CL203 – FLUID MECHANICS

III Semester BTech (Chemical Engineering)

CL203 FLUID MECHANICS

- **Module 5:**
- **Flow measurement: Introduction;**
- **general equation for internal flow meters; Orifice meter; Venturimeter;**
- **concept of area meters: rotameter;**
- **Local velocity measurement: Pitot tube.**
- Fluid moving machines: Introduction; Basic classification of pumps,
- Mechanical pump: Centrifugal and Positive displacement pumps (rotary, piston, plunger, diaphragm pumps);
- pump specification;
- basic characteristics curves for centrifugal pumps;
- fan, blower and compressor. [8]

LECTURE PLAN AND LEARNING OBJECTIVES FOR 40 [ONE HOUR] LECTURES

Module 5: Flow measurement: Introduction; general equation for internal flow meters; Orifice meter; Venturimeter; concept of area meters: rotameter; Local velocity measurement: Pitot tube. Fluid moving machines: Introduction; Basic classification of pumps, Mechanical pump: Centrifugal and Positive displacement pumps (rotary, piston, plunger, diaphragm pumps); pump specification; basic characteristics curves for centrifugal pumps; fan, blower and compressor. [8]

Lecture I

Flow measurement: Introduction.

Lecture II

General equation for internal flow meters; Orifice meter; Venturi meter.

Lecture III

Concept of area meters: rotameter.

Lecture IV

Local velocity measurement: Pitot tube..

Lecture V

Fluid moving machines

LECTURE PLAN AND LEARNING OBJECTIVES FOR 40 [ONE HOUR] LECTURES

Module 5: Flow measurement: Introduction; general equation for internal flow meters; Orifice meter; Venturimeter; concept of area meters: rotameter; Local velocity measurement: Pitot tube. Fluid moving machines: Introduction; Basic classification of pumps, Mechanical pump: Centrifugal and Positive displacement pumps (rotary, piston, plunger, diaphragm pumps); pump specification; basic characteristics curves for centrifugal pumps; fan, blower and compressor. [8]

Lecture VI

Introduction; Basic classification of pumps, Mechanical pump: Centrifugal and Positive displacement pumps (rotary, piston, plunger, diaphragm pumps); pump specification.

Lecture VII

Introduction; Basic classification of pumps, Mechanical pump: Centrifugal and Positive displacement pumps (rotary, piston, plunger, diaphragm pumps); pump specification.

Lecture VIII

Basic characteristics curves for centrifugal pumps; fan, blower and compressor.

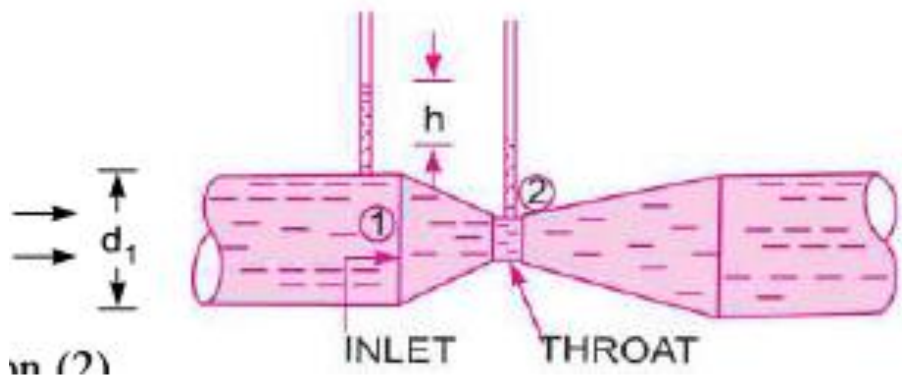
- **Flow Measurement : Introduction**
- To control industrial processes, it is essential to know the amount of material entering and leaving the process.
- Materials are transported in the form of fluids wherever possible, it is important to measure the rate at which a fluid is flowing through a pipe.
- Many different types of meters are used industrially.
- Selection of meters is based on the applicability of the instrument to the specific problem, its installed cost and costs of operation, the range of flow rates it can accommodate, and its accuracy.
- Few types of flowmeters measure the mass flow rate directly, but the majority measure the volumetric flow rate or the average fluid velocity, from which the volumetric flow rate can be calculated.
- To convert the volumetric flow rate to the mass flow rate requires that the fluid density under the operating conditions be known.
- The simplest and cheapest device that gives the desired accuracy should be chosen.
- The common types of flow meters that find industrial applications are:
- Venturimeter, Orificemeter, Pitot tube, Variable area meter

- **Flow Measurement : Venturi meter**
- A venturi meter is a device used for measuring the rate of a flow of a fluid flowing through a pipe.
- It consists of three parts 1. A short converging part, 2. Throat, 3. Diverging part.
- It is based on the principle of Bernoulli's equation.
- Consider a venturi meter fitted in a horizontal pipe through which a fluid is flowing as shown in the Fig.

Let d_1 = diameter at inlet or at section (1),
p_1 = pressure at section (1)
v_1 = velocity of fluid at section (1),

$$a = \text{area at section (1)} = \frac{\pi}{4} d_1^2$$

and d_2, p_2, v_2, a_2 are corresponding values at section (2).



- **Flow Measurement : Venturi meter**
- A venturi meter is a device used for measuring the rate of a flow of a fluid flowing through a pipe.

Applying Bernoulli's equation at sections (1) and (2), we get

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

As pipe is horizontal, hence $z_1 = z_2$

$$\therefore \quad \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} \quad \text{or} \quad \frac{p_1 - p_2}{\rho g} = \frac{v_2^2}{2g} - \frac{v_1^2}{2g}$$

But $\frac{p_1 - p_2}{\rho g}$ is the difference of pressure heads at sections 1 and 2 and it is equal to h or $\frac{p_1 - p_2}{\rho g} = h$

Substituting this value of $\frac{p_1 - p_2}{\rho g}$ in the above equation, we get

- **Flow Measurement : Venturi meter**
- A venturi meter is a device used for measuring the rate of a flow of a fluid flowing through a pipe.

$$h = \frac{v_2^2}{2g} - \frac{v_1^2}{2g}$$

Now applying continuity equation at sections 1 and 2

$$a_1 v_1 = a_2 v_2 \quad \text{or} \quad v_1 = \frac{a_2 v_2}{a_1}$$

- Substitute the value of v1 in the above equation, we get:

$$h = \frac{v_2^2}{2g} - \frac{\left(\frac{a_2 v_2}{a_1}\right)^2}{2g} = \frac{v_2^2}{2g}\left[1 - \frac{a_2^2}{a_1^2}\right] = \frac{v_2^2}{2g}\left[\frac{a_1^2 - a_2^2}{a_1^2}\right]$$

$$v_2{}^2 = 2gh \frac{a_1^2}{a_1^2 - a_2^2}$$

$$v_2 = \sqrt{2gh \frac{a_1^2}{a_1^2 - a_2^2}} = \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$$

- **Flow Measurement : Venturi meter**
- A venturi meter is a device used for measuring the rate of a flow of a fluid flowing through a pipe.

Discharge, $Q = a_2 v_2$

$$= a_2 \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh} = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh}$$

- The above equation gives the discharge under ideal conditions and is called theoretical discharge.
- Actual discharge will be less than theoretical discharge.

$$Q_{act} = C_d \times \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh}$$

where C_d = Co-efficient of venturimeter and its value is less than 1.

- **Flow Measurement : Venturi meter**

A horizontal venturimeter with inlet and throat diameters 30 cm and 15 cm respectively is used to measure the flow of water. The reading of differential manometer connected to the inlet and the throat is 20 cm of mercury. Determine the rate of flow. Take $C_d = 0.98$.

- Take h = 252 cm

Solution. Given :

Dia. at inlet, $d_1 = 30$ cm

∴ Area at inlet, $a_1 = \frac{\pi}{4} d_1^2 = \frac{\pi}{4}(30)^2 = 706.85 \text{ cm}^2$

Dia. at throat, $d_2 = 15$ cm

∴ $a_2 = \frac{\pi}{4} \times 15^2 = 176.7 \text{ cm}^2$

$C_d = 0.98$

- **Flow Measurement : Venturi meter**

A horizontal venturimeter with inlet and throat diameters 30 cm and 15 cm respectively is used to measure the flow of water. The reading of differential manometer connected to the inlet and the throat is 20 cm of mercury. Determine the rate of flow. Take $C_d = 0.98$.

- Take h = 252 cm

The discharge through venturimeter is given by

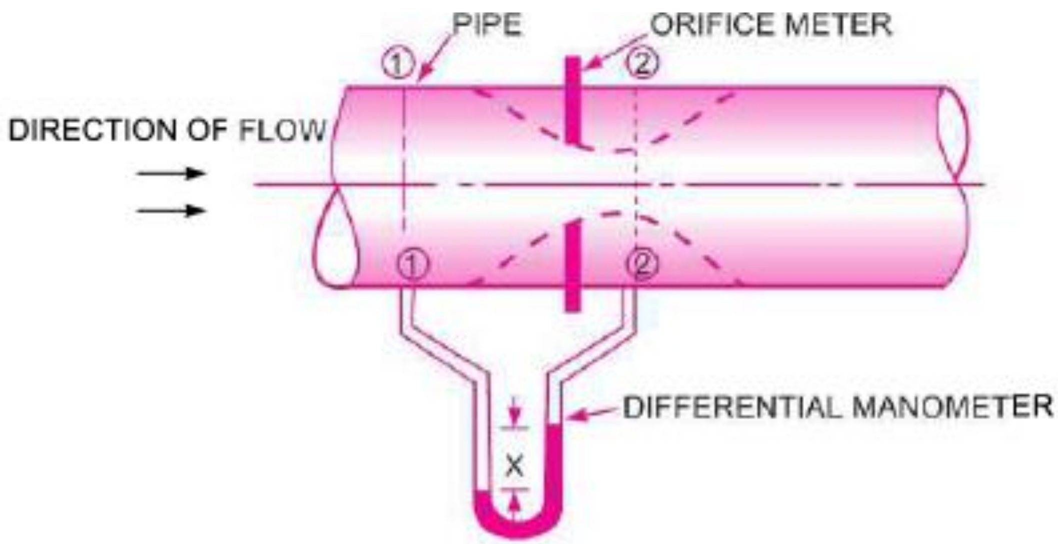
$$Q = C_d \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh}$$

$$= 0.98 \times \frac{706.85 \times 176.7}{\sqrt{(706.85)^2 - (176.7)^2}} \times \sqrt{2 \times 9.81 \times 252}$$

$$= \frac{86067593.36}{\sqrt{499636.9 - 31222.9}} = \frac{86067593.36}{684.4}$$

$$= 125756 \text{ cm}^3/\text{s} = \frac{125756}{1000} \text{ lit/s} = \mathbf{125.756 \text{ lit/s}}. \textbf{ Ans.}$$

- **Flow Measurement : Orifice meter or Orifice Plate**
- It is a device used for measuring the rate of flow of a fluid through a pipe.
- It is a cheaper device as compared to venturi meter.
- It also works on the principle of Bernoulli's equation.
- It consists of a flat circular plate which has a circular sharp edged hole called orifice, which is concentric with the pipe.
- The orifice diameter is kept generally 0.5 times the diameter of the pipe.
- A differential manometer is connected at section 1, which is at a distance of about 1.5 to 2 times the pipe diameter upstream from the orifice plate and at section 2, which is at a distance of about half the diameter of the orifice on the downstream side from the orifice plate.

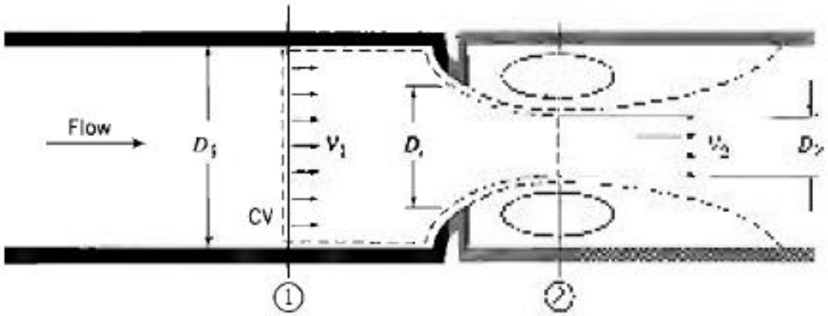


- **Flow Measurement : Orifice meter or Orifice Plate**
- The theoretical flow rate may be related to the pressure differential between sections
- (1) and (2) by applying the continuity and Bernoulli equations.
- Then empirical correction factors may be applied to obtain the actual flow rate.

Basic equations:

$$\overset{=0(1)}{\cancel{\frac{\partial}{\partial t}}\int_{CV} \rho \, d\forall} + \int_{CS} \rho \vec{V} \cdot d\vec{A} = 0$$

$$\frac{p_1}{\rho} + \frac{V_1^2}{2} + \cancel{gz_1} = \frac{p_2}{\rho} + \frac{V_2^2}{2} + \cancel{gz_2}$$



Assumptions:
(1) Steady flow.
(2) Incompressible flow.
(3) Flow along a streamline.
(4) No friction.
(5) Uniform velocity at sections ① and ②.
(6) No streamline curvature at sections ① or ②, so pressure is uniform across those sections.
(7) $z_1 = z_2$.

- **Flow Measurement : Orifice meter or Orifice Plate**
- It is a device used for measuring the rate of flow of a fluid through a pipe.

Then, from the Bernoulli equation,

$$p_1 - p_2 = \frac{\rho}{2}\left(V_2^2 - V_1^2\right) = \frac{\rho V_2^2}{2}\left[1 - \left(\frac{V_1}{V_2}\right)^2\right]$$

and from continuity

$$(-\rho V_1 A_1) + (\rho V_2 A_2) = 0$$

$$V_1 A_1 = V_2 A_2 \qquad \text{so} \qquad \left(\frac{V_1}{V_2}\right)^2 = \left(\frac{A_2}{A_1}\right)^2$$

- **Flow Measurement : Orifice meter or Orifice Plate**
- It is a device used for measuring the rate of flow of a fluid through a pipe.

Substituting gives

$$p_1 - p_2 = \frac{\rho V_2^2}{2}\left[1 - \left(\frac{A_2}{A_1}\right)^2\right]$$

Solving for the theoretical velocity, V_2,

$$V_2 = \sqrt{\frac{2(p_1 - p_2)}{\rho[1 - (A_2/A_1)^2]}}$$

The theoretical mass flow rate is then given by

$$\dot{m}_{\text{theoretical}} = \rho V_2 A_2$$

$$= \rho\sqrt{\frac{2(p_1 - p_2)}{\rho[1 - (A_2/A_1)^2]}}\,A_2$$

- **Flow Measurement : Orifice meter or Orifice Plate**
- It is a device used for measuring the rate of flow of a fluid through a pipe.

$$\dot{m}_{theoretical} = \frac{A_2}{\sqrt{1-(A_2/A_1)^2}} \sqrt{2\rho(p_1 - p_2)}$$

- The above Equation shows that, under our set of assumptions, for a given fluid (ρ) and flow meter geometry (A1 and A2), the flow rate is directly proportional to the square root of the pressure drop across the meter taps,

$$\dot{m}_{theoretical} \propto \sqrt{\Delta p}$$

- **Flow Measurement : Orifice meter or Orifice Plate**
- Several factors limit the utility of Eq. for calculating the actual mass flow rate through a meter.
- The actual flow area at section (2) is unknown when the vena contracta is pronounced (e.g., for orifice plates when Dt, is a small fraction of D1).
- The theoretical equation is adjusted for Reynolds number and diameter ratio Dt / D1 by defining an empirical discharge coefficient C such that

$$\dot{m}_{\text{actual}} = \frac{CA_t}{\sqrt{1-(A_t/A_1)^2}}\sqrt{2\rho(p_1-p_2)}$$

Letting $\beta = D_t/D_1$, then $(A_t/A_1)^2 = (D_t/D_1)^4 = \beta^4$, so

$$\dot{m}_{\text{actual}} = \frac{CA_t}{\sqrt{1-\beta^4}}\sqrt{2\rho(p_1-p_2)}$$

- Discharge coefficient, C is defined as the ratio between actual volumetric flow rate and ideal volumetric flow rate.

$$C_d = \frac{q_{\text{actual}}}{q_{\text{ideal}}}$$

- **Flow Measurement : Orifice meter or Orifice Plate**
- The discharge coefficient and velocity of approach factor frequently are combined into a single flow coefficient

$1/\sqrt{1-\beta^4}$ is the *velocity-of-approach factor.*

$$K \equiv \frac{C}{\sqrt{1-\beta^4}}$$

In terms of this flow coefficient, the actual mass flow rate is expressed as

$$\dot{m}_{\text{actual}} = KA_t\sqrt{2\rho(p_1 - p_2)}$$

- **Flow Measurement : Orifice meter or Orifice Plate**

An orifice meter with orifice diameter 10 cm is inserted in a pipe of 20 cm diameter.

The pressure gauges fitted upstream and downstream of the orifice meter gives readings of 19.62 N/cm² and 9.81 N/cm² respectively. Co-efficient of discharge for the orifice meter is given as 0.6. Find the discharge of water through pipe.

$$d_0 = 10 \text{ cm}$$

$$a_0 = \frac{\pi}{4}(10)^2 = 78.54 \text{ cm}^2$$

$$d_1 = 20 \text{ cm}$$

$$a_1 = \frac{\pi}{4}(20)^2 = 314.16 \text{ cm}^2$$

$$p_1 = 19.62 \text{ N/cm}^2 = 19.62 \times 10^4 \text{ N/m}^2$$

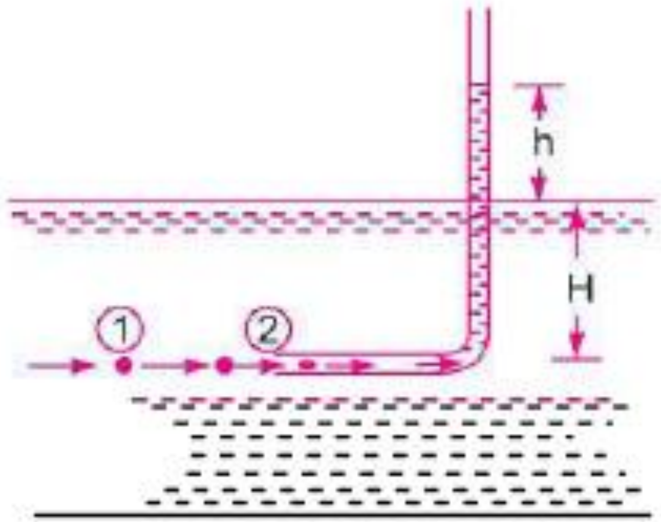
$$p_2 = 9.81 \times 10^4$$

$$C_d = 0.6$$

$$\dot{m}_{\text{actual}} = \frac{CA_t}{\sqrt{1-(A_t/A_1)^2}}\sqrt{2\rho(p_1 - p_2)}$$

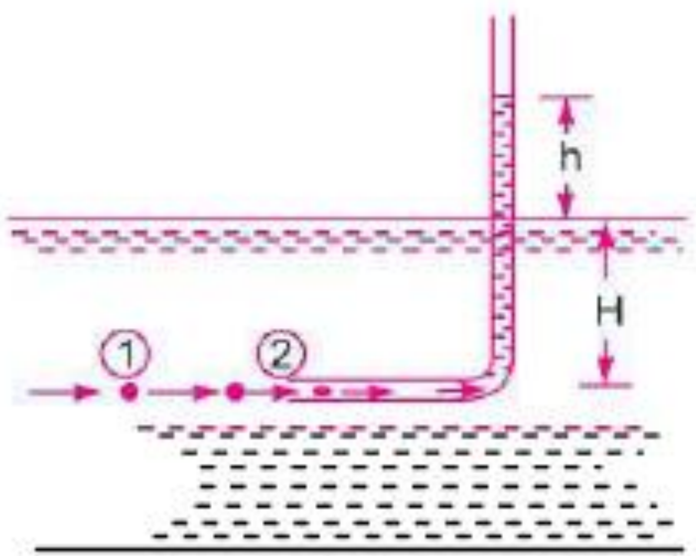
$$= \frac{20736838.09}{304} = 68213.28 \text{ cm}^3\text{/s} = \mathbf{68.21 \text{ litres/s.}}$$

- **Flow Measurement : Pitot tube**
- It is a device used for measuring the local velocity of flow at any point in a pipe or a channel.
- It is based on the principle that if the velocity of flow at a point becomes zero, the pressure there is increased due to the conversion of the kinetic energy into pressure energy.
- In its simplest form, the pitot-tube consists of a glass tube, bent at right angles.
- The lower end, which is bent through 90° is directed in the upstream direction.
- The liquid rises up in the tube due to the conversion of kinetic energy into pressure energy.
- The velocity is determined by measuring the rise of liquid in the tube.



- **Flow Measurement : Pitot tube**
- Consider two pints 1 and 2 at the same level in such a way that point 2 is just as the inlet of the pitot-tube and point 1 is far away from the tube.
- Let

p_1 = intensity of pressure at point (1)
v_1 = velocity of flow at (1)
p_2 = pressure at point (2)
v_2 = velocity at point (2), which is zero
H = depth of tube in the liquid
h = rise of liquid in the tube above the free surface.



- **Flow Measurement : Pitot tube**
- Consider two pints 1 and 2 at the same level in such a way that point 2 is just as the inlet of the pitot-tube and point 1 is far away from the tube.

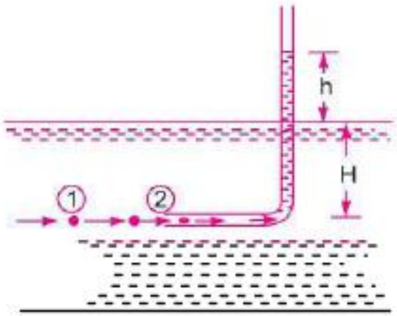
Applying Bernoulli's equation at points (1) and (2), we get

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

But $z_1 = z_2$ as points (1) and (2) are on the same line and $v_2 = 0$.

$$\frac{p_1}{\rho g} = \text{pressure head at (1)} = H$$

$$\frac{p_2}{\rho g} = \text{pressure head at (2)} = (h + H)$$



- **Flow Measurement : Pitot tube**
- Consider two pints 1 and 2 at the same level in such a way that point 2 is just as the inlet of the pitot-tube and point 1 is far away from the tube.

Substituting these values, we get

$$\therefore \quad H + \frac{v_1^2}{2g} = (h + H) \quad \therefore \quad h = \frac{v_1^2}{2g} \quad \text{or} \quad v_1 = \sqrt{2gh}$$

This is theoretical velocity. Actual velocity is given by

$$(v_1)_{act} = C_v \sqrt{2gh}$$

where C_v = Co-efficient of pitot-tube

$$\therefore \quad \text{Velocity at any point} \quad v = C_v \sqrt{2gh}$$

- **Flow Measurement : Pitot tube**
- Consider two pints 1 and 2 at the same level in such a way that point 2 is just as the inlet of the pitot-tube and point 1 is far away from the tube.

A pitot-static tube placed in the centre of a 300 mm pipe line has one orifice pointing upstream and other perpendicular to it. The mean velocity in the pipe is 0.80 of the central velocity. Find the discharge through the pipe if the pressure difference between the two orifices is 60 mm of water. Take the co-efficient of pitot tube as $C_v = 0.98$.

Solution. Given :

Dia. of pipe, $d = 300 \text{ mm} = 0.30 \text{ m}$

Diff. of pressure head, $h = 60 \text{ mm of water} = .06 \text{ m of water}$

$C_v = 0.98$

Mean velocity, $\overline{V} = 0.80 \times \text{Central velocity}$

Central velocity is given by equation (6.14)

$$= C_v \sqrt{2gh} = 0.98 \times \sqrt{2 \times 9.81 \times .06} = 1.063 \text{ m/s}$$

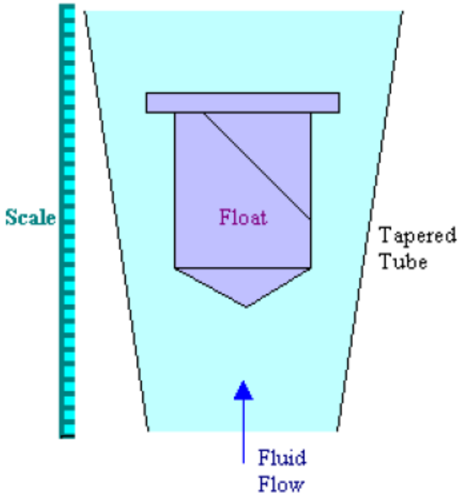
$\therefore$ $\overline{V} = 0.80 \times 1.063 = 0.8504 \text{ m/s}$

Discharge, $Q = \text{Area of pipe} \times \overline{V}$

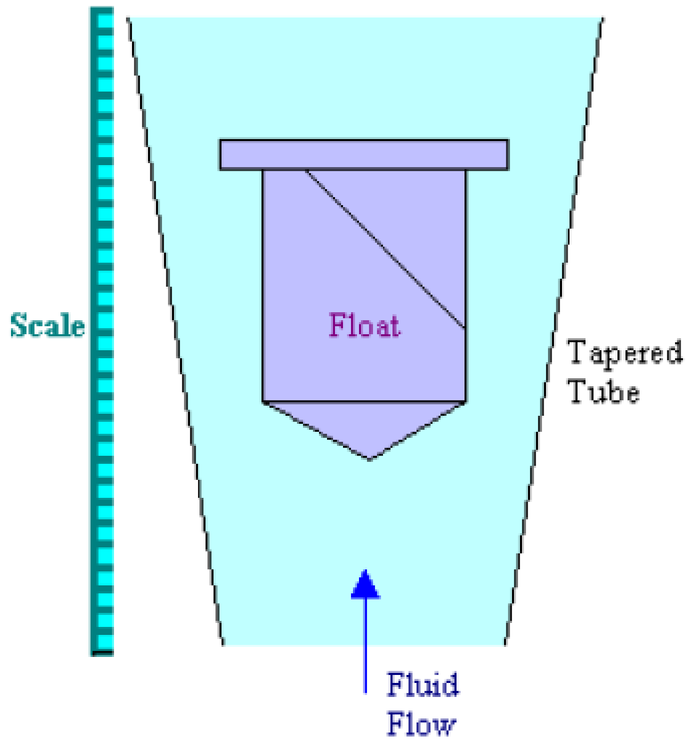
$$= \frac{\pi}{4} d^2 \times \overline{V} = \frac{\pi}{4} (.30)^2 \times 0.8504 = \mathbf{0.06 \text{ m}^3\text{/s. Ans.}}$$

- **Flow Measurement : Rotameter**
- The orificemeter, Venturimeter and flow nozzle work on the principle of constant area variable pressure drop.
- Here the area of obstruction is constant, and the pressure drop changes with flow rate.
- On the other hand Rotameter works as a constant pressure drop variable area meter.
- It can be only be used in a vertical pipeline.
- Its accuracy is also less (2%) compared to other types of flow meters.
- But the major advantages of rotameter are, it is simple in construction, ready to install and the flow rate can be directly seen on a calibrated scale, without the help of any other device, e.g. differential pressure sensor etc.
- Moreover, it is useful for a wide range of variation of flow rates (10:1).
- In the variable area meter, the drop in pressure is constant and the flow rate is a function of the area of constriction.

- **Flow Measurement : Rotameter**
- A typical meter of this kind, which is commonly known as rotameter consists of a tapered glass tube with the smallest diameter at the bottom.
- The tube contains a freely moving float which rests on a stop at the base of the tube.
- When the fluid is flowing the float rises until its weight is balanced by the upthrust of the fluid, the float reaches a position of equilibrium, its position then indicating the rate of flow.
- The flow rate can be read from the adjacent scale, which is often etched on the glass tube.
- The float is often stabilized by helical grooves incised into it, which introduce rotation - hence the name.



- **Flow Measurement : Rotameter**
- The fluid flows upward through the gap between the tube and the float.
- As the float moves up or down there is a change in the gap, as a result changing the area of the orifice.
- In fact, the float settles down at a position, where the pressure drop across the orifice will create an upward thrust that will balance the downward force due to the gravity.
- The position of the float is calibrated with the flow rate.



- **Flow Measurement : Rotameter**
- This meter may thus be considered as an orifice meter with a variable aperture, and the formula derived for orifice meter / venturi meter are applicable with only minor changes.
- Both in the orifice-type meter and in the rotameter the pressure drop arises from the conversion of pressure energy to kinetic energy (recall Bernoulli's equation) and from frictional losses which are accounted for in the coefficient of discharge.

$$\Delta p/(\rho g) = u_2^2/(2g) - u_1^2/(2g) \rightarrow 1$$

Continuity equation:

$$A_1 u_1 = A_2 u_2 \rightarrow 2$$

Where A_1 is the tube cross-section, and A_2 is the cross-section of annulus (area between the tube and float)

- **Flow Measurement : Rotameter**

From equn.1 and 2,

$$u_2 = \frac{1}{\sqrt{1-(A_2/A_1)^2}}\sqrt{\frac{2\Delta p}{\rho}} \rightarrow 3$$

$$\Delta p = V_f(\rho_f - \rho)g / A_f \rightarrow 4$$

where V_f is the volume of the float, ρ_f the density of the material of the float, and A_f is the maximum cross sectional area of the float in a horizontal plane.

The pressure drop over the float Δp, is given by:

F_d = Downward thrust on the float
F_u = Upward thrust on the float

W = Apparent weight of the float

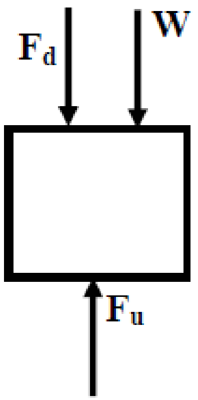
At balance,

$$W = F_u - F_d$$

or, $$V_f(\gamma_1 - \gamma_2) = p_1 A_f - p_2 A_f$$

Therefore,

$$p_1 - p_2 = \frac{v_f}{A_f}(\gamma_1 - \gamma_2)$$



- **Flow Measurement : Rotameter**

Substituting for Δp from equn.4 in equn.3, and for the flow rate the equation is arrived as

$$Q = C_D A_2 \sqrt{\frac{2V_f(\rho_f - \rho)g}{\rho A_f (1 - (A_2 / A_1)^2)}}$$

- **CL203 FLUID MECHANICS**
- **FLUID STATICS:**

- **Reference:**
- Fluid Mechanics by Fox
- Fluid Mechanics by Bansal
- Fluid Mechanics by Young
- NPTEL

CL203 – FLUID MECHANICS

III Semester BTech (Chemical Engineering & Chemical Engineering – Plastics & Polymer)

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- concept of area meters: rotameter;
- Local velocity measurement: Pitot tube.
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- **Mechanical pump: Centrifugal and Positive displacement pumps (rotary, piston, plunger, diaphragm pumps);**
- **pump specification;**
- **basic characteristics curves for centrifugal pumps;**
- **fan, blower and compressor.** [8]

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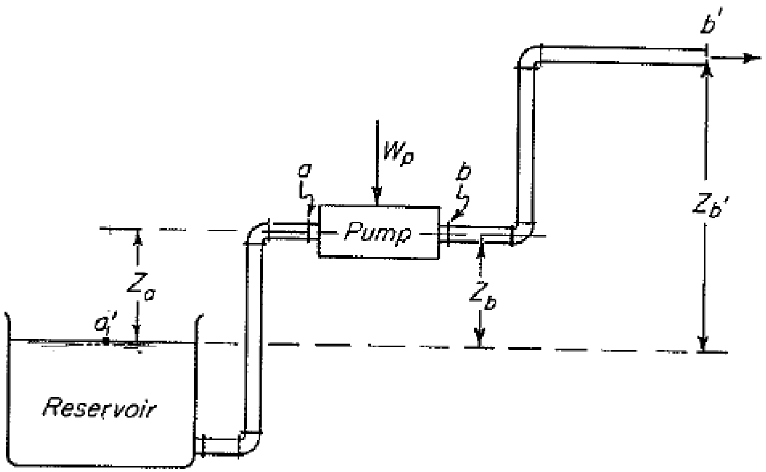
Basic characteristics curves for centrifugal pumps; fan, blower and compressor.

- **Fluid Moving Machinery: Introduction**
- Fluids are moved through pipe, equipment by pumps, fans, blowers and compressors.
- Such devices increase the mechanical energy of the fluid.
- The energy increase may be used to increase the velocity, the pressure or the elevation of the fluid.
- The most common method of adding energy is by positive displacement or centrifugal action supplied by outside forces.
- These methods lead to the two major classes of fluid moving machinery: 1. those applying direct pressure to the fluid and 2. those using torque to generate rotation.
- The first group includes positive-displacement devices and the second includes centrifugal pumps, blowers and compressors.
- Also, in positive-displacement devices, the force may be applied to the fluid either by a piston acting in a cylinder or by rotating pressure members.
- The first type is called reciprocating machines and the second is called rotary positive-displacement machines.

- **Fluid Moving Machinery: Introduction**
- The term pump, fan, blower and compressor do not always have precise meanings.
- For example, air pump and vacuum pump designate machines for compressing a gas.
- Generally, however, a pump is a device for moving a liquid; a fan, a blower or a compressor adds energy to a gas.
- Fans discharge large volumes of gas into open spaces or large ducts.
- They are low speed rotary machines and generate pressures of the order of a few inches of water.
- Blowers are high-speed rotary devices that develop a maximum pressure of about 2 atm.
- Compressors discharge at pressures from 2 atm to thousands of atmospheres.

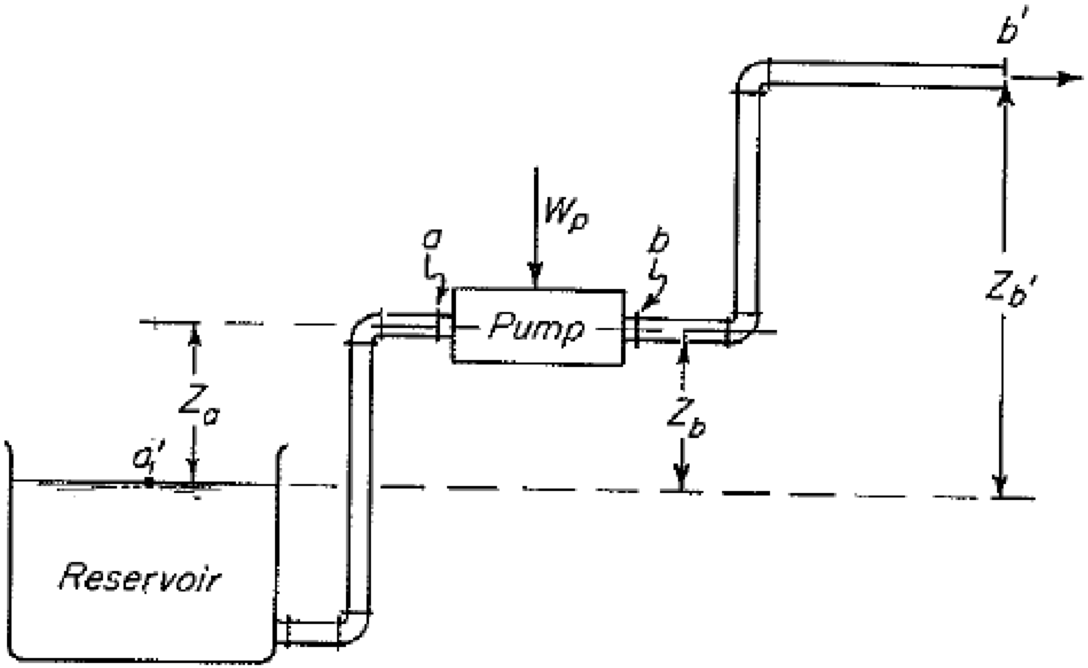
- **Fluid Moving Machinery: Pumps**
- The devices which convert the mechanical energy into hydraulic energy are called pumps.
- The hydraulic energy is in the form of pressure energy.
- In pumps, the density of the fluid is both constant and large.
- Pressure differences are usually considerable, and heavy construction is needed.
- DEVELOPED HEAD:
- The pump is installed in a pipeline to provide the energy needed to draw liquid from a reservoir and discharge a constant volumetric flow rate at the exit of the pipeline, Z_b above the level of the liquid.
- At the pump itself, the liquid enters the suction connection at station a and leaves the discharge connection at station b.



- **Fluid Moving Machinery: Pumps**
- DEVELOPED HEAD:
- A Bernoulli equation can be written between stations a and b.

$$\frac{p_a}{\rho} + \frac{gZ_a}{g_c} + \frac{\alpha_a \bar{V}_a^2}{2g_c} + \eta W_p = \frac{p_b}{\rho} + \frac{gZ_b}{g_c} + \frac{\alpha_b \bar{V}_b^2}{2g_c} + h_f$$

- The above equation is a final working equation for problems on the flow of incompressible fluids.
- Where Wp be the work done by the pump per unit mass of fluid and η pump efficiency



- **Fluid Moving Machinery: Pumps**
- DEVELOPED HEAD:
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- The above equation is a final working equation for problems on the flow of incompressible fluids.
- Since the only friction is that occurring in the pump itself and is accounted for by the mechanical efficiency η, hf = 0.
- Then the equation can be written as:

$$\eta W_p = \left(\frac{p_b}{\rho} + \frac{gZ_b}{g_c} + \frac{\alpha_b \overline{V}_b^2}{2g_c}\right) - \left(\frac{p_a}{\rho} + \frac{gZ_a}{g_c} + \frac{\alpha_a \overline{V}_a^2}{2g_c}\right)$$

- **Fluid Moving Machinery: Pumps**
- DEVELOPED HEAD:
- The quantities in the parentheses are called total heads and are denoted by H or

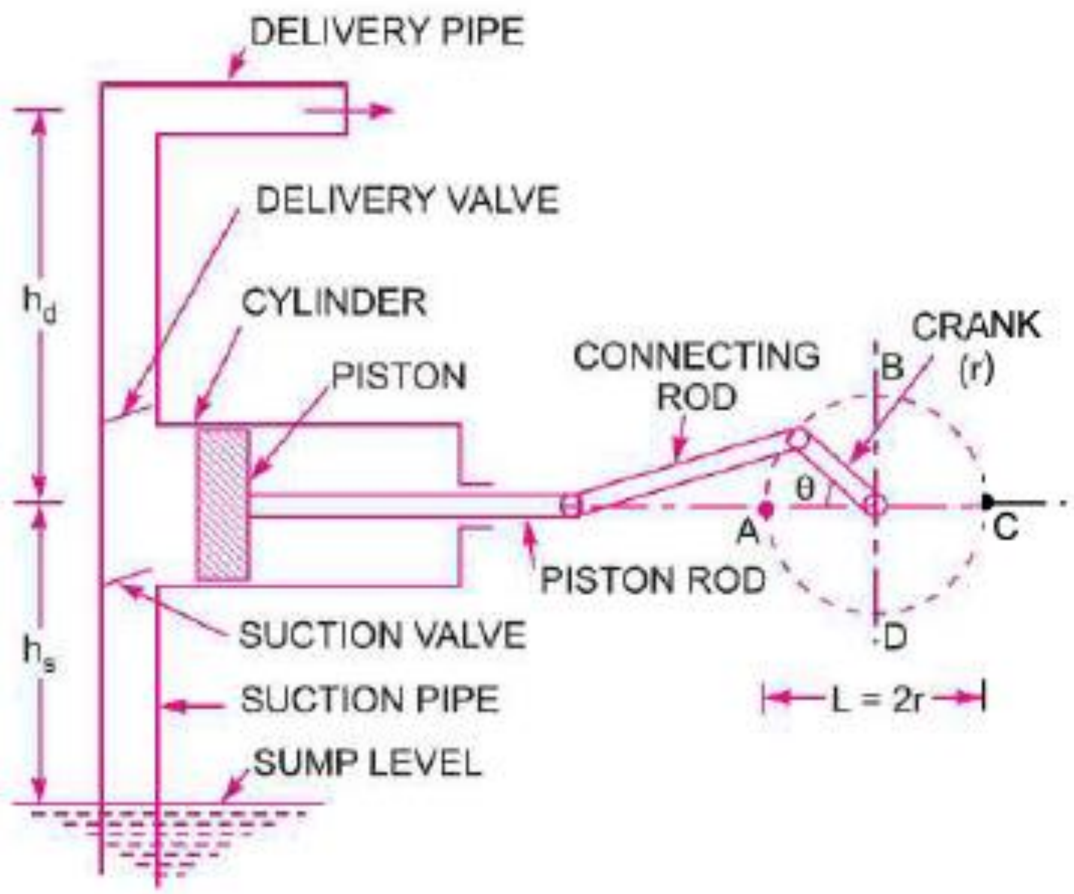
$$H = \frac{p}{\rho} + \frac{gZ}{g_c} + \frac{\alpha \overline{V}^2}{2g_c}$$

- In pumps the difference between the heights of the suction and discharge connections is usually negligible and Z_a and Z_b can be dropped from the equation.
- If H_a is the total suction head, H_b is the total discharge head, and $\Delta H = H_b - H_a$.
- Then the equation can be written as:

$$W_p = \frac{H_b - H_a}{\eta} = \frac{\Delta H}{\eta}$$

- **Fluid Moving Machinery: Pumps**
- Positive Displacement Pumps:
- In the first major class of pumps a definite volume of liquid is trapped in a chamber, which is alternately filled from the inlet and emptied at a higher pressure through the discharge.
- There are two subclasses of positive displacement pumps.
- In reciprocating pumps the chamber is a stationary cylinder that contains a piston or plunger.
- In rotary pumps the chamber moves from inlet to discharge and back to the inlet.

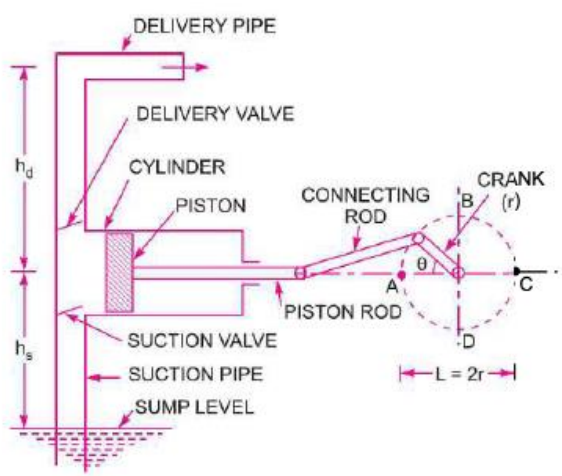
- **Fluid Moving Machinery: Pumps**
- Positive Displacement Pumps: Reciprocating Pump
- If the mechanical energy is converted into hydraulic energy by sucking the liquid into a cylinder in which a piston is reciprocating which exerts the thrust on the liquid and increases its hydraulic energy, then the pump is known as reciprocating pumps.



- **Fluid Moving Machinery: Pumps**
- Positive Displacement Pumps: Reciprocating Pump

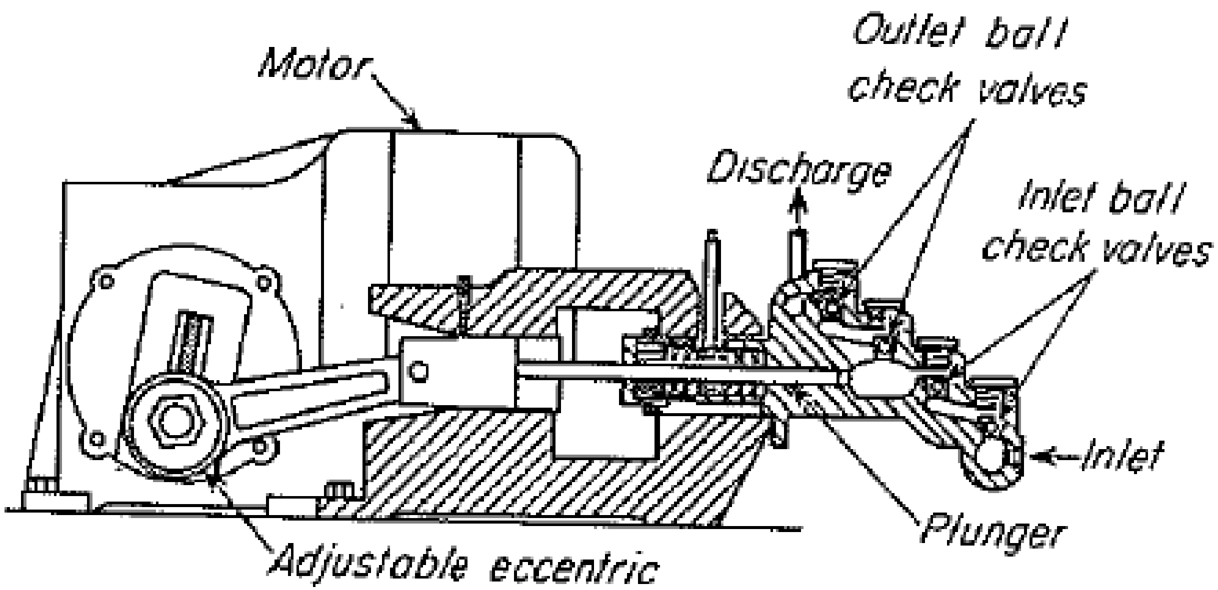
When crank starts rotating, the piston moves to and fro in the cylinder. When crank is at *A*., the piston is at the extreme left position in the cylinder. As the crank is rotating from *A* to *C*, (*i.e.*, from $\theta = 0^{\circ}$ to $\theta = 180^{\circ}$), the piston is moving towards right in the cylinder. The movement of the piston towards right creates a partial vacuum in the cylinder. But on the surface of the liquid in the sump atmospheric pressure is acting, which is more than the pressure inside the cylinder. Thus, the liquid is forced in the suction pipe from the sump. This liquid opens the suction valve and enters the cylinder.

When crank is rotating from *C* to *A* (*i.e.*, from $\theta = 180^{\circ}$ to $\theta = 360^{\circ}$), the piston from its extreme right position starts moving towards left in the cylinder. The movement of the piston towards left increases the pressure of the liquid inside the cylinder more than atmospheric pressure. Hence suction valve closes and delivery valve opens. The liquid is forced into the delivery pipe and is raised to a required height.



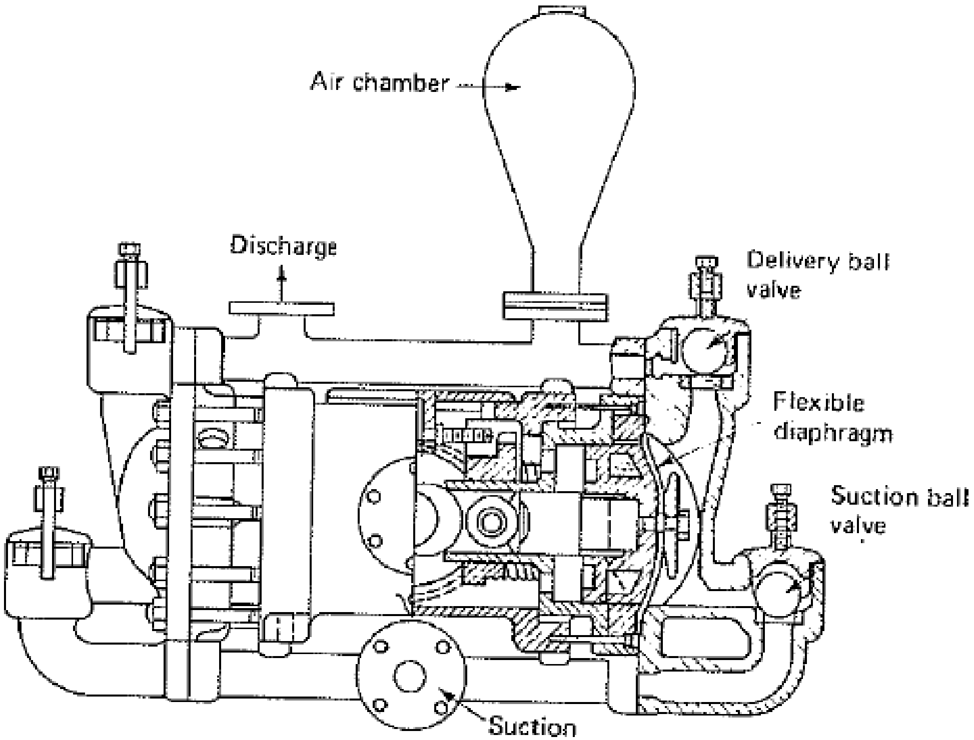
- **Fluid Moving Machinery: Pumps**
- Positive Displacement Pumps: Reciprocating Pump
- Piston pumps, plunger pumps, and diaphragm pumps are examples of reciprocating pumps.
- In a piston pump liquid is drawn through an inlet check valve into the cylinder by the withdrawal of a piston and then forced out through a discharge check valve on the return stroke.
- Most piston pumps are double acting with liquid admitted alternately on each side of the piston so that one part of the cylinder is being filled while the other is being emptied.
- Often two or more cylinders are used in parallel with common suction and discharge headers.
- The piston may be motor driven through reducing gears or a steam cylinder may be used to drive the piston rod directly.
- They can discharge against a pressure of 50 atm.

- **Fluid Moving Machinery: Pumps**
- Positive Displacement Pumps: Reciprocating Pump – Plunger Pumps
- For higher pressures plunger type pumps are used.
- A heavy walled cylinder of small diameter contains a close fitting reciprocating plunger, which is merely an extension of the piston rod.
- At the time of its stroke the plunger fills nearly all the space in the cylinder.
- Plunger pumps are single acting and usually are motor driven.
- They can discharge against a pressure of 1500 atm or more.

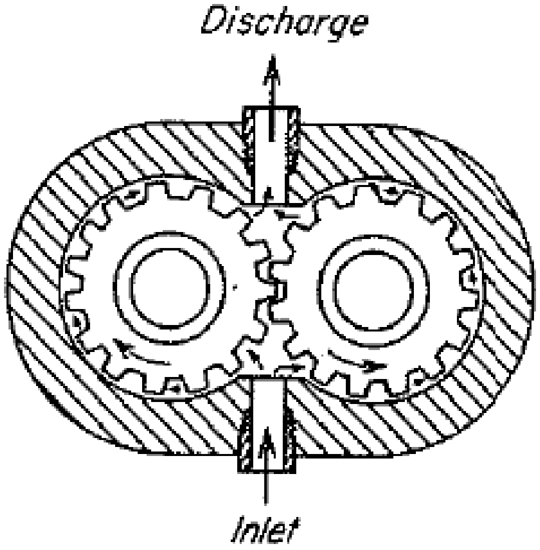


(a)

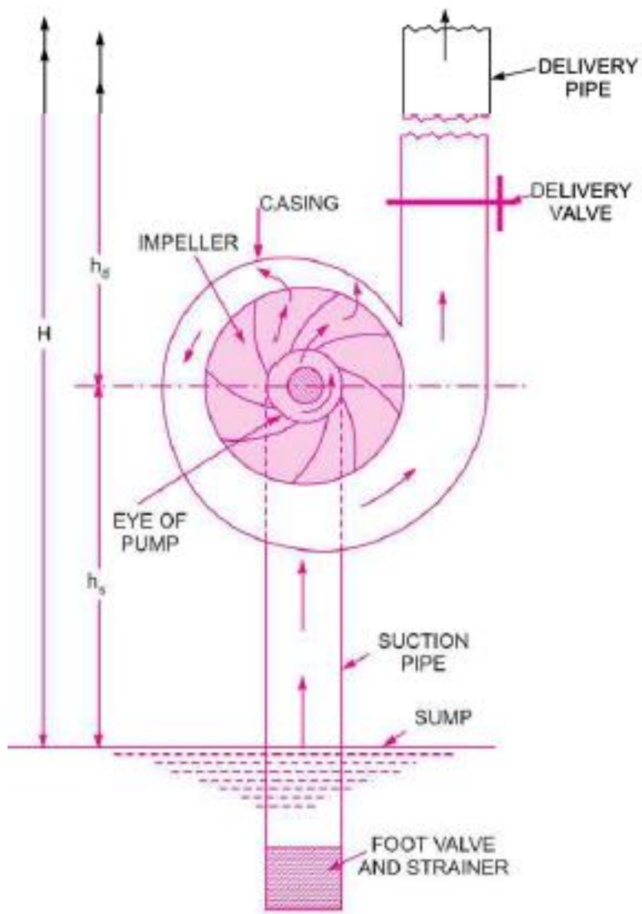
- **Fluid Moving Machinery: Pumps**
- Positive Displacement Pumps: Reciprocating Pump – Diaphragm Pumps
- In this type of pump the reciprocating member is a flexible diaphragm of metal, plastic or rubber.
- This eliminates the nee for packing or seals exposed to the liquid being pumped, a great advantage when handling toxic or corrosive liquids.
- Diaphragm pumps handle small to moderate amounts of liquid and can develop pressures in excess of 100 atm.



- **Fluid Moving Machinery: Pumps**
- Positive Displacement Pumps: Rotary Pump
- A wide variety of rotary positive displacement pumps are available.
- They bear such names as gear pumps, lobe pumps, screw pumps, cam pumps and vane pumps.
- Unlike reciprocating pumps, rotary pumps contain no check valves.
- Close tolerances between the moving and stationary parts minimize leakage from the discharge space back to the suction space.
- Rotary pumps operate best on clean, moderately viscous fluids.
- Discharge pressures upto 200 atm or more can be attained.



- **Fluid Moving Machinery: Pumps**
- Centrifugal Pump:
- Pumps as hydraulic machines which convert the mechanical energy into hydraulic energy which is mainly in the form of pressure energy,
- If the mechanical energy is converted into hydraulic energy, by means of centrifugal force acting on the liquid, the pump is known as centrifugal pump.

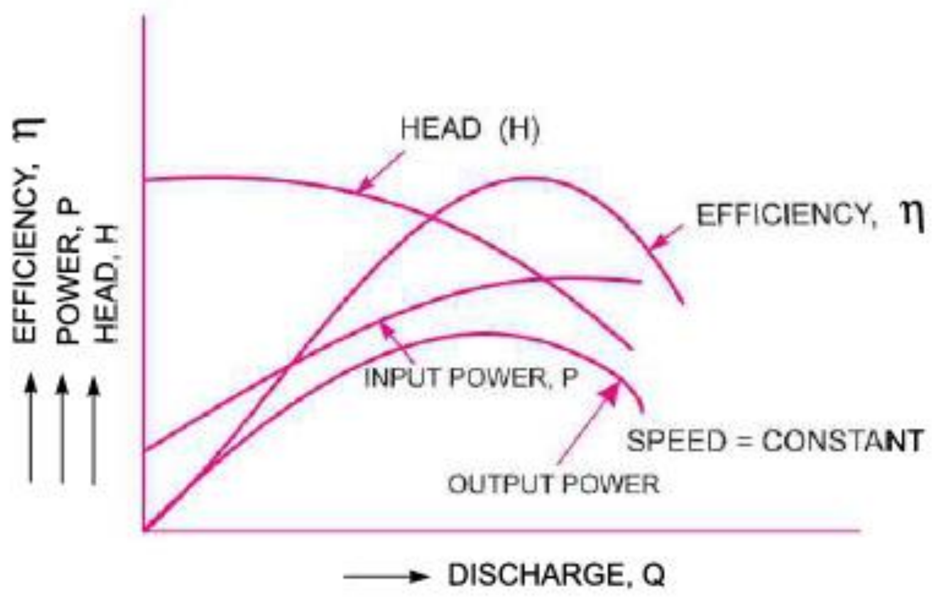


- **Fluid Moving Machinery: Pumps**
- Centrifugal Pump:
- The liquid enters through a suction connection concentric with the axis of a high speed rotary element called the impeller, which carries radial vanes integrally cast in it.
- Liquid flows outward in the spaces between the vanes and leaves the impeller at a considerably greater velocity with respect to the ground than at the entrance to the impeller.
- In a pump the space between the vanes is completely filled with liquid.
- The liquid leaving the outer periphery of the impeller is collected in a spiral casing called the volute and leaves the pump through a tangential discharge connection.
- In the volute the velocity head of the liquid from the impeller is converted into pressure head.
- The power is applied to the fluid by the impeller and is transmitted to the impeller by the torque of the drive shaft.

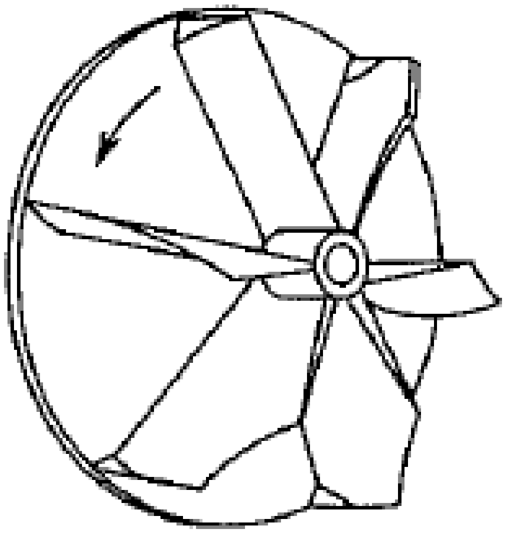
- **Fluid Moving Machinery: Pumps**
- Pump Specification:
- **Suction Head:**
- It is the vertical height of the centre line of the centrifugal pump above the water surface in the tank or pump from which water is to be fitted.
- The height is also called suction lift.
- **Delivery Head:**
- The vertical distance between the centre line of the pump and the water surface in the tank to which water is delivered is known as delivery head.
- **Static Head:**
- The sum of suction head and delivery head is known as static head.
- **Manometric Head:**
- It is defined as the head against which a centrifugal pump has to work.

- **Fluid Moving Machinery: Pumps**
- Pump Specification:
- **Efficiencies of Centrifugal Pump:**
- In case of a centrifugal pump, the power is transmitted from the shaft of the electric motor to the shaft of the pump and then to the impeller.
- From the impeller, the power is given to the water.
- Thus power is decreasing from the shaft of the pump to the impeller and then to the water.
- The following are the important efficiencies of a centrifugal pump:
- Manometric efficiency; Mechanical efficiency; and Overall efficiency.
- **Manometric efficiency:** The ratio of the manometric head to the head imparted by the impeller to the water is known as manometric efficiency.
- **Mechanical Efficiency:** The ratio of the power available at the impeller to the power at the shaft of the centrifugal pump is known as mechanical efficiency.
- **Overall Efficiency:** The ratio of power output of the pump to the power input to the pump is known as overall efficiency.

- **Fluid Moving Machinery: Pumps**
- Characteristics Curve of Centrifugal Pump: **Operating Characteristics Curve:**
- If the speed is kept constant, the variation of manometric head, power and efficiency with respect to discharge gives the operating characteristics of the pump.
- The input power curve for pumps shall not pass through the origin. It will be slightly away from the origin on the y-axis, as even at zero discharge some power is needed to overcome mechanical losses.
- The head curve will have maximum value of head when discharge is zero.
- The output power curve will start from origin as at Q = 0, output power will be zero.
- The efficiency curve will start from origin as at Q = 0, η = 0.



- **Fluid Moving Machinery: Fan, Blower and Compressor:**
- **FAN:**
- Large fans are usually centrifugal, operating on exactly the same principle as centrifugal pumps.
- Their impeller blades, however may be curved forward, this would lead to instability in a pump but not in a fan.
- Clearances are large and discharge heads low from 5 to 60 in (130 to 1500 mm).
- Sometimes, as in ventilating fans, nearly all the added energy is converted into velocity energy and almost none into pressure head.
- Since the change in density in a fan is small, the incompressible flow equations used in the discussion of centrifugal pumps are adequate.



- **Fluid Moving Machinery: Fan, Blower and Compressor:**
- **Blower and Compressor:**
- When the pressure on a compressible fluid is increased adiabatically, the temperature of the fluid also increases.
- The temperature rise has a number of disadvantages.
- Because the specific volume of the fluid increases with temperature, the work required to compress a pound of fluid is larger than if the compression were isothermal.
- The fluid may be one that cannot tolerate high temperatures without decomposing.

- **CL203 FLUID MECHANICS**
- **FLUID STATICS:**

- **Reference:**
- Fluid Mechanics by Fox
- Fluid Mechanics by Bansal
- Fluid Mechanics by Young
- NPTEL