Pumps

Introduction

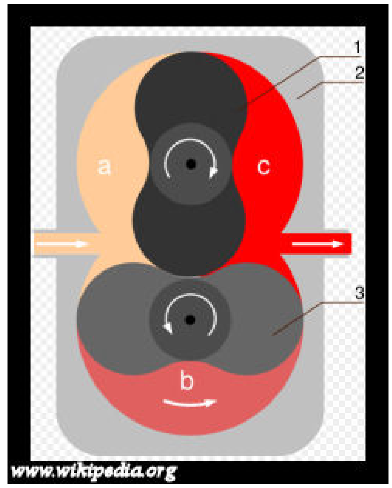
A pump is a device used to move gases, liquids or slurries. A pump moves liquids or gases from lower pressure to higher pressure, and overcomes this difference in pressure by adding energy to the system (such as a water system). A gas pump is generally called a compressor, except in very low pressure-rise applications, such as in heating, ventilating, and air-conditioning, where the operative equipment consists of fans or blowers.

Pumps work by using mechanical forces to push the material, either by physically lifting, or by the force of compression. The earliest type of pump was the Archimedes screw, first used by Sennacherib, King of Assyria, for the water systems at the Hanging Gardens of Babylon and Nineveh in the 7th century BC, and later described in more detail by Archimedes in the 3rd century BC. In the 13th century AD, al-Jazari described and illustrated different types of pumps, including a reciprocating pump, double-action pump with suction pipes, water pump, and piston pump.

Types

Pumps fall into two major groups:

- **Rotodynamic pumps**



- **Positive displacement pumps**

Their names describe the method for moving a fluid.

Positive Displacement Pumps

A positive displacement pump causes a liquid or gas to move by trapping a fixed amount of fluid and then forcing (displacing) that trapped volume into the discharge pipe. The periodic fluid displacement results in a direct increase in pressure. A positive displacement pump can be further classified as either

- A rotary-type (for example the rotary vane),
- Lobe pump similar to oil pumps used in car engines, or
- The Wendelkolben pump or the helical twisted Roots pump.

Roots-Type Pumps

The low pulsation rate and gentle performance of this Roots-type positive displacement pump is achieved due to a combination of its two 90° helical twisted rotors, and a triangular shaped sealing line configuration, both at the point of suction and at the point of discharge. This design produces a continuous and non-vorticuless flow with equal volume. High capacity industrial "air compressors" have been designed to employ this principle as well as most "superchargers" used on internal combustion engines.

Reciprocating-Type Pumps

Reciprocating-type pumps use a piston and cylinder arrangement with suction and discharge valves integrated into the pump. Pumps in this category range from having "simplex" one cylinder, to in some cases "quad" four cylinders or more. Most reciprocating-type pumps are "duplex" (two) or "triplex" (three) cylinder. Furthermore, they are either "single acting" independent suction and discharge strokes or "double acting" suction and discharge in both directions. The pumps can be powered by air, steam or through a belt drive from an engine or motor. This type of pump was used extensively in the early days of steam propulsion (19th century) as boiler feed water pumps. Though still used today, reciprocating pumps are typically used for pumping highly viscous fluids including concrete and heavy oils.

Compressed-Air-Powered Double-Diaphragm Pumps

Another modern application of positive displacement pumps are compressed-air-powered double-diaphragm pumps, commonly called SandPiper or Wilden Pumps after their major manufacturers. They are relatively inexpensive and are used extensively for pumping water out of bunds, or pumping low volumes of reactants out of storage drums.

Kinetic Pumps

1. Continuous energy addition
2. Conversion of added energy to increase in kinetic energy (increase in velocity)

3. Conversion of increased velocity to increase in pressure
4. Conversion of Kinetic head to Pressure Head.
5. Meet all heads like Kinetic , Potential, and Pressure

Application

Pumps are used throughout society for a variety of purposes. Early applications includes the use of the windmill or watermill to pump water. Today, the pump is used for irrigation, water supply, gasoline supply, air conditioning systems, refrigeration (usually called a compressor), chemical movement, sewage movement, flood control, marine services, etc.

Because of the wide variety of applications, pumps have a plethora of shapes and sizes: from very large to very small, from handling gas to handling liquid, from high pressure to low pressure, and from high volume to low volume.

Pumps as Public Water Supplies

One sort of pump once common worldwide was a hand-powered water pump over a water well where people could work it to extract water, before most houses had individual water supplies. From this came the expression "parish pump" for "the sort of matter chattered about by people when they meet when they go to get water", "matter of only local interest".

Today, hand operated village pumps are considered the most sustainable low cost option for safe water supply in resource poor settings, often in rural areas in developing countries. A hand pump opens access to deeper groundwater that is often not polluted and also improves the safety of a well by protecting the water source from contaminated buckets. Pumps like the Afridev pump are designed to be cheap to build and install, and easy to maintain with simple parts. It was assumed that spare parts would become available in the local market by for-profit wholesalers. However, it became clear with time that often spare parts are not available locally, because of the low profit margins for wholesalers, especially in Africa. This means that communities are often stuck without spares and cannot use their handpump anymore and have to go back to traditional and sometimes distant, polluted resources. This is unfortunate, as water projects often have put in a lot of resources to provide that community with a handpump. As a result, spare parts free handpumps are now being developed, like the Afripump.

Power Source

Pumps have been powered by water flow (as with the noria), an internal combustion engine, electric motor, manually (as with the hand pump used for pumping groundwater, called walking beam pump), or by wind power (common for irrigation). Solar power has been used to power an electric motor, for remote locations.

Affinity Laws

The affinity laws are used in hydraulics and HVAC to express the relationship between several 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 various rotary implements, the Affinity Laws apply both to centrifugal and axial flows.

Law 1. With impeller diameter (D) held constant:

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: $\frac{Q_1}{Q_2} = \left(\frac{D_1}{D_2}\right)$

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 : $\frac{P_1}{P_2} = \left(\frac{D_1}{D_2}\right)^3$

where

- **Q** is the volumetric flow rate (e.g. CFM or GPM),

- **D** is the impeller diameter (e.g. in),
- **N** is the shaft rotational speed (e.g. rpm),
- **H** is the pressure or head developed by the fan/pump, and
- **P** is the shaft power.

These laws assume that the pump/fan efficiency remains constant. In other words, $\eta_1 = \eta_2$.

Different Types of Pumps

Rope Pump

A rope pump is a kind of pump used in developing areas to raise water from wells. Rope pumps consist of a PVC pipe, and a rope with washers attached to it. The water is held in between the washers in the pipe, and is pulled to the surface. Rope pumps are very simple, and can be easily repaired. The rope and washer pump is made from a nylon rope, old car tire and class C pipe or stronger.

Chain Pump

The chain pump is a type of water pump where an endless chain has positioned on it a series of circular discs. One end of the chain dips in to the water, and the chain runs through a tube, slightly bigger than the diameter of the discs. As the chain is drawn up the tube, water becomes trapped between the discs and is lifted to and discharged at the top. Historically, chain pumps were known and used for centuries in the ancient Middle East, Europe, and China.

Treadle Pump

Treadle pump is a human-powered pump designed to lift water from a depth of seven meters or less. A treadle is a lever device pressed by the foot to drive a machine, in this case a pump. The treadle pump can do most of the work of a motorized pump, but costs considerably less (75%) to purchase. Because it needs no fossil fuel (it is driven by the operator's body weight and leg muscles), it can also cost less (50%) to operate than a motorized pump. It can lift five to seven cubic meters of water per hour from wells and boreholes up to seven meters deep and can also be used to draw water from lakes and rivers. Most treadle pumps used are of local manufacture, as they are simple and inexpensive to build.

In some areas, the treadle pump can greatly increase the income that farmers generate from their land, both by extending the traditional growing season and by expanding the types of crops that can be cultivated.

Standard treadle pumps are suction pumps, and were first developed in the early 1980s in Bangladesh. Most treadle pumps manufactured in Africa are pressure treadle pumps, a modification to the original design that means water is forced out of the pump under pressure. Pressure treadle pumps are more versatile, as they allow farmers to pump water uphill, over long distances, or to elevated tanks.

Lately, special, low cost **treadle pumps** have been developed in Nepal, under the guidance of Practical Action, which have high efficiency and low-cost.

Airlift Pump

Am airlift pump is a simple pump which is powered by compressed air. Airlift pumps are often used in deep dirty wells where sand would quickly abrade mechanical parts. (The compressor is on the surface and no mechanical parts are needed in the well). However airlift wells must be much deeper than the water table to allow for submergence. Air is generally pumped at least as deep under the water as the water is to be lifted. (If the water table is 50 ft below, your air should be pumped 100 feet deep). It is also sometimes used in part of the process on a wastewater treatment plant if a small head is required (typically around 1 foot head).

Typically, the compressed air is pumped down a pipe into a well and bubbles into another larger diameter pipe. The air bubbles return to the surface in the larger pipe. Since the resulting air-water mixture is less dense than the surrounding water, it rises and a fizzy spurting flow of air and water results.

Axial Flow Pump

An axial flow pump is a common type of water pump that essentially consists of a propeller in a tube. The propeller can be driven directly by a sealed motor in the tube or by a right-angle drive shaft that pierces the tube.

The main advantage of an AFP is that it can easily be adjusted to run at peak efficiency at low-flow/high-pressure and high-flow/low-pressure by changing the pitch on the propeller. These pumps have the smallest of the dimensions among any of the conventional pumps and are more suited for low heads and higher discharges. An application example of an AFP would be transfer pumps used for sailing ballast.

Water Well Pump

A water well pump is a pump that is used in extracting water from a water well. There are many makes of pumps, the foremost being Franklin Electric (American), and Pedrollo (Italian). They include different kinds of pumps, yet most of them are submersible pumps:

- Manual pumpless/hand pump wells requiring a human operator
- Mechanical or rotary pump requiring mechanical parts to pump water
- Solar water pumps
- DC Submersible Well Pump
- Pumps driven by air as used by the Amish

The pump replaces the use of a bucket and pulley system to extract water.

Fire Pump

A fire pump is a part of a fire sprinkler system's water supply. The pump intake is either connected to the public underground water supply piping, or a static water source (e.g., tank, reservoir, lake). The pump provides water flow at a higher pressure to the sprinkler system risers and hose standpipes. A fire pump is tested and listed for its use specifically for fire service by a third-party testing and listing agency, such as UL or FM Global. The main code that governs fire pump installations in North America is the National Fire Protection Association's NFPA 20 Standard for the Installation of Stationary Fire Pumps for Fire Protection.

Fire pumps may be powered either by an electric motor or a diesel engine, or, very occasionally a steam turbine. If the local building code requires power independent of the local electric power grid, a pump using an electric motor may utilize, when connected via a listed transfer switch, the installation of an emergency generator.

The fire pump starts when the pressure in the fire sprinkler system drops below a threshold. The sprinkler system pressure drops significantly when one or more fire sprinklers are exposed to heat above their design temperature, and opens, releasing water. Alternately, other fire hose reels or other firefighting connections are opened, causing a pressure drop in the fire fighting main.

Fire pumps are needed when the local municipal water system cannot provide sufficient pressure to meet the hydraulic design requirements of the fire sprinkler system. This usually occurs if the building is very tall, such as in high-rise buildings, or in systems which require a relatively high terminal pressure at the fire sprinkler in order to flow a large volume of water, such as in storage warehouses. Fire pumps are also needed if fire protection water supply is provided from a ground level water storage tank.

Types of pumps used for fire service include: horizontal split case, vertical split case, vertical inline, vertical turbine, and end suction. A jockey pump is a small pump connected to a fire sprinkler system in parallel with the fire pump. It maintains pressure in a fire protection piping system to an artificially high level so that the operation of a single fire sprinkler will cause an appreciable pressure drop which will be easily sensed by the fire pump automatic controller, causing the fire pump to start. The jockey pump is essentially a portion of the fire pump's control system.

Handpumps

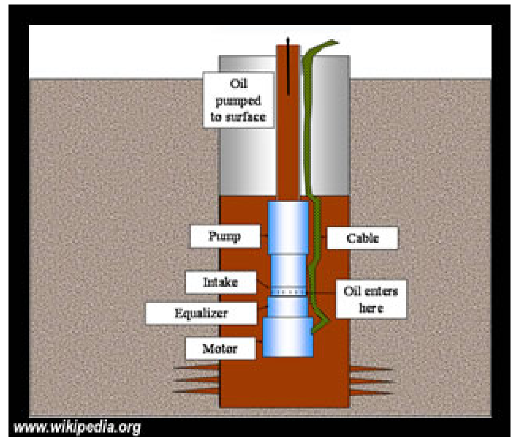
Handpumps are used primarily in developing nations as a manually powered means of bringing water to the surface from a borehole, rainwater tank or well. The main types of traditional hand pumps are the India Mark II, the India Mark III, and the Afridev deep-well (30 - 40 m deep) pumps. However, these pumps cannot pump from very deep and require many spare parts that are often not available in developing countries. Therefore, these pumps are often not functional within a few years. New handpumps that do not require spare parts are being developed that can also pump from up to 100 m deep, like the Afripump.

Village Level Operation and Maintenance (VLOM) refers to low maintenance handpumps which can be maintained at a village level, intended to provide reliable long-term service.

Thousands of handpumps have been installed in developing countries of the last two decades, especially in India, Bangladesh, and Sub-Sahara Africa. Lately, appropriate technology organizations as Practical Action are supplying information on how to build/set-up (diy) handpumps and treadle pumps in practice.

Submersible Pump

A submersible pump is a pump which has a hermetically sealed motor close-coupled to the pump body. The whole assembly is submerged in the fluid to be pumped. The advantage of this type of pump is that it can provide a significant lifting force as it does not rely on external air pressure to lift the fluid.



A system of mechanical seals are used to prevent the fluid being pumped from entering the motor and causing a short circuit. The pump can either be connected to a pipe, flexible hose or lowered down guide rails or wires so that the pump sits on a "ducks foot" coupling, thereby connecting it to the delivery pipework.

Submersible pumps are found in many applications, single stage pumps are used for drainage, sewage pumping, general industrial pumping and slurry pumping. They are also popular with aquarium filters. Multiple stage submersible pumps are typically lowered down a borehole and used for water abstraction or in water wells.

Hydraulic Ram

A hydraulic ram is a cyclic water pump powered by hydropower. It functions as a hydraulic transformer that takes in water at one hydraulic head and flow-rate, and outputs water at a different hydraulic-head and flow-rate. The device utilizes a phenomenon called stagnation pressure, also known as water hammer, that is based on Bernoulli's principle. In operation, a portion of the input water that powers the pump is 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 water.

In 1772 John Whitehurst of Cheshire in the United Kingdom invented a manually controlled precursor of the hydraulic ram called the "pulsation engine". The first one he installed, in 1775 at Oulton, Cheshire, raised water to a height of 16 ft (4.9m). He installed another in an Irish property in 1783. He did not patent it, and details are obscure, but it is known to have had an air vessel.

The first self-acting ram pump was invented by the Frenchman Joseph Michel Montgolfier in 1796 for raising water in his paper mill at Voiron. His friend Matthew Boulton took out a British patent on his behalf in 1797. The sons of Montgolfier obtained an English patent for an improved version in 1816, and this was acquired, together with Whitehurst's design, in 1820 by Josiah Easton, a Somerset-born engineer who had just moved to London.

Easton's firm, inherited by his son James (1796 - 1871), grew during the nineteenth century to become one of the more important engineering manufacturers in the United Kingdom, with a large works at Erith, Kent. They specialised in water supply and sewerage systems world-wide, as well as land drainage projects. Eastons had a good business supplying rams for water supply purposes to large country houses, and also to farms and village communities, and a number of their installations still survived as of 2004.

The firm was eventually closed in 1909, but the ram business was continued by James R Easton. In 1929 it was acquired by Green & Carter, of Winchester, Hampshire, who were engaged in the manufacturing and installation of the well-known Vulcan and Vacher Rams. The first US patent was issued to J. Cerneau and S.S. Hallet in 1809. American interest in hydraulic rams picked up around 1840, as further patents were issued and domestic companies started offering rams for sale. Toward the end of the 19th Century, interest waned as electricity and electric pumps became widely available.

By the end of the twentieth century interest in hydraulic rams has revived, due to the needs of sustainable technology in developing countries, and energy conservation in developed ones.

Metering Pump

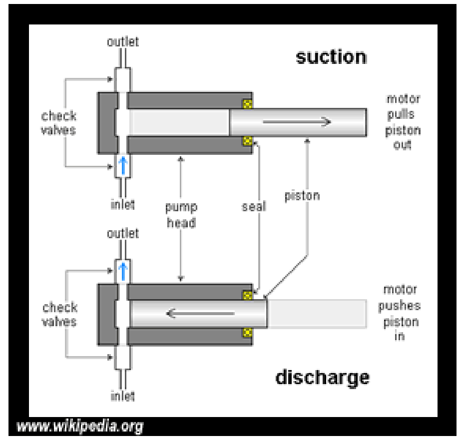
A Metering pump is a pump used to pump liquids at adjustable flow rates which are precise when averaged over time. Delivery of fluids in precise adjustable flow rates is sometimes called metering. The term "metering pump" is based on the application or use rather than the exact kind of pump used, although a couple types of pumps are far more suitable than most other types of pumps.

Although metering pumps can pump water, they are often used to pump chemicals, solutions, or other liquids. Many metering pumps are rated to be able to pump into a high discharge pressure. They are typically made to meter at flow rates which are practically constant (when averaged over time) within a wide range of discharge (outlet) pressure. Manufacturers provide each of their models of metering pumps with a maximum discharge pressure rating against which each model is guaranteed to be able to pump against. An engineer, designer, or user should ensure that the pressure and temperature ratings and wetted pump materials are compatible for the application and the type of liquid being pumped.

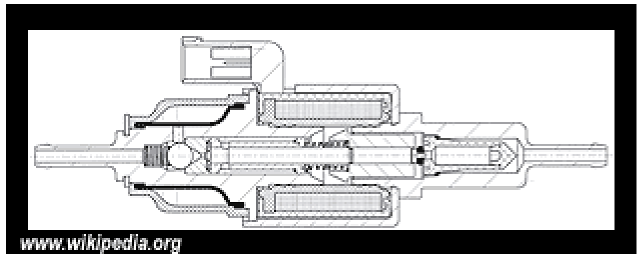
Most metering pumps have a pump head and a motor. The liquid being pumped goes through the pump head, entering through an inlet line and leaving through an outlet line. The motor is commonly an electric motor which drives the pump head.

Many metering pumps are piston-driven. Piston pumps are positive displacement pumps which can be designed to pump at practically constant flow rates (averaged over time) against a wide range of discharge pressure, including high discharge pressures of thousands of psi.

Piston-driven metering pumps commonly work as follows: There is a piston (sometimes called plunger), typically cylindrical, which can go in and out of a correspondingly shaped chamber in the pump head. The inlet and outlet lines are joined to the piston chamber. There are two check valves, often ball check valves, attached to the pump head, one at the inlet line and the other at the outlet line. The inlet valve allows flow from the inlet line to the piston chamber, but not in the reverse direction. The outlet valve allows flow from the chamber to the outlet line, but not in reverse. The motor repeatedly moves the piston into and out of the piston chamber, causing the volume of the chamber to repeatedly become smaller and larger. When the piston moves out, a vacuum is created. Low pressure in the chamber causes liquid to enter and fill the chamber through the inlet check valve, but higher pressure at the outlet causes the outlet valve to shut. Then when the piston moves in, it pressurizes the liquid in the chamber. High pressure in the chamber causes the inlet valve to shut and forces the outlet valve to open, forcing liquid out at the outlet. These alternating suction and discharge strokes are repeated over and over to meter the liquid. In back of the chamber, there is packing around the piston or a doughnut-shaped seal with a toroid-shaped sphincter-like spring inside compressing the seal around the piston. This holds the fluid pressure when the piston slides in and out and makes the pump leak-tight. The packing or seals can wear out after prolonged use and can be replaced. The metering rate can be adjusted by varying the strokelength by which the piston moves back and forth or varying the speed of the piston motion.



A single-piston pump delivers liquid to the outlet only during the discharge stroke. If the piston's suction and discharge strokes occur at the same speed and liquid is metered out half the time the pump is working, then the overall metering rate averaged over time equals half the average flow rate during the discharge stroke. Some single-piston pumps may have a constant slow piston motion for discharge and a quick retract motion for refilling the pump head. In such cases, the overall metering rate is practically equal to the pumping rate during the discharge stroke.



Pumps used in high pressure chromatography such as HPLC and ion chromatography are much like small piston metering pumps. For wear resistance and chemical resistance to solvents, etc., typically the pistons are made of artificial sapphire and the ball check valves have ruby balls and sapphire seats. To produce good chromatograms, it is desirable to have a pumping flow rate as constant as possible. Either a single piston pump with a quick refill is used or a double pump head with coordinated piston strokes is used to provide as constant a pumping rate as possible.

In order to avoid leakage at the packing or seal particularly when a liquid is dangerous, toxic, or noxious, diaphragm pumps are used for metering. Diaphragm pumps have a diaphragm through which repeated compression/decompression motion is transmitted. The liquid does not penetrate through the diaphragm, so the liquid inside the pump is sealed off from the outside. Such motion changes the volume of a chamber in the pump head so that liquid enters through an inlet check valve during decompression and exits through an outlet check valve during compression, in a manner similar to piston pumps. Diaphragm pumps can also be made which discharge at fairly high pressure. Diaphragm metering pumps are commonly hydraulically driven.

Peristaltic pumps use motor-driven rollers to roll along flexible tubing, compressing it to push forward a liquid inside. Although peristaltic pumps can be used to meter at lower pressures, the flexible tubing is limited in the level of pressure it can withstand.

The maximum pressure rating of a metering pump is actually the top of the discharge pressure range the pump is guaranteed to pump against at a reasonably controllable flow rate. The pump itself is a pressurizing device often capable of exceeding its pressure rating, although not guaranteed to. For this reason, if there is any stop valve downstream of the pump, a pressure relief valve should be placed in between to prevent overpressuring of the tubing or piping line in case the stop valve is inadvertently shut while the pump is running. The relief valve setting should be below the maximum pressure rating that the piping, tubing, or any other components there could withstand.

Liquids are only very slightly compressible. This property of liquids lets metering pumps discharge liquids at high pressure. Since a liquid can be only slightly compressed during a discharge stroke, it is forced out of the pump head. Gases are much more compressible. Metering pumps are not good at pumping gases. Sometimes, a metering or similar pump has to be primed before operation, i. e. the pump head filled with the liquid to be pumped. When gas bubbles enter a pump head, the compression motion compresses the gas but has a hard time forcing it out of the pump head. The pump may stop pumping liquid with gas bubbles in the pump head even though mechanically the pump is going through the motions, repeatedly compressing and decompressing the bubbles. To prevent this type of "vapor lock", chromatography solvents are often degassed before pumping.

If the pressure at the outlet is lower than the pressure at the inlet and remains that way in spite of the pumping, then this pressure difference opens both check valves simultaneously and the liquid flows through the pump head uncontrollably from inlet to outlet. This can happen whether the pump is working or not. This situation can avoided by placing a correctly-rated positive pressure differential check valve downstream of the pump. Such a valve will only open if a minimum rated pressure differential across the valve is exceeded, something which most high pressure metering pumps can easily exceed.