Textbook: Fluid Mechanics and Hydraulic Machines
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FLUID MECHANICS I

Fundamental Concepts:

Definition: Fluids mechanics is a branch of Engineering which deals with the behaviour of fluids under the condition of rest and motion.

Fluid mechanics
- Statics
- Kinematics
- Dynamics

Statics - deals with fluids under static conditions

Kinematics - deals with the velocities, accelerations and patterns of flow only. The forces causing the velocity and acceleration are not considered.

Dynamics - deals with the relationship the velocities and accelerations of the fluid, and the forces causing them.

Fluid

A fluid is a substance which is capable of flowing.

Fluid has the flowing characteristics:

1. It has no definite shape, but takes the shape of the container
2. A small amount of shear force exerted on a fluid will cause it to deform continously so long as the force is applied.

Fluids may be classified as follows:

A. (i) Liquid (ii) Gas (iii) Vapour
B. (i) Ideal fluids (ii) Real fluids

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Ideal fluids : An ideal fluid is one which has no viscosity and surface tension, and is incompressible. No such fluid exist in nature. However, fluids with low viscosity such water and air can be treated as ideal fluids.

Real fluids. A real fluid is one which has viscosity, surface tension and compressibility in addition to density.

Some important properties of fluid are:
(i) Density (ii) Specific gravity (iii) Viscosity (iv) Vapour pressure (v) Cohesion (vi) Adhesion (vii) Surface tension (viii) Capillarity and (ix) Compressibility.

Density

Mass density : The density (also known as mass density or specific mass) of a liquid may be defined as the mass per unit volume at a standard temperature and pressure. It is denoted by ρ (rho). Its units is kg/m^3.

$$\rho = \frac{\text{Mass } (m)}{\text{Volume } (V)}.$$

Weight density ; The weight density (also known as specific weight) is defined as the weight per unit volume at a standard temperature and pressure. It is usually denoted by w.

$$w = \rho g \qquad w = \frac{\text{Weight}}{\text{Volume}}$$

g = acceleration due to gravity

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For water $w = 9.81\ kN/m^3$

Specific Volume: The specific volume is defined as the volume per unit mass of a fluid. It is denoted v.

$$v = \frac{V}{m} = \frac{1}{\rho}$$

Specific gravity: This is the ratio of the specific weight of a fluid to the specific of a standard fluid. It has no units.

For liquid, the standard fluid is pure water at $4^\circ C$

$$\therefore \text{specific gravity} = \frac{\text{specific weight of liquid}}{\text{specific weight of water}}$$

Example 1

Calculate the specific weight, specific mass, specific volume and specific gravity of a liquid having a volume of $6\ m^3$ and weight of $44\ kN$.

Solution

Volume of the liquid $= 6\ m^3$.

Weight of the liquid $= 44\ kN$

Specific weight, w:

$$w = \frac{\text{weight of liquid}}{\text{volume of liquid}} = \frac{44\ kN}{6\ m^3}$$

$$= 7.333\ kN/m^3.$$

Specific mass or mass density, ρ:

$$\rho = \frac{w}{g} = \frac{(7.333 \times 1000)\ N/m^3}{9.81\ m/s^2} = 747.5\ kg/m^3$$

Specific volume, $v = \frac{1}{\rho} = \frac{1}{747.5} = 0.00134\ m^3/kg$.

Specific gravity, $S = \frac{w_{liquid}}{w_{water}} = \frac{7.333}{9.81} = 0.747$.

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Viscosity

Viscosity is the property of fluid which determines its resistance to shearing stresses. It is a measure of the internal fluid friction which causes resistance to flow.

Newton's law of viscosity states that the shear stress (τ) on a fluid element is directly proportional to the rate of shear strain

$$\tau \propto \frac{du}{dy} \quad \text{or}$$

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

where μ is a constant called the coefficient of dynamic viscosity or viscosity.

The fluids which follows the law is known as Newtonian fluids. Examples are water and kerosene.

Fluids that don't follow the linear relationship between shear stress and rate of deformation (given by Newton's law) are termed as Non-Newtonian fluids. Examples include slurries, mud flows, blood, polymer solutions e.t.c.

The S.I unit of viscosity (μ) is $N.s/m^2$.

Kinematic viscosity is the ratio between the dynamic viscosity and density of fluid. It is denoted by ν (called nu)

$$\nu = \frac{\text{viscosity}}{\text{density}} = \frac{\mu}{\rho}$$

S.I unit of kinematic viscosity (ν) is m^2/s.

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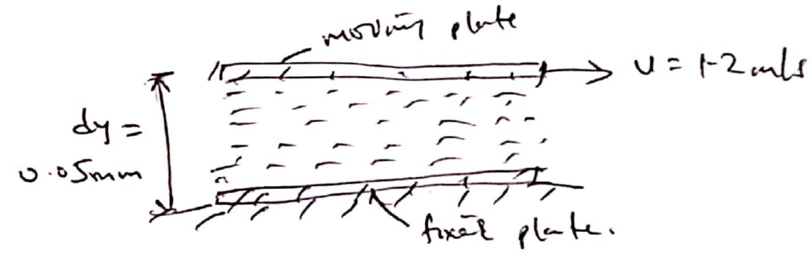
Example 2

A plate 0.05mm distant from a fixed plate moves at 1.2 m/s and requires a force of 2.2 N/m² to maintain this ~~f~~ speed. Find the viscosity of the fluid between the plates.

Solution

Velocity of moving plate, $u = 1.2\ m/s$
Distance between plates, $dy = 0.05mm = 0.05 \times 10^{-3}\ m$
force on the moving plate, $F = 2.2\ N/m^2$.

We know that



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

where τ = shear stress or force per unit area $= 2.2\ N/m^2$

du = change in velocity $= u - 0 = 1.2\ m/s$.
dy = change in distance $= 0.05 \times 10^{-3}\ m$

$$\therefore \quad 2.2 = \mu \times \frac{1.2}{0.05 \times 10^{-3}}$$

$$\text{or} \quad \mu = \frac{2.2 \times 0.05 \times 10^{-3}}{1.2} = 9.16 \times 10^{-5}\ Ns/m^2.$$

Exercise

The space between two square flat parallel plates is filled with oil. Each side of the plate is 720mm. The thickness of the oil film is 15mm. The upper plate which moves at 3m/s requires a force of 120N to maintain the speed. Determine

i) The dynamic viscosity of the oil
ii) The kinematic viscosity of oil if the specific gravity of the oil is 0.95.

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