RPSC 2024

Rajasthan Public Service Commission

Assistant Engineer

CIVIL ENGINEERING

Fluid Mechanics including Open Channel Flow

MADE EASY PUBLICATIONS

CONTENTS

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FLUID PROPERTIES

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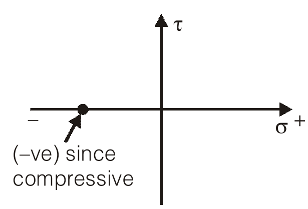
FLUID

- A fluid is a substance which is capable of flowing under the action of shear force, however small the force may be for e.g., liquid, gases and vapours.
- For a static fluid there is no shear force.
- Since there is no shear force in static fluid hence the Mohr's circle is a point.



Ideal Fluid (Perfect Fluid)

- Non-viscous, friction less & incompressible.
- Does not offer shear resistance against flow.
- Bulk modulus is infinite
- Used in mathematical analysis and flow problems.

Real Fluid

- Possess the properties such as viscosity, surface tension and compressibility.
- Offers resistance against flow.

Specific Gravity (G or s)

- $G \text{ or } s = \dfrac{\text{Density of substance}}{\text{Density of water at } 4^\circ\text{C}}$
- Specific gravity for water is 1.0 at 4°C and mercury is 13.6
- Specific gravity varies with temperature therefore it should be determined at specified temperature (4°C or 27°C).

Specific Weight (unit weight)

$\gamma = \rho g$

ρ = mass density

g = acceleration due to gravity

Newton's Law of Viscosity

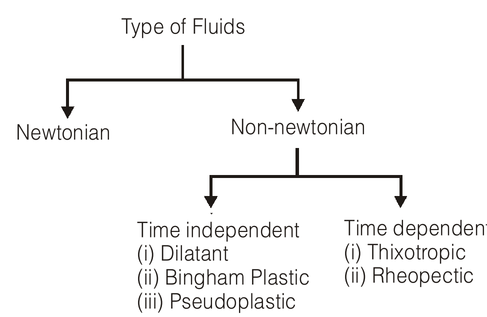
- Shear stress, $\tau = \mu\left(\dfrac{du}{dy}\right)$

  ρ = mass density

  g = acceleration due to gravity

  μ = dynamic viscosity

  $\left(\dfrac{du}{dy}\right)$ = rate of shear strain or velocity gradient or rate of angular deformation

- 

Non-Newtonian Fluids

- These do not follow Newton's law of viscosity. The relation between shear stress and velocity gradient is

$$\tau = A\left(\frac{du}{dy}\right)^n + B$$

  where A and B are constants depending upon type of fluid and condition of flow.
- The study of Non-Newtonian fluid is knows as Rheology.

(i) For Dilatant Fluids: $n > 1$ & $B = 0$,
Ex. Butter, Quick sand, Rice starch, Sugar in H_2O

(ii) For Bingham Plastic Fluids: $n = 1$ & $B \neq 0$
Ex. Sewage sludge, Drilling mud, Tooth paste, Gel.
These fluids always have certain minimum shear stress before they yield.

(iii) For Pseudoplastic Fluids: $n < 1$ & $B = 0$
Ex. Paper pulp, Rubber solution, Lipsticks, Paints, Blood, Polymetric solutions, milk, etc.

(iv) For Thixotropic Fluids: $n < 1$ & $B \neq 0$
Viscosity increases with time.
Ex. Printers ink and Enamels.

(v) For Rheopectic Fluids: $n > 1$ & $B \neq 0$
Viscosity decreases with time.
Ex. Gypsum solution in water & Bentonite solution.

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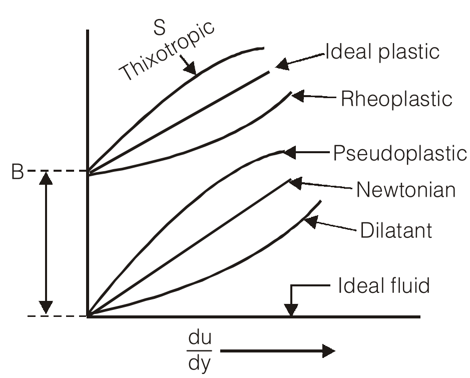

Viscosity

- It is the internal resistance offered by one layer of fluid to the other layer. It is due to cohesion and intermolecular attraction.

  (i) Dynamic Viscosity (μ):
  Its SI unit is pascal-second or N-sec/m^2
  Its CGS unit is Poise = Dyne-sec/cm^2
  1 poise = 0.1 N-s/m^2

  (ii) Kinematic Viscosity

$$\nu = \frac{\text{Dynamic viscosity } (\mu)}{\text{Mass density } (\rho)}$$

  Its SI unit is m^2/s.
  Its CGS unit is cm^2/s or stoke.
  1 stoke = 10^{-4} m^2/s

- Viscosity of liquids decreases with temperature whereas viscosity of gases increases with increase in temperature.
- Fluids with increasing order of viscosity are air, gasoline, water, crude oil, castor oil.
- Viscosity of water at 1°c is 1 centipoise.
- Viscosity of liquids is due to *cohesion and molecular momentum transfer.*

Surface Tension (σ)

- Surface tension is due to cohesion only.
- Surface tension decreases with increase in temperature.

$$\sigma_{water} = 0.0736 \text{ N/m at } 20°C$$
$$\sigma_{mercury} = 4.51 \text{ N/m}$$

(i) Pressure inside a liquid drop.

$$p = \frac{4\sigma}{d}$$

where σ is surface tension
d is diameter of drop

(ii) Pressure inside a soap bubble

$$p = \frac{8\sigma}{d}$$

Note: *At critical point of a liquid its surface tension is zero.*

Capillary Action

- Capillary action is due to adhesion and cohesion, both.
- Capillary rise is due to adhesion being greater than cohesion and capillary fall is due to cohesion being greater than adhesion.

$$h = \frac{4\sigma\cos\theta}{\gamma d}$$

where,
h = rise in capillary
σ = surface tension of liquid
d = diameter of tube
θ = angle of contact between the liquid and the material.
g = Specific weight of liquid
$\theta \to 0°$ for, Pure water and glass
$\theta \to 128°$ for mercury and glass

For capillary action diameter of tube should be less than 3 cm.

- When a liquid surface supports another liquid of density "ρ_b", then rise in capillary is given as.

$$h = \frac{4\sigma\cos\theta}{(\rho-\rho_b)gd}$$

Compressibility

- It refers to change in volume/density due to change in pressure.
- The compressibility coefficient is inversely proportional to bulk modulus of elasticity (K),

$$K = \frac{dP}{-dV/V} = \frac{dP}{d\rho/\rho}$$

Compressibility Coefficient, $\beta = \frac{1}{K}$.

- In compressible fluids the velocity of sound is given by

$$C = \sqrt{\frac{K}{\rho}}$$

C = velocity of sound in fluid
K = Bulk modulus of fluid
ρ = Density of fluid

Practice Questions : Level-1

Q.1 The pressure inside a soap bubble of 50 mm diameter is 25 N/m^2 above the atmospheric pressure. What is the surface tension in soap film?
(a) 0.156 N/m (b) 0.312 N/m
(c) 0.624 N/m (d) 0.948 N/m

Practice Questions : Level-2

Q.2 Consider the following statements:
1. Gases are considered incompressible when Mach number is less than 0.2
2. A Newtonian fluid is incompressible and non-viscous
3. An ideal fluid has negligible surface tension

Which of these statement(s) is/are correct?
(a) 2 and 3 (b) 2 only
(c) 1 only (d) 1 and 3

Q.3 Match **List-I** (Physical properties of fluid) with **List-II** (Dimension/Definitions) and select the correct answers:

List-I
A. Absolute viscosity
B. Kinematic viscosity
C. Newtonian fluid
D. Surface tension

List-II
1. du/dy is constant
2. Newton per meter
3. Poise
4. Stress/Strain is constant
5. Stokes

Codes:

	A	B	C	D
(a)	5	3	1	2
(b)	3	5	2	4
(c)	5	3	4	2
(d)	3	5	1	2

Q.4 The relations between shear stress (τ) and velocity gradient for ideal fluids, Newtonian fluids and non-Newtonian fluids are given below. Select the correct combination
(a) $\tau = 0$, $\tau = \mu(du/dy)^2$; $\tau = \mu(du/dy)^3$
(b) $\tau = 0$, $\tau = \mu(du/dy)$; $\tau = \mu(du/dy)^2$
(c) $\tau = \mu(du/dy)$; $\tau = \mu(du/dy)^2$; $\tau = \mu(du/dy)^3$
(d) $\tau = \mu(du/dy)$; $\tau = \mu(du/dy)^2$; $\tau = 0$

ANSWERS

1. (a) 2. (d) 3. (a) 4. (b)

Hints & Solutions

1. (a)

For soap bubble

$$P = \frac{8\sigma}{D}\text{; P = Excess pressure}$$

$$\sigma = \frac{PD}{8} = 6.156\text{N/m}$$

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