Pumps and Pumping Machinery

Purposes

- Lifting water from source and flow into the mains by gravity
- Boosting water from low service to high service areas
- Transporting water through treatment plant:
  - draining component in settling tanks and filter beds
  - withdraw deposited solids
  - supply water
  - pumping chemical solutions to treatment units
- Lifting water to the overhead water tanks

Types of Pumps

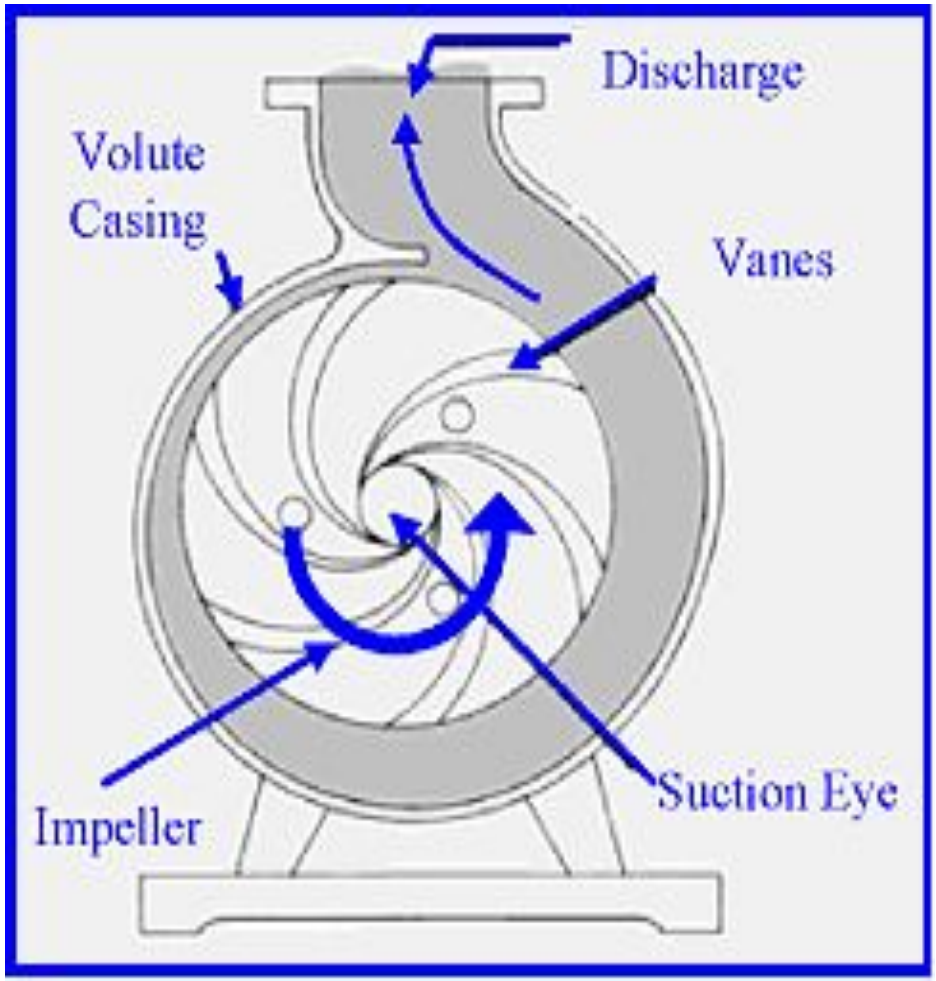
- On the basis of type of service
  - Deep well pump
  - Low lift pump
  - High lift pump
  - Booster pump
  - Fire service pump
  - Stand-by pump
- On the basis of power to drive
  - Steam pump
  - Gasoline pump
  - Diesel pump
  - Electric pump

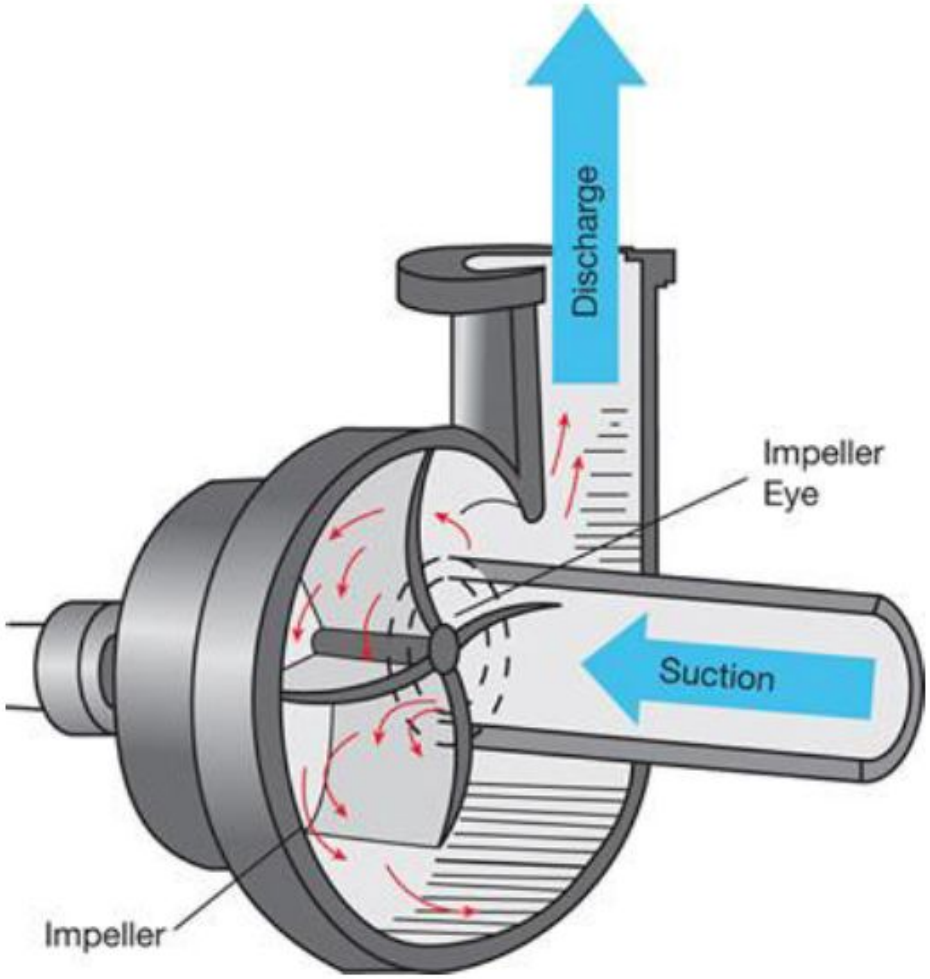
Types of Pumps

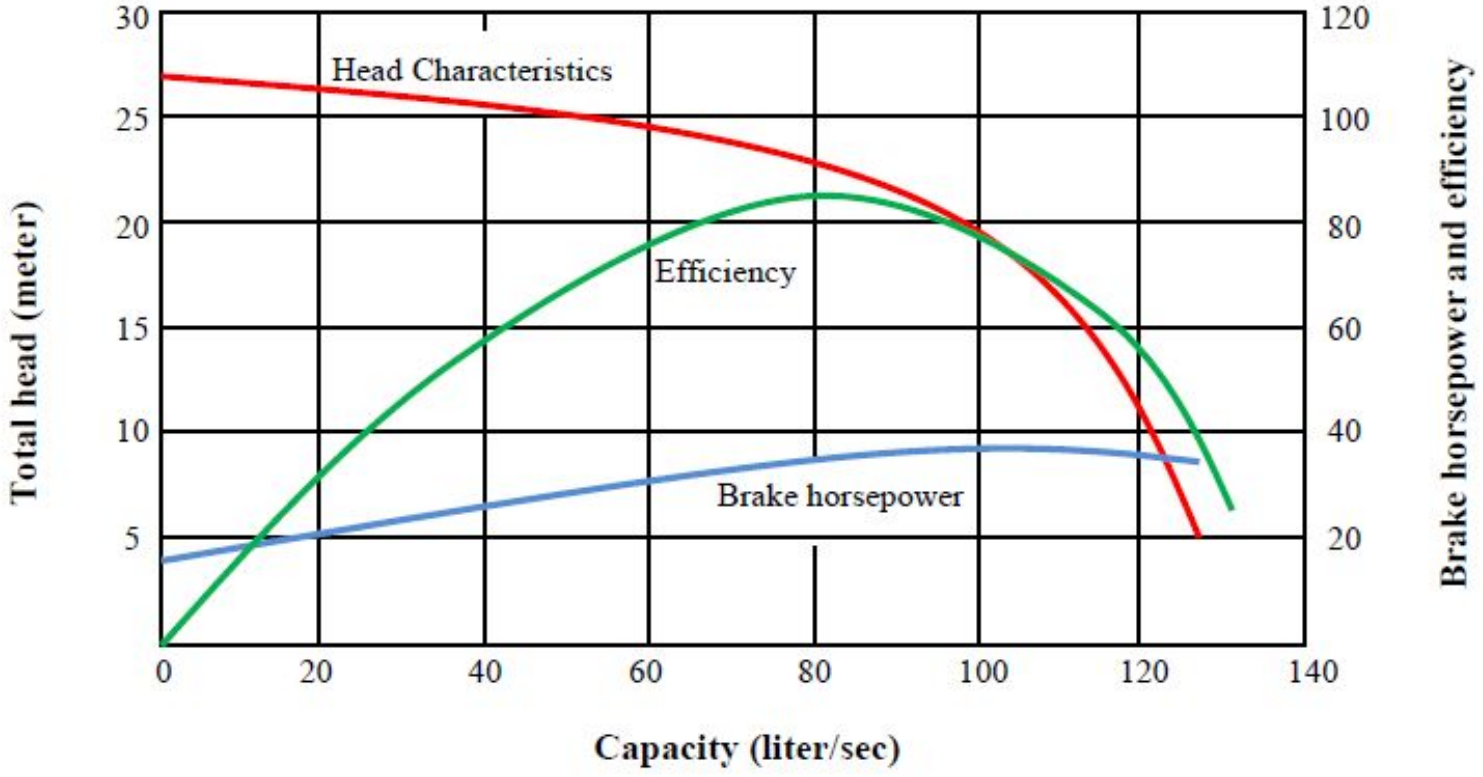
- On the basis of Mechanical principles of operation
  - Displacement pump
  - Centrifugal pump
- On the basis of position of pump shaft
  - Deep well turbine pump
  - Air lift pump
  - Submersible pump

Centrifugal Pump

- Employ the principles of centrifugal force to impart energy to the water.
- Kinetic energy of water is converted into static energy or pressure head.
- Water entering into pump-casing is revolved by a wheel called impeller which discharges water at right angles to the direction of flow.
- High speed normally more than 1,000 rpm in some cases 3,500 rpm are possible.
- Discharge is uniform and power requirements are also uniform.


Discharge
Volute
Casing
Vanes
Impeller
Suction Eye


Discharge
Impeller
Eye
Suction
Impeller



- As the discharge increases, the head decreases. The resulting efficiency is observed to increase from zero where the discharge is zero to a maximum of 82% when the discharge is 86 liter/sec and the head 23 m (and then found to decrease to zero at zero head).
- The BHP curve for a centrifugal pump usually increases over most of the range as the discharge increases, reaching a somewhat higher rate of discharge then that which produce maximum efficiency.

Centrifugal Pump

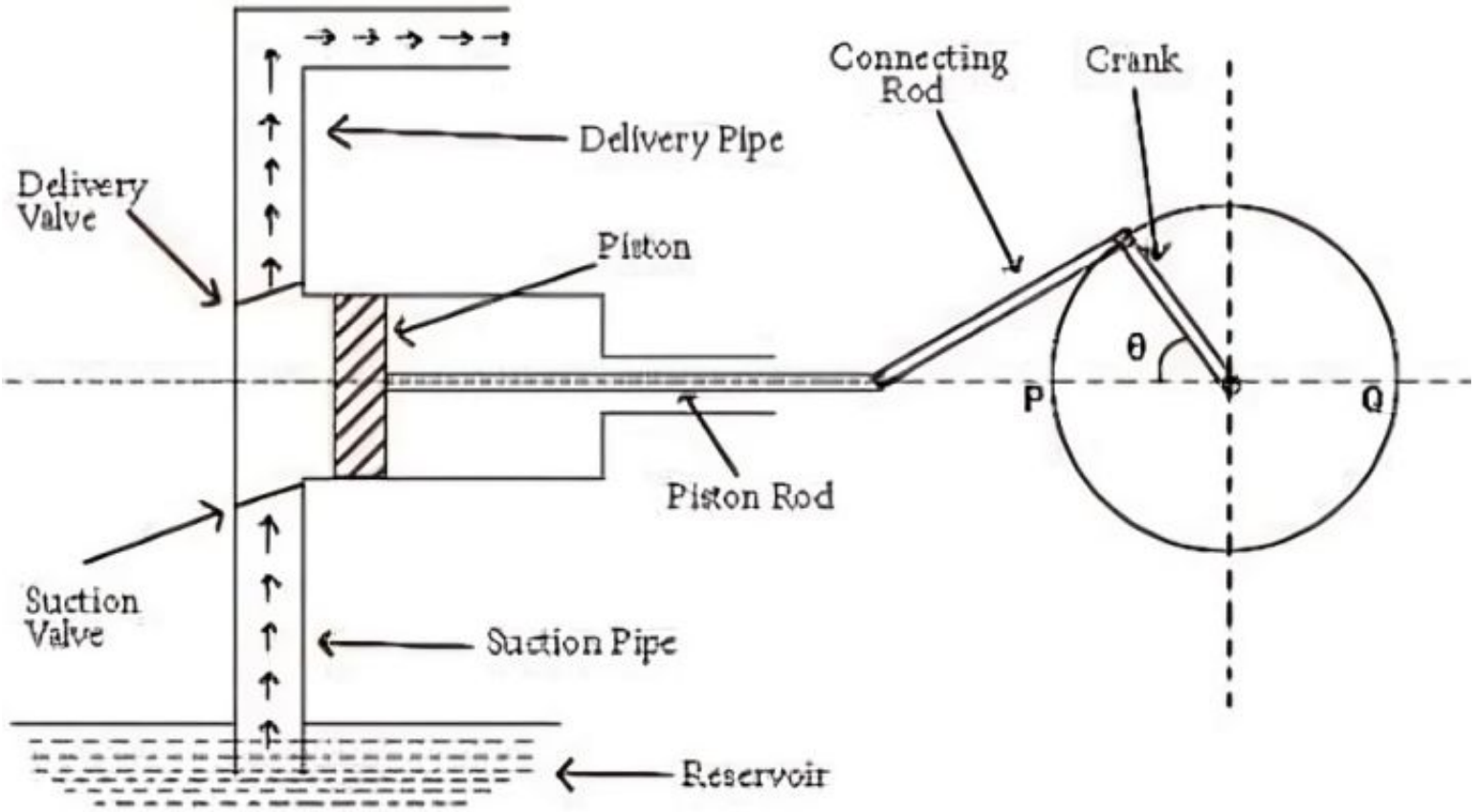
- **Advantages**
  - Requires minimum space for installation as it is compact in design.
  - Can be installed for high speed driving mechanism.
  - Working principle is simple and no valve in the pump, it is reliable and durable.
  - Initial and maintenance cost are comparatively low.
  - Less skilled labor is required for its operation and repair.
  - Can be operated with high speed electric motors, or gas engines and steam turbines.
  - Discharge is steady and non pulsating.
  - Can be used for pumping water containing silt, sand etc.
  - Safe against pressure.

Centrifugal Pump

- **Disadvantages**
  - Will not work, if the chamber is not full of water. Priming should always be done before starting the pump.
  - Will not work if there is any leakage in the suction side.
  - For higher head, efficiency is low.
  - Discharge pipe has to be provided with check valve, to avoid the backflow when the pump suddenly stops due to power failure, with the discharge valve open.
  - Discharge varies with the head of water. When uniform discharge is required at varying heads, the pumps has to be rotated at variable speeds which is neither, practical nor economical.
  - Ordinary suction lift is limited(about 6m or so).

Reciprocating Pump

- Pump consists of a closed cylinder in which a piston moves to and from by a connecting rod.
- Connecting rod is again hinged with a wheel which is rotated by a motor.
- During the suction stroke, the suction valve is opened and delivery valve remains closed and water enters the cylinder.
- During the delivery stroke, the delivery valve is opened and suction valve remains closed and water is forced through the delivery pipe.


Connecting Rod
Crank
Delivery Pipe
Delivery Valve
Piston
θ
P
O
Q
Piston Rod
Suction Valve
Suction Pipe
Reservoir

Components

- **Cylinder** - It is made of cast iron or steel alloy.
- **Piston** - The piston reciprocates inside the cylinder.
- **Connecting Rod** - It connects piston and rotating crank.
- **Suction Pipe** - It connects the source of water and cylinder.
- **Delivery Pipe** - Water sucked by pump is discharged through the delivery pipe.
- **Suction Valve** - It adjusts the flow from the suction pipe into delivery pipe.
- **Delivery Valve** - It admits the flow from the cylinder into the delivery pipe.

Reciprocating Pump

Advantages

- Continuous rate of discharge
- Can deliver water at high pressure
- Can work in wide pressure range
- Precise delivery of required flow rate
- Higher efficiency (10% to 20% greater) compared to centrifugal pumps
- No need for priming

Reciprocating Pump

Disadvantages

- More parts mean high initial cost
- High maintenance cost
- Occupies more space
- Needs skilled supervision during operations
- Low discharging capacity
- High wear in parts

Air Lift Pump

- Consists of a casing pipe in which an educator and an air pipe is introduced.
- Bottom end of the air pipe carries an air diffuser which is introduced into the educator pipe in upward direction.
- Compressed air is forced through the air pipe, a mixture of air and water is formed and rises up in the form of bubbles.

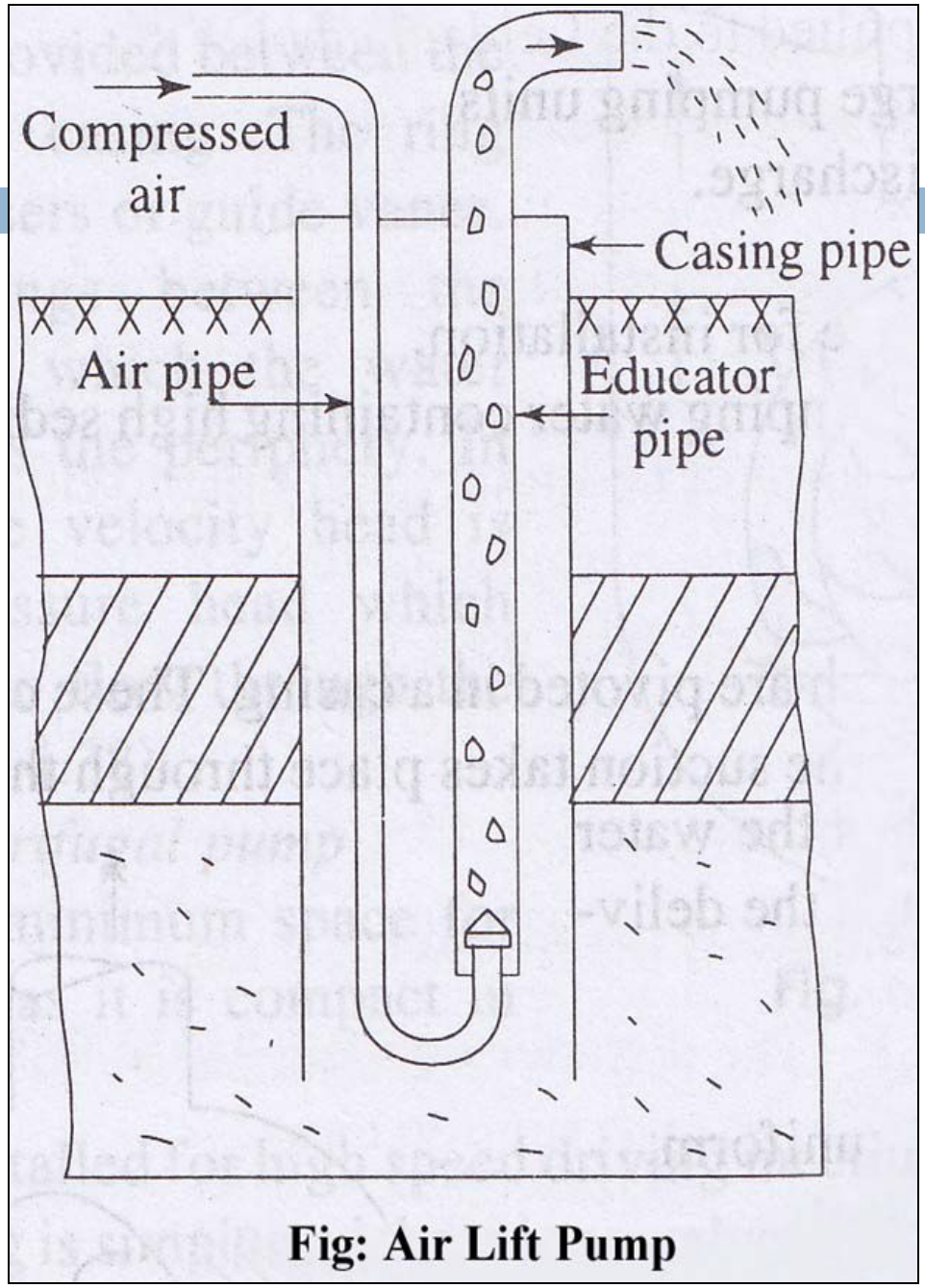


Fig: Air Lift Pump

Air Lift Pump

- Pressure difference forces the water to rise through the educator pipe and finally the water is discharged through the outlet.
- Efficient working of the pump depends on the air pipe's submergence depth.
- Used for pumping water from deep wells for lifting of about 60 – 80m.
- Can be used for high lifts about 150 meters but their efficiency is generally low.

Air Lift Pump

Advantages :

- Inspite of low efficiency, an air lift pump can deliver large amounts of water from small dia wells.
- Not harmed by sedimented water.
- Cheaper, reliable and simple in operation.
- No moving parts which may be in contact with water– used for highly acidic or alkaline water.
- Yield of a well, using such pump, can be increased by using more amount of compressed air.

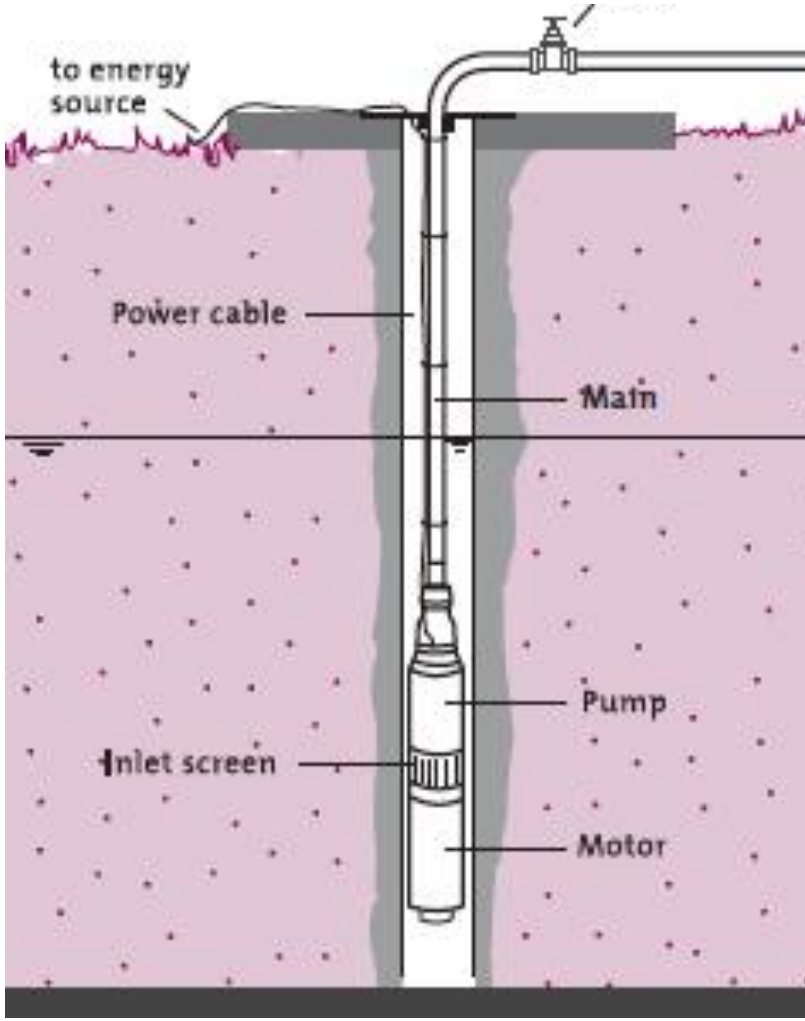
Air Lift Pump

Disadvantages

- Not adopted for raising water much above the ground level, and if this is necessary, a second pump has to be installed.
- Efficiency is low
- Flow obtained is not continuous but is intermittent.
- Less flexible in fulfilling variable demands.
- In order to obtain sufficient value of submergence, the depth of submergence has to be increased and thus the well has to be made deeper than required. This increases the cost.

Submersible Pump

- Driving motor is placed below the pump bowls within the well water level.
- Driving shaft is completely eliminated reducing the bearing friction.
- Electrical parts or the motor bearing are enclosed by a oil filled case with mercury seal.
- Water rises to the surface through a riser pipe on which the assemble is suspended.



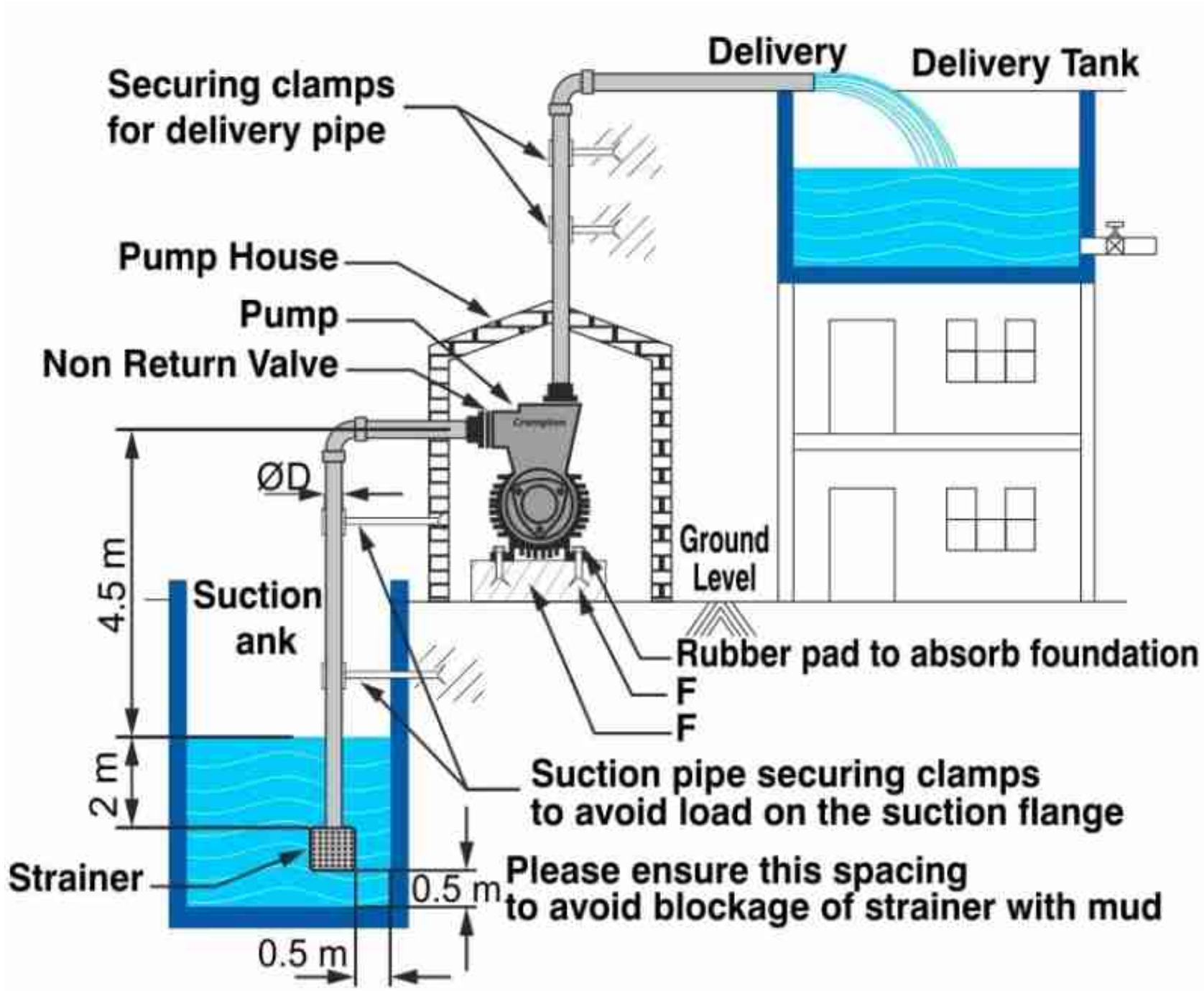
Submersible Pump

Advantage

- Safer than other types of surface pumps
- It produces low or almost no noise
- Submersible pumps are Self-Priming
- Corrosion resist
- Easy to run & are space-saving
- Can run for 15 years smoothly without trouble

Disadvantage

- Seals can become corroded with time
- Must submerge totally before use
- Routine inspections and maintenance are challenging


Delivery
Delivery Tank
Securing clamps
for delivery pipe
Pump House
Pump
Non Return Valve
ØD
4.5 m
Suction
ank
Ground
Level
Rubber pad to absorb foundation
F
F
2 m
Suction pipe securing clamps
to avoid load on the suction flange
Strainer
0.5 m
Please ensure this spacing
to avoid blockage of strainer with mud
0.5 m

General considerations

- **Suction lift:**
  - Due to friction losses, loss of velocity head maximum lift of 32 ft cannot be achieved.
  - Elevation of any pump above the source of water supply should not exceed 22 ft.
  - Suction pipe should be short, straight and ample diameter.
  - Strainer should have clear waterway area 1.5 times the cross sectional area of the suction pipe.
- **Power of pump:**
  - Cost of power to operate the pump is mainly the cost of pumping.
  - Steam engine, gasoline engine, diesel engine and electric motors are commonly used to drive pumps.

General considerations

- **Stand-by or reserve power:**
  - Extra pump units for use in case of breakdown or repairing of regular pumps are necessary.
- **Size of Units:**
  - Pumping station is not operated at full capacity all the time.
  - The complete pump installation should be so designed that some units may be operated of full capacity at all times regardless of the variation in demand.

Power of Pump

- Total lift of pump:

  It is the algebraic sum of (i) **Discharge Lift** or the vertical distance from the centre of the pump to the level where water is to be raised. (ii) **Suction Lift** or the vertical distance from the level of the source of water supply to the centre of the pump.

- The **Horse Power** of pump is determined by work done in raising a particular quantity of water to some height.

  Let, W = Quantity of water (kg)

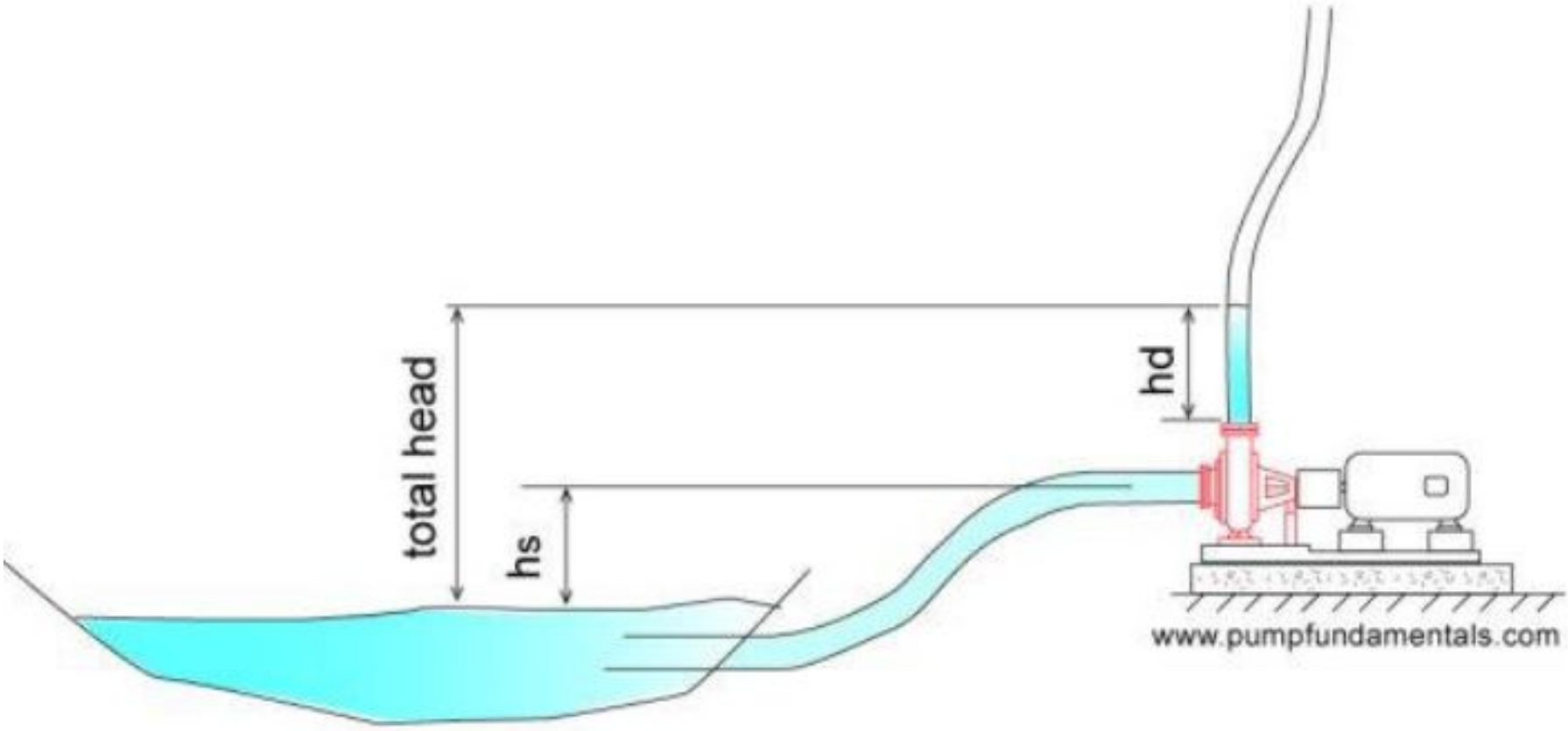
  H = Total head (m)

  Then, work done by pump = $W \times H = \rho \times Q \times H$ $[W = \rho \times Q]$

  Where, ρ = Density of water (1000 kg/m^3)

  Q = Discharge (m^3/s)

Head



Essential Equations

- Pump Head, $h_p = h_s + h_v + h_f = h_s + \frac{v^2}{2g} + h_L$
- h_s = static head including ($h_{suction} + h_{delivery}$)
- h_v = velocity head
- h_L = frictional head loss = $f.\frac{L}{D}.\frac{v^2}{2g}$ (Darcy-Weisbach Equation)
- **P =** $\frac{HQ}{3960}$, theoretical Horse power required to operate the pump (WHP-Water Horse Power)

Essential Equations

- $\mathbf{P = \frac{HQ}{3960}}$, H =total lift or head of the pump,
- $H = h_p$
- Q = volume of water to be pumped in unit time, or discharge, in gpm
- Actual horsepower required to operate the pump depends on the efficiency (E) of the pump
- $\boldsymbol{P' = \frac{P}{E}}$, BHP = Break Horse Power
- $\mathbf{BHP = \frac{WHP}{E}}$

Essential Equations

- Continuity Eqn, Q = AV
- Area, $A = \frac{\pi d^2}{4}$

Pump Design Example

- Ex-01: Design a suitable set of pumping unit to deliver 4,50,000 gph 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

- Sol: Q = 450000/60 = 7500 gpm;
- Q = 450000/(60*60*6.24) = 20 cfs
- Cross sectional area = 20/12 = 1.667 sq.ft
- $1.667 = \pi d^2/4$
- d= 1.5 ft= 18 inch
- $H_f = f.\frac{L}{D}.\frac{v^2}{2g} = \frac{2\times0.0075\times800\times12^2}{2\times32.2\times1.5}$ = 36 ft
- $H_v = \frac{v^2}{2g} = \frac{12^2}{2\times32.2}$ =2.24

Solution

- Total Head = hs + hf + hv = 60+ 36+2.24 = 98.24ft
- **P =** $\frac{HQ}{3960} = \frac{98.24 \times 7500}{3960}$ = 188 WHP
- **BHP =** $\frac{WHP}{E} = \frac{188}{0.7}$ **= 268**

PROBLEM 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 per cent ?

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 centre 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.

Total head $H = 205 + 12 + 1.5 + 1.5 = 220$ ft.

$$P = \frac{HQ}{3,960} = \frac{220 \times 6,750}{3,960} = 375 \text{ (WHP)}$$

$$P^1 = \frac{375}{0.67} = 560 \text{ (BHP) Ans.}$$

PROBLEM 2 : Design a suitable set of pumping unit to deliver 4,50,000 gph 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.

$$Q = 4,50,000 \div 60 = 7,500 \text{ gpm}$$

again $$Q = \frac{4,50,000}{60 \times 60 \times 6.24} = 20 \text{ cfs}$$

$Q = AV$

$A = \frac{Q}{V} = \frac{16.71}{12} = 1.39$:

Cross-sectional area $= \frac{20}{12} = 1,667$ sq. ft.

$$\frac{\pi d^2}{4} = 1.667 \quad (d = \text{diameter of pipe})$$

$$d = \sqrt{\frac{1.567 \times 4}{\pi}} = 1.5 \text{ ft} = 18 \text{ inch}$$

Frictional head loss, $h_f = \frac{4flv^2}{2gd} = \frac{4 \times 0.0075 \times 800 \times (12)^2}{2 \times 32.2 \times 1.5} = 36$ ft.

Velocity head, $h_v = v^2/2g = (12)^2/2 \times 32.2 = 2.24$ ft.

Total head $H = h_s + h_f + h_v = 60 + 36 + 2.24 = 98.24$ ft.

$$P = \frac{HQ}{3,960} = \frac{98.24 \times 7,500}{3,960} = 188 \text{ (WHP)}$$

$$P^1 = \frac{180}{0.70} = 265 \text{ (BHP) Ans.}$$

PROBLEM 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. What size cast iron pipe would you use ?

Assume $f = 0.0075$

Solution :

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

$$\frac{v^2}{d} = 4.06 \qquad \therefore \quad v^2 = 4.06 \times d \quad \ldots (1)$$

Again, $Q = 425$ mgd $= 425 \times 1.547 = 787$ cfs [1 mgd = 1.547 cfs]

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

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

Substituting the value of v^2 from Eq. 2 to Eq. 1.

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

$$d^5 = \frac{16 \times (787)^2}{\pi^2 \times 4.07} = 246,800$$

$\therefore \quad d = 11.98 \simeq 12$ ft. Ans.

Problem 4 : Design a pumping unit capable of lifting 5 mgd of water from an intake well to the treatment plant against a static head of 60 ft ; length of suction main is 120 ft. and that of rising main is 400 ft. The pump will work in two shifts of eight hours each.

Assume : velocity of flow = 6 fps
friction factor = 0.01
efficiency = 75%

Solution :

Total length of pipe = 120 + 400 = 520 ft.

Discharge, Q = 5mgd = $\frac{5 \times 10^6}{6.24} = 8 \times 10^5$ cuft/day

Since total pumping time is 16 hrs/day.

∴ Pumping capacity = $\frac{8 \times 10^5}{16}$ = 50,000 cuft/hr.

= $\frac{50{,}000}{60 \times 60}$ = 13.9 cfs

$$Q = \frac{\pi d^2}{4} = 13.9$$

$$\therefore \quad d = \sqrt{\frac{4 \times 13.9}{\pi \times 6}} = 1.7 \simeq 21.75 \text{ ft} = 21 \text{ inch}$$

$$h_f = \frac{4 \times 0.01 \times 520 \times 6^2}{2 \times 32.2 \times 1.75} = 6.7 \text{ ft.}$$

$$h_v = \frac{6^2}{2 \times 32.2} = 0.56 \text{ ft.}$$

$$H = h_s + h_f + h_v = 60 + 6.7 + 0\ 56 = 67.26 \text{ ft.}$$

$$Q = \frac{50,00,000}{16 \times 60} = 5,220 \text{ gpm}$$

$$P = \frac{HQ}{3,960} = \frac{67.26 \times 5,220}{3,960} = 88.5 \text{ (WHP)}$$

$$\therefore P^1 = \frac{P}{E} = \frac{88.5}{0.75} = 118 \text{ (BHP) Ans.}$$

Problem 5 : Design the transmission main and the pumping unit from the following data :

Water supply rate = 40 gpcd
Estimated population = 85,000
Ground R. L. = at the pum house = 102.50 ft.
Treatment plant R. L. = 193.00 ft.
Velocity through pipes = 8 fps
Pumping time = 10 hrs. daily
Total length of pipe = 3,500 ft.
Friction factor = 0.01
Efficiency = 65%

Solution :

Total water required = $40 \times 85{,}000 = 34{,}00{,}000$ gpd

$$= \frac{34{,}00{,}000}{6.24} = 5.45 \times 10^5 \text{ cuft/day}$$

$$\text{Pumping rate} = \frac{5.45 \times 10^5}{10} = 5.45 \times 10^4 \text{ cu ft/hr}$$

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

12.63 cfs.

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

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

Use a 21 inch diameter pipe, d = 1.75 ft.

Static head = 193.00 – 102.50 = 90.50

$$\text{Friction head} = \frac{4 \times 0.01 \times 3500 \times 8^2}{2 \times 32.2 \times 1.75} = 80.0 \text{ ft.}$$

$$\text{Velocity head} = \frac{v8^2}{2 \times 3..2} = 1.0 \text{ ft}$$

Total head, H = 90.5 + 80.0 + 1.0 = 171.5 ft

$$\text{Discharge, } Q = \frac{34,00,000}{10 \times 60} = 5,667 \text{ gpm}$$

$$\therefore \quad P = \frac{HQ}{3,960} = \frac{171.5 \times 5667}{3,960} = 246 \text{ (WHP)}$$

$$\therefore \quad P^1 = \frac{P}{E} = \frac{246}{0.65} = 380 \text{ (BHP) Ans.}$$

Practice Problem 1

- Design a suitable set of pumping unit to deliver 450000 gph 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 ~tatic hand is 60 ft. Design also the cast iron main. Assume: Velocity of water = 12 fps; Friction factor = 0.0075; Efficiency = 70%.

Practice Problem 2

Water supply to a small town with ultimate population of one lakh (1,00,000) supplied with 60 gpcd has to be arranged from a river flowing nearby. Design the economical section of the rising main and the necessary pumping unit from the following data :

Static head	60 ft
Total length of pipe	520 ft.
Coefficient of friction	0.01
Velocity of water in the pipe	6 ft/sec
Pump efficiency	70%

The pumps will work in two shifts of six hours each in a day,