Chapter 1: Generality and Fluid Properties

1.1 Introduction to Fluid Mechanics

Fluid mechanics is the study of fluids either in motion (fluid *dynamics*) or at rest (fluid *statics*). Both gases and liquids are classified as fluids, and the number of fluid engineering applications is enormous: breathing, blood flow, swimming, pumps, fans, turbines, airplanes, ships, rivers, windmills, pipes, missiles, icebergs, engines, filters, jets, and sprinklers, to name a few.

The study of fluid mechanics is categorized as:

- *Hydrodynamics*: It deals with the study of the motion of fluids that are practically incompressible (such as liquids, especially water, and gases at low speeds).
- *Hydraulics*: It deals with the liquid flows in pipes and open channels.
- *Gas dynamics*: It deals with the flow of fluids that undergo significant density changes, such as the flow of gases through nozzles at high speeds.
- *Aerodynamics*: It deals with the flow of gases (especially air) over bodies such as aircraft, rockets, and automobiles at high or low speeds

1.1.1 Solids and Fluids:

A/ **Solid**: A solid can resist a shear stress by a static deflection; the amount of deflection is proportional to the magnitude of applied stress upto some limiting condition. When the applied shear force is constant, a solid stops deforming.

The molecules of a solid are more closely packed. Hence the force of attraction between the molecules of solid is more larger than that of a fluid.

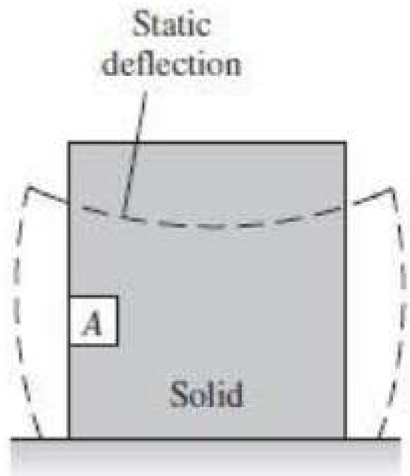


Fig. 1 Deformation in a solid

B/ **Fluid**: Any shear stress applied to a fluid, no matter how small, will result in motion of that fluid. The fluid moves and deforms continuously as long as the shear stress is applied. When constant shear force is applied, the fluid continues to deform and stops at certain strain rate. In fluids the applied stress is proportional to rate of deformation. A fluid may be either liquid or gas.

Liquid: A liquid is composed of relatively close-packed molecules with strong cohesive forces which tends to retain its volume and will form a free surface in a gravitational field if unconfined from above.

Examples: water, oil, mercury, gasoline, alcohol etc.

Gas: A gas, expands until it encounters the walls of the container and fills the entire available space. This is because the gas molecules are widely spaced, and the cohesive forces between them are very small. A gas has no definite volume, and when left to itself without confinement, it forms an atmosphere that is essentially hydrostatic.

Examples: air, helium, hydrogen, steam etc.,

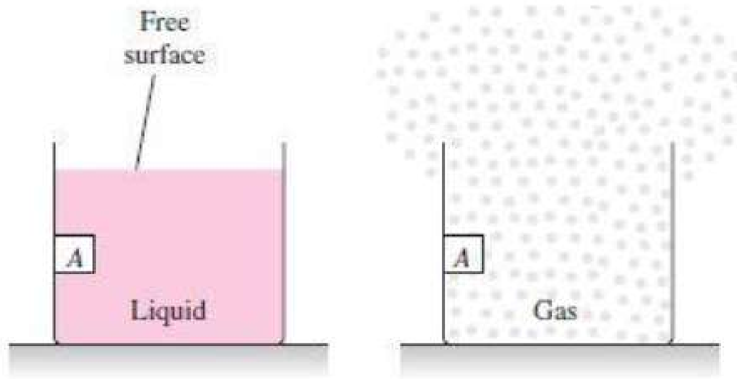
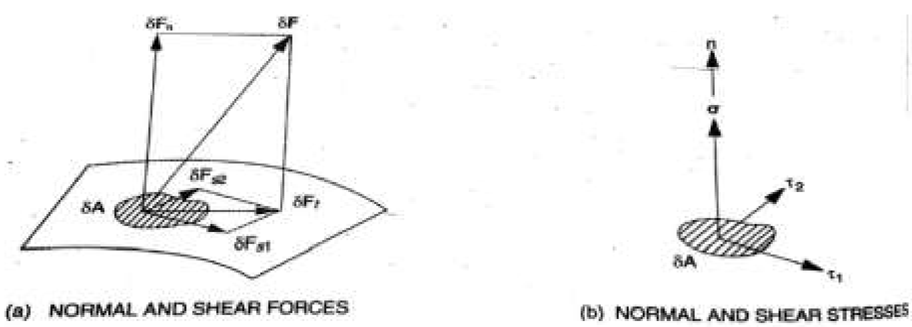


Fig. 2 Liquid and Gas

1.1.2 Ideal and Real Fluids :

Let us consider a small element on the surface of a body upon which a force is acting as δF
The force can be resolved into two components, δF_n and δF_t .



δF_n =Normal force acting on the area

$\delta\ F_t$ = horizontal force to the area, i.e., (tangential force or shear force)

Ideal Fluids: a fluid with no friction, so the tangential force or shear force is negligible ($\delta\ F_t\ =0$). Internal forces at any section within are normal δF_n

Real Fluids: Tangential or shearing forces δF_t always develop where there is motion relative to solid body , thus, fluid friction is created.

1.1.3 Incompressible fluids : A fluid is said to be incompressible when the volume occupied by a given mass does not vary as a function of external pressure. Liquids may be preferred as incompressible fluids (water, oil, etc.).

1.1.4 Compressible fluids: A fluid is said to be compressible when the volume occupied by a given mass varies as a function of external pressure. Gases are compressible fluids. For example, air, hydrogen, methane in the gaseous state are considered compressible fluids

1.2 Basic Fluid physical Properties:

Characteristics of a fluid which are independent of motion are called basic properties.

1.2.1. **Density (ρ):** Density of a fluid is its mass per unit volume. *Units*: kg/m^3 in SI system

$$\rho = \frac{masse\ (kg)}{volume\ (m^3)}$$

The density of most gases is proportional to pressure and inversely proportional to temperature. Liquids and solids, on the other hand, are essentially incompressible substances, and the variation of their density with pressure is usually negligible. Thus liquid flows are analytically treated as incompressible.

Examples:

liquids	Density (**ρ**) kg/m^3
Water	1000
Mercury	13600
Glycerol	1260
Ethanol	789
Benzene	879
Gas	Density (**ρ**) kg/m^3
Air	1.29
Oxygen	1.43
Hydrogen	0.089
Methane	0.714

1.2. 2 Specific gravity (δ): It is the ratio of density of fluid to the density of standard fluid. It is also referred as relative density.

In general, water is the standard fluid for liquids while air is for gases.

For liquids $\delta = \frac{\rho_{\ liquid}}{\rho_{\ water}}$ for gas $\delta = \frac{\rho_{\ gas}}{\rho_{\ air}}$

1.2.3. **Specific weight** (ω): It is the weight of the fluid to the volume occupied with it.

$$\omega = \frac{weig\,ht\ P}{volume\ \ V} = \frac{m.g}{V} = \rho.g \quad \textit{Units}\textbf{:}\ \ (\mathrm{N/m^3})$$

1.2 4. Specific volume (V): It is the volume occupied by the unit mass of fluid and is the reciprocal of density.

$$V = \frac{Volume\ \ (V)}{masse\ \ (m)} = \frac{1}{\rho} \qquad \textit{Units}\textbf{:}\ \mathrm{m^3/kg}\ \text{in SI system}$$

1.2. 5 Compressibility:

the compressibility is a measure of the instantaneous relative volume change of a fluid or solid as a response to a pressure (or mean stress) change. In its simple form, the compressibility (denoted β in some fields) may be expressed as

$$\beta_V = -\frac{1}{V}\left(\frac{dV}{dP}\right)$$

where V is volume and p is pressure. The choice to define compressibility as the negative of the fraction makes compressibility positive in the (usual) case that an increase in pressure induces a reduction in volume.

1.2 6 Viscosity:

It is a quantitative measure of a fluid's resistance to flow. It determines the strain rate in a fluid that is generated by a given applied shear stress. This property is due to the cohesive forces of attraction between the fluid molecules (internal friction of a fluid).

To obtain a relation for viscosity, consider a fluid layer between two very large parallel plates (or equivalently, two parallel plates immersed in a large body of a fluid) separated by a distance h (Fig. 3). Now a constant parallel force F is applied to the upper plate while the lower plate is held fixed. After the initial transients, it is observed that the upper plate moves continuously under the influence of this force at a constant velocity V. The fluid in contact with the upper plate sticks to the plate surface and moves with it at the same velocity, and the shear stress τ acting on this fluid layer is

$$\tau = \frac{F}{A}$$

Where A is the contact area between the plate and the fluid. Note that the fluid layer deforms continuously under the influence of shear stress.

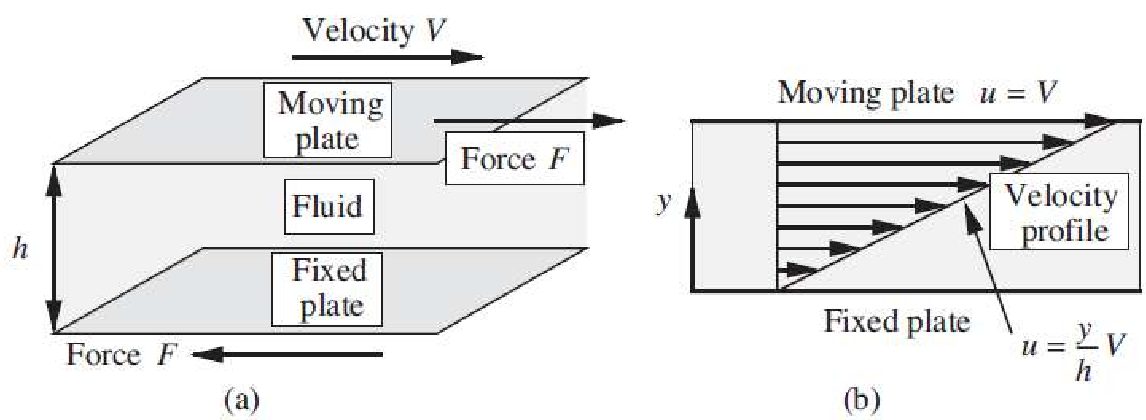


Fig.3 (a) Fluid in shear between parallel plat

(b) The ensuing linear velocity profile

Under these circumstances, the velocity u of the fluid to the right is found experimentally to vary linearly from zero at the lower plate ($y = 0$) to V itself at the upper plate, as in Fig. 1.8(b), corresponding to no-slip conditions at each plate. At any intermediate distance y from the lower plate, the velocity is simply:

$$u = \frac{y}{h} V$$

Experimentally, for a large class of materials, called *Newtonian* fluids, the shear stress is directly proportional to the velocity *gradient*:

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

The shear force acting on a Newtonian fluid layer (or, by Newton's third law, the force acting on the plate) is

$$F = \tau A = \mu A \frac{du}{dy} \qquad \text{(N)}$$

The proportionality constant μ is called the *viscosity* of the fluid; its dimensions can be found by substituting those for F (ML/T^2), A (L^2), and du/dy (T^{-1}), giving:

$$\mu [=] \frac{M}{LT} \qquad \textit{Units}\textbf{:(}\frac{\boldsymbol{kg}}{\boldsymbol{m.s}}\textbf{)} \text{ in SI system or(Pa.s)}$$

μ : absolute viscosity or dynamic viscosity.

Common unit is poise. 1 poise = 0.1 Pa.s

On the basis of relation between the applied shear stresses and the flow or rate of deformation, fluids can be categorized as Newtonain and Non-Newtonian fluid

For non-Newtonian fluids, the relationship between shear stress and rate of deformation is not linear, as shown in Fig. 4. The slope of the curve on the **τ** versus **du/dy** chart is referred to as the apparent viscosity of the fluid

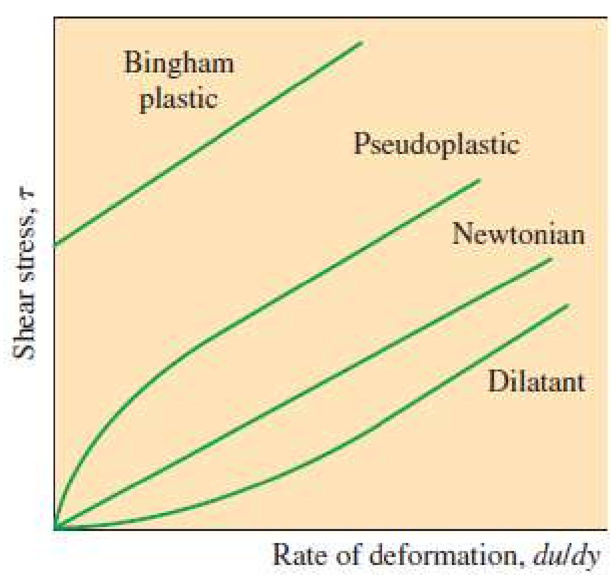


Fig 4 Variation of shear stress with the rate of deformation for Newtonian and non-Newtonian fluids (the slope of a curve at a point is the apparent viscosity of the fluid at that point).

1.2.6.1 Kinematic viscosity*:* It is the ratio of dynamic viscosity to the density of the fluid.

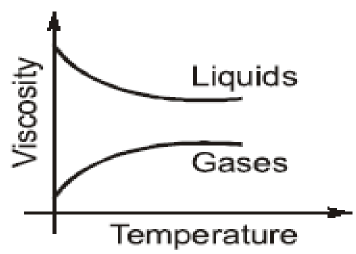
$$\nu = \frac{\mu}{\rho}$$

Units: It is expressed in m^2/sec or cm^2/sec.

1 stoke = 1 cm^2/sec = $10^{-4} m^2$/sec

Variation of Viscosity with temperature:

Increase in temperature cause a decrease in the viscosity of liquid whereas viscosity of gases increases with temperature growth.



Exercise 1:

Three liters of petrol weighs 23.7 N. calculate the mass density, specific weight, specific volume and specific gravity of petrol.

Mass density of petrol $\rho_p = \frac{Mass}{Volume} = \frac{\left(\frac{23.7}{9.81}\right)}{3.0} = 0.805 \frac{kg}{litres} = 805\ kg/m^3$

Mass density of water ρ_w=1000kg/m^3

Specific gravity of petrol $\delta = \frac{\rho_p}{\rho_w} = \frac{805}{1000} = 0.805$

Specific weight of petrol $\omega = \rho g = 805 \times \frac{9.81}{1000}\ kN/m^3 = 7.9KN/m^3$

Specific volume of petrol $V_s = \frac{1}{\rho_p} = \frac{1}{805} = 1.242\ \times 10^{-3}\ {m^3}/{kg}$

Exercise 2:

A plate 0.05 mm distant from a fixed plate moves at 1.2 m/sec and requires a shear stress of 2.2 N/m^2 to maintain this velocity. Find the viscosity of the fluid between the plates.

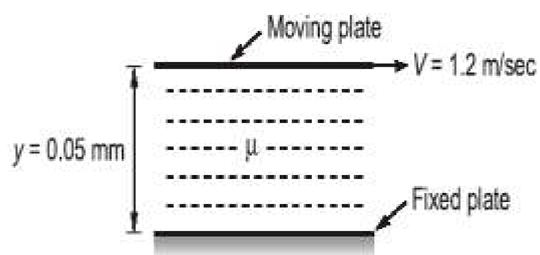
Solution:

Let μ be the viscosity of fluid between the plates.

Given, V=1.2 m/sec

y=0.05 mm =0.05 × 10^{-3}m

Shear stress τ = 2.2 N/m^2, To find μ=?



By Newton's law of viscosity we know that

$$\tau = \mu . \frac{V}{y}$$

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

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

μ=9.16× 10^{-5} kg/m.s