UNIT-3 FLUID MECHANICS & FLUID MACHINERY

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Fluid Mechanics:

It is that branch of science which deals with the behaviour of fluid (liquid or gas) at rest as well as in motion.

Properties of fluid:

1- Density or mass density:

It is defined as the ratio of the mass of a fluid to its volume.

It is denoted by ρ.

Its unit is kg/m^3.

Mathematically $\boxed{\rho = \frac{m}{V}}$ mass per unit volume.

$\Rightarrow \rho = 1000\ kg/m^3$ for water.

2- Specific weight or weight density:

It is the ratio of the weight of a fluid to its volume.

It is denoted by 'w'.

Its unit is N/m^3.

Mathematically, $w = \frac{W}{V} = \frac{m \cdot g}{V} = \rho \cdot g$

$\boxed{w = \rho \cdot g}$

3- Specific volume: It is defined as the volume of a fluid occupied by a unit mass.

It is the reciprocal of mass density. It is expressed as m^3/kg.

specific volume $= \frac{V}{m} = \frac{1}{m/V} = \frac{1}{\rho}$

4- Specific gravity: It is defined as the ratio of weight density (density) of a fluid to the weight density (density) of a standard fluid.

for liquid: Standard fluid is water.

for gases: Standard fluid is air.

→ It is also called relative density.

→ It is denoted by S.

→ It is dimensionless quantity.

NOTE: 1 litre = 10^{-3} m^3

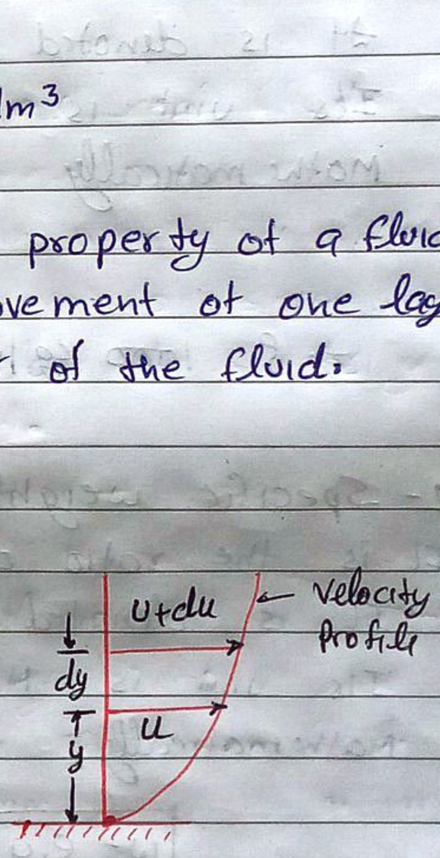
Density of water = 1000 kg/m^3

Viscosity: It is defined as the property of a fluid which offers resistance to the movement of one layer of fluid to another adjacent layer of the fluid.

It is of two types:

1- Dynamic viscosity:

When two layers of fluid, a distance 'dy' apart, move one over the other at different velocities, say u and u+du,



The viscosity together with relative velocity causes a shear stress acting between the fluid layers.

This shear stress is proportional to the rate of change of velocity with respect to y. It is denoted by 'τ'.

Mathematically $\tau \propto \frac{du}{dy}$

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

The constant of proportionality (μ) is known as coefficient of dynamic viscosity or simply viscosity.

So,

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

Dynamic viscosity is defined as the shear stress required to produce unit rate of shear strain.

It unit is $N \cdot s/m^2$. [SI unit]

Another unit of viscosity is Poise. [CGS unit]

$$\boxed{1 \text{ Poise} = \frac{1}{10} \ N\text{-}s/m^2}$$

Kinematic viscosity: It is defined as the ratio of dynamic viscosity to density of fluid.

It is denoted by 'ν'.

Its unit is m^2/s in SI and stoke in CGS.

$$\boxed{1 \text{ stoke} = 10^{-4} \ m^2/s.}$$

mathematically,

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

Newton's law of viscosity:

It state that the shear stress (τ) on a fluid element layer is directly proportional to the rate of shear strain. The constant of proportionality is called the coefficient of viscosity.

$$\tau \propto \frac{du}{dy}$$

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

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Types of fluid:

Fluid may be classified into the following types.

1- Ideal fluid:

A fluid which is incompressible and is having no viscosity, is known as ideal fluid.

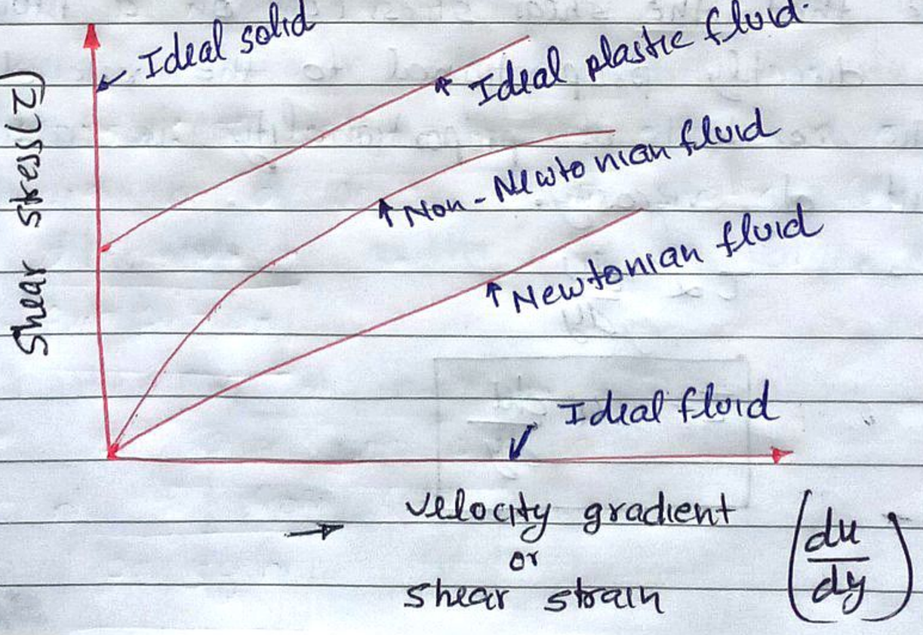
Ideal fluid is only an imaginary fluid as all the fluid which exist, have some viscosity.

2- Real fluid: A fluid which possesses viscosity, is known as real fluid.

All the fluid in actual practice are real fluid.

3- Newtonian fluid: A real fluid, in which the shear stress is directly proportional to rate of shear strain. i.e. fluids which obey Newton's law of viscosity, are known as newtonian fluid.

4- Non Newtonian fluid: A fluid, in which the shear stress is not directly proportional to rate of shear strain i.e. fluid which do not obey newton's law of viscosity, is known as non-newtonian fluid.



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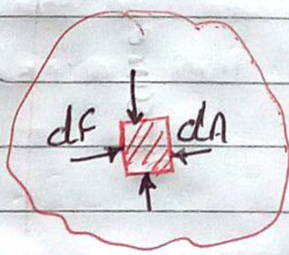
Fluid pressure at a point:

Consider a small area 'dA' in large mass of fluid, then the force exerted 'dF', by the surrounding fluid on 'dA' will always perpendicular to the surface dA.

Then the ratio of 'dF/dA' is known as intensity of pressure or simply pressure.

It is denoted by 'p'.

Mathematically,



$$\boxed{p = \frac{dF}{dA}}$$

If force (F) is uniformally distributed over the area(A) then

$$\boxed{p = \frac{F}{A}}$$

Unit of pressure is N/m^2 or Pascal (Pa)

$$\boxed{\begin{aligned} 1\,Pa &= 1\,N/m^2 \\ 1\,MPa &= 1\,N/mm^2 \end{aligned}}$$

Measurement of Pressure [Absolute, Gauge, Atmospheric and vaccuum pressure]:

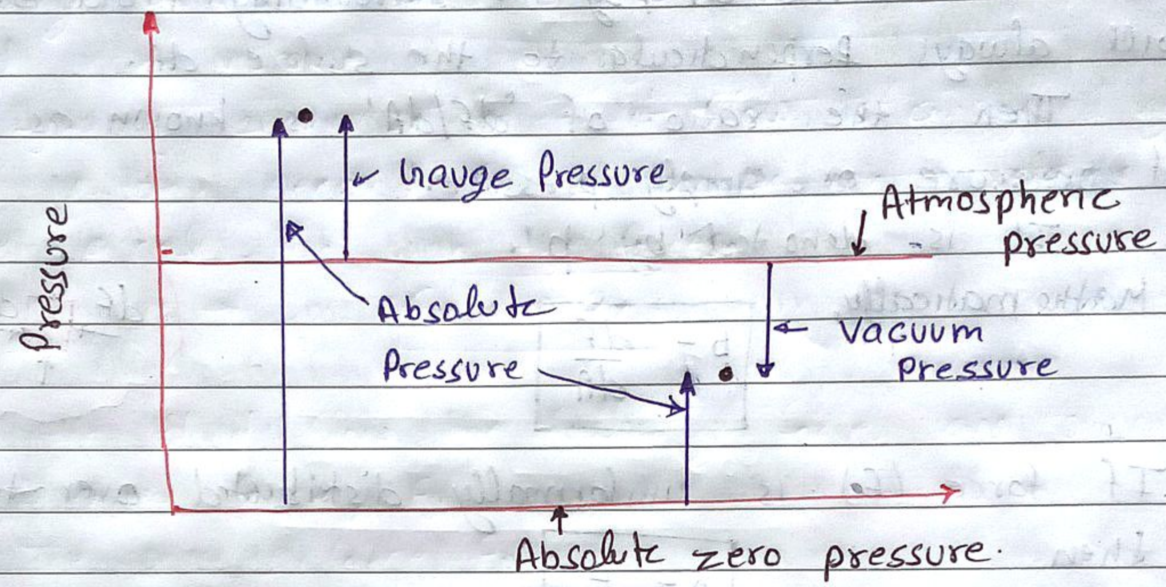
The pressure on a fluid is measured in two different systems. In one system, it is measured below atmospheric pressure (vaccuum) & other is above atmospheric pressure.

1- Absolute pressure: It is defined as the pressure which is measured with reference to absolute vacuum pressure.

2- Gauge pressure: It is defined as the pressure which is measured with the help of a pressure measuring instrument in which the atmospheric pressure is taken as datum. The atmp pressure on the scale is marked as zero.

Spiral

3- Vacuum pressure: It is defined as the pressure below the atmospheric pressure.



Mathematically,

Absolute pressure = Atmospheric pressure + Gauge Pressure

$$\boxed{P_{abs} = P_{atm} + P_{gauge}}$$

Vacuum pressure = Atmospheric pressure − Absolute pressure

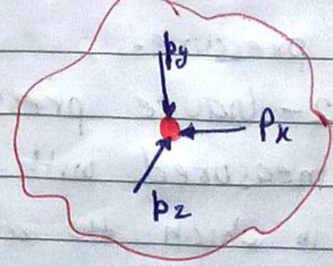
$$\boxed{P_{vac} = P_{atm} - P_{abs}}$$

→ Atmospheric pressure is taken as $101.3\ KN/m^2$ or $1.013 \times 10^5\ N/m^2$ or 1.013×10^5 Pa or $10.13\ N/cm^2$.

→ Atmospheric pressure ~~head~~ is 760 mm of Hg or 10.33 m of water.

Pascal's Law: It state that the pressure or intensity of pressure at a point in a static fluid is equal in all direction.

$$\boxed{p_x = p_y = p_z}$$



Pressure at any point 'A' at a height of 'h' from free surface

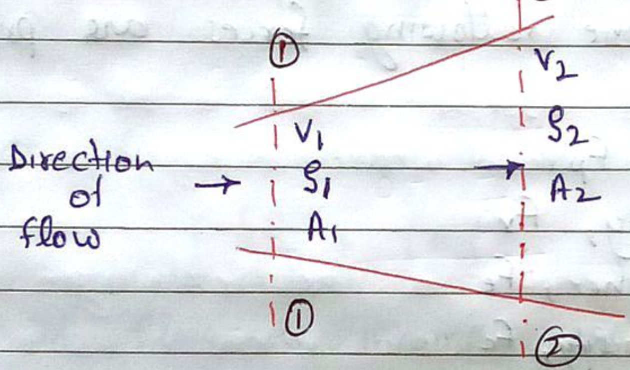
$$\boxed{p = \rho g h}$$

Continuity Equation:

Continuity equation is derived for kinematics of flow, which deals with motion of particles without considering the forces causing the motion. (study ρ, V, and a only)

The equation based on the principle of conservation of mass is called continuity equation.

Thus for a fluid flowing through the pipe at all the cross section, the quantity of fluid per second is constant.



Fluid kinematics
- → Lagrangian approach (Video) observ motion of each particle wrt time from original Position. $\vec{s} = f(x_0, y_0, z_0, t)$
- → Eulerian approach (Picture) (Instantanious behaviour of fluid)

Consider two cross sections of a pipe as shown in fig

Let V_1 → Average velocity at cross section 1-1

ρ_1 → Density at section 1-1

A_1 → Area at section 1-1

and V_2, ρ_2, A_2 are corresponding values at section 2-2

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

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

According to law of conservation of mass

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

$$\boxed{\rho_1 A_1 V_1 = \rho_2 A_2 V_2}$$

This equation is applicable to the compressible as well as incompressible fluids & is called continuity equation.

If fluid is incompressible then $\rho_1 = \rho_2$, So

$$\boxed{A_1 V_1 = A_2 V_2}$$

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Dynamics of fluid flow:

It is the study of fluid motion with the forces causing flow. The fluid is assumed to be incompressible and non- viscous.

Dynamic behaviour of fluid flow is analysed by the newton's second law of motion, which relates the acceleration with the forces.

$$\boxed{F_x = m a_x}$$

In the fluid flow, the following forces are present.

(1) Gravity force, F_g

(2) The pressure force, F_p

(3) Force due to viscosity, F_v

(4) Force due to turbulence, F_t

(5) Force due to compressibility, F_c

Thus the net force.

$$\boxed{F_x = F_g + F_p + F_v + F_t + F_c}$$

NOTE: (A) If F_c, is negligible then resultant equations of motion are known as Reynold's equation of motion.

$$\boxed{F_x = F_g + F_p + F_v + F_t}$$

(B) If F_t is negligible then resultant equations of motion are known as Navier- stokes Equation.

$$\boxed{F_x = F_g + F_p + F_v}$$

(C) If the flow is assumed to be Ideal, F_v is zero then resultant equations of motion are known as Euler's equation of motion.

$$\boxed{F_x = F_g + F_p}$$

Differential form of Euler's eq. $\rightarrow \frac{dP}{\rho} + g\,dz + V\,dV = 0$

Bernoulli's equation:

Assumptions

(i) The fluid is ideal ie viscosity is zero
(ii) The flow is steady
(iii) The flow is incompressible
(iv) The flow is irrotational

Bernoulli equation is derived using Euler's equation of motion. ie

$$\boxed{\frac{\delta P}{\rho} + g\,dz + v\,dv = 0} \quad \text{Euler's equation.}$$

Bernoulli's equation is obtain by integrating Euler's eq.

$$\int \frac{\delta P}{\rho} + \int g\,dz + \int v\,dv = \text{constant}$$

If flow is incompressible, ρ is constant then.

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

$$\boxed{\frac{P}{\rho g} + \frac{v^2}{2g} + z = \text{Constant}}$$

This is called ~~Euler's~~ Bernoulli's equation of motion. in which

$\frac{P}{\rho g}$ → Pressure energy per unit weight of fluid OR pressure head
work required to maintain the flow / weight

$\frac{v^2}{2g}$ → Kinetic energy per unit weight or kinetic head

z → Potential energy per unit weight or potential head.

So $\boxed{\text{Pressure head + Kinetic head + potential head = constant}}$

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + Z_2$$

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Bernoulli's equation for real fluid:

The Bernoulli equation for real fluid between point 1 and 2 is given as

$$\boxed{\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + h_L}$$

where

$h_L \rightarrow$ loss of energy between point 1 and 2.

Practical applications of Bernoulli's equation:

Bernoulli equation is applied in all problems of incompressible fluid flow where energy considerations are involved.

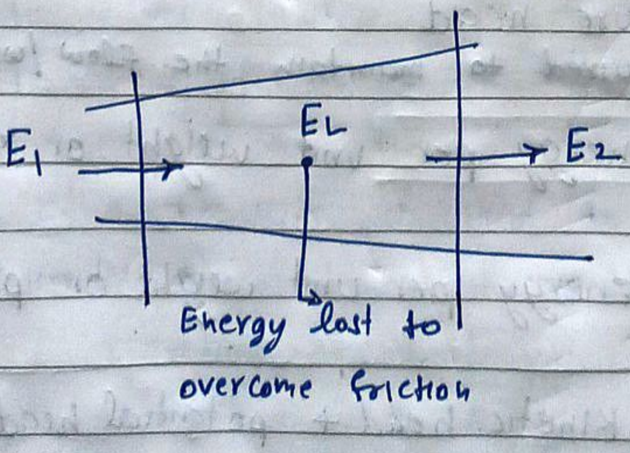
Its practical application to the following measuring devices.

1- Venturimeter
2- Orifice meter
3- Pitot tube.

C_d, C_c and C_v are the coefficient of venturimeter, contraction or orifice meter and pitot tube respectively

$$(C_d)_{orific} << (C_d)_{venturi}$$

$$E_1 = E_2 + E_L$$



$$\frac{E_1}{\rho g} = \frac{E_2}{\rho g} + h_L$$

i.e. $$\boxed{h_L = \frac{E_{in} - E_{out}}{\rho g}}$$

Ques.1: Calculate specific weight, density and specific gravity of one litre of a liquid which weights 7 N.

Ques.2: A flat plate of area 1.5×10^6 mm^2 is pulled with a speed of 0.4 m/s relative to another plate located at a distance of 0.15 mm from it. Find the force and power required to maintain this speed, if the fluid separating them is having viscosity as 1 Poise.

Ques.3 Calculate the pressure due to a column of 0.3m for
(a) water, take density of water $\rho = 1000$ kg/m3
(b) an oil of specific gravity 0.8.
(c) mercury of specific gravity 13.6.

Ques.4. What are the gauge pressure and absolute pressure at a point 3m below the free surface of a liquid having a density of 1.53×10^3 kg/m3. If the atmospheric pressure is equivalent to 750 mm of mercury? The specific gravity of mercury is 13.6 and density of water is 1000 kg/m3.

Ques.5. A 30cm diameter pipe, conveying water, branches into two pipes of diameters 20cm and 15cm respectively. If the average velocity in the 30cm diameter pipe is 2.5 m/s. find the discharge in this pipe. Also determine the velocity in 15cm pipe if the average velocity in 20cm diameter is 2 m/s.

Ques.6. The water is flowing through a pipe having diameters 20cm and 10cm at sections 1 and 2 respectively. The rate of flow through pipe is 35 liters/s. The section 1 is 6 m above datum and section 2 is 4 m above datum. If the pressure at section 1 is 39.24 N/cm^2, find the intensity of pressure at section 2.