4. PUPMS AND PUMPING STATIONS

4.1 Purpose and types of pumps

Pump is a mechanical machine. It is used for lifting water or any fluid to a higher elevations or at higher pressures. The operation of lifting water or any fluid is called pumping. Pumping may be adopted for following purposes in a water supply scheme.

1. To increase the water pressure at certain points in the distribution system.
2. To lift treated water to elevated storage tanks, so that it may flow automatically under gravity into distribution system.
3. To lift raw river water or lake water to carry it to treatment plant.
4. To lift water available from wells to an elevated storage tank in stages.
5. To pump water directly into the distribution system.
6. To take out water from basins, sumps, tanks etc.

Types of pumps

(A) Classification based on mechanical principle of operation

(i) Displacement pumps
(ii) Centrifugal pumps
(iii) Air lift pumps
(iv) Miscellaneous pumps

(B) Classification based on type of power required

(i) Steam engine pumps
(ii) Diesel engine pumps
(iii) Electrically driven pumps

(C) Classification based on the type of service called for

(i) Low lift pumps
(ii) High lift pumps
(iii) Deep well pumps
(iv) Booster pumps

Selection of a particular type of pump

- Capacity of pump
- Number of pump units required
- Suction conditions
- Lift (total head)
- Discharge conditions and variations in load
- Floor space requirement
- Flexibility of operation
- Starting and priming characteristics

- Type of drive required
- Initial costs and running costs.

4.2. Centrifugal pumps

Centrifugal Pumps are rotodynamic pumps which convert Mechanical energy into Hydraulic energy by centripetal force on the liquid. Figure 4.1 shows a typical centrifugal pump. Centrifugal pumps are classified in to three categories: Radial flow, Mixed flow, and Axial flow.

Radial Flow - a centrifugal pump in which the pressure is developed wholly by centrifugal force.

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

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

The discharge of a centrifugal pump is fixed by the design of the impeller and by the speed of rotation. Typical operating curves for a centrifugal pump are shown in Fig. 4.5.

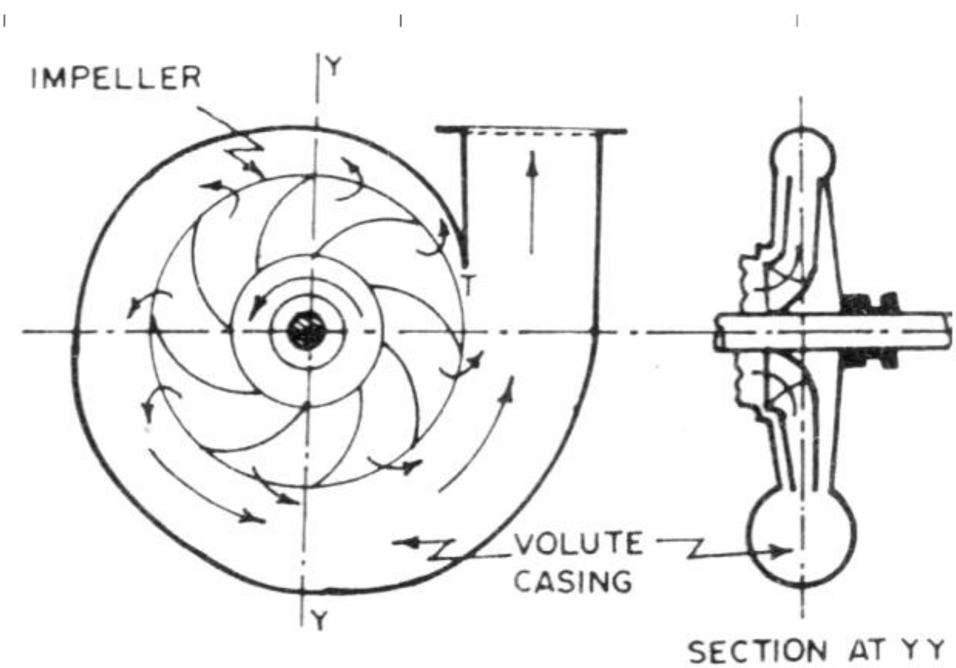
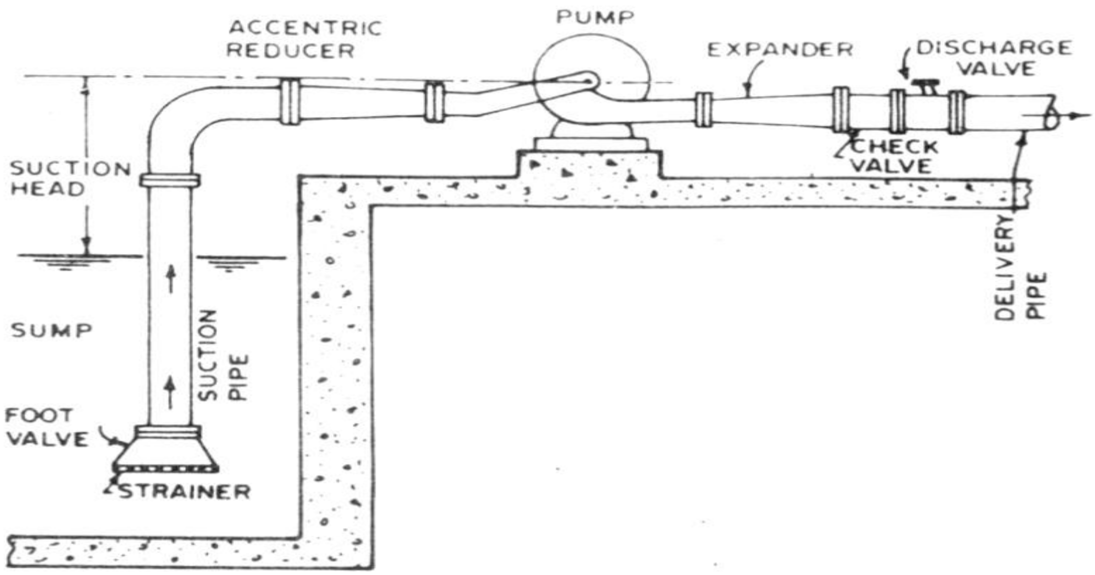


Figure. 4.1. Centrifugal pumps (Volute pump)

Centrifugal pump installation



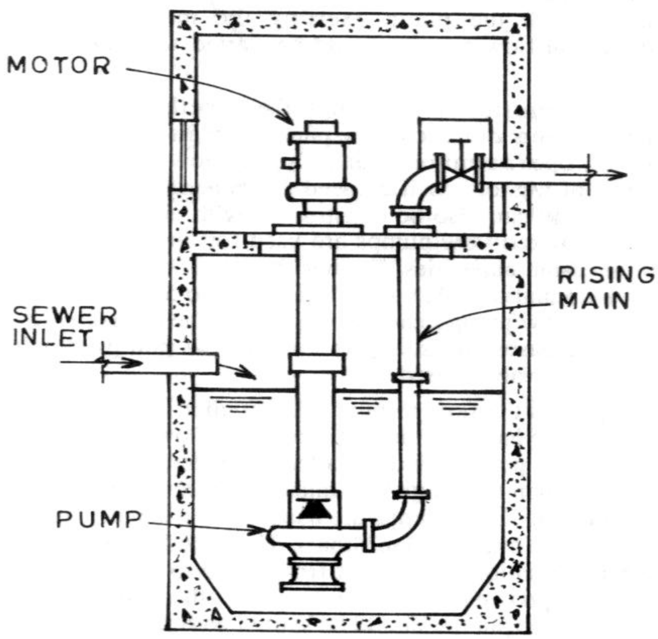


Figure 4.2. Vertical shaft centrifugal pump installed in a wet well

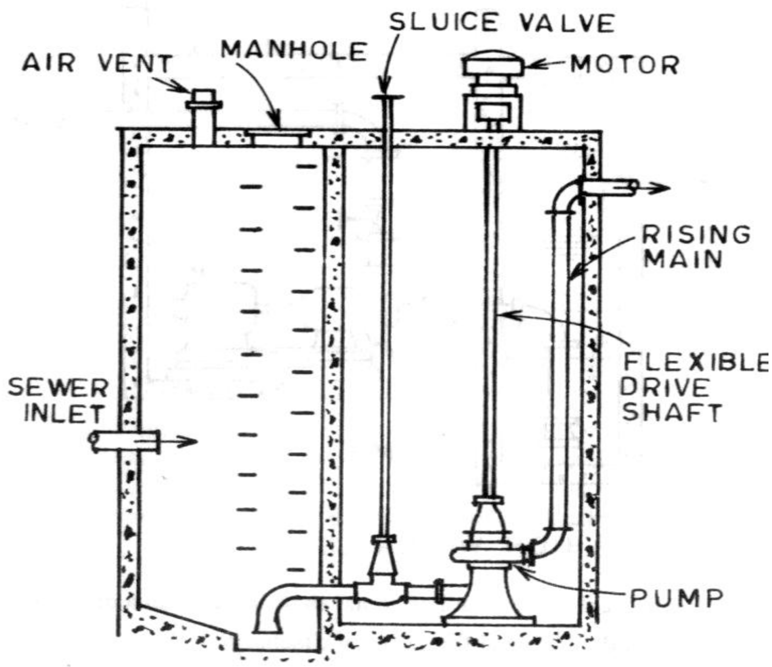


Figure 4.3. Centrifugal pump with vertical shaft installed in a dry well or dry pit

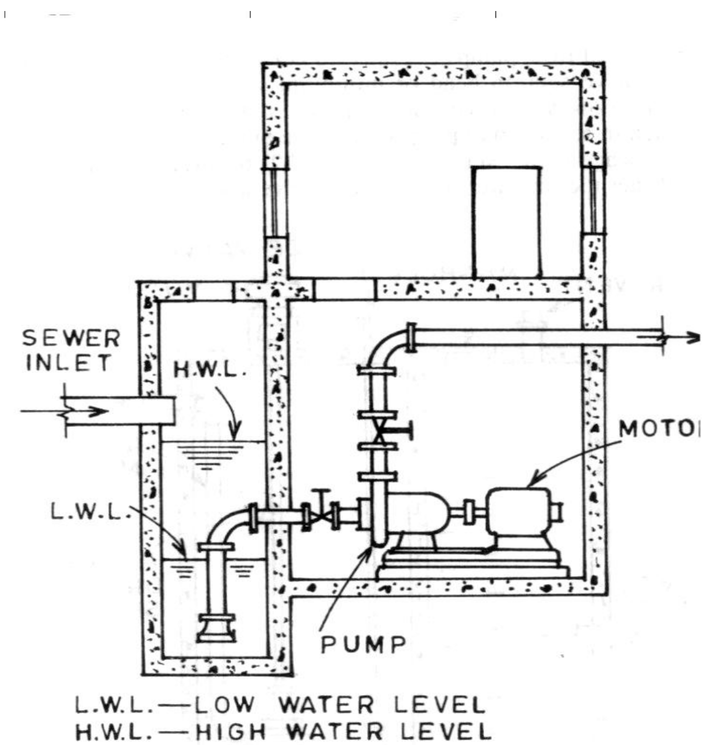


Figure 4.4. Centrifugal pump with horizontal shaft installed in a dry well or dry pit.

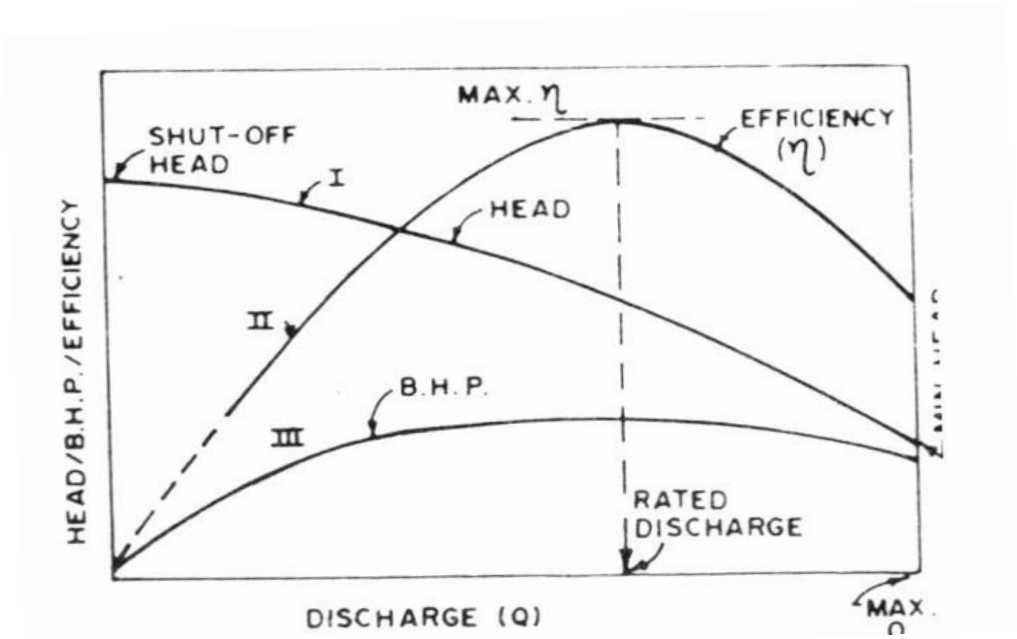


Figure 4.5. Characteristics of centrifugal pump

4.2.1 Pumping terms

The key performance parameters of centrifugal pumps are capacity, head, BHP (Brake horse power), BEP (Best efficiency point) and specific speed. The pump curves provide the operating window within which these parameters can be varied for satisfactory pump operation. The following parameters or terms are discussed in detail in this section.

Head

A Centrifugal pump imparts velocity to a liquid. This velocity energy is then transformed largely into pressure energy as the liquid leaves the pump. Therefore, the head developed is approximately equal to the velocity energy at the periphery of the impeller This relationship is expressed by the following well-known formula:

$$H = \frac{v^2}{2g}$$

Where H = Total head developed in meter.

v = Velocity at periphery of impeller in meter per sec.

g = 9.81 m/Sec^2

We can predict the approximate head of any centrifugal pump by calculating the peripheral velocity of the impeller and substituting into the above formula. A handy formula for peripheral velocity is:

$$v = \frac{RPM \times D}{60}$$

D = Impeller diameter in meter

v = Velocity in m/sec

SUCTION LIFT exists when the source of supply is below the center line of the pump. Thus the STATIC SUCTION LIFT is the vertical distance in meter from the centerline of the pump to the free level of the liquid to be pumped.

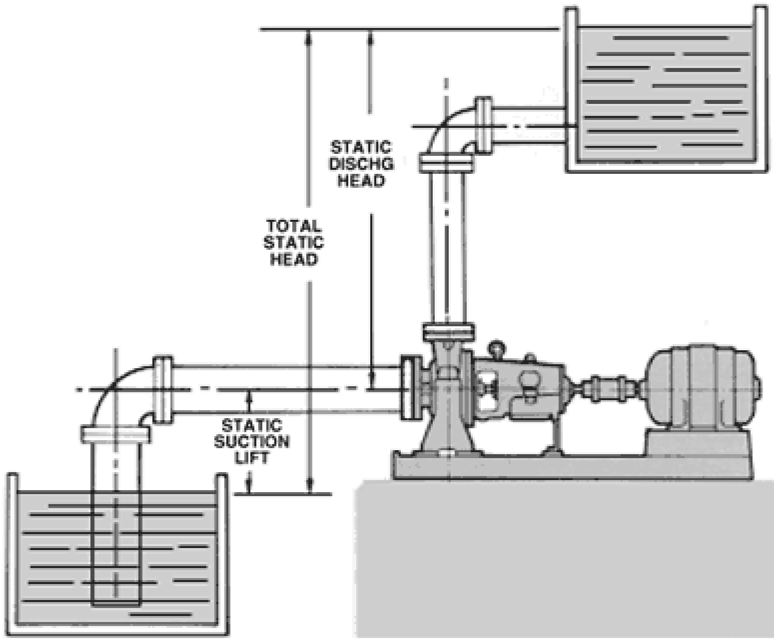


Fig.4.6 Suction Lift. Showing Static Heads in a Pumping System Where the Pump is Located Above the Suction Tank. (Static Suction Head)

SUCTION HEAD exists when the source of supply is above the centerline of the pump. Thus the STATIC SUCTION HEAD is the vertical distance in meter from the centerline of the pump to the free level of the liquid to be pumped.

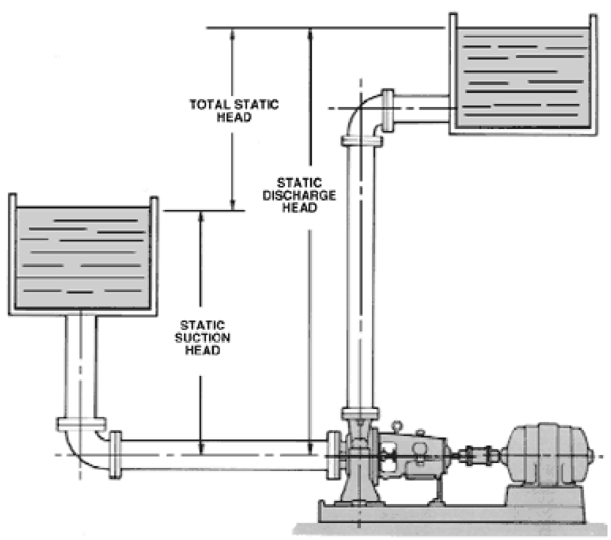


Fig. 4.7 Suction Head. Showing Static Heads in a Pumping System Where the Pump is Located Below the Suction Tank. (Static Suction Head)

STATIC DISCHARGE HEAD is the vertical distance in meter between the pump centerline and the point of free discharge or the surface of the liquid in the discharge tank.

TOTAL STATIC HEAD is the vertical distance in meter between the free level of the source of supply and the point of free discharge or the free surface of the discharge liquid.

FRICTION HEAD (hf) is the head required to overcome the resistance to flow in the pipe and fittings. It is dependent upon the size, condition and type of pipe, number and type of pipe fittings, flow rate, and nature of the liquid.

VELOCITY HEAD (hv) is the energy of a liquid as a result of its motion at some velocity V. It is the equivalent head in meter through which the water would have to fall to acquire the same velocity, or in other words, the head necessary to accelerate the water. Velocity head can be calculated from the following formula:

$$h_v = \frac{V^2}{2g}$$

The velocity head is usually insignificant and can be ignored in most high head systems. However, it can be a large factor and must be considered in low head systems.

PRESSURE HEAD must be considered when a pumping system either begins or terminates in a tank which is under some pressure other than atmospheric. The pressure in such a tank must first be converted to meter of liquid. A vacuum in the suction tank or a positive pressure in the discharge tank must be added to the system head, whereas a positive pressure in the suction tank or vacuum in the discharge tank would be subtracted. The following is a handy formula for converting mm of mercury vacuum into meter of liquid.

$$Vacuum, meter\ of\ liquid = \frac{Vacuum, mm\,of\ Hg \times 1.13}{Sp.Gr.}$$

The above forms of head, namely static, friction, velocity, and pressure, are combined to make up the total system head at any particular flow rate. Following are definitions of these combined or "Dynamic" head terms as they apply to the pump.

TOTAL DYNAMIC SUCTION LIFT (hs) is the static suction lift minus the velocity head at the pump suction flange plus the total friction head in the suction line. The total dynamic suction lift, as determined on pump test, is the reading of a gauge on the suction flange, converted to meter of liquid and corrected to the pump centerline*, minus the velocity head at the point of gauge attachment.

TOTAL DYNAMIC SUCTION HEAD (hs) is the static suction head plus the velocity head at the pump suction flange minus the total friction head in the suction line. The total dynamic suction head, as determined on pump test, is the reading of the gauge on the suction flange, converted to meter of liquid and corrected to the pump centerline*, plus the velocity head at the point of gauge attachment.

TOTAL DYNAMIC DISCHARGE HEAD (hd) is the static discharge head plus the velocity head at the pump discharge flange plus the total friction head in the discharge line. The total dynamic discharge head, as determined on pump test, is the reading of a gauge at the discharge flange, converted to meter of liquid and corrected to the pump centerline*, plus the velocity head at the point of gauge attachment.

TOTAL HEAD (H) or TOTAL Dynamic HEAD (TDH) is the total dynamic discharge head minus the total dynamic suction head or

TDH = hd + h_s (with a suction lift)
TDH = hd - h_s (with a suction head

Capacity

Capacity (Q) is normally expressed in liter per minute (lpm). Since liquids are essentially incompressible, there is a direct relationship between the capacity in a pipe and the velocity of flow. This relationship is as follows:

$$Q = 60 \times A \times V \; or \; V = \frac{Q}{60 \times A}$$

Where
A = area of pipe or conduit in square meter.
V = velocity of flow in meter per second.
Q = Capacity in liter per minute

NOTE: On vertical pumps the correction should be made to the eye of the suction or lowest impeller.

Power and Efficiency

The work performed by a pump is a function of the total head and the weight of the liquid pumped in a given time period. The pump capacity in lpm and the liquid specific gravity are normally used in the formulas rather than the actual weight of the liquid pumped.

Let H be the total head (TDH) against which water is to be lifted by the pump. Suppose pump lifts W kg water.

Therefore work done by the pump = W x H m-kg/sec = γ x Q x H m-kg/sec

Where γ = density of liquid in kg/m^3 (1000 kg/m^3 for water)

Q = water discharge in m^3/sec

Pump input or brake horsepower (BHP) is the actual horsepower delivered to the pump shaft. Pump output or hydraulic horsepower (WHP) is the liquid horsepower delivered by the pump. These two terms are defined by the following formulas.

$$WHP = \frac{Q \times TDH \times Sp.\ Gr.}{75}$$

$$BHP = \frac{Q \times TDH \times Sp.Gr.}{75 \times Pump\ Efficiency}$$

The brake horsepower or input to a pump is greater than the hydraulic horsepower or output due to the mechanical and hydraulic losses incurred in the pump. Therefore the pump efficiency is the ratio of these two values.

$$Pump\ Efficiency = \frac{WHP}{BHP} = \frac{Q \times TDH \times Sp.\ Gr.}{75 \times BHP}$$

Specific Speed and Pump Type

Specific speed (N_s) is a non-dimensional design index used to classify pump impellers as to their type and proportions. It is defined as the speed in revolutions per minute at which a geometrically similar impeller would operate if it were of such a size as to deliver one liter per minute against one meter head.

The understanding of this definition is of design engineering significance only, however, and specific speed should be thought of only as an index used to predict certain pump characteristics. The following formula is used to determine specific speed:

$$Ns = \frac{N\sqrt{Q}}{H^{3/4}}$$

Where

N = Pump speed in RPM

Q = Capacity in lpm at the best efficiency point

H = Total head per stage at the best efficiency point

The specific speed determines the general shape or class of the impeller as depicted in Fig. 3. As the specific speed increases, the ratio of the impeller outlet diameter, D2, to the inlet or eye diameter, Di, decreases. This ratio becomes 1.0 for a true axial flow impeller.

Radial flow impellers develop head principally through centrifugal force. Pumps of higher specific speeds develop head partly by centrifugal force and partly by axial force. A higher specific speed indicates a pump design with head generation more by axial forces and less by centrifugal forces. An axial flow or propeller pump with a specific speed of 10,000 or greater generates it's head exclusively through axial forces.

Radial impellers are generally low flow high head designs whereas axial flow impellers are high flow low head designs.

Values of Specific Speed, N_s

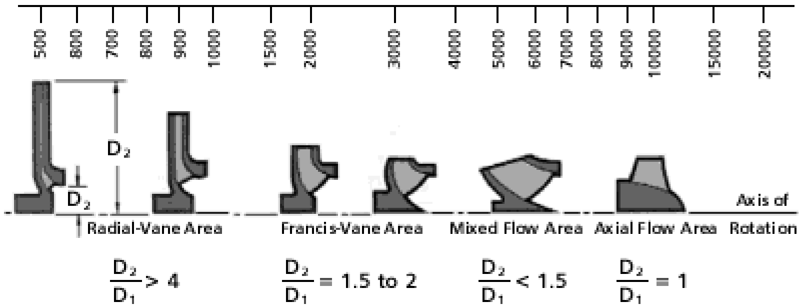


Fig.4.8 Impeller Design vs Specific Speed

Affinity Laws for a Centrifugal Pump Application

The operating conditions for a centrifugal pump may be estimated by using the Affinity Laws. The Affinity Laws are a group of relationships that may be used for estimating Flow, Head Condition and Horsepower requirements of a centrifugal pump when the speed of the pump is changed from a known speed or the specific speed, to some other value. The plot that follows governs the operating relationships for all centrifugal pumps. They apply to all types of centrifugal and axial flow pumps. They are as follows:

1. With impeller diameter D held constant:

   Where: Q = Capacity, GPM
   H = Total Head, Meter
   BHP = Brake Horsepower
   N = Pump Speed, RPM

   A. $$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$$

   B. $$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

   C. $$\frac{BHP_1}{BHP_2} = \left(\frac{N_1}{N_2}\right)^3$$

2. With speed N held constant:

   A. $$\frac{Q_1}{Q_2} = \frac{D_1}{D_2}$$

   B. $$\frac{H_1}{H_2} = \left(\frac{D_1}{D_2}\right)^2$$

   C. $$\frac{BHP_1}{BHP_2} = \left(\frac{D_1}{D_2}\right)^3$$

When the performance (Q_1, H_1, & BHP_1) is known at some particular speed (N_1) or diameter (D_1), the formulas can be used to estimate the performance (Q_2, H_2, & BHP_2) at some other speed (N_2) or diameter (D_2). The efficiency remains nearly constant for speed changes and for small changes in impeller diameter.

4.2.2 Pump Characteristic Curves

The performance of a centrifugal pump can be shown graphically on a characteristic curve. A typical characteristic curve shows the total dynamic head, brake horsepower, efficiency, and net positive Suction head all plotted over the capacity range of the pump.

Figure 4.9 shows non-dimensional curves which indicate the general shape of the characteristic curves for the various types of pumps. It shows the head, brake horsepower, and efficiency plotted as a percent of their values at the design or best efficiency point of the pump. It shows that the head curve for a radial flow pump is relatively flat and that the head decreases gradually as the flow increases. Note that the brake horsepower increases gradually over the flow range with the maximum normally at the point of maximum flow.

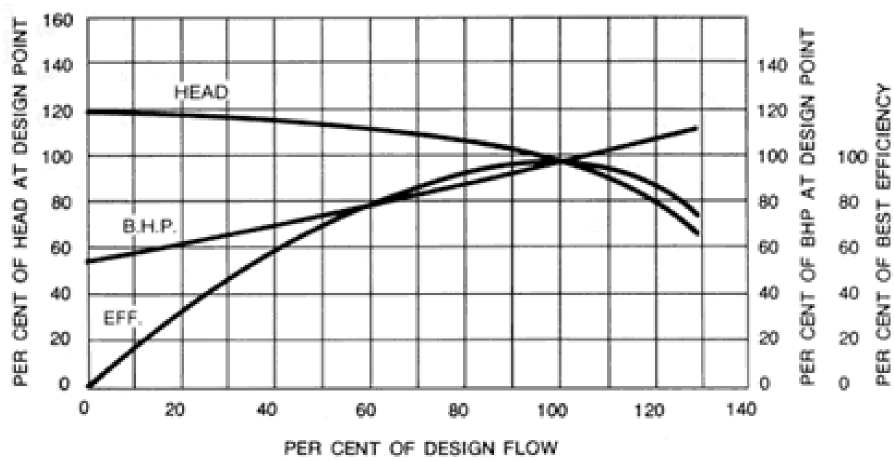
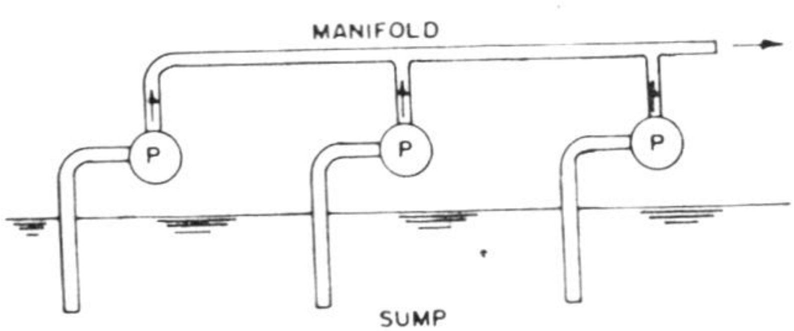


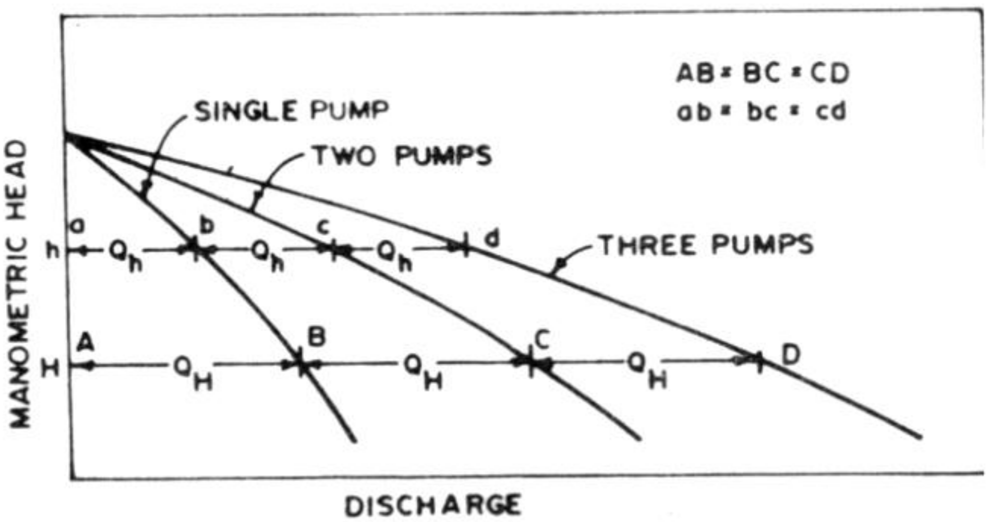
Fig. 4.9 Radial Flow Pump

Pumps operating in parallel

Pumps may be operated in parallel connection (See Fig below) for a purpose of increasing the total discharge. In this case the pumps connected should deliver the same head. The total system flow rate is equal to the sum of the flow rates or contributions from each pump at the system head or discharge pressure.

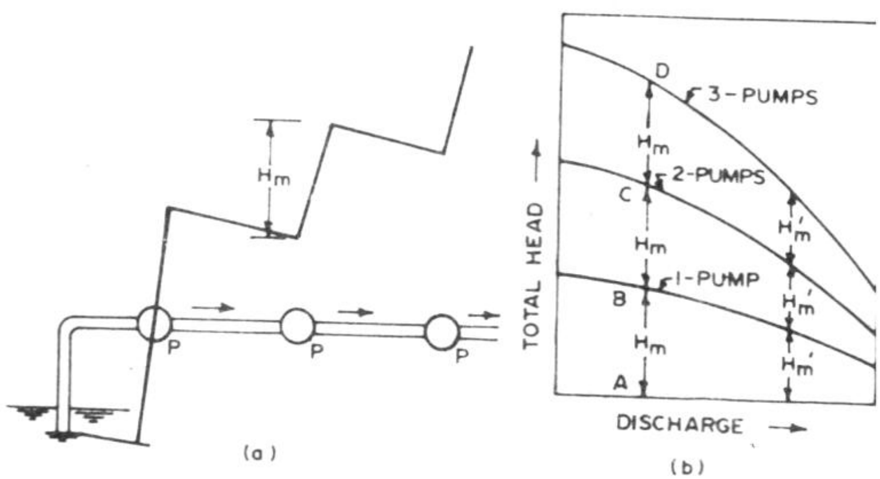


Characteristic curves for identical pumps in parallel



Series operation of pumps

To increase the system head pumps can be operated in series. In this case the pumps are operated at the same discharge rate and the system head is the sum of the individual pumps contribution.



Computation of total head of pumping

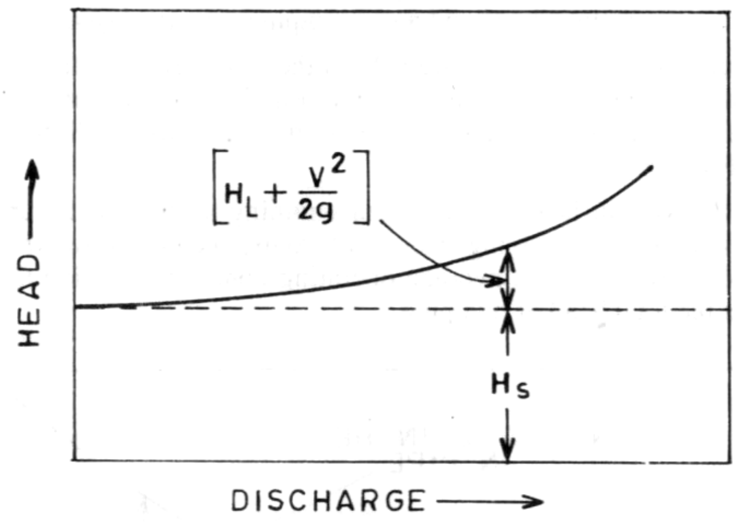
- Static head H_s is the difference between the level of liquid in the suction sump i.e., the wet well and the level of liquid in the high level of the storage tank to which the water is delivered by the pump.
- Velocity head ($v^2/2g$) at the point of discharge

(iii) Head loss (H_L)

Therefore, $H = H_s + H_L + v^2/2g$

System-head curve for a pumping system

For a specified impeller diameter and speed, a centrifugal pump has a fixed and predictable performance curve. The point where the pump operates on its curve is dependent upon the characteristics of the system in which it is operating, commonly called the System Head Curve or, the relationship between flow and hydraulic losses in a system. This representation is in a graphic form and, since friction losses vary as a square of the flow rate, the system curve is parabolic in shape.



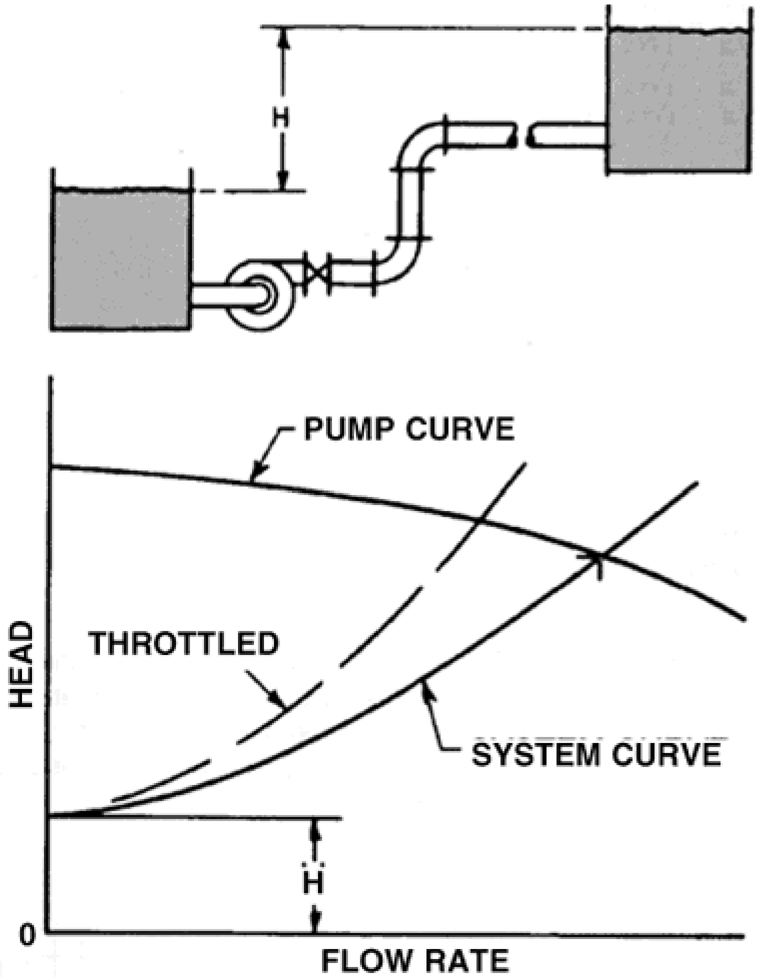


Figure 4.10. System-head curves with change in pipe sizes

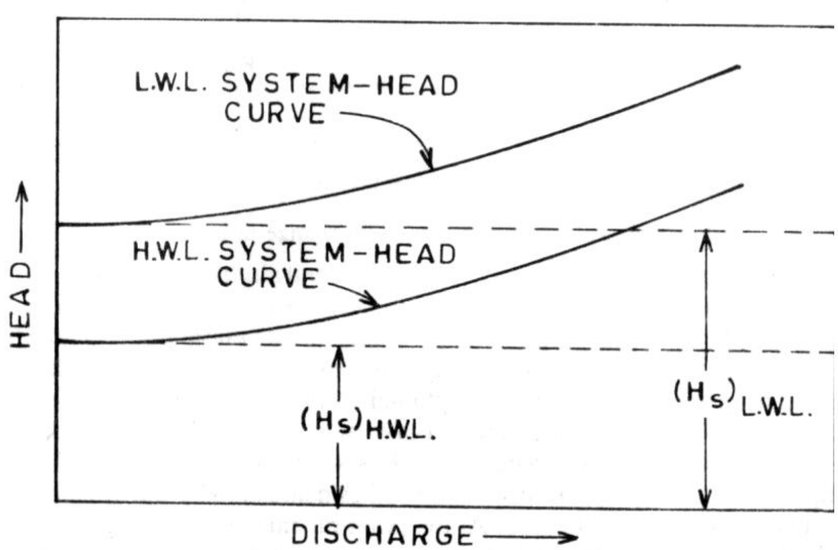


Figure 4.11 System-head curves for low water level (L.W.L.) and high water level (H.W.L.) in suction sump

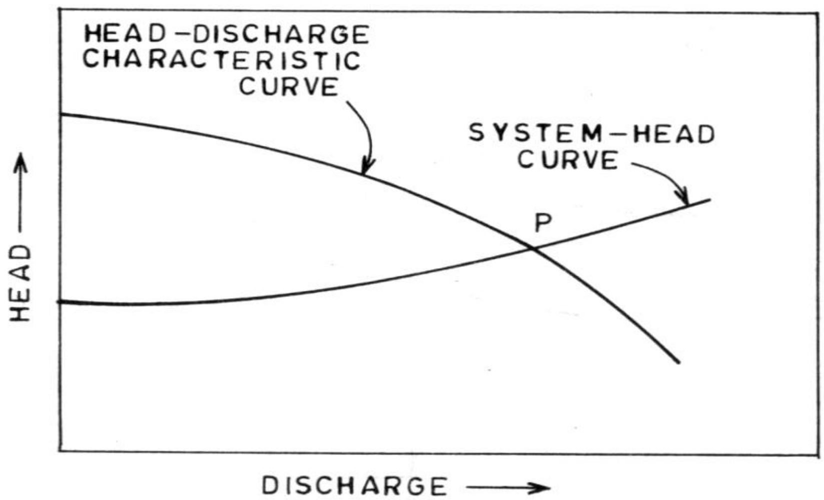


Figure 4.12 Operating point of a centrifugal pump

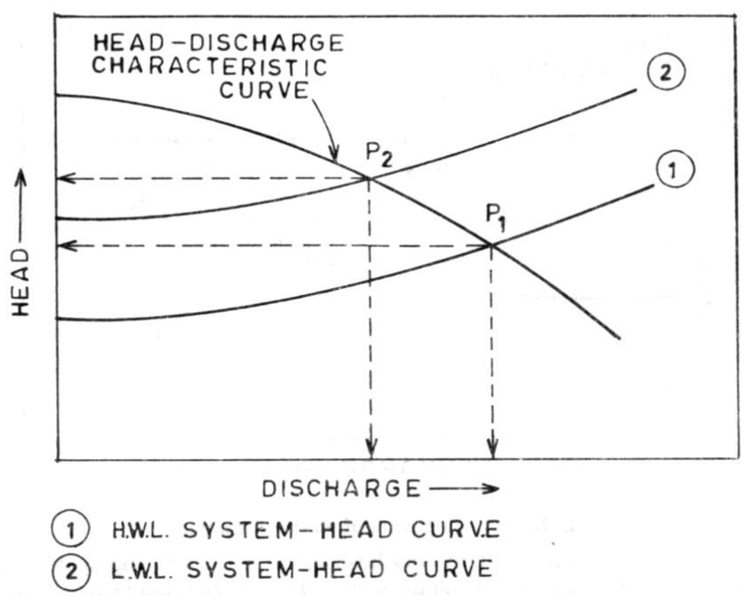


Figure 4.13. Operating range of a centrifugal pump

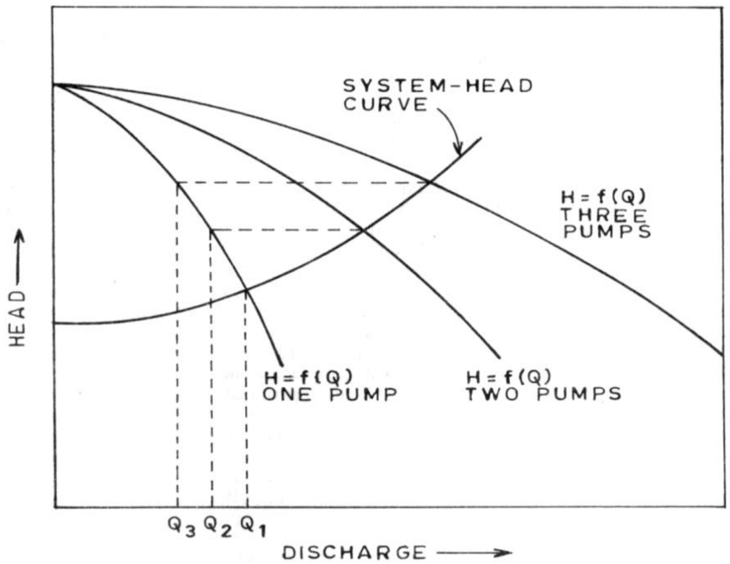


Figure 4.14 Operation of pumps in parallel

4.3 Cavitation

Cavitation is a phenomenon of cavity formation or the formation and collapse of cavities. Cavities develop when the absolute pressure in a liquid reaches the vapor pressure related to the liquid temperature. As the net positive suction head (NPSH) for a pump is reduced, a point is reached where cavitation becomes detrimental. This point is usually referred to as the minimum net positive suction head (NPSHmin) and is a function of the type of pump and the discharge through the pump.

The minimum value static lift can be determined as

$$Z_{min} = \frac{p_a - p_v}{\gamma} - NPSH_{min} - h_{ls}$$

Where p_a is atmospheric pressure, p_v is vapor pressure of fluid and h_{ls} head loss in the suction pipe NPSH is obtained from manufactures

4.4 PUMPING STATIONS

Pumping station refers to hydraulic installations, which are used for delivering water at the required rate (discharge) and head (pressure). They generally consist of the following components:

- ✓ The pumps (plus accessories:, delivery and suction pipes, valves, air-vessel, etc)
- ✓ The intake structure,
- ✓ The sump (or suction well) and other ancillary structures.

Raw-water pumping stations (Abstraction from surface sources):

The pumping station is fed from an open-surface such as a canal, a river, or a reservoir, often through a sump and an intake. With water levels varying over a large range, sediment may enter the sump and intake. Sediment traps and screens (to trap floating debris) are therefore usually provided. The station will probably also have multiple pumps (including standby units) which cater for the changes in sump levels.

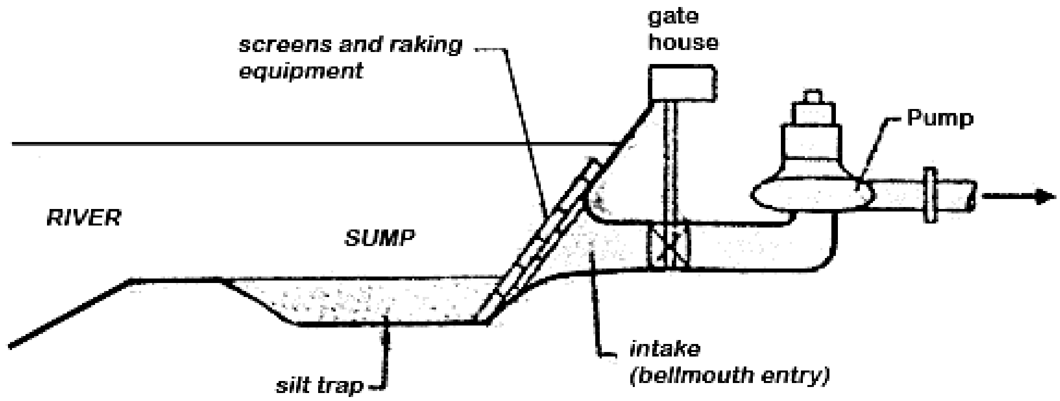


Figure 4.15 River intake with pump

Clean-water pumping stations (water supply from treatment plants):

In the absence of gravity flow, treated water is supplied to a distribution network or a storage tower reservoir through a pumping station. Silt and debris-free water is directed to either a wet or dry sump (without screens or traps) from which it is pumped to the network (booster pumps) or to another storage tank. The possible arrangements of the sump layout are shown in Figure 4.16.

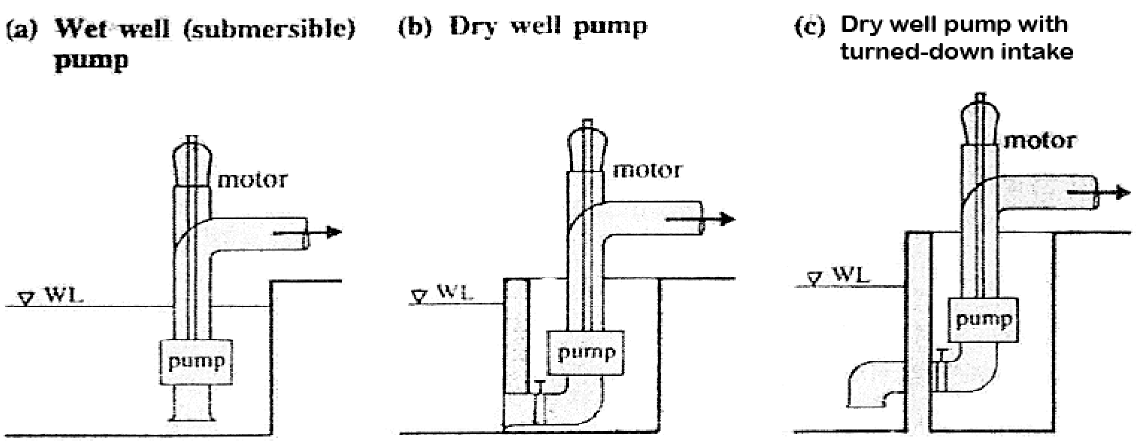


Figure 4.16: Wet and dry well (sump) pump installation

The well arrangement (Fig. 4.16a) is simple, economical and most widely used. Pumps installed below water level (submersible) are preferable (reduction is suction lift and no priming needed) but involve maintenance problems. The dry well arrangement (Fig. 4.16b) is more reliable because of easy access for pump maintenance at all times.

The bellmouth entry to the pump suction pipe suppresses flow separation and ensures uniform flow throughout the intake cross section. The turned-down bellmouth (Fig. 4.16c) allows a lower sump water level than a horizontal intake (Fig. 4.16b) and is less prone to vortex formation.

Groundwater pumping station (Abstraction from boreholes)

The installations are normally of the wet well type with pumps located within the wells. In deep wells special multistage (submersible) pumps are used, whereas for shallow wells the pumps may be located at ground level. Well screens are essential to prevent sand from entering into the system. The deep well pumps are normally less bulky (around 100-400 mm diameter) to fit into well diameters of 150-600 mm.

4.5 PUMP OPERATION AND MAINTENANCE

4.5.1 OPERATION

a) Close the discharge valve and open the suction valve fully to ensure full supply and priming.
b) Ensure that the discharge check valve is not leaking.
c) Ensure that the priming fluid has filled up the pump casing.
d) For the standby pumps, close the discharge valve and open the suction valve fully.
e) Start the pump.
f) Now open the discharge valve on the operating pump fully.
g) All pumps should be operated in turn by rotation to avoid abnormal wear and tear.

4.5.2 MAINTENANCE

a) Check regularly
    i. Lubrication.
    ii. For any over heating or pump gland, bearing or motor.
    iii. Any leaks, and
    iv. Loose mechanical parts, misalignment and unusual noise
b) If am defect is noticed. take corrective action immediately as prescribed in the manufacturer's instructional manual

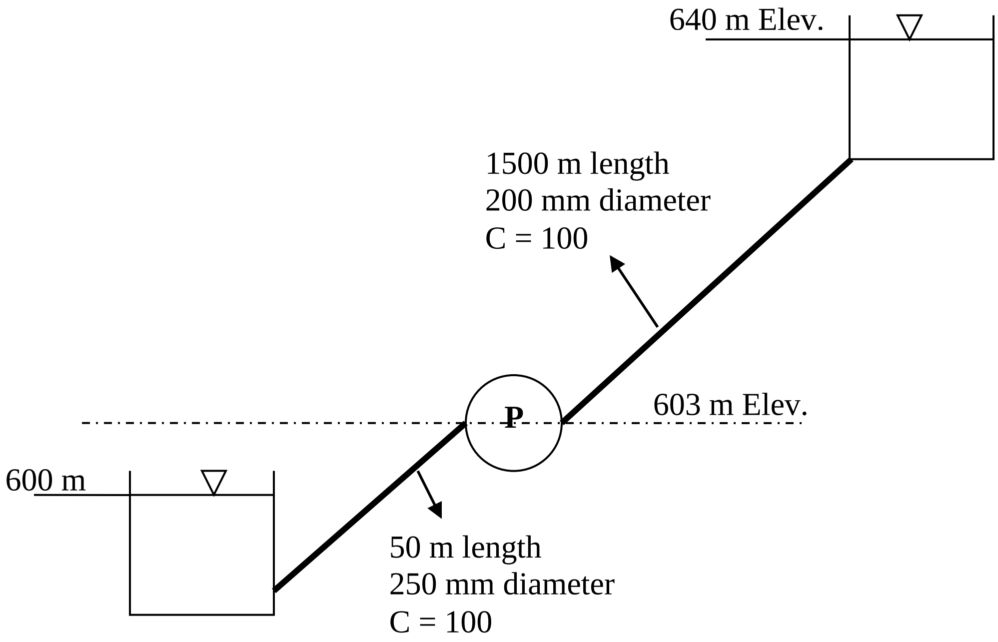
Example 1. Population of a city is 120000 and rate of water supply per head per day is 200 liters. Calculate the BHP of motor to raise the water to an overhead tank 50 m high. Length and diameter of the rising main is 200 m and 40 cm, respectively. Assume motor efficiency 90 % and the of the pump 60 %. Take *f* = 0.01 and peak hourly demand as 1.5 times the average demand.

Example 2. The pump shown in the figure below has a head characteristics that can be expressed by

$$\mathbf{H = 100 - 6000Q^{1.85}}$$

Where H = pump head in meters and Q = discharge in m^3/s.

(a) Calculate the head and discharge of the pump.
(b) Check the potential for cavitation if the anticipated maximum vapor pressure and minimum absolute barometric pressure are 0.40 m and 9.70 m, respectively. NPSH required for the pump is 3.0 m. Neglect minor head losses.


640 m Elev.
1500 m length
200 mm diameter
C = 100
P
603 m Elev.
600 m
50 m length
250 mm diameter
C = 100