

Chapter 5

PUMPS AND PUMPING MACHINERIES

5.1 Introduction

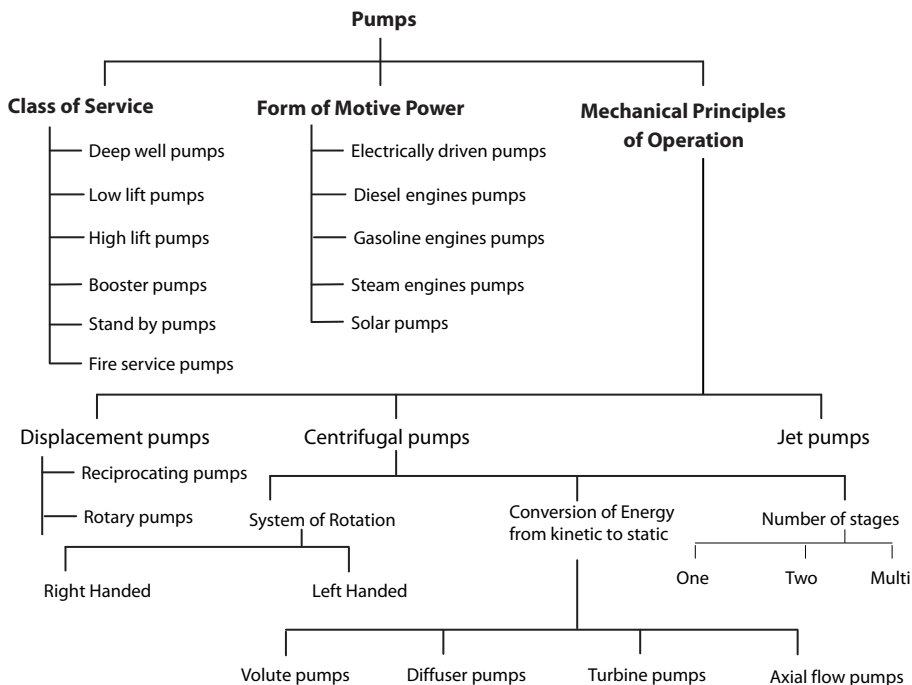
A pump is a device used to move fluids, such as liquids, gases or slurries. A pump displaces a volume by physical or mechanical action. The location of the pump station and intake structure, and the anticipated heads and capacities are the major factors in the selection of pumps. The function of a pump station in the overall distribution system operation can also affect the determination of capacities.

Water may be required to be pumped under following situations

- When the elevation of the source of water supply is such that the water will not flow into the mains by gravity.
- When it is required to increase or boost up pressure in the mains.
- When water has to be lifted from one level to another.

5.2 Classification of Pumps

Depending upon the functions to be performed, pumps can be classified into various categories as described below.



5.2.1 Pumps according to the class of service.

These may be deep-well pumps, low lift pumps, high lift pumps, booster pumps, stand-by pumps etc.

- **Deep well pumps** operate in tube wells and pump water into service reservoirs or directly into the distribution system.
- **Low lift pumps** operate for small heads such as at treatment plants for pumping water from storage tanks to high-level tanks or mixing chambers.
- **High lift pumps** are for large heads as for pumping water from clear-water reservoirs into the elevated tanks or directly into the distribution system.
- **Booster pumps** are used to increase pressures in parts of distribution system, where adequate pressures cannot be had either because of greater elevation or excessive loss of head in the distributing pipes. They are also used to provide water in the upper storeys of tall buildings. Booster pump may be above-ground or underground. Figure 5.1 illustrates schematic piping of two types. Pump and controls selection for in line booster pumps will consider minimum suction pressure, and automatic discharge cut-off pressure. For small booster pump applications, as for remote housing

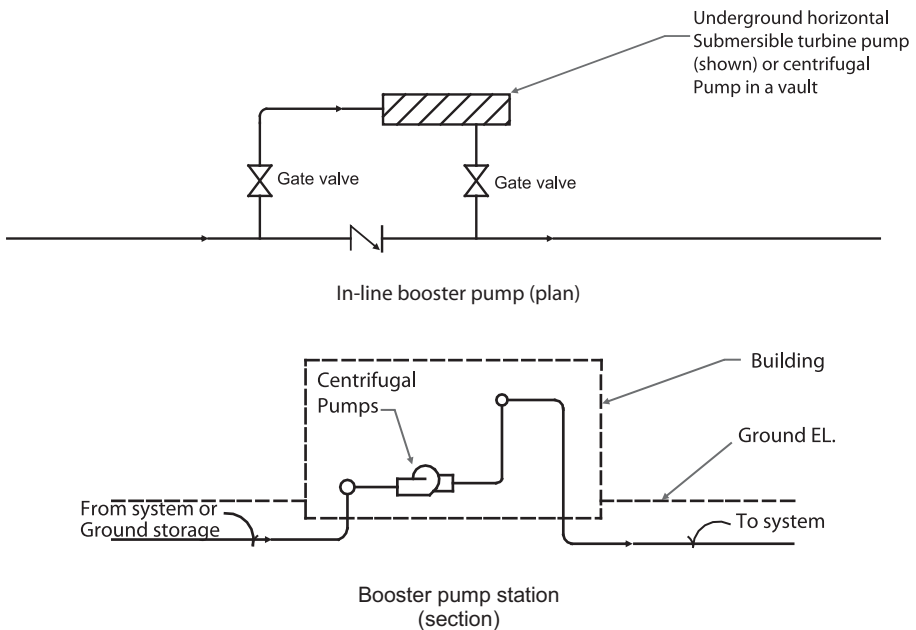


Figure 5.1: Booster pump station

facilities with peak water demands of less than approximately 1500 gpm the designer should consider a pre-assembled skid mounted package unit including all of its hydrostatic, flow, instrument and electrical components.

- **Stand-by pumps** are essential features of large pumping installations where auxiliary forms of power are available also. In case of temporary shutdown of electric power, the stand-by units can be driven on steam, diesel etc.
- **Pumps for fire service** are intended to build up pressure to the extent required for efficient fire-fighting in case of multi-storeyed buildings and factories.

5.2.2 Pumps according to the form of motive power i.e., electric motors; diesel engines, gasoline engines and steam engines. Economic factors such as size of plant cost of electricity, oil, gasoline, coal and the cost of supervision chiefly effect the selection.

- **Electrically driven pumps** are generally employed in all modern medium and small pumping-plants. Advantages are freedom from smoke and dust, quiet operation, economical supervision, and economy of floor space for pumps and motors. Main disadvantage is the frequency of power interruption, necessitating provision of stand-by power arrangement. Electric motors are of two types—squirrel-cage induction motors commonly used for small high- speed pumps and synchronous motors used for large low-speed pumps.
- **Diesel engines** are reliable, economical for pump drives but not very commonly used because of lower speeds than those required for centrifugal pumps. As compared to the electrically-driven pumps, they are costlier to install and maintain. They are suitable for use only in small capacity water pumping plants and as stand-by units.
- **Gasoline engines** are rarely used because of high cost in continuous operation. They are, however, suitable for stand-by service and are effective for moderate heads.
- **Steam engines** find use in case of large pumping plants where considerations are production of power at a lower cost, durability of service and flexibility of operation.

- **Solar pumps** use the renewable solar energy, which is recently developed (Short and Thompson 2003; Meah, Ula et al. 2008).

5.2.3 Pumps according to the mechanical principles of operation.

This is, by far, the most important classification. Based on this are the following three types Displacement pumps, Centrifugal pumps, and Jet (Ejector) pumps are very commonly used.

- **Displacement pumps** work on the principle of mechanically inducing vacuum in a chamber thereby drawing in a volume of water which is then mechanically displaced and forced out of the chamber. They are of two types:

- **Reciprocating pump:** In a reciprocating pump, a piston or plunger operates in a closed cylinder, its 'forward' stroke producing vacuum which draws in water through an inlet valve from a suction-pipe, the 'return' stroke pushing water out through an outlet valve in a delivery pipe. Reciprocating pumps may be single acting (Figure 5.2) or double acting (Figure 5.3) depending on whether it is arranged for water to be discharged only during return stroke of the piston or both during its forward and return strokes. These pumps operate at low speed, deliver a constant pulsating discharge, and possess considerable leakage through valves and piston and known as 'slip', and are generally used for high heads.

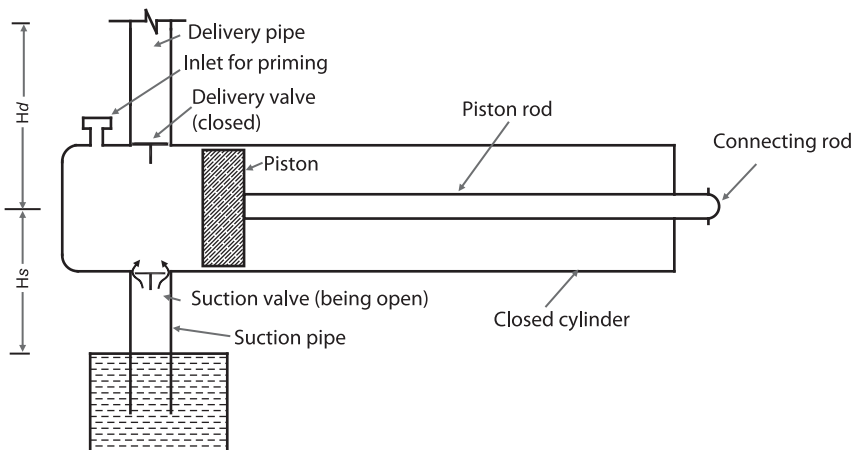


Figure 5.2: Single acting reciprocating pump

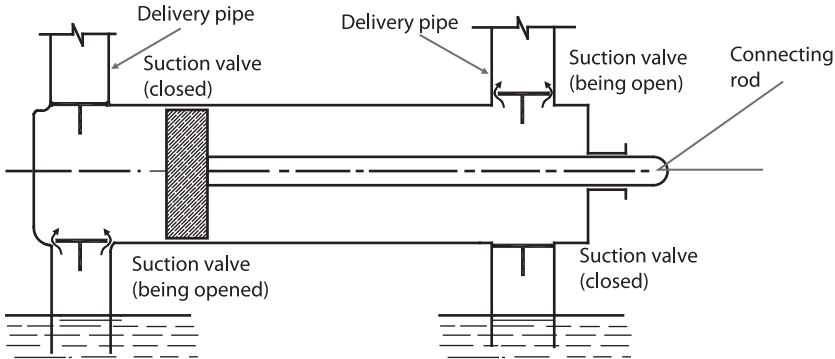


Figure 5.3: Double acting reciprocating pump

The hand-operated reciprocating pump finds an important application in case of individual and rural water supply systems. In such a pump (Figure 5.4) a piston or plunger reciprocates in a closed vertical cylinder, the upstroke producing vacuum, opening a valve v_1 at the base of the pump thus drawing in water which fills cylinder below the piston while water in the cylinder above the piston is forced out of the spout; the down stroke opening a valve v_2 at the base of the piston thus filling in water in cylinder above the piston, keeping v_1 closed at the same time.

The hand operate pump can be used in any depth. For wells where static water level is up to 6m; the cylinder is placed above ground. This however, necessitates using a foot valve at tower end of the suction pipe to avoid priming. Where static water depth is more than 6m; the cylinder is attached to a drop pipe and placed in the well.

- **Rotary pump:** In a rotary pump, gears, cams or screws enmesh rotating in opposite directions in the casing and force the water around and out in each revolution (Figure 5.5). Rotary pumps require no valves, are self-priming. As in their case, rotation is substituted for reciprocatory motion, they can be operated at higher speeds, and thus larger capacity with smaller size can be obtained. They have the disadvantage of showing excessive slip which increases with wear of pumping parts. Further, because of the close fit of the gears or cams in the casing, water containing grit or other Suspended matter is injurious to them. Hence they are used only to a small extent in water works practice.

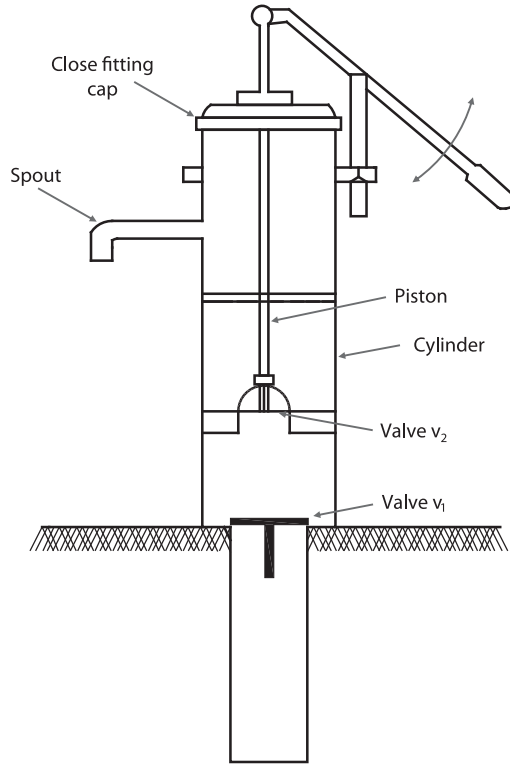


Figure 5.4: Hand operate reciprocating pump

- **Centrifugal Pumps** employ the principle of centrifugal force to impart energy to the water. Water entering into the pump-casing is revolved by a wheel called impeller which discharges it in a direction at right angles to its original direction of flow. In so doing, the kinetic energy of water is converted into static or pressure-head.

The centrifugal pumps may be classified in the following different ways:

- According to the system of rotation as right-handed or left-handed. Thus the pump is said Lobe right-handed if the rotation is clockwise when the pump is faced from the power end (Skinner 1993).
- According to the manner of conversion of kinetic energy into static head as volute pumps, diffuser pumps, turbine pumps and axial flow pumps. In a volute pump (Figure 5.6), the impeller discharges into a gradually expanding spiral casing which is so proportioned as to maintain a constant velocity of flow of liquid all around its

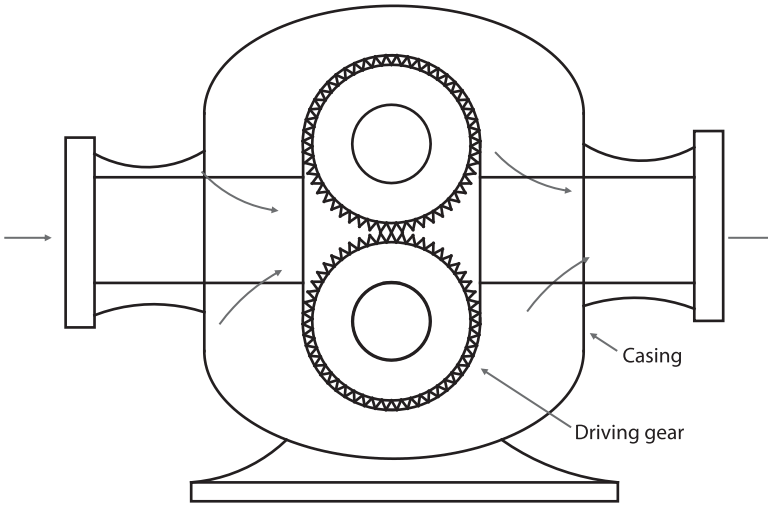


Figure 5.5: Rotary pump

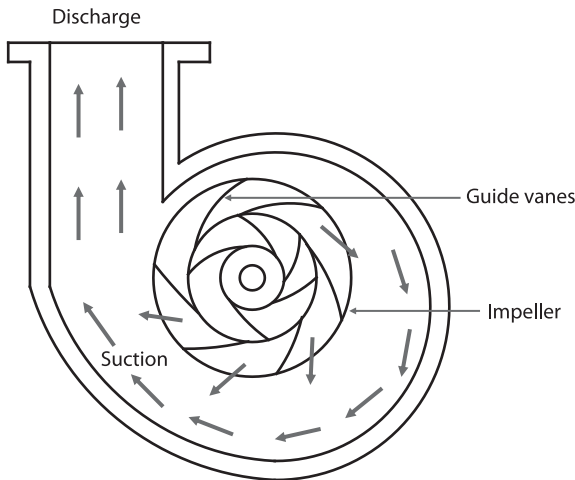


Figure 5.6: Volute pump

circumference. The velocity of flow is decreased as liquid flows to the discharge end thus enabling the velocity head to be changed into pressure head. In a diffuser pump (Figure 5.7), stationary guide vanes with expanding passages surround the impeller and liquid flow velocity

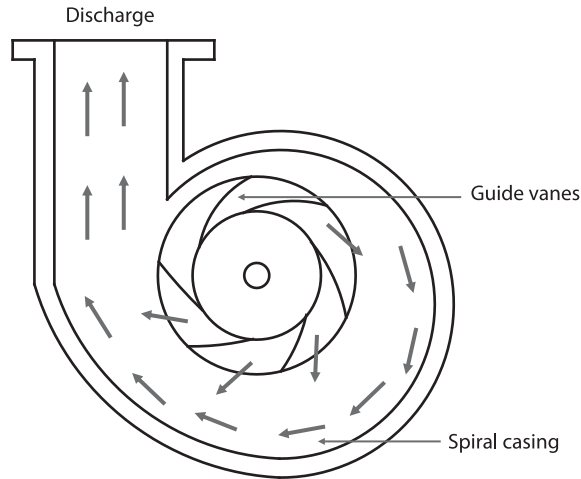


Figure 5.7: Diffuser pump

head is converted into pressure head before liquid leaves the impeller and enters the volute. The velocity head of the liquid is thus more completely converted into pressure head resulting in higher efficiency than is possible with the volute pump. In a turbine pump (Figure 5.8), a double row of vanes is cut in the impeller's rim, the vanes rotating in a channel of constant cross-section in the pump casing; the revolving liquid gets a number of impulses during each revolution of the impeller. Because of this action, the liquid as it is carried forward, flows in a helical path like a screw thread. Consequently, energy is added to the liquid in a number of impulses by the impeller's vanes as it moves from suction to discharge. In an axial flow pump, the head is developed by the propelling or lifting action of the vanes on the liquid. Such pumps are also called propeller pumps and are useful for pumping large quantities against low heads.

- According to the number of stages as single-stage, two-stage, or multi stage etc.; depending upon the number of stages of pressure developed by impellers. Each stage of the pressure-head is added together by leading the discharge from one impeller into the Suction of another when added to the initial pressure at the inlet, results in an increased discharge-pressure of the centrifugal pump.

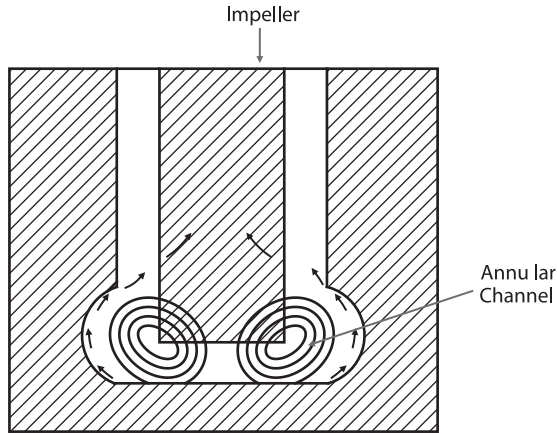


Figure 5.8: Turbine pump

Advantage of centrifugal pumps: The centrifugal pumps possess advantages as

- low initial costs
- simple mechanism simple operation and repair
- stability of flow
- safe against high pressures
- adaptability to high heads
- small space require and
- good durability.

Disadvantage of centrifugal pumps: A few inherent draw back are:

- limited suction lift (4.5m)
- absence of self priming arrangements
- necessity of employing speed regulating gears for adjusting speed and
- Low efficiency over wide range of head and discharge.
- **Jet (ejector) pumps** are actually combined centrifugal and ejector pumps. A portion of the discharged water from the centrifugal pump is diverted through a nozzle and venturi tube. A pressure zone lower than that of the surrounding area exists in the venturi tube; therefore, water from the source (well) flows into this area of reduced pressure. The velocity of the water from the nozzle pushes it through the pipe toward the surface where the centrifugal pump can lift it by suction. The centrifugal pump then forces it into the distribution system (see Figure 5.9).

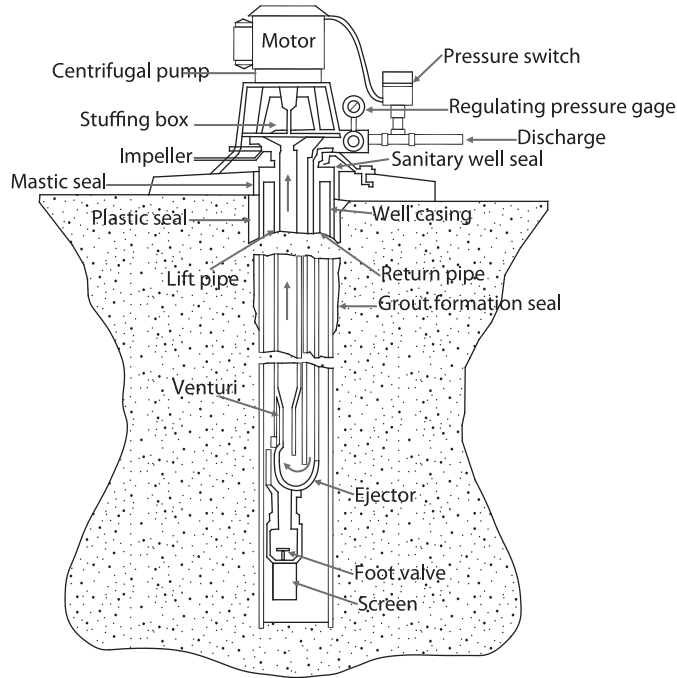


Figure 5.9: "Over-the-well" jet pump installment

5.3 Selection of Pumps

The type of pump selected for a particular installation should be determined on the basis of the following fundamental considerations.

- Yield of the well or water source
- Daily needs and instantaneous demand of the users
- The "usable water" in the pressure or storage tank
- Size and alignment of the well casing
- Total operating head pressure of the pump at normal delivery rates, including lift and all friction losses
- Difference in elevation between ground level and water level in the well during pumping
- Availability of power
- Ease of maintenance and availability of replacement parts
- First cost and economy of operation
- Reliability of pumping equipment

Table 5.1 presents the criteria of selecting pumps

Table 5.1: Information on pump selection

Type of pump	Practical Suction lift*(ft(m))	Usual well pumping depth, ft (m)	Usual pressure heads, ft (m)	Advantages	Disadvantages	Remarks
Positive displacement 1.Shallow well (Reciprocating) 2.Deep well (Reciprocating)	22-25 (6.71-7.62)	22-25 (6.71-7.62)	100-2200 (30.48-670.56)	1. Positive action 2. Discharge against variable head. 3. Pumps water containing sand and silt. 4. Especially adapted to low capacity and high lifts.	1. Pulsating discharge. 2. Subject to vibration and noise. 3. Maintenance cost may be high. 4. may cause destructive pressure if operated against closed valve	1. Best suited for capacity of 5-25 gpm against moderated to high heads. 2. Adaptable to hand operation 3. Can be installed in very small diameter wells (2-in casing) 4. Pump must be set directly over well(deep well only)
Centrifugal 1.Shallow well a.Straight centrifugal (single stage)	20 ft (6.10 max)	10-20 (3.50-6.10)	100-150 (30.48-45.72)	1. Smooth even flow 2. Pumps water containing sand and silt 3. Pressure on system is even and free from shock 4. Low starting torque 5. Usually reliable and good service life	1. loses primary easily 2. Efficiency depends on operation under design heads and speed	

Type of pump	Practical Suction lift* ft(m)	Usual well pumping depth, ft (m)	Usual pressure heads, ft (m)	Advantages	Disadvantages	Remarks
b.Regenerative wane turbine type (Single impeller)	28 (8-53max)	28(8.53)	100-200 (30.48-45.72)	<ol style="list-style-type: none"> 1. Same as straight centrifugal except not suitable for pumping water containing sand and silt. 2. Self priming 	<ol style="list-style-type: none"> 1. same as straight centrifugal except 	
2.Deep well shaft turbine(multistage)	Impeller submerged	50-300 (15.24-91.44)	100-800 (30.48-243)	<ol style="list-style-type: none"> 1. Same as shallow well turbine 2. All electrical component are accessible, above ground 	<ol style="list-style-type: none"> 1. Efficiency depends on operating under design head and speed 2. require straight well large enough for turbine bowls and housing 3. Lubrication and alignment of shaft critical 4. Abrasion from sand 	
a.Vertical line shaft turbine(multistage)	Impeller submerged	50-300 (15.24-91.44)	100-800 (30.48-243)	<ol style="list-style-type: none"> 1. Easy to frostproof installation 3. Short pump shaft to motor 4. Quite operator 5. Well straightness not critical 		

Type of pump	Practical Suction lift*ft(m)	Usual well pumping depth, ft (m)	Usual pressure heads, ft (m)	Advantages	Disadvantages	Remarks
b.Submersible turbine (multistage)	Pump and motor submerged	50-400 (15.24-121.92)	50-400 (15.24-121.92)		<ol style="list-style-type: none"> 1. Repair to motor or pump requires pulling from well 2. Scaling of electrical equipment from water vapor critical 3. Abrasions from sand 	<p>1. 3500-rpm model, while popular because of smaller diameters or greater capacity, are more vulnerable to wear and failure from sand and other causes.</p>

Type of pump	Practical Suction lift* ft(m)	Usual well pumping depth, ft (m)	Usual pressure heads, ft (m)	Advantages	Disadvantages	Remarks
Jet (ejector):						
1.Shallow well (4.57-6.10)	15-20 (4.57-6.10)	15-20 (24.38-45.72)	80-150	<ol style="list-style-type: none"> 1. High capacity at low heads 2. Simple in operation 3. Dose not have to be installed over the well 4. No moving parts in the well 	<ol style="list-style-type: none"> 1. Capacity reduce as lift increases 2. Air in suction or return line will stop pumping 	
2.Deep well	15-20 (4.57-6.10)	25-120 (7.62-36.58)	80-150 (24.38-45.72)	<ol style="list-style-type: none"> 1. Same as shallow well jet 2. Well Straightness not critical 	<ol style="list-style-type: none"> 1. Same as shallow well jet 2. Lower efficiency, especially at greater lifts 	<ol style="list-style-type: none"> 1. The amount of water returned to ejector increases with increased lift 50% of total water pumped at 50 ft (15.24m) lift and 75% lift at 100 ft (30.48m) lift

5.4 Pump Curves

With the system head curve defined, it is possible to select a pump to deliver the required capacity. Manufacturer's published pump head-capacity curves for the selected type of pump will be used for this purpose. Since these pump curves usually apply to a particular impeller and pump design, different manufacturers may show slightly different performance for the same type and size of pump. Therefore, several manufacturers' pump curves should be checked to establish a realistic and cost effective criterion for the pump selection. Figure 5.10 shows three types of pump head capacity (performance) curves; a "normal rising" curve, a "drooping" curve and a "steeply rising" curve. For pumps in a typical water supply and distribution system, only pumps with "normal rising" to "steeply rising" performance curves should be used. Pumps with these characteristics will perform well in parallel operation and will have relatively small capacity change with pressure changes. In addition, the brake-horse power curve will be relatively flat, which will minimize the risk of overloading the motor particularly in applications in direct pressure systems with possible high pressure fluctuations.

5.5 Valving

Valves used in pump station piping system will include: gate valves, globe and angle valves, cone valves, butterfly valves, ball valves, check valves, and relief valves. Globe, ball, cone, and butterfly valves will be best suited as control valves for modulating the flow to provide desired pressure or flow rate. Check valves will not be used in vertical piping.

Suction piping valves: A gate valve will be installed in the suction piping so that the pump can be isolated from the line. The stem of this valve may be installed horizontal to avoid air pockets. Butterfly valves will not be installed in pump suction piping.

Discharge piping valves: A check valve and a gate or butterfly valve will be installed in the discharge piping with the check valve between the pump and the gate valve. The check valve will protect the pump from excessive back pressure and prevent liquid from running backwards through the pump in case of power failure. The gate valve will be used to isolate the pump and check valve for maintenance purposes. In installations where an automatic surge control valve is needed the check valve will be eliminated provided the drive will not be a wound

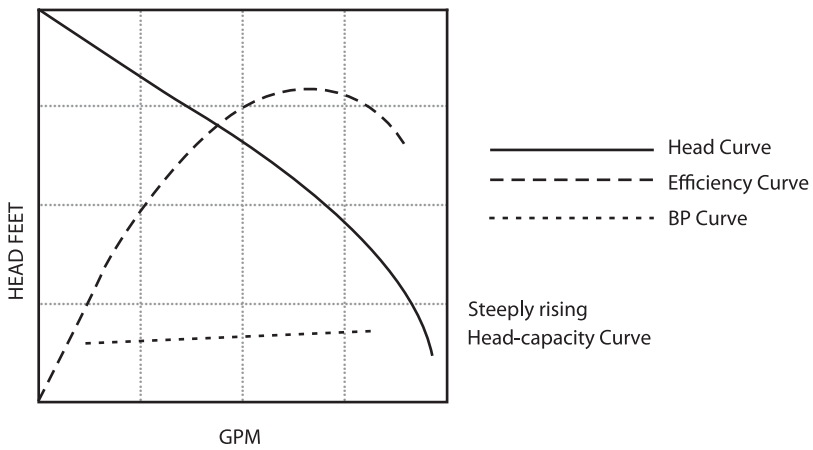
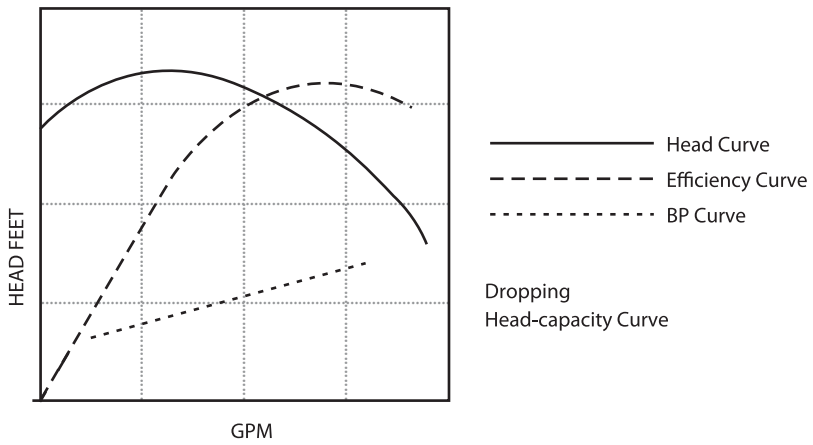
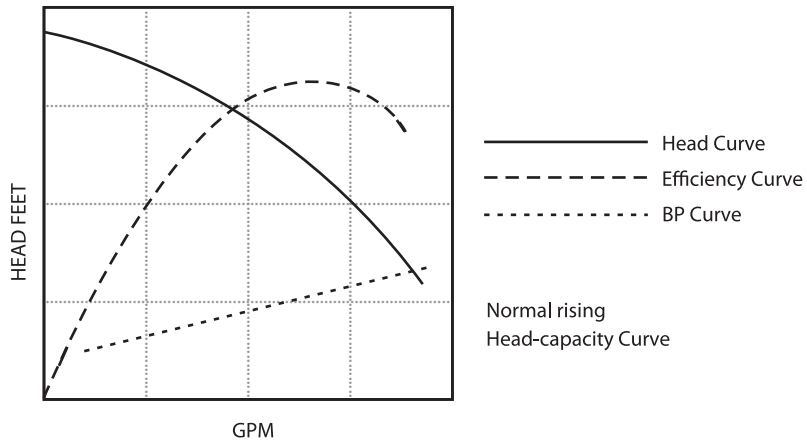


Figure 5.10: Pump curves

rotor motor and pump design will allow some reverse rotation. Pressure relief valves, commonly diaphragm activated globe or angle type, will be installed in discharge piping system for flow control and/or pressure regulation, and to protect pump equipment and piping system from excessive surge pressures which could exceed the ratings of system components.

Air release and vacuum relief: Air release and vacuum relief valves will be used on discharge piping for vertical turbine pumps.

Control system valving: Pump control systems range from single hand-operated valves to highly advanced, automatic flow control or pump speed control systems. Particularly, in an unattended high head pump station the control valve may have a controller to close automatically when the pump is stopped and to open once the pump has reached specified speed after the pump is started. Control valves are installed to prevent surge pressures, which otherwise cause water hammer and high pressures. A good surge control valve with low head loss will consist of a hydraulically operated valve on the pump discharge complete with speed control device to permit independent timing of both the valve opening and closing speeds. The controller will include hydraulic and safety equipment wired to function in sequence with the pump motor starting gear.

- **Hydraulic accumulator system:** A properly selected hydraulic accumulator system can operate on clean water, oil and other fluids. The water system may allow formation of algae, scale and create corrosion in the controls and cylinders and must be constantly checked. Hydraulic oil specially selected for this application provides the best and most trouble free qualities.
- **Other control valve systems:** Control valves design and versatility are constantly improving. The selection of a control valve for a specific installation should be made only after consultation with the manufacturers.

5.6 Flow Meters

Pump station water is metered for several reasons: to calculate distribution system losses by subtracting the total of meter readings from total supply, to monitoring pump efficiency, and to determine gross billings for water supplied. High rate of accuracy and wide range criteria will be desirable in most pump

station flow meter applications. Because of constant improvements in old technologies and because new technological developments continuously provide the market with new products, the designer must review the state of the art before making final meter selection. The design criteria of the flow meters might include the following considerations.

- Accuracy: + 1% of rate
- Rangeability: To cover complete design range
- Maintainability: Routine by user. Major overhaul by readily available factory service
- Initial cost: Minimal
- Operating cost: Minimal
- Design life: 20 years minimum

5.6.1 Selection of meter

The most common flow meters in water pumping installations identified in the order that they best comply with the design criteria are as follows:

- **Ultrasonic meter:** Ultrasonic meter for clean liquids using "transit time" technology will meet all the set criteria. Straight approach length equivalent to 10 pipe diameters is important. No maintenance is required. Additional advantages of the ultrasonic meter include non-contact with liquid, versatile design regarding data monitoring and clamp-on transducer for any size pipe over 1 inch in diameter. The meter is most cost effective for larger pipe applications. This type of meter does not require any pipe by-pass arrangement with shut-off valves.
- **Current meters:** Current type meters used for pump station discharge and mainline measurements include turbine and propeller meters. Accuracy of these meters are +2% instead of +1% over an approximate rangeability of 10:1. These meters require a length equivalent to 5 pipe diameters straight approach and periodic maintenance. Turbine meter standards for sizes 1 to 1½ inch through 12 inches are covered in the manual of American Water Works Association ((AWWA)) C701 and propeller meter standards for sizes 2 inches to 36 inches in ((AWWA)) C704. The advantages of current meters are lower initial cost for small size meters, simplicity in design, and historically a proven product over many years.

5.7 Pumping Layouts

5.7.1 Suction piping

Proper design of suction piping is important to minimize pressure losses and allow sufficient flow into the pump. Many net positive suction head (NPSH) problems will be eliminated by proper suction piping design. Suction piping must be kept free of air leaks. Pipe joints will be screwed or flanged joints for smaller sizes and flanged for larger sizes.

- **Suction pipe sizing:** Suction piping should be as short as possible as but never smaller than pump suction opening. If a longer suction pipe is required, it should be one or two sizes larger than the pump suction opening depending on the length. Suction piping of same size as pump suction nozzle for a double suction pump will have a minimum of 10 pipe diameters straight run from the suction flange of the pump. The pump manufacturer of the selected pump will be consulted regarding special piping arrangement for vertically mounted pumps or for other space limitations. Suction pipe headers in multiple pump installations will have headers sized so that each pump receives its proportional flow amount.
- **Suction elbows:** To avoid high unequalized thrust loads that will overheat bearings and cause undue wear as well as affecting hydraulic performance, suction elbows for double suction pumps will be positioned in a vertical position only to allow the liquid to enter evenly on both sides of the impeller. Long radius elbows will be used.
- **Pipe slope:** Suction pipe will slope upward to the pump connection when operating on suction lift. When reducing the piping to the suction opening of the pump and where operating on suction lift, an eccentric reducer with the eccentric side down will be used to avoid air pockets.

5.7.2 Discharge piping

If the discharge pipe is short, the diameter of the pipe will be same as pump discharge nozzle. If the discharge pipe is long, the diameter will be increased by one or two sizes depending on length.

5.7.3 Meter runs

At meter locations the required straight approach and downstream length of straight pipe must be considered. It is good practice to allow straight runs of 10

and 5 pipe diameters for upstream (approach) and downstream of meters in the piping layout. This will accommodate any type of meter.

5.8 Control

Pump controls will have the capability to provide the desired flow rates, pressures and liquid levels; to provide protection from pump and piping system damage; and to serve as a tool to find system problems which may need operational adjustment, repair or maintenance. Control systems consist of the following:

- Sensing and measuring elements (primary device).
- Comparison and relaying element (controller).
- Final control element (as a valve) to produce the required change including an actuator to move the control element.

The successful operation of the control system depends on several factors as follows:

- An accurate definition of the control job to be done.
- A review and evaluation of available devices/systems suited to do this specific job.
- Selection of device and system design in cooperation with the manufacturer of the selected equipment.

5.8.1 Sensing and measuring elements

Automatic pump control and valve operation sensing and measuring elements will detect values of changes in liquid level pressure or flow rate and emit a signal which may be amplified and/or converted into another medium in a transducer as rotary motion or air pressure to electric voltage. The most common primary devices used in waterworks are liquid level sensors, pressure sensors and flow meters.

5.8.2 Comparison and relaying element

The variable that is most convenient or advantageous to measure is rarely the one best suited for direct use in the control system or for actuation of the final control element. Conversion of sensed or measured variable values into another signal medium is therefore necessary. The comparison and relaying means, the transducers and transmitters, are usually housed together in the controller which often is physically separated from the primary device.

5.8.3 Final control element

For the final control element, valves and pumps serve for on-off control and modulating needs in water pumping systems. A control valve is a valve that modulates the flow through it to provide the desired downstream or upstream pressure or flow rate. Although almost all valves can be partly closed and control flow to some degree, the term "control valve" means a specialized type of power-activated valve designed to modulate flow to meet system demands or for control element is a pump provided with automatic surge protection. The term "pump" as a final variable speed control drives to maintain an essentially fixed flow rate and for controlled flow rate increase/decrease at start/stop of pump to minimize surges in the system. Because of unique features available from control equipment manufacturers, the designer should contact the manufacturers before selecting valve and pump control equipment.

5.8.4 Instrumentation

Instrumentation for a water pumping station will supervise and monitor the routine operation of pumps, their drives and accessories to sustain a desired level of performance and reliability. Alarm situations will be identified, such as low delivery flow and low pressure, pump failure, power failure, and low suction head (water loss). Alarm situations will include engine drives as required to support the system reliability factors. The type and extent of supervisory instrumentation for the installation will be determined from:

- Pump application in terms of what effect the pump will have on the system if it failed to perform its function.
- Pump design, type, size and parameters that could affect reliability and hydraulic performance such as variable speed pumps and long shaft high speed pumps, which may need monitoring of vibration, bearing and hydraulic performance.
- Operator experience with similar pumps may indicate a need for applying supervisory instrumentation.
- Installations with operators in attendance will need minimum monitoring while unattended pump stations in remote location will require substantial monitoring of measurements and alarms.

5.9 Reliability Factors

A pumping station usually represents one of the major and most costly

components of a water distribution system, therefore pump station reliability will be considered. The number of pumps will depend upon present and future needs. An economic analysis should be performed to determine the number of pumps to be installed. In smaller stations a single pump may be most economical to meet the peak demand. Whenever a single pump is sufficient, two equal size pumps, each able to handle the peak demand, must be provided and set-up to alternate. Whenever two or more pumps are cost-effective to meet the peak demand, additional pump capacity or pumps must be installed so that peak demand can be met with the largest pump out of service. All pumps should alternate. Raw water pumping stations must have a minimum of three pumps. To prevent large pumps from repeatedly cycling on and off during periods of low demand, one small modulating pump, commonly known as a jockey pump, shall be installed.

5.9.1 Emergency power

During curtailed power or brown-out, emergency power is usually provided by a diesel generator although other standby fuels such as gasoline and natural gas may be used if available and economical. Diesel engines and diesel engine fueling systems are preferred as more reliable. Emergency power will not be provided for standby equipment. Emergency power will be limited to average demand conditions for water distribution and transmission systems and to 50 percent of the treatment plant's capacity for raw water supply stations.

5.9.2 Factors

The reliability of the pumping station as a whole and of its individual components must be determined. Some typical factors and components which may be included in a reliability and availability evaluation are listed as follows:

- water demand and emergency storage
- Preventative maintenance
- wear/life expectancy of subcomponent
- repair
- power transmission
- parallel operation and stand-by equipment
- emergency power
- surge protection
- pumps

- valves
- piping
- motors
- controls
- time factors

Reliability evaluation should be part of the planning and design process to make certain that a reliable and cost effective design alternative will be implemented. Two independent power supplies might be considered for the most critical main pumping stations. Existing power supplies will be investigated to determine historically the number of power outages and length of outages occurring over a pumping period. Where direct connection of an engine drive to a pump is considered, a cost analysis will be made comparing engine generated electric power versus direct engine connection.

5.10 Pump Hydraulics

The location and required capacity of a potable water pumping installation will be determined from a hydraulic network analysis of the distribution system.

5.10.1 Pump and pumping

Pumps are mechanical devices for converting other forms of energy to hydraulic energy. When interposed in a pipe, they add energy to the liquid passing through the pipes. The added energy is almost always pressure energy. Pumps, like motor vehicles, are not individually designed for public works projects, except for very large and unusual installations. Rather, they are selected from predesigned and manufactured units readily available for a wide range of applications. Economical selection requires that attention be given to:

- the normal pumping rate and the minimum and maximum rates that the pump will ever be called on to deliver;
- the total head capacity to meet flow requirements;
- suction head, or lift;
- pump characteristics, including speed, number of pumps, power source, and other spatial and environmental requirements; and
- the nature of the liquid to be pumped.

Rotodynamic and displacement pumps are the two types most often encountered in environmental engineering. Rotodynamic pumps impart kinetic

The static discharge head is the vertical distance from the pump centerline to the free surface on the discharge line. Thus, the net discharge head is the sum of the static discharge head and the friction head losses. The total head H is given by

$$H = h_d - h_s \tag{5.1}$$

where h_d is the net discharge head and h_s is the net static head.

In pumping liquids, the pressure anywhere in the suction line should remain higher than the vapor pressure of the liquid in order to avoid air binding, priming loss, and cavitation. The energy available for moving liquid through the suction line to the impeller, known as the net positive suction head (NPSH), is the sum of the net suction head and any pressure existing in the suction supply line, less the vapor pressure of the liquid at the pumping temperature. Any vacuum is to be treated as a negative pressure. The useful work done by a pump is the product of the weight of liquid pumped and the head developed by the pump. The power, or work time, required is the working horsepower (WHP). Thus

$$WHP = QH\omega \tag{5.2}$$

Where Q = pump discharge, H = total head, and ω = specific weight.

For water at 68°F, Q in gallons per minute, and H in feet,

$$WHP = \frac{QH}{3960}$$

For water at 68°F, $\omega = 1000 \text{ kg/s}$, Q in m^3/s , and H in m,

$$WHP = \frac{Q\omega H}{75}$$

The brake horsepower (BHP) is the total power required to drive a pump. The pump efficiency E is the ratio of the water horsepower to the brake horsepower, or

$$E = \frac{WHP}{BHP} \times 100 \tag{5.3}$$

For water at 68°F

$$BHP = \frac{100QH}{3960E}$$

BHP for other water temperatures and other liquids can be determined by correcting for the change in specific weight. The temperature correction for natural water is usually negligible.

The total head developed by a pump, the power required driving it and the resulting efficiency vary with the capacity. The interrelations of head, power, efficiency, and capacity are shown in pump curve (see also article 5.4) in the Figure 5.12:

- The head capacity curve $H-Q$ shows the relationship between capacity and total head. Pumps are often classified according to the shape of the head capacity curve.
- The efficiency curve $E-Q$ shows the relationship between capacity and efficiency.
- The power curve $P-Q$ shows the relationship between capacity and power input.

Head loss in a pumping system increases with increasing flow through the system, and can be shown graphically as a system head curve like that in Figure 5.13. The system head loss for any flow rate is the sum of friction head loss and the total static head in the system. Static head is present whether the pump is operating or not, and is plotted as the lower portion of the system head curve. The friction head loss can be calculated using the following formula

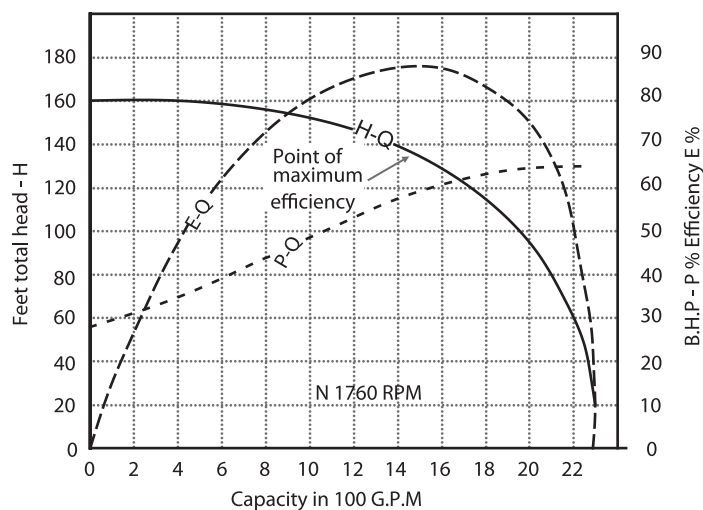


Figure 5.12: Pump characteristic curves

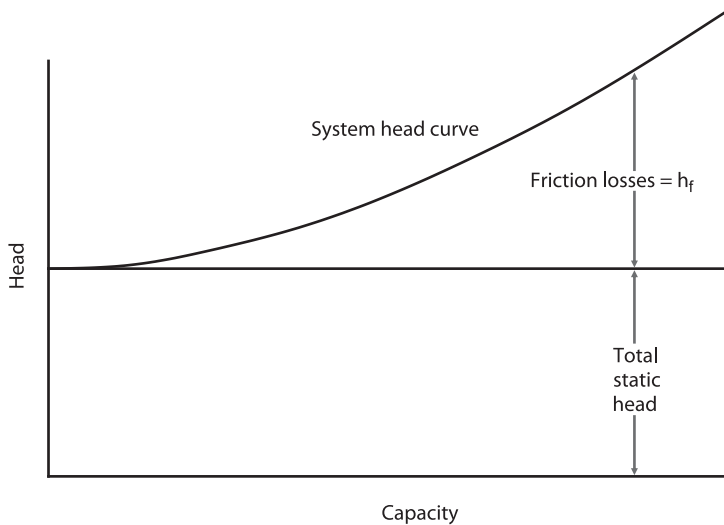


Figure 5.13: System head curve

$$h_f = \frac{4flv^2}{2gd}$$

where,

f = friction factor

l = Total length of the rising main

v = velocity of water

d = diameter of pipe

The system piping and fittings may be converted to one equivalent pipe, and head losses for several flow rates may be determined readily from the Hazen-Williams nomograph. Alternatively, the head loss through all pipes and fittings may be computed for a single flow rate, and losses for other flow rates may be determined from the relationship

$$\frac{Q_1}{Q_2} = \left[\frac{h_{L_1}}{h_{L_2}} \right]^{0.54} \quad 5.3$$

For zero discharge, total head is equal to the total static head. This point plus several computed points will suffice to plot the curve. Static head in a system will vary as tanks and reservoirs are filled or drawn down. In such cases, system curves may readily be constructed for minimum and maximum heads, thereby enabling

prediction of system pumping capacity for the entire range of possible static head conditions. For elaborate installations, an economic analysis of the trade off between pumping and piping costs may be justified. For comparatively short pipelines, however, friction losses should not be more than about 20% of the static head.

5.10.2 Operating head and discharge

The usual design condition is that a system will be given and the proper pump must be selected. The intersection of a pump head capacity curve with a system curve on which it is superimposed is the operating point. Figure 5.14 is an example. The operating point is the discharge and head at which a given system and given pump will operate. Operating efficiency and power requirements will also be located by this superposition. A pump that has an operating point at or near its peak efficiency should be selected.

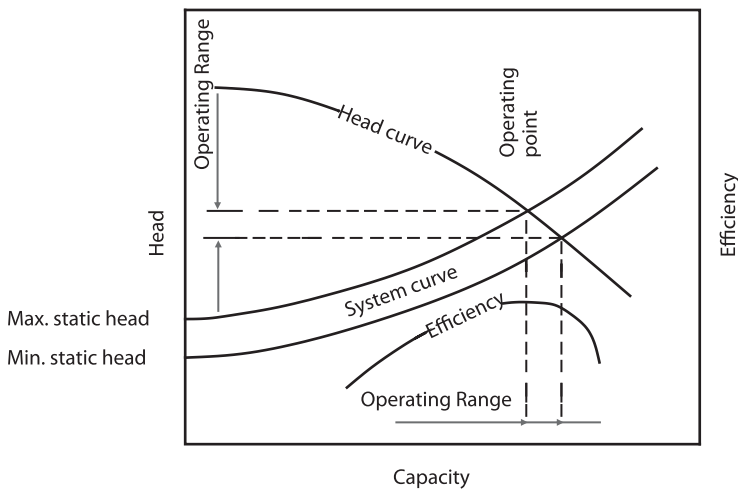


Figure 5.14: Determination of pump operation point

Placing two identical pumps in series doubles the pumping head. Conversely, two identical pumps in parallel will double the pumping capacity (Figure 5.15). Doubling the pumping head or capacity will not double the system capacity, however Figure 5.16 shows that the added capacity for two pumps in parallel results in a greater friction head loss and that the system capacity is not doubled. Similarly, pumping in series will double neither the system head nor the discharge.

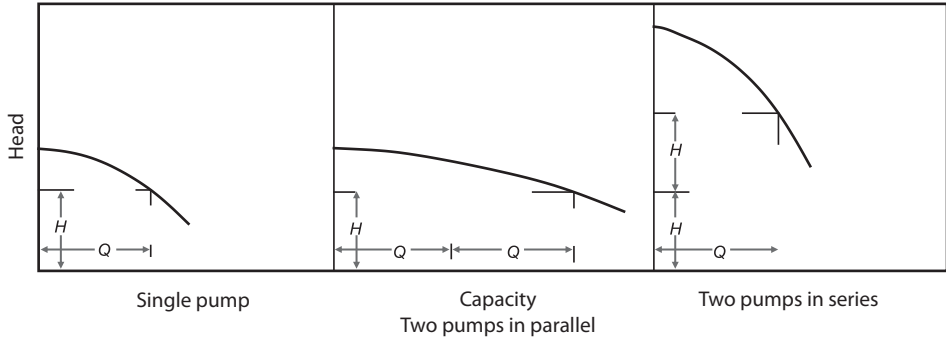


Figure 5.15: Pump characteristic curves with two pumps in parallel and in series.

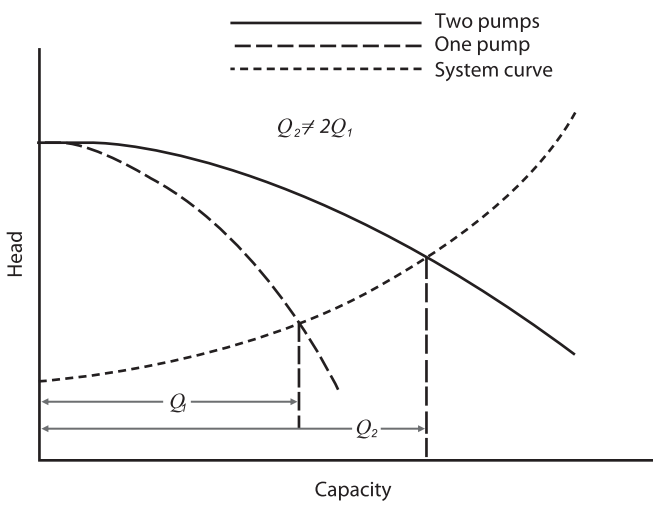


Figure 5.16: System head curve with two pumps in parallel

5.11 Economical Diameter of Pumping Main

The economical diameter is a particular size of the pumping or rising main which while passing a given discharge of water, makes the total annual expense to be a minimum (Figure 5.17). The total annual' expense is the sum of the annual operation, interest and depreciation of the main and the annual cost of pumping. The utility of finding economical diameter can be understood in a simple way as follows.

If the size of the main is less than its economical diameter, the cost of the main by itself would no doubt be less, but frictional loss of head will be increased making

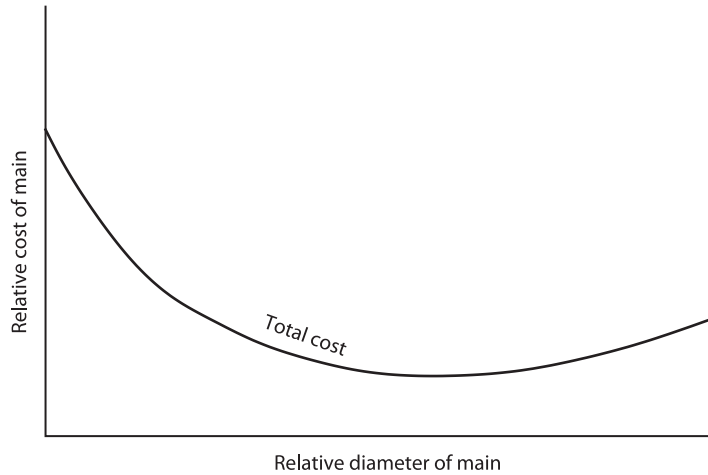


Figure 5.17: Variation curve of diameter of main and its cost

cost of pumping higher. On the other hand, if the size of the main is more than its economical diameter, costs of pumping and of pumping machinery will be less but the cost of conduit will rise.

An empirical formula due to Lea commonly used in practice gives

$$D = 0.969 \text{ to } 1.222 Q^{0.5}$$

where,

D = Economical diameter in m.

Q = Quantity pumped in m^3/sec

This gives the velocity of flow as lying between 0.82 and 1.35 m/sec.

Example 5.1: It is required to pump water at the rate of 6.750 gpm from a reservoir whose surface is at an elevation of 180 ft to a tank whose bottom is at an elevation of 372 ft, The pump is placed at an elevation of 192 ft, the diameter of the suction pipe is 30 inch, the length of the pipe from the pump to the tank is 290 ft, and the estimated size of this pipe is 24 inch. The sum of the minor head losses in the suction and discharge pipe may be taken as 1.5 ft, if the maximum depth of water in the tank is to be 25 ft, what is the required horsepower of a pump for which the overall efficiency is 67 percent?

Assume head loss due to friction in 290 ft + 1.5 ft

Neglect all other head losses.

Solution:

Elevation of water surface in the tank = $372 + 25 = 397$ ft,

Discharge lift or the vertical distance from the center of the pump to that surface = $397 - 192 = 205$ ft.

Suction lift or the vertical distance from the water surface in the reservoir to the centre of the pump = $192 - 180 = 12$ ft,

Since the pump is above the water surface this lift is positive.

$$\text{Total head } H = 205 + 12 + 1.5 + 1.5 = 220 \text{ ft}$$

$$P = \frac{HQ}{3960} = \frac{220 \times 6750}{3960} = 375 \text{ (WHP)}$$

$$P = \frac{375}{0.67} = 560 \text{ (BHP)}$$

Example 5.2: Design a suitable set of pumping unit to deliver 450.00 gpm from an intake well of a river bank to the treatment plant. Total length of rising main from the intake well to the treatment plant is 800 ft. and the static head is 60 ft. Design also the cast iron main.

Assume: Velocity of water = 12 fps

Friction factor = 0.0075

Efficiency = 70%

Solution:

$$Q = 450000 \div 60 = 7200 \text{ gpm}$$

$$\text{Again } Q = \frac{450000}{60 \times 60 \times 6.24} = 20 \text{ cfs}$$

$$\text{Cross sectional area} = \frac{20}{12} = 1.667 \text{ sqft}$$

Considering d as diameter of the unit,

$$\frac{\pi d^2}{4} = 1.667$$

$$d = \sqrt{\frac{1.667 \times 4}{\pi}} = 1.5 \text{ ft} = 18 \text{ inch}$$

$$\text{Frictional head loss, } h_f = \frac{4fv^2}{2gd} = \frac{4 \times 0.0075 \times 800 \times (12)^2}{2 \times 32.2 \times 1.2} = 36 \text{ ft}$$

$$\text{Velocity head, } h = \frac{v^2}{2g} = (12)^2 / (2 \times 32.2) = 2.24 \text{ ft.}$$

$$\text{Total head, } H = h + h + h = 60 + 36 + 2.24 = 98.24 \text{ ft}$$

$$P = \frac{HQ}{3960} = \frac{9824 \times 7500}{3960} = 188 \text{ (WHP)}$$

$$P = \frac{180}{0.70} = 265 \text{ (BHP).}$$

Example 5.3: Water is supplied from an impounding reservoir 30 miles away to a service reservoir near the town. A cast iron main is to be designed to supply 425 mgd. Loss of head due to friction in the pipe is estimated to be 300 ft. All other head losses are neglected. Water size cast iron pipe would you use?

Solution:

$$h_f = \frac{4 \times 0.0075 \times (30 \times 5280) \times v^2}{2 \times 32.2 \times d} = 300$$

$$\frac{v^2}{d} = 4.06 \quad \therefore v^2 = 4.06 \times d \quad 5.5$$

$$\text{Again, } Q = 425 \text{ mgd} = 425 \times 1.547 = 787 \text{ cfs}$$

$$Q = av = \frac{\pi d^2}{4} \times v \therefore v = \frac{4Q}{\pi d^2}$$

$$\therefore v^2 = \frac{16Q^2}{(\pi d)^2} \quad 5.6$$

Substituting the value of v^2 from Eq. 5.5 to Eq. 5.6

$$\frac{16Q^2}{\pi^2 d^5} = 4.07$$

$$d^5 = \frac{16 \times (787)^2}{\pi^2 \times 4.07}$$

$$\therefore d = 11.98 \approx 12 \text{ ft Ans.}$$

Example 5.4: Design the transmission main and the pumping unit from the following data:

Water supply rate = 40 gpcd

Estimated population = 85000

Ground R.L = at the pump house = 102.50 ft

Treatment plant R.L = 193.00 ft

Velocity through pipe = 8 fps

Pumping time = 10 hrs. daily

Total length of pipe = 3500 ft

Friction factor = .01

Efficiency = 65%

Solution:

$$\text{Total water required} = 40 \times 85000 = 3400000 \text{ gpd}$$

$$= \frac{3400000}{6.24} = 5.45 \times 10^6 \text{ cuft / day}$$

$$\text{Pumping rate} = \frac{5.45 \times 10^6}{10} = 5.45 \times 10^4 \text{ cuft / hr}$$

$$= \frac{5.45 \times 10^4}{60 \times 60} = 15.15 \text{ cfs}$$

$$Q = \frac{\pi d^2}{4} \times v = 15.15$$

$$\therefore d = \sqrt{\frac{4 \times 15.15}{\pi \times 8}} = 1.56 \text{ ft}$$

Use a 21 inch diameter pipe, $d = 1.56 \text{ ft}$

Static head = $193,00 - 102,50 = 90.50$

$$\text{Friction head} = \frac{4 \times 0.01 \times 3500 \times 8^2}{2 \times 32.2 \times 1.75} = 89 \text{ ft}$$

$$\text{Velocity head} = \frac{8^2}{2 \times 32.2} = 1.0 \text{ ft}$$

$$\text{Total head, } H = 90.5 + 80.0 + 1.0 = 171.4 \text{ ft}$$

$$\text{Discharge, } Q = \frac{3400000}{10 \times 60} = 5667 \text{ gpm}$$

$$\therefore P = \frac{HQ}{3960} = \frac{171.5 \times 5667}{3960} = 246 \text{ (WHP)}$$

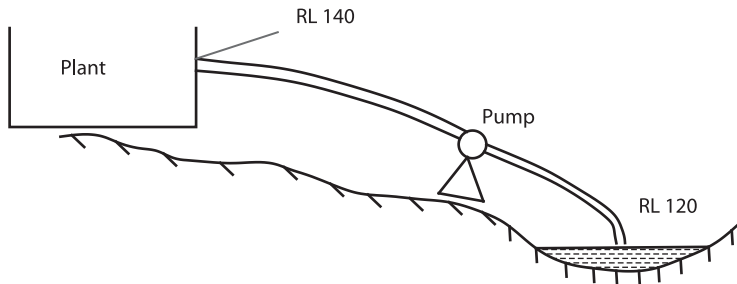
$$\therefore P = \frac{P}{E} = \frac{246}{.65} = 380 \text{ (BHP) Ans.}$$

Example 5.5:

Find the capacity for a pumping station for the following data:-

- Population to be served 2 lacs,
- Daily water demand 135 lpcd,
- Water level in the river RL 120m,
- Pumping hour 24 hrs/day,
- To be pumped to a treatment plant of RL 140m,
- Rising main dia 90cm with friction loss 2m,
- Efficiency of pumps and driving motors 70% and 90%

Solution:



$$\text{Total water demand} = 2 \times 10^5 \times 135 \text{ L/day}$$

$$= \frac{2 \times 10^5 \times 135}{10^3 \times 24 \times 3600}$$

$$= 0.312 \text{ m}^3/\text{s}$$

$$\text{Water to be lifted} = 140 - 120 = 20 \text{ m}$$

$$\text{Head loss} = 2 \text{ m}$$

Total head against which water is lifted = 20+2=22m

$$\text{W.H.P} = \frac{Q \omega H}{75} = \frac{0.312 \times 1000 \times 22}{75} = 83 \text{ h.p.}$$

$$\text{B.H.P} = \frac{83}{0.9 \times 0.7} = 132 \text{ hp}$$

Example 5.6: For water supply of a town, water is pumped from a river 3km away into a reservoir. The maximum level difference of river and reservoir is 20m. Town population is 50,000 and per capita water demand is 120 lpcd. If the pumps operate for a total of 8hrs and pump efficiency is 80%, calculate pump B.H.P Assume friction factor as 0.0075 and pipe velocity as 2m/s and maximum daily demand as 1.5 times avg. daily demand.

Solution:

$$L = 3\text{km} = 3000\text{m},$$

$$Q = \frac{50,000 \times 120}{1000} = 6000\text{m}^3/\text{d}$$

$$\text{Peak} = 1.5 \times 6000 = 9000\text{m}^3/\text{d}$$

Pumping has to be done 8hrs/day, so pumping rate

$$= 3 \times 9000\text{m}^3/\text{d}$$

$$= \frac{3 \times 9000}{24 \times 3600} = 0.31\text{m}^3/\text{s}$$

Velocity of flow = 2m/s

$$\text{Pipe area, } A = \frac{0.31}{2} = 0.1505\text{m}^2$$

$$\Rightarrow \frac{\pi}{4} d^2 = 0.1505$$

$$\therefore d = 0.436\text{m}$$

Provide actual d=0.5m

$$\text{Actual velocity} = \frac{0.31}{\frac{\pi}{4} \times 0.5^2}$$

$$= 1.58 \text{ m/s}$$

$$\text{Friction head} = \frac{4flv^2}{2gd}$$

$$= \frac{4 \times 0.0075 \times 3000 \times 1.58^2}{2 \times 9.81 \times 0.5}$$

$$= 22.89 \text{ m}$$

$$\text{Effective head} = 22.89 + 20 = 42.89$$

$$\text{WHP} = \frac{0.31 \times 1000 \times 42.89}{75} = 177 \text{ H.P}$$

$$\text{BHP} = \frac{177}{0.8} = 222 \text{ H.P}$$

5.12 Conclusion

In this chapter, the detail of mechanism of pumping water is discussed. From this discussion, it is evident that selection of pump is critical for each type of pump to be selected for specific purpose. And each type of pump has its own pump curve, which should be provided by the respective pump manufacturer. Moreover, the efficiency of pump is highly dependable on the losses due to friction and other minor reasons.

The next chapter describes the water treatment technologies for drinking purpose.

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