

Lecture 5: BMEE204L

Fluid Mechanics & Machinery



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Vandalur - Kelambakkam Road, Chennai - 600127

❑ **Fluid Properties – Fundamentals**

G. Vinayagamurthy Dr. Engg.
School of Mechanical Engineering
VIT Chennai

1.2.1 Density or Mass Density. Density or mass density of a fluid is defined as the ratio of the mass of a fluid to its volume. Thus mass per unit volume of a fluid is called density. It is denoted by the symbol ρ (rho). The unit of mass density in SI unit is kg per cubic metre, *i.e.*, kg/m^3 . The density of liquids may be considered as constant while that of gases changes with the variation of pressure and temperature.

Mathematically, mass density is written as

$$\rho = \frac{\text{Mass of fluid}}{\text{Volume of fluid}}.$$

The value of density of water is 1 gm/cm^3 or 1000 kg/m^3 .

1.2.2 Specific Weight or Weight Density. Specific weight or weight density of a fluid is the ratio between the weight of a fluid to its volume. Thus weight per unit volume of a fluid is called weight density and it is denoted by the symbol w .

Thus mathematically,

$$\begin{aligned} w &= \frac{\text{Weight of fluid}}{\text{Volume of fluid}} = \frac{(\text{Mass of fluid}) \times \text{Acceleration due to gravity}}{\text{Volume of fluid}} \\ &= \frac{\text{Mass of fluid} \times g}{\text{Volume of fluid}} \\ &= \rho \times g \end{aligned} \quad \left\{ \because \frac{\text{Mass of fluid}}{\text{Volume of fluid}} = \rho \right\}$$

$\therefore w = \rho g$... (1.1)

The value of specific weight or weight density (w) for water is $9.81 \times 1000 \text{ Newton/m}^3$ in SI units.

1.2.3 Specific Volume. Specific volume of a fluid is defined as the volume of a fluid occupied by a unit mass or volume per unit mass of a fluid is called specific volume. Mathematically, it is expressed as

$$\text{Specific volume} = \frac{\text{Volume of fluid}}{\text{Mass of fluid}} = \frac{1}{\frac{\text{Mass of fluid}}{\text{Volume of fluid}}} = \frac{1}{\rho}$$

Thus specific volume is the reciprocal of mass density. It is expressed as m^3/kg . It is commonly applied to gases.

1.2.4 Specific Gravity. Specific gravity is defined as the ratio of the weight density (or density) of a fluid to the weight density (or density) of a standard fluid. For liquids, the standard fluid is taken water and for gases, the standard fluid is taken air. Specific gravity is also called relative density. It is dimensionless quantity and is denoted by the symbol S .

$$\text{Mathematically, } S(\text{for liquids}) = \frac{\text{Weight density (density) of liquid}}{\text{Weight density (density) of water}}$$

$$S(\text{for gases}) = \frac{\text{Weight density (density) of gas}}{\text{Weight density (density) of air}}$$

$$\begin{aligned}\text{Thus weight density of a liquid} &= S \times \text{Weight density of water} \\ &= S \times 1000 \times 9.81 \text{ N/m}^3\end{aligned}$$

$$\begin{aligned}\text{The density of a liquid} &= S \times \text{Density of water} \\ &= S \times 1000 \text{ kg/m}^3.\end{aligned}\tag{1.1A}$$

If the specific gravity of a fluid is known, then the density of the fluid will be equal to specific gravity of fluid multiplied by the density of water. For example, the specific gravity of mercury is 13.6, hence density of mercury = $13.6 \times 1000 = 13600 \text{ kg/m}^3$.

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 (1.1A),

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

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

1.3.2 Kinematic Viscosity. It is defined as the ratio between the dynamic viscosity and density of fluid. It is denoted by the Greek symbol (ν) called 'nu'. Thus, mathematically,

$$\nu = \frac{\text{Viscosity}}{\text{Density}} = \frac{\mu}{\rho} \quad \dots(1.4)$$

The units of kinematic viscosity is obtained as

$$\begin{aligned} \nu &= \frac{\text{Units of } \mu}{\text{Units of } \rho} = \frac{\text{Force} \times \text{Time}}{(\text{Length})^2 \times \frac{\text{Mass}}{(\text{Length})^3}} = \frac{\text{Force} \times \text{Time}}{\frac{\text{Mass}}{\text{Length}}} \\ &= \frac{\text{Mass} \times \frac{\text{Length}}{(\text{Time})^2} \times \text{Time}}{\left(\frac{\text{Mass}}{\text{Length}} \right)} \quad \left\{ \begin{array}{l} \because \text{Force} = \text{Mass} \times \text{Acc.} \\ = \text{Mass} \times \frac{\text{Length}}{\text{Time}^2} \end{array} \right\} \\ &= \frac{(\text{Length})^2}{\text{Time}}. \end{aligned}$$

In MKS and SI, the unit of kinematic viscosity is metre²/sec or m²/sec while in CGS units it is written as cm²/s. In CGS units, kinematic viscosity is also known as stoke.

Thus, one stoke $= \text{cm}^2/\text{s} = \left(\frac{1}{100} \right)^2 \text{m}^2/\text{s} = 10^{-4} \text{m}^2/\text{s}$

Centistoke means $= \frac{1}{100} \text{ stoke}.$

Problem 1.13 The velocity distribution for flow over a flat plate is given by $u = \frac{3}{4} y - y^2$ in which u is the velocity in metre per second at a distance y metre above the plate. Determine the shear stress at $y = 0.15$ m. Take dynamic viscosity of fluid as 8.6 poise.

Solution. Given : $u = \frac{3}{4} y - y^2$

$$\therefore \frac{du}{dy} = \frac{3}{4} - 2y$$

$$\text{At } y = 0.15, \quad \frac{du}{dy} = \frac{3}{4} - 2 \times 0.15 = 0.75 - 0.30 = 0.45$$

$$\text{Viscosity, } \mu = 8.5 \text{ poise} = \frac{8.5}{10} \frac{\text{Ns}}{\text{m}^2} \quad \left(\because 10 \text{ poise} = 1 \frac{\text{Ns}}{\text{m}^2} \right)$$

$$\text{Using equation (1.2), } \tau = \mu \frac{du}{dy} = \frac{8.5}{10} \times 0.45 \frac{\text{N}}{\text{m}^2} = \mathbf{0.3825 \frac{N}{m^2} \cdot \text{Ans.}}$$

Practice Problems

Problem 1.18 *Two large plane surfaces are 2.4 cm apart. The space between the surfaces is filled with glycerine. What force is required to drag a very thin plate of surface area 0.5 square metre between the two large plane surfaces at a speed of 0.6 m/s, if :*

- (i) the thin plate is in the middle of the two plane surfaces, and*
- (ii) the thin plate is at a distance of 0.8 cm from one of the plane surfaces ? Take the dynamic viscosity of glycerine = $8.10 \times 10^{-1} \text{ N s/m}^2$.*

Problem 1.19 *A vertical gap 2.2 cm wide of infinite extent contains a fluid of viscosity 2.0 N s/m^2 and specific gravity 0.9. A metallic plate $1.2 \text{ m} \times 1.2 \text{ m} \times 0.2 \text{ cm}$ is to be lifted up with a constant velocity of 0.15 m/sec, through the gap. If the plate is in the middle of the gap, find the force required. The weight of the plate is 40 N.*

Problem 1.16 *A Newtonian fluid is filled in the clearance between a shaft and a concentric sleeve. The sleeve attains a speed of 50 cm/s, when a force of 40 N is applied to the sleeve parallel to the shaft. Determine the speed if a force of 200 N is applied.*

Problem 1.17 *A 15 cm diameter vertical cylinder rotates concentrically inside another cylinder of diameter 15.10 cm. Both cylinders are 25 cm high. The space between the cylinders is filled with a liquid whose viscosity is unknown. If a torque of 12.0 Nm is required to rotate the inner cylinder at 100 r.p.m., determine the viscosity of the fluid.*