FLUID MECHANICS AND HYDRAULIC MACHINERSIES

Fluid:

Fluids deform continuously under the influence of a shear stress.

In fluids, stress is directly proportional to strain rate.

When a constant shear force is applied, a solid eventually stops deforming at some fixed strain angle but;

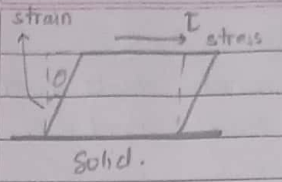
a fluid never stops deforming and approaches a constant strain rate.

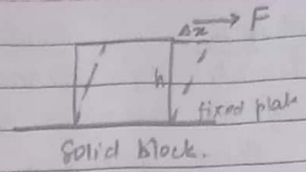
⊛ Applications of Fluid Dynamics:

i) Study of ocean tides, water pattern, blood circulation, plate tectonics.

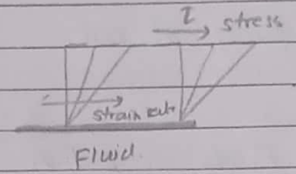
ii) Used in wind turbines, oil pipelines, AC systems.

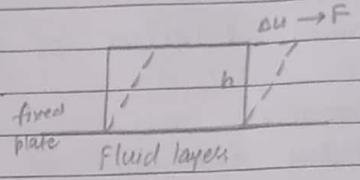
In liquids, the atoms are randomly arranged. The force between the atoms are weaker and can flow past one another quiet easily.





$S = \frac{\text{Shear stress}}{\text{shear strain}} = \frac{(F/A)}{(\Delta x/h)}$





$\mu = \frac{\text{Shear stress}}{\text{shear strain rate}} = \frac{(F/A)}{(\Delta u/h)}$

In fluids, applied shear stress produces a proportional continuously-increasing deformation ie, strain rate.

Coefficient of viscosity for fluid $(\mu) = \frac{F/A}{\Delta u/h}$

Where,
F = shear force
A = cross-sectional area
h = height betn two liquid layers.
Δu = velocity gradient betn two adjacent liquid layers.

⊛ Summarization of Fluid Definition:

- Fluid has no definite shape.
- Fluid doesn't have resistance against attempts to change its shape.
- Fluid is unable to retain an unsupported shape.
- Fluid is the substance that changes its shape as well as direction uniformly whenever an external force is applied on it.

Fluids Mechanics

The branch of science which deals with the behaviour of fluids is called fluid mechanics.

It has three branches:

i) **Fluid statics:**

It studies behaviour of fluids at rest.

ii) **Fluid kinematics:**

It studies behaviour of fluids in motion but no force is acting on it.

ie, study of only viscous force.

iii) **Fluid dynamics:**

It studies fluids in motion considering all the forces acting on them.

Difference: Liquids and Gases

Liquid	Gas.
Incompressible	Compressible.
Given mass of liquid occupies fixed volume regardless of shape.	E.g. It has no fixed volume and expands continuously.
For liquids, a free surface is formed in the volume of the container is greater than that of the liquid.	Gas doesn't have a free surface.

Classification of Fluids

(A): According to behaviour under the action of Externally Applied forces

It is of two types:

a) **Compressible Fluids:**

- Fluids dependent on temperature and pressure.
- Volume and density change with pressure and temperature. Eg: gases.

b) **Incompressible fluids:**

- Fluids independent on temperature and pressure.
- Volume and density don't change with pressure and temperature. Eg: liquids.

Newton's law of Viscocity:

It states that, "the ratio of shear stress and shear rate of a fluid is a constant defined as viscocity or coefficient of viscocity.

Mathematically,

$$\tau = \mu \cdot \frac{dc}{dy}$$

where,

τ = shear stress

μ = viscocity of fluid

$\frac{dc}{dy}$ = shear rate, velocity gradient

B) According to the effect produced by the action of shear stress,
It is of two types:

i) Newtonian Fluids:
Fluids obeying Newton's law of viscosity are called as Newtonian fluids.
- The viscosity is independent of the shear rate.

ii) Non-Newtonian Fluids:
fluids not obeying Newton's law of viscosity are called non-newtonian fluids.
- The viscosity is dependent of shear rate.

Properties of Fluid:

(i): Density:
Mass per unit volume.

$$\rho = \frac{\text{mass of fluid}}{\text{volume of fluid}}$$

SI unit = kg/m³ Dimension: M/L^3

(ii) Specific volume(v):
Volume per unit mass.

$$\text{Sp. volume } (V) = \frac{1}{\rho} = \frac{\text{volume of fluid}}{\text{mass of fluid}}$$

SI unit = m³/kg Dimension: L^3/M

(iii) Specific gravity:
Ratio of density of substance to standard density.

$$\text{sp. gra} = \frac{\text{density of substance}}{\text{density of water at } 4°C}$$

iv) Specific weight:
Ratio of weight of fluid to its volume.

$$w = \frac{\text{mass of fluid} \times \text{acceleration due to gravity}}{\text{volume of fluid}}$$

SI unit = N/m³ Dimension: $ML^{-2}T^{-2}$.

Viscocity:

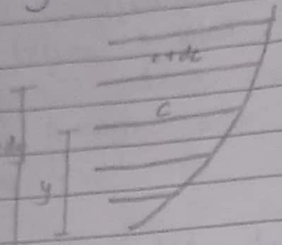
The property of the fluid which offers resistance to the movement of one layer of the fluid over adjacent layer of the fluid is called viscocity.

Viscosity is the measure of resistance of fluid to the gradual deformation by shear stress.
It is caused by inter-molecular friction when two layers slide by one another.

Fluid viscocity has two measures: dynamic and kinematic.

(i): Dynamic / Absolute Viscosity:

Dynamic viscosity is the tangential force per unit area required to move one horizontal plane with respect to another plane at an unit velocity when maintaining unit distance apart in the fluid.



For a Newtonian fluid, the shearing stress between the layers of fluid having streamlined parallel flow is

$$\tau = \mu \frac{dc}{dy} \quad \text{or} \quad \mu = \frac{\tau}{(dc/dy)}$$

SI unit = Ns/m^2 (poise), $10\ Ns/m^2 = 1$ poise.

*) Significance:

→ Internal # stickness of a fluid.
→ Represents internal friction in fluids.
→ dependent on temperature.
→ Measure of resistance of relative translational motion of adjacent fluid layers.

(ii) Kinematic Viscosity:

Kinematic viscosity is the ratio of absolute viscosity to density.
Here, no force is involved.

Mathematically,

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

Here, ν = Kinematic viscosity. μ = absolute viscosity
ρ = density.

⊛ Effect of Temperature on Dynamic Viscosity

(i): For liquid,

$$\mu_T = \frac{\mu_0}{1 + AT + BT^2}$$

(ii) For gas,

$$\mu_T = \mu_0 + \alpha T + \beta T^2$$

Types of Flow: :

The types of ~~liqui~~ flow in liquids are as follows:

i) Uniform and Non-uniform Flow.
ii) Steady and Non-steady flow.
iii) Laminar and Turbulent flow.
iv) Compressive and Incompressible flow.
v) Ideal and Real flow.

(i): Uniform and Non-uniform Flow:

Uniform flow is the type of flow in which the fluid parameters (ie, pressure, velocity, density, viscosity and temperature) at any given time doesn't change with respect to space (ie, length of flow direction.).

Mathematically,

$$\frac{\partial v}{\partial s} = 0 \quad , \quad \frac{\partial P}{\partial s} = 0 \quad \frac{\partial \rho}{\partial s} = 0.$$

Non-uniform flow is the type of flow in which the velocity at any given time changes with respect to space (ie, length of direction of flow)

Mathematically,

$$\frac{\partial v}{\partial s} \neq 0, \quad \frac{\partial P}{\partial s} \neq 0, \quad \frac{\partial \rho}{\partial s} \neq 0$$

⊛ For uniform flow, cross-sectional area must be constant.

(ii): Steady and Non-steady Flow:

Steady flow is defined as the type of flow in which the fluid parameters at a point don't change with time.

Mathematically,

$$\left(\frac{dP}{dt}\right)_{x_0 y_0 z_0} = 0$$

Eg: flow of water in centrifugal pump run at uniform rotational speed.

Non-steady flow is the flow in which the fluid parameters changes with time.

Mathematically,

$$\left(\frac{dP}{dt}\right)_{x_0 y_0 z_0} \neq 0.$$

(iii) Compressible and Incompressible flow:

Compressible flow is the type of flow in which the density of the fluid is not constant.

Mathematically, $\rho \neq$ constant. Eg: gas.

Incompressible flow is the type of flow in which density is constant for fluid flow.

Mathematically, $\rho =$ constant Eg: liquid.

⊛ Mach Number:

The ratio of local flow velocity to the sonic velocity of the fluid is called mach number.

Mathematically,

$$M = \frac{\text{local flow velocity}}{\text{sonic velocity of fluid.}}$$

If $M < 0.3$, compressibility effect ignored.
If $M < 1$, subsonic.
If $M = 1$, sonic
If $M > 1$, supersonic

(iv): Ideal flow and Real Flow:

The flow in which viscousity doesn't exist between two adjacent liquid layers is called ideal flow.

The flow in which the viscocity ~~exist~~ i.e., resistance to liquid flow exists betn two adjacent layers is called real flow.

(v): Laminar and Turbulent Flow:

Laminar flow is the type of flow in which the fluid particles moves along well-defined paths.

The particles move in layer and glide smoothly over another adjacent layer.

Turbulent flow is the flow in which the fluid particles don't move along well-defined paths.

The flow path is erradic and unpredictable.

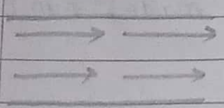


Fig: Laminar

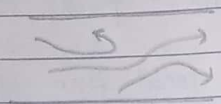


Fig: Turbulent

(vi): Reynold's Number

Dimensionless number used to determine the type of flow.

Mathematically,

$$Re = \frac{VD}{v}$$

Here, Re = Reynold's number.

V = Mean velocity of flow D = diameter.

v = Kinematic viscocity.

If Re < 2000 (Laminar)

Re > 4000 (Turbulent)

2000 < Re < 4000 (Laminar & Turbulent)

Rate of Flow: (Q):

It is also known as rate of discharge or flow rate.

The quantity of a fluid flowing per second through a section of pipe or channel is called discharge.

Mathematically,

$$Q = A \times V$$

Here,

Q = discharge.

A = cross-sectional area of pipe

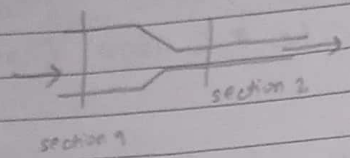
v = average velocity across pipe.

Continuity Equation:

It is based upon the principle of conservation of mass.

Mathematically,

$$A_1 V_1 = A_2 V_2.$$



For crossection 1,

V_1 = average velocity ρ_1 = density.

A_1 = Area of pipe

For crosssection 2,

V_2 = average velocity ρ_2 = density.

A_2 = Area of pipe.

According to principle of mass conservation,

Since discharge from 1 = discharge from 2,

$$Q_1 = Q_2$$

or, $A_1 V_1 \rho_1 = A_2 V_2 \rho_2$

Since the fluid is incompressible, $\rho_1 = \rho_2$.

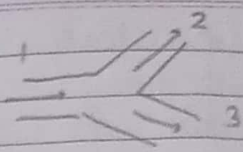
So,

$$A_1 V_1 = A_2 V_2 \quad -(i)$$

Eq^n (i) is continuity equation.

Here,

total flow into junction = total flow out of junction.



or $\rho_1 Q_1 = \rho_2 Q_2 + \rho_3 Q_3$.

If the fluid is incompressible, $\rho_1 = \rho_2 = \rho$.

$$Q_1 = Q_2 + Q_3$$

$$\therefore A_1 V_1 = A_2 V_2 + A_3 V_3.$$

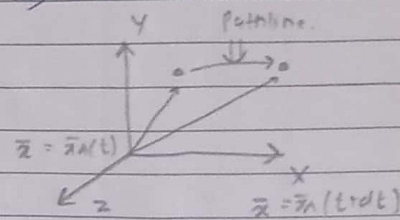
Types of Flow Lines:

Flow lines are of three types:

i) Pathline ii) Streamline iii) Streakline.

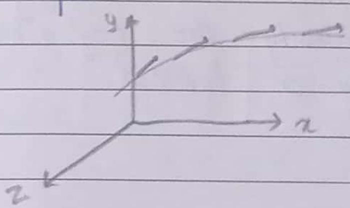
i) Pathline:

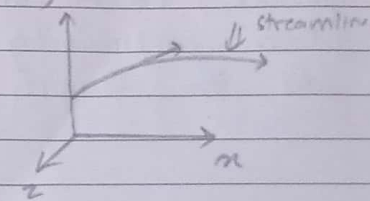
The path or trajectory traced out by an identified fluid particles.



ii) Streamline:

An imaginary line drawn in the flow field such that the tangent drawn at any point on this line represents direction of vector at that point.





Date :

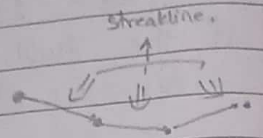
Page:

for steady flow, streamline pattern don't change with time.

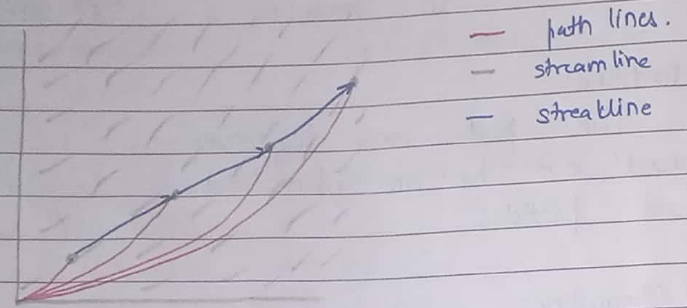
but for unsteady flow, streamline pattern changes continuously with time.

(iii) streakline:

The line joining fluid particles that once passed through the same fixed point in space is called streakline.



for unsteady flow.



Bernoulli's Theorem:

This theorem gives the relation betn the pressure, velocity and elevation in a moving fluid where compressibility and viscosity are negligible and the flow is steady or laminar.

Date :

Page:

Bernoulli's theorem states that,

" the total mechanical energy of the flowing fluid, comprising the energy associated with fluid pressure, the gravitational potential energy of elevation, and the kinetic energy of fluid motion, remains constant."

For a steady flow of incompressible ideal fluid, the sum of pressure energy (P), kinetic energy per unit volume ($\rho v^2/2$) and the potential energy per unit volume is constant

ie,

$$P + \frac{\rho v^2}{2} + \rho g h = \text{constant}.$$

$$KE/V = \frac{1}{2}\rho v^2 \qquad PE/V = \frac{mgh}{V} = \rho g h.$$

$$\therefore \frac{P}{\rho g} + \frac{v^2}{2g} + h = \text{constant}$$

ie, pressure head $= \dfrac{P}{\rho g}$

potential head $= h$

velocity head $= \dfrac{v^2}{2g}$

Special cases: i) When fluid is at rest, $v_1 = v_2 = 0$ $\therefore P_1 - P_2 = \rho g(h_2 - h_1)$

ii) When pipe is horizontal $h_1 = h_2$, no PE by virtue of height

$$\therefore P + \frac{\rho v^2}{2} = \text{constant}.$$

Turbomachine:

A turbomachine is a device where mechanical energy in the form of shaft work, is transferred either to or from ~~the a~~ continuously flowing fluid by the dynamic action of rotating blade rows.

If the device extracts energy from the fluid, it is generally called turbine.

If the device delivers energy to the fluid, it is called compressor, fan blower or pump depending on the ~~field~~ fluid used and the magnitude of the change in pressure ~~it~~ that results.

(*) Types of Turbomachine:

On the basis of fluid-machine interaction, it is of two types:

a) Open-turbo machines
- Extend of fluid machine interaction is infinite.

Eg: propellers, windmills, unshrouded fans, etc.

b) Closed-turbo machines
- ~~Closed~~ Extend of fluid machine interaction is finite.

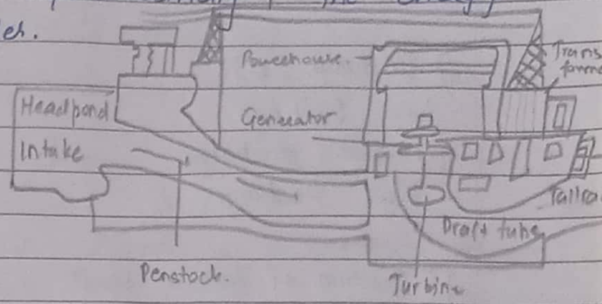
Eg: pumps, turbines, compressors.

Hydropower:

The power derived from the energy of falling water or fast running water which is harvested for useful ~~pro~~ purposes is called hydropower.

In deriving hydro-electricity, the energy conversion is in order.

i) Potential energy
ii) Kinetic Energy
iii) Mechanical Energy
iv) Electrical Energy.



(*): Classification of Hydropower:

Hydropowers are classified on the basis of their capacity:

a) Large: > 100 MW
b) Medium: 10 – 100 MW
c) Small: 1 – 10 MW
d) Mini: 100 kW – 1 MW
e) Micro: 5 – 100 kW
f) Pico: < 5 kW

Hydraulic Turbines

The turbomachines which uses the energy of flowing water present in the form of pressure, kinetic energy and converts into mechanical energy which is in the form of runner rotation.

Page:

(*) Classification of Hydraulic Turbines

i) Operating principle:
- impulse
- reaction

ii) Head [H]:
- High head
- Medium head
- Low Head.

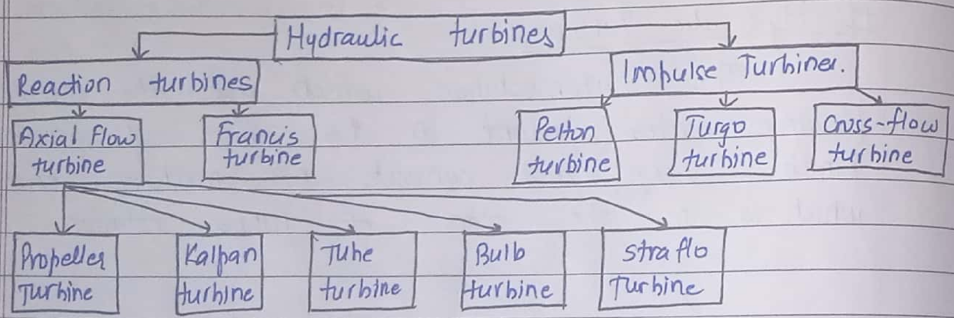
iii) Discharge [Q]:
- Low Discharge
- Medium dicharge
- High Discharge.

iv) Specific Speed [Ns]
- Low specific speed
- Medium specific speed
- High specific speed.

v) Disposition of turbine shaft
- Vertical Shaft Turbine
- Horizontal shaft Turbine

vi) Flow Direction:
- Axial Flow
- Radial Flow
- Tangential flow
- Mixed flow.

vii) Name of organizer:
- Pelton: Lester Allen Pelton
- Francis: James Bichens Francis
- Kalpan: Dr. Victor Kalpan.



Date:
Page:

(a): Impulse Turbine (Partial Turbines):
Hydraulic energy is completely converted to kinetic energy before transformation in the runner.
Eg: Pelton, Cross-flow, Turgo.

(b) Reaction Turbine (Full turbines):
Two different effects cause the energy transfer from the flow to mechanical energy on turbine shaft.
Here,
reaction part = drop in pressure from inlet to outlet of the runner.
Impulse part = changes in directions of velocity vectors of the flow through the canals between running blades.
Eg: Francis, Kaplan, Propeller, Bulb.

(*) Differences: Impulse and Reaction turbines

Impulse turbines	Reaction turbines
- All available energy is converted to KE before striking runner.	- A portion of energy was converted to KE and rest remained at pressure energy
- Pressure remains constant both in inlet and outlet	- Pressure changes in inlet and in outlet
- Water is partially admitted to runner	- Water is fully admitted to runner.
- Turbine is above water level	- Turbine is submerged under water.
- Change of pressure across the blade don't take place.	- Change of pressure ~~according~~ across the blade take place.
- Casing has no hydraulic function to perform.	- Casing keeps the water at high pressure.
Eg: Pelton turbines, Crossflow turbine.	Eg: Francis turbine, Kaplan turbine.

Date:
Page:

Hydraulic Pumps:

Hydraulic pumps is mechanical device that converts mechanical power into hydraulic energy.

Pump increases the mechanical energy of the fluid.

and work is done by pump to impart energy of fluid.

General Working Mechanism:

When the hydraulic pump operates, it performs two functions.

First, its mechanical action creates a vaccum at the pump inlet which allows the atmospheric pressure to force liquid from the reservoir into the inlet of the pump.

Second, its mechanical action delivers this liquid to the pump outlet and forces into the hydraulic ~~fans~~. system.

Types of Pumps:

Classification is done on the basis of displacement, delivery and on motion.

(A) On basis of displacement:

It is of two types: hydrodynamic and hydrostatic pumps.

Date:
Page:

(i): Non-positive Displacement Pumps/ Hydrodynamic Pumps:

- A non-positive displacement pump produces continuous flow of liquid discharge.
- Output varies considerably as pressure varies.
- Here, liquid velocity and movement are large ie, output pressure actually depends on velocity at which the liquid is made to flow.

Eg: axial flow pump, propeller pump, centrifugal pump.

(ii) Positive Displacement Pumps/ Hydrostatic pumps:

- A positive displacement pump displaces (delivers) the same amount of liquid for each rotating cycle of pumping element.
- Constant delivery during each cycle is possible because of the close-tolerance fit between pumping element and the pump case.
- Hydrostatic means that the pump converts mechanical energy to hydraulic energy with comparatively small quantity and velocity of liquid.

Eg: gear pumps, vane pumps, piston pumps, etc.

(B): Based on delivery:

It is of two types: constant and variable delivery pumps.

(i) Constant Delivery Pumps:

- always deliver the same quantity of fluid in given time at operatoring speed and temperature.

Eg: used with relatively simple machines like saws or drill presses.

(ii) Variable Delivery Pumps:

- output of variable volume pumps may vary manually or automatically with no change in the input speed of pump.

- used for rewinds, constant tension devices.

(C) Based on Motion

i) Reciprocating pump: piston, plunger, diaphragm.
ii) Rotary pump: internal gear, external gear, lobe, vane.

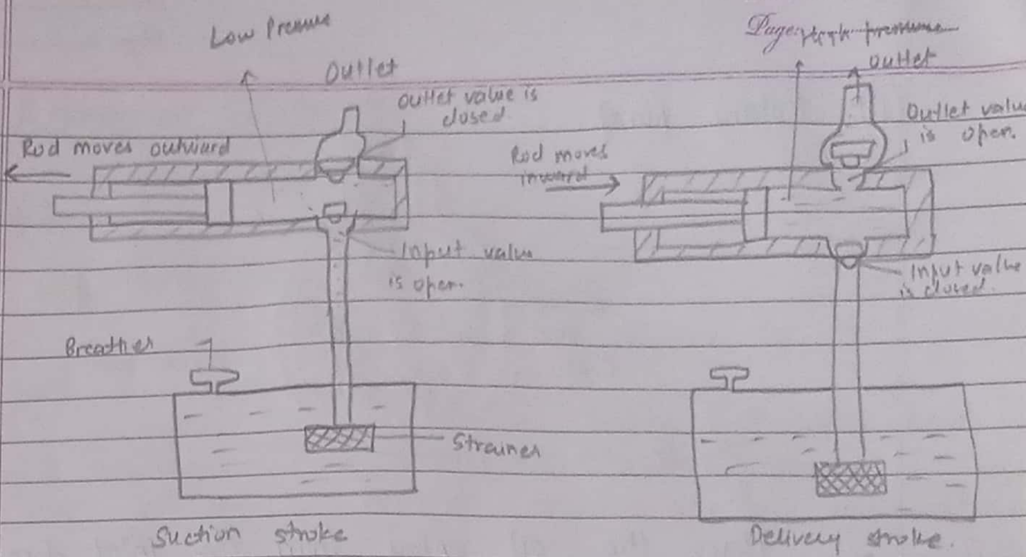


Fig: Operation of Reciprocating pump.

Reciprocating pump has two strokes: suction stroke and delivery stroke.

In suction stroke, the rod moves outwards which ~~pres~~ creates a low pressure area ~~at~~ inside piston. Here, outlet value is closed and inlet value is opened. The water is sucked into the piston.

In delivery stroke, the rod moves inward ~~gre~~ creating high pressure area inside piston. Here, inlet value is closed and outlet value is opened. The water is then pushed out.

Date:
Page:

(ii) Rotary pump:

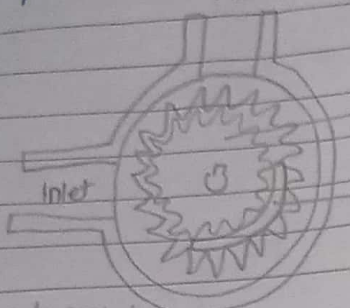
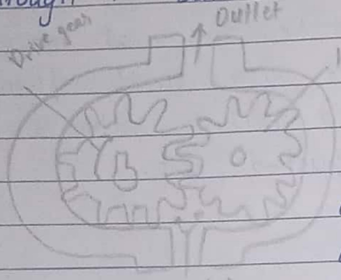


Fig: Internal gear pump

Here, the oil enters from the inlet due to the vaccum caused by the unmeshing of teeth of the gears.

The oil is carried between the spaces of between the teeths of the two gears.

As the oil passes from cresent seal, the constant meshing of teeth forces the oil out through the outlet.



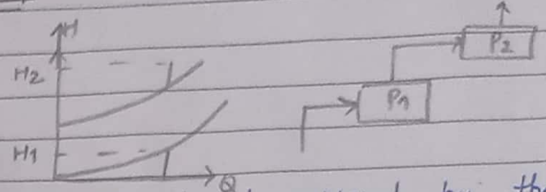
Here, the oil enters from the inlet due to the vaccum created by movement of drive gear and the ideal gear.

The oil is carried between the spaces of the teeth which rotates and eventually pushes out the oil from the outlet.

Date:
Pages:

Arrangement of Pump:

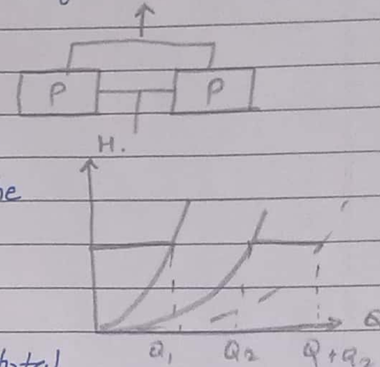
a) Series:



When two pumps are operated in series, the head supplied by the pump is increased.

When the two identical pumps with same head and discharge is connected to in series, the net head supplied is doubled keeping the discharge constant.

b) Parallel



When two pumps are arranged in parallel, discharge through the pump is increased.

When two identical pumps are arranged in parallel, the total discharge through single pump with constant head.