UNIT 1

BASIC PROPERTIES OF FLUID

1. Introduction to fluid mechanics

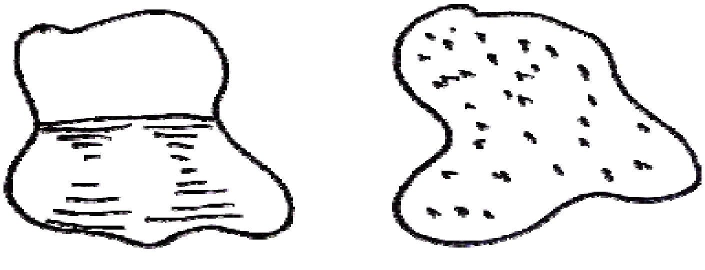
The air we breathe, the water we drink, and the blood and other liquids that flow in our bodies demonstrate the close dependence of our lives on various fluids. Not only must these fluids, as well as many others, be present when we need them, it is important that they are present where we need them with not only satisfactory quality; but also sufficient quantity.

Fluid mechanics deals with the study of all fluids under static and dynamic situations. Fluid mechanics is a branch of continuous mechanics which deals with a relationship between forces, motions, and static conditions in a continuous material. This study area deals with many and diversified problems such as surface tension, fluid statics, and flow in enclose bodies, or flow round bodies (solid or otherwise), flow stability, etc. In fact, almost any action a person is doing involves some kind of a fluid mechanics problem.

2. Solids, liquids and gases

In general matter can be distinguished by the physical forms known as solid, liquid, and gas. The liquid and gaseous phases are usually combined and given a common name of fluid. Solids differ from fluids on account of their molecular structure (spacing of molecules and ease with which they can move). The intermolecular forces are large in a solid, smaller in a liquid and extremely small in gas.

Fluid mechanics is the study of fluids at rest or in motion. It has traditionally been applied in such area as the design of pumps, compressor, design of dam and canal, design of piping and ducting in chemical plants, the aerodynamics of airplanes and automobiles. In recent years fluid mechanics is truly a ‘high-tech’ discipline and many exciting areas have been developed like the aerodynamics of multi-storey buildings, fluid mechanics of atmosphere, sports, and micro fluids.


Liquid showing free surface Gas filling volume

Behaviour of fluids in containers

3. Fluids

A fluid is a substance that deforms continuously under the action of a shear force. A fluid may be a liquid or a gas; it offers resistance to a change of shape and is capable of flowing. Liquid and gas are distinguished as follows:

- A gas completely fills the space in which it is contained; a liquid usually has a free surface.
- A gas is a fluid which can be compressed relatively easily and is often treated as such; a liquid can be compressed only with difficulty.

For static fluids:

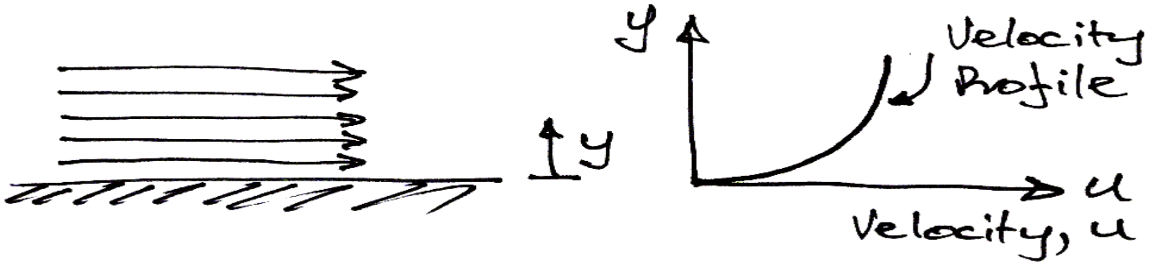
According to this definition, if we apply a shear force to a fluid it will deform and take up a state in which no shear force exists. Therefore, we can say:

> *If a fluid is at rest there can be no shearing forces acting and therefore all forces in the fluid must be perpendicular to the planes in which they act.*

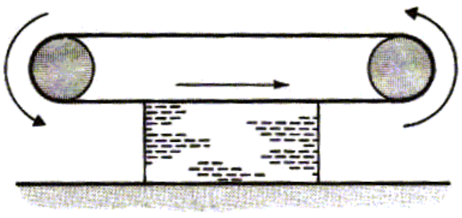
Note here that we specify that the fluid must be at rest. This is because, it is found experimentally that fluids in motion can have slight resistance to shear force. This is the source of *viscosity*.

For fluids in motion:

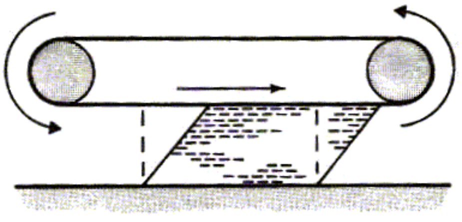
Consider the fluid shown flowing along a fixed surface. At the surface there will be little movement of the fluid (it will ‘stick’ to the surface), whilst further away from the surface the fluid flows faster (has greater velocity):



If one layer of is moving faster than another layer of fluid, there must be shear forces acting between them. For example, if we have fluid in contact with a conveyor belt that is moving we will get the behaviour shown:



Ideal fluid



Real (Viscous) Fluid

When fluid is in motion, any difference in velocity between adjacent layers has the same effect as the conveyor belt does .Therefore, to represent real fluids in motion we must consider the action of shear forces.

4. System of units

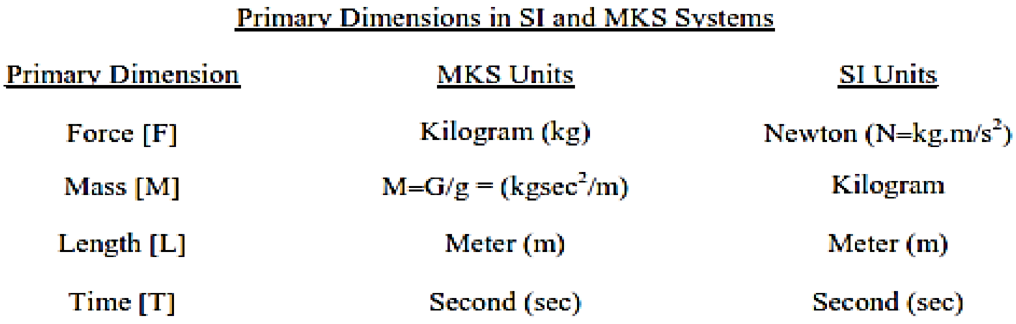
The official international system of units (System International Units). Strong efforts are underway for its universal adoption as the exclusive system for all engineering and science, but older systems, particularly the cgs and fps engineering gravitational systems are still in use and probably will be around for some time. The chemical engineer finds many physiochemical data given in cgs units; that many calculations are most conveniently made in fps units; and that SI units are increasingly encountered in science and engineering. Thus it becomes necessary to be expert in the use of all three systems.

DIMENSIONS AND UNITS

Dimension = A dimension is the measure by which a physical variable is expressed quantitatively.

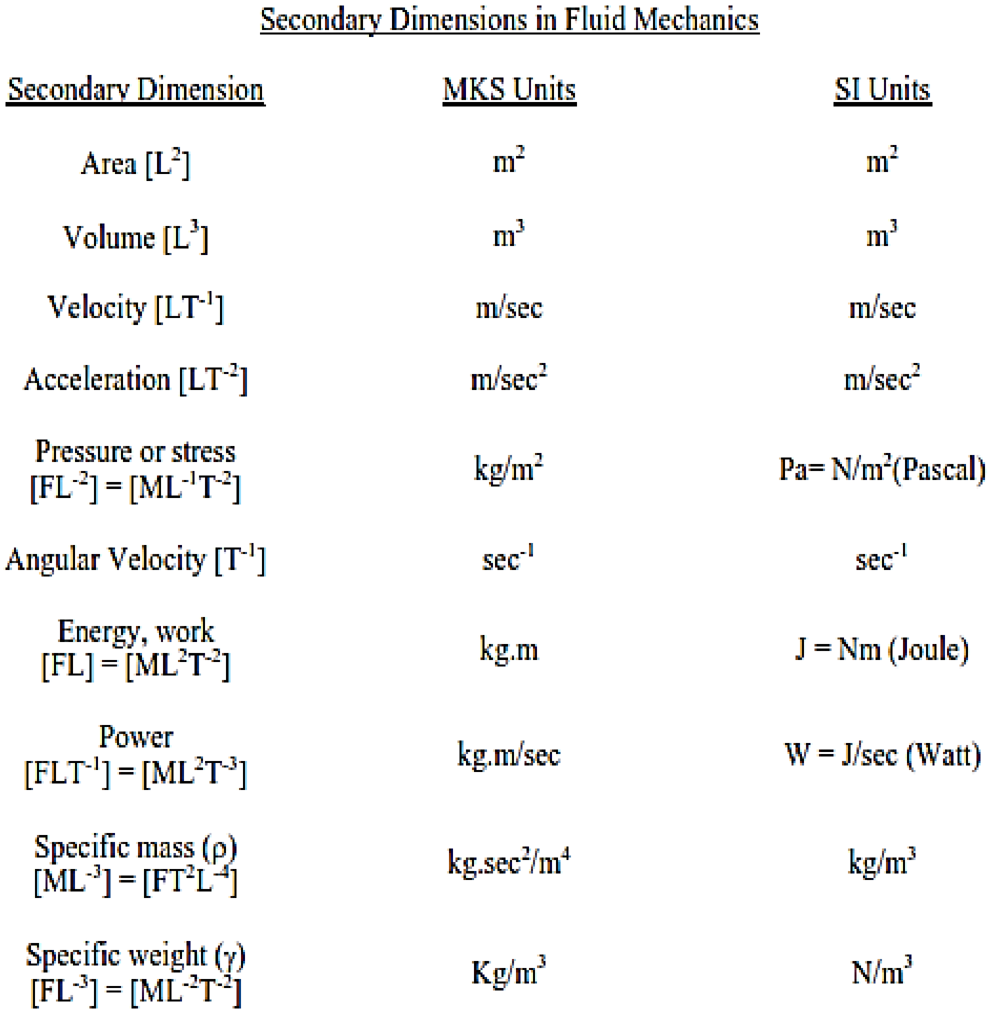
Unit = A unit is a particular way of attaching a number to the quantitative dimension.

Thus length is a dimension associated with such variables as distance, displacement, width, deflection, and height, while centimeters or meters are both numerical units for expressing length.



Primary Dimensions in SI and MKS Systems

Primary Dimension	MKS Units	SI Units
Force [F]	Kilogram (kg)	Newton ($N=kg.m/s^2$)
Mass [M]	$M=G/g = (kgsec^2/m)$	Kilogram
Length [L]	Meter (m)	Meter (m)
Time [T]	Second (sec)	Second (sec)



Secondary Dimensions in Fluid Mechanics

Secondary Dimension	MKS Units	SI Units
Area $[L^2]$	m^2	m^2
Volume $[L^3]$	m^3	m^3
Velocity $[LT^{-1}]$	m/sec	m/sec
Acceleration $[LT^{-2}]$	m/sec^2	m/sec^2
Pressure or stress $[FL^{-2}] = [ML^{-1}T^{-2}]$	kg/m^2	$Pa= N/m^2$(Pascal)
Angular Velocity $[T^{-1}]$	sec^{-1}	sec^{-1}
Energy, work $[FL] = [ML^2T^{-2}]$	kg.m	J = Nm (Joule)
Power $[FLT^{-1}] = [ML^2T^{-3}]$	kg.m/sec	W = J/sec (Watt)
Specific mass (ρ) $[ML^{-3}] = [FT^2L^{-4}]$	$kg.sec^2/m^4$	kg/m^3
Specific weight (γ) $[FL^{-3}] = [ML^{-2}T^{-2}]$	Kg/m^3	N/m^3

5. Fluid as a continuum

Fluid mechanics is supposed to describe motion of fluids and related phenomena at macroscopic scales, which assumes that a fluid can be regarded as a continuous medium. This means that any small volume element in the fluid is always supposed so large that it still contains a very great number of molecules. Accordingly, when we consider infinitely small elements of volume, we mean very small compared with the volume of the body under consideration, but large compared with the distances between the molecules. The expressions fluid particle and point in a fluid are to be understood in this sense.

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.”

That is, properties such as density, pressure, temperature, and velocity are taken to be well-defined at infinitely small points. These properties are then assumed to vary continuously and smoothly from one point to another. Consequently, the fact that the fluid is made up of discrete molecules is ignored. If, for example, we deal with the displacement of some fluid particle, we do mean not the displacement of an individual molecule, but that of a volume element containing many molecules, though still regarded as a point in space. That’s why fluid mechanics is a branch of continuum mechanics, which models matter from a macroscopic viewpoint without using the information that it is made out of molecules.

Limitations of Continuum hypothesis:

According to the continuous assumption, the physical quantities (like velocity, pressure and density) are supposed to vary smoothly on macroscopic scales. However, this may not be the case everywhere in the flow. Also, if we are interesting by scale invariant properties of fluid in some particular cases, we need to keep in mind that there is a scale at which the equations of fluid mechanics break up, which is the molecular scale characterized by the mean free path of molecules between collisions.

6. Specific properties:

Properties are considered to be either intensive or extensive. Intensive properties are those that are independent of the mass of a system, such as temperature, pressure, and density. Extensive properties are those whose values depend on the size or extent of the system. Total mass, total volume V and total momentum are some examples of extensive properties. An easy way to determine whether a property is intensive or extensive is to divide the system into two equal parts with an imaginary partition. Each part will have the same value of intensive properties as the original system, but half the value of the extensive properties.

Generally, uppercase letters are used to denote extensive properties (with mass m being a major exception), and lowercase letters are used for intensive properties (with pressure P and temperature

T being the obvious exceptions). Extensive properties per unit mass are called specific properties.

I. Specific density

Specific density or specific mass or mass density is the mass per unit volume of the fluid.

$$\therefore \quad \rho = \frac{Mass}{Volume}$$

$$\rho = \frac{\mathrm{M}}{\mathrm{V}} \text{ or } \frac{\mathrm{dM}}{\mathrm{dV}}$$

Unit: kg/m^3

With the increase in temperature volume of fluid increases and hence mass density decreases in case of fluids as the pressure increases volume decreases and hence mass density increases.

The mass per unit volume of a substance, usually denoted as ρ . Typical values are:

- Water: 1000 kg/m3;
- Mercury: 13546 kg/m3;
- Air: 1.23 kg/m3;
- Paraffin: 800 kg/m3.

II. Specific weight

Specific weight or weight density of a fluid is the weight per unit volume.

$$\therefore \quad \gamma = \frac{Weight}{Volume} = \frac{\mathrm{W}}{\mathrm{V}} \text{ or } \frac{\mathrm{dW}}{\mathrm{dV}}$$

Unit: N/m^3 or Nm^{-3}.

With increase in temperature volume increase and hence specific weight decreases. With increase in pressure volume decreases and hence specific weight increases.

Therefore specific weight = specific density * acceleration due to gravity

$$\text{We have } \gamma = \frac{Weight}{Volume}$$

$$\gamma = \frac{mass\ x\ g}{Volume}$$

$$\gamma = \rho \text{ x } g$$

III. Specific volume:

It is the volume per unit mass of the fluid. Unit is m^3/kg.

$$\therefore \quad \forall = \frac{Volume}{mass} = \frac{V}{M} \text{ or } \frac{dV}{dM}$$

IV. Specific gravity:

It is the ratio of density of the fluid to the density of a standard fluid.

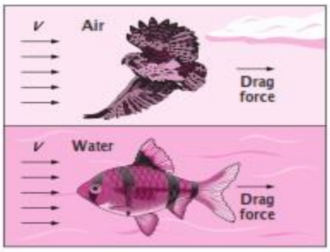
$$S = \frac{\rho_{fluid}}{\rho_{standard\,fluid}}$$

Unit: It is a dimensionless quantity and has no unit.

In case of liquids water at $4^{O}C$ is considered as standard liquid. $\rho_{water} = 1000\ kg/m^3$

7. Viscosity

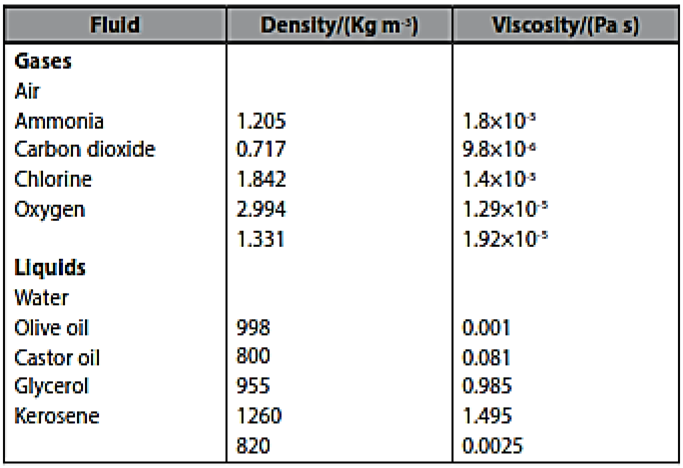
When two solid bodies in contact move relative to each other, a friction force develops at the contact surface in the direction opposite to motion. To move a table on the floor, for example, we have to apply a force to the table in the horizontal direction large enough to overcome the friction force. The magnitude of the force needed to move the table depends on the *friction coefficient* between the table and the floor. The situation is similar when a fluid moves relative to a solid or when two fluids move relative to each other. We move with relative ease in air, but not so in water. Moving in oil would be even more difficult, as can be observed by the slower downward motion of a glass ball dropped in a tube filled with oil. It appears that there is a property that represents the internal resistance of a fluid to motion or the “fluidity,” and that property is the viscosity. The force a flowing fluid exerts on a body in the flow direction is called the drag force, and the magnitude of this force depends, in part, on viscosity.



A fluid moving relative to a body exerts a drag force on the body, partly because of friction caused by viscosity.

Viscosity is the property by virtue of which fluid offers resistance against the flow or shear deformation. In other words, it is the reluctance of the fluid to flow. Viscous force is that force of resistance offered by a layer of fluid for the motion of another layer over it.

In case of liquids, viscosity is due to cohesive force between the molecules of adjacent layers of liquid. In case of gases, molecular activity between adjacent layers is the cause of viscosity.



Fluid	Density/(Kg m^{-3})	Viscosity/(Pa s)
Gases		
Air		
Ammonia	1.205	1.8×10^{-5}
Carbon dioxide	0.717	9.8×10^{-6}
Chlorine	1.842	1.4×10^{-5}
Oxygen	2.994	1.29×10^{-5}
	1.331	1.92×10^{-5}
Liquids		
Water		
Olive oil	998	0.001
Castor oil	800	0.081
Glycerol	955	0.985
Kerosene	1260	1.495
	820	0.0025

Table 1.1 Properties of common gasses and liquids at 20 C and 1 atm pressure.

I. Newton's law of viscosity

Let us consider a liquid between the fixed plate and the movable plate at a distance 'Y' apart, 'A' is the contact area (Wetted area) of the movable plate, 'F' is the force required to move the plate with a velocity 'U' According to Newton's law shear stress is proportional to shear strain.

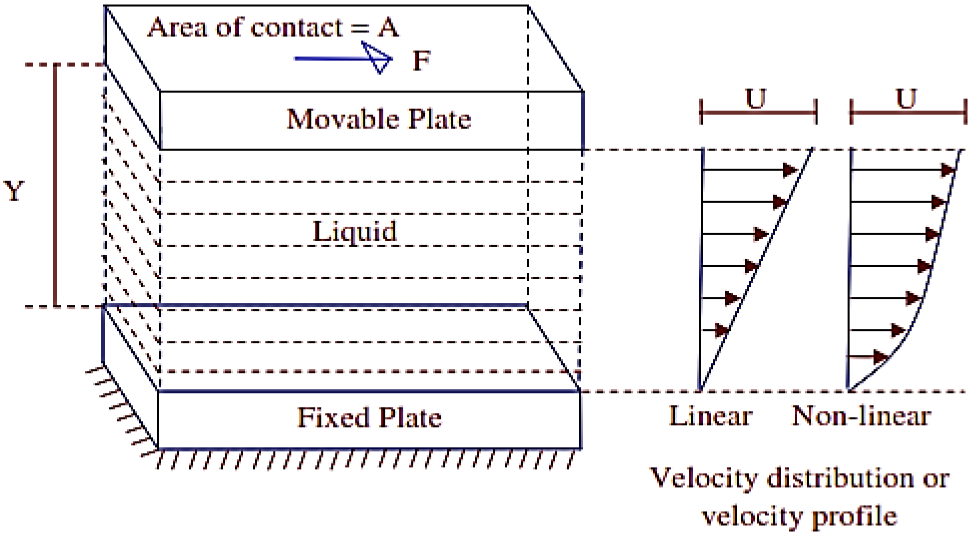


Fig.2 Definition diagram of Liquid viscosity

$$\tau \ \alpha \ A$$

$$\tau \ \alpha \ (1/y)$$

$$\tau \ \alpha \ du$$

$$\text{Therefore,} \quad \tau \ \alpha \ \frac{du}{dy}$$

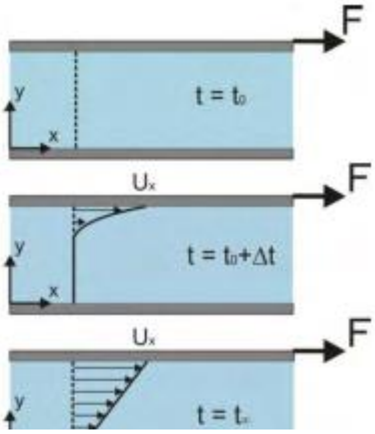
$$\tau = \mu \ \frac{du}{dy}$$

This equation is called Newton's law of viscosity.

'μ' is the constant of proportionality called Dynamic Viscosity or Absolute Viscosity or Coefficient of Viscosity or Viscosity of the fluid.

Velocity gradient or rate of shear strain:

It is the difference in velocity per unit distance between any two layers. If the velocity profile is linear then velocity gradient is given by U. If the velocity profile
Y is non – linear then it is given by du /dy



- Unit of velocity gradient : $\frac{U}{Y} = \frac{m/s}{m} = /s = s^{-1}$

- Unit of dynamic viscosity (τ): $\tau = \mu \ . \ \frac{u}{y}$

$$\mu = \frac{\tau y}{U}$$

$$\Rightarrow \frac{N/m^2 \ . \ m}{m/s}$$

$$\mu \Rightarrow \frac{N\text{-}sec}{m^2} \quad \text{or} \quad \mu \Rightarrow P_a\text{-}S$$

NOTE: In CGS system unit of dynamic viscosity is $\frac{dyne\ .\ S}{Cm^2}$ and is called poise (P).

If the value of μ is given in poise, multiply it by 0.1 to get it in $\frac{NS}{m^2}$.

1 Centipoises = 10^{-2} Poise.

- **Effect of Pressure on Viscosity of fluids:**

  Pressure has very little or no effect on the viscosity of fluids.

- **Effect of Temperature on Viscosity of fluids:**

  1. *Effect of temperature on viscosity of liquids:* Viscosity of liquids is due to cohesive force between the molecules of adjacent layers. As the temperature increases cohesive force decreases and hence viscosity decreases.
  2. *Effect of temperature on viscosity of gases:* Viscosity of gases is due to molecular activity between adjacent layers. As the temperature increases molecular activity increases and hence viscosity increases.

- **Kinematics Viscosity:** It is the ratio of dynamic viscosity of the fluid to its mass density.

$$\therefore \text{Kinematic Viscosity} = \frac{\mu}{\rho}$$

Unit of KV:

$$KV \Rightarrow \frac{\mu}{\rho}$$

$$\Rightarrow \frac{NS/m^2}{kg/m^3}$$

$$= \frac{NS}{m^2} x \frac{m^3}{kg}$$

$$= \left(\frac{kg\,m}{s^2}\right) x \frac{s}{m^2} x \frac{m^3}{kg} = m^2/s$$

$$F = ma$$

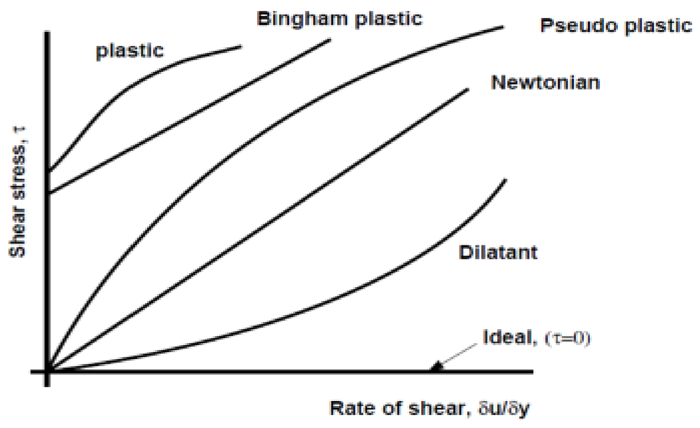
$$N = Kg.m/s^2$$

$$\therefore \text{Kinematic Viscosity} = m^2/s$$

NOTE: Unit of kinematics Viscosity in CGS system is cm^2/s and is called stoke (S)

If the value of KV is given in stoke, multiply it by 10^{-4} to convert it into m^2/s.

II. Types of fluids



Type of fluid	Description	Equation	Example
Ideal Fluid	Fluids with zero viscosity	$\tau = 0$	
Newtonian Fluid	These follow Newton's law of viscosity, Dynamic viscosity does not change with deformation.	$\tau = \mu \frac{du}{dy}$	Water, Kerosene, air
Non-Newtonian fluids	Fluids which do not follow linear relationship between shear stress and rate of deformation.	$\tau = \mu \left(\frac{du}{dy}\right)^n$	Solutions, suspensions, slurries, mud flows, polymer solutions, blood
- Dilatent Fluids		$n > 1$	Sugar solutions, butter, printing ink
- Psuedo plastic fluids		$n < 1$	Paper pulp, rubber suspension paints.
Plastic Fluids	This is a non-Newtonian fluid which has an initial yield stress is to be exceeded to cause continuous deformation,		
- Ideal plastic or Bingham fluid		$\tau = \text{const} + \mu \frac{du}{dy}$	Sewage sludge, water suspension of clay and fly ash
- Thixotropic substance		$\tau = \text{const} + \mu \left(\frac{du}{dy}\right)^n$	Printer's ink

IV. Effect of pressure on viscosity

Pressure has very little or no effect on the viscosity of fluids.

V. Effect of temperature on viscosity

1. *Effect of temperature on viscosity of liquids:* Viscosity of liquids is due to cohesive force between the molecules of adjacent layers. As the temperature increases cohesive force decreases and hence viscosity decreases.
2. *Effect of temperature on viscosity of gases:* Viscosity of gases is due to molecular activity between adjacent layers. As the temperature increases molecular activity increases and hence viscosity increases.

Gases:

$$\mu = \frac{aT^{1/2}}{1 + b/T}$$

Liquids:

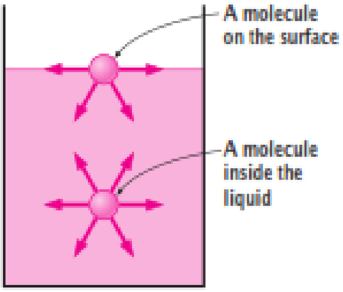
$$\mu = a10^{b/(T-c)}$$

Where a,b,c are constants and t is the temperature

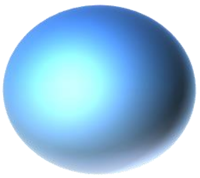
8. Surface tension

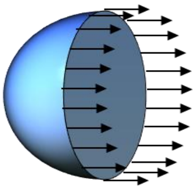
It is often observed that a drop of blood forms a hump on a horizontal glass; a drop of mercury forms a near-perfect sphere and can be rolled just like a steel ball over a smooth surface; water droplets from rain or dew hang from branches or leaves of trees; a liquid fuel injected into an engine forms amidst of spherical droplets; water dripping from a leaky faucet falls as spherical droplets; a soap bubble released into the air forms a spherical shape; and water beads up into small drops on flower petals. In these and other observances, liquid droplets behave like small spherical balloons filled with the liquid, and the surface of the liquid acts like a stretched elastic membrane under tension. The pulling force that causes this tension acts parallel to the surface and is due to the attractive forces between the molecules of the liquid. The magnitude of this force per unit length is called surface tension s and is usually expressed in the unit N/m. This effect is also called surface energy. In this case, s represents the stretching work that needs to be done to increase the surface area of the liquid by a unit amount.

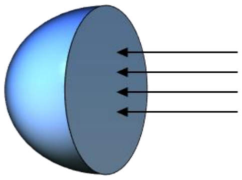
- Cohesive forces: are the forces that exist between molecules of one phase.
- Adhesive forces: are the forces that exist between molecules of two different phases.



I. Pressure inside a water droplet, soap bubble and liquid jet


DROPLET


SURFACE TENSION ON A DROPLET


PRESSURE FORCES ACTING ON A DROPLET

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

Let;

σ = the surface tension of the liquid
p = pressure intensity inside the droplet (in excess of the outside pressure intensity)
d = Diameter of the droplet

Let the droplet cut into two halves.
The forces acting on one half (say on left half) will be tensile force due to surface tension acting around the circumference of the cut portion as shown in the below figure and this equal to: σ x circumference = σ.πd N
Pressure force on the area = p.πd2/4 N

These two forces will be equal and opposite and under equilibrium,

$$\frac{\pi d^2}{4} p = \sigma.\pi d$$

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

For general curved surface with radii of curvature r_1 and r_2 at a point of interest

$$p = \sigma\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

Hollow bubbles such as soap bubbles have two surfaces on which surface tension can act. In such cases:

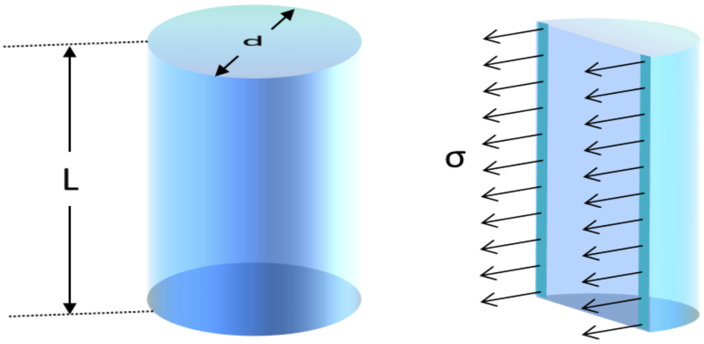
$$2\pi d\sigma = \frac{p\pi d^2}{4}$$

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

Interestingly, soap solution has a high value of σ which makes it possible for the soap bubble to be large in diameter for small pressure of blowing.

Surface tension on Liquid jet:

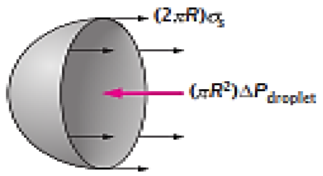
Consider a liquid jet of diameter d and length L as shown in the figure:



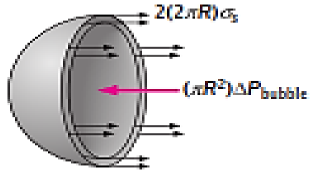
Let p = Pressure intensity inside the jet above the outside pressure
σ = Surface tension of the liquid
L = length of the jet
Consider the equilibrium of the semi jet, we have
Force due to pressure = p x area = p.L.d
Force due to surface tension = σ. 2L
Equating the two forces, we have:

$$p.L.d = \sigma.2L$$

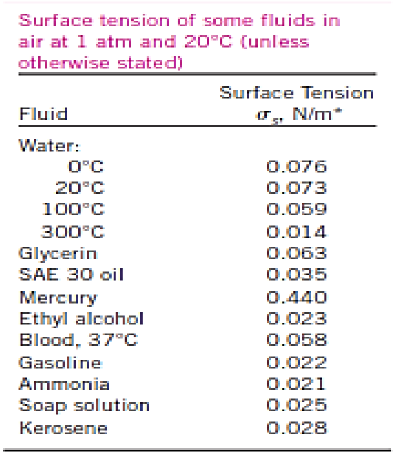
$$p = \frac{2\sigma}{d}$$



(a) Half a droplet



(b) Half a bubble



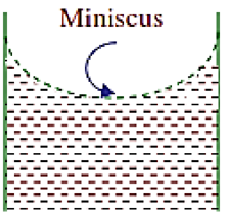
Surface tension of some fluids in air at 1 atm and 20°C (unless otherwise stated)

Fluid	Surface Tension σ_s, N/m*
Water:	
0°C	0.076
20°C	0.073
100°C	0.059
300°C	0.014
Glycerin	0.063
SAE 30 oil	0.035
Mercury	0.440
Ethyl alcohol	0.023
Blood, 37°C	0.058
Gasoline	0.022
Ammonia	0.021
Soap solution	0.025
Kerosene	0.028

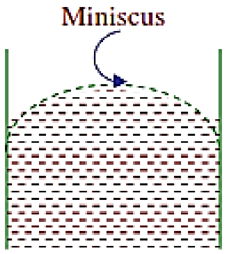
9. Capillarity

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 rise of kerosene through a cotton wick inserted into the reservoir of a kerosene lamp is due to this effect. The capillary effect is also partially responsible for the rise of water to the top of tall trees. The curved free surface of a liquid in 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. This effect is usually expressed by saying that water wets the glass (by sticking to it) while mercury does not.

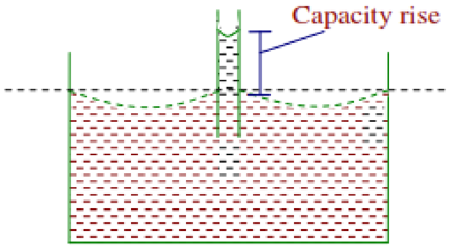
The strength of the capillary effect is quantified by the contact (or wetting) angle f, defined as the angle that the tangent to the liquid surface makes with the solid surface at the point of contact. The surface tension force acts along this tangent line toward the solid surface. A liquid is said to wet the surface when f + 90° and not to wet the surface when f 90°. In atmospheric air, the contact angle of water (and most other organic liquids) with glass is nearly zero, of “0°. Therefore, the surface tension force acts upward on water in a glass tube along the circumference, tending to pull the water up.



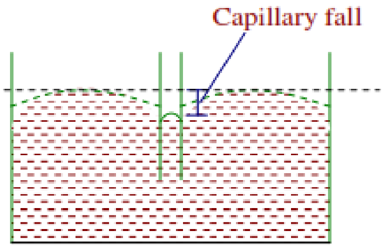
Cohesion < Adhesion
Eg: Water



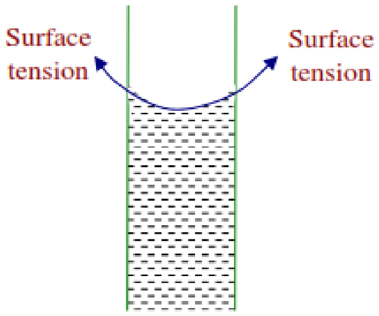
Cohesion > Adhesion
Eg: Mercury

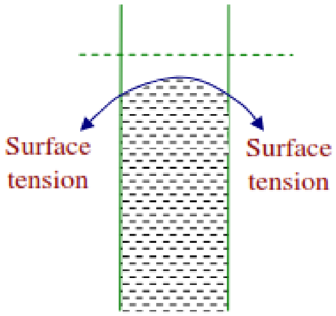


Cohesion < Adhesion
Eg: Water

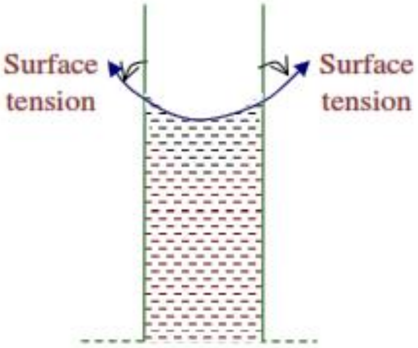


Cohesion > Adhesion
Eg: Mercury

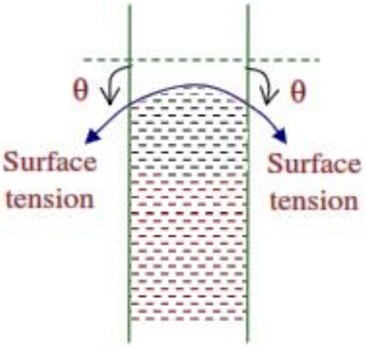




Angle of contact:



θ → Angle of contact
→ Acute



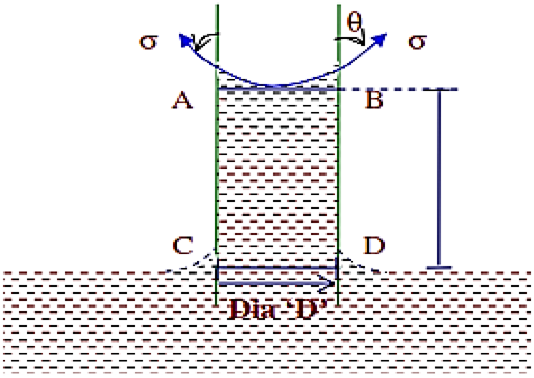
θ → Angle of contact
→ Obtuse

The angle between surface tensile force and the vertical is called angle of contact. If adhesion is more than cohesion then angle of contact is obtuse.

To derive an expression for capillary rise of a liquid in a small tube dipped in it:

Let us consider a small tube of diameter 'D' dipped in a liquid of specific weight γ. 'h' is the capillary rise. For the equilibrium,

Vertical force due to surface tension = Weight of column of liquid ABCD



$$[\sigma(\Pi D)]\cos\theta = \gamma \text{ x volume}$$

$$[\sigma(\Pi D)]\cos\theta = \gamma \text{ x } \frac{\Pi D^2}{4} \text{ x h}$$

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

It can be observed that the capillary rise is inversely proportional to the diameter of the tube. The same equation can be used to calculate capillary depression. In such cases ' θ ' will be obtuse 'h' works out to be –ve.

10. Compressibility and bulk modulus

All materials, whether solids, liquids or gases, are compressible, i.e. the volume V of a given mass will be reduced to V - δV when a force is exerted uniformly all over its surface. If the force per unit area of surface increases from p to p + δp, the relationship between change of pressure and change of volume depends on the bulk modulus of the material.

Bulk modulus (K) = (change in pressure) / (volumetric strain)

Volumetric strain is the change in volume divided by the original volume. Therefore,

(Change in volume) / (original volume) = (change in pressure) / (bulk modulus)

i.e., $-\delta V/V = \delta p/K$

Negative sign for δV indicates the volume decreases as pressure increases.

The concept of the bulk modulus is mainly applied to liquids, since for gases the compressibility is so great that the value of K is not a constant.

The relationship between pressure and mass density is more conveniently found from the characteristic equation of gas.

For liquids, the changes in pressure occurring in many fluid mechanics problems are not sufficiently great to cause appreciable changes in density. It is therefore usual to ignore such changes and consider liquids as incompressible.

Gases may also be treated as incompressible if the pressure changes are very small, but usually compressibility cannot be ignored. In general, compressibility becomes important when the velocity of the fluid exceeds about one-fifth of the velocity of a pressure wave (velocity of sound) in the fluid.

Typical values of Bulk Modulus:

$K = 2.05 \times 10^9$ N/m^2 for water

$K = 1.62 \times 10^9$ N/m^2 for oil.

11. Vapour Pressure:

It is well-established that temperature and pressure are dependent properties for pure substances during phase-change processes, and there is one-to-one correspondence between temperatures and pressures. At a given pressure, the temperature at which a pure substance changes phase is called the saturation temperature T. Likewise, at a given temperature, the pressure at which a pure substance changes phase is called the saturation pressure P_{sat} . At an absolute pressure of 1 standard atmosphere (1 atm or 101.325 kPa), for example, the saturation temperature of water is 100°C. Conversely, at a temperature of 100°C, the saturation pressure of water is 1 atm. of a pure substance is defined as the pressure exerted by its vapour in phase equilibrium with its liquid at a given temperature.

The vapour pressure P is a property of the pure substance, and turns out to be identical to the saturation pressure Psat of the liquid (P). We must be careful not to confuse vapour pressure with partial pressure. Partial pressure is defined as the pressure of a gas or vapour in a mixture with other gases. For example, atmospheric air is a mixture of dry air and water vapour, and atmospheric pressure is the sum of the partial pressure of dry air and the partial pressure of water vapour. The partial pressure of water vapour constitutes a small fraction (usually under 3 percent) of the atmospheric pressure since air is mostly nitrogen and oxygen. The partial pressure of a vapour must be less than or equal to the vapour pressure if there is no liquid present. However, when both vapour and liquid are present and the system is in phase equilibrium, the partial pressure of the vapour must equal the vapour pressure, and the system is said to be saturated. The rate of evaporation from open water bodies such as P sat

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