal setting. It is recommended that the seal be loosened from the shaft until the adjustment is complete and then reset.

Pump Lubrication
Other than the stuffing box lubrication, mechanical seal, and/or lineshaft lubrication, the pump will not require further periodic lubrication. On water pumps and sumps, the suction bearing on the bowl assembly should be repacked when repairs are made, however, no attempt should be made to repack until repairs to the bowl assembly are necessary. Pumps that pump hydrocarbons or have carbon or rubber bearings do not have the suction bearing packed.

Driver Lubrication
Drivers will require periodic attention. Refer to the Driver Instruction Manual for recommendations.

General Maintenance
Maintenance of the stuffing box will consist of greasing the box when required, tightening the packing gland occasionally as the leakage becomes excessive, and installing new packing rings or sets as required.

Replacing Packing
Remove gland and all old packing. If the box contains a lantern ring remove this and all packing below it using two long threaded machine screws. Inspect shaft or sleeve for score marks or rough spots. Be sure by-pass holes (if supplied) are not plugged. Repair or replace badly worn shaft or sleeve. If wear is minor, dress down until smooth and concentric. Clean box bore. Oil inside and outside or replacement rings lightly and install in box, staggering joints 90 degrees.

Be sure to replace lantern ring in proper position when used. Replace gland and tighten nuts finger tight. The packing gland must never be tightened to the point where leakage from the packing is stopped. A small amount of leakage is required for packing lubrication.

Start-Up Procedures with New Packing

Check to see that the by-pass line (if used) is connected and the packing gland is loose. Start pump and allow to run for 20 to 30 minutes. Do not tighten the gland during this “run-in” period even if leakage is excessive. If the leakage continues to be more than normal. Should the new packing cause excess heating during “run-in” flush the shaft and packing box area with cold water or shut the pump down and allow to cool if necessary.

Components of a Vertical Turbine Pump

Drivers

A variety of drivers may be used; however, electric motors are most common. For the purposes of this manual all types of drivers supplied will be hollow shaft. On a hollow shaft driver, the headshaft extends through a tube in the center of the rotor and is connected to the driver by a coupling assembly at the top of the driver.

Head Assembly

The discharge head supports the driver, column and bowl assembly as well as supplying a discharge connection. 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 a mechanical seal assembly. However, some applications require rope packing.

Column Assembly

Column assembly is of open lineshaft construction. It utilizes the fluid being pumped to lubricate the lineshaft bearings. The column assembly will consist of a column pipe, which connects the bowl assembly to the discharge head and carries the pumped fluid to the discharge head; shaft, connecting the pump shaft driver; and may contain bearings if required for the particular unit.

Bowl Assemblies

The suction strainer, when supplied, is attached to the suction bell. It is used to prevent large objects from entering the pump. The bowl assembly consists of a discharge case, impellers, a shaft, intermediate bowls, suction bell, and bearings. The suction bell directs the flow of liquid into the first stage impeller. The impellers are rigidly mounted to the shaft with tapered collets or keys with lock rings. Bearings are located in the suction bell, intermediate bowls and discharge case to support the shaft. The discharge case connects the pump to the bottom of the column pipe.

Understanding Pump Bowl Assembly

The suction strainer, when supplied, is attached to the suction bell. It is used to prevent large objects from entering the pump. The bowl assembly consists of a discharge case, impellers, a shaft, intermediate bowls, suction bell, and bearings. The suction bell directs the flow of liquid into the first stage impeller. The impellers are rigidly mounted to the shaft with tapered collets or keys with lock rings. Bearings are located in the suction bell, intermediate bowls and discharge case to support the shaft. The discharge case connects the pump to the bottom of the column pipe.

Understanding Pump Drivers

A variety of drivers may be used; however, electric motors are most common. For the purposes of this manual all types of drivers supplied will be hollow shaft. On a hollow shaft driver, the headshaft extends through a tube in the center of the rotor and is connected to the driver by a coupling assembly at the top of the driver.

The parts in the driver section can consist of the following:

- Motor (Driver)
- Coupling
- Motor adapter
- Belts
- Gears

The driver section need not contain all of the items listed above. As a minimum, a driver (usually a motor) is required. The coupling, belts and gears are power transmission devices that may or may not be required with the pump.

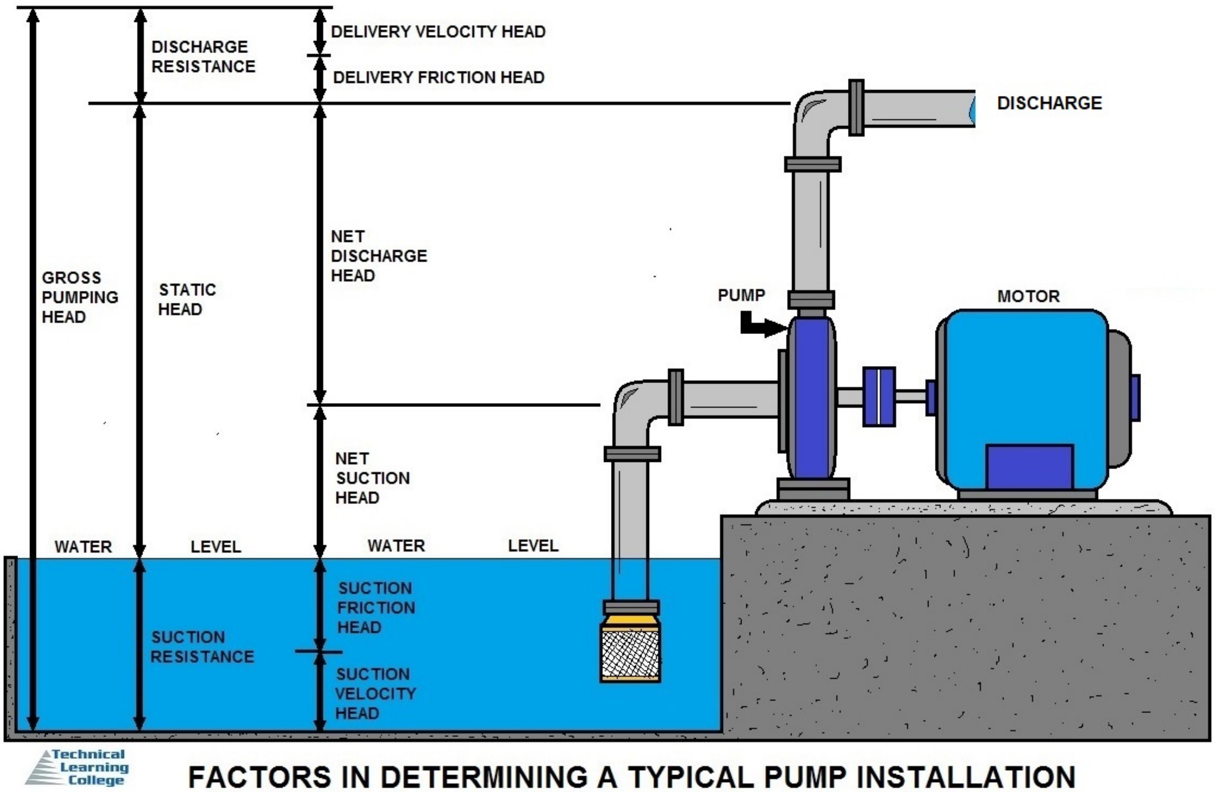
A coupling is a power transmission device that is used to connect the motor (driver) shaft to the power end shaft of the pump. The primary purpose of a coupling is to transmit rotary motion and torque from the motor to the pump.

Couplings often are required to perform other secondary functions as well. These other functions include accommodating misalignment between shafts, transmitting axial thrust loads from one machine to another, permitting adjustment of shafts to compensate for wear and maintaining precise alignment between connected shafts.

Many times pumps use couplings installed with a spacer. A spacer coupling allows the pump to be disassembled without moving piping, the pump casing or motor.

Understanding Discharge Head Assembly
Head Assembly

The discharge head supports the driver, column and bowl assembly as well as supplying a discharge connection. 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 a mechanical seal assembly. However, some applications require rope packing.



FACTORS IN DETERMINING A TYPICAL PUMP INSTALLATION

General Pumping Review/Troubleshooting Section

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

Backsiphonage is a condition in which the pressure in the distribution system is less than atmospheric pressure. In other words, something is "sucked" into the system because the main is under a vacuum.

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

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

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

The axial-flow pump is often referred to as a Propeller Pump. In all centrifugal pumps, there must be a flow restriction between the Impeller discharge and Suction areas that will prevent excessive circulation of water between the two parts.

Altitude-Control Valve is designed to, 1. Prevent overflows from the storage tank or reservoir, or 2. Maintain a constant water level as long as water pressure in the distribution system is adequate. Float mechanisms, diaphragm elements, bubbler tubes, and direct electronic sensors are common types of level sensors.

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

A chlorine demand test from a well water sample produces a result of 1.2 mg/L. The water supplier would like to maintain a free chlorine residual of 0.2 mg/L throughout the system. The chlorine dose should be 1.4 in mg/L from either a chlorinator or a hypochlorinator. The vacuum created by a chlorine ejector moves through this device. Check valve assembly prevents water from back feeding or entering the vacuum-regulator portion of the chlorinator.

A water storage facility should be able to provide water for the Fire and Peak demands. Surge tanks are used to control Water Hammer.

A couple of limitations of hydro-pneumatic tanks is; do not provide much storage to meet peak demands during power outages and you have a small or very limited time to do repairs on equipment.

Peak demand is defined as the maximum momentary load placed on a water treatment plant, pumping station or distribution system.

Concerning a single phase motor: If it is a split-phase motor, the motor will not have windings. A repulsion-induction motor is very simple and less expensive than other single phase motors. On most kilowatt meters, the current kilowatt load is indicated by Disk revolutions on the meter.

A foot valve is a check valve is located at the bottom end of the suction on a pump. This valve opens when the pump operates to allow water to enter the suction pipe but closes when the pump shuts off to prevent water from flowing out of the suction pipe.

Distribution system water quality can be adversely affected by improperly constructed or poorly located blowoffs of vacuum/air relief valves. Air relief valves in the distribution system lines must be placed in locations that cannot be flooded. This is to prevent water contamination. Milky water is a common customer complaint is sometimes solved by the installation of air relief valves.

A Centrifugal pump is consisting of an impeller fixed on a rotating shaft that is enclosed in a casing, and having an inlet and discharge connection? As the rotating impeller spins the liquid around, force builds up enough pressure to force the water through the discharge outlet. A pump engineer will normally design a system that would use multiple pumps for a parallel operation to provide for a fluctuating demand.

When the superintendent is inspecting the plans for a new ground water storage tank, the superintendent should pay attention to the inlet and outlet of this tank. The outlet and inlet should be on opposite sides of the tank.

Water quality in a storage facility could degrade due to excessive water age caused by low demands for water and short-circuiting within the distribution storage reservoir. The following are not other reasons for water quality degradation: Poor design, Inadequate maintenance and/or Improperly applied coating and linings.

Older transmitting equipment requires installation where temperature will not exceed 130 F. A diaphragm element being used as a level sensor would be used in conjunction with Pressure Sensor. Inspection of magnetic flow meter instrumentation should include checking for corrosion or insulation deterioration.

The most frequent problem that affects a liquid pressure-sensing device is air accumulation at the sensor. The following are common pressure sensing devices: Helical Sensor, Bourdon Tube and Bellows Sensor.

Common Pump and Troubleshooting Questions

1. 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. One of the most serious problems an operator will encounter is cavitation. It can be identified by a noise that sounds like marbles or rocks are being pumped. The pump may also vibrate and shake, to the point that piping is damaged, in some severe cases. Cavitation occurs when the pump starts discharging water at a rate faster than it can be drawn into the pump. This situation is normally caused by the loss of discharge head pressure or an obstruction in the suction line. When this happens, a partial vacuum is created in the impeller causing the flow to become very erratic. These vacuum-created cavities are formed on the backside of the impeller vanes. When cavitation occurs, immediate action must be taken to prevent the impeller, pump and motor bearings, and piping from being damaged. Cavitation can be temporarily corrected by throttling the discharge valve. This action prevents damage to the pump until the cause can be found and corrected. Remember that the discharge gate valve is there to isolate the pump, not control its flow. If it is left in a throttled position the valve face may become worn to the point that it won't seal when the pump must be isolated for maintenance. Butterfly valves can be throttled, but it is still not a good idea to throttle a pump with an isolation valve.

2. What purpose do air and/or vacuum release valves serve on well casings?
Air and/or vacuum release valves are used to release trapped air or vacuums created in water pipelines. This unique structure allows the dynamic valves to discharge air from the water system in a controlled and gradual manner, preventing slam and local up-surges. When vacuum occurs, the valves fast reaction will draw in large volumes of air into the water system, impeding down-surges and, consequently, all pressure surges in the line. The valves are normally closed when the line is not operating, thus preventing the infiltration of foreign particles and insects into the water system.

3. What is a sanitary seal and what purpose does it serve on a wellhead?
Sanitary seal: A device placed into the topmost part of a well casing which, by means of an expanding gasket, excludes foreign material from entering the well and may be provided with a means for introducing disinfecting agents directly into the well, or a device producing an equivalent effect. Such device shall be watertight to prevent the entrance of surface water and other contaminants into the well.

4. What are the functions of a well casing and well casing perforations?
Well Casing is used to maintain an open access in the earth while not allowing any entrance or leakage into the well from the surrounding formations. The most popular materials used for casing are black steel, galvanized steel, PVC pipe and concrete pipe.

5. Well Casing Perforations: Is the process of creating holes in production casing to establish communication between the well and formation. Perforation holes are used to recover water from the ground.

6. Which condition might cause a positive displacement diaphragm pump to cycle improperly? Plugged exhaust port

7. How can ball bearing failure in a pump shaft bearing generally be first detected? Perform vibration monitoring to detect failures or wait for excessive noise or heat. 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.

8. What is the purpose of the curved diffuser vanes on the inside of a pump volute?
Generation of Centrifugal Force: The process liquid enters the suction nozzle and then into eye (center) of a revolving device known as an impeller. When the impeller rotates, it spins the liquid sitting in the cavities between the vanes outward and provides centrifugal acceleration. As liquid leaves the eye of the impeller a low-pressure area is created causing more liquid to flow toward the inlet. Because the impeller blades are curved, the fluid is pushed in a tangential and radial direction by the centrifugal force. This force acting inside the pump is the same one that keeps water inside a bucket that is rotating at the end of a string.

9. What would be the advantage of starting and stopping a centrifugal pump against a closed discharge valve? Keeping the prime in the pipe and not allowing air to fill the pump.

10. What precautions should be taken when opening and closing the discharge valve?
Turbulent flows caused by pump discharges, elbows and swedges upstream of a valve will also cause the discs to flutter excessively. Be careful not to create a water hammer.

11. What effect could over-lubrication of grease-packed bearings have on a pump shaft?
Excessive friction and heat!

12. What are the three different designs of impellers in relation to shrouds that are used on centrifugal pumps?
Semi-Closed also called Free passage (Vortex), Open and Closed.

13. What is the proper procedure for starting a pump?
Fill the pump with liquid, crack open the discharge valve and start the motor. But, as you would guess, it is a little more complicated than that.
We'll begin by making sure the pump is filled with liquid. There are several ways to do that:

- Install a foot valve in the suction piping to insure the liquid will not drain from the pump casing and suction piping. Keep in mind that these valves have a nasty habit of leaking.
- Or you could evacuate the air in the piping system with a positive displacement priming pump operating between the pump and a closed discharge valve. Be sure the priming pump stuffing box is sealed with a mechanical seal and not conventional packing because packing will let air into the priming pump suction side. A balanced, O-ring seal would be a good choice for the priming pump stuffing box.
- Convert the application to a self-priming pump that maintains a reservoir of liquid at its suction.
- Fill the pump with liquid from an outside source prior to starting it.

Here is the proper way to vent a centrifugal pump after it has been initially installed, or the system has been opened. Assuming the pump is empty of liquid and both the suction and discharge valves are shut.

- Open the suction valve. The pump fills part way.
- Close the suction valve.
- Open the discharge valve part way. Once the pressure equalizes the air will rise in the discharge piping.
- Open the suction valve.
- Start the pump.
- When the pump hits its operating speed open the discharge valve to its proper setting to operate close to the BEP. (Best efficiency point)

14. What precautions should be taken before starting a water-lubricated pump?
The pump casing and suction piping must be filled with water. Bearings and stuffing boxes should be watched closely to make sure they do not overheat or require adjusting.

15. What factors would determine the size of well casing to use on a well?
Pump type, pump size and pumping depth. Well casings are installed in wells to prevent the collapse of the walls of the borehole, to exclude pollutants (either surface or subsurface) from entering the water source, and to provide a column of stored water to the well pump.

16. What is the main concern when using a coupling on a horizontal pump?
Proper alignment of the pump to the driver.

17. Why should accurate records be kept on pump operations?
For a record of the past and a database for planning future pumping.

18. What are the two most common speeds of a centrifugal pump?
High speed (critical) and slower speed (variable).

19. What is a close-coupled pump and what purpose do the motor bearings serve?
Close-coupled pump has the motor and pump together without a shaft between the two. The motor bearings will also support the impeller.

20. What should the operating pressure of seal water be in relation to the suction pressure of a pump? An independent supply of water is needed for the seal water and its pressure should be higher than the pump's suction.

21. What is the main purpose of a finished water storage reservoir?
To provide sufficient amount of water to an average or equalize the daily demands on the public water supply system. Also meeting the needs for average and peak demands and adequate pressures throughout the system. Meeting the needs for fire protection, industrial requirements and reserve storage.

22. What is the primary operation of drinking water storage tanks?
Fill tanks at night or during periods of low demand. Operated to design engineer's and manufacturer's instructions. Normally storage tanks are designed to provide or supply water during periods of high demand. And to maintain minimum pressures at critical points in the distribution system.

23. Standpipe: A method of storing water and equalizing water pressure to minimize the pulsations of water flowing in the mains, used prior to modern pumping methods, consisting of a large vertical pipe in which a column of water rises and falls; often built inside towers.

24. What is water hammer, how is it caused, and how can it be prevented?
A large pressure surge that damages pipes and equipment. It is caused by rapid rising or falling of water pressures or opening and shutting of valves. A hydropneumatic tank and careful opening of valves can limit water hammer damage.

25. Hydropneumatic tank: A method of storing water prior to distribution in a water supply system, whereby the water system pressure is maintained between a specified pressure range and is also called pressure tanks.

26. What is a hydro pneumatic tank and how does it operate?
These tanks store water prior to distribution in a water supply system, working with the pumps to maintain a stable water system pressure. The system pressure is controlled by a pressure switch set for minimum and maximum pressures – giving you a cut-in and a cut-out pressure for the pumps. When the pumps cut-out or stop running, water demand is met by the water volume in the piping and the tank. As water is drawn down, the system pressure starts to drop. When it reaches the minimum system pressure, the pump cuts back in and runs until the system pressure reaches the normal maximum pressure.

Pump Not Delivering Water

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

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

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

Pump Maintenance Tasks
Twice a year:

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

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

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

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

On the Suction Side of Pump:

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

- A vacuum gauge to indicate whether the primer is pulling a vacuum or just moving air through the pump.

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

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

Control Panel for Electric Motors
The importance of a properly installed control panel cannot be overemphasized for personal safety and for protecting your investment in your pump and motor. Your control panel should:
- Have a shade over it to keep thermal breakers cool.
- Be mounted on secure poles or foundation.
- Have any missing knockout plugs and other holes in the starting switch box replaced and screened or puttied against rodents, insects, and dirt.
- Have a small hole (3/16-inch diameter) in the bottom of the panel to allow moisture to drain.

Your control panel should include the following controls at a minimum:
- Circuit breaker(s) for overload currents.
- Lightning arrester.
- Surge protector.
- Phase failure relay, to protect the motor from phase reversal or failure and from low voltage.
- A pressure switch to shut off the motor if pumping pressure drops to undesirable levels.

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

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

Residents in some areas have a choice between steel and PVC, both of which have advantages. PVC is lightweight, resistant to corrosion, and relatively easy for contractors to install. However, it is not as strong and not as resistant to heat as steel.

Steel, though, is susceptible to corrosion, can have scale build-up, and can cost more than PVC.

Some contractors also use concrete, fiberglass, and asbestos cement casing.

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

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

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

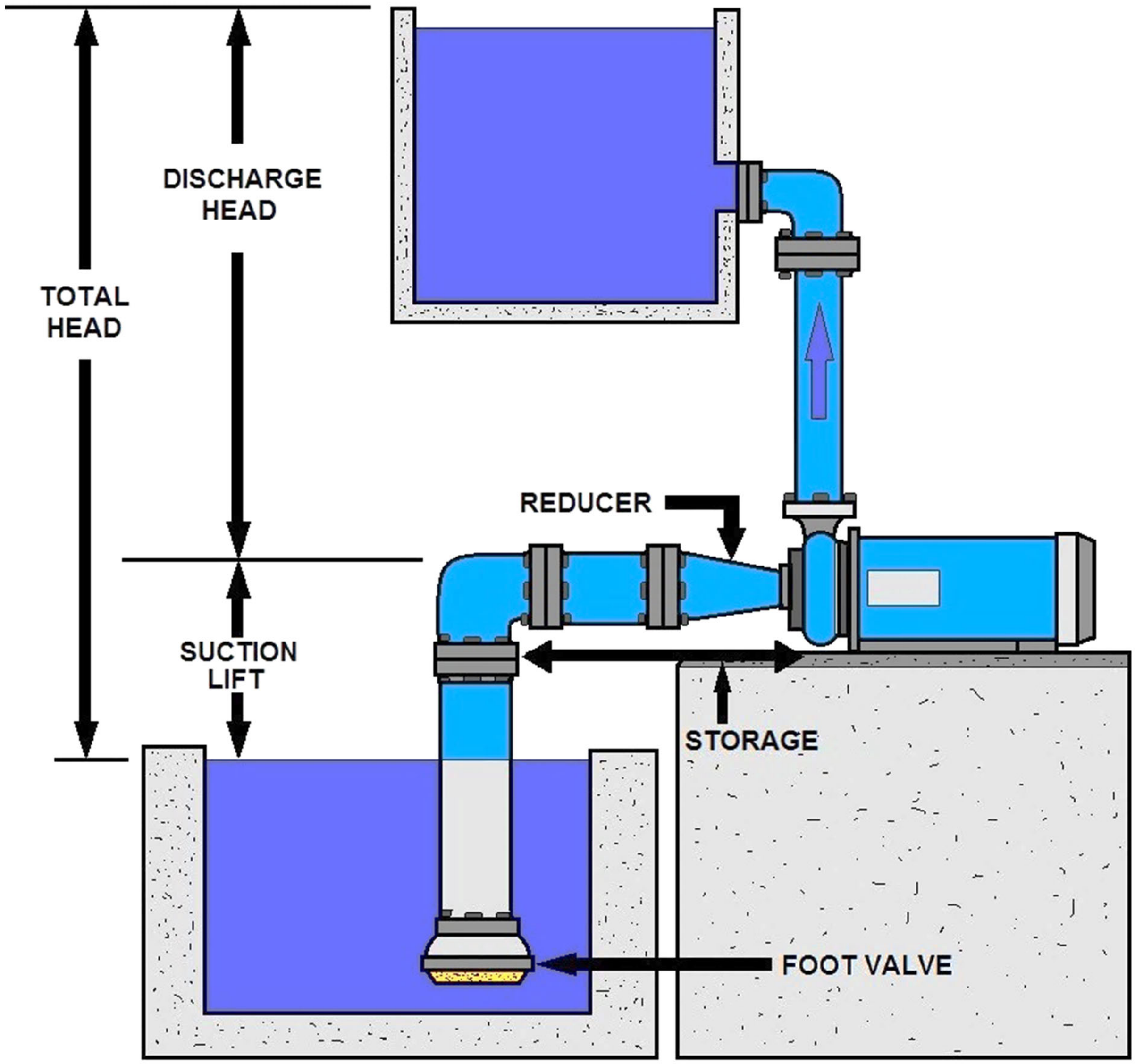
Well Screens
Well screens are filtering devices used to prevent excess sediment from entering the well. They attach to the bottom of the casing, allowing water to move through the well, while keeping out most gravel and sand. The most popular screens are continuous slot, slotted pipe, and perforated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

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

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

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

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



PUMPING PRINCIPAL FACTOR DIAGRAM #1

Control Systems

There is no single control strategy that is optimal for all pumping systems. In one case, on/off control is clearly preferred while in another, pump speed control is the obvious choice.

However, there are many systems for which the choice is not so clear or in which two or more different control schemes would work equally well. And there are some systems that merit a combination of controls, such as multiple parallel pumps with adjustable speed drives for each pump.

Each system must be evaluated on its own terms. The nature of the system curve, the performance characteristics of the installed pumps, the nature of the load variability, and other factors influence the decision process. It is important to note that all of these best practices are likelihoods, not necessarily guarantees.

The following best practices will be discussed in the context of control strategies:

- ✓ Understand the fundamental nature of the system head requirements.
- ✓ Understand the variability of the required flow rate and head.
- ✓ Systems with essentially constant requirements and/or large storage inventories.
- ✓ Systems with continuously varying requirements (and lacking stored inventory).
- ✓ Systems that operate in two or three principal operating zones.
- ✓ Minimize the use of throttling valves or bypass operation for flow regulation.
- ✓ Demand charge minimization.

The most commonly selected control strategies for regulation of pumping systems are:

- ✓ Control valve throttling
- ✓ Bypass (pump recirculation) valve operation
- ✓ Multiple parallel pump operation
- ✓ On/off control
- ✓ Pump speed control
- ✓ Combinations of the above
- ✓ No control – the pumps just run

Systems in which neither the flow rate nor head need to be regulated (under normal, steady-state conditions) are prime candidates for on/off control. This is a general rule of thumb and does not apply to all systems.

An excellent example of this type of system is the municipal water system, where filtered and treated water is pumped from the clear well of a chemical plant to elevated storage tanks.

Although customer demands vary with the time of day and weather conditions, the system storage in most municipal operations provides a sufficient buffer to meet these demand fluctuations. The elevated tanks, of course, also provide a relative constant source of pressure.

Multiple Flow Regime (Parallel Pump) Controls

Systems with varying flow requirements that operate in discrete regimes can generally be well served by a parallel pump operation, where pumps are properly sized and selected for the individual flow regimes. In the case of the static-dominated system, two options would merit consideration. Two pumps could be chosen to operate solo under the two flow regimes. Or, one pump could be used for the lower flow regime (1000 gpm) and a second pump turned on to run in parallel with the smaller pump to meet the 5000 gpm requirement.

One important note regarding distinct regime operation: In some cases, the intervals for these flow regimes are long and in others, they're short. The parallel pump operation is most readily applied to the longer intervals (such as once per shift). Where the cycles occur in relatively quick fashion (minutes), special care is needed. Frequent direct across-the-line motor starting is hard on switchgear, motors, pumps, and systems. If frequent starting is needed, the use of electronic soft starters or other alternatives (such as adjustable speed drives) should definitely be considered.

Best Practice —Parallel Pump Control
If there are multiple obvious flow regimes noticed from the system, investigate the option of parallel pumps to handle the different regimes.

Minimize the Use of Throttling Valves or Bypass Operation

One generic best practice is to minimize the use of valve throttling and bypass losses in system control. Throttled valves convert hydraulic energy that the pump has imparted to the fluid into frictional heat, thus wasting a portion of the pump's energy. Bypass control simply routes some of the fluid that the pump has energized right back where it came from (dissipating the energy into heat in the process). Even this best practice, which is about as close as one can get to simplistic rules of thumb in pumping systems, has its exceptions.

General Centrifugal Pump Maintenance Procedures

Centrifugal Pump Start-up- (Beginning of Season)

Maintenance Tasks

- Using new gaskets and pipe-dope, reconnect to the pump any piping removed during shutdown.
- Re-install the primer and priming valve if they were removed during shutdown.
- Check that the pump shaft turns freely and is free of foreign objects. Applying power could break the impeller if it's rusted to the case.
- Check the pump for leaks caused by drying gaskets.
- Check intake and discharge piping for proper support and make sure the pump is securely bolted to the platform.
- Clean the drain hole on the underside of the pump.

General
To avoid water leaks, make sure that all gaskets are the correct ones for the coupling or flange. Eliminate air leaks in your pump's suction line by coating threaded connections with pipe cement or white lead and drawing them tight. Also examine suction line welds for cracks, which will allow air leaks.

Complicated Pumps Post Quiz

1. ______________________ 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.

2. Cavitation can be temporarily corrected by throttling the______.

3. _________________are used to release trapped air or vacuums created in water pipelines.

4. ________________is used to maintain an open access in the earth while not allowing any entrance or leakage into the well from the surrounding formations.

5. Turbulent flows caused by pump discharges, elbows and swedges upstream of a valve will also cause the discs to flutter excessively. Be careful not to create a_________________.

6. Proper procedure for starting a pump**.** Fill the pump with liquid, crack open the _____________and start the motor.

7. Install a _______________in the suction piping to insure the liquid will not drain from the pump casing and suction piping. Keep in mind that these valves have a nasty habit of leaking.

8. Convert the application to a _______________that maintains a reservoir of liquid at its suction.

9. Questions 9-14 – in order- Here is the proper way to vent a centrifugal pump after it has been initially installed, or the system has been opened. Assuming the pump is empty of liquid and both the suction and discharge valves are shut. Open the suction valve. The pump fills part way.
A. True B. False

10. Open the suction valve.
A. True B. False

11. Open the discharge valve part way. Once the pressure equalizes the air will rise in the discharge piping.
A. True B. False

12. Close the suction valve.
A. True B. False

13. Shut off the pump.

A. True B. False

14. When the pump hits its operating speed open the discharge valve to its proper setting to operate close to the BEP. (Best efficiency point)

A. True B. False

15. Close-coupled pump has the motor and pump together without a shaft between the two. The ______________will also support the impeller.

16. An independent supply of water is needed for the _____________and its pressure should be higher than the pump's suction.

17. The system pressure is controlled by a pressure switch set for minimum and maximum pressures – giving you a cut-in and a cut-out pressure for the pumps.

A. True B. False

18. When the pumps cut-out or stop running, water demand is met by the water volume in the piping and the tank. As water is drawn down, the system pressure starts to drop. When it reaches the minimum system pressure, the pump cuts back in and runs until the system pressure reaches the normal maximum pressure.

A. True B. False

Answers: 1. Cavitation, 2. Discharge valve, 3. Air and/or vacuum release valves, 4. Well Casing, 5. Water hammer, 6. Discharge valve, 7. Foot valve, 8. Self-priming pump, 9. True, 10. False, 11. True, 12. False, 13. False, 14. True, 15. Motor bearings, 16. Seal water, 17. True, 18. True

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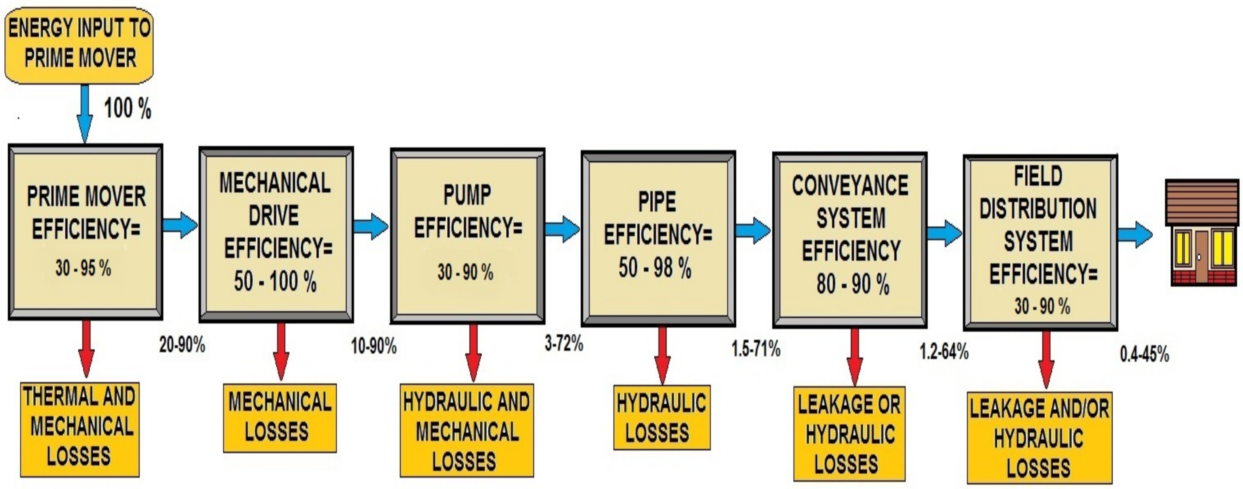
Section 5- Pump Operation & Performance

Section Focus: You will learn the basics of pump operation. At the end of this section, you the student will be able to describe principles required to pump water. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: You also need to be aware of a pump's requirements i.e. various pumping head, net positive suction head, etc.



SYSTEM ENERGY EFFICIENCY LOSSES DIAGRAM

Pumps transfer liquids from one point to another by converting mechanical energy from a rotating impeller into pressure energy (head).

The pressure applied to the liquid forces the fluid to flow at the required rate and to overcome friction (or head) losses in piping, valves, fittings, and process equipment.

The pumping system designer must consider fluid properties, determine end use requirements, and understand environmental conditions.

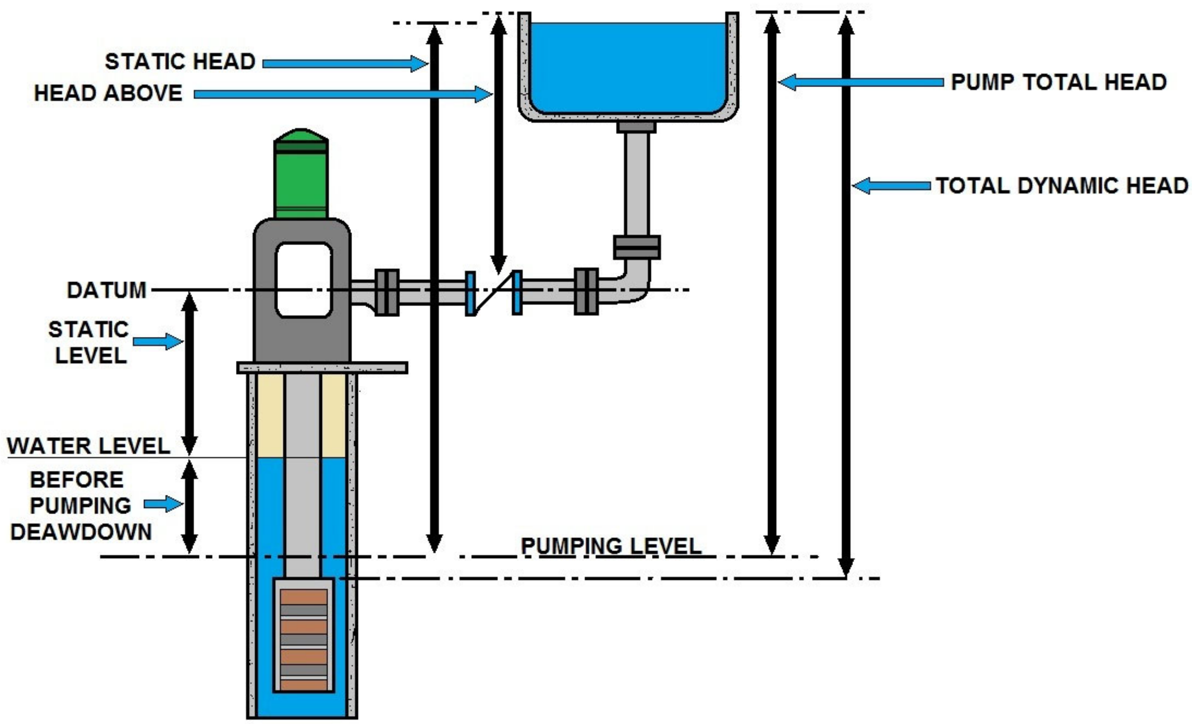
Pumping applications include constant or variable flow rate requirements, serving single or networked loads, and consisting of open loops (non-return or liquid delivery) or closed loops (return systems).

Depending on the industry or plant that you work in, you will probably work on or around a certain type of pump or manufacturer or both.

Pump manufacturers are normally a very good source of information for final pump selection and you should always consult with them, do your own selection first and confirm it with the manufacturer.

They can help you select the right type, model, and speed if you have all the operating conditions and if not they will rarely be able to help you. Most websites will help you gather all the information pertinent to operation and selection of your pump.

Aside from the normal end suction pump, vertical turbine and submersible pumps, there is a wide variety of specialized pumps- that you should consider for your application if you have unusual conditions.



PUMPING HEAD DIAGRAM #1

Pump Operation and Performance Key Terms

Hyperlink to the Glossary and Appendix
http://www.abctlc.com/downloads/PDF/PumpGlossary.pdf

Best Efficiency Point (BEP)
The rate of flow and total head at which the pump efficiency is maximum at a given speed and impeller diameter.

Casing
The portion of the pump that includes the impeller chamber and volute diffuser.

Diffuser
A piece, adjacent to the impeller exit, which has multiple passages of increasing area for converting velocity to pressure.

Displacement (D)
For a positive displacement pump, it is the theoretical volume per revolution of the pump shaft. Calculation methods and terminology may differ between different types of positive displacement pumps.

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

Head (h) [H]
Head is the expression of the energy content of a liquid in reference to an arbitrary datum. It is expressed in units of energy per unit weight of liquid. The measuring unit for head is meters (feet) of 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.

Head, Total (H) [Htx]
This is the measure of energy increase, per unit weight of liquid, imparted to the liquid by the pump, and is the difference between total discharge head and total suction head. This is the head normally specified for pumping applications because the complete characteristics of a system determine the total head required.

Hydraulics
Engineering science pertaining to liquid pressure and flow.

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

Inducer
A single-stage axial flow helix installed in the suction eye of an impeller to lower the NPSHR.

Impeller
The bladed member of a rotating assembly of the pump which imparts the principal force to the liquid pumped.

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

Net Positive Suction Head Available (NPSHA)
NPSHA is determined by the conditions of the installation and is the total suction head of liquid absolute, determined at the first-stage impeller datum minus the absolute vapor pressure in meters (feet) of the liquid at a specific rate of flow expressed in meters (feet) of liquid. Note that for positive displacement pumps the term Net Positive Inlet Pressure Available (NPIPA) is used and is expressed in pressure absolute kPa (psi).

Net Positive Suction Head Required (NPSHR)
NPSHR is the minimum NPSH given by the manufacturer/supplier for a pump achieving a specified performance at the specified capacity, speed, and pumped liquid. Note that occurrence of visible cavitation, increase of noise and vibration due to cavitation, beginning of head or efficiency drop, and cavitation erosion can occur when margin above NPSHr is present. Note that for positive displacement pumps the term Net Positive Inlet Pressure Required (NPIPR) is expressed in pressure absolute kPa (psi).

Net Positive Suction Head 3% (NPSH3)
For rotodynamic pumps NPSH3 is defined as the value of NPSHR at which the first-stage total head drops by 3% due to cavitation. This is determined by the vendor by testing with water as outlined in. ANSI/HI 14.6 Rotodynamic Pumps for Hydraulic Performance Acceptance Tests

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

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

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

Pressure, Static
The pressure in a fluid at rest.

Rate of Flow [Q]
The rate of flow of a pump is the total volume throughput per unit of time at suction conditions. The term capacity is also used.

Specific Gravity S.G.
The weight of liquid in comparison to water at approx. 20 degrees C (SG = 1).

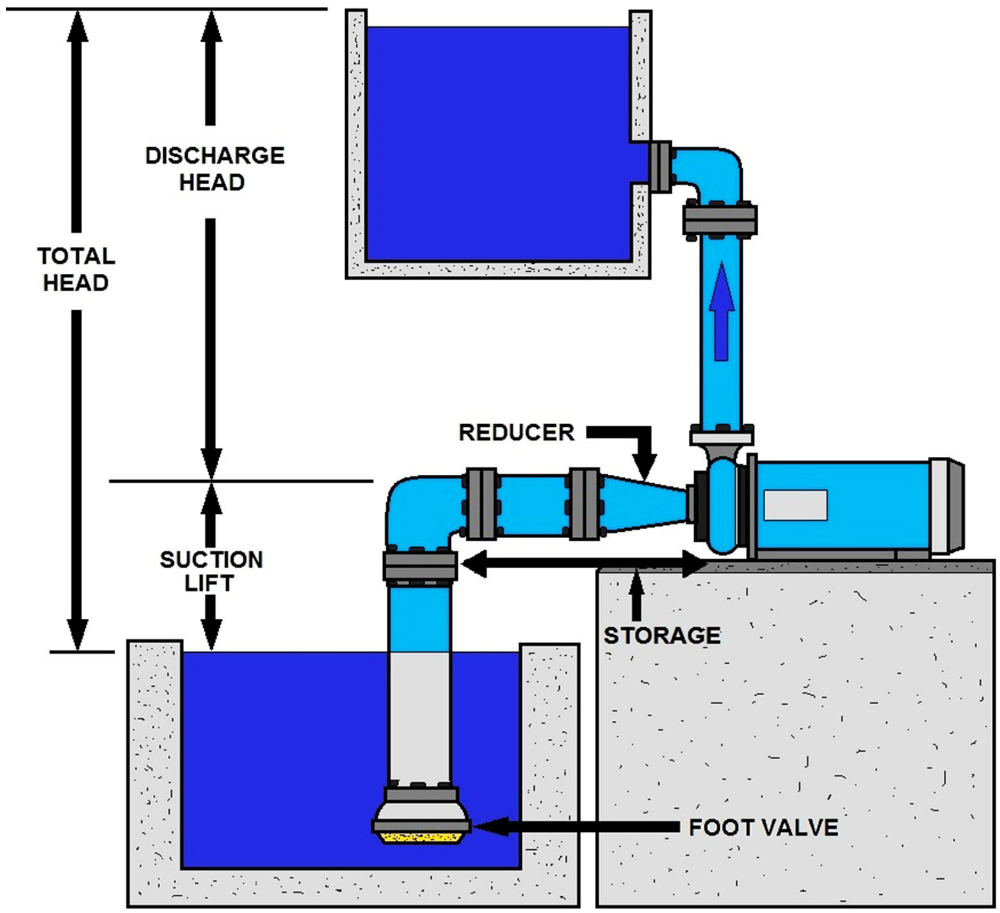
Specific Speed
A number which is the function of pump flow, head, efficiency etc. Not used in day to day pump selection, but very useful, as pumps with similar specific speed will have similar shaped curves, similar efficiency / NPSH / solids handling characteristics.

Suction Specific Speed (S)
Suction specific speed is an index of pump suction operating characteristics. It is determined at the BEP rate of flow with the maximum diameter impeller. Suction specific speed is an indicator of the net positive suction head required [NPSH3] for given values of capacity and also provides an assessment of a pump's susceptibility to internal recirculation. Suction specific speed is expressed by the following equation: Suction Specific Speed

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.

Volute
The pump casing for a centrifugal type of pump, typically spiral or circular in shape.



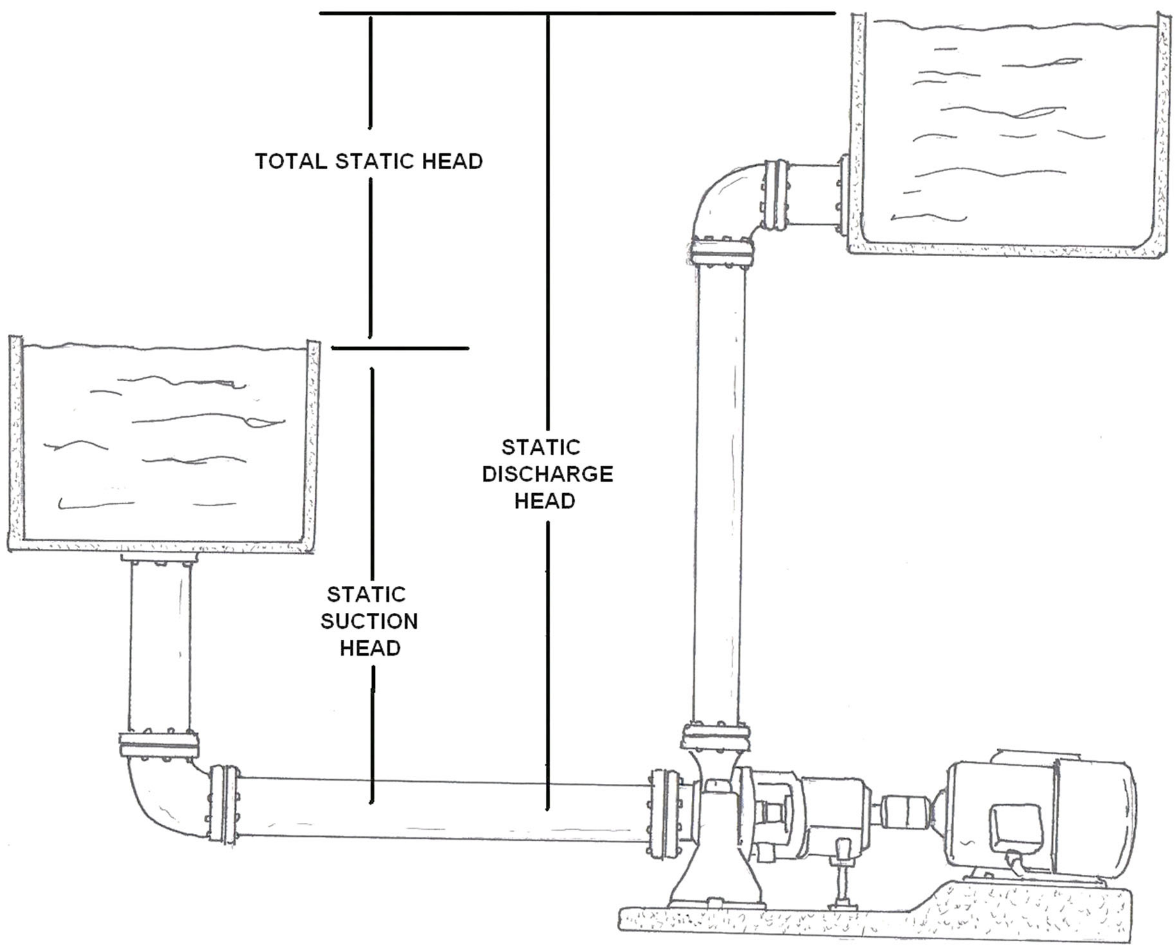
PUMPING FACTORS

Pump Requirements/Operation Introduction

Understanding Your Pumping System Requirements

Pumps transfer liquids from one point to another by converting mechanical energy from a rotating impeller into pressure energy (head). The pressure applied to the liquid forces the fluid to flow at the required rate and to overcome friction (or head) losses in piping, valves, fittings, and process equipment.

The pumping system designer must consider fluid properties, determine end use requirements, and understand environmental conditions. Pumping applications include constant or variable flow rate requirements, serving single or networked loads, and consisting of open loops (non-return or liquid delivery) or closed loops (return systems).



End Use Requirements—System Flow Rate and Head

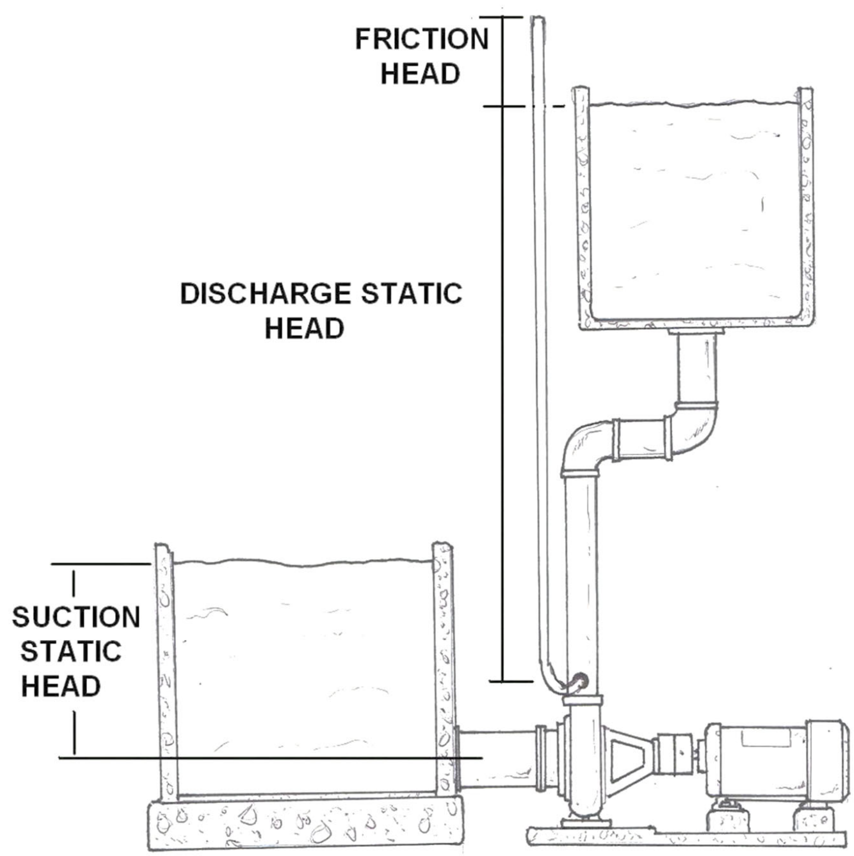
The design pump capacity, or desired pump discharge in gallons per minute (gpm) is needed to accurately size the piping system, determine friction head losses, construct a system curve, and select a pump and drive motor.

Process requirements may be met by providing a constant flow rate (with on/off control and storage used to satisfy variable flow rate requirements), or by using a throttling valve or variable speed drive to supply continuously variable flow rates.

The total system head has three components: static head, elevation (potential energy), and velocity (or dynamic) head. Static head is the pressure of the fluid in the system, and is the quantity measured by conventional pressure gauges.

The height of the fluid level can have a substantial impact on system head.

The dynamic head is the pressure required by the system to overcome head losses caused by flow rate resistance in pipes, valves, fittings, and mechanical equipment.



PUMPING FUNDAMENTALS

Dynamic head losses are approximately proportional to the square of the fluid flow velocity, or flow rate.

If the flow rate doubles, dynamic losses increased fourfold.

For many pumping systems, total system head requirements vary.

For example, in wet well or reservoir applications, suction and static lift requirements may vary as the water surface elevations fluctuate.

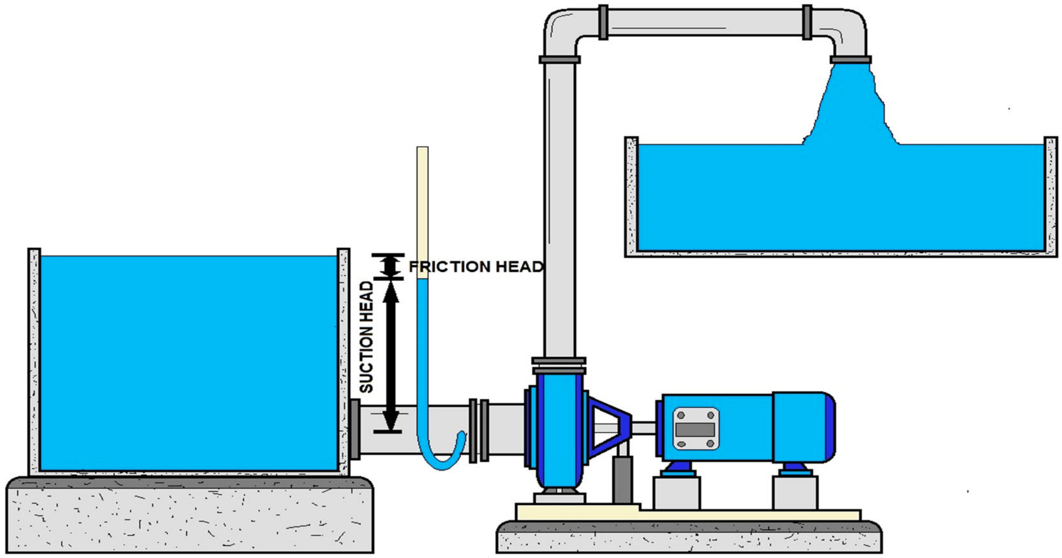
For return systems such as HVAC circulating water pumps, the values for the static and elevation heads equal zero.

You also need to be aware of a pump's net positive suction head requirements.

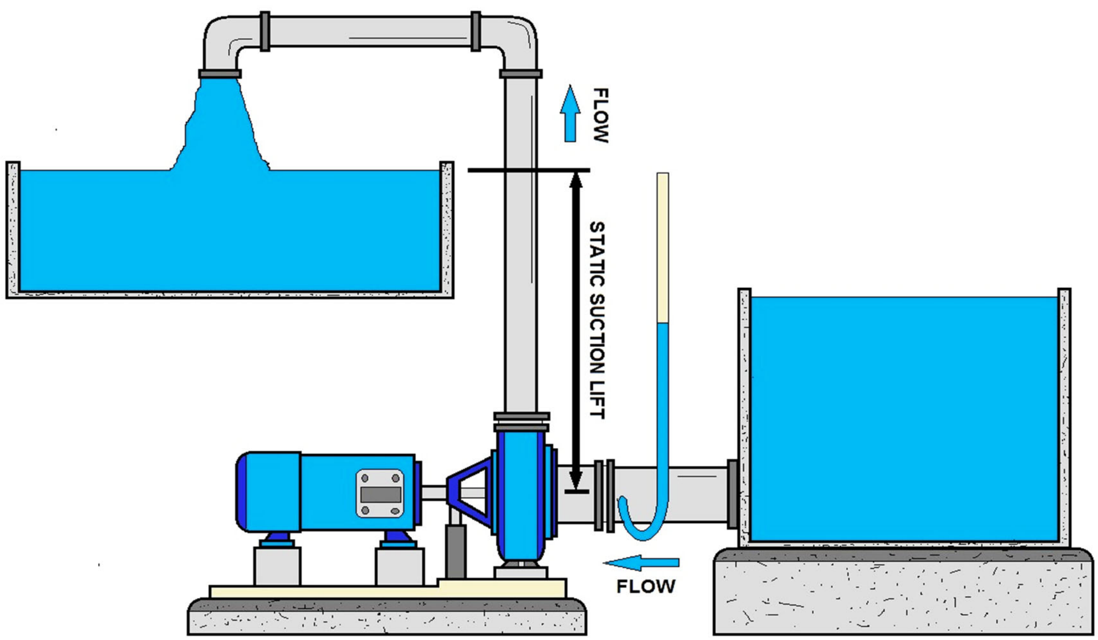
Centrifugal pumps require a certain amount of fluid pressure at the inlet to avoid cavitation.

A rule of thumb is to ensure that the suction head available exceeds that required by the pump by at least 25% over the range of expected flow rates.

Diagrams - Pumping Dynamics

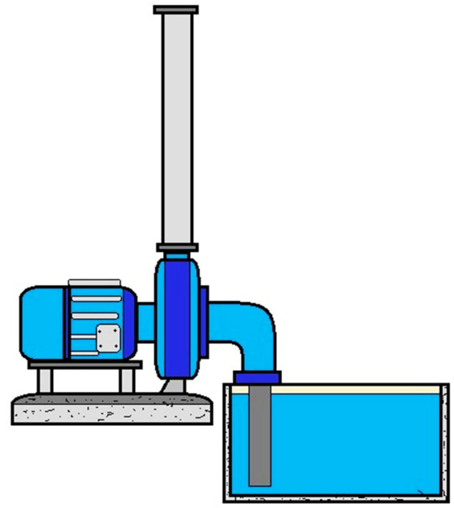


SUCTION HEAD (Suction Lift)



STATIC SUCTION LIFT

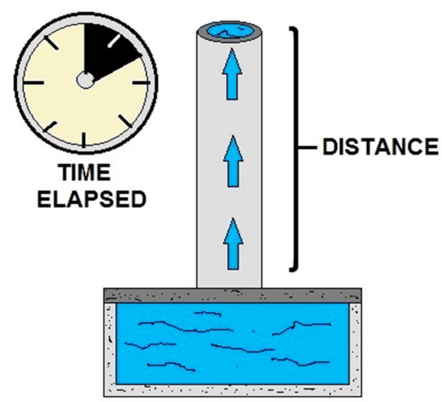
$$BHP = \frac{Q \times H}{3960 \times n} \times s.g.$$



BHP= Brake Horsepower
Q= Flow
H= Head
n= Efficiency
s.g.= Specific Gravity (always constant)

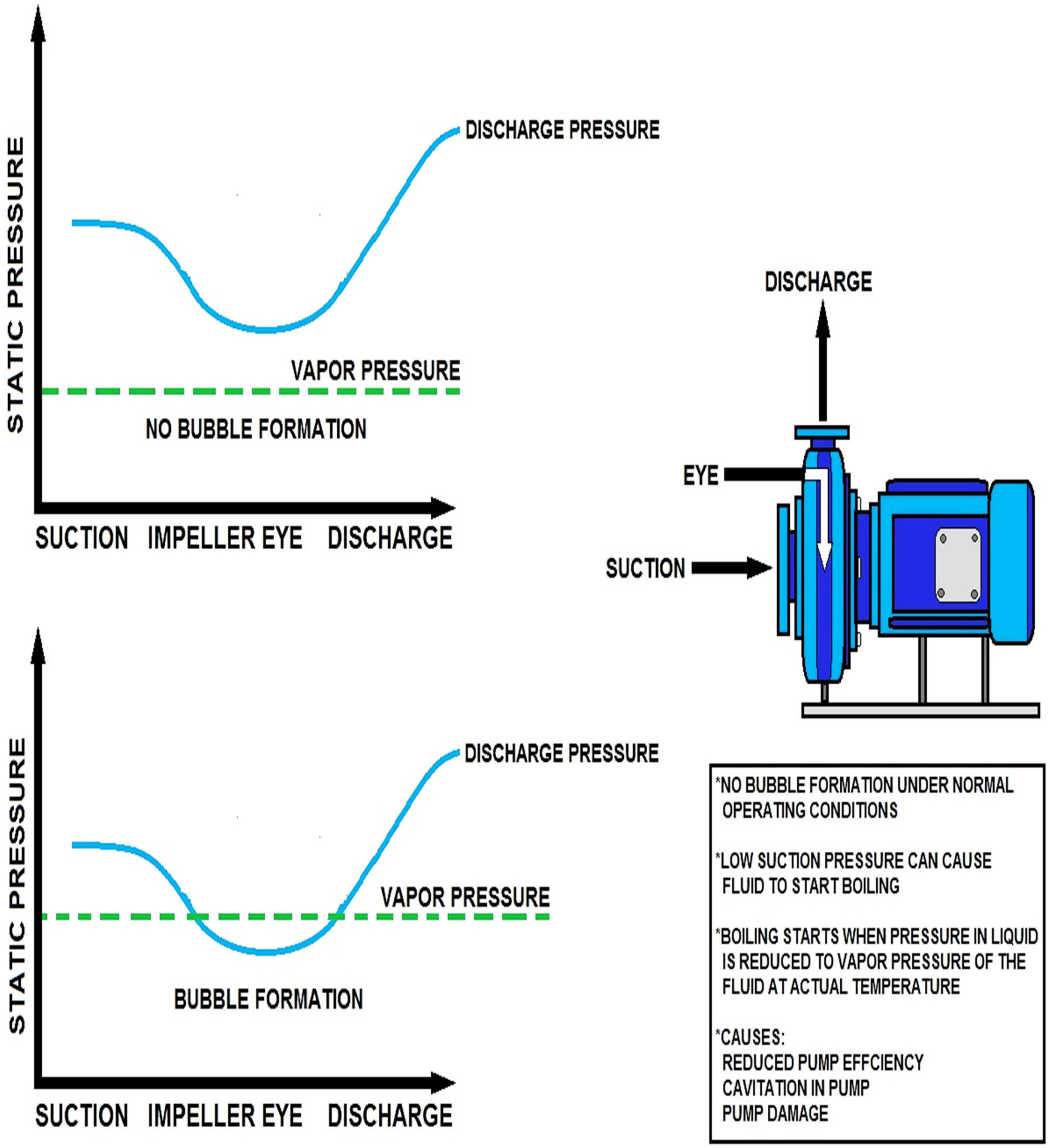
BRAKE HORSEPOWER
(The available power of a motor assesed by measuring the force needed to brake motor)

$$WHP = \frac{Q \times H}{3960}$$

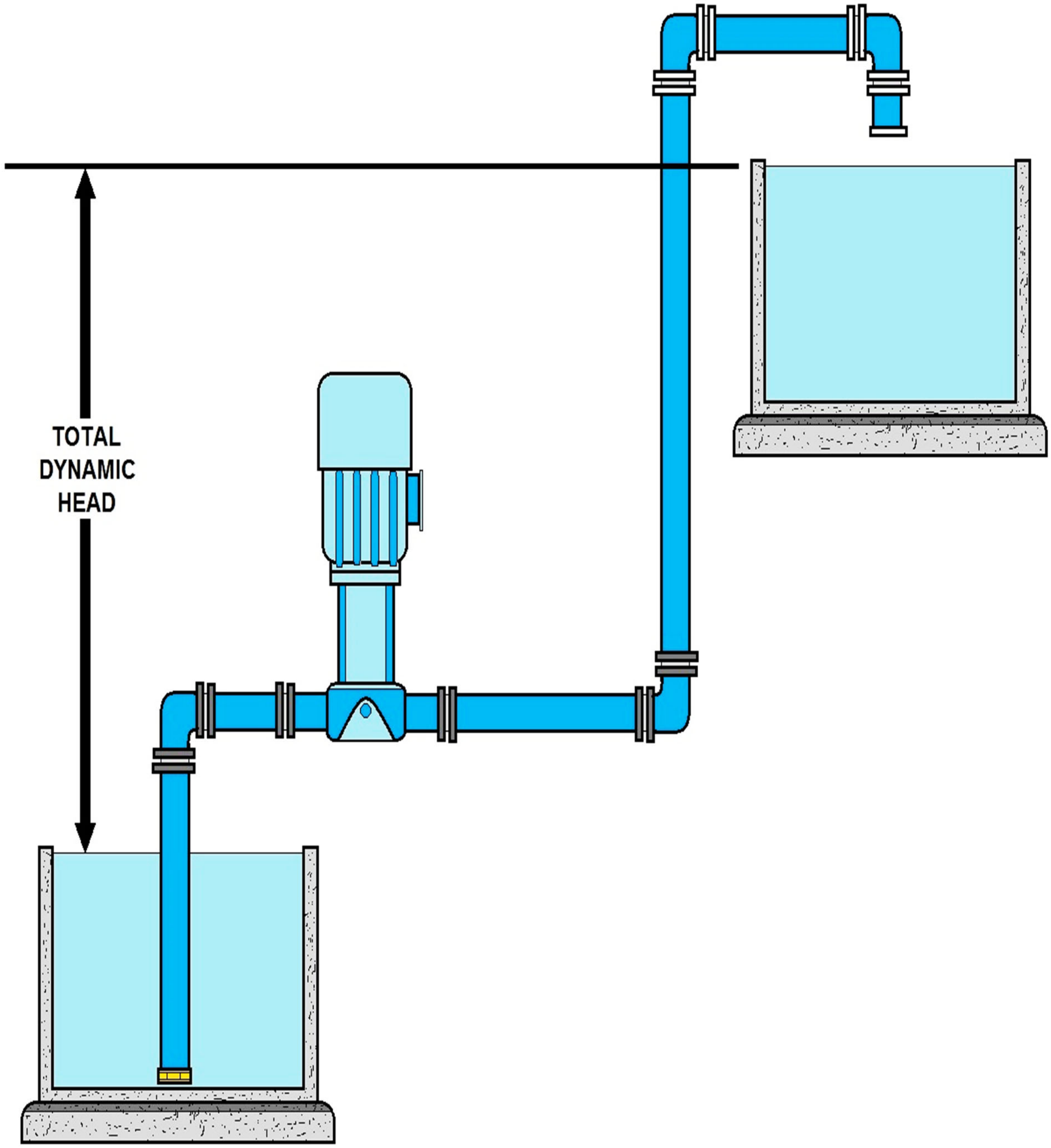


Q= FLUID FLOW RATE (gal/min)
H= TOTAL DYNAMIC HEAD (feet)
3960= FACTOR THAT CONVERTS HORSEPOWER INTO PUMPING TERMS

WATER HORSEPOWER
(THE ENERGY ADDED TO THE WATER BY THE PUMP ITSELF)

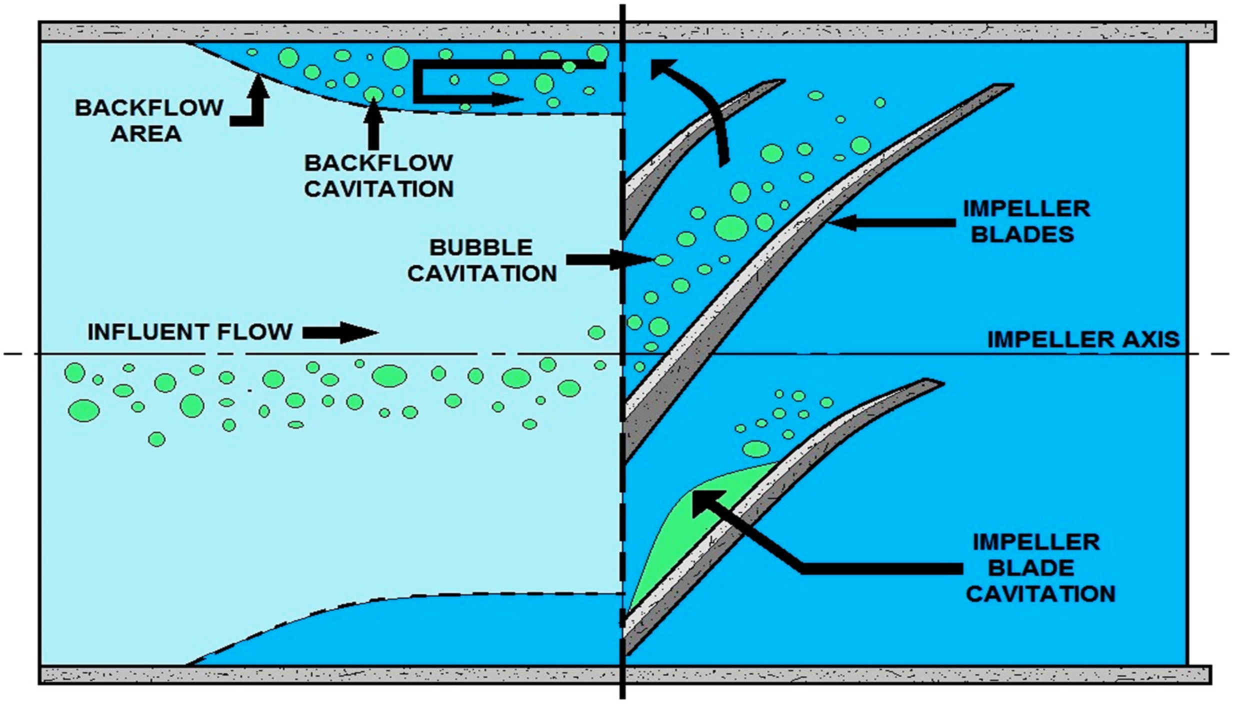


NET POSITIVE SUCTION HEAD

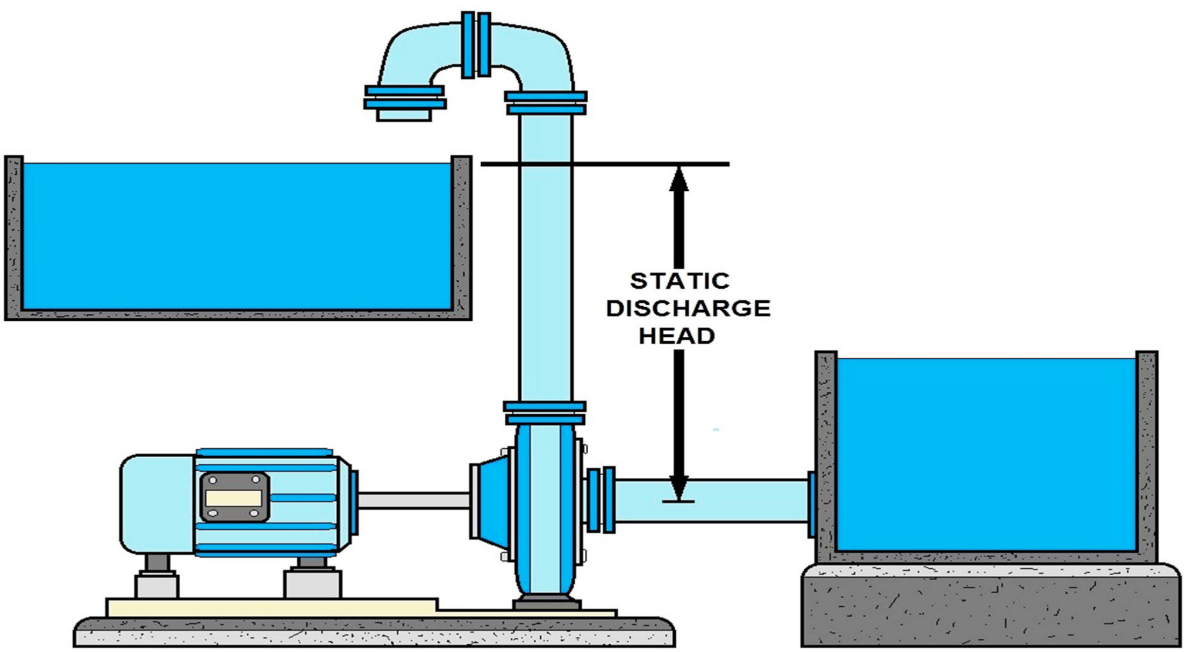


EXAMPLE OF TOTAL DYNAMIC HEAD

(The total equivalent height that fluid is to be pumped)



PUMP CAVITATION



EXAMPLE OF STATIC DISCHARGE HEAD

(The vertical distance from discharge outlet to point of discharge)

Pump Specifications

Pumps are commonly rated by horsepower, flow rate, outlet pressure in meters (or feet) of head, inlet suction in suction feet (or meters) of head. The head can be simplified as the number of feet or meters the pump can raise or lower a column of water at atmospheric pressure. From an initial design point of view, engineers often use a quantity termed the specific speed to identify the most suitable pump type for a particular combination of flow rate and head.

Pump Construction Material
The pump material can be Stainless steel (SS 316 or SS 304), cast iron etc. It depends on the application of the pump. In the water industry and for pharma applications SS 316 is normally used, as stainless steel gives better results at high temperatures.

Pumping Power
The power imparted into a fluid will increase the energy of the fluid per unit volume. Thus the power relationship is between the conversion of the mechanical energy of the pump mechanism and the fluid elements within the pump. In general, this is governed by a series of simultaneous differential equations, known as the Navier-Stokes equations. A simpler equation relating to the different energies in the fluid is known as Bernoulli's equation.

Hence the power, P, required by the pump:

$$P = \frac{\Delta P Q}{\eta}$$

where ΔP is the change in total pressure between the inlet and outlet (in Pa), and Q, the fluid flowrate is given in m^3/s. The total pressure may have gravitational, static pressure and kinetic energy components; i.e. energy is distributed between change in the fluid's gravitational potential energy (going up or down hill), change in velocity, or change in static pressure. η is the pump efficiency, and may be given by the manufacturer's information, such as in the form of a pump curve, and is typically derived from either fluid dynamics simulation (i.e. solutions to the Navier-stokes for the particular pump geometry), or by testing. The efficiency of the pump will depend upon the pump's configuration and operating conditions (such as rotational speed, fluid density and viscosity etc.)

$$\Delta P = \frac{(v_2^2 - v_1^2)}{2} + \Delta z g + \frac{\Delta p_{\mathrm{static}}}{\rho}$$

For a typical "pumping" configuration, the work is imparted

Suction Lift Chart
The vertical distance that a pump may be placed above the water level (and be able to draw water) is determined by pump design and limits dictated by altitude. The chart below shows the absolute limits. The closer the pump is to the water level, the easier and quicker it will be to prime.

Suction Lift at Various Elevations

Altitude:	**Suction Lift In Feet**
Sea Level	25.0
2,000 ft.	22.0
4,000 ft.	19.5
6,000 ft.	17.3
8,000 ft.	15.5
10,000 ft.	14.3

Centrifugal pumps are particularly vulnerable especially when pumping heated solution near the vapor pressure, whereas positive displacement pumps are less affected by cavitation, as they are better able to pump two-phase flow (the mixture of gas and liquid), however, the resultant flow rate of the pump will be diminished because of the gas volumetrically displacing a disproportion of liquid. Careful design is required to pump high temperature liquids with a centrifugal pump when the liquid is near its boiling point.

The violent collapse of the cavitation bubble creates a shock wave that can literally carve material from internal pump components (usually the leading edge of the impeller) and creates noise often described as "pumping gravel".

Additionally, the inevitable increase in vibration can cause other mechanical faults in the pump and associated equipment.

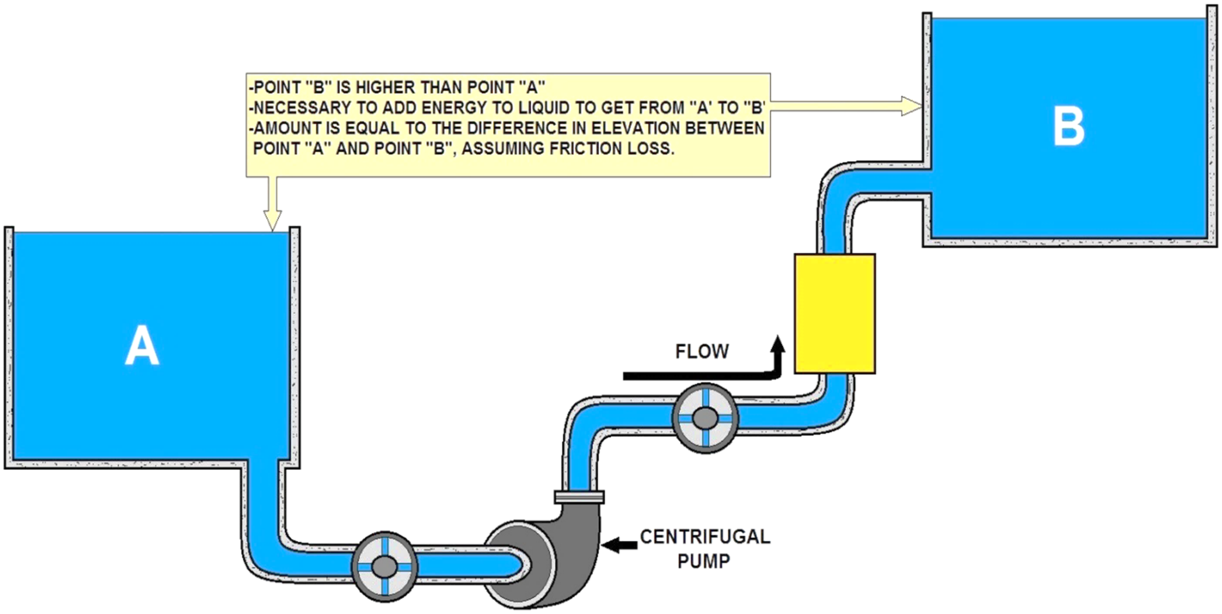
For a typical "pumping" configuration, the work is imparted on the fluid, and is thus positive. For the fluid imparting the work on the pump (i.e. a turbine), the work is negative power required to drive the pump is determined by dividing the output power by the pump efficiency. Furthermore, this definition encompasses pumps with no moving parts, such as a siphon.

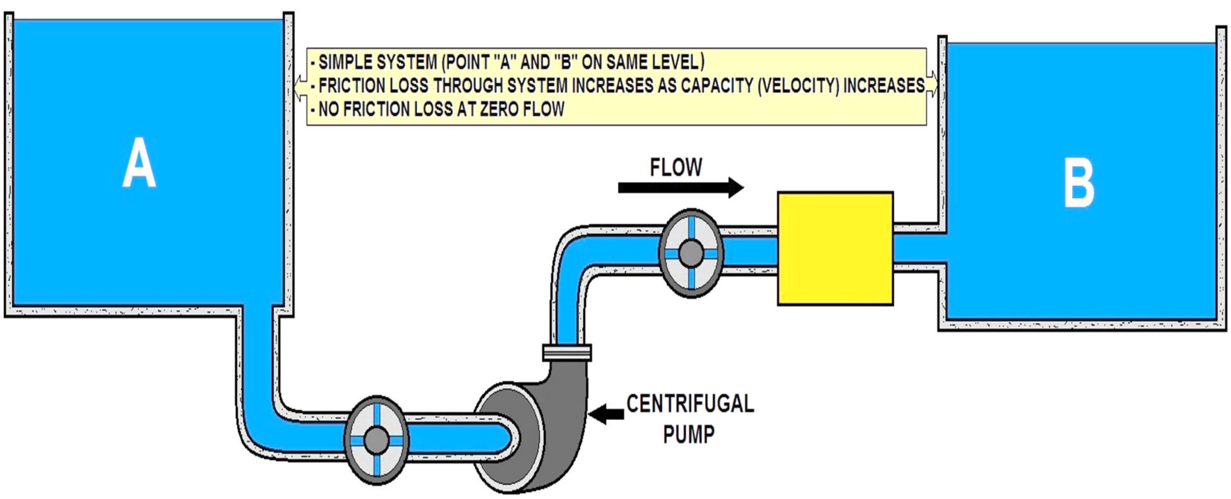
When asked how a pump operates, most reply that it “sucks.” While not a false statement, it’s easy to see why so many pump operators still struggle with pump problems. Fluid flows from areas of high pressure to areas of low pressure.

Pumps operate by creating low pressure at the inlet which allows the liquid to be pushed into the pump by atmospheric or head pressure (pressure due to the liquid’s surface being above the centerline of the pump). Consider placing a pump at the top of the mercury barometer above:

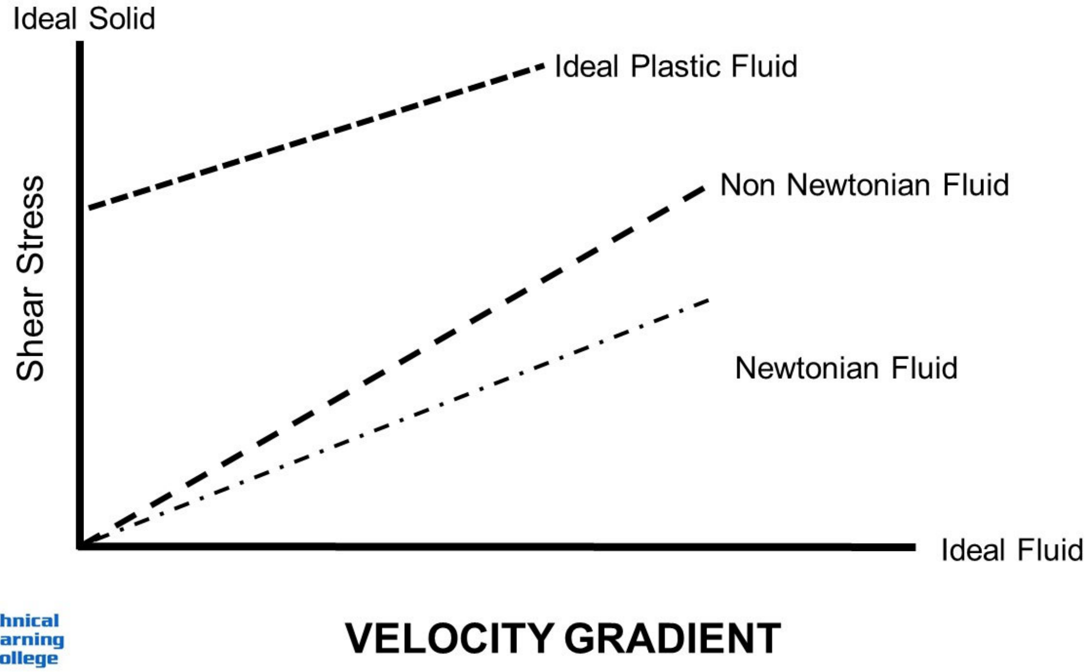
Even with a perfect vacuum at the pump inlet, atmospheric pressure limits how high the pump can lift the liquid. With liquids lighter than mercury, this lift height can increase, but there’s still a physical limit to pump operation based on pressure external to the pump. This limit is the key consideration for Net Positive Suction Head.

Reference Centrifugal/Vertical NPSH Margin (ANSI/HI 9.6.1-1998), www.pumps.org, Hydraulic Institute, 1998.





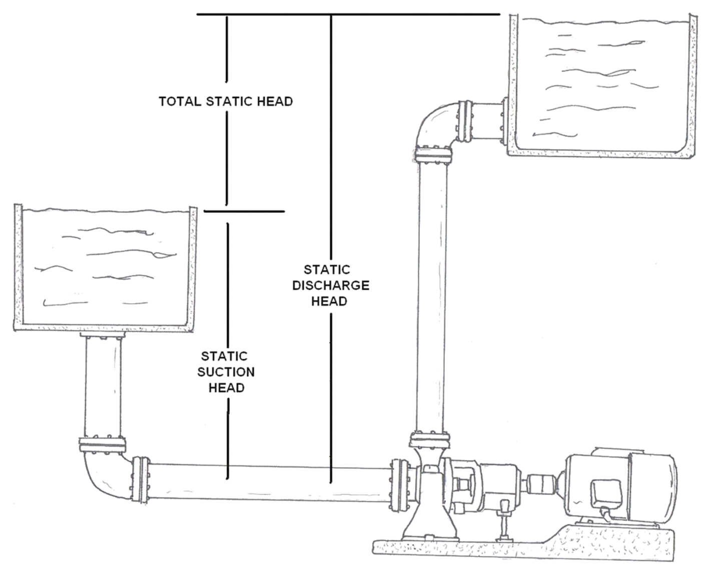
CENTRIFUGAL PUMP CURVE CHARACTERISITICS


Ideal Solid
Ideal Plastic Fluid
Non Newtonian Fluid
Shear Stress
Newtonian Fluid
Ideal Fluid
VELOCITY GRADIENT

Pump Efficiency

Pump efficiency is defined as the ratio of the power imparted on the fluid by the pump in relation to the power supplied to drive the pump. Its value is not fixed for a given pump; efficiency is a function of the discharge and therefore also operating head. For centrifugal pumps, the efficiency tends to increase with flow rate up to a point midway through the operating range (peak efficiency) and then declines as flow rates rise further.

Pump performance data such as this is usually supplied by the manufacturer before pump selection. Pump efficiencies tend to decline over time due to wear (e.g. increasing clearances as impellers reduce in size).



When a system design includes a centrifugal pump, an important issue it its design is matching the head loss-flow characteristic with the pump so that it operates at or close to the point of its maximum efficiency.

Pump efficiency is an important aspect and pumps should be regularly tested. Thermodynamic pump testing is one method.

Depending on how the measurement is taken suction lift and head may also be referred to as static or dynamic.

Static indicates the measurement does not take into account the friction caused by water moving through the hose or pipes. Dynamic indicates that losses due to friction are factored into the performance. The following terms are usually used when referring to lift or head.

Static Suction Lift - The vertical distance from the water line to the centerline of the impeller.

Static Discharge Head - The vertical distance from the discharge outlet to the point of discharge or liquid level when discharging into the bottom of a water tank.

Dynamic Suction Head - The Static Suction Lift plus the friction in the suction line. Also referred to as a Total Suction Head.

Dynamic Discharge Head - The Static Discharge Head plus the friction in the discharge line. Also referred to as Total Discharge Head.

Total Dynamic Head - The Dynamic Suction Head plus the Dynamic Discharge Head. Also referred to as Total Head.

Net Positive Suction Head (NPSH)

NPSH can be defined as two parts:

NPSH Available (NPSHA): The absolute pressure at the suction port of the pump.

AND

NPSH Required (NPSHR): The minimum pressure required at the suction port of the pump to keep the pump from cavitating.

NPSHA is a function of your system and must be calculated, whereas NPSHR is a function of the pump and must be provided by the pump manufacturer. NPSHA MUST be greater than NPSHR for the pump system to operate without cavitating. Put another way, you must have more suction side pressure available than the pump requires.

Specific Gravity
The term specific gravity compares the density of some substance to the density of water. Since specific gravity is the ratio of those densities, the units of measure cancel themselves, and we end up with a dimensionless number that is the same for all systems of measure. Therefore, the specific gravity of water is 1— regardless of the measurement system. Specific gravity is important when sizing a centrifugal pump because it is indicative of the weight of the fluid and its weight will have a direct effect on the amount of work performed by the pump. One of the beauties of the centrifugal pump is that the head (in feet) and flow it produces has nothing to do with the weight of the liquid. It is all about the velocity that is added by the impeller. The simplest way to prove the validity of this statement is to use the falling body equation:

v2 = 2gh

Where:
v = Velocity
g = The universal gravitational constant
h = height.

This equation will predict the final velocity some object will attain when falling from some height (ignoring friction of course). When rearranged, it takes the form of h = v2/2g and predicts the maximum height an object can attain based on its initial velocity. The final velocity attained by a falling object is actually the same as the initial velocity required for it to rise to the same height from which it fell. When this equation is applied to a centrifugal pump, h becomes the maximum theoretical head that it can produce. As the equation illustrates, that head depends upon the exit velocity of the liquid from the impeller vanes and the effect of gravity; it has absolutely nothing to do with the weight of the liquid.

The weight of the liquid does affect the amount of work done by a pump and, therefore, the HP required. A good way to understand the impact of liquid weight is to convert flow in GPM and head in feet into units of work. The equation below performs this conversion.

(gpm X 8.34 lb/gal X h) = w

Here the flow is multiplied by the weight of a gallon of water and then multiplied by the head in feet. The result is the work performed in ft-lb/minute. The equation shows us that the amount of work done by a centrifugal pump is directly proportional to the weight of the pumped liquid.

If you divide w by 33,000, the result is the HP required at that particular point of flow and head. The downward sloping curve in the upper portion of the graph is the H/Q curve and the red, blue and green curves are the horsepower curves for three different liquids. The scale of the Y axis is both head and horsepower. The blue curve shows the HP required for water (SG=1). The red and green curves show the HP required to pump sugar syrup (SG=1.29) and gasoline (SG=0.71). If you analyze the three HP curves at each flow point, you will see that the increase or decrease is directly proportional to the SG of that particular liquid.

As long as the viscosity of a liquid is similar to that of water, its specific gravity will have no effect on pump performance. It will, however, directly affect the input power required to pump that particular liquid.

The equation below can be used to compute the horsepower required to pump liquids of varying specific gravities (where BHP is brake horsepower, Q is flow in GPM, H is head in feet, SG is specific gravity and Eff is the hydraulic efficiency of the pump). It assumes a viscosity similar to that of water.

$$\mathbf{BHP = (Q \times H \times SG) / (3960 \times Eff)}$$

SG can also have an effect on the onset of cavitation in a particular pump. Heavier liquids cause a proportional increase in a pump's suction energy and those with a high suction energy level are more likely to experience cavitation damage. Next month we will review the effect of viscosity on centrifugal pump performance.

Pump Testing
To minimize energy use, and to ensure that pumps are correctly matched to the duty expected pumps, and pumping stations should be regularly tested. In water supply applications, which are usually fitted with centrifugal pumps, individual large pumps should be 70 - 80% efficient. They should be individually tested to ensure they are in the appropriate range, and replaced or prepared as appropriate.

Pumping stations should also be tested collectively, because where pumps can run in combination to meet a given demand, it is often possible for very inefficient combination of pumps to occur. For example: it is perfectly possible to have a large and a small pump operating in parallel, with the smaller pump not delivering any water, but merely consuming energy. Pumps are readily tested by fitting a flow meter, measuring the pressure difference between inlet and outlet, and measuring the power consumed.

Another method is thermodynamic pump testing where only the temperature rises and power consumed need be measured. Depending on how the measurement is taken suction lift and head may also be referred to as static or dynamic. Static indicates the measurement does not take into account the friction caused by water moving through the hose or pipes.

Dynamic indicates that losses due to friction are factored into the performance. The following terms are usually used when referring to lift or head.

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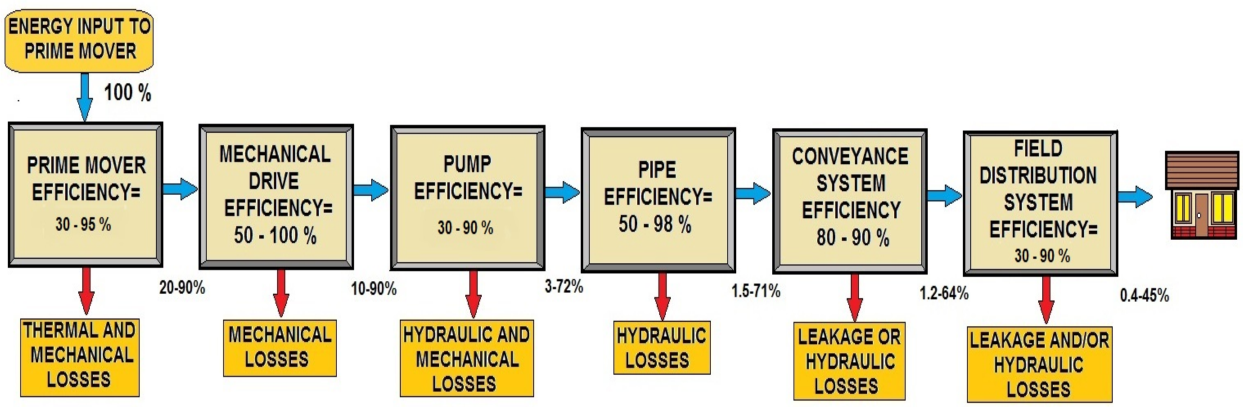


SYSTEM ENERGY EFFICIENCY LOSSES DIAGRAM

Hyperlink to the Glossary and Appendix
http://www.abctlc.com/downloads/PDF/PumpGlossary.pdf

Understanding Pump Viscosity

When to use a centrifugal or a Positive Displacement pump ("PD Pump") is not always a clear choice. To make a good choice between these pump types it is important to understand that these two types of pumps behave very differently.

First, let's examine the density of the substance to be pumped. The density of a substance is defined as its mass per unit volume, but here on the earth's surface, we can substitute weight for mass. At 39-deg F (4-deg C), water has a density of 8.34 pounds per gallon or 62.43 pounds per cubic foot. In the metric system, its density is one gram per cubic centimeter, or 1,000-kg per cubic meter.

Understanding Pump Friction Loss
To optimize a fluid piping system, it is important to have a clear understanding of how the various system items interact. Regardless of the methods used to gain a thorough picture of piping system operations, a variety of calculations must be performed. Among the formulas are the Bernoulli equation to calculate the pressure in the system, and the Darcy-Weisbach equation, which is commonly used to calculate head loss in a pipe run. The Bernoulli Equation is a way of expressing the total energy of fluid as it flows through a pipe run

The Piping System
A piping system is configured of individual pipe runs connected in series and parallel combinations with pumps, control valves, flowmeters and components. It is essential to recognize how these unique elements interact and work together as a system. There are both graphical and analytical methods that provide an understanding of how the various items interact as a total system.

The head loss is calculated using the graphical method for a variety of flow rates for each pipe run. The results can be read off the graph after the information is plotted. Using the analytical method, the results are calculated directly, which eliminates the need for further graphics.

In fluid dynamics, the Darcy–Weisbach equation is a phenomenological equation, which relates the head loss — or pressure loss — due to friction along a given length of pipe to the average velocity of the fluid flow. The equation is named after Henry Darcy and Julius Weisbach.

The Darcy–Weisbach equation contains a dimensionless friction factor, known as the Darcy friction factor. This is also called the Darcy–Weisbach friction factor or Moody friction factor. The Darcy friction factor is four times the Fanning friction factor, with which it should not be confused.

Head Loss Formula
Head loss can be calculated with

$$h_f = f_D \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

where

- *hf* is the head loss due to friction (SI units: m);
- L is the length of the pipe (m);

- D is the hydraulic diameter of the pipe (for a pipe of circular section, this equals the internal diameter of the pipe) (m);
- *V* is the average velocity of the fluid flow, equal to the volumetric flow rate per unit cross-sectional wetted area (m/s);
- *g* is the local acceleration due to gravity (m/s^2);
- *fD* is a dimensionless coefficient called the Darcy friction factor. It can be found from a Moody diagram or more precisely by solving the Colebrook equation. Do not confuse this with the Fanning Friction factor, f.

  However, the establishment of the friction factors was still an unresolved issue which needed further work.

Darcy-Weisbach Formula

Flow of fluid through a pipe
The flow of liquid through a pipe is resisted by viscous shear stresses within the liquid and the turbulence that occurs along the internal walls of the pipe, created by the roughness of the pipe material. This resistance is usually known as pipe friction and is measured is feet or meters head of the fluid, thus the term head loss is also used to express the resistance to flow.

Many factors affect the head loss in pipes, the viscosity of the fluid being handled, the size of the pipes, the roughness of the internal surface of the pipes, the changes in elevations within the system and the length of travel of the fluid. The resistance through various valves and fittings will also contribute to the overall head loss. A method to model the resistances for valves and fittings is described elsewhere.

In a well-designed system the resistance through valves and fittings will be of minor significance to the overall head loss, many designers choose to ignore the head loss for valves and fittings at least in the initial stages of a design.

Much research has been carried out over many years and various formulas to calculate head loss have been developed based on experimental data. Among these is the Chézy formula which dealt with water flow in open channels. Using the concept of 'wetted perimeter' and the internal diameter of a pipe the Chézy formula could be adapted to estimate the head loss in a pipe, although the constant 'C' had to be determined experimentally.

The Darcy-Weisbach Equation
Weisbach first proposed the equation we now know as the Darcy-Weisbach formula or Darcy-Weisbach equation:

hf = f (L/D) x (v2/2g)

where:
hf = head loss (m)
f = friction factor
L = length of pipe work (m)
d = inner diameter of pipe work (m)
v = velocity of fluid (m/s)
g = acceleration due to gravity (m/s^2)
or:
hf = head loss (ft)
f = friction factor
L = length of pipe work (ft)
d = inner diameter of pipe work (ft)
v = velocity of fluid (ft/s)
g = acceleration due to gravity (ft/s^2)

The Moody Chart

In 1944 LF Moody plotted the data from the Colebrook equation and this chart which is now known as 'The Moody Chart' or sometimes the Friction Factor Chart, enables a user to plot the Reynolds number and the Relative Roughness of the pipe and to establish a reasonably accurate value of the friction factor for turbulent flow conditions.

The Moody Chart encouraged the use of the Darcy-Weisbach friction factor and this quickly became the method of choice for hydraulic engineers. Many forms of head loss calculator were developed to assist with the calculations, amongst these a round slide rule offered calculations for flow in pipes on one side and flow in open channels on the reverse side.

The development of the personnel computer from the 1980's onwards reduced the time needed to perform the friction factor and head loss calculations, which in turn has widened the use of the Darcy-Weisbach formula to the point that all other formula are now largely unused.

This dimensionless chart is used to work out pressure drop, ΔP(Pa) (or head loss, h_{f}(m)) and flow rate through pipes. Head loss can be calculated using the Darcy–Weisbach equation:

$$h_{\mathrm{f}} = f \frac{l}{d} \frac{V^2}{2g};$$

not to be confused with the Fanning equation and the Fanning friction factor:

$$h_{\mathrm{f}} = 4f \frac{l}{d} \frac{V^2}{2g},$$

which uses a friction-factor equal to one fourth the Darcy-Weisbach friction factor. Pressure drop can then be evaluated as:

$$\Delta P = \rho\, g\, h_{\mathrm{f}}$$ or directly from $$\Delta P = f \frac{\rho V^2}{2} \frac{l}{d},$$

where ρ is the density of the fluid, V is the average velocity in the pipe, f is the friction factor from the Moody chart, l is the length of the pipe and d is the pipe diameter.

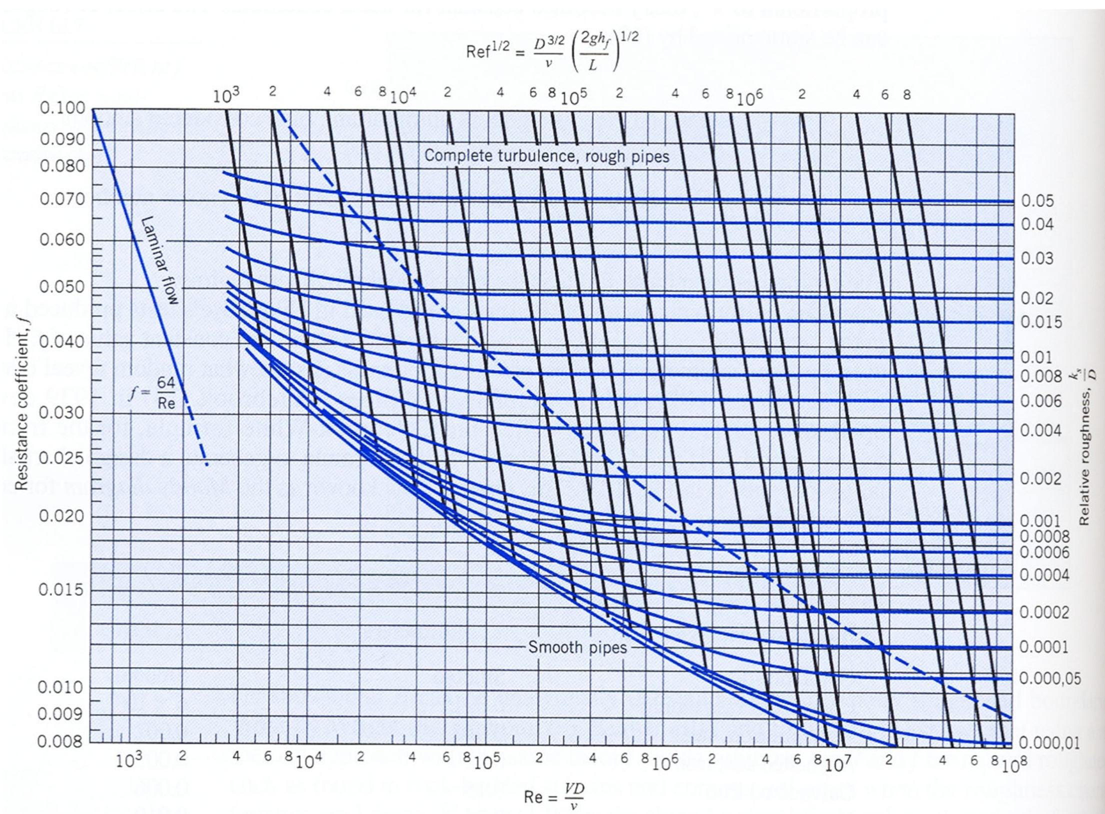
The basic chart plots Darcy–Weisbach friction factor against Reynolds number for a variety of relative roughnesses and flow regimes. The relative roughness being the ratio of the mean height of roughness of the pipe to the pipe diameter or $\frac{\epsilon}{d}$.

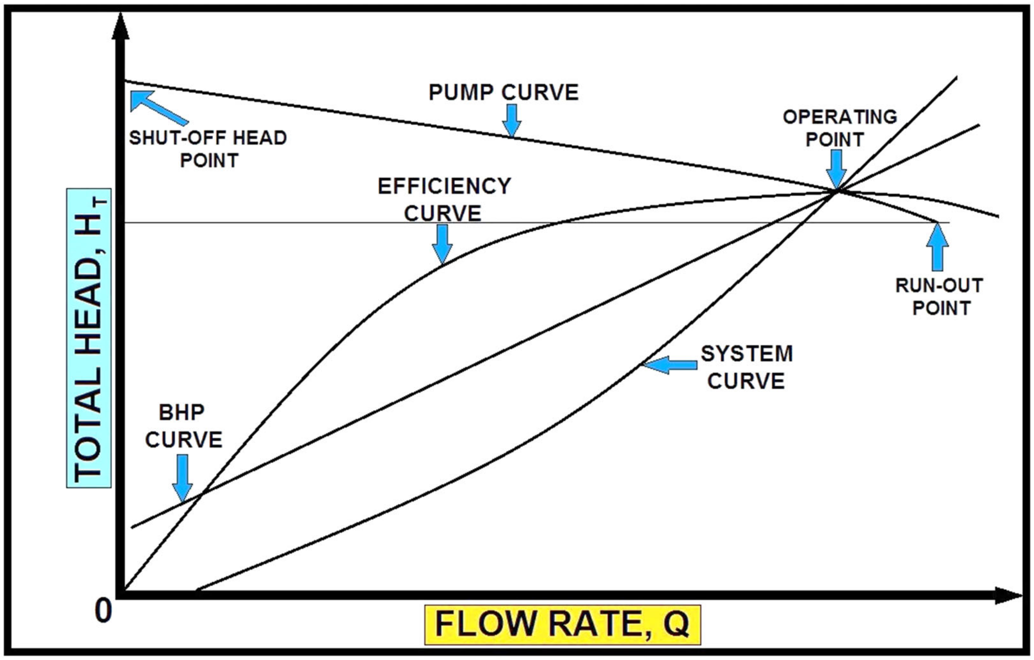
The Moody chart can be divided into two regimes of flow: laminar and turbulent. For the laminar flow regime, the Darcy–Weisbach friction factor was determined analytically by

Poiseuille and $\frac{64}{Re}$ is used. In this regime roughness has no discernible effect. For the turbulent flow regime, the relationship between the friction factor and the Reynolds number is more complex and is governed by the Colebrook equation which is implicit in f:

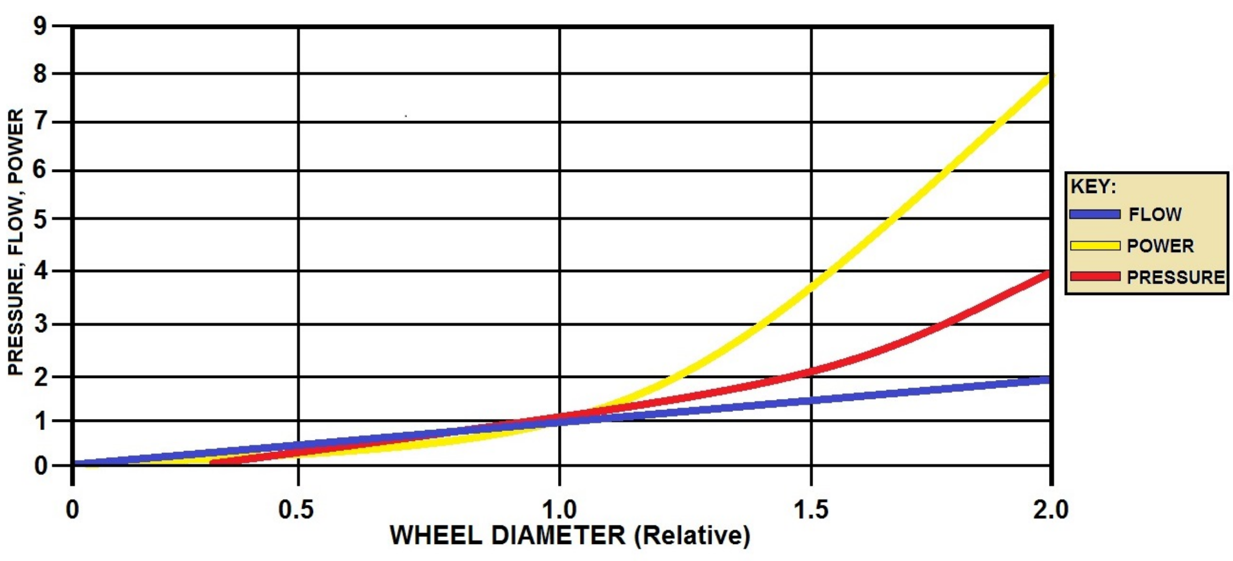
$$\frac{1}{\sqrt{f}} = -2.0 \log_{10} \left(\frac{\frac{\epsilon}{d}}{3.7} + \frac{2.51}{Re\sqrt{f}} \right), \text{turbulent flow.}$$

In 1944, Lewis Ferry Moody plotted the Darcy–Weisbach friction factor into what is now known as the Moody chart.
The Fanning friction factor is 1/4 the Darcy–Weisbach one and the equation for pressure drop has a compensating factor of four.



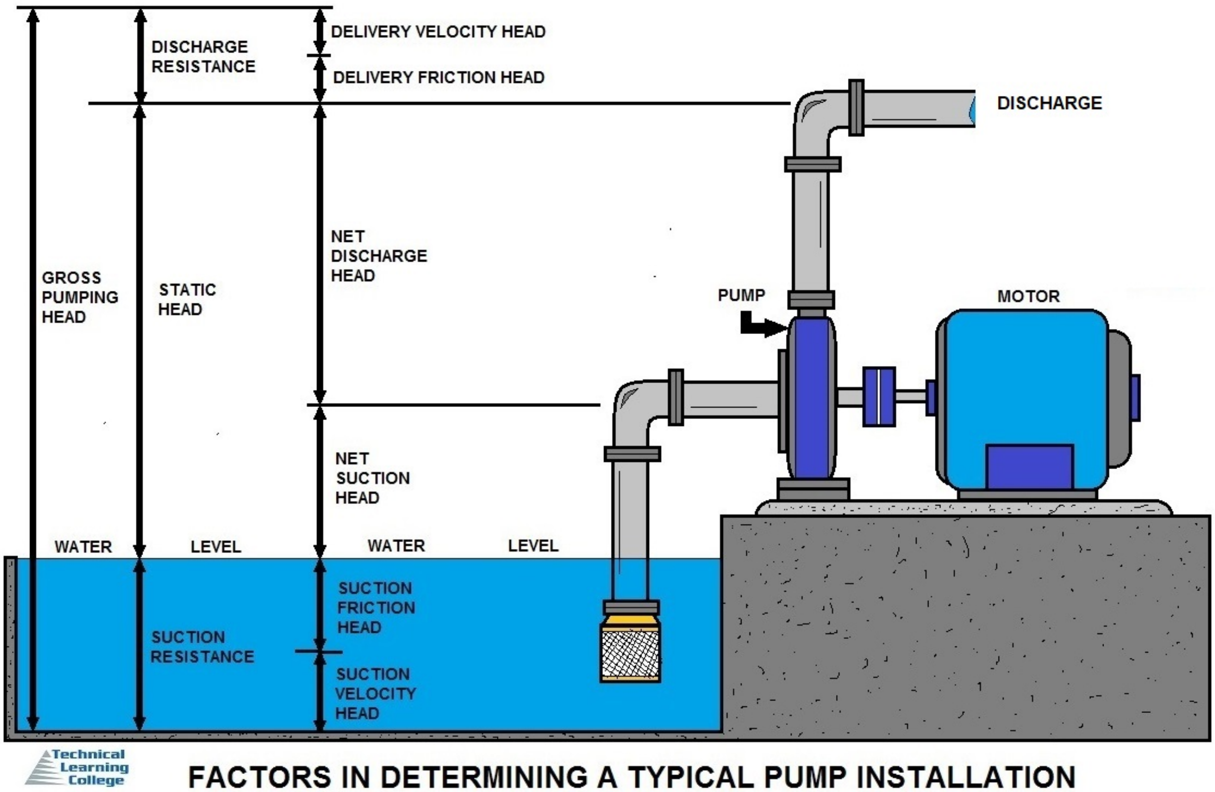


PUMP PERFORMANCE CURVE (CENTRIFUGAL PUMP)



PUMP AFFINITY LAWS

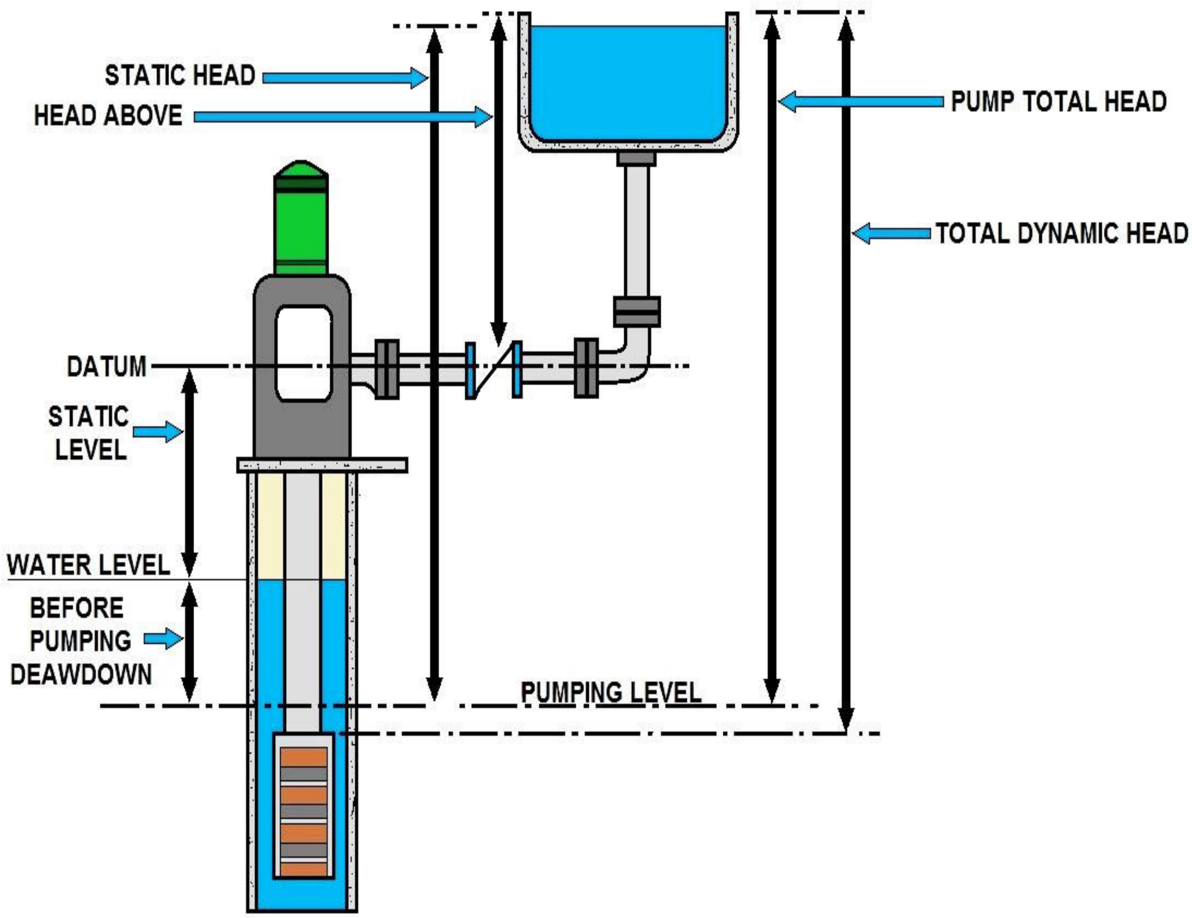
(PUMP AFFINITY INDICATES THE INFLUENCE ON VOLUME CAPACITY, HEAD PRESSURE, AND POWER CONSUMPTION OF A PUMP DUE TO CHANGE IN SPEED OF WHEEL (RPM) AND CHANGE IN IMPELLER DIAMETER)



FACTORS IN DETERMINING A TYPICAL PUMP INSTALLATION

Understanding Suction Lift

Suction lift deals with the maximum distance to the intake of a pump. Fire pumps and others may lift about 5' to 10' of suction. You must lower the pump continually towards the water to keep them pumping. This creates a water risk, and when they put it back in, it pumps for a while, and if it quits again, then the same process must be repeated until it is pumping properly. Pumps operating at a negative minimum inlet pressure are capable of creating a suction lift (non-self-priming). The suction capacity is approximately equal to the level of the negative minimum inlet pressure minus a 3 foot safety factor.



PUMPING HEAD DIAGRAM

NPSH is initialism for Net Positive Suction Head. In any cross-section of a generic hydraulic circuit, the NPSH parameter shows the difference between the actual pressure of a liquid in a pipeline and the liquid's vapor pressure at a given temperature.

NPSH is an important parameter to take into account when designing a circuit: whenever the liquid pressure drops below the vapor pressure, liquid boiling occurs, and the final effect will be cavitation: vapor bubbles may reduce or stop the liquid flow, as well as damage the system.

Centrifugal pumps are particularly vulnerable especially when pumping heated solution near the vapor pressure, whereas positive displacement pumps are less affected by cavitation, as they are better able to pump two-phase flow (the mixture of gas and liquid), however, the resultant flow rate of the pump will be diminished because of the gas volumetrically displacing a disproportion of liquid. Careful design is required to pump high temperature liquids with a centrifugal pump when the liquid is near its boiling point.

The violent collapse of the cavitation bubble creates a shock wave that can literally carve material from internal pump components (usually the leading edge of the impeller) and creates noise often described as "pumping gravel". Additionally, the inevitable increase in vibration can cause other mechanical faults in the pump and associated equipment.

$$NPSH = \frac{p_0 - p_v}{\rho g} + \Delta z - h_L$$

where h_L is the head loss between 0 and 1, p_0 is the pressure at the water surface, p_v is the vapor pressure (saturation pressure) for the fluid at the temperature T_1 at 1, Δz is the difference in height $z_1 - z_0$ from the water surface to the location 1, and ρ is the fluid density, assumed constant, and g is gravitational acceleration.

where is the head loss between 0 and 1, is the pressure at the water surface, is the vapor pressure (saturation pressure) for the fluid at the temperature at 1, is the difference in height (shown as H on the diagram) from the water surface to the location 1, and is the fluid density, assumed constant, and is gravitational acceleration.

Suction Limitations
Regardless of the extent of the vacuum, water can only be “lifted” a set distance or height due to its' vaporization pressure.

As the pressure above the water is reduced, the water will tend to rise as a result of the atmospheric pressure, which is tending to push the water into the pump suction piping. The theoretical maximum suction lift for water is 33.9 feet.

From a practical standpoint, in consideration of the friction loss of the piping, the altitude of the station, etc., the normal maximum lift for any pump is approximately 25 ft. However, it must be remembered that cavitation of the impeller increases as the suction lift increases, and therefore, the pump, where possible, should be located so that the suction line is submerged at all times.

Pumps lift water with the help of atmospheric pressure, then pressurize and discharge the water from the casing. The practical suction lift, at sea level is 25 feet.

Most pump manufacturers will list this as the maximum suction lift. Static suction lift is the maximum distance from the water level, to the centerline of the impeller. The main type of pump used for suction lift is a vertical shaft turbine pump.

Suction lift exists when a liquid is taken from an open tank to an atmospheric tank where the liquid level is below the centerline of the pump suction.

he Following Relationships May help to Better Understand Suction Lift

Total Dynamic Head = Total discharge head + Total Suction Lift

Total Suction Lift = static + friction

Depending on how the measurement is taken suction lift and head may also be referred to as static or dynamic. Static indicates the measurement does not take into account the friction caused by water moving through the hose or pipes. Dynamic indicates that losses due to friction are factored into the performance. The following terms are usually used when referring to lift or head.

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Total Dynamic Head - The Dynamic Suction Head plus the Dynamic Discharge Head. Also referred to as Total Head.

Suction Lift Chart
The vertical distance that a pump may be placed above the water level (and be able to draw water) is determined by pump design and limits dictated by altitude.

The chart below shows the absolute limits. The closer the pump is to the water level, the easier and quicker it will be to prime.

Suction Lift at Various Elevations

Altitude:	Suction Lift In Feet
Sea Level	25.0
2,000 ft.	22.0
4,000 ft.	19.5
6,000 ft.	17.3
8,000 ft.	15.5
10,000 ft.	14.3

Understanding Pump Performance

The formula for calculating NPSHA:
NPSHA
Term = HA ± HZ - HF + HV - HVP

The formula for calculating $NPSH_A$:

$NPSH_A$ Term = $H_A \pm H_Z - H_F + H_V - H_{VP}$	Definition	Notes
H_A	The absolute pressure on the surface of the liquid in the supply tank	Typically, atmospheric pressure (vented supply tank), but can be different for closed tanks. Don't forget that altitude affects atmospheric pressure (H_A in Denver, CO will be lower than in Miami, FL). Always positive (may be low, but even vacuum vessels are at a positive absolute pressure)
H_Z	The vertical distance between the surface of the liquid in the supply tank and the centerline of the pump	Can be positive when liquid level is above the centerline of the pump (called static head) Can be negative when liquid level is below the centerline of the pump (called suction lift) Always be sure to use the lowest liquid level allowed in the tank.
H_F	Friction losses in the suction piping	Piping and fittings act as a restriction, working against liquid as it flows towards the pump inlet.
H_V	Velocity head at the pump suction port	Often not included as it's normally quite small.
H_{VP}	Absolute vapor pressure of the liquid at the pumping temperature	Must be subtracted in the end to make sure that the inlet pressure stays above the vapor pressure. Remember, as temperature goes up, so does the vapor pressure.

Understanding Affinity Laws

The Affinity Laws
The affinity laws are used in hydraulics and HVAC to express the relationship between variables involved in pump or fan performance (such as head, volumetric flow rate, shaft speed) and power. They apply to pumps, fans, and hydraulic turbines. In these rotary implements, the affinity laws apply both to centrifugal and axial flows.

The affinity laws are useful as they allow prediction of the head discharge characteristic of a pump or fan from a known characteristic measured at a different speed or impeller diameter. The only requirement is that the two pumps or fans are dynamically similar, that is the ratios of the fluid forced are the same.

These laws assume that the pump/fan efficiency remains constant i.e. When applied to pumps the laws work well for constant diameter variable speed case (Law 1) but are less accurate for constant speed variable impeller diameter case (Law 2).

Law 1a. Flow is proportional to shaft speed:

$$\frac{Q_1}{Q_2} = \left(\frac{N_1}{N_2}\right)$$

Law 1b. Pressure or Head is proportional to the square of shaft speed:

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

Law 1c. Power is proportional to the cube of shaft speed:

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$$

Law 2. With shaft speed (N) held constant:
Law 2a. Flow is proportional to impeller diameter:

$$\frac{Q_1}{Q_2} = \left(\frac{D_1}{D_2}\right)^3$$

Law 2b. Pressure or Head is proportional to the square of impeller diameter:

$$\frac{H_1}{H_2} = \left(\frac{D_1}{D_2}\right)^2$$

Law 2c. Power is proportional to the cube of impeller diameter:

$$\frac{P_1}{P_2} = \left(\frac{D_1}{D_2}\right)^5$$

where

- Q is the volumetric flow rate (e.g. CFM, GPM or L/s),
- D is the impeller diameter (e.g. in or mm),
- N is the shaft rotational speed (e.g. rpm),
- H is the pressure or head developed by the fan/pump (e.g. ft. or m), and
- P is the shaft power (e.g. W).

These laws assume that the pump/fan efficiency remains constant i.e. $\eta_1 = \eta_2$.

When applied to pumps the laws work well for constant diameter variable speed case (Law 1) but are less accurate for constant speed variable impeller diameter case (Law 2).

Hyperlink to the Glossary and Appendix
http://www.abctlc.com/downloads/PDF/PumpGlossary.pdf

NPSH - Net Positive Suction Head

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

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

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^O if the pressure acting on it is less than its vapor pressure, i.e. water at 95 deg C is just hot water at sea level, but at 1500m above sea level it is boiling water and vapor.

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

Suction Lift

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

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

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

Atmospheric pressure, as measured at sea level, is 14.7 PSIA. In feet of head it is:
Head = PSI X 2.31 / Specific Gravity

For Water it is:
Head = 14.7 X 2.31 / 1.0 = 34 Ft

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

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

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

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

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

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

Cavitation - Two Main Causes:

A. NPSH (r) EXCEEDS NPSH (a)
Due to low pressure the water vaporizes (boils), and higher pressure implodes into the vapor bubbles as they pass through the pump, causing reduced performance and potentially major damage.
B. Suction or discharge recirculation. The pump is designed for a certain flow range, if there is not enough or too much flow going through the pump, the resulting turbulence and vortexes can reduce performance and damage the pump.

Affinity Laws

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

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

2) Head varies as the square of the change in speed
3) Brake horsepower varies as the cube of the change in speed

If, for example, the pump speed were doubled:
1) Capacity will double
2) Head will increase by a factor of 4 (2 to the second power)
3) Brake horsepower will increase by a factor of 8 (2 to the third power)

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

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

First we find the speed ratio.

Speed Ratio = 2000/1750 = 1.14

From the Laws of Affinity:
1) Capacity varies directly or:
1.14 X 210 GPM = 240 GPM

2) Head varies as the square or:
1.14 X 1.14 X 75 = 97.5' TDH

3) BHP varies as the cube or**:**
1.14 X 1.14 X 1.14 X 5.2 = 7.72 BHP

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

Whether it be a speed change or change in impeller diameter, the Laws of Affinity give results that are approximate.

The discrepancy between the calculated values and the actual values obtained in test are due to hydraulic efficiency changes that result from the modification.

The Laws of Affinity give reasonably close results when the changes are not more than 50% of the original speed or 15% of the original diameter.

Affinity Laws - Centrifugal Pumps

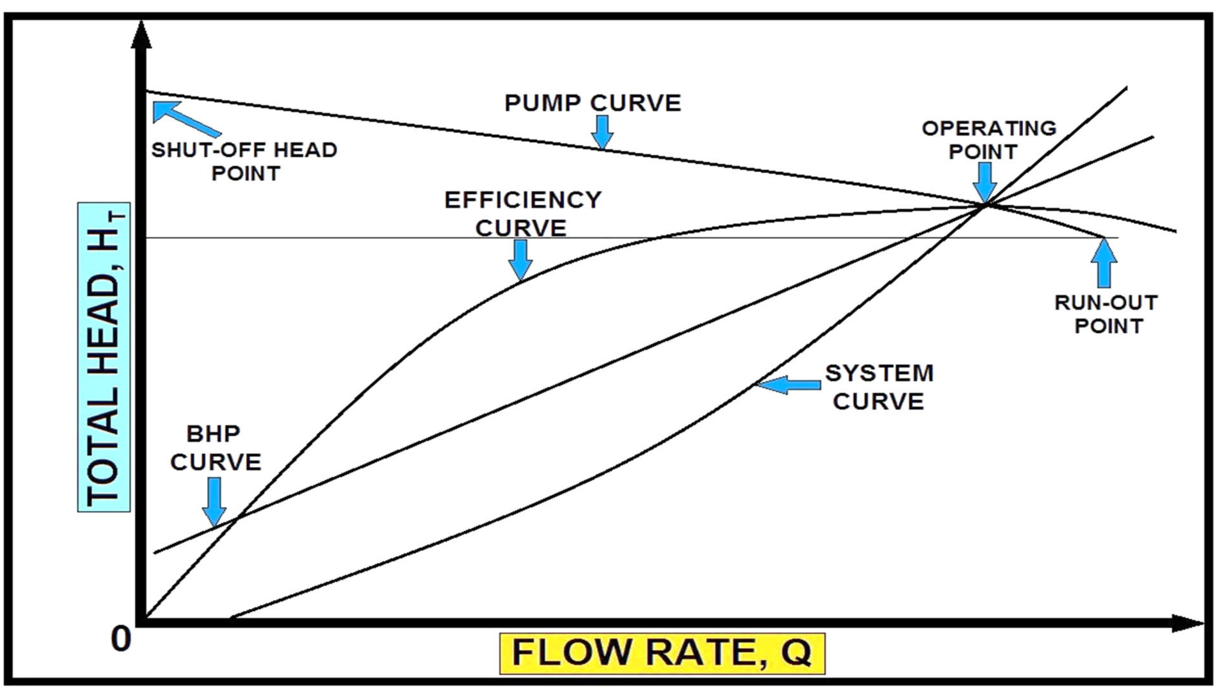
If the speed or impeller diameter of a pump changes, we can calculate the resulting performance change using:

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

Pump Performance and Curves

Let's 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



PUMP PERFORMANCE CURVE (CENTRIFUGAL PUMP)

Motor and Pump Calculations Defined

Discharge head defined.
It is the vertical distance between the intake level of a water pump and the level at which it discharges water freely to the atmosphere. The energy per unit weight of fluid on the discharge side of a pump.

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 suctions heads are subtracted from the pump discharge head.

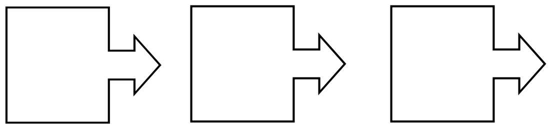
Total Dynamic Head (TDH) is the total height that a fluid is to be pumped, taking into account friction losses in the pipe.

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.



Motor hp **Brake hp** **Water hp**

Horsepower

Horsepower (hp) is a unit of measurement of power (the rate at which work is done). There are many different standards and types of horsepower. The term was adopted in the late 18th century by Scottish engineer James Watt to compare the output of steam engines with the power of draft horses.

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

1 hp = 33,000 ft-lbs/min

Motor Horsepower (mhp)

1 hp = 746 watts or .746 Kilowatts

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

Brake Horsepower (bhp)

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

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. Brake refers to the device which was used to load an engine and hold it at a desired rotational speed. During testing, the output torque and rotational speed were measured to determine the brake horsepower. Horsepower was originally measured and calculated by use of the "indicator diagram" (a James Watt invention of the late 18th century), and later by means of a Prony brake connected to the engine's output shaft. Lately, an electrical brake dynamometer is used instead of a Prony brake. Although the output delivered to the drive wheels is less than that obtainable at the engine's crankshaft, use of a chassis dynamometer gives an indication of an engine's "real world" horsepower after losses in the drive train and gearbox

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

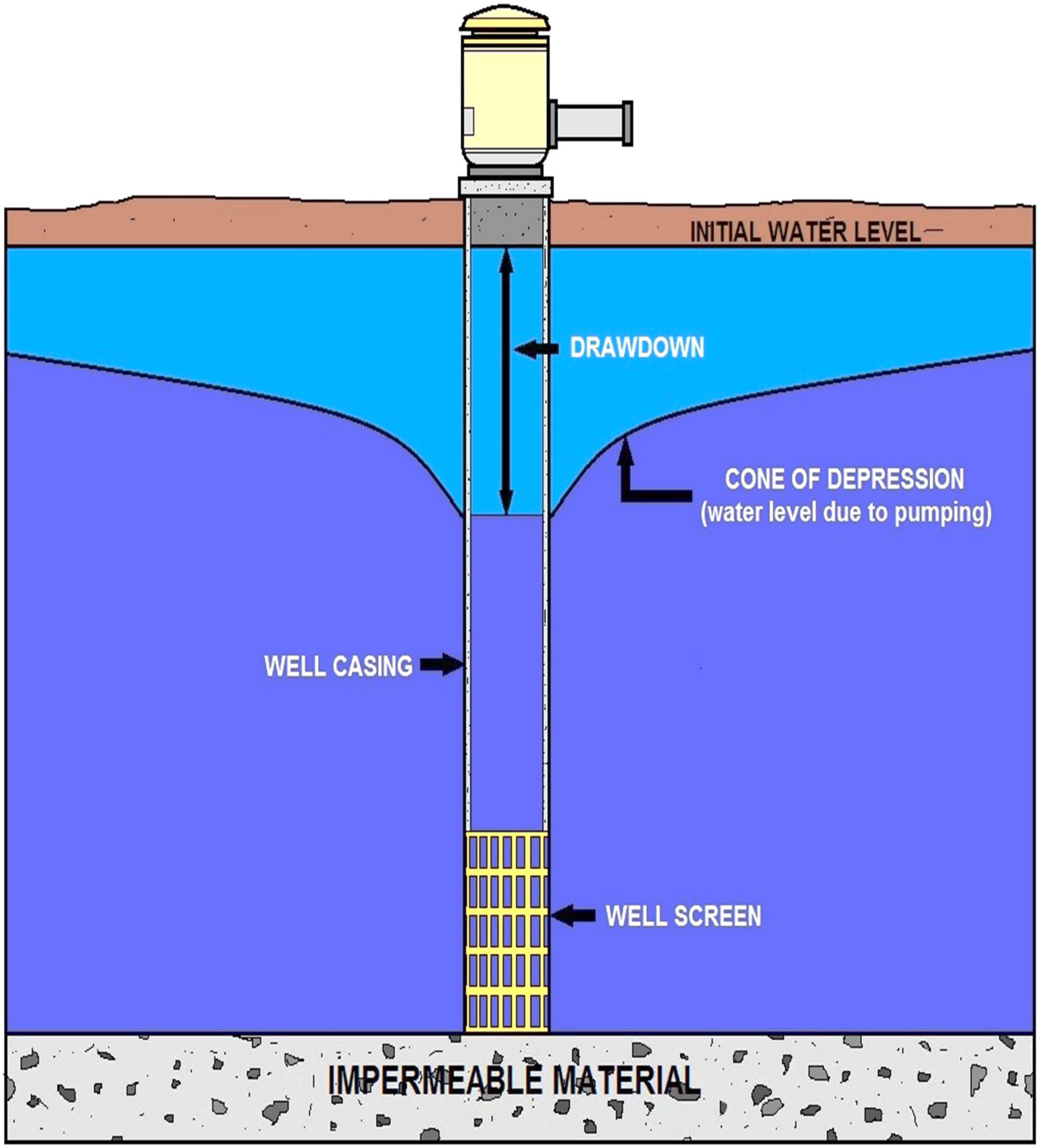
The specific gravity of a liquid is an indication of its density or weight compared to water. The difference in specific gravity, include it when calculating ft-lbs/min pumping requirements.

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

MHP and Kilowatt Requirements

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

Hyperlink to the Glossary and Appendix
http://www.abctlc.com/downloads/PDF/PumpGlossary.pdf



CONE OF DEPRESSION CAUSED BY WATER PUMPING DIAGRAM

Well Calculations

1. Well drawdown

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

2. Well yield

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

3. Specific yield

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

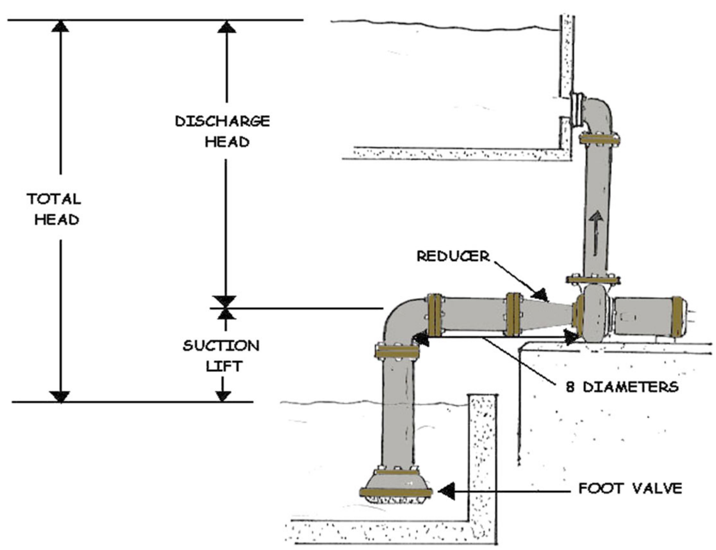
4. Deep well turbine pump calculations.

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

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

Bowl head, ft = field head + column friction

1 psi = 2.31 feet of head
1 foot of head = .433 psi



Example 1

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

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

   Suction side:

   Discharge side:

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

3. **Calculate the following head measurements:**

SSH:

SDH:

TSH:

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

6 psi:

48 psi:

110 psi:

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

20 ft:

205 ft:

185 ft:

Pump Operation and Performance Post Quiz

1. What term is used to express the rate of flow of a pump is the total volume throughput per unit of time at suction conditions?

2. What term is used to express the pressure above zero absolute, i.e. the sum of atmospheric and gauge pressure. In vacuum related work it is usually expressed in millimeters of mercury?

3. What term is used to express how much suction lift a pump can achieve by creating a partial vacuum?

4. What term is used to express the amount of pressure / head required to 'force' liquid through pipe and fittings?

5. What term is used to express the energy content of a liquid in reference to an arbitrary datum?

6. What term is used to express the head required to overcome the friction at the interior surface of a conductor and between fluid particles in motion?

7. What term is used to express the height of a column or body of fluid above a given point?

8. What term is used to express the single-stage axial flow helix installed in the suction eye of an impeller to lower the NPSHR?

9. What term is used to express the bladed member of a rotating assembly of the pump which imparts the principal force to the liquid pumped?

10. What term is used to express the pressure applied to a confined fluid at rest is transmitted with equal intensity throughout the fluid?

Answers 1. Rate of Flow [Q], 2. Pressure, Absolute, 3. NPSH, 4. Friction Loss, 5. Head (h) [H]
6. Head, Friction, 7. Head, Static, 8. Inducer, 9. Impeller, 10. Pascal's Law

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Glossary

A

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

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

Aeronautics: The mathematics and mechanics of flying objects, in particular airplanes.

Air Break: A physical separation which may be a low inlet into the indirect waste receptor from the fixture, or device that is indirectly connected. You will most likely find an air break on waste fixtures or on non-potable lines. You should never allow an air break on an ice machine.

Air Gap Separation: A physical separation space that is present between the discharge vessel and the receiving vessel, for an example, a kitchen faucet.

Altitude-Control Valve: If an overflow occurs on a storage tank, the operator should first check the altitude-control valve. Altitude-Control Valve is designed to, 1. Prevent overflows from the storage tank or reservoir, or 2. Maintain a constant water level as long as water pressure in the distribution system is adequate.

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

$\omega = \theta / t$ *(2a)*

where
ω *= angular velocity (rad/s)*
θ *= angular displacement (rad)*
t *= time (s)*

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

$\omega = \omega_o + \alpha t$ *(2b)*

where
ω_o *= angular velocity at time zero (rad/s)*
α *= angular acceleration (rad/s²)*

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

$\theta = \omega_o t + 1/2 \alpha t^2$ *(2c)*

Combining 2a and 2c:
$\omega = (\omega_o^2 + 2 \alpha \theta)^{1/2}$

Angular acceleration can be expressed as:

$\alpha = d\omega / dt = d^2\theta / dt^2$ *(2d)*

where
$d\theta$ *= change of angular displacement (rad)*
dt *= change in time (s)*

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

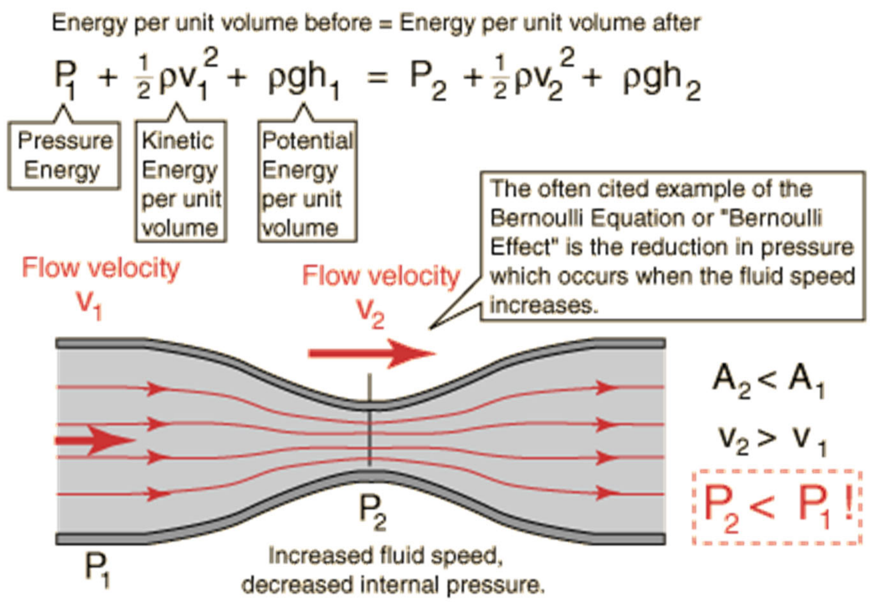
B

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

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

Backsiphonage: A liquid substance that is carried over a higher point. It is the method by which the liquid substance may be forced by excess pressure over or into a higher point. Is a condition in which the pressure in the distribution system is less than atmospheric pressure? In other words, something is “sucked” into the system because the main is under a vacuum.

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



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

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

where

v = flow speed

p = pressure

ρ = density

g = gravity

h = height

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

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

where

$\gamma = \rho \cdot g$

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

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

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

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

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

Bernoulli's Equation Continued:

Dynamic Pressure

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

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

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

Bernoulli's Equation Continued:

Pressurized Tank

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

Example - outlet velocity from a pressurized tank

The outlet velocity of a pressurized tank where

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

can be calculated as

$V_2 = [(2/(1-(0.01)^2)\ (\ (0.2 - 0.1)x10^6 /1x10^3 + 9.81 \times 10)]^{1/2} = \underline{19.9\ m/s}$

Coefficient of Discharge - Friction Coefficient

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

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

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

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

The Bulk Modulus Elasticity can be expressed as

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

where
E = bulk modulus elasticity
dp = differential change in pressure on the object
dV = differential change in volume of the object
V = initial volume of the object

The Bulk Modulus Elasticity can be alternatively expressed as

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

where
dρ = differential change in density of the object
ρ = initial density of the object

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

- The SI unit of the bulk modulus elasticity is N/m^2 (Pa)
- The imperial (BG) unit is lb_f/in^2 (psi)

- 1 lb_f/in^2 (psi) = 6.894 10^3 N/m^2 (Pa)

A large Bulk Modulus indicates a relatively incompressible fluid.

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

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

C

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

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

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

where
h = height of liquid (ft, m)
σ = surface tension (lb/ft, N/m)
θ = contact angle
ρ = density of liquid (lb/ft^3, kg/m^3)
g = acceleration due to gravity (32.174 ft/s^2, 9.81 m/s^2)
r = radius of tube (ft, m)

Cauchy Number: A dimensionless value useful for analyzing fluid flow dynamics problems where compressibility is a significant factor.
The Cauchy Number is the ratio between inertial and the compressibility force in a flow and can be expressed as

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

where
ρ = density (kg/m^3)
v = flow velocity (m/s)
E = bulk modulus elasticity (N/m^2)

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

The Cauchy Number is the square root of the Mach Number

$M^2 = Ca$ *(3)*

where

C = Mach Number

Cavitation: Under the wrong condition, cavitation will reduce the components life time dramatically. Cavitation may occur when the local static pressure in a fluid reach a level below the vapor pressure of the liquid at the actual temperature. According to the Bernoulli Equation this may happen when the fluid accelerates in a control valve or around a pump impeller. The vaporization itself does not cause the damage - the damage happens when the vapor almost immediately collapses after evaporation when the velocity is decreased and pressure increased. Cavitation means that cavities are forming in the liquid that we are pumping.

When these cavities form at the suction of the pump several things happen all at once: We experience a loss in capacity. We can no longer build the same head (pressure). The efficiency drops. The cavities or bubbles will collapse when they pass into the higher regions of pressure causing noise, vibration, and damage to many of the components. The cavities form for five basic reasons and it is common practice to lump all of them into the general classification of cavitation.

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

Avoiding Cavitation

Cavitation can in general be avoided by:

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

This can be done by:

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

Reengineering of Components Initiating High Speed Velocity and Low Static Pressure

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

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

Cavitation Continued: Increasing the Total or Local Pressure in the System
By increasing the total or local pressure in the system, the distance between the static pressure and the vaporization pressure is increased and vaporization and cavitation may be avoided.

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

Cavitation Continued: Reducing the Temperature of the Fluid
The vaporization pressure is highly dependent on the fluid temperature. Water, our most common fluid, is an example:

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

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

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

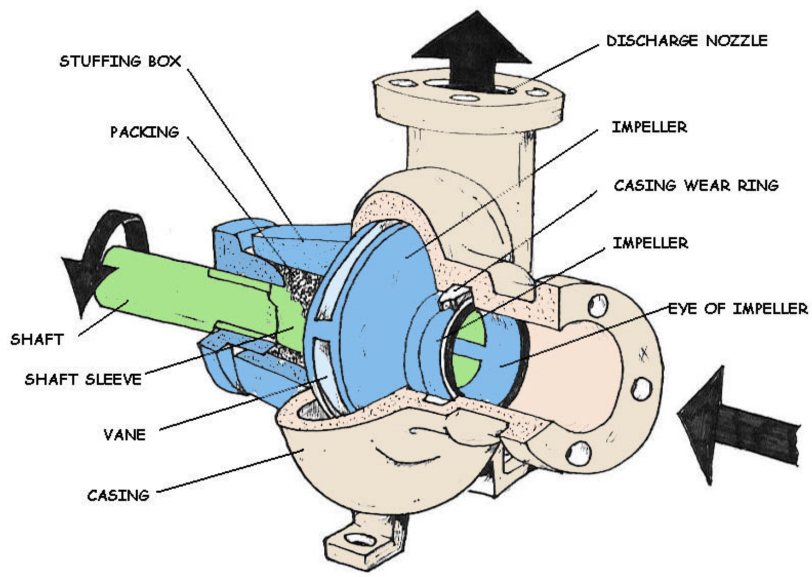
Cavitations Number: A "special edition" of the dimensionless Euler Number.

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

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

where
Ca = Cavitations number
p_r = reference pressure (Pa)
p_v = vapor pressure of the fluid (Pa)
ρ = density of the fluid (kg/m^3)
v = velocity of fluid (m/s)

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



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

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

where
v = mean velocity (m/s, ft/s)
c = the Chezy roughness and conduit coefficient
R = hydraulic radius of the conduit (m, ft)
S = slope of the conduit (m/m, ft/ft)

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

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

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

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

where
λ *= D'Arcy-Weisbach friction coefficient*
Re = Reynolds Number
k = roughness of duct, pipe or tube surface (m, ft)
d_h *= hydraulic diameter (m, ft)*

The Colebrook equation is only valid at turbulent flow conditions.
Note that the friction coefficient is involved on both sides of the equation and that the equation must be solved by iteration.

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

Common Pressure Measuring Devices: The Strain Gauge is a common measuring device used for a variety of changes such as head. As the pressure in the system changes, the diaphragm expands which changes the length of the wire attached. This change of length of the wire changes the Resistance of the wire, which is then converted to head. Float mechanisms, diaphragm elements, bubbler tubes, and direct electronic sensors are common types of level sensors.

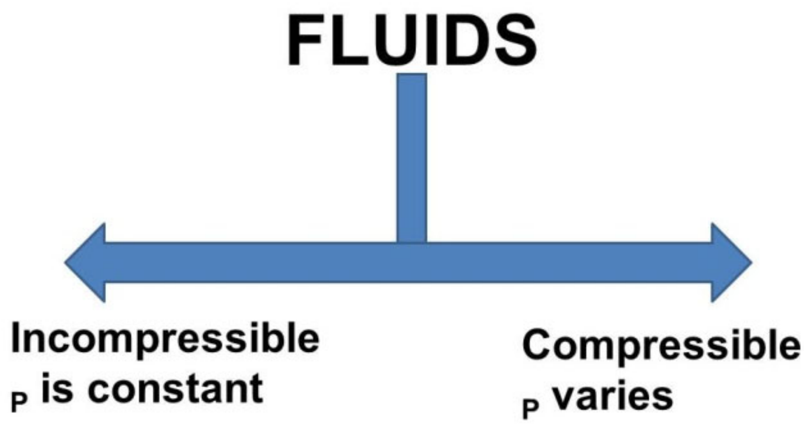
Compressible Flow: We know that fluids are classified as Incompressible and Compressible fluids. Incompressible fluids do not undergo significant changes in density as they flow. In general, liquids are incompressible; water being an excellent example. In contrast compressible fluids do undergo density changes. Gases are generally compressible; air being the most common compressible fluid we can find. Compressibility of gases leads to many interesting features such as shocks, which are absent for incompressible fluids. Gas dynamics is the discipline that studies the flow of compressible fluids and forms an important branch of Fluid Mechanics. In this book we give a broad introduction to the basics of compressible fluid flow.

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

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

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

where
p = absolute pressure
ρ = density



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

Conservation Laws: The conservation laws states that particular measurable properties of an isolated physical system does not change as the system evolves: Conservation of energy (including mass). Fluid Mechanics and Conservation of Mass - The law of conservation of mass states that mass can neither be created or destroyed.

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

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

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

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

D

Darcy-Weisbach Equation: The **pressure loss** (or major loss) in a pipe, tube or duct can be expressed with the D'Arcy-Weisbach equation:

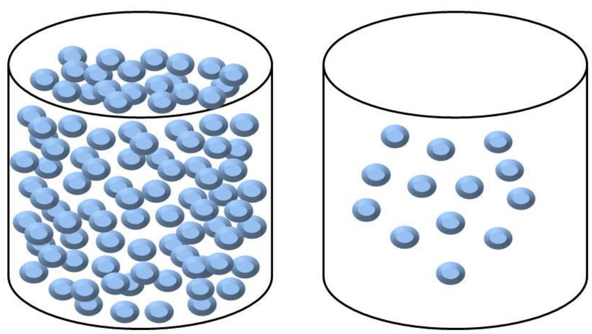
$\Delta p = \lambda \, (l / d_h) \, (\rho \, v^2 / 2)$ *(1)*

where
Δp = *pressure loss (Pa, N/m^2, lb$_f$/ft^2)*
λ = *D'Arcy-Weisbach friction coefficient*
l = *length of duct or pipe (m, ft)*
d_h = *hydraulic diameter (m, ft)*
ρ = *density (kg/m^3, lb/ft^3)*

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
ρ = density (kg/m^3)
m = mass (kg)
V = volume (m^3)
v_g = specific volume (m^3/kg)

The SI units for density are kg/m^3. The imperial (BG) units are lb/ft^3 (slugs/ft^3). 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

ρ = [18.5 (g) / 1000 (g/kg)] / [23.4 (ml) / 1000 (ml/l) 1000 (l/m^3)]
= 18.5 10^{-3} (kg) / 23.4 10^{-6} (m^3)
= <u>790</u> kg/m^3

If we look up densities of some common substances, we can find that ethyl alcohol, or ethanol, has a density of <u>790</u> kg/m^3. 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^3 . Calculate the mass of 0.17 m^3 titanium!

m = 0.17 (m^3) 4507 (kg/m^3)
= <u>766.2</u> kg

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

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

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

Distribution System Water Quality: Can be adversely affected by improperly constructed or poorly located blowoffs of vacuum/air relief valves. Air relief valves in the distribution system lines must be placed in locations that cannot be flooded. This is to prevent water contamination. The common customer complaint of Milky Water or Entrained Air is sometimes solved by the installation of air relief valves. The venting of air is not a major concern when checking water levels in a storage tank. If the vent line on a ground level storage tank is closed or clogged up, a vacuum will develop in the tank may happen to the tank when the water level begins to lower.

Drag Coefficient: Used to express the drag of an object in moving fluid. Any object moving through a fluid will experience a drag - the net force in direction of flow due to the pressure and shear stress forces on the surface of the object.

The drag force can be expressed as:

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

where
F_d *= drag force (N)*
c_d *= drag coefficient*
ρ *= density of fluid*
v *= flow velocity*
A *= characteristic frontal area of the body*

The drag coefficient is a function of several parameters as shape of the body, Reynolds Number for the flow, Froude number, Mach Number and Roughness of the Surface.
The characteristic frontal area - *A* - depends on the body.

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

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

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

where
p_d *= dynamic pressure (Pa)*
ρ *= density of fluid (kg/m*^{3}*)*
v *= velocity (m/s)*

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

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

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

Common used units for viscosity are

- CentiPoises (cp) = CentiStokes (cSt) × Density
- SSU[1] = Centistokes (cSt) × 4.55
- Degree Engler[1] × 7.45 = Centistokes (cSt)
- Seconds Redwood[1] × 0.2469 = Centistokes (cSt)

[1]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

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

where
τ *= shearing stress*
μ *= dynamic viscosity*

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

In the SI system the dynamic viscosity units are **N s/m^2**, **Pa s** or **kg/m s** where
- *1 Pa s = 1 N s/m^2 = 1 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^2** or **poise (p)** where
- *1 poise = dyne s/cm^2 = g/cm s = 1/10 Pa s*

For practical use the Poise is to large and its usual divided by 100 into the smaller unit called the **centiPoise (cP)** where
- *1 p = 100 cP*

Water at 68.4^{o}F (20.2^{o}C) has an absolute viscosity of one - 1 - centiPoise.

E

E. Coli, *Escherichia coli*: A bacterium commonly found in the human intestine. For water quality analyses purposes, it is considered an indicator organism. These are considered evidence of water contamination. Indicator organisms may be accompanied by pathogens, but do not necessarily cause disease themselves.

Elevation Head: The energy possessed per unit weight of a fluid because of its elevation. 1 foot of water will produce .433 pounds of pressure head.

Energy: The ability to do work. Energy can exist in one of several forms, such as heat, light, mechanical, electrical, or chemical. Energy can be transferred to different forms. It also can exist in one of two states, either potential or kinetic.

Energy and Hydraulic Grade Line: The hydraulic grade and the energy line are graphical forms of the Bernoulli equation. For steady, in viscid, incompressible flow the total energy remains constant along a stream line as expressed through the Bernoulli

Equation:

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

where
p = static pressure (relative to the moving fluid)
ρ = density
γ = specific weight
v = flow velocity
g = acceleration of gravity
h = elevation height

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

The Head

By dividing each term with the specific weight - $\gamma = \rho\ g$ - (1) can be transformed to express the "head":

$p / \gamma + v^2 / 2\ g + h$ = constant along a streamline = H (2)
where
H = the total head

Each term of this equation has the dimension length - ft, m.

The Total Head

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

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

Energy and Hydraulic Grade Line Continued:

The Piezometric Head

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

Energy and Hydraulic Grade Line Continued:

The Energy Line

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

$EL = H = p / \gamma + v^2 / 2\ g + h$ = 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: Fluids need some length to develop the velocity profile after entering the pipe or after passing through components such as bends, valves, pumps, and turbines or similar.

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

$El = l_e / d$ *(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:

$El_{laminar} = 0.06\ Re$ *(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:

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

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

$ds = c_v \ln(T_2 / T_1) + R \ln(\rho_1 / \rho_2)$ (1)
or
$ds = c_p \ln(T_2 / T_1) - R \ln(p_2 / p_1)$ (2)

where
ds = entropy change
c_v *= specific heat capacity at a constant volume process*
c_p *= specific heat capacity at a constant pressure process*
T = absolute temperature
R = individual gas constant
ρ = density of gas
p = absolute pressure

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

The Equation of Continuity and can be expressed as:

$$m = \rho_{i1} v_{i1} A_{i1} + \rho_{i2} v_{i2} A_{i2} +..+ \rho_{in} v_{in} A_{im}$$
$$= \rho_{o1} v_{o1} A_{o1} + \rho_{o2} v_{o2} A_{o2} +..+ \rho_{om} v_{om} A_{om} \quad (1)$$

where
m = mass flow rate (kg/s)
ρ = density (kg/m^3)
v = speed (m/s)
A = area (m^2)
With uniform density equation (1) can be modified to

$$q = v_{i1} A_{i1} + v_{i2} A_{i2} +..+ v_{in} A_{im}$$
$$= v_{o1} A_{o1} + v_{o2} A_{o2} +..+ v_{om} A_{om} \quad (2)$$

where
q = flow rate (m^3/s)
$\rho_{i1} = \rho_{i2} = . . = \rho_{in} = \rho_{o1} = \rho_{o2} = . .= \rho_{om}$

Example - Equation of Continuity
10 m^3/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

$(10\ m^3/h)(1 / 3600\ h/s) = v_{100}\ (3.14 \times 0.1\ (m) \times 0.1\ (m) / 4)$
or
$v_{100} = (10\ m^3/h)(1 / 3600\ h/s) / (3.14 \times 0.1\ (m) \times 0.1\ (m) / 4)$
$= \underline{0.35}\ m/s$
Using equation (2) the velocity in the 80 mm pipe can be calculated
$(10\ m^3/h)(1 / 3600\ h/s) = v_{80}\ (3.14 \times 0.08\ (m) \times 0.08\ (m) / 4)$

or

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

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

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

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

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

where

p = static pressure

ρ = density

v = flow velocity

g = acceleration of gravity

h = elevation height

w_{shaft} = net shaft energy 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 ($ft^2/s^2 = ft\ lb/slug$ *or* $m^2/s^2 = N\ m/kg$)

Efficiency

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

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

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

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

The Mechanical Energy Equation in Terms of Energy per Unit Volume

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

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

where
$\gamma = \rho\, g$ = specific weight

The dimensions of equation (5) are
energy per unit volume ($ft.lb/ft^3 = lb/ft^2$ or $N.m/m^3 = N/m^2$)

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.lb/lb = ft or N.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^3/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:

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

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

Combined with (8):

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

The pump efficiency can be calculated from (3) modified for head:

$\eta = ((17.6\ ft) - (7.6\ ft)) / (17.6\ ft) = 0.58$

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

$$\operatorname{sech} x - 1 \equiv -\frac{E_1^* x^2}{2!} + \frac{E_2^* x^4}{4!} - \frac{E_3^* x^6}{6!} + \ldots$$

$$\sec x - 1 \equiv \frac{E_1^* x^2}{2!} + \frac{E_2^* x^4}{4!} + \frac{E_3^* x^6}{6!} + \ldots,$$

where $\operatorname{sech}(z)$the hyperbolic secant and sec is the secant. Euler numbers give the number of odd alternating permutations and are related to Genocchi numbers. The base *e* of the natural logarithm is sometimes known as Euler's number. A different sort of Euler number, the Euler number of a finite complex K, is defined by

$$\chi(K) = \sum (-1)^p \operatorname{rank}(C_p(K)).$$

This Euler number is a topological invariant. To confuse matters further, the Euler characteristic is sometimes also called the "Euler number," and numbers produced by the prime-generating polynomial $n^2 - n + 41$are sometimes called "Euler numbers" (Flannery and Flannery 2000, p. 47).

F

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

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

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

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

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

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

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

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

G

Gas: A gas is one of the four major phases of matter (after solid and liquid, and followed by plasma) that subsequently appear as solid material when they are subjected to increasingly higher temperatures. Thus, as energy in the form of heat is added, a solid (e.g., ice) will first melt to become a liquid (e.g., water), which will then boil or evaporate to become a gas (e.g., water vapor). In some circumstances, a solid (e.g., "dry ice") can directly turn into a gas: this is called sublimation. If the gas is further heated, its atoms or molecules can become (wholly or partially) ionized, turning the gas into a plasma. Relater Gas Information: The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law. Properties of Gas Mixtures - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density. The Individual and Universal Gas Constant - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.

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

H

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

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

Hazen-Williams Equation - Calculating Friction Head Loss in Water Pipes
Friction head loss (ft H2O per 100 ft pipe) in water pipes can be obtained by using the empirical Hazen-Williams equation. The Darcy-Weisbach equation with the Moody diagram are considered to be the most accurate model for estimating frictional head loss in steady pipe flow. Since the approach requires a not so efficient trial and error solution, an alternative empirical head loss calculation that does not require the trial and error solutions, as the Hazen-Williams equation, may be preferred:

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

where
f = friction head loss in feet of water per 100 feet of pipe (ft_{h20}*/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 =6.30888×10^{-5} m^3/s = 0.0227 m^3/h = 0.0631 dm^3(liter)/s = 2.228×10^{-3} ft^3/s = 0.1337 ft^3/min = 0.8327 Imperial gal (UK)/min

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

The results for the formula are acceptable for cold water at 60^o F (15.6^o C) with kinematic viscosity 1.13 cSt. For hot water with a lower kinematic viscosity (0.55 cSt at 130^o F (54.4^o C)) the error will be significant. Since the Hazen Williams method is only valid for water flowing at ordinary temperatures between 40 to 75^o 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 if 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:

$p / \rho^k = constant$ *(2)*

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

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

K

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

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

where
v *= kinematic viscosity*
μ *= absolute or dynamic viscosity*
ρ *= density*

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

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

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

1 St = 100 cSt

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

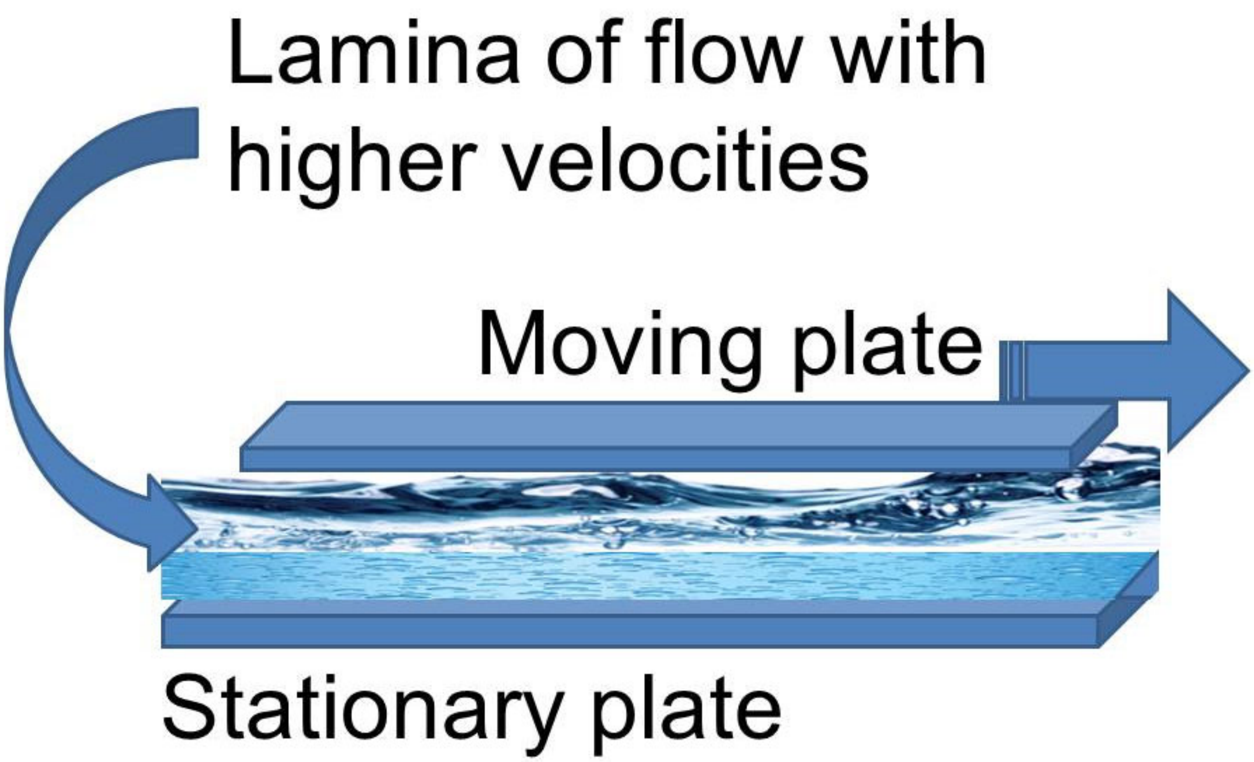
Since the specific gravity of water at 68.4°F (20.2°C) is almost one - 1, the kinematic viscosity of water at 68.4°F is for all practical purposes 1.0 cSt.

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

Knudsen Number: Used by modelers who wish to express a non-dimensionless speed.

L

Laminar Flow: The resistance to flow in a liquid can be characterized in terms of the viscosity of the fluid if the flow is smooth. In the case of a moving plate in a liquid, it is found that there is a layer or lamina which moves with the plate, and a layer which is essentially stationary if it is next to a stationary plate. There is a gradient of velocity as you move from the stationary to the moving plate, and the liquid tends to move in layers with successively higher speed. This is called laminar flow, or sometimes "streamlined" flow. Viscous resistance to flow can be modeled for laminar flow, but if the lamina breaks up into turbulence, it is very difficult to characterize the fluid flow.



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

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

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

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

where ∇^2 is the Laplacian.
Note that the operator ∇^2 is commonly written as Δ by mathematicians (Krantz 1999, p. 16).
Laplace's equation is a special case of the Helmholtz differential equation

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

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

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

with $\rho = 0$.

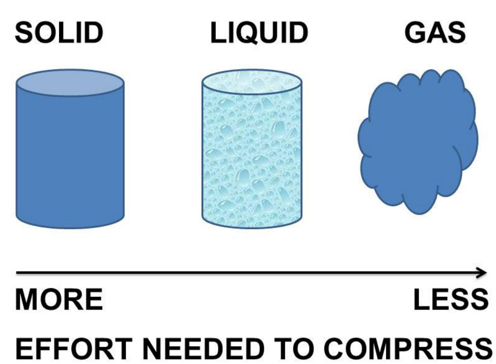
The vector Laplace's equation is given by

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

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

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

Liquids: An in-between state of matter. They can be found in between the solid and gas states. They don't have to be made up of the same compounds. If you have a variety of materials in a liquid, it is called a solution. One characteristic of a liquid is that it will fill up the shape of a container. If you pour some water in a cup, it will fill up the bottom of the cup first and then fill the rest. The water will also take the shape of the cup. It fills the bottom first because of **gravity**. The top part of a liquid will usually have a flat surface. That flat surface is because of gravity too. Putting an ice cube (solid) into a cup will leave you with a cube in the middle of the cup; the shape won't change until the ice becomes a liquid.



Another trait of liquids is that they are difficult to compress.

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

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

M

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

Magnetic Flow Meter: Inspection of magnetic flow meter instrumentation should include checking for corrosion or insulation deterioration.

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

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

where
q = volume flow (ft^3/s, m^3/s)
A = cross-sectional area of flow (ft^2, m^2)

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

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

Mg/L: milligrams per liter

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

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

ML: milliliter

N

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

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

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

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

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

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

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

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

O

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

P

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

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

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

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

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

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

Pipe Velocities: For calculating fluid pipe velocity.

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

$v = 0.4085\, q / d^2$ (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

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

where
v = *velocity (m/s)*
q = *volume flow (m^3/s)*
d = *pipe inside diameter (m)*

Pollution: To make something unclean or impure. Some states will have a definition of pollution that relates to non-health related water problems, like taste and odors. See Contaminated.

Positive Flow Report-back Signal: When a pump receives a signal to start, a light will typically be illuminated on the control panel indicating that the pump is running. In order to be sure that the pump is actually pumping water, a Positive flow report-back signal should be installed on the control panel.

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

Potential Energy: The energy that a body has by virtue of its position or state enabling it to do work.

PPM: Abbreviation for parts per million.

Prandtl Number: The Prandtl Number is a dimensionless number approximating the ratio of momentum diffusivity and thermal diffusivity and can be expressed as

$Pr = v / \alpha$ (1)
where
Pr = Prandtl's number
v = kinematic viscosity (Pa s)
α = thermal diffusivity (W/m K)

The Prandtl number can alternatively be expressed as

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

where
μ = absolute or dynamic viscosity (kg/m s, cP)
c_p = specific heat capacity (J/kg K, Btu/(lb ^oF))
k = thermal conductivity (W/m K, Btu/(h ft^2 ^oF/ft))

The Prandtl Number is often used in heat transfer and free and forced convection calculations.

Pressure: An introduction to pressure - the definition and presentation of common units as psi and Pa and the relationship between them.

The pressure in a fluid is defined as
"the normal force per unit area exerted on an imaginary or real plane surface in a fluid or a gas"

The equation for pressure can expressed as:
$p = F / A$ (1)

where
p = pressure [lb/in^2 (psi) or lb/ft^2 (psf), N/m^2 or kg/ms^2 (Pa)]
F = force [1), N]
A = area [in^2 or ft^2, m^2]

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

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

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

$p_g = p_a - p_o$ *(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^{o}K (0^{o}C) and is **1.01325 bar** or 101325 Pa (absolute). The temperature of 293^{o}K (20^{o}C) is also used.

In imperial units the Standard Atmospheric Pressure is 14.696 psi.
- *1 atm = 1.01325 bar = 101.3 kPa = 14.696 psi (lb_f/in^2)= 760 mmHg =10.33 mH_2O = 760 torr = 29.92 in Hg = 1013 mbar = 1.0332 kg_f/cm^2 = 33.90 ftH_2O*

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

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

Pressure Units: Since 1 Pa is a small pressure unit, the unit hectopascal (hPa) is widely used, especially in meteorology. The unit kilopascal (kPa) is commonly used designing technical applications like HVAC systems, piping systems and similar.
- *1 hectopascal = 100 pascal = 1 millibar*
- *1 kilopascal = 1000 pascal*

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

Some Alternative Units of Pressure

- *1 bar - 100,000 Pa*
- *1 millibar - 100 Pa*
- *1 atmosphere - 101,325 Pa*
- *1 mm Hg - 133 Pa*
- *1 inch Hg - 3,386 Pa*

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

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

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

1 Bar = 0.9869 atm

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

1 millibar = 0.001 bar = 0.750 torr = 100 Pa

R

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

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

$$Re = (\rho u^2) / (\mu u / L)$$
$$= \rho u L / \mu$$
$$= u L / v \quad (1)$$

where

Re = Reynolds Number (non-dimensional)

ρ = *density* (kg/m^3, lb_m/ft^3)

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

μ = *dynamic viscosity* (Ns/m^2, $lb_m/s\ ft$)

L = *characteristic length (m, ft)*

v = *kinematic viscosity* (m^2/s, ft^2/s)

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

S

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

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

Kinematic viscosity versus dynamic or absolute viscosity can be expressed as

$v = 4.63\ \mu / SG$ *(3)*
where
v *= kinematic viscosity (SSU)*
μ *= dynamic or absolute viscosity (cP)*

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

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

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

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

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

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

$SG = = \rho / \rho_{H2O}$ *(3)*

where
SG *= specific gravity*
ρ *= density of fluid or substance (kg/m³)*
ρ_{H2O} *= density of water* (kg/m^3)

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

Example - Specific Gravity
If the density of iron is 7850 kg/m^3, 7.85 grams per cubic millimeter, 7.85 kilograms per liter, or 7.85 metric tons per cubic meter - the specific gravity of iron is:

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

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

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

Specific Weight can be expressed as

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

where
γ = *specific weight (kN/m^3)*
g = *acceleration of gravity (m/s^2)*

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

Example - Specific Weight Water
Specific weight for water at 60 ^{o}F is 62.4 lb/ft^3 in imperial units and 9.80 kN/m^3 in SI-units.

Example - Specific Weight Some other Materials

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

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

Static Pressure: The pressure in a fluid at rest.

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

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

How pressure changes with elevation can be expressed as

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

where
dp = change in pressure
dz = change in height
γ = specific weight

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

Specific Weight: Specific Weight can be expressed as:

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

where
γ = specific weight
g = acceleration of gravity

In general, the specific weight - γ - is constant for fluids. For gases the specific weight - γ - varies with the elevation.

Static Pressure in a Fluid: For an incompressible fluid - as a liquid - the pressure difference between two elevations can be expressed as:

$p_2 - p_1 = - \gamma (z_2 - z_1)$ (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:

$p_1 - p_2 = \gamma (z_2 - z_1)$ (4)
or
$p_1 - p_2 = \gamma\, h$ (5)

where
$h = z_2 - z_1$ difference in elevation - the depth down from location z_2.
or
$p_1 = \gamma\, h + p_2$ (6)

Static Pressure and Pressure Head in Fluids Continued:

The Pressure Head

(6) can be transformed to:

$h = (p_2 - p_1) / \gamma$ (6)

h expresses **the pressure head** - the height of a column of fluid of specific weight - γ - required to give a pressure difference of ($p_2 - p_1$).

Example - Pressure Head
A pressure difference of 5 psi (lbf/in^2) is equivalent to

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

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

when specific weight of water is 62.4 (lb/ft^3) and specific weight of mercury is 847 (lb/ft^3).

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

$St = \omega\, l / v$ *(1)*

where
St = Strouhal Number
ω = oscillation frequency
l = characteristic length
v = flow velocity

The Strouhal Number represents a measure of the ratio of inertial forces due to the unsteadiness of the flow or local acceleration to the inertial forces due to changes in velocity from one point to another in the flow field.

The vortices observed behind a stone in a river, or measured behind the obstruction in a vortex flow meter, illustrate these principles.

Stuffing Box: That portion of the pump which houses the packing or mechanical seal.

Submerged: To cover with water or liquid substance.

Supersonic Flow: Flow with speed above the speed of sound, 1,225 km/h at sea level, is said to be supersonic.

Surface Tension: Surface tension is a force within the surface layer of a liquid that causes the layer to behave as an elastic sheet. The cohesive forces between liquid molecules are responsible for the phenomenon known as surface tension. The molecules at the surface do not have other like molecules on all sides of them and consequently they cohere more strongly to those directly associated with them on the surface.

This forms a surface "film" which makes it more difficult to move an object through the surface than to move it when it is completely submersed. Surface tension is typically measured in dynes/cm, the force in dynes required to break a film of length 1 cm. Equivalently, it can be stated as surface energy in ergs per square centimeter. Water at 20°C has a surface tension of 72.8 dynes/cm compared to 22.3 for ethyl alcohol and 465 for mercury.

Surface tension is typically measured in *dynes/cm* or *N/m*.

Liquid	Surface Tension	
	N/m	dynes/cm
Ethyl Alcohol	0.0223	22.3
Mercury	0.465	465
Water 20°C	0.0728	72.75
Water 100°C	0.0599	58.9

Surface tension is the energy required to stretch a unit change of a surface area. Surface tension will form a drop of liquid to a sphere since the sphere offers the smallest area for a definite volume.

Surface tension can be defined as

$\sigma = F_s / l$ *(1)*

where
σ = surface tension (N/m)
F_s = stretching force (N)
l = unit length (m)

Alternative Units
Alternatively, surface tension is typically measured in dynes/cm, which is
- the force in dynes required to break a film of length 1 cm

or as surface energy J/m^2 or alternatively ergs per square centimeter.
- 1 dynes/cm = 0.001 N/m = 0.0000685 lb_f/ft = 0.571 10^{-5} lb_f/in = 0.0022 poundal/ft = 0.00018 poundal/in = 1.0 mN/m = 0.001 J/m^2 = 1.0 erg/cm^2 = 0.00010197 kg_f/m

Common Imperial units used are lb/ft and lb/in.
Water surface tension at different temperatures can be taken from the table below:

Temperature (°C)	Surface Tension - σ - (N/m)
0	0.0757
10	0.0742
20	0.0728
30	0.0712
40	0.0696
50	0.0679
60	0.0662
70	0.0644
80	0.0626
90	0.0608
100	0.0588

Surface Tension of some common Fluids

- benzene : 0.0289 (N/m)
- diethyl ether : 0.0728 (N/m)
- carbon tetrachloride : 0.027 (N/m)
- chloroform : 0.0271 (N/m)
- ethanol : 0.0221 (N/m)
- ethylene glycol : 0.0477 (N/m)
- glycerol : 0.064 (N/m)
- mercury : 0.425 (N/m)
- methanol : 0.0227 (N/m)
- propanol : 0.0237 (N/m)
- toluene : 0.0284 (N/m)
- water at 20^{o}C : 0.0729 (N/m)

Surge Tanks: Surge tanks can be used to control Water Hammer. A limitation of hydropneumatic tanks is that they do not provide much storage to meet peak demands during power outages and you have very limited time to do repairs on equipment.

T

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

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

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

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

U

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

V

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

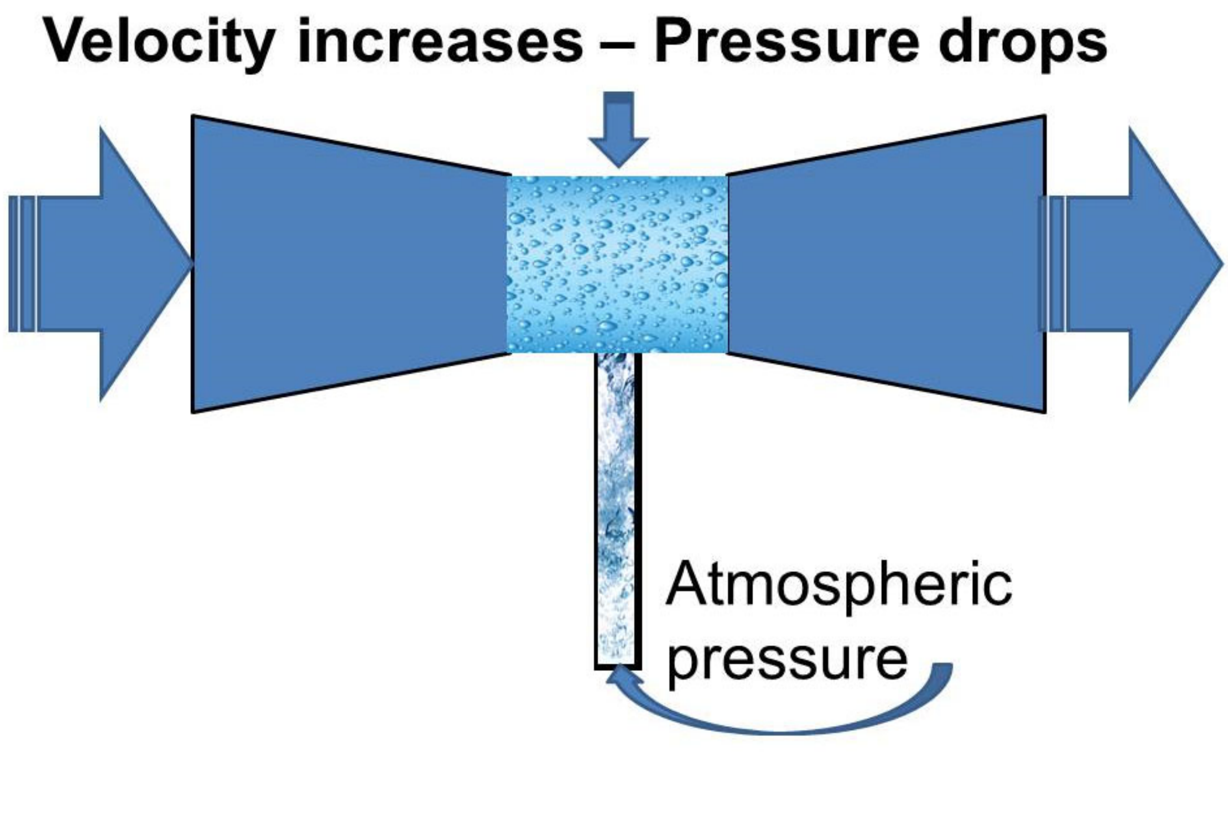
Vane: That portion of an impeller which throws the water toward the volute.

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

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

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

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



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

The cavitation effect at the injection chamber provides an instantaneous mixing, creating thousands of very tiny bubbles of gas in the liquid. The small bubbles provide and increased gas exposure to the liquid surface area, increasing the effectiveness of the process (i.e. ozonation).

Vibration: A force that is present on construction sites and must be considered. The vibrations caused by backhoes, dump trucks, compactors and traffic on job sites can be substantial.

Viscosity: Informally, viscosity is the quantity that describes a fluid's resistance to flow. Fluids resist the relative motion of immersed objects through them as well as to the motion of layers with differing velocities within them. Formally, viscosity (represented by the symbol η "eta") is the ratio of the shearing stress (F/A) to the velocity gradient ($\Delta v_x/\Delta z$ or dv_x/dz) in a fluid.

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

The more usual form of this relationship, called Newton's equation, states that the resulting shear of a fluid is directly proportional to the force applied and inversely proportional to its viscosity. The similarity to Newton's second law of motion ($F = ma$) should be apparent.

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

$$\Updownarrow \qquad\qquad \Updownarrow$$

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

The SI unit of viscosity is the pascal second [Pa·s], which has no special name. Despite its self-proclaimed title as an international system, the International System of Units has had very little international impact on viscosity. The pascal second is rarely used in scientific and technical publications today. The most common unit of viscosity is the dyne second per square centimeter [dyne·s/cm^2], which is given the name poise [P] after the French physiologist Jean Louis Poiseuille (1799-1869). Ten poise equal one pascal second [Pa·s] making the centipoise [cP] and millipascal second [mPa·s] identical.

1 pascal second = 10 poise = 1,000 millipascal second
1 centipoise = 1 millipascal second

There are actually two quantities that are called viscosity. The quantity defined above is sometimes called dynamic viscosity, absolute viscosity, or simple viscosity to distinguish it from the other quantity, but is usually just called viscosity. The other quantity called kinematic viscosity (represented by the symbol v "nu") is the ratio of the viscosity of a fluid to its density.

$$v = \frac{\eta}{\rho}$$

Kinematic viscosity is a measure of the resistive flow of a fluid under the influence of gravity. It is frequently measured using a device called a capillary viscometer -- basically a graduated can with a narrow tube at the bottom. When two fluids of equal volume are placed in identical capillary viscometers and allowed to flow under the influence of gravity, a viscous fluid takes longer than a less viscous fluid to flow through the tube. Capillary viscometers are discussed in more detail later in this section. The SI unit of kinematic viscosity is the square meter per second [m^2/s], which has no special name. This unit is so large that it is rarely used. A more common unit of kinematic viscosity is the square centimeter per second [cm^2/s], which is given the name stoke [St] after the English scientist George Stoke. This unit is also a bit too large and so the most common unit is probably the square millimeter per second [mm^2/s] or centistoke [cSt].

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

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

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

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

Vortex: A vortex is a whirlpool in the water.

W

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

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

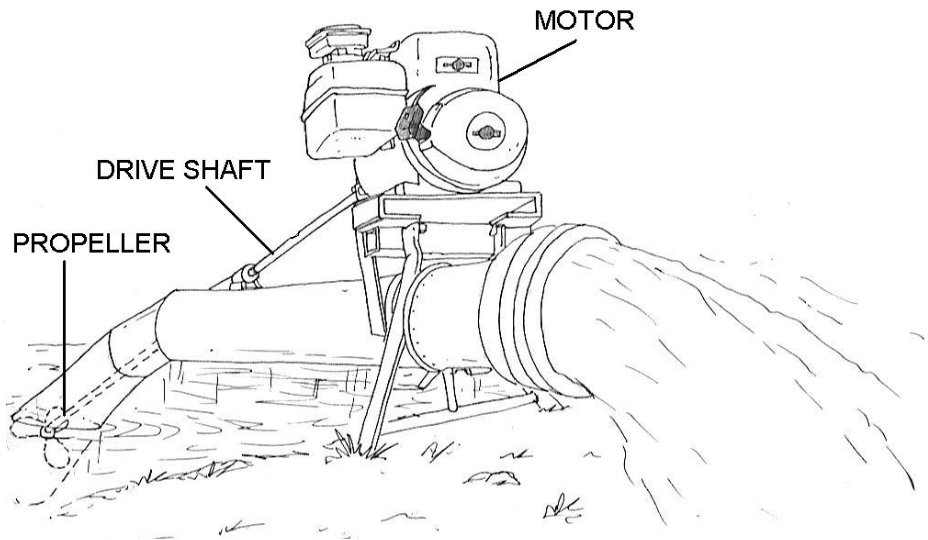
Wave Drag: Wave drag refers to a sudden and very powerful drag that appears on aircrafts flying at high-subsonic speeds.

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

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

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

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



Appendixes and Charts

Density of Common Liquids

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

Liquid	Temperature - *t* - (ºC)	Density - *ρ* - (kg/m^3)
Acetic Acid	25	1049
Acetone	25	785
Acetonitrile	20	782
Alcohol, ethyl	25	785
Alcohol, methyl	25	787
Alcohol, propyl	25	780
Ammonia (aqua)	25	823
Aniline	25	1019
Automobile oils	15	880 - 940
Beer (varies)	10	1010
Benzene	25	874
Benzyl	15	1230
Brine	15	1230
Bromine	25	3120
Butyric Acid	20	959
Butane	25	599
n-Butyl Acetate	20	880
n-Butyl Alcohol	20	810
n-Butylhloride	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, 48º API	60ºF	790

Crude oil, 40º API	60ºF	825
Crude oil, 35.6º API	60ºF	847
Crude oil, 32.6º API	60ºF	862
Crude oil, California	60ºF	915
Crude oil, Mexican	60ºF	973
Crude oil, Texas	60ºF	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	60ºF	890
Furan	25	1416
Furforol	25	1155
Gasoline, natural	60ºF	711
Gasoline, Vehicle	60ºF	737
Gas oils	60ºF	890
Glucose	60ºF	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	60ºF	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	60ºF	711
Petrol, Vehicle	60ºF	737
Phenol	25	1072
Phosgene	0	1378
Phytadiene	25	823
Pinene	25	857
Propane	-40	583

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

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

Dynamic or Absolute Viscosity Units Converting Table

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

Multiply by	Convert to				
Convert from	Poiseuille (Pa s)	Poise (dyne s/ cm^2 = g / cm s)	centiPoise	kg / m h	kg_f s / m^2
Poiseuille (Pa s)	1	10	10^3	3.63 10^3	0.102
Poise (dyne s / cm^2 = g / cm s)	0.1	1	100	360	0.0102
centiPoise	0.001	0.01	1	3.6	0.00012
kg / m h	2.78 10^{-4}	0.00278	0.0278	1	2.83 10^{-5}
kg_f s / m^2	9.81	98.1	9.81 10^3	3.53 10^4	1
lb_f s / $inch^2$	6.89 10^3	6.89 10^4	6.89 10^6	2.48 10^7	703
lb_f s / ft^2	47.9	479	4.79 10^4	1.72 10^5	0.0488
lb_f h / ft^2	1.72 10^5	1.72 10^6	1.72 10^8	6.21 10^8	1.76 10^4
lb / ft s	1.49	14.9	1.49 10^3	5.36 10^3	0.152
lb / ft h	4.13 10^{-4}	0.00413	0.413	1.49	4.22 10^{-5}

Multiply by	Convert to				
Convert from	lb_f s / $inch^2$	lb_f s / ft^2	lb_f h / ft^2	lb / ft s	lb / ft h
Poiseuille (Pa s)	1.45 10^{-4}	0.0209	5.8 10^{-6}	0.672	2.42 10^3
Poise (dyne s / cm^2 = g / cm s)	1.45 10^{-5}	0.00209	5.8 10^{-7}	0.0672	242
centiPoise	1.45 10^{-7}	2.9 10^{-5}	5.8 10^{-9}	0.000672	2.42
kg / m h	4.03 10^{-8}	5.8 10^{-6}	1.61 10^{-9}	0.000187	0.672
kg_f s / m^2	0.00142	20.5	5.69 10^{-5}	6.59	2.37 10^4
lb_f s / $inch^2$	1	144	0.04	4.63 10^3	1.67 10^7
lb_f s / ft^2	0.00694	1	0.000278	32.2	1.16 10^5
lb_f h / ft^2	25	3.6 10^3	1	1.16 10^5	4.17 10^8
lb / ft s	0.000216	0.0311	8.63 10^{-6}	1	3.6 10^3
lb / ft h	6 10-^{8}	1.16 10^5	2.4 10^{-9}	0.000278	1

Friction Loss Chart

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

Pipe Size (inches)	Flow Rate		Kinematic Viscosity - SSU					
	(gpm)	(l/s)	31 (Water)	100 (~Cream)	200 (~Vegetable oil)	400 (~SAE 10 oil)	800 (~Tomato juice)	1500 (~SAE 30 oil)
1/2	3	0.19	10.0	25.7	54.4	108.0	218.0	411.0
3/4	3	0.19	2.5	8.5	17.5	35.5	71.0	131.0
	5	0.32	6.3	14.1	29.3	59.0	117.0	219.0
1	3	0.19	0.8	3.2	6.6	13.4	26.6	50.0
	5	0.32	1.9	5.3	11.0	22.4	44.0	83.0
	10	0.63	6.9	11.2	22.4	45.0	89.0	165.0
	15	0.95	14.6	26.0	34.0	67.0	137.0	
	20	1.26	25.1	46	46.0	90.0	180.0	
1 1/4	5	0.32	0.5	1.8	3.7	7.6	14.8	26.0
	10	0.63	1.8	3.6	7.5	14.9	30.0	55.0
	15	0.95	3.7	6.4	11.3	22.4	45.0	84.0
1 1/2	10	0.63	0.8	1.9	4.2	8.1	16.5	31.0
	15	0.95	1.7	2.8	6.2	12.4	25.0	46.0
	20	1.26	2.9	5.3	8.1	16.2	33.0	61.0
	30	1.9	6.3	11.6	12.2	24.3	50.0	91.0
	40	2.5	10.8	19.6	20.8	32.0	65.0	121.0
2	20	1.26	0.9	1.5	3.0	6.0	11.9	22.4
	30	1.9	1.8	3.2	4.4	9.0	17.8	33.0
	40	2.5	3.1	5.8	5.8	11.8	24.0	44.0
	60	3.8	6.6	11.6	13.4	17.8	36.0	67.0
	80	5.0	1.6	3.0	3.2	4.8	9.7	18.3
2 1/2	30	1.9	0.8	1.4	2.2	4.4	8.8	16.6
	40	2.5	1.3	2.5	3.0	5.8	11.8	22.2
	60	3.8	2.7	5.1	5.5	8.8	17.8	34.0
	80	5.0	4.7	8.3	9.7	11.8	24.0	44.0
	100	6.3	7.1	12.2	14.1	14.8	29.0	55.0
3	60	3.8	0.9	1.8	1.8	3.7	7.3	13.8
	100	6.3	2.4	4.4	5.1	6.2	12.1	23.0
	125	7.9	3.6	6.5	7.8	8.1	15.3	29.0
	150	9.5	5.1	9.2	10.4	11.5	18.4	35.0
	175	11.0	6.9	11.7	13.8	15.8	21.4	40.0
	200	12.6	8.9	15.0	17.8	20.3	25.0	46.0
4	80	5.0	0.4	0.8	0.8	1.7	3.3	6.2
	100	6.3	0.6	1.2	1.3	2.1	4.1	7.8
	125	7.9	0.9	1.8	2.1	2.6	5.2	9.8

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

Hazen-Williams Coefficients

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

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

Pressure Head

A pressure difference of 5 psi (lbf/in^2) is equivalent to

5 (lbf/in^2) 12 (in/ft) 12 (in/ft) / 62.4 (lb/ft^3) = 11.6 ft of water

5 (lbf/in^2) 12 (in/ft) 12 (in/ft) / 847 (lb/ft^3) = 0.85 ft of mercury

When specific weight of water is 62.4 (lb/ft^3) and specific weight of mercury is 847 (lb/ft^3).

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

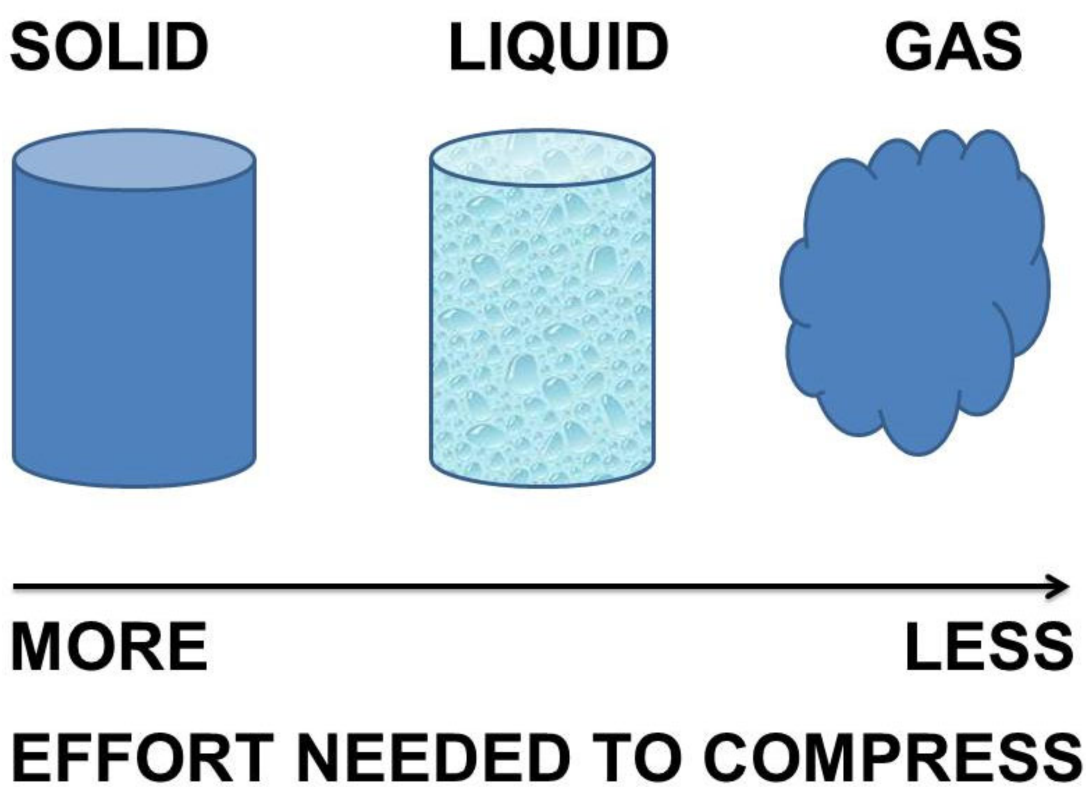
Velocity (ft/sec)	Head Water (ft)
0.5	0.004
1.0	0.016
1.5	0035
2.0	0.062
2.5	0.097
3.0	0.140
3.5	0.190
4.0	0.248
4.5	0.314
5.0	0.389
5.5	0.470
6.0	0.560
6.5	0.657
7.0	0.762
7.5	0.875
8.0	0.995
8.5	1.123
9.0	1.259
9.5	1.403
10.0	1.555
11.0	1.881
12.0	2.239
13.0	2.627
14.0	3.047
15.0	3.498
16.0	3.980
17.0	4.493
18.0	5.037
19.0	5.613
20.0	6.219
21.0	6.856
22.0	7.525

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

Thermal Properties of Water

Temperature - t - (°C)	Absolute pressure - p - (kN/m^2)	Density - ρ - (kg/m^3)	Specific volume - v - (m^3/kgx10^{-3})	Specific Heat - c_p - (kJ/kgK)	Specific entropy - e - (kJ/kgK)
0	0.6	1000	100	4.217	0
5	0.9	1000	100	4.204	0.075
10	1.2	1000	100	4.193	0.150
15	1.7	999	100	4.186	0.223
20	2.3	998	100	4.182	0.296
25	3.2	997	100	4.181	0.367
30	4.3	996	100	4.179	0.438
35	5.6	994	101	4.178	0.505
40	7.7	991	101	4.179	0.581
45	9.6	990	101	4.181	0.637
50	12.5	988	101	4.182	0.707
55	15.7	986	101	4.183	0.767
60	20.0	980	102	4.185	0.832
65	25.0	979	102	4.188	0.893
70	31.3	978	102	4.190	0.966
75	38.6	975	103	4.194	1.016
80	47.5	971	103	4.197	1.076
85	57.8	969	103	4.203	1.134
90	70.0	962	104	4.205	1.192
95	84.5	962	104	4.213	1.250
100	101.33	962	104	4.216	1.307
105	121	955	105	4.226	1.382
110	143	951	105	4.233	1.418
115	169	947	106	4.240	1.473
120	199	943	106	4.240	1.527
125	228	939	106	4.254	1.565
130	270	935	107	4.270	1.635
135	313	931	107	4.280	1.687
140	361	926	108	4.290	1.739
145	416	922	108	4.300	1.790
150	477	918	109	4.310	1.842
155	543	912	110	4.335	1.892
160	618	907	110	4.350	1.942
165	701	902	111	4.364	1.992
170	792	897	111	4.380	2.041
175	890	893	112	4.389	2.090
180	1000	887	113	4.420	2.138

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



Viscosity Converting Chart

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

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

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

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

Various Flow Section Channels and their Geometric Relationships:

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

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

Rectangular Channel

Flow Area

Flow area of a rectangular channel can be expressed as

$A = b\ h$ *(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

$P = b + 2\ h$ *(1b)*

where

P *= wetted perimeter (m, in)*

Hydraulic Radius

Hydraulic radius of a rectangular channel can be expressed as

$R_h = b\ h / (b + 2\ y)$ *(1c)*

where

R_h *= hydraulic radius (m, in)*

Trapezoidal Channel

Flow Area

Flow area of a trapezoidal channel can be expressed as

$A = (a + z\ h)\ h$ *(2)*

where

z *= see figure above (m, in)*

Wetted Perimeter

Wetted perimeter of a trapezoidal channel can be expressed as

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

Hydraulic Radius

Hydraulic radius of a trapezoidal channel can be expressed as

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

Triangular Channel

Flow Area

Flow area of a triangular channel can be expressed as

$A = z h^2$ *(3)*

where

z = see figure above (m, in)

Wetted Perimeter

Wetted perimeter of a triangular channel can be expressed as

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

Hydraulic Radius

Hydraulic radius of a triangular channel can be expressed as

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

Circular Channel

Flow Area

Flow area of a circular channel can be expressed as

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

where

D = diameter of channel

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

Wetted Perimeter

Wetted perimeter of a circular channel can be expressed as

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

Hydraulic Radius

Hydraulic radius of a circular channel can be expressed as

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

Velocity Head: Velocity head can be expressed as

$h = v^2/2g$ *(1)*

where

v = velocity (ft, m)

g = acceleration of gravity ($32.174 ft/s^2$, $9.81 m/s^2$)

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	0035
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 ^oC - 1,000 kg/m^3, 62.43 Lbs./Cu.Ft., 8.33 Lbs./Gal., 0.1337 Cu.Ft./Gal.
- Freezing temperature - 0 ^oC
- Boiling temperature - 100 ^oC
- Latent heat of melting - 334 kJ/kg
- Latent heat of evaporation - 2,270 kJ/kg
- Critical temperature - 380 - 386 ^oC
- Critical pressure - 23.520 kN/m^2
- 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 ^oC to 100 ^oC - $4.2x10^{-2}$
- Bulk modulus elasticity - 2,068,500 kN/m^2

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 **one (1) liter/min**	835	550	420	280	210	140	105	85	70	46
Reynolds number with **one (1) gal/min**	3800	2500	1900	1270	950	630	475	380	320	210

Linear Motion Formulas

Velocity can be expressed as (velocity = constant):

$v = s / t$ *(1a)*

where
v = *velocity (m/s, ft/s)*
s = *linear displacement (m, ft)*
t = *time (s)*

Velocity can be expressed as (acceleration = constant):
$v = V_0 + a\, t$ *(1b)*

where
V_0 = *linear velocity at time zero (m/s, ft/s)*

Linear displacement can be expressed as (acceleration = constant):
$s = V_0\, t + 1/2\, a\, t^2$ *(1c)*

Combining 1a and 1c to express velocity
$v = (V_0^2 + 2\, a\, s)^{1/2}$ *(1d)*

Velocity can be expressed as (velocity variable)
$v = ds / dt$ *(1f)*

where
ds = *change of displacement (m, ft)*
dt = *change in time (s)*

Acceleration can be expressed as
$a = dv / dt$ *(1g)*

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

Water - Dynamic and Kinematic Viscosity

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

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

Dynamic and Kinematic Viscosity of Water in SI Units:

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

Water and Speed of Sound

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

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

Temperature - *t* - (°F)	Speed of Sound - *c* - (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 - *t* - (°C)	Speed of Sound - *c* - (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

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 ^{2} X Length = ? To obtain gallons multiply by 7.48

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

Circumference = 3.14 X Diameter

General Conversions

Multiply	—>	to get
to get	**<—**	**Divide**
cc/min	1	mL/min
cfm (ft^3/min)	28.31	L/min
cfm (ft^3/min)	1.699	m^3/hr
cfh (ft^3/hr)	472	mL/min
cfh (ft^3/hr)	0.125	GPM
GPH	63.1	mL/min
GPH	0.134	cfh
GPM	0.227	m^3/hr
GPM	3.785	L/min
oz/min	29.57	mL/min

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

PERCENT EFFICIENCY = $\frac{\text{In – Out}}{\text{In}}$ X 100

TEMPERATURE: $^0F = (^0C \times 9/5) + 32$ 9/5 =1.8
$^0C = (^0F - 32) \times 5/9$ 5/9 = .555

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

FLOW RATE (Q): Q = A X V (**Q**uantity = **A**rea X **V**elocity)

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

% SLOPE = $\frac{\text{Rise (feet)}}{\text{Run (feet)}}$ X 100

ACTUAL LEAKAGE = $\frac{\text{Leak Rate (GPD)}}{\text{Length (mi.) X Diameter (in)}}$

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

N = Manning's Coefficient of Roughness
R = Hydraulic Radius (ft.)
S = Slope of Sewer (ft/ft.)

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

WATER HORSEPOWER = $\frac{\text{Flow (gpm) X Head (ft)}}{3960}$

BRAKE HORSEPOWER = $\frac{\text{Flow (gpm) X Head (ft)}}{\text{3960 X Pump Efficiency}}$

MOTOR HORSEPOWER = $\frac{\text{Flow (gpm) X Head (ft)}}{\text{3960 X Pump Eff. X Motor Eff.}}$

MEAN OR AVERAGE = $\frac{\text{Sum of the Values}}{\text{Number of Values}}$

TOTAL HEAD (ft) = Suction Lift (ft) X Discharge Head (ft)

SURFACE LOADING RATE (gal/min/sq.ft.) = $\frac{\text{Flow Rate (gpm)}}{\text{Surface Area (sq. ft)}}$

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

DETENTION TIME (hrs.) = $\frac{\text{Volume of Basin (gals) X 24 hrs.}}{\text{Flow (GPD)}}$

SLOPE = $\frac{\text{Rise (ft)}}{\text{Run (ft)}}$ **SLOPE (%)** = $\frac{\text{Rise (ft)}}{\text{Run (ft)}}$ X 100

POPULATION EQUIVALENT (PE):

1 PE = .17 Pounds of BOD per Day
1 PE = .20 Pounds of Solids per Day
1 PE = 100 Gallons per Day

LEAKAGE (GPD/inch) = $\frac{\text{Leakage of Water per Day (GPD)}}{\text{Sewer Diameter (inch)}}$

CHLORINE DEMAND (mg/L) = Chlorine Dose (mg/L) – Chlorine Residual (mg/L)

MANNING'S EQUATION

τQ = Allowable time for decrease in pressure from 3.5 PSI to 2.5 PSI
τq = As below

$\tau Q = (0.022)\,(d_1^2 L_1)/Q \quad \tau q = \frac{[0.085]}{q}\,[(d_1^2 L1)/(d_1 L_1)]$

Q = 2.0 cfm air loss
θ = .0030 cfm air loss per square foot of internal pipe surface
δ = Pipe diameter (inches)
L = Pipe Length (feet)

$V = \frac{1.486}{\nu} R^{2/3} S^{1/2}$

V = Velocity (ft./sec.)
ν = Pipe Roughness
R = Hydraulic Radius (ft)
S= Slope (ft/ft)

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

WIDTH OF TRENCH (ft) = Base (ft) + (2 Sides) X $\frac{\text{Depth (ft 2)}}{\text{Slope}}$

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