Introduction to Fluid Mechanics and applications

MIET GROUP OF INSTITUTIONS

UNIT-4

Lecture No. 24

Fluid Mechanics

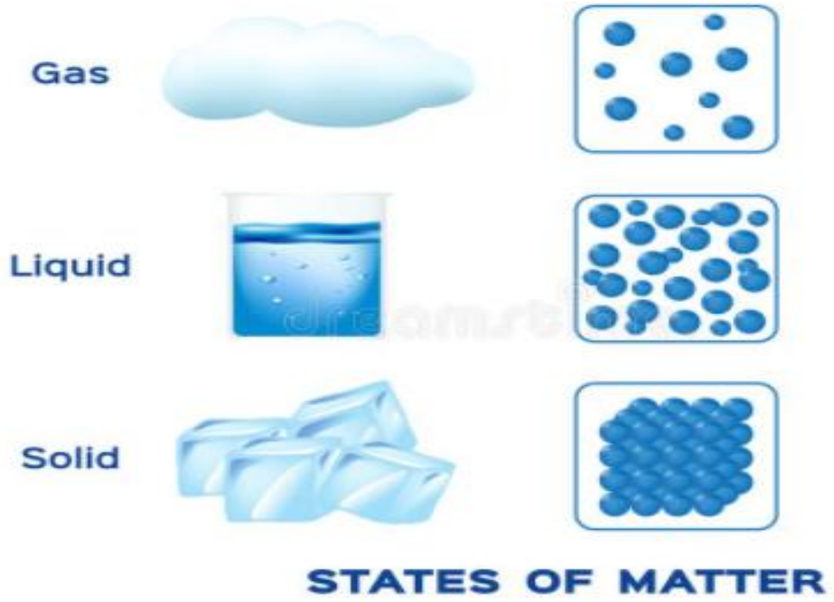
- A matter exists in either the solid state or the fluid state.

- The fluid state is further divided into
  - Liquid state
  - Gaseous state

- In fact the same matter may exist in any one of the three states i.e. solid, liquid and gaseous.
- For example water occurs in a liquid state, may also occur in solid state as ice and in a gaseous state as vapour.

Fluid Mechanics

- In solids the molecules are very closely spaced.
- In liquids the spacing between the molecules is relatively large.
- In gases the space between the molecules is still larger.



Fluid Mechanics

- "Fluid mechanics is that branch of science which deals with the behavior of the fluids at rest as well as in motion."

- In general the scope of fluid mechanics is very wide which includes the study of all liquids and gases.

- It has applications in mechanical, civil, chemical and biomedical engineering etc.

Fluid

- Fluid may be defined as a substance which is capable of flowing. It has no definite shape of its own, but conforms to the shape of the containing vessel.

OR

- "A fluid is a substance which deforms continuously under the action of tangential or shear force."

- A liquid is a fluid, which possesses a definite volume, which may vary slightly with temperature and pressure.

- A gas is a fluid, which is compressible and possesses no definite volume but it always expands until its volume is equal to that of the container.

- Examples of fluids are : Water, Milk, Kerosene, Petrol, Gases etc

Basic Properties of Fluid

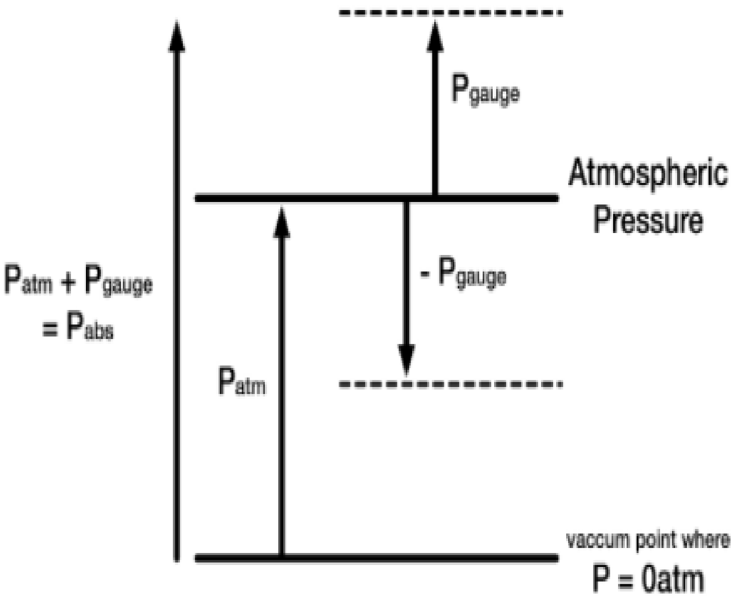
1. Pressure
2. Density
3. Specific Weight
4. Specific Gravity
5. Dynamic Viscosity
6. Kinematic Viscosity

1. Pressure

- "It is defined as normal force per unit area."

$$P = \frac{F}{A}$$

- It is a scalar quantity.

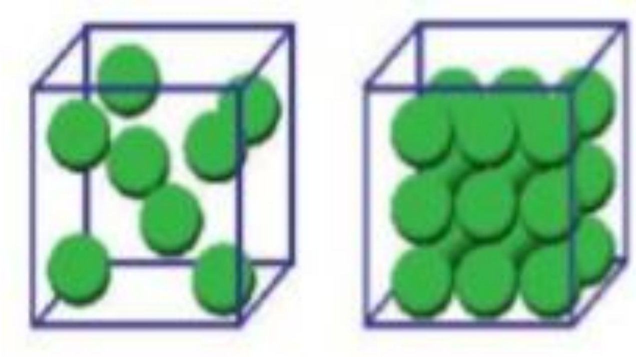


- **Units of Pressure :**
- N/m^2
- Pascal (Pa) (1 Pa = 1 N/m^2)
- atm (1 atm = 101325 Pa = 101.325 kPa)
- Bar (1 bar = 10^5 Pa = 10^5 N/m^2)

2. Density(ρ) or Mass Density

- "It is defined as mass per unit volume of the substance."

$$\rho = \frac{m}{V}$$



- **Units of density**
- Kg/m^3
- g/cm^3 or g/cc(1 g/cc = 10^3 kg/m^3)

- For example
- ρ_{water} = 1000 kg/m^3
- ρ_{air}= 1.2 kg/m^3
- ρ_{steel} = 7850 kg/m^3

3.Specific Weight (ω)

- Specific weight is also known as weight density.

- "It is defined as weight per unit volume of substance."

$$\omega = \frac{weight}{Volume} = \frac{mg}{V} = \rho g \qquad [\rho = \frac{m}{V}]$$

- Unit of specific weight is N/m^3

4. Specific Gravity(s)

- “ It is defined as the density of the fluid w.r.t. the density of standard fluid.”

- Specific Gravity(s) = $\frac{density\ of\ fluid}{density\ of\ standard\ fluid}$

- For liquid, standard fluid is water at 4˚C(39.2˚F), 1 atm, 1000 kg/m^3).

- For gases, standard fluid is Air.

Numerical

Problem 1.1 *Calculate the specific weight, density and specific gravity of one litre of a liquid which weighs 7 N.*

Solution. Given :

$$\text{Volume} = 1 \text{ litre} = \frac{1}{1000} \text{ m}^3 \quad \left(\because \ 1 \text{ litre} = \frac{1}{1000} \text{ m}^3 \text{ or } 1 \text{ litre} = 1000 \text{ cm}^3\right)$$

$$\text{Weight} = 7 \text{ N}$$

(*i*) Specific weight (w)

$$= \frac{\text{Weight}}{\text{Volume}} = \frac{7 \text{ N}}{\left(\frac{1}{1000}\right) \text{m}^3} = \mathbf{7000 \ N/m^3. \ Ans.}$$

(*ii*) Density (ρ)

$$= \frac{w}{g} = \frac{7000}{9.81} \text{ kg/m}^3 = \mathbf{713.5 \ kg/m^3. \ Ans.}$$

(*iii*) Specific gravity

$$= \frac{\text{Density of liquid}}{\text{Density of water}} = \frac{713.5}{1000} \quad \{\because \ \text{Density of water} = 1000 \text{ kg/m}^3\}$$

$$= \mathbf{0.7135. \ Ans.}$$

Numerical

Problem 1.2 *Calculate the density, specific weight and weight of one litre of petrol of specific gravity = 0.7*

Solution. Given : Volume = 1 litre = $1 \times 1000 \text{ cm}^3 = \frac{1000}{10^6} \text{ m}^3 = 0.001 \text{ m}^3$

Sp. gravity $S = 0.7$

(*i*) *Density* (ρ)

Using equation (1.1*A*),

Density (ρ) $= S \times 1000 \text{ kg/m}^3 = 0.7 \times 1000 = \mathbf{700 \text{ kg/m}^3}$. **Ans.**

(*ii*) *Specific weight* (*w*)

Using equation (1.1), $w = \rho \times g = 700 \times 9.81 \text{ N/m}^3 = \mathbf{6867 \text{ N/m}^3}$. **Ans.**

(*iii*) *Weight* (*W*)

We know that specific weight $= \frac{\text{Weight}}{\text{Volume}}$

or $w = \frac{W}{0.001}$ or $6867 = \frac{W}{0.001}$

∴ $W = 6867 \times 0.001 = \mathbf{6.867 \text{ N}}$. **Ans.**

5. Dynamic Viscosity

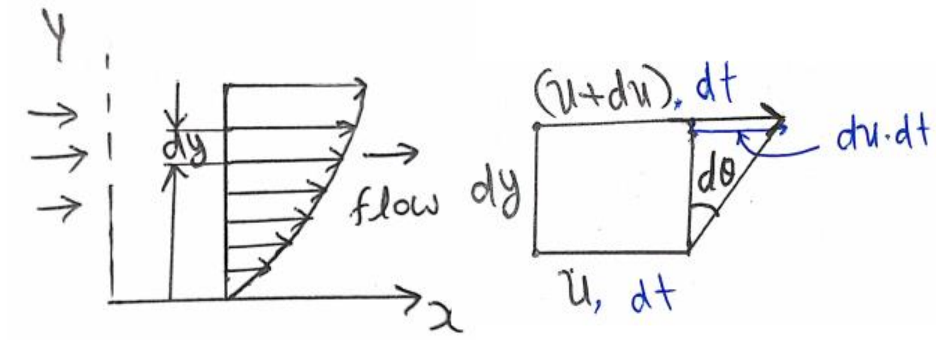
- "Two adjacent layers of the fluid **resist** the motion of each other such a fundamental property of the fluid is known as **viscosity or dynamic viscosity.**"

- Therefore the frictional force between the adjacent layers is known as viscous shear force.

tan dθ = $\frac{du.dt}{dy}$

if dθ is very small, dθ= $\frac{du.dt}{dy}$

$$\frac{d\theta}{dt} = \frac{du}{dy}$$



Where $\frac{d\theta}{dt}$ = Rate of angular(shear) deformation and

$\frac{du}{dy}$= Velocity gradient.

Cause of Viscosity

- Basic cause of viscosity is **cohesive forces** between the molecules.

- Because in case of liquid cohesive force is high and in case of gases cohesive force is very less.

- Therefore viscosity of liquid is very high as compared to viscosity of gases.

Lecture No. 25

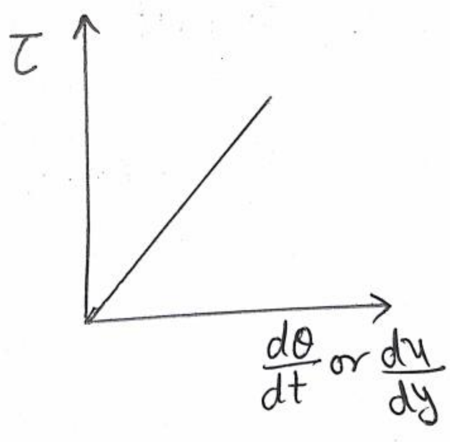
Newton's law of Viscosity

- According to Newton's law of viscosity "Shear stress between the layers of fluid is directly proportional to rate of shear deformation."

$$\tau \propto \frac{d\theta}{dt}$$

or, $$\tau \propto \frac{du}{dy}$$ [Because $\frac{d\theta}{dt} = \frac{du}{dy}$]

$$\tau = \mu \frac{du}{dy}$$



- Where **μ** is proportionality constant(**property of fluid**) which is known as viscosity or dynamic viscosity.

Unit of Viscosity

- **Unit of viscosity**

- MKS : $\frac{N-s}{m^2} = \frac{kg-m}{s^2} \times \frac{s}{m^2} = \frac{kg}{m-s}$ [F = ma]

- **CGS :** $\frac{gm}{cm-s} = \frac{10^{-3}kg}{10^{-2}\,m-s} = 0.1\,\frac{kg}{m-s} = 0.1\,\frac{N-s}{m^2}$

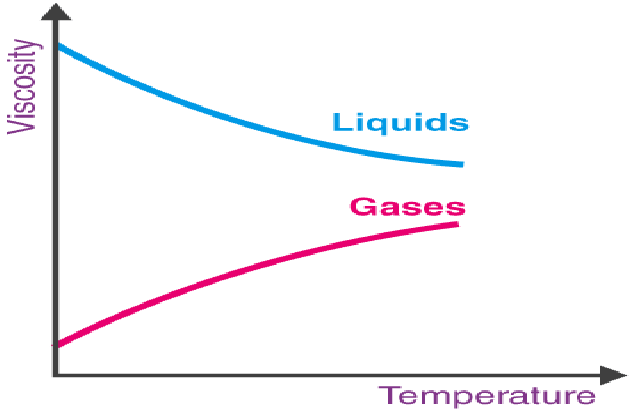
- $\frac{gm}{cm-s}$ = 1 Poise = 0.1 $\frac{N-s}{m^2}$

Comparison

Fluid-1	Fluid-2
Viscosity (μ) is high	**μ is low**
Shear stress (Ʈ) is high	Ʈ is less
Angular deformation($\frac{d\Theta}{dt}$) is less	$\frac{d\Theta}{dt}$ is high
Fluid is Difficult to flow	Fluid is Easy to flow
Examples : Tooth paste, cosmetic cream etc.	Examples : water, milk etc.

Dependency of Viscosity on Temperature

❖ Viscosity of liquid decreases with increase in temperature.[if T↑ then cohesion ↓]



❖ Viscosity of gases increaseswith increase in temperature.[if T↑ then randomness↑]

6. Kinematic Viscosity(v)

- “Ratio of dynamic Viscosity and density is called Kinematic Viscosity.

$$v = \frac{\mu}{\rho}$$

- **Unit of Kinematic Viscosity**

- MKS : m^2/s
- CGS : cm^2/s

$$1\,\frac{cm^2}{s} = 10^{-4}\,\frac{m^2}{s} = 1 \text{ stoke}$$

Types of Fluid

The fluid may be classified into the following five types:

1. Ideal fluid

2. Real fluid

3. Newtonian fluid

4. Non-Newtonian fluid

5. Ideal plastic fluid

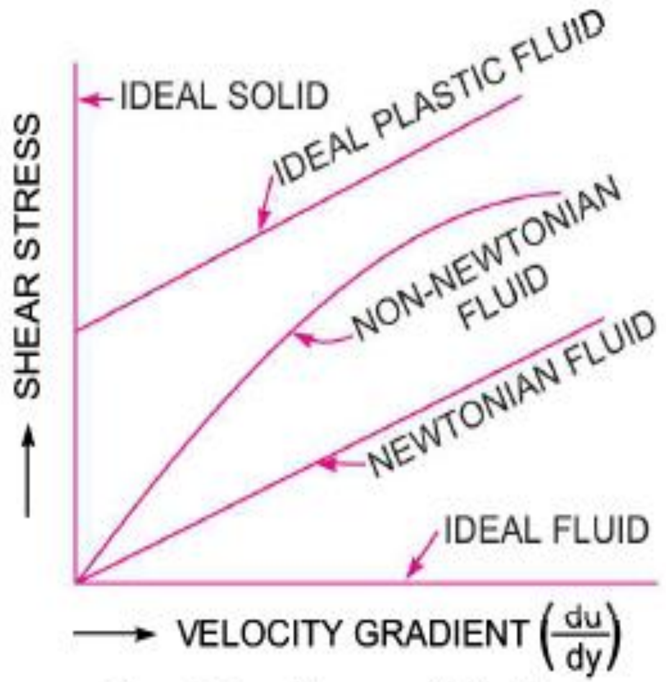


Fig. 1.2 *Types of fluids.*

Types of Fluid

❖ **REAL FLUID:** A fluid, which possess viscosity is known as real fluid. All the fluids, in actual practice are real fluids.

❖ Example : Air, water, kerosene, petrol etc.

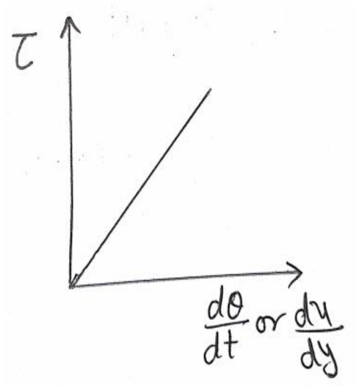
❖ **IDEAL FLUID:-** Incompressible fluid having zero viscosity is called ideal fluid($\tau = 0$).

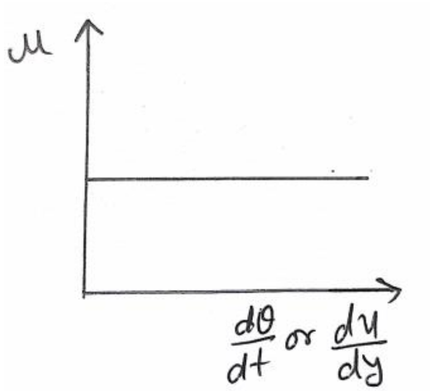
Types of Fluid

- **NEWTONIAN FLUID:**
- All the fluids which obey Newton's law of viscosity are known as Newtonian fluids.
- There is a linear relation between magnitude of τ and $\frac{d\theta}{dt}$.
- Example : Air, water, kerosene, petrol etc.

- $\tau = \mu\frac{du}{dy}$ Or $\tau = \mu\frac{d\theta}{dt}$

- $\mu = \tau/(\frac{d\theta}{dt})$





Types of Fluid

- **NON-NEWTONIAN FLUID:-**

- The fluids which do not follow Newton's law viscosity are known as Non-Newtonian Fluid.
- Example : Blood, paint mud etc.

- There is a non-linear relation between magnitude of Ʈ and $\frac{d\theta}{dt}$.

- **ELASTIC SOLID:-** may be represented by vertical line.

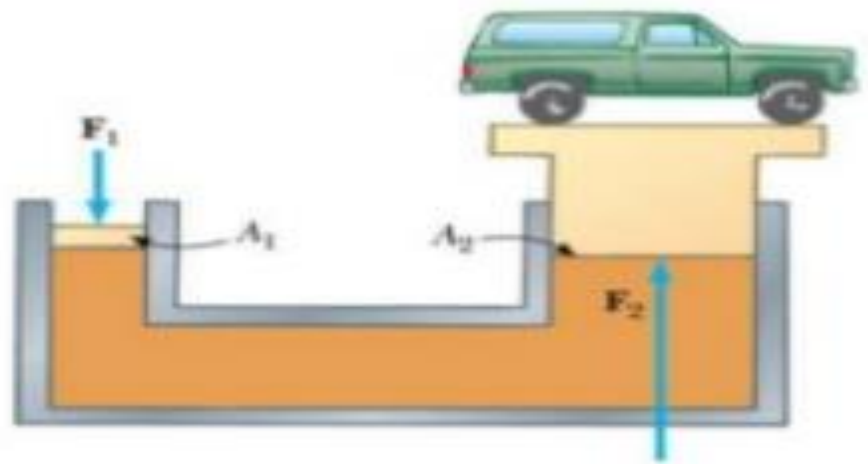
Lecture No. 26

Pascal's Law

- In a fluid at rest the intensity of pressure is same in all directions.
- In other words, when a certain pressure is applied in a fluid at rest, the pressure is equally transmitted in all the directions.

$$P = \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$\frac{F_2}{F_1} = \frac{A_2}{A_1}$$



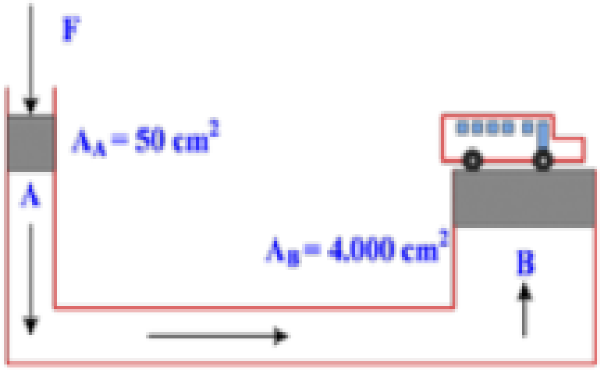
Applications of Pascal's law

- Applications of Pascal's law are-

- Hydraulic lift
- Hydraulic Jacks
- Hydraulic brakes
- Hydraulic pumps

Numerical

Q. Car's weight = 16,000 N. What is the external input force F ?



$A_1 = 50\ cm^2$
$A_2 = 4000\ cm^2$
$F_2 = 16{,}000\ N$
$F_1 = ?$

$$\frac{F_2}{F_1} = \frac{A_2}{A_1}$$

$$F_1 = F_2 \frac{A_1}{A_2} = 16000\ N\ X \frac{50\ cm^2}{4000\ cm^2}$$

$F_1 = 200\ N$ **Answer**

CONTINUITY EQUATION

- This equation is based on the principle of conservation of mass.

- The quantity of fluid per second is constant at all the cross sections through the pipe.

- Flow Rate → Volume flow rate ($\frac{m^3}{s}$) = $\frac{AL}{s}$ = A V [V = velocity]
- Flow Rate → mass flow rate ($\frac{kg}{s}$) = $\frac{\rho AL}{s}$ = ρA V

- This **Continuity Equation is** applicable for the **compressible** as well as **In- compressible** fluids .

CONTINUITY EQUATION

Consider two cross sections as shown in figure:

Let v_1 = Average velocity at cross-section 1-1

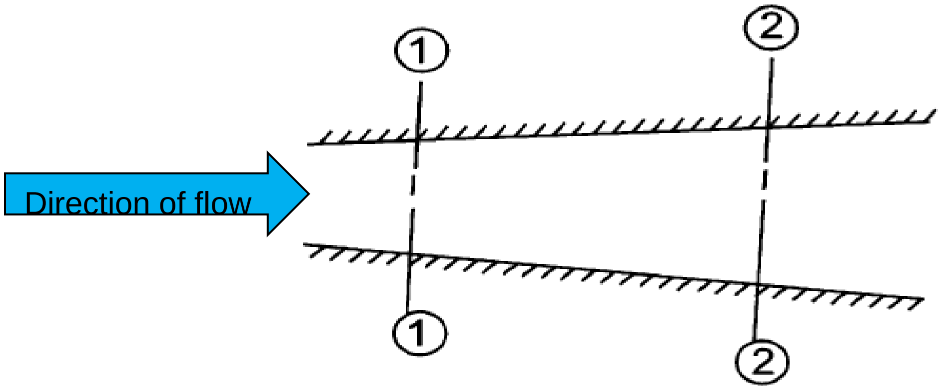
ρ_1 = density at section 1-1

A_1 = Area of pipe at section 1-1

and v_2,ρ_2, A_2 are corresponding values at section 2-2.

Rate of flow at section at 1-1 = $\rho_1 A_1 V_1$

Rate of flow at section at 2-2 = $\rho_2 A_2 V_2$



CONTINUITY EQUATION

- According to law of conservation of mass:

Rate of flow at section at **1-1** = Rate of flow at section at **2-2**

$$Q = \rho_1 A_1 V_1 = \rho_2 A_2 V_2 = \text{Constant}$$

- If the fluid is **In-compressible**, i.e. water then $\rho_1 = \rho_2$ and continuity equation becomes

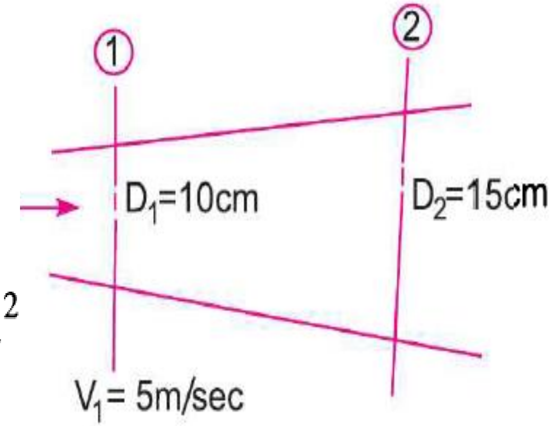
$$Q = A_1 V_1 = A_2 V_2 = \text{Constant}$$

Numerical

Problem 5.1 *The diameters of a pipe at the sections 1 and 2 are 10 cm and 15 cm respectively. Find the discharge through the pipe if the velocity of water flowing through the pipe at section 1 is 5 m/s. Determine also the velocity at section 2.*

Numerical

Problem 5.1 *The diameters of a pipe at the sections 1 and 2 are 10 cm and 15 cm respectively. Find the discharge through the pipe if the velocity of water flowing through the pipe at section 1 is 5 m/s. Determine also the velocity at section 2.*



Solution. Given :

At section 1, $D_1 = 10 \text{ cm} = 0.1 \text{ m}$

$$A_1 = \frac{\pi}{4} (D_1^2) = \frac{\pi}{4} (.1)^2 = 0.007854 \text{ m}^2$$

$V_1 = 5 \text{ m/s.}$

At section 2, $D_2 = 15 \text{ cm} = 0.15 \text{ m}$

$$A_2 = \frac{\pi}{4} (.15)^2 = 0.01767 \text{ m}^2$$

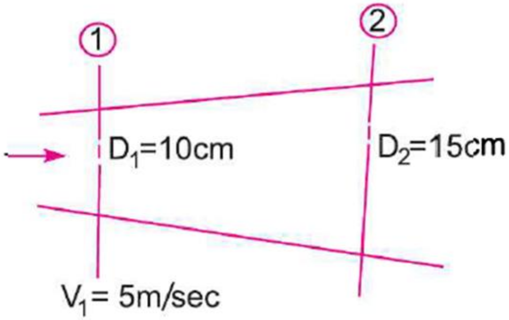
Q = ? and V_2 = ?

Numerical

(*i*) Discharge through pipe is given by equation (5.1)

or $$Q = A_1 \times V_1$$

$$= 0.007854 \times 5 = \mathbf{0.03927\ m^3/s.\ Ans.}$$



Using continuity equation for In-compressible fluid , we have $$A_1V_1 = A_2V_2$$

(*ii*) $\therefore$ $$V_2 = \frac{A_1V_1}{A_2} = \frac{0.007854}{0.01767} \times 5.0 = \mathbf{2.22\ m/s.\ Ans.}$$

Lecture No. 27

Hydraulic Machines

- Hydraulic machines are defined as those machines which convert either *hydraulic energy* into *mechanical energy* or ***mechanical energy*** **into *hydraulic energy*.**

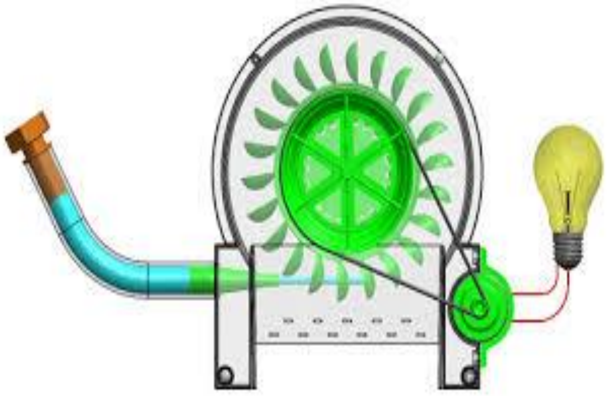
- Hydraulic Energy- Energy possessed by water.

- Mechanical Energy- power produced at shaft of turbine.

- Mechanical energy further converted into electrical energy.

Hydraulic Machines

- The **hydraulic machines** which converts the hydraulic energy into mechanical energy, are called as **turbines**.



- The **hydraulic machines** which converts mechanical energy into hydraulic energy , are called as **pump**.

Turbine

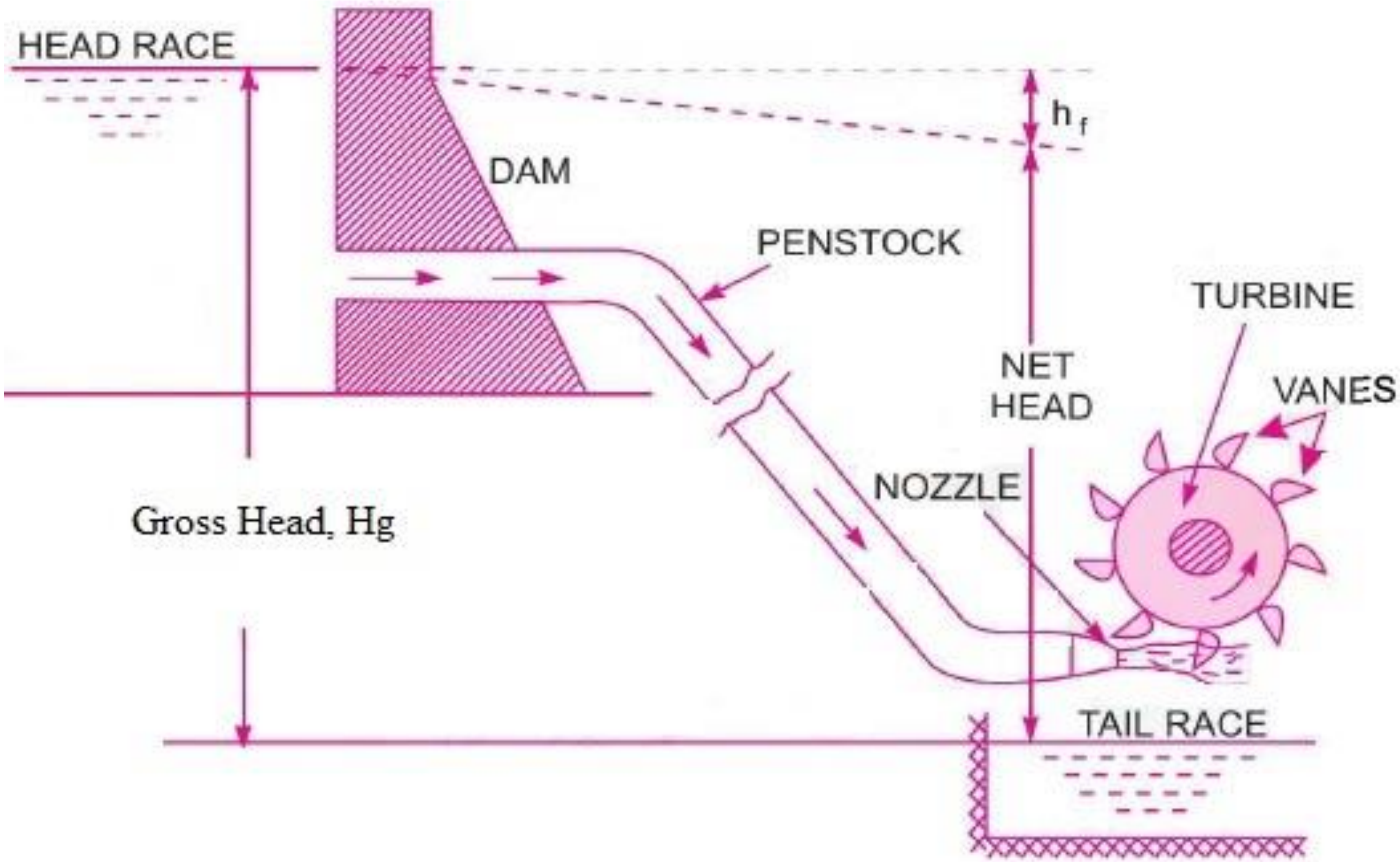
- Turbines are defined as the machines which convert the hydraulic energy into mechanical energy.

- This mechanical energy is used in running an electric generator which is directly coupled to the shaft of the turbine.

- Thus the mechanical energy is converted into electrical energy.

- The electric power which is obtained from hydraulic energy is known as *Hydro-electric power*.

General Layout of Hydro-electric power plant



Classification of turbine

The turbines are classified in the following ways:-

1. **According to the type of energy available at inlet**

(a) **Impulse turbine** (b) **Reaction turbine**

- If at the inlet of the turbine , **only kinetic energy**, the turbine is known as ***impulse turbine*.**
- e.g. Pelton Turbine.

- If at the inlet of the turbine, water possesses **kinetic energy** as well as **pressure energy**, the turbine is known as ***reaction turbine*.**
- e.g. Francis turbine, Kaplan turbine.

Classification of turbine

2. According to the *direction of flow* of water through runner:

a) Tangential flow turbine (e.g. Pelton Turbine)

b) Radial flow turbine (e.g. Francis Turbine)

c) Axial flow turbine (e.g. KaplanTurbine)

d) Mixed flow turbine (e.g. ModernFrancisTurbine)

Classification of turbine

4. According to the specific speed of turbine

a) Low specific speed turbine, ($N_s < 50$) e.g. P.T.

b) Medium specific speed turbine,($50 < N_s < 250$) e.g. F.T.

c) High specific speed turbine. ($N_s > 250$) e.g. K.T

Classification of turbine

5. According to the position of shaft of turbine

a) Horizontal shaft turbine

b) Vertical shaft turbine

(Pelton turbine has horizontal shaft whereas the rest have vertical shaft)

6. According to name of originator

a) Pelton Turbine(Pelton Wheel)

b) Francis Turbine,

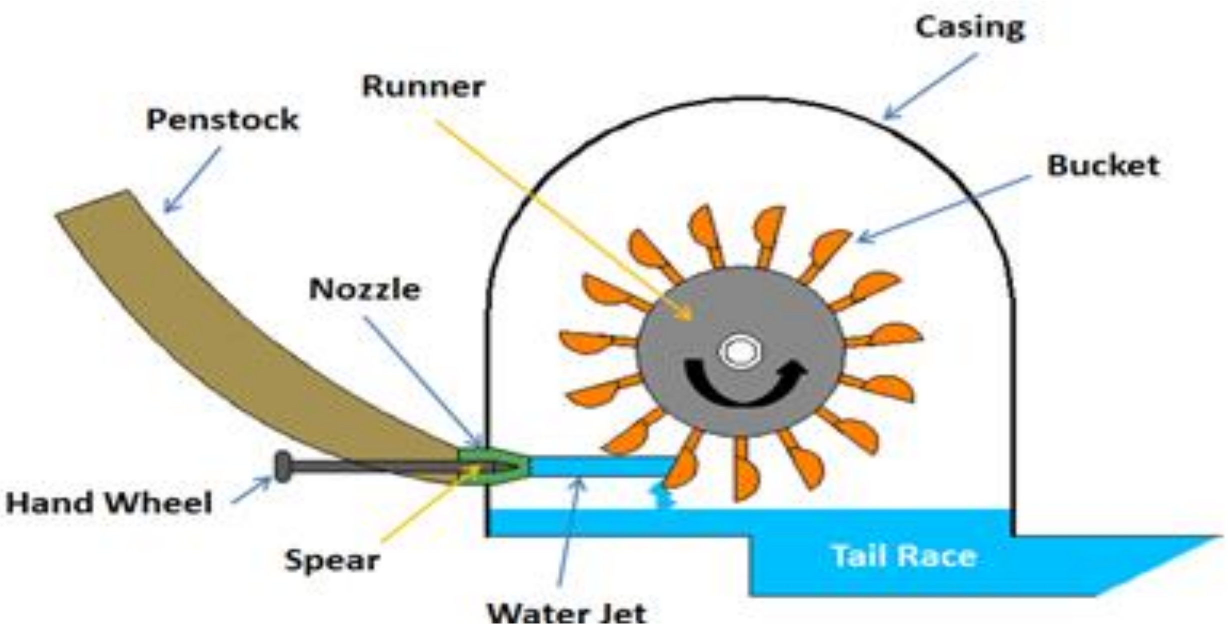
c) Kaplan Turbine.

Lecture No. 28

Impulse Turbine

Main parts of Impulse turbine are :-

1. Nozzle and flow regulating device
2. Runner and bucket
3. casing



Impulse Turbine

- Nozzle with guide mechanism- It is provided to convert the pressure energy into kinetic energy in the form of jet and it also regulates the quantity of water according to the load on turbine.

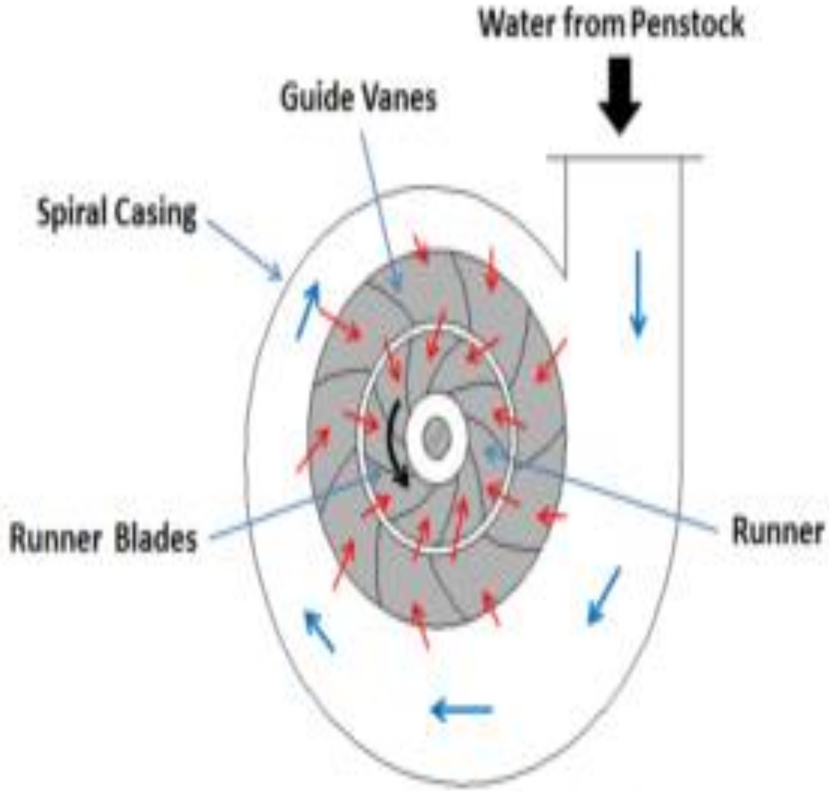
- Runner- A wheel of the turbine consist of series of buckets/blades/vanes mounted on its periphery.

- Casing- It is used to avoid accident and prevents the splashing of water. It does not perform any hydraulic function. The pressure throughout the turbine from inlet to outlet is **atmospheric** in case Impulse turbine.

Reaction Turbine

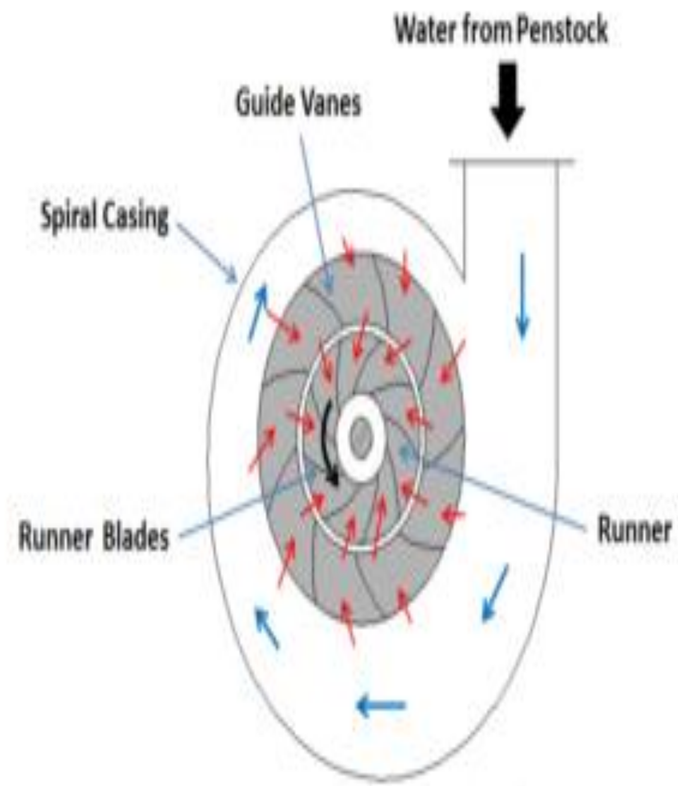
Main parts of reaction turbine are :-

1. Casing
2. Guide mechanism
3. Runner
4. Draft tube



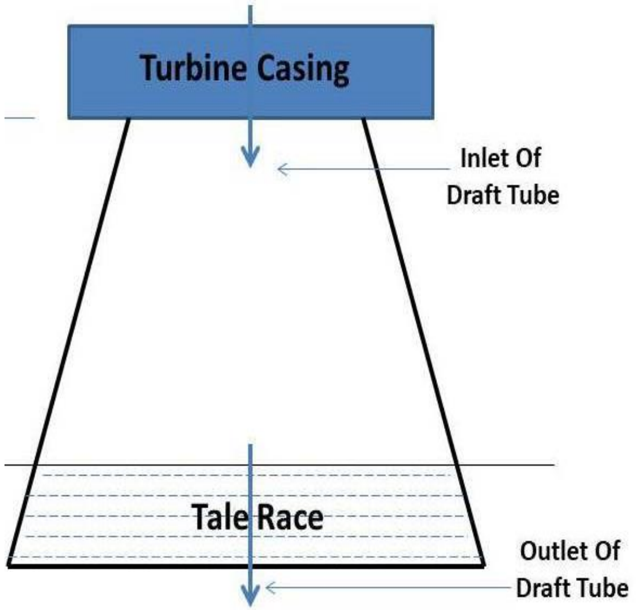
Reaction Turbine

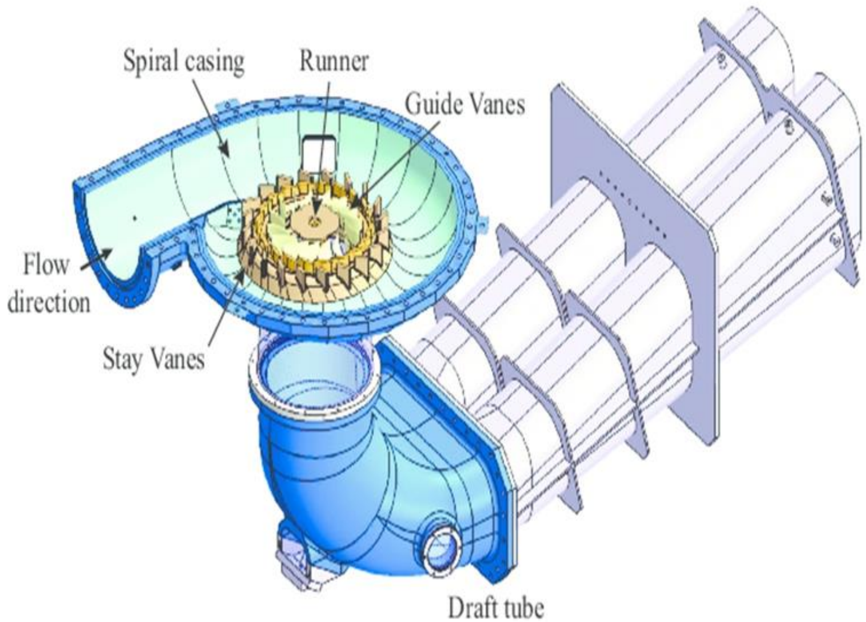
- **Casing-** In reaction turbine, casing and runner are always full of water. It is of spiral shape.
- **Runner-** A wheel of the turbine consist of series of buckets/blades/vanes mounted on its periphery.
- **Guide mechanism-** The guide vanes allow the water to strike the fixed blades on the runner without shock at inlet.



Reaction Turbine

- **Draft tube-** Draft Tube is a diverging tube fitted at the exit of runner of turbine and used to utilize the kinetic energy available with water at the exit of runner.
- Pressure head is increased by decreasing the exit velocity.
- Overall efficiency and the output of the turbine can be improved.





Lecture No. 29

Pump

- The hydraulic machine which converts ***Mechanical energy*** *into* ***Hydraulic energy*** is known as pump.

- The hydraulic energy is in the form of ***Pressure Energy***.

- If the mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid, the hydraulic machine is called ***Centrifugal Pump***.

- The centrifugal pump works on the principle of ***forced vortex flow.***

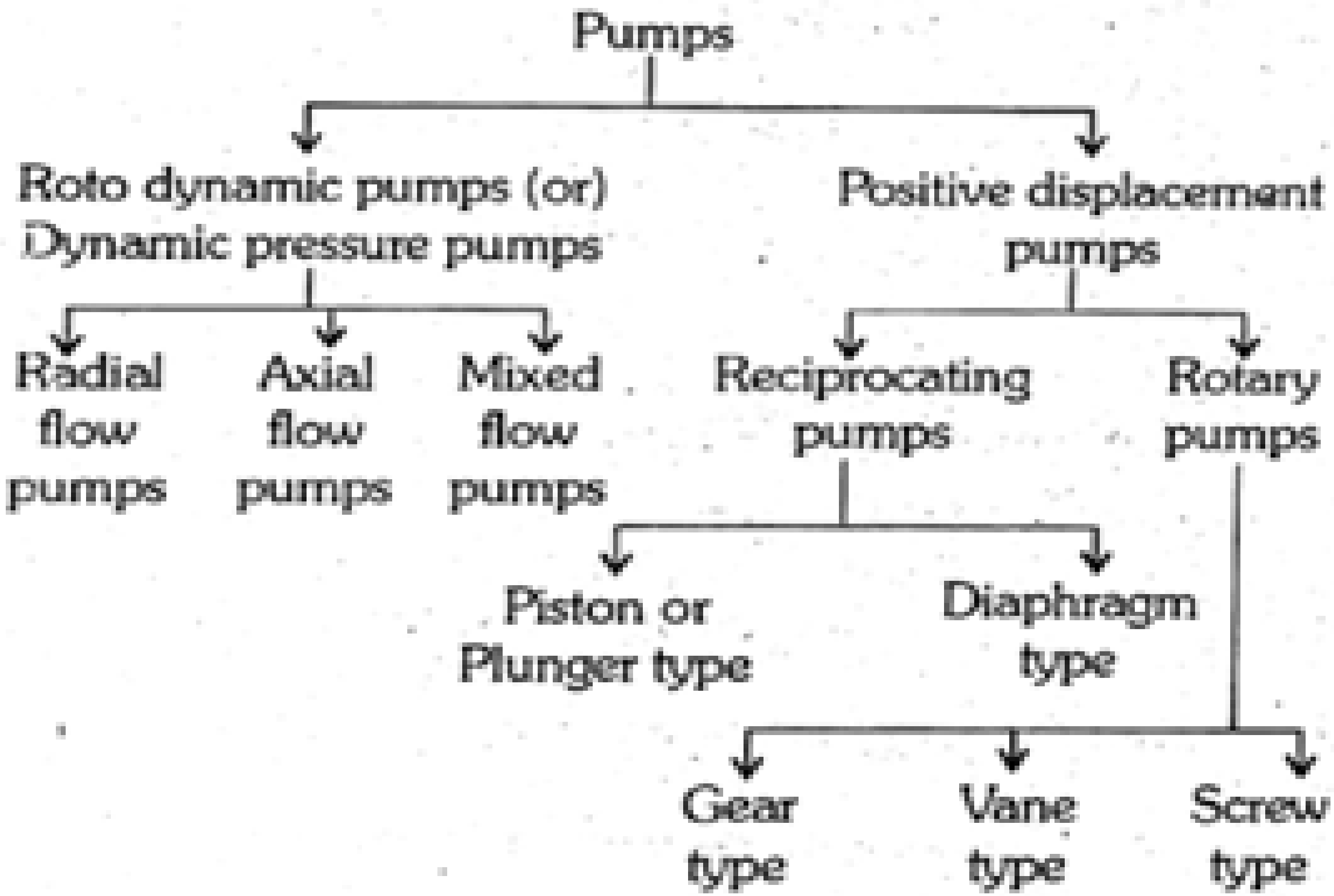
Classification of Pump

There exist a wide variety of pumps that are designed for various specific applications. However, most of them can be broadly classified into two categories as mentioned below-

1. Dynamic Pressure Pumps

2. Positive Displacement Pump

Classification of Pump



Centrifugal Pump

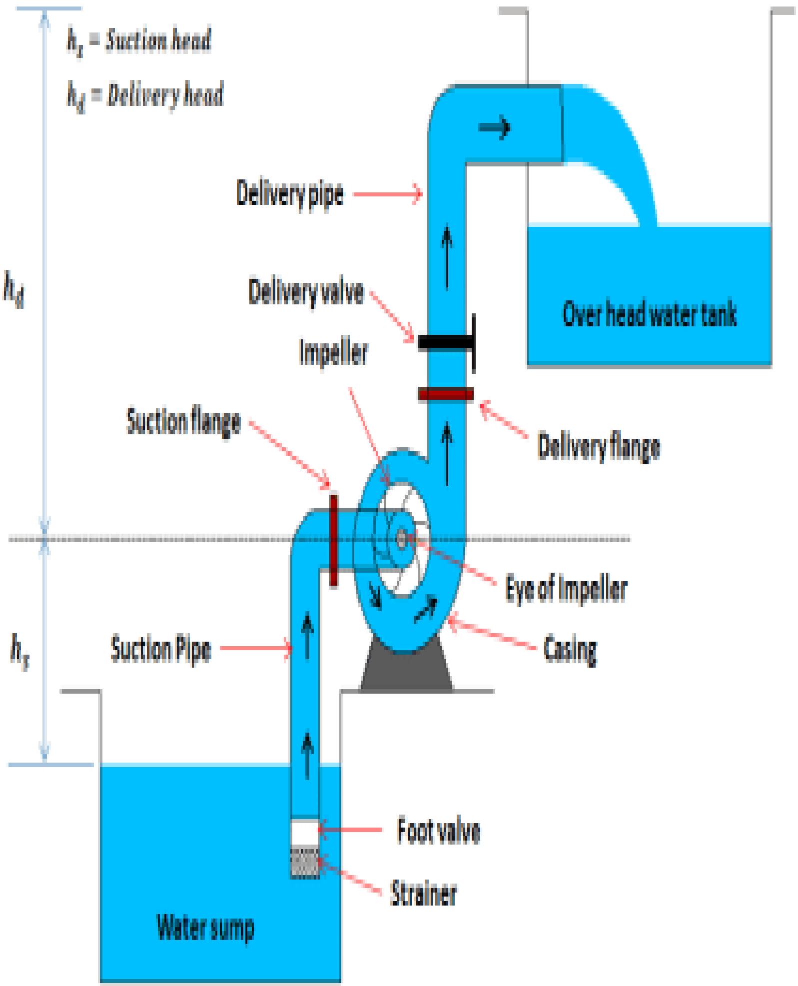
Main parts of a C.P. are :-

1. Impeller

2. Casing

3. Suction pipe with foot valve and a strainer.

4. Delivery pipe

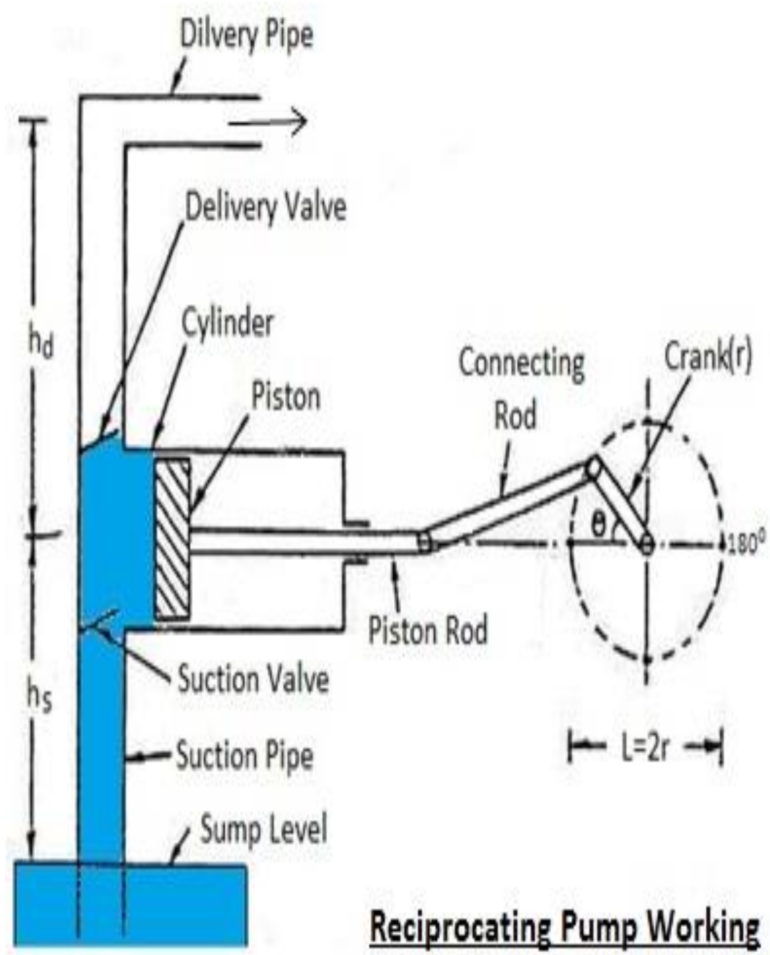


Centrifugal Pump Working

Reciprocating Pump

The main components of R.P. are:

1. Cylinder.
2. Piston and Piston Rod.
3. Crank and Connecting Rod.
4. Suction Pipe.
5. Suction Valve.
6. Delivery Pipe.
7. Delivery Valve.



Types of Reciprocating Pump

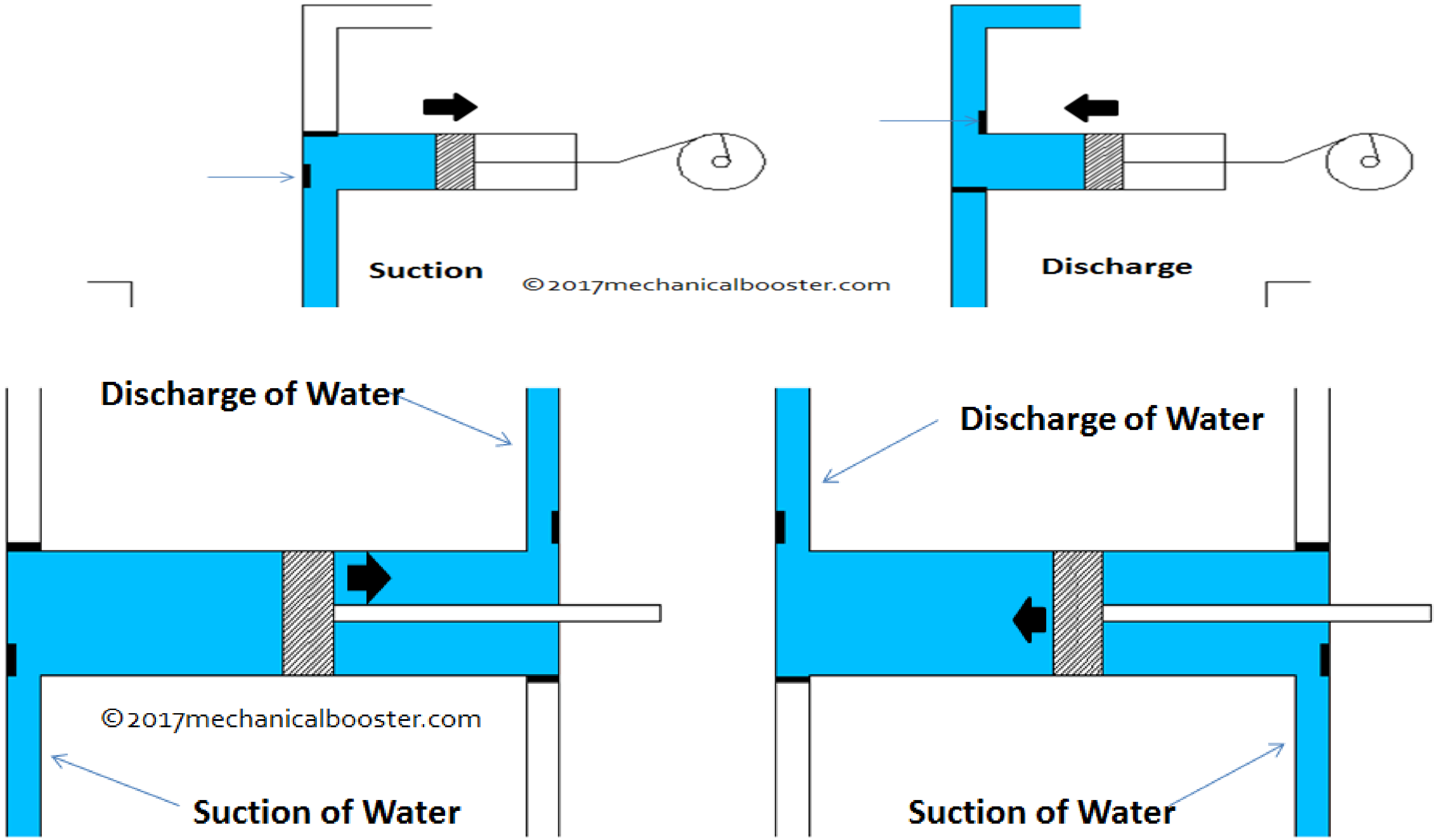
1. According to the water being in contact with one side or both sides of the piston-

A. Single acting pump
B. Double acting pump

2. According to the number of cylinder provided

A. Single cylinder pump,
B. Double cylinder pump,
C. Triple cylinder pump.

Double acting R.P.



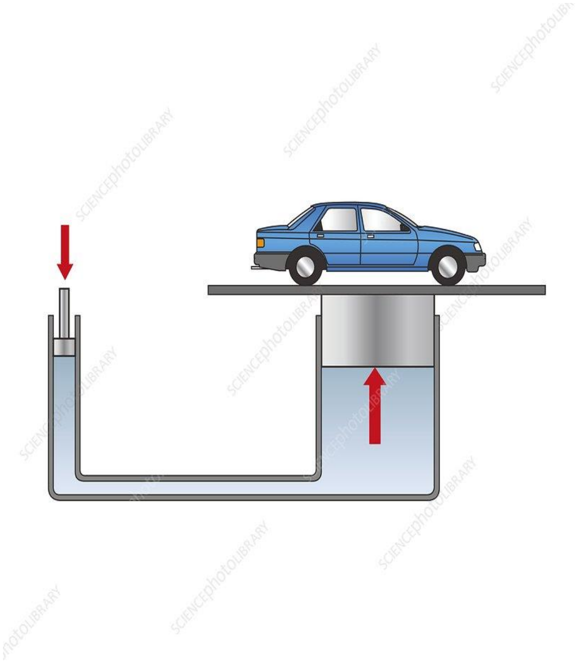
Double Acting Reciprocating Pump

Lecture No. 30

Hydraulic Lift

- Hydraulic lift is a device used for carrying passenger or goods from one floor to another in multistoried building to raise heavy objects.

- It works on the principle of Pascal's Law.



Types of Hydraulic Lift

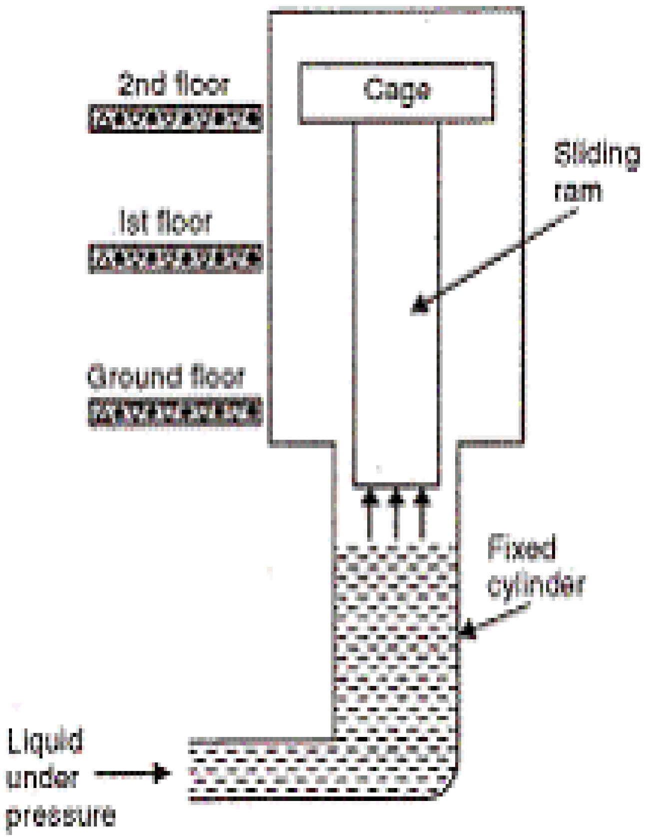
The Hydraulic Lifts are of two types-

1. Direct acting hydraulic lift

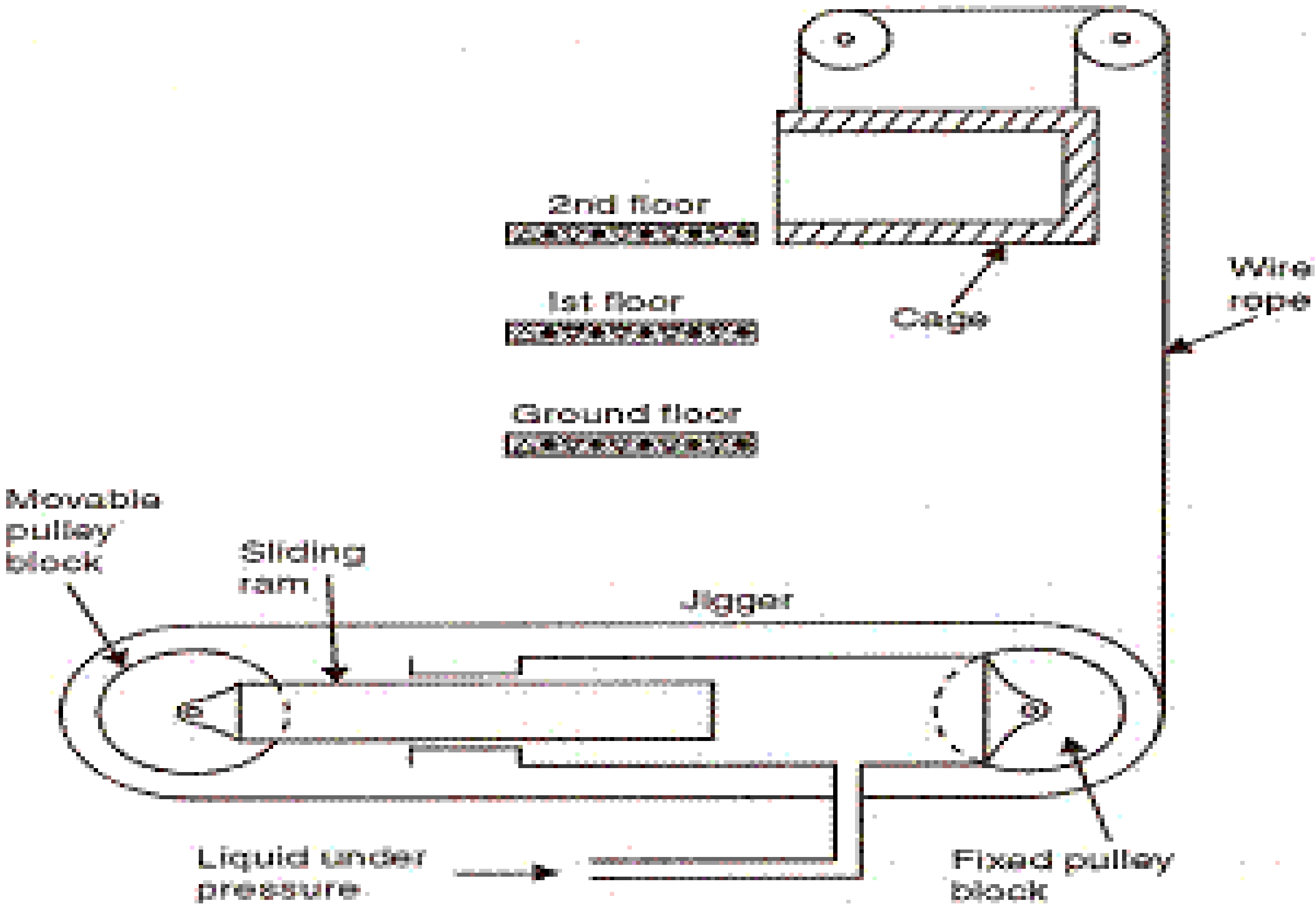
2. Suspended hydraulic lift

Direct Acting Hydraulic Lift

- It consists of a ram, sliding in the fixed cylinder.
- At the top of the sliding ram a cage is fitted.
- Cage- on which the person may be stand or goods may be placed.
- The liquid under pressure flows into fixed cylinder.
- This liquid exerts force on the sliding ram, which moves vertically up and thus raises the cage to the required height.



2. Suspended Hydraulic Lift



Suspended Hydraulic Lift

- When water under high pressure is admitted into the fixed cylinder of the jigger, the sliding ram is forced to move towards left.

- As one of the end of the sliding ram is connected to the movable pulley block.

- Hence the movable pulley block moves towards the left , thus increasing the distance between two pulley blocks.

- The wire rope connected to cage is pulled and the cage is lifted.

Suspended Hydraulic Lift

- For lowering the cage, water from fixed cylinder is taken out.

- The sliding ram moves towards right and hence movable pulley block also moves towards right.

- This decrease the distance between two pulley blocks and cage is lowered due to increased length of the rope