

## Chapter 1

# PROPERTIES OF FLUIDS

**Fluid mechanics** is defined as the science that deals with the behavior of fluids (liquids or gases) at rest (fluid statics) or in motion (fluid dynamics) and the interaction of fluids with solids or other fluids at the boundaries. Fluid mechanics itself is also divided into several categories. The study of fluids at rest is called as fluid statics. The study of fluids in motion, where pressure force are not considered, is called as fluid kinematics and if the pressure forces are also considered for the fluids in motion, is called as fluid dynamics.

The study of the motion of fluids that are practically incompressible (such as liquids, especially water, and gases at low speeds) is usually referred to as hydrodynamics. A subcategory of hydrodynamics is hydraulics, which deals with liquid flows in pipes and open channels. Gas dynamics deals with the flow of fluids that undergo significant density changes, such as the flow of gases through nozzles at high speeds. The category aerodynamics deals with the flow of gases (especially air) over bodies such as aircraft, rockets, and automobiles at high or low speeds. Some other specialized categories such as meteorology, oceanography, and hydrology deal with naturally occurring flows.

### PROPERTIES OF FLUIDS

#### Density or Mass Density

It is defined as the ratio of mass of a fluid to its volume. Thus mass per unit volume of a fluid is called Density. It is denoted by symbol  $\rho$  (rho). The unit of density is  $\text{kg/m}^3$ . The density of liquids is considered to be constant, while that of gases changes with respect to change in temperature and pressure.

Mathematically it is given as,

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

#### Specific Weight or Weight Density

It is defined as the ratio of weight of fluid to volume of fluid. It is weight per unit volume, thus it is called as weight density, and it is denoted by symbol  $w$ , and its unit is  $\text{Newton/m}^3$ .

Mathematically it is given as,

$$w = \frac{\text{Weight of fluid}}{\text{Volume of fluid}} = \frac{\text{Mass of fluid} \times \text{gravity}}{\text{Volume of fluid}} = \rho \times g$$

#### Specific Volume

Specific Volume is defined as the ratio of volume of fluid to mass of the fluid, or volume of fluid to mass of the fluid, is called specific volume. Simple it is the reciprocal of mass density.

Mathematically it is given as,

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

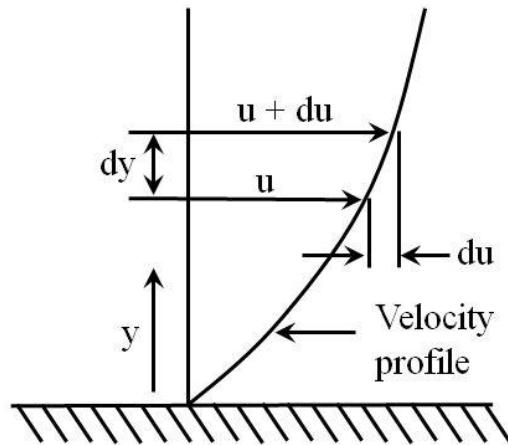
#### Specific Gravity

It is defined as the ratio of the weight density (density) of a fluid to the weight density of standard fluid. For liquids, standard liquid is water, and for gases, standard gas is air. It is also called as relative density. It is dimensionless quantity and it is denoted by the symbol  $S$ .

## Fluid Mechanics

### Viscosity

It is property of fluid and defined as resistance offered to movement of one layer of fluid by the adjacent layer of the fluid. Viscosity of fluid is assumed to be nearly constant, but in actual practice, viscosity of liquids and gases changes with respect to change in temperature.



When two layers of a fluid, considered at a distance 'dy' apart, move one over another at different velocities, let 'u' and 'u+du' as shown in figure. Viscosity and relative velocity together causes shear stress acting between two fluid layers. This shear stress is found to be proportional to the rate of change of velocity with respect to perpendicular distance from surface 'y', it is given by Newton and so it is called as Newton's Law of Viscosity.

Mathematically it is given as,

$$\tau \propto \frac{du}{dy} \quad \text{Or} \quad \tau = \mu \frac{du}{dy}$$

Where,  $\mu$  ( $\mu$ ) is called as coefficient of dynamic viscosity, or only viscosity

And  $du/dy$  = rate of shear strain or velocity gradient

SI unit of viscosity is Newton.Sec/m<sup>2</sup>

MKS unit of viscosity is kgf.sec/m<sup>2</sup>

CGS unit of viscosity is dyne.sec/cm<sup>2</sup>

$$1 \text{ Ns/m}^2 = 10 \text{ poise}$$

and

$$100 \text{ centipoise} = 1 \text{ poise}$$

### Kinematic Viscosity

It is defined as the ratio of dynamic viscosity to density of the fluid. It is denoted by symbol ' $\nu$ ' (nu).

Mathematically, 
$$\nu = \frac{\text{Dynamic viscosity}}{\text{Density}} = \frac{\mu}{\rho}$$

SI and MKS unit of kinematic viscosity is m<sup>2</sup>/sec

CGS unit of viscosity is cm<sup>2</sup>/sec

$$1 \text{ stoke} = \text{cm}^2/\text{sec} = 10^{-4} \text{ m}^2/\text{sec} \quad \text{and} \quad 100 \text{ centistoke} = 1 \text{ stoke}$$

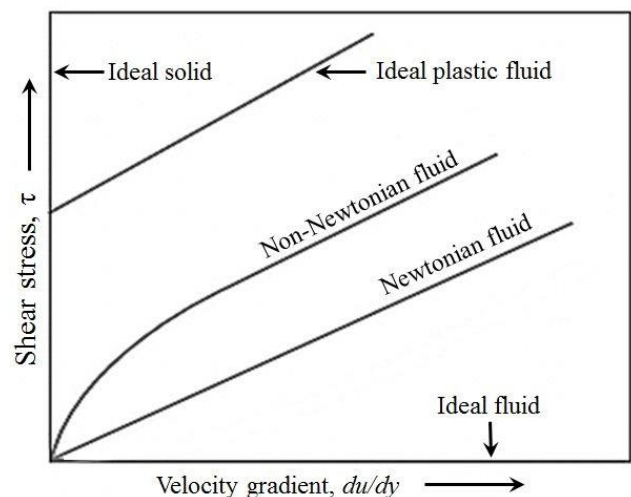
### Types of Fluids

The fluids may be classified into the following five types;

1. Ideal fluid
2. Real fluid
3. Newtonian fluid
4. Non Newtonian fluid
5. Ideal plastic fluid

#### 1. Ideal Fluid

A fluid which is incompressible and is having no viscosity is known as an ideal fluid. It is only imaginary fluid; all the fluids will have some viscosity.



## **Fluid Mechanics**

### **2. Real Fluid**

*A fluid, which possesses viscosity, is called as real fluid. All the fluids are real fluids.*

### **3. Newtonian fluid**

*A real fluid, in which the shear stress is directly proportional to the rate of shear strain (or velocity gradient), is known as newtonian fluid.*

### **4. Non Newtonian fluid**

*A real fluid, in which the shear stress is not directly proportional to the rate of shear strain (or velocity gradient), is known as non-newtonian fluid.*

### **5. Ideal plastic fluid**

*A fluid in which shear stress is more than the yield value and shear stress is proportional to the rate of shear strain (or velocity gradient), is known as ideal plastic fluid.*

## **Concept of Continuum**

*Matter is made up of atoms that are widely spaced in the gas phase. Yet it is very convenient to disregard the atomic nature of a substance and view it as a continuous, homogeneous matter with no holes, that is, a Continuum. The continuum idealization allows us to treat properties as point functions and to assume that the properties vary continually in space with no jump discontinuities. This idealization is valid as long as the size of the system we deal with is large relative to the space between the molecules. This is the case in practically all problems, except some specialized ones. The continuum idealization is implicit in many statements we make, such as “the density of water in a glass is the same at any point.”*

## **Coefficient of Compressibility**

*We know that the volume (or density) of a fluid changes with a change in its temperature or pressure. Fluids usually expand as they are heated or depressurized and contract as they are cooled or pressurized. But the amount of volume change is different for different fluids, and we need to define properties that relate volume changes to the changes in pressure and temperature. Two such properties are the bulk modulus of elasticity  $\mathbf{k}$  and the coefficient of volume expansion  $\beta$ .*

*It is a common observation that a fluid contracts when more pressure is applied on it and expands when the pressure acting on it is reduced. That is, fluids act like elastic solids with respect to pressure. Therefore, in an analogous manner to Young's modulus of elasticity for solids, it is appropriate to define a coefficient of compressibility  $\mathbf{k}$  (also called the bulk modulus of compressibility or bulk modulus of elasticity) for fluids as,*

$$\kappa = -v \left( \frac{\partial P}{\partial v} \right)_T = \rho \left( \frac{\partial P}{\partial \rho} \right)_T$$

*It can also be expressed approximately in terms of finite changes as*

$$\kappa \cong \frac{\Delta P}{\frac{\Delta v}{v}} \cong \frac{\Delta P}{\frac{\Delta \rho}{\rho}} \quad (T = \text{constant})$$

*The coefficient of compressibility represents the change in pressure corresponding to a fractional change in volume or density of the fluid while the temperature remains constant. Then it follows that the coefficient of compressibility of a truly incompressible substance ( $v = \text{constant}$ ) is infinity. The inverse of the coefficient of compressibility is called the isothermal compressibility is expressed as,*

$$\alpha = \frac{1}{\kappa} = -\frac{1}{v} \left( \frac{\partial v}{\partial P} \right)_T = \frac{1}{\rho} \left( \frac{\partial \rho}{\partial P} \right)_T$$

## Fluid Mechanics

### Coefficient of Volume Expansion

The density of a fluid, in general, depends more strongly on temperature than it does on pressure, and the variation of density with temperature is responsible for numerous natural phenomena such as winds, currents in oceans, heat transfer by natural convection, and even the rise of hot air. To quantify these effects, we need a property that represents the variation of the density of a fluid with temperature at constant pressure.

The property that provides that information is the coefficient of volume expansion (or volume expansivity)  $\beta$ , defined as

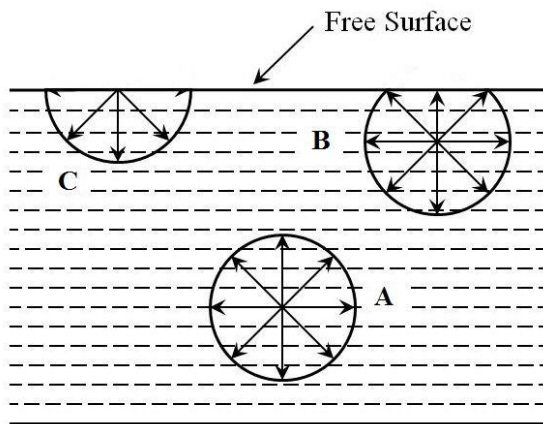
$$\beta = \frac{1}{v} \left( \frac{\partial v}{\partial T} \right)_P = -\frac{1}{\rho} \left( \frac{\partial \rho}{\partial T} \right)_P$$

It can also be expressed approximately in terms of finite changes as,

$$\beta \approx \frac{\frac{\Delta v}{v}}{\Delta T} \approx -\frac{\frac{\Delta \rho}{\rho}}{\Delta T} \quad (P = \text{constant})$$

### Surface Tension and Capillarity

Surface tension is defined as the tensile force acting on the surface of a liquid in contact with a gas or on the surface between two immiscible liquids such that the contact surface behaves like a membrane under tension. The magnitude of this force per unit length of the free surface will have the same value as the surface energy per unit area. It is denoted by Greek letter  $\sigma$  (called sigma). In MKS units, it is expressed as kgf/m while in SI units as N/m.



The phenomenon of surface tension is explained by Figure. Consider three molecules A, B, and C of a liquid in a mass of liquid. The molecule A is attracted in all directions equally by the surrounding molecules of the liquid. Thus the resultant force acting on the molecule A is zero. But the molecule B, which is situated near the free surface, is acted upon by upward and downward forces which are unbalanced. Thus a net resultant force on molecule B is acting in the downward direction. The molecule C, situated on the free surface of the liquid, doesn't experience a resultant downward force.

All the molecules on the free surface experience a downward force. Thus the free surface of the liquid acts like a very thin film under tension of the surface of the liquid acts as through it is an elastic membrane under tension.

### Surface tension on liquid droplet

Consider a small spherical droplet of a liquid of radius 'r'. On the entire surface of the droplet, the tensile force due to surface tension will be acting.

Let,

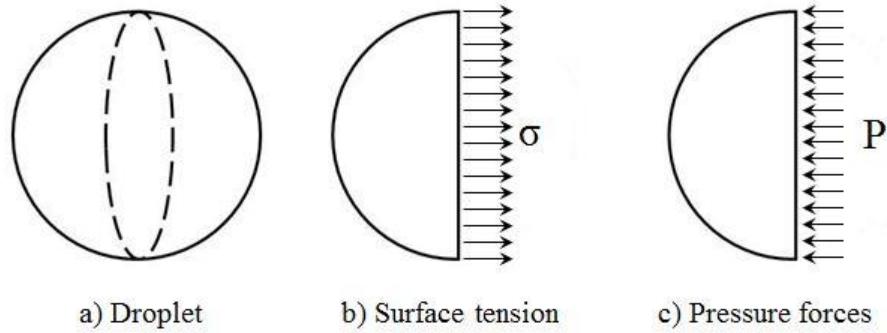
$\sigma$  = surface tension of the liquid

P = pressure intensity inside the droplet (in excess of the outside pressure intensity)

d = diameter of droplet.

Let the droplet is cut into two halves. The forces acting on one half (say left half) will be

## Fluid Mechanics



i) Tensile force due to surface tension acting around the circumference of the cut portion as shown in Figure (B), and this is equal to

$$= \sigma \times \text{Circumference}$$

$$= \sigma \times \pi d$$

ii) Pressure force on the area  $(\pi/4)d^2 = P \times (\pi/4)d^2$  as shown in Figure (C). These two forces will be equal and opposite under equilibrium conditions, i.e.,

$$P \times \frac{\pi}{4}d^2 = \sigma \times \pi d$$

Rearranging above,

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

The above equation shows that with the decrease of diameter of the droplet, pressure intensity inside the droplet increases.

### Surface tension on a hollow bubble

A hollow bubble like a soap bubble in air has two surfaces in contact with air, one inside and other outside. Thus two surfaces are subjected to surface tension. In such case, we have

$$P \times \frac{\pi}{4}d^2 = 2 \times \sigma \times \pi d$$

Rearranging above,

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

### Surface tension on a liquid jet

Consider a liquid jet of diameter 'd' and length 'L' as shown in Figure.

Let,  $P$  = pressure intensity inside the liquid jet above the outside pressure

$\sigma$  = surface tension of the liquid

Consider the equilibrium of the semi jet, we have

Force due to pressure

$$= P \times \text{area of semi jet}$$

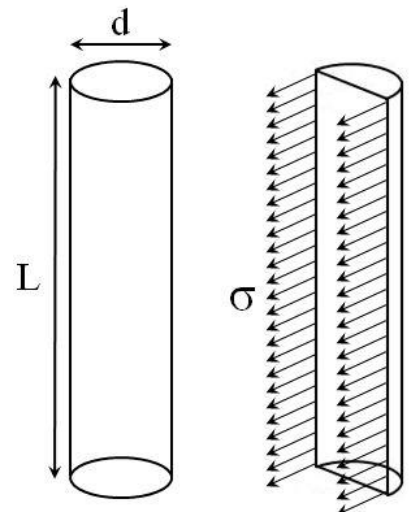
$$= P \times L \times d$$

Force due to surface tension =  $\sigma \times 2L$

Equating the forces, we have

$$P \times L \times d = \sigma \times 2L$$

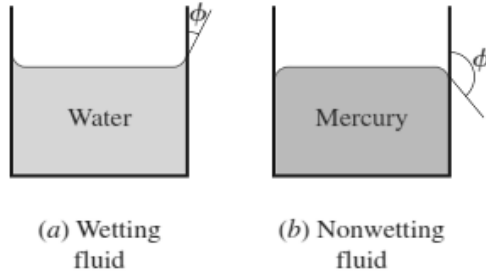
$$P = \frac{\sigma \times 2L}{L \times d}$$



## Fluid Mechanics

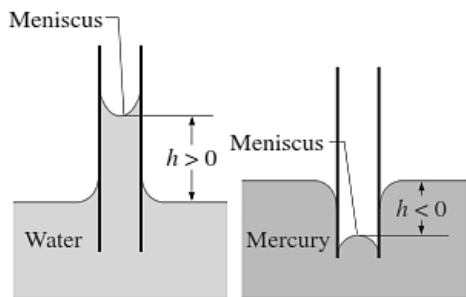
### Capillarity Effect

Another interesting consequence of surface tension is the capillary effect, which is the rise or fall of a liquid in a small-diameter tube inserted into the liquid. Such narrow tubes or confined flow channels are called capillaries. The curved free surface of a liquid in a capillary tube is called the meniscus.



It is commonly observed that water in a glass container curves up slightly at the edges where it touches the glass surface; but the opposite occurs for mercury: it curves down at the edges (Figure). This effect is usually expressed by saying that water wets the glass (by sticking to it) while mercury does not. The strength of the capillary effect is quantified by the **contact** (or wetting) **angle**  $\Phi$ , defined as the angle that the tangent to the liquid surface makes with the solid surface at the point of contact. The

surface tension force acts along this tangent line toward the solid surface. A liquid is said to wet the surface when  $\Phi < 90^\circ$  and not to wet the surface when  $\Phi > 90^\circ$ .



The phenomenon of capillary effect can be explained microscopically by considering cohesive forces (the forces between like molecules, such as water and water) and adhesive forces (the forces between unlike molecules, such as water and glass). The liquid molecules at the solid-liquid interface are subjected to both cohesive forces by other liquid molecules and adhesive forces by the molecules of the solid. The relative magnitudes of these forces determine whether a liquid wets a solid surface or not. Obviously, the water

molecules are more strongly attracted to the glass molecules than they are to other water molecules, and thus water tends to rise along the glass surface. The opposite occurs for mercury, which causes the liquid surface near the glass wall to be suppressed (Figure).