RECIPROCATING PUMP

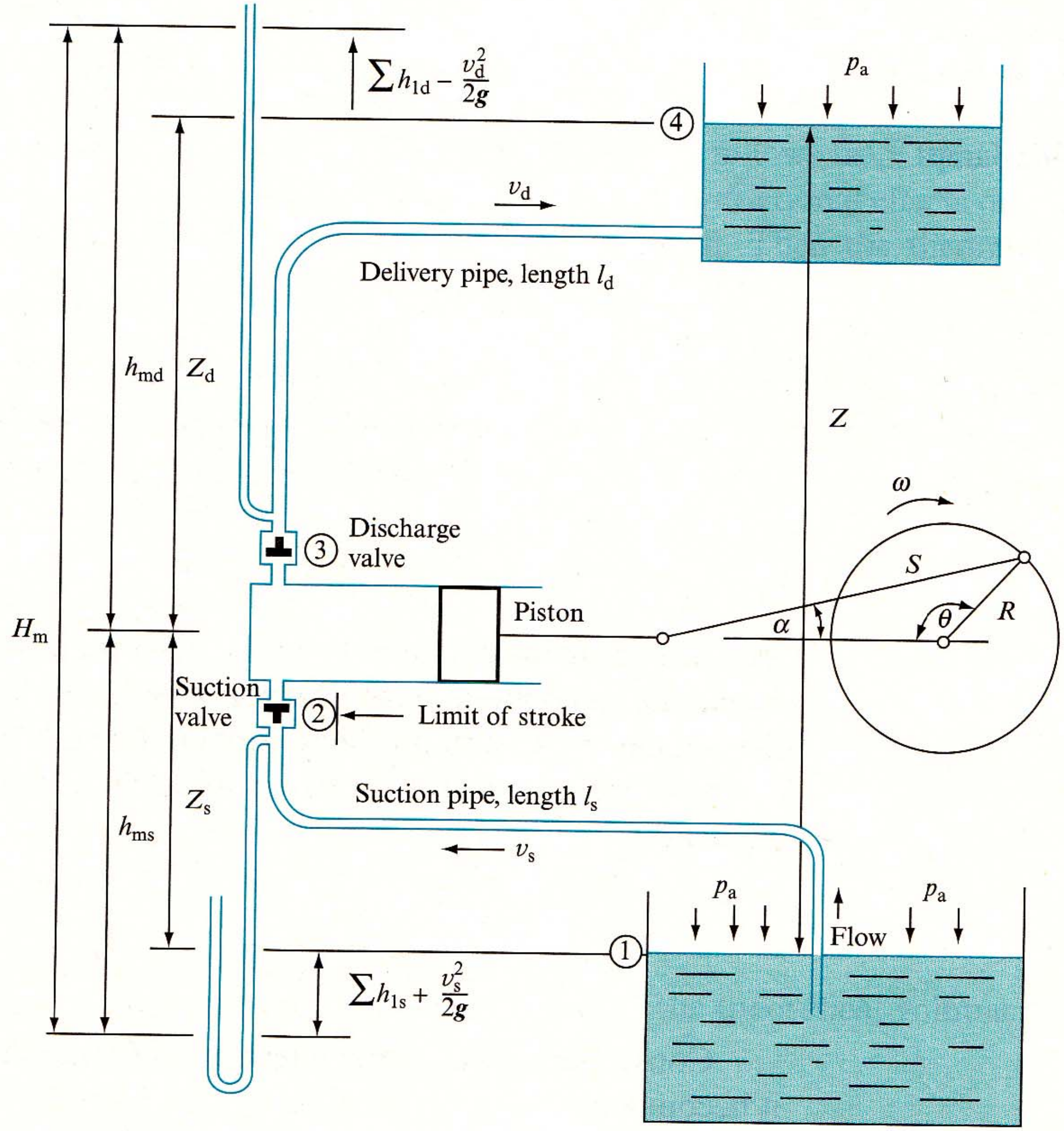
Pumps can be broadly classified into positive displacement pumps and rotodynamic pumps (dynamic pressure pump).

Reciprocating pump is a positive displacement pump which fluid is drawn or forced into a finite space and is then sealed in it by mechanical means.

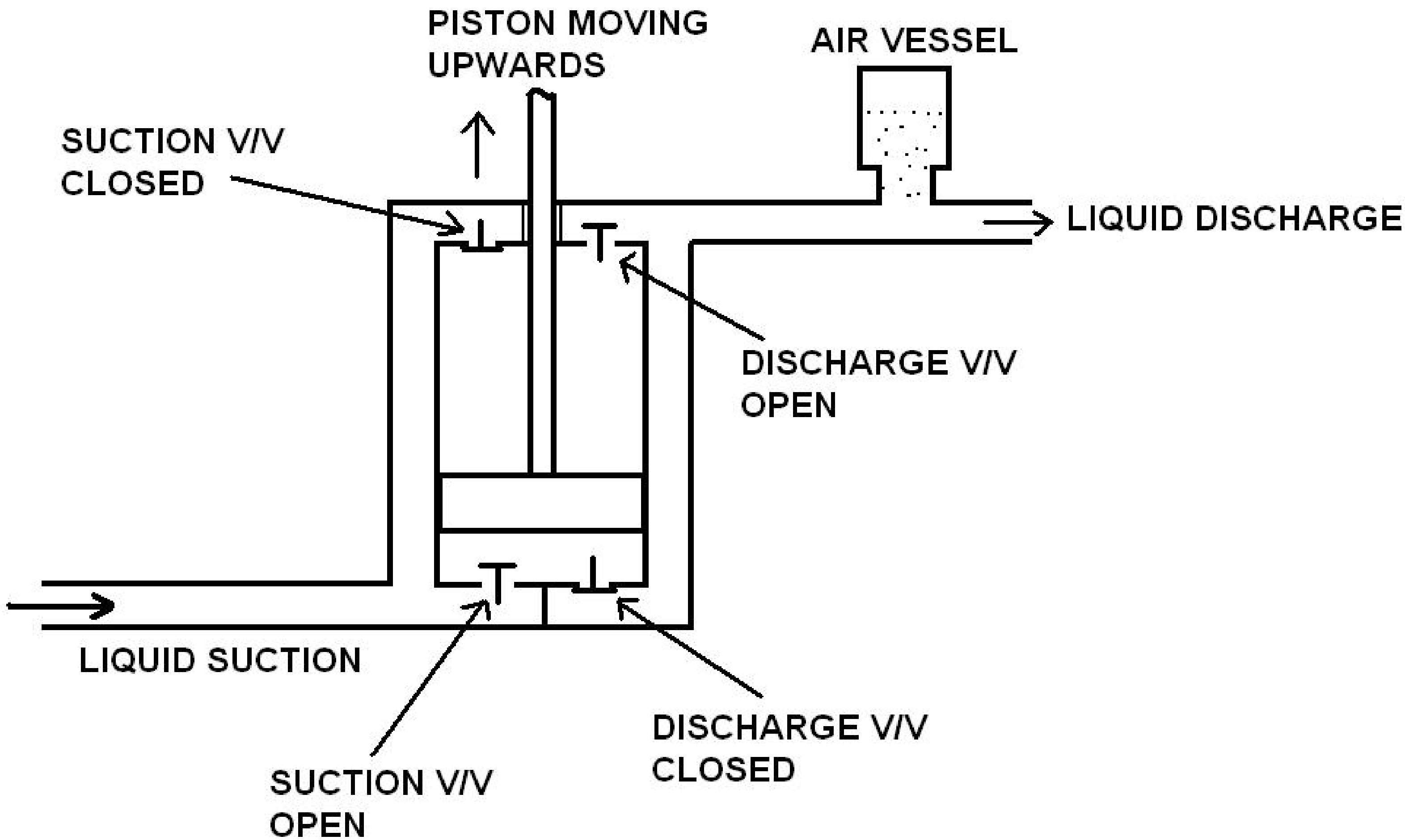
The fluid is then forced out to flow and the cycle is repeated.

Reciprocating pump can be single acting or double acting.

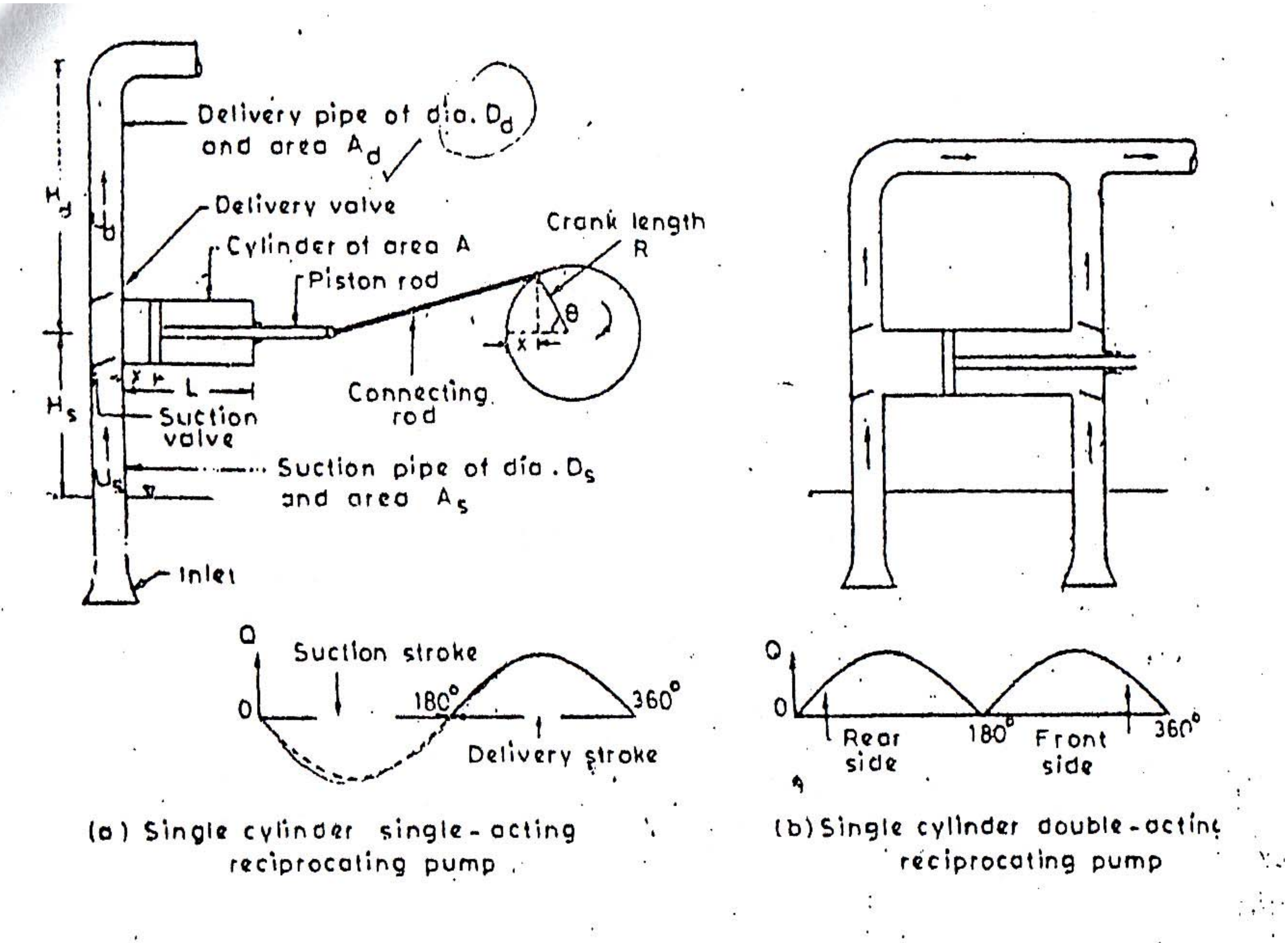
Among the positive displacement pumps, there are pumps in which there is rotary action instead of reciprocating action, such as gear pumps, lobe pumps and vane pumps.



Single acting reciprocating pump



Double acting reciprocating pump



Reciprocating pump

Flow rate:

Theoretical discharge of single acting reciprocating pumps:

$$Q_1 = \frac{ALN}{60}$$

Theoretical discharge of double acting reciprocating pumps:

$$Q_2 = \frac{2ALN}{60}$$

A : Cross sectional of the cylinder
L : Stroke length
N : Speed rotation in rpm

The slip of pump:

$$Slip = \frac{Q_T - Q_A}{Q_T} \times 100\%$$

Q_T : Theoretical flow rate
Q_A : Actual flow rate

The slip of the pump is usually positive.

However, slip can be negative if suction pipe is long, delivery pipe is short and speed rotation (N) is high.

Generally, the higher the speed, the smaller the length.

Following expression can be derived from the geometry and working of the pump.

Displacement of piston:

$$x = R(1 - \cos \omega t) = R\cos\theta$$

R : Crank radius or half-stroke length.

$$\omega = \frac{2\pi N}{60}$$

$$\theta = \omega t$$

Velocity of piston:

$$U_P = \frac{dx}{dt} = R\omega \sin \omega t$$

Continuity equation:

$$A_P U_P = A_S U_S = A_D U_D$$

$_P$: Piston
$_S$: Suction
$_D$: Delivery

Acceleration:

Acceleration head represents the energy required to accelerate the water column in suction or delivery pipe.

$$a = \frac{dU_P}{dt} = R\omega^2 \cos \omega t$$

Acceleration head in suction pipe:

$$H_{aS} = \frac{L_S}{g}\left(\frac{A_P}{A_S}\right) \times R\omega^2 \cos \omega t$$

Acceleration head in delivery pipe:

$$H_{aD} = \frac{L_D}{g}\left(\frac{A_P}{A_D}\right) \times R\omega^2 \cos \omega t$$

L_S : Length of suction pipe
L_D : Length of delivery pipe

Friction head in suction pipe:

$$H_{fS} = f\frac{L_S}{D_S}\frac{1}{2g}\left(\frac{A_P}{A_S}R\omega\sin\omega t\right)^2$$

Friction head in delivery pipe:

$$H_{fD} = f\frac{L_D}{D_D}\frac{1}{2g}\left(\frac{A_P}{A_D}R\omega\sin\omega t\right)^2$$

Since H_{fS} and H_{fD} vary with the position of piston (or ωt), their averages during the suction and delivery strokes are $\frac{2}{3}H_{fS}$ and $\frac{2}{3}H_{fD}$, where H_{fS} and H_{fD} are the maximum value of friction head in suction and delivery pipes. Maximum value occur at $\omega = \frac{\pi}{2}$

$$H_{fS-\max} = \frac{2}{3}f\frac{L_S}{D_S}\frac{1}{2g}\left(\frac{A_P}{A_S}R\omega\right)^2$$

$$H_{fD-\max} = \frac{2}{3} f \frac{L_D}{D_D} \frac{1}{2g} \left(\frac{A_P}{A_D} R\omega \right)^2$$

Power or work done per second:

$$P = \rho g Q H = \rho g Q \left[H_S + H_D + \frac{2}{3} f \frac{L_S}{D_S} \frac{1}{2g} \left(\frac{A_P}{A_S} R\omega \right)^2 + \frac{2}{3} f \frac{L_D}{D_D} \frac{1}{2g} \left(\frac{A_P}{A_D} R\omega \right)^2 \right]$$

AIR VESSEL

Air vessel can be fitted on one or both sides of the pump (on suction and delivery side)

There are located close to the cylinder.

Volume of air vessel on the delivery side is about 6 to 9 time the volume of cylinder, and that on the suction side 3 to 4 times the cylinder volume.

Air vessel serves the following functions:

1. Fluctuations in discharge are decreased.
2. Pump can be run at higher speed because there is less danger of separation flow.
3. There is less friction loss and hence saving in work done.

When air vessels are provided, the flow before air vessel on the delivery side and the flow between air vessel and cylinder on the suction side are varying. Hence acceleration heads are calculated on in lengths L_{SA} and L_{SD} ;

Velocity beyond air vessel on delivery side;

$$U_D = \frac{ALN}{60A_D} = \frac{A_P}{A_D}\frac{R\omega}{\pi}$$

Discharge beyond air vessel;

$$Q = A_D \times U_D = \frac{A_P R\omega}{\pi}$$

Discharge in air vessel;

$$Q_A = Q_D - Q = A_P R\omega\left(\sin\omega t - \frac{1}{\pi}\right)$$

If Q_A is positive, water flows into air vessel and if it is negative, it flows out from air vessel.

When air vessel is fitted on the suction side, the same expression is valid for Q_A but signs get reversed. For air vessel on the suction side, water flow out of air vessel is Q_A is positive and into it if it is negative.

For double acting cylinder,

$$Q_A = A_P R\omega\left(\sin\omega t - \frac{2}{\pi}\right)$$

Power or work done by a single acting reciprocating pump with air vessel on both sides is given by:

$$P = \rho g Q\left[H_S + \frac{f\left(L_S - L_{SA}\right)}{2gD_S}\left(\frac{Q}{A_S}\right)^2 + \frac{1}{3}f\frac{L_{SA}}{gD_S}\left(\frac{A_P}{A_S}R\omega\right)^2 + H_D + \frac{f\left(L_D - L_{DA}\right)}{2gD_D}\left(\frac{Q}{A_D}\right)^2 + \frac{1}{3}f\frac{L_{SA}}{gD_D}\left(\frac{A_P}{A_D}R\omega\right)^2\right]$$

Similar expression can be written for double acting reciprocating pump with air vessel.

Example 01

For a single acting reciprocating pump, piston diameter is 150mm, stroke length is 300mm, rotational speed is 50rpm and the water is to be raised through 18m. Determine theoretical discharge. If the actual discharge is 4 liter per second, determine volumetric efficiency, slip and actual power required. Take the mechanical efficiency as 80 percent.

Example 02

A single acting reciprocating pump has a plunger diameter of 125m and stroke of 300mm. The length of suction pipe is 10m and diameter 75mm. Find acceleration head at the beginning, middle and end of suction stroke. If the suction head is 3m, determine the pressure head in the cylinder at the beginning of stroke when the pump runs at 30rpm, take atmosphere head as 10.23m of water.

Example 03

A single acting reciprocating pump has the following data:
Stroke = 300mm
Piston diameter = 125mm
Suction pipe length = 5m
Suction pipe diameter = 75mm
Suction head = 3m
Atmospheric head = 10.23m abs
Safe minimum pressure head = 2m abs

What is the minimum speed at which it can be run without causing separation during suction stroke?

Example 04

A single cylinder double acting reciprocating pump has a piston diameter of 300mm and stroke length of 400mm. When the pump runs at 45rpm, it discharges 0.039 m3/s under a total head of 15m. What will be the volumetric efficiency, work done per second and power required if the mechanical efficiency of the pump is 75 percent?

Example 05

Following details of a single acting, single cylinder, reciprocating pump are given:

$L = 500mm$	$D = 125mm$	$H_{atm} = 10.2m$
$L_S = 5m$	$D_S = 100mm$	$H_S = 3m$
$L_D = 15m$	$D_D = 100mm$	$H_D = 10m$

$f = 0.02$ for both suction and delivery pipes.
Safe minimum head = 2.4m

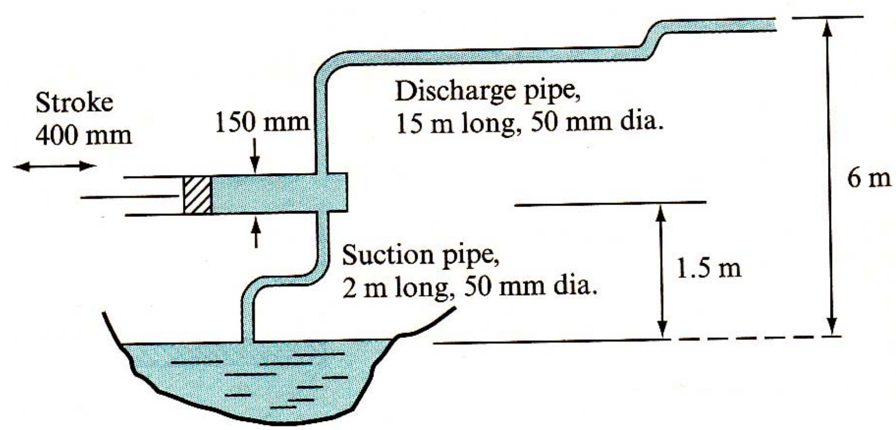
Neglect slip and calculate:

1. maximum permissible speed
2. energy required to drive the pump if an air vessel is provided on the delivery side very close to the cylinder.

Example 06

A single-acting, single-cylinder, positive displacement pump is used to drain an excavation. The pump has a bore of 150mm and a stroke of 400mm. The suction and discharge pipes are both of 50mm diameter, the suction pipe being 2m long and the discharge is 6m above the level of the water excavation. The suction lift to the pump is 1.5m while the discharge is 6m above the level of the water surface in the excavation. In the absence of any air chambers on either (a) pump suction or (b) discharge, calculate for (a,b) the absolute pressure head in the cylinder at the start, end and middle of each stroke if the pump drive is at 0.2rev/s and may be assumed to be simple harmonic.

Also determine the maximum pump speed if separation is to be avoided on the piston face. Assume a friction factor of 0.01, for both pipes, a pump slip of 4%, an atmospheric pressure of 10.3 m of water, and a fluid vapor pressure of 2.4m.



Example 07

A single-acting, single-cylinder, positive displacement pump, driven at 0.4rev/s, has a bore of 200mm and a stroke of 500mm. The suction and discharge pipe are both 100mm in diameter. The suction lift is 0.4m and the suction pipe is 3m long. The water is discharge at a point 20m above the pump level by means of a pipe 200m long, fitted with a large air chamber 20m from the pump. Calculate the absolute pump cylinder pressures at the start, end and mid-stroke times for both suction and discharge assuming no slip at the pump and a friction factor of 0.008 for both pipes. Take atmospheric pressure as 10.3m