PUMPS & PUMPING SYSTEMS

1. INTRODUCTION

This section briefly describes the main features of pumps and pumping systems.[1]

1.1 What are pumps and pumping systems?

Pumping systems account for nearly 20% of the world's electrical energy demand and range from 25-50% of the energy usage in certain industrial plant operations (US DOE, 2004).

Pumps have two main purposes:
- Transfer of liquid from one place to another place (e.g. water from an underground aquifer into a water storage tank)
- Circulate liquid around a system (e.g. cooling water or lubricants through machines and equipment)

The main components of a pumping system are:
- Pumps (different types of pumps are explained in section 2)
- Prime movers: electric motors, diesel engines or air system
- Piping, used to carry the fluid
- Valves, used to control the flow in the system
- Other fittings, controls and instrumentation
- End-use equipment, which have different requirements (e.g. pressure, flow) and therefore determine the pumping system components and configuration. Examples include heat exchangers, tanks and hydraulic machines.

Figure 1. A Pumping System in an Industry
(US DOE, 2001)

[1] Information was sourced from three US DOE publications: *Improving Pumping System Performance – a Sourcebook for Industry* (1999); *Pump Life Cycle Costs – A Guide to LCC Analysis for Pumping Systems* (2001); and *Variable Speed Pumping – A Guide to Successful Applications* (2004). These publications are recommended for further reading.

The pump and the prime mover are typically the most energy inefficient components.

1.2 Pumping system characteristics

1.2.1 Resistance of the system: head

Pressure is needed to pump the liquid through the system at a certain rate. This pressure has to be high enough to overcome the resistance of the system, which is also called "head". The total head is the sum of static head and friction head:

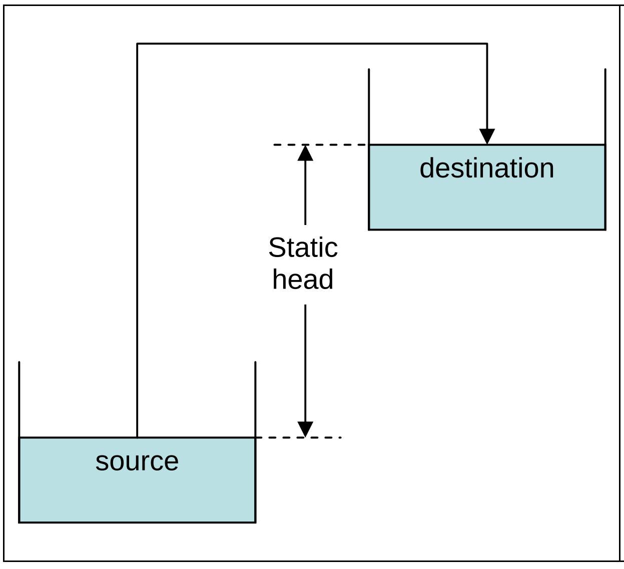
a) Static head

Static head is the difference in height between the source and destination of the pumped liquid (see Figure 2a). Static head is independent of flow (see Figure 2b). The static head at a certain pressure depends on the weight of the liquid and can be calculated with this equation:

$$\text{Head (in feet)} = \frac{\text{Pressure (psi)} \times 2.31}{\text{Specific gravity}}$$

Static head consists of:

- Static suction head (hS): resulting from lifting the liquid relative to the pump center line. The hS is positive if the liquid level is above pump centerline, and negative if the liquid level is below pump centerline (also called "suction lift)
- Static discharge head (hd): the vertical distance between the pump centerline and the surface of the liquid in the destination tank.



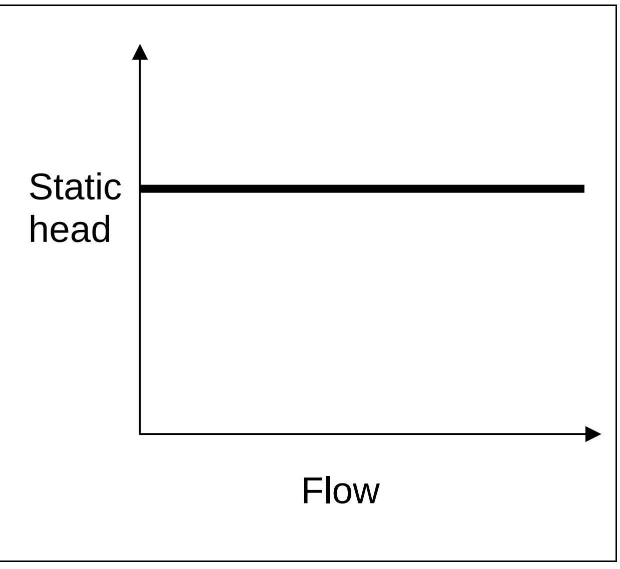


Figure 2a. Static Head **Figure 2b. Static Head Versus Flow**

b) Friction head (hf)

This is the loss needed to overcome that is caused by the resistance to flow in the pipe and fittings. It is dependent on size, condition and type of pipe, number and type of pipe fittings, flow rate, and nature of the liquid. The friction head is proportional to the square of the flow rate as shown in figure 3. A closed loop circulating system only exhibits friction head (i.e. not static head).

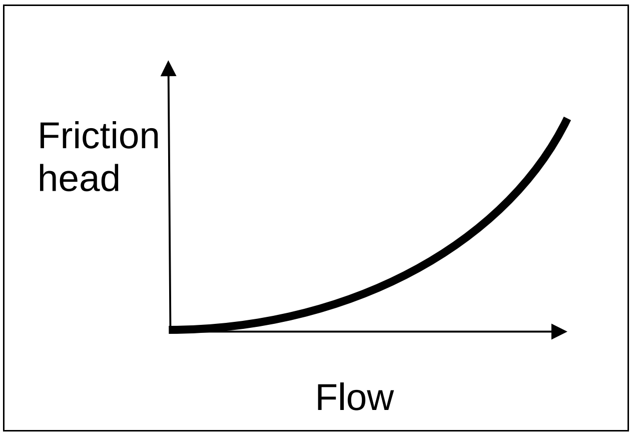


Figure 3. Frictional Head versus Flow

In most cases the total head of a system is a combination of static head and friction head as shown in Figures 4a and 4b.

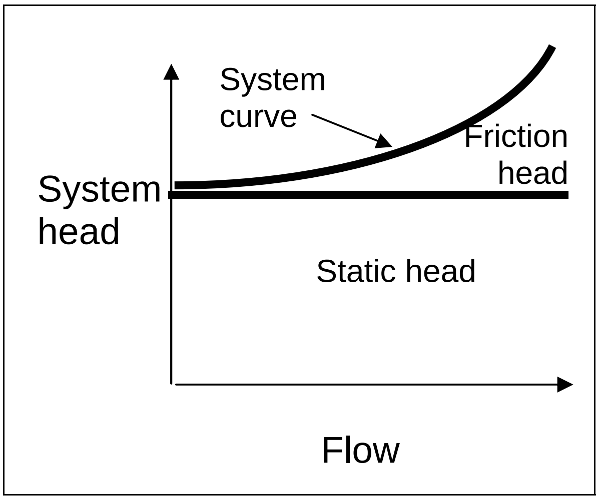


Figure 4a. System with High Static Head

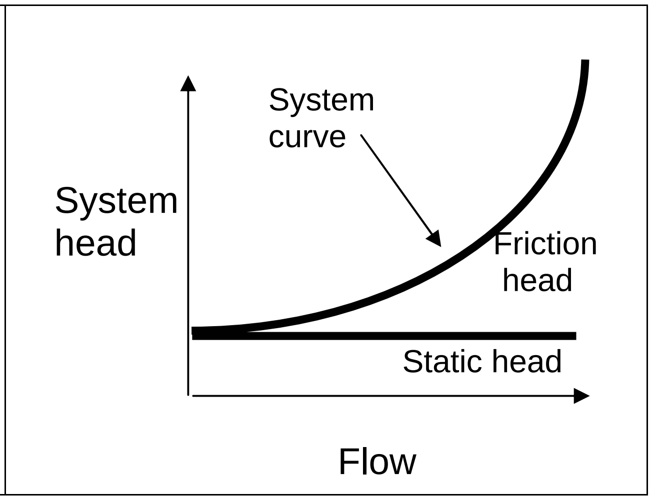


Figure 4b. System with Low Static Head

1.2.2 Pump performance curve

The head and flow rate determine the performance of a pump, which is graphically shown in Figure 5 as the performance curve or pump characteristic curve. The figure shows a typical curve of a centrifugal pump where the head gradually decreases with increasing flow.

As the resistance of a system increases, the head will also increase. This in turn causes the flow rate to decrease and will eventually reach zero. A zero flow rate is only acceptable for a short period without causing to the pump to burn out.

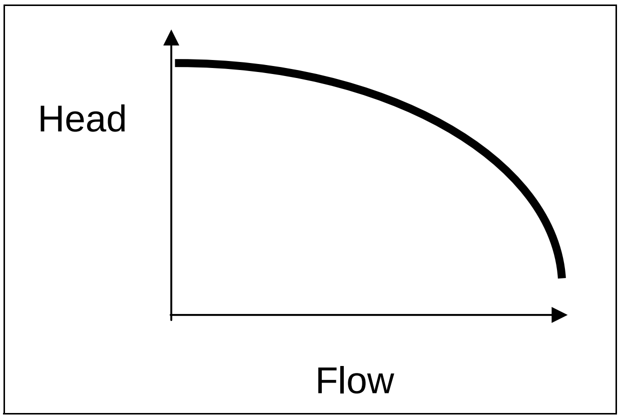


Figure 5. Performance Curve of a Pump

1.2.3 Pump operating point

The rate of flow at a certain head is called the duty point. The pump performance curve is made up of many duty points. The pump operating point is determined by the intersection of the system curve and the pump curve as shown in Figure 6.

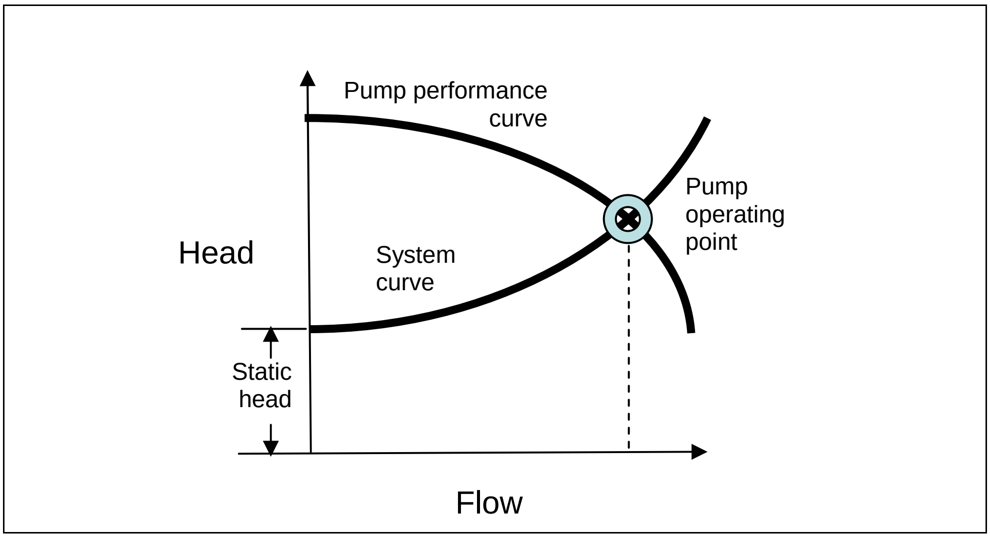


Figure 6. Pump Operating Point (US DOE, 2001)

1.2.4 Pump suction performance (NPSH)

Cavitation or vaporization is the formation of bubbles inside the pump. This may occur when at the fluid's local static pressure becomes lower than the liquid's vapor pressure (at the actual temperature). A possible cause is when the fluid accelerates in a control valve or around a pump impeller.

Vaporization itself does not cause any damage. However, when the velocity is decreased and pressure increased, the vapor will evaporate and collapse. This has three undesirable effects:

- Erosion of vane surfaces, especially when pumping water-based liquids
- Increase of noise and vibration, resulting in shorter seal and bearing life

- Partially choking of the impeller passages, which reduces the pump performance and can lead to loss of total head in extreme cases.

The Net Positive Suction Head Available (NPSHA) indicates how much the pump suction exceeds the liquid vapor pressure, and is a characteristic of the system design. The NPSH Required (NPSHR) is the pump suction needed to avoid cavitation, and is a characteristic of the pump design.

2. TYPE OF PUMPS

This section describes the various types of pumps.[2] Pumps come in a variety of sizes for a wide range of applications. They can be classified according to their basic operating principle as dynamic or positive displacement pumps (Figure 7).

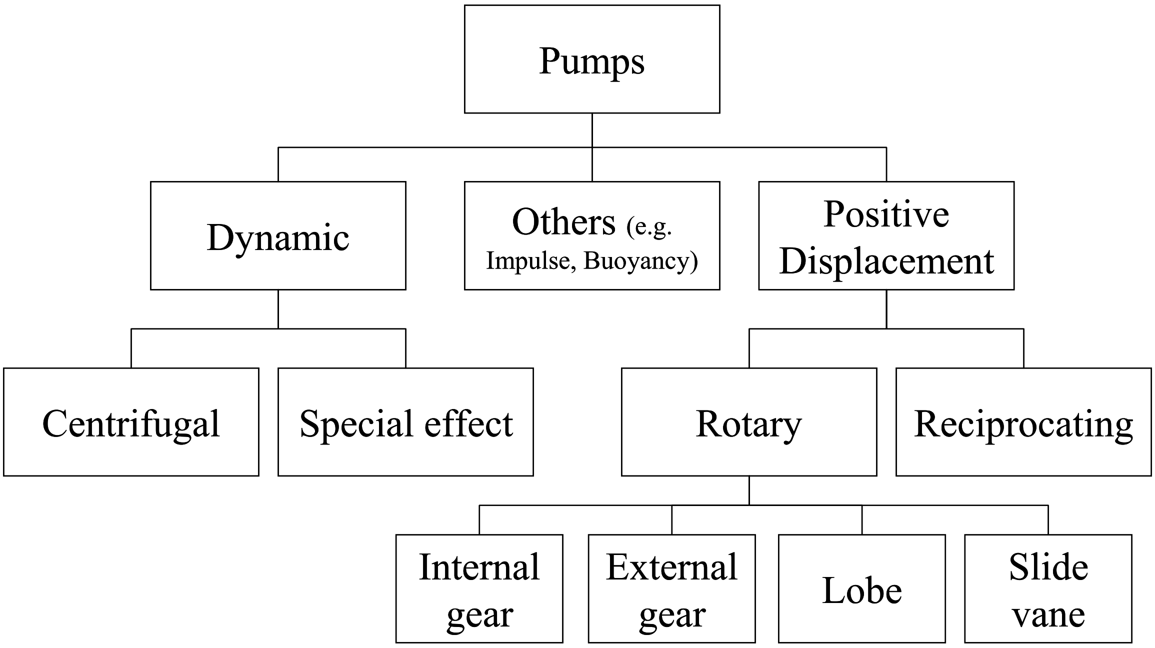


Figure 7. Different types of pumps

In principle, any liquid can be handled by any of the pump designs. Where different pump designs could be used, the centrifugal pump is generally the most economical followed by rotary and reciprocating pumps. Although, positive displacement pumps are generally more efficient than centrifugal pumps, the benefit of higher efficiency tends to be offset by increased maintenance costs.

2.1. Positive displacement pumps

Positive displacement pumps are distinguished by the way they operate: liquid is taken from one end and positively discharged at the other end for every revolution. Positive displacement pumps are widely used for pumping fluids other than water, mostly viscous fluids.

[2] Section 2 is taken (with edits) from *Pumps and Pumping Systems,* with permission from the Bureau of Energy Efficiency, India

Positive displacement pumps are further classified based upon the mode of displacement:

- ***Reciprocating pump*** if the displacement is by reciprocation of a piston plunger. Reciprocating pumps are used only for pumping viscous liquids and oil wells.
- ***Rotary pumps*** if the displacement is by rotary action of a gear, cam or vanes in a chamber of diaphragm in a fixed casing. Rotary pumps are further classified such as internal gear, external gear, lobe and slide vane etc. These pumps are used for special services with particular conditions existing in industrial sites.

In all positive displacement type pumps, a fixed quantity of liquid is pumped after each revolution. So if the delivery pipe is blocked, the pressure rises to a very high value, which can damage the pump.

2.2 Dynamic pumps

Dynamic pumps are also characterized by their mode of operation: a rotating impeller converts kinetic energy into pressure or velocity that is needed to pump the fluid.

There are two types of dynamic pumps:

- ***Centrifugal pumps*** are the most common pumps used for pumping water in industrial applications. Typically, more than 75% of the pumps installed in an industry are centrifugal pumps. For this reason, this pump is further described below.
- ***Special effect pumps*** are particularly used for specialized conditions at an industrial site.

2.2.1 How a centrifugal pump works

A centrifugal pump is one of the simplest pieces of equipment in any process plant. Figure 8 shows how this type of pump operates:

- Liquid is forced into an impeller either by atmospheric pressure, or in case of a jet pump by artificial pressure.
- The vanes of impeller pass kinetic energy to the liquid, thereby causing the liquid to rotate. The liquid leaves the impeller at high velocity.
- The impeller is surrounded by a volute casing or in case of a turbine pump a stationary diffuser ring. The volute or stationary diffuser ring converts the kinetic energy into pressure energy.

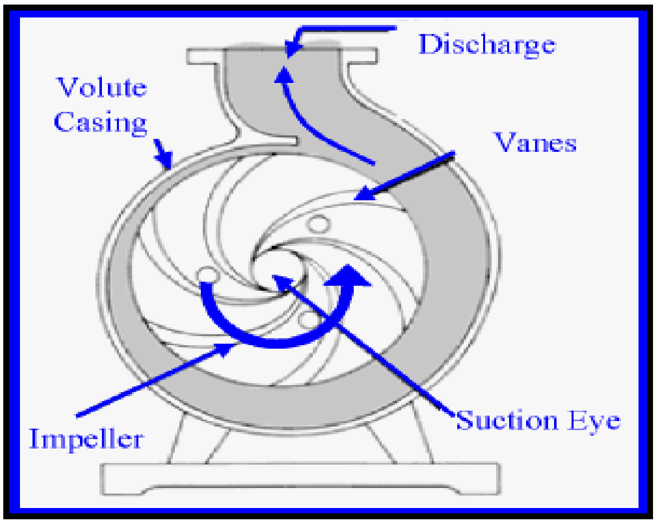
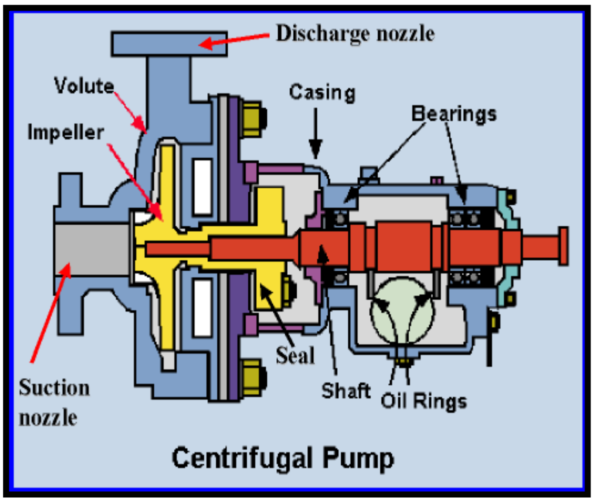


Figure 8. Liquid Flow Path of a Centrifugal Pump (Sahdev M)

2.2.2 Components of a centrifugal pump

The main components of a centrifugal pump are shown in Figure 9 and described below:

- Rotating components: an impeller coupled to a shaft
- Stationary components: casing, casing cover, and bearings.



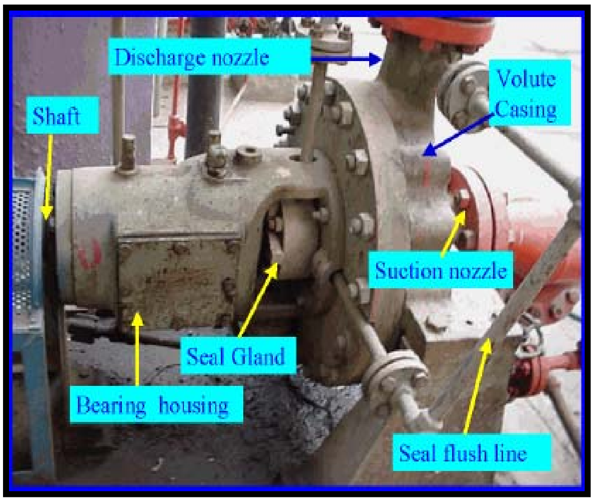


Figure 9. Main Components of a Centrifugal Pump (Sahdev)

a) Impeller

An impeller is a circular metallic disc with a built-in passage for the flow of fluid. Impellers are generally made of bronze, polycarbonate, cast iron or stainless steel, but other materials are also used. As the performance of the pump depends on the type of impeller, it is important to select a suitable design and to maintain the impeller in good condition.

The number of impellers determines the number of stages of the pump. A single stage pump has one impeller and is best suited for low head (= pressure) service. A two-stage pump has two impellers in series for medium head service. A multi-stage pump has three or more impellers in series for high head service.

Impellers can be classified on the basis of:

- ***Major direction of flow*** from the rotation axis: radial flow, axial flow, mixed flow
- ***Suction type***: single suction and double suction
- ***Shape or mechanical construction:***
  - Closed impellers have vanes enclosed by shrouds (= covers) on both sides (Figure 10). They are generally used for water pumps as the vanes totally enclose the water. This prevents the water from moving from the delivery side to the suction side, which would reduce the pump efficiency. In order to separate the discharge chamber from the suction chamber, a running joint is necessary between the impeller and pump casing. This joint is provided by wearing rings, which are mounted either over extended portion of impeller shroud or inside the cylindrical surface of pump casing. A disadvantage of closed impellers is the higher risk of blockage.
  - Open and semi-open impellers (Figure 10) are less likely to clog. But to avoid clogging through internal re-circulation, the volute or back-plate of the pump must be manually adjusted to get the proper impeller setting.
  - Vortex pump impellers are suitable for solid and "stringy" materials but they are up to 50% less efficient than conventional designs.

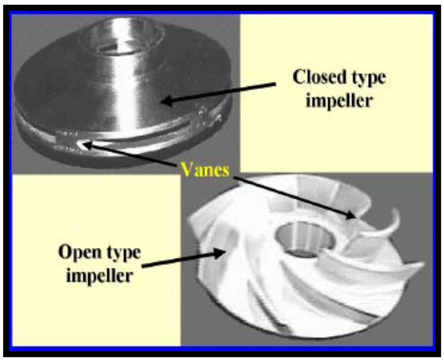


Figure 10. Closed and Open Impeller Types (Sahdev)

b) Shaft

The shaft transfers the torque from the motor to the impeller during the startup and operation of the pump.

c) Casing

The main function of casing is to enclose the impeller at suction and delivery ends and thereby form a pressure vessel. The pressure at suction end may be as little as one-tenth of atmospheric pressure and at delivery end may be twenty times the atmospheric pressure in a single-stage pump. For multi-stage pumps the pressure difference is much higher. The casing is designed to withstand at least twice this pressure to ensure a large enough safety margin.

A second function of casing is to provide a supporting and bearing medium for the shaft and impeller. Therefore the pump casing should be designed to

- Provide easy access to all parts of pump for inspection, maintenance and repair
- Make the casing leak-proof by providing stuffing boxes
- Connect the suction and delivery pipes directly to the flanges
- Be coupled easily to its prime mover (i.e. electric motor) without any power loss.

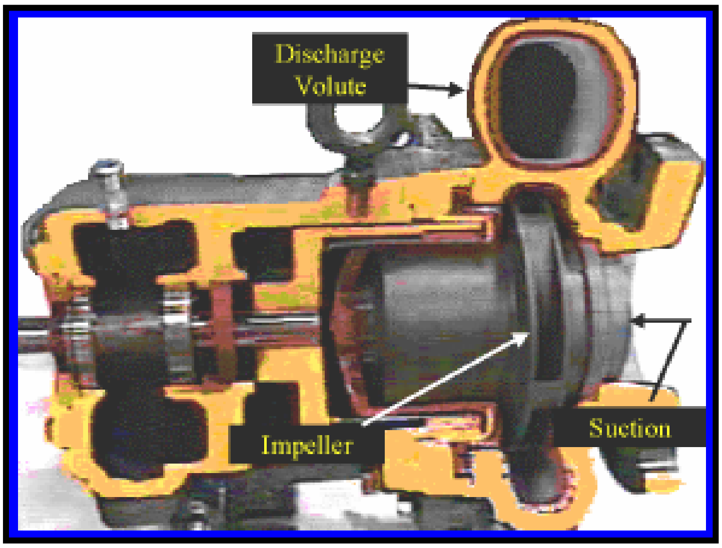


Figure 11. Cut-away of a pump showing Volute Casing (Sahdev)

Figure 12. Solid Casing (Sahdev)

There are two types of casings

- ***Volute casing*** (Figure 11) has impellers that are fitted inside the casings. One of the main purposes is to help balance the hydraulic pressure on the shaft of the pump. However, operating pumps with volute casings at a lower capacity than the manufacturer's recommended capacity, can result in lateral stress on the shaft of the pump. This can cause increased wearing of the seals, bearings, and the shaft itself. Double-volute casings are used when the radial force becomes significant at reduced capacities.
- ***Circular casing*** has stationary diffusion vanes surrounding the impeller periphery that convert speed into pressure energy. These casings are mostly used for multi-stage pumps. The casings can be designed as:
  - ***Solid casing*** (Figure 12): the entire casing and the discharge nozzle are contained in one casting or fabricated piece.
  - ***Split casing:*** two or more parts are joined together. When the casing parts are divided by horizontal plane, the casing is called horizontally split or axially split casing.

3. ASSESSMENT OF PUMPS

This section explains how the performance of pumps and pumping systems can be assessed.[3]

3.1. How to calculate pump performance

The work performed by a pump is a function of the total head and of the weight of the liquid pumped in a given time period. Pump shaft power (Ps) is the actual horsepower delivered to the pump shaft, and can be calculated as follows:

$$\text{Pump shaft power Ps} = \text{Hydraulic power hp} / \text{Pump efficiency } \eta_{pump}$$

or

$$\text{Pump efficiency } \eta_{pump} = \text{Hydraulic power} / \text{Pump shaft power}$$

Pump output, water horsepower or hydraulic horsepower (hp) is the liquid horsepower delivered by the pump, and can be calculated as follows:

$$\text{Hydraulic power hp} = Q\ (m^3/s) \times (h_d - h_s \text{ in m}) \times \rho\ (kg/m^3) \times g\ (m/s^2) / 1000$$

Where:

Q = flow rate
h_d = discharge head
h_s = suction head
ρ = density of the fluid
g = acceleration due to gravity

[3] This section is based on *Pumps and Pumping Systems.* In: Energy Efficiency in Electrical Utilities, chapter 6, 2004, with permission from the Bureau of Energy Efficiency, Ministry of Power, India.

3.2 Difficulties in the assessment of pumps

In practice, it is more difficult to assess pump performance. Some important reasons are:

- ***Absence of pump specification data*:** Pump specification data (see Worksheet 1 in section 6) are required to assess the pump performance. Most companies do not keep original equipment manufacturer (OEM) documents that provide these data. In these cases, the percentage pump loading for a pump flow or head cannot be estimated satisfactorily.
- ***Difficulty in flow measurement*:** It is difficult to measure the actual flow. The methods are used to estimate the flow. In most cases the flow rate is calculated based on type of fluid, head and pipe size etc, but the calculated figure may not be accurate. Another method is to divide the tank volume by the time it takes for the pump to fill the tank. This method can, however, only be applied if one pump is in operation and if the discharge valve of the tank is closed. The most sophisticated, accurate and least time consuming way to measure the pump flow is by measurement with an ultrasonic flow meter.
- ***Improper calibration of pressure gauges and measuring instruments*:** Proper calibration of all pressure gauges at suction and discharge lines and other power measuring instruments is important to obtain accurate measurements. But calibration has not always been carried out. Sometimes correction factors are used when gauges and instruments are not properly calibrated. Both will lead to incorrect performance assessment of pumps.

4. ENERGY EFFICIENCY OPPORTUNITIES

This section includes main areas for improving pumps and pumping systems. The main areas for energy conservation include:
- Selecting the right pump
- Controlling the flow rate by speed variation
- Pumps in parallel to meet varying demand
- Eliminating flow control valve
- Eliminating by-pass control
- Start/stop control of pump
- Impeller trimming

4.1 Selecting the right pump[4]

In selecting the pump, suppliers try to match the system curve supplied by the user with a pump curve that satisfies these needs as closely as possible. The pump operating point is the point where the pump curve and the system resistance curve intersect (as explained in section 1.2.3). However, it is impossible for one operating point to meet all desired operating conditions. For example, when the discharge valve is throttled, the system resistance curve shifts to the left and so does the operating point (see Figure 13).

Figure 13 below shows a typical vendor-supplied pump performance curves for a centrifugal pump where clear water is the pumping liquid.

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[4] Section 4.1 is taken (with edits) from *Pumps and Pumping Systems.* In: Energy Efficiency in Electrical Utilities, chapter 6, 2004, with permission from the Bureau of Energy Efficiency, Ministry of Power, India.

The Best Efficiency Point (BEP) is the pumping capacity at maximum impeller diameter, in other words, at which the efficiency of the pump is highest. All points to the right or left of the BEP have a lower efficiency. The BEP is affected when the selected pump is oversized. The reason is that the flow of oversized pumps must be controlled with different methods, such as a throttle valve or a by-pass line. These provide additional resistance by increasing the friction. As a result the system curve shifts to the left and intersects the pump curve at another point. The BEP is now also lower. In other words, the pump efficiency is reduced because the output flow is reduced but power consumption is not. Inefficiencies of oversized pumps can be overcome by, for example, the installation of VSDs, two-speed drives, lower rpm, smaller impeller or trimmed impeller (BEE, 2004).

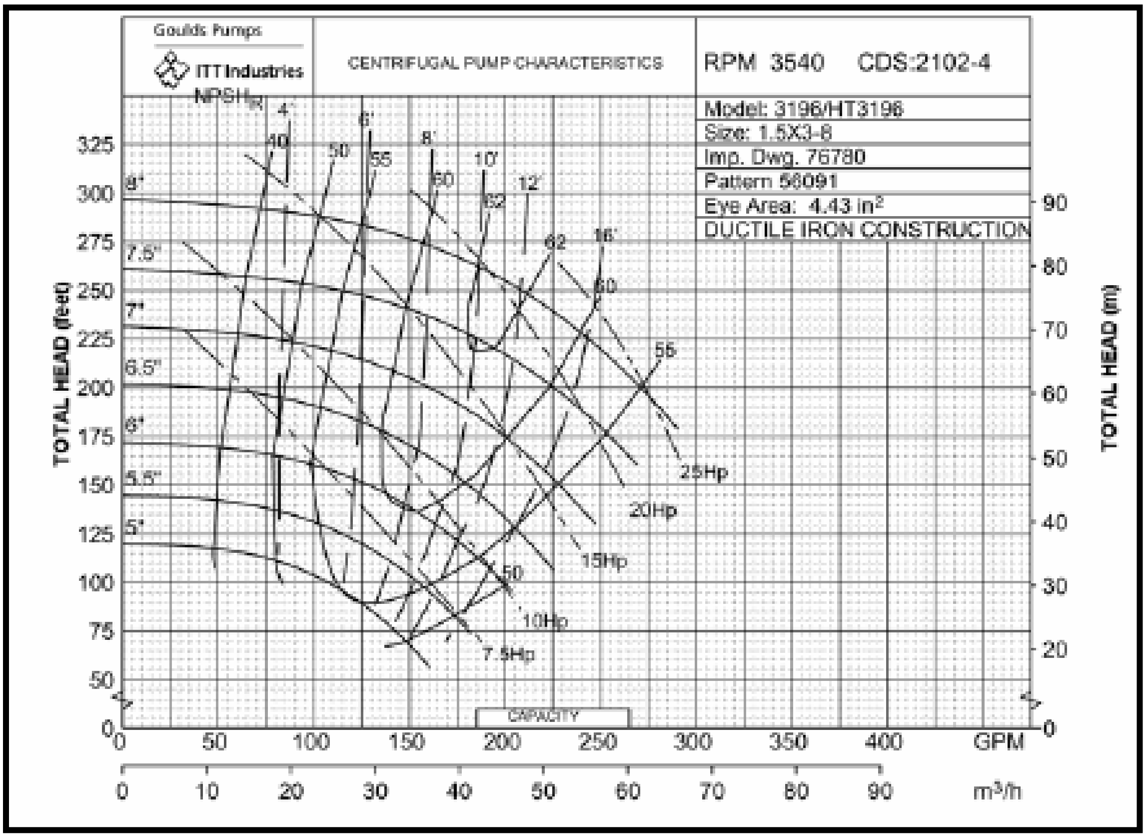

Figure 13: Typical centrifugal pump performance curve given by suppliers
(Bureau of Energy Efficiency, 2004)

4.2 Controlling flow rate by speed variation

4.2.1 Explaining the effect of speed[5]

A centrifugal pump's rotating impeller generates head. The impeller's peripheral velocity is directly related to shaft rotational speed. Therefore varying the rotational speed has a direct effect on the performance of the pump.

[5] Section 4.2.1 is taken (with edits) from *Pumps and Pumping Systems.* In: Energy Efficiency in Electrical Utilities, chapter 6, 2004, with permission from the Bureau of Energy Efficiency, Ministry of Power, India.

The pump performance parameters (flow rate, head, power) will change with varying rotating speeds. To safely control a pump at different speeds it is therefore important to understand the relationships between the two. The equations that explain these relationships are known as the "Affinity Laws":

- Flow rate (Q) is proportional to the rotating speed (N)
- Head (H) is proportional to the square of the rotating speed
- Power (P) is proportional to the cube of the rotating speed

$$\mathbf{Q \propto N}$$
$$\mathbf{H \propto N^2}$$
$$\mathbf{P \propto N^3}$$

As can be seen from the above laws, doubling the rotating speed of the centrifugal pump will increase the power consumption by 8 times. Conversely a small reduction in speed will result in a very large reduction in power consumption. This forms the basis for energy conservation in centrifugal pumps with varying flow requirements.

It is relevant to note that flow control by speed regulation is always more efficient than by a control valve. This is because valves reduce the flow, but not the energy consumed by pumps. In addition to energy savings, there could be other benefits of lower speeds.

- Bearings life is increased. This is because bearings carry the hydraulic forces on the impeller (created by the pressure profile inside the pump casing), which are reduced approximately with the square of speed. For a pump, bearing life is proportional to the seventh power of speed (N^7)!
- Vibration and noise are reduced and seal life is increased, provided that the duty point remains within the allowable operating range.

4.2.2 Using variable speed drive (VSD)

As explained earlier, controlling the pump speed is the most efficient way to control the flow, because when the pump's speed is reduced, the power consumption is also reduced. The most commonly used method to reduce pump speed is Variable Speed Drive (VSD).

VSDs allow pump speed adjustments over a continuous range, avoiding the need to jump from speed to speed as with multiple-speed pumps. VSDs control pump speeds use two types of systems:

- Mechanical VSDs include hydraulic clutches, fluid couplings, and adjustable belts and pulleys.
- Electrical VSDs include eddy current clutches, wound-rotor motor controllers, and variable frequency drives (VFDs). VFDs are the most popular and adjust the electrical frequency of the power supplied to a motor to change the motor's rotational speed.

For many systems, VFDs offer a means to improve the pump operating efficiency under different operating conditions. The effect of slowing pump speed on the pump operation is illustrated in Figure 14. When a VFD reduced the RPM of a pump, the head/flow and power curves move down and to the left, and the efficiency curve also shifts to the left.

The major advantages of VSD application in addition to energy saving are (US DOE, 2004):

- Improved process control because VSDs can correct small variations in flow more quickly.

- Improved system reliability because wear of pumps, bearings and seals is reduced.
- Reduction of capital & maintenance cost because control valves, by-pass lines, and conventional starters are no longer needed.
- Soft starter capability: VSDs allow the motor the motor to have a lower startup current.

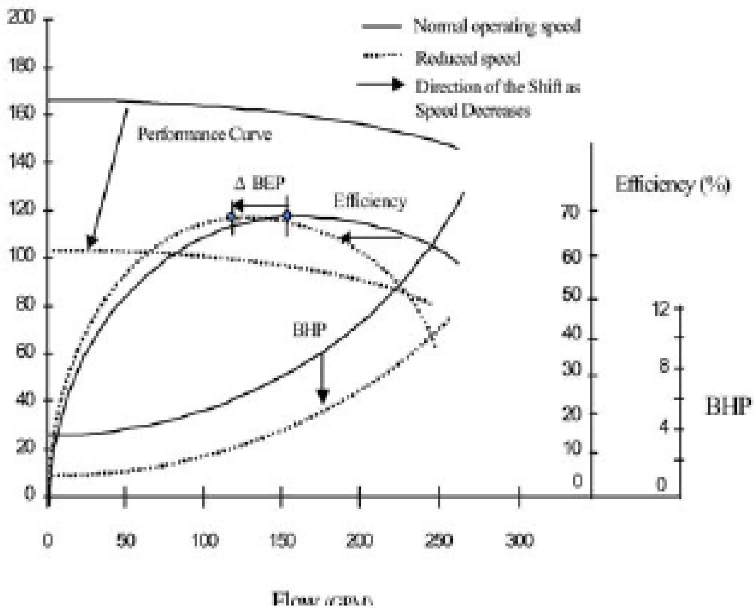

Figure 14. Effect of VFD (US DOE, 2004)

4.3 Pumps in parallel to meet varying demand

Operating two pumps in parallel and turning one of when the demand is lower, can result in significant energy savings. Pumps providing different flow rates can be used. Parallel pumps are an option when the static head is more than fifty percent of the total head. Figure 15 shows the pump curve for a single pump, two pumps operating in parallel and three pumps operating in parallel. It also shows that the system curve normally does not change by running pumps in parallel. The flow rate is lower than the sum of the flow rates of the different pumps.

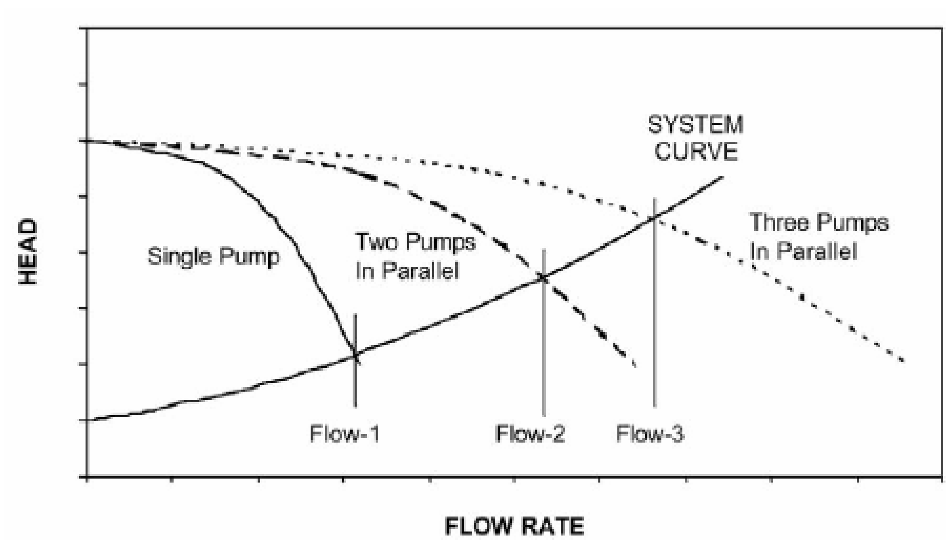

Figure 15. Typical performance curves for pumps in parallel (BPMA)

4.4 Eliminating flow control valve

Another method to control the flow by closing or opening the discharge valve (this is also known as "throttling" the valves). While this method reduces the flow, it does not reduce the power consumed, as the total head (static head) increases. Figure 16 shows how the system curve moves upwards and to the left when a discharge valve is half closed.

This method increases vibration and corrosion and thereby increases maintenance costs of pumps and potentially reduces their lifetimes. VSDs are a better solution from an energy efficiency perspective.

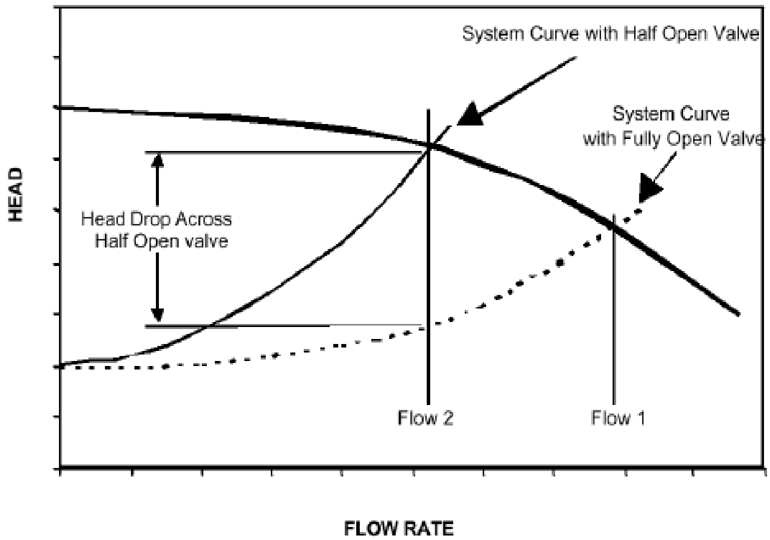

Figure 16. Control of Pump Flow by Valve (BPMA)

4.5 Eliminating by-pass control

The flow can also be reduced by installing a by-pass control system, in which the discharge of the pump is divided into two flows going into two separate pipelines. One of the pipelines delivers the fluid to the delivery point, while the second pipeline returns the fluid to the source. In other words, part of the fluid is pumped around for no reason, and thus is an energy wastage. This option should therefore be avoided.

4.6 Start/stop control of pump

A simple and reasonable energy efficient way to reduce the flow rate is by starting and stopping the pump, provided that this does not happen to frequently. An example where this option can be applied, is when a pump is used to fill a storage tank from which the fluid flows to the process at a steady rate. In this system, controllers are installed at the minimum and maximum level inside the tank to start and stop the pump. Some companies use this method also to avoid lower the maximum demand (i.e. by pumping at non-peak hours).

4.7 Impeller trimming

Changing the impeller diameter gives a proportional change in the impeller's peripheral velocity. Similar to the affinity laws, the following equations apply to the impeller diameter D:

Q α D
H α D^2
P α D^3

Changing the impeller diameter is an energy efficient way to control the pump flow rate. However, for this option, the following should be considered:

- This option cannot be used where varying flow patterns exist.
- The impeller should not be trimmed more than 25% of the original impeller size, otherwise it leads to vibration due to cavitation and therefore decrease the pump efficiency.
- The balance of the pump has to been maintained, i.e. the impeller trimming should be the same on all sides.

Changing the impeller itself is a better option than trimming the impeller, but is also more expensive and sometimes the smaller impeller is too small.

Figure 17 illustrates the effect of impeller diameter reduction on centrifugal pump performance.

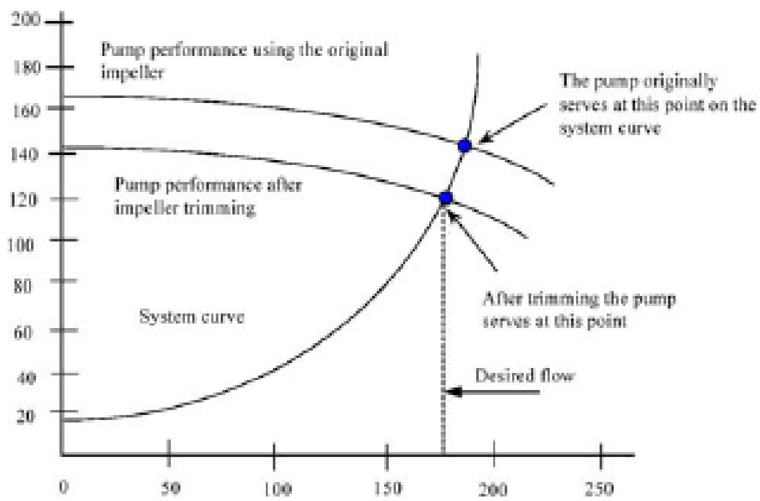

Figure 17. Impeller diameter reduction on centrifugal pump performance
(Bureau of Energy Efficiency, 2004)

A comparison of different energy conservation options in pumps and pumping system is summarized below.

Table 1. Comparison of different energy conservation options in pumps
(adapted from US DOE 2001)

Parameter	Change control valve	Trim impeller	VFD
Impeller diameter	430 mm	375 mm	430 mm
Pump head	71.7 m	42 m	34.5 m
Pump efficiency	75.1%	72.1%	77%
Rate of flow	80 m^3/hr	80 m^3/hr	80 m^3/hr
Power consumed	23.1 kW	14 kW	11.6 kW

5. OPTION CHECKLIST

This section includes most important options to improve energy efficiency of pumps and pumping systems.

- Operate pumps near their best efficiency point (BEP)
- Ensure adequate NPSH at site of installation
- Modify pumping system and pumps losses to minimize throttling.
- Ensure availability of basic instruments at pumps like pressure gauges, flow meters
- Adapt to wide load variation with variable speed drives or sequenced control of multiple units
- Avoid operating more than one pump for the same application
- Use booster pumps for small loads requiring higher pressures
- To improve the performance of heat exchangers, reduce the difference in temperature between the inlet and outlet rather than increasing the flow rate
- Repair seals and packing to minimize water loss by dripping
- Balance the system to minimize flows and reduce pump power requirements
- Avoid pumping head with a free-fall return (gravity), and use the siphon effect
- Conduct a water balance to minimize water consumption, thus optimum pump operation
- Avoid cooling water re-circulation in DG sets, air compressors, refrigeration systems, cooling towers feed water pumps, condenser pumps and process pumps
- In multiple pump operations, carefully combine the operation of pumps to avoid throttling
- Replace old pumps with energy efficient pumps
- T improve the efficiency of oversized pumps, install variable speed drive, downsize / replace impeller, or replace with a smaller pump
- Optimize the number of stages in multi-stage pump if margins in pressure exist
- Reduce the system resistance by pressure drop assessment and pipe size optimization
- Regularly check for vibration to predict bearing damage, misalignments, unbalance, foundation looseness etc.

6. WORKSHEETS

This section includes following worksheets:
- Pump Specification Data
- Pump Efficiency Calculation

Worksheet 1: PUMP SPECIFICATION DATA

No.	Parameter	Units	Pump number		
			1	2	3
1	Make				
2	Type (reciprocating/centrifugal)				
3	Discharge capacity	m^3/hr			
4	Head developed	mmWC			
5	Fluid Handled				
6	Density of fluid	kg/m^3			
7	Temperature of fluid	^{0}C			
8	Pump input power	kW			
9	Pump speed	RPM			
10	Pump rated efficiency	%			
11	Specific power consumption	kW/(m^3/hr)			
12	Pump motor				
	Rated power	kW			
	Full load current	Amp			
	Rated speed	RPM			
	Supply voltage	Volts			
	Rated efficiency	%			
	Rated power factor				
	Supply frequency	Hz			
13	Bearing type				
	Pump (driving end)				
	Pump (non-driving end)				
	Motor (driving end)				
	Motor (non-driving end)				
14	Lubricant grade				

Worksheet 2: PUMP EFFICIENCY CALCULATION

No.	**Parameter**	**Units**	**Pump number**		
			1	**2**	**3**
1	Fluid flow measured or estimated (Q)	m^3/sec			
2	Suction head (Including head correction due to pressure gauge location)	m			
3	Discharge head (including head correction due to pressure gauge location)	m			
4	Total dynamic head (TDH)	m			
5	Density of fluid (γ)	kg/m^3			
6	Motor input power (P)	kW			
7	Supply frequency	Hz			
8	Pump input power	kW			
9	Hudraulic power (Ph) Q x H x γ x 9.81/1000	kW			
10	Combined efficiency (ηc) Ph/P x 100	%			
11	Pump efficiency (ηp) (ηc/motor efficiency) x 100	%			
12	Specific power consumption P/Q	kW/(m^3/sec)			
13	% Motor loading with respect to power	%			
14	% Pump loading with respect to flow	%			
15	% Pump loading with respect to total dynamic head (TDH)	%			

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