

Chapter - 2

2 FLUID PROPERTIES

2.1 General Description

Matter can be distinguished by the physical form of its existence (**phases**) as solid, liquid and gases, for example water appears in liquid, solid (Snow and ice), or gaseous (moisture or water vapor) form depending on the extent of hydrogen bonding. Liquid and gaseous phases are usually combined and given a common name of fluid.

Exercise: Distinguish solid, liquid and gas.

Definitions

Fluids: *Fluids are substances, which deform continuously under the application of a shear force, no matter how small the force might be. They are characterized by their ability to flow.*

(Shear force = force component tangent to a surface. This force divided by the area = average shear stress).

2.2 Properties: intensive, extensive, physical and chemical.

Every fluid has certain characteristics by which its physical condition may be described. These properties can be divided into two broad categories: Extensive properties, which depend on the size of a sample of matter; and intensive properties, which are independent of the sample size. Of the two intensive properties are the more useful because a fluid will exhibit the same intensive property regardless of how much of it we examine. Examples of extensive property are mass and volume as the amount of a substance increases; its mass and volume also increase. Intensive properties include density, pressure and temperature.

In speaking of the properties of fluids, we also distinguish between physical and chemical properties. A physical property can be specified without reference to any other fluid. Density, mass volume, colour etc are all examples of physical properties. A chemical property on the other hand states some interaction between chemical substances.

The way fluid (water) behaves under various conditions encountered in practice depends primarily on its fundamental and physical properties, which are briefed as follows.

2.3 Physical Properties

An understanding of fluid behavior and application of its basic laws through experimentation advances the subject of hydraulics. Fluid properties play principal roles both in open channel and pipe flow.

The principal physical properties of fluids are described as follows.

Density

There are three forms of density

- a. Mass density or density, denoted by ρ (Greek, rho)
It is defined as the mass per unit volume.

$$\text{or density} = \frac{\text{Mass of fluid (m)}}{\text{Volume occupied (v)}} , \rho = \frac{m}{v}$$

SI unit Kg/ m^3

Dimensionally ML^{-3}

For an incompressible fluid, ' ρ ' is constant

For water, ρ is 1000 kg/ m^3 at 4°C and standard pressure (760 - mm Hg) (There is a slight decrease in density with increasing temperature, but for normal practical purposes the value is constant)

Generally, the density of liquids is only slightly dependent on either temperature or pressure and the variation can be ignored but for gases, it significantly varies with both temperature and pressure.

- b. Specific weight / unit weight / unit gravity force /, designated by γ (Gk, gamma)

It is defined as the weight per unit volume.

$$\gamma = \frac{W}{V} = \frac{mg}{v} = \rho g$$

$\gamma = \rho g$ $W = \text{weight} = \text{mass} \times \text{gravitational acceleration (g)}$

- 📄 SI unit N/m^3 (usually KN/m^3)
- 📄 Dimensionally ($\text{ML}^{-2} \text{T}^{-2}$)
- 📄 At 4°C ' γ ' for water is $9.806 / 9.81 \text{ KN/m}^3$
- 📄 It changes with location on the earth's surface depending upon g .

c. Specific gravity (S) or relative density (rl. dn.)

It is defined as the ratio of mass of a body to mass of an equal volume of a substance taken as a standard (for liquids water at 4°C)

$$\text{Relative density} = \text{mass of fluid} \times \frac{\text{mass of equal volume of water}}{\text{density of fluid}} = \frac{\text{density of fluid}}{\text{density of water}}$$

- 📄 It is a pure no (dimensionless parameter)

Typical values of specific gravities:

- 📄 Relative density of water is 1.00 (R.D of water = 1.00, standard for measuring relative density of other liquids).
- 📄 R.D of mercury = 13.6, commonly used secondary fluid in manometers for pressure measurement.
- 📄 Oils usually have a relative density less than one and they float on water.
- 📄 If relative density of a given oil is 0.8 its density is $0.8 (1000 \text{ kg/m}^3) = 800 \text{ kg/m}^3$

Note:

It is clear that density, specific weight, and specific gravity are all interrelated and from knowledge of any one of the three the others can be calculated.

Specific Volume (V_s)

It is the volume occupied by a unit mass of fluid or simply the reciprocal of density.

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

- 📄 Commonly applied to gases

Example 1

A mass of liquid weights 600N when exposed to standard earths gravity $g = 9.81\text{m/sec}^2$

- What is its mass?
- What will be its weight in a planet with acceleration due to gravity is 4m/sec^2 .
- What will be its density if the volume of the liquid is equal to 0.06116m^3 ?

Solution

Let w = weight of liquid

m = mass of liquid

a) $W = mg$

$$m = \frac{W}{g} = \frac{600\text{ N}}{9.81\text{ m/sec}^2} = 61.16\text{ kg} \quad (\text{ans})$$

b) if $g = 4\text{m/sec}^2$

$$\begin{aligned} \text{Therefore weight} &= mg \\ &= 61.16 * 4 \\ &= 244.6\text{ N} \end{aligned}$$

c)
$$\rho = \frac{m}{V} = \frac{61.16\text{ kg}}{0.06116} = 1000\text{ kg/m}^3$$

Example 2

10 litres of a liquid of specific gravity 1.3 is mixed with 8 litres of a liquid of specific gravity 0.8. If the bulk of the liquid shrinks by 1% on mixing, calculate the specific gravity, mass density, the volume and weight of the mixture.

Solution

Let $V_1 = 10\text{ litres} = 0.01\text{m}^3$, Sp. gr 1 = 1.3

$V_2 = 8\text{ litres} = 0.008\text{m}^3$, Sp. gr 2 = 0.8

$$\begin{aligned} \text{Total volume} &= V_1 + V_2 \\ &= 0.01 + 0.008 \\ &= 0.018\text{m}^3 \end{aligned} \quad (\text{ans})$$

After shrink by 1%, volume of mixture = $0.018 * 0.99$
 $= 0.01782\text{m}^3$

$$\text{Sp. gr} = \frac{\rho_{\text{liquid}}}{\rho_{\text{water}}}$$

$$\rho_{\text{liquid 1}} = \text{Sp. gr 1} * \rho_{\text{water}} \quad \rho_{\text{liquid 2}}$$

$$= \text{Sp. gr 2} * \rho_{\text{water}}$$

$$\begin{aligned}
 &= 0.8 * 1000 \\
 &= 800 \text{kg/m}^3 \\
 &= \rho_{\text{liquid 2}} * \text{Vol. 2} \\
 &0.008 \\
 m_2 &= 6.4 \text{ kg} \\
 \text{Total mass} &= m_1 + m_2 = 13 + 6.4 = 19.4 \text{ kg} \\
 \text{Density of mixture} &= \frac{\text{Total mass}}{\text{Total volume}} = \frac{19.4 \text{kg}}{0.01782 \text{m}^3} = 1088.7 \text{kg/m}^3 \quad (\text{ans}) \\
 \text{Specific gravity} &= \frac{1088.7 \text{kg/m}^3}{1000 \text{kg/m}^3} = 1.0887 \quad (\text{ans}) \\
 \text{Weight of mixture} &= \text{mass} * g \\
 &= 19.4 * 9.81 \\
 &= \mathbf{190.314 \text{N}} \quad (\text{ans})
 \end{aligned}$$

Bulk modulus of elasticity or Compressibility, K (kappa)

For most practical purposes liquids may be regarded as incompressible. All fluids may be compressed by the application of external force and when the external force is removed the compressed volumes of fluids expand to their original volumes. Thus fluids also possess elastic characteristics like elastic solids. Compressibility of a fluid quantitatively expressed as inverse of the bulk modulus of elasticity k of the fluid.

If the pressure of a volume of fluid is increased by dp , it will cause a volume decrease dv , then the bulk modulus of elasticity is defined as

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

$$K = - \frac{dp}{dv/v} \quad v = \text{original fluid volume}$$

The negative sign indicates a decrease in volume with the increase in pressure.

$$\rho = m/v$$

Mass of a certain volume is constant, differentiating ρ .

$$d\rho = d\left(\frac{m}{v}\right) = m d\left(\frac{1}{v}\right) = -m \frac{dv}{v^2} = -\frac{m}{v} \frac{dv}{v} = -\rho \frac{dv}{v} \Rightarrow \frac{d\rho}{\rho} = -\frac{dv}{v}$$

$$k = \frac{dp}{d\rho/\rho}$$

Substituting:

- ☞ 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
- ☞ For water, k is approximately 2150 N/ mm² at normal temperatures and pressures.
- ☞ For steel $k = 215000$ N/ mm² (i.e. water is 100 times more compressible than steel)

Absolute / (Dynamic) Viscosity ($\mu = \text{mu}$)

The resistance to flow because of internal friction is called viscous resistance and the property, which enables the fluid to offer resistance to relative motion between adjacent layers, is called the viscosity of liquid. It is a measure of resistance to tangential or shear stress and arises from the interaction and cohesion of fluid molecules.

The liquid molecules are closely spaced, with strong cohesive forces between molecules, and the resistance to relative motion between adjacent layers of fluid is related to these intermolecular forces. As the temperature increases, the cohesive forces are reduced with a corresponding reduction in resistance to motion, since viscosity is an index of this resistance, it follows that the viscosity is reduced by an increase in temperature.

A gas, on the other hand, has very small cohesive forces. Most of its resistance to shear stress is the result of molecular interaction. As the

temperature of the gas increases, the random molecular activity increases hence viscosity increases with temperature.

The effect of temperature on viscosity is approximated by
for gases

$$\mu = \frac{C T^{3/2}}{T+S}$$

C and S empirical constant
(Sutherland equation)

for liquids

$$\mu = D e^{B/T}$$

D and B constant, T=absolute

temperature

(Andrade's equation)

Consider two plates sufficiently large placed a small distance Y apart, the space b/n them being filled with fluid. The lower plate is assumed to be at rest, while the upper one is moved parallel to it with a velocity V by the application of a force F, corresponding to area A, of the moving plate in contact with the fluid.

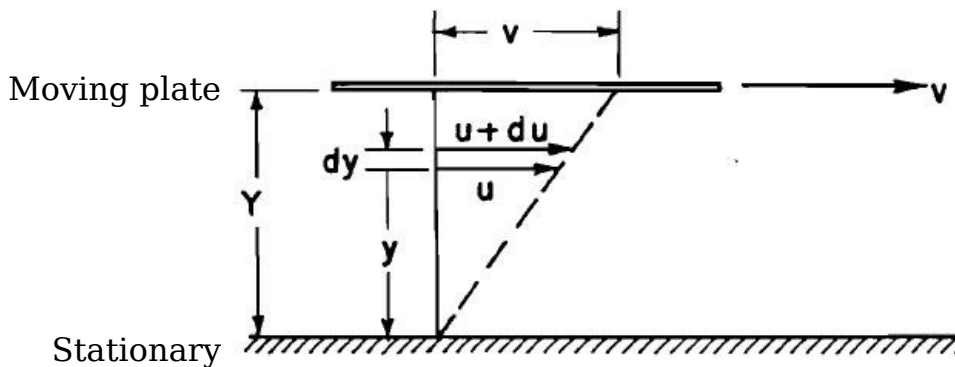


Fig1.1. Fluid motion between two parallel plates.

It may be seen from similar triangles in figure 1.1 that the ratio $\frac{V}{Y}$ can be replaced by the velocity gradient $\frac{dv}{dy}$, which is the rate of angular deformation of the fluid. If a constant of proportionality μ be introduced, the

shear stress τ equal to $\frac{F}{A}$ b/n any two thin sheets of fluid may be expressed as

$$\tau = \frac{F}{A} = \mu \frac{V}{Y} = \mu \frac{dv}{dy} \quad 1$$

Where A = area of upper plate

- τ (tau) = shear stress

Equation 1 is called Newton's equation of viscosity, and in the transposed form it serves to define the proportionality constant.

$$\mu = \frac{\tau}{\frac{dv}{dy}} \quad 2$$

Which is called the coefficient of viscosity, or the dynamic viscosity or simply viscosity of the fluid. Thus the dynamic viscosity μ , may be defined as the shear stress required to produce unit rate of angular deformation.

☞ Heavy oils have greater viscosity than water and water is more viscous than air.

☞ All real fluids possess viscosity, though to varying degrees.

☞ There can be no shear stress in a fluid, which is at rest

☞ The SI unit of μ is N.s /m² or Pa.s (kg/ m.s),

gm

☞ Or in cgs system cm.s termed as poise

☞ One poise = 0.1 Ns/m² = 0.1 kg m⁻¹ s⁻¹ = 0.1 Pa.s

☞ Dimensionally = (ML⁻¹ T⁻¹) (FL⁻² T)

In many problems concerning fluid motion the viscosity appears in the form of μ/ρ and it is convenient to employ a single term ν (nu), known as kinematic viscosity, and so called because the units m²/s (L²T⁻¹) is independent of force.

$$\text{Kinematic viscosity} = \frac{\text{absolute viscosity } (\mu)}{\text{mass density } (\rho)} \text{ i.e. } \nu = \frac{\mu}{\rho}$$

☞ SI unit of ν is m²/s in cgs system cm²/s called stoke.

☞ For water, $\nu = 1.14 \text{ mm}^2/\text{s}$ at 15°C

☞ For heavy air ν may be as high as 900mm²/s.

☞ Viscosities (absolute or dynamic) of liquids decrease with increasing temperature but are not affected appreciably by pressure changes.

Determination of viscosity

The following methods may be employed to determine the viscosity of liquid

- I. Capillary Tube (Reading exercise)
- II. Sphere Resistance (attend the experimental demonstration)
- III. Rotating cylinder

Viscometer

It is an instrument to measure viscosity. It measures some quantity which is a function of viscosity. The quantity measured is usually the time taken to pass a certain volume of liquid through an orifice fitted in the bottom of viscometer. The temperature of liquid while it is being passed through the orifice should be maintained constant.

Example

If the velocity distribution over a plate is given by $u = \frac{2}{3}y - y^2$ in which u is the velocity in m/sec at a distance y meters above the plate, determine shear stress in N/m² at y=0 and y=0.15m. Take $\mu = 8.63 \text{ poise}$

Solution

$$u = \frac{2}{3}y - y^2$$

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

$$\therefore \left(\frac{du}{dy} \right)_{y=0} = \frac{2}{3}$$

$$\text{Hence } \tau_y = \mu \left(\frac{du}{dy} \right)_{y=0} = 0.863 * \frac{2}{3} = 0.575 \text{ N/m}^2 \quad (\text{ans})$$

$$\left(\frac{du}{dy} \right)_{y=0.15} = \frac{2}{3} - 2 * 0.15 = 0.367$$

$$\text{hence } \tau_y = \mu \left(\frac{du}{dy} \right)_{y=0.15} = 0.367 * 0.863 = 0.315 \text{ N/m}^2 \quad (\text{ans})$$

Newtonian and Non - Newtonian fluids

Fluids are classified as Newtonian or non - Newtonian.

A fluid, which obeys Newton's law of viscosity, is known as a Newtonian fluid and they will have a certain constant viscosity. For these fluids the

plotting of shear stress against velocity gradient is a straight line passing through the origin. The slope of the line gives viscosity.

Examples of Newtonian fluid are water, air, gasoline and light oils. (Under normal condition)

In a non-Newtonian fluid there is a non-linear relation between the magnitude of applied shear stress and the rate of angular deformation.

Ex: non-Newtonian fluid: human blood, butter, printers ink etc....

☞ Gases and most common liquids tend to be Newtonian.

☞ Newtonian and Non-Newtonian fluids are real fluid.

Ideal fluid

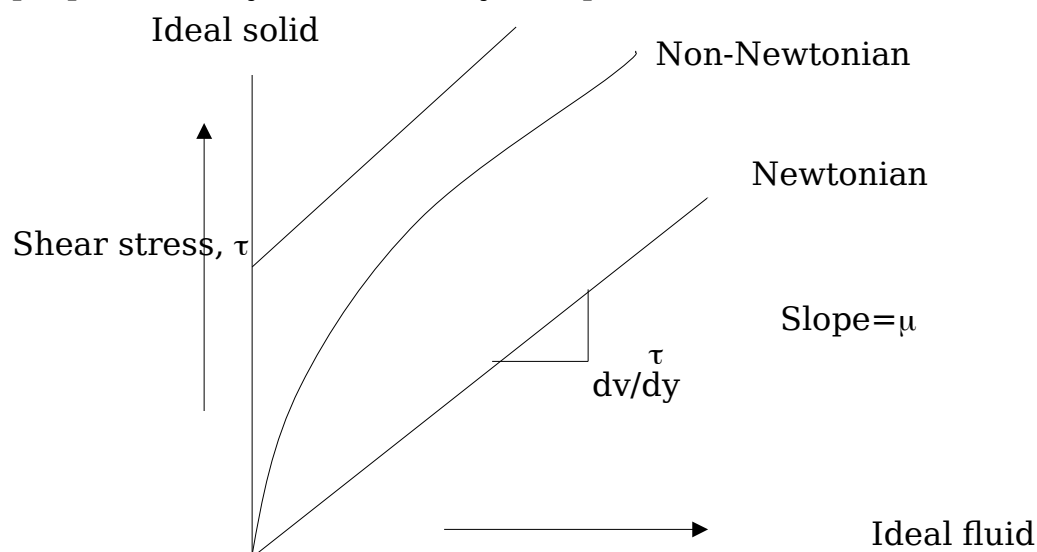
For purposes of analysis, the assumption is frequently made that a fluid is non-viscous (frictionless) and incompressible (inelastic). Such an imaginary fluid is called ideal or perfect fluid.

Ideal solid

No deformation will occur under any loading condition, and the plotting coincides with the y-axis. Real solids have some deformation; within the proportional limit (Hooke's law) the plotting is straight line, which is almost vertical.

Ideal plastic

Sustain a certain amount of shearing stress without deformation and thereafter it would deform in proportion to the shearing stress. If not proportion they are called plastic fluid.



Velocity gradient (rate of deformation), dv/dy
 Fig1.2. Plot of τ versus dv/dy

2.4 Surface tension and Capillarity

a. Surface tension denoted by σ (Gk. Sigma)
 Considering the behavior of molecules at the interior & along the surface of a fluid mass can give us a clear understanding of surface phenomena. Take molecules in the interior of a fluid mass. They are under attractive forces in all directions and the vector sum of these forces is zero. However, at the surface between liquid and air or two immiscible liquids the upward and downward attraction are unbalanced (acted on by a net inward cohesive force that is perpendicular to the surface) which causes the surface to behave as if it were a 'skin' or elastic membrane stretched over the fluid mass giving rise to the phenomenon of surface tension. Actually such a skin doesn't present, but this conceptual analogy allows us to explain several commonly observed phenomenon. This is demonstrated schematically in the following figure for water with a free surface.

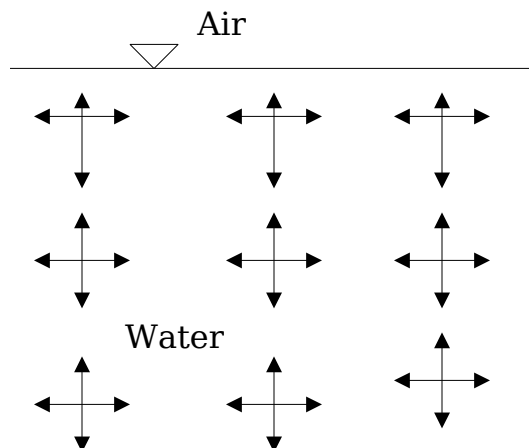


Fig1.3 . Surface tension due to molecular attraction.

Generally surface tension is a force, which exists on the surface of a liquid when it is in contact with another fluid or a solid boundary. Its magnitude depends up on nature of the liquid, and the surrounding matter which may be a solid, liquid or a gas, Kinetic energy and hence the temperature of liquid molecules (or the relative magnitude of cohesive and adhesive forces.)

Surface tension effect enables:

- 📖 An isolated drop of liquid to take nearly a spherical shape.
- 📖 A drop of water to be held in suspension at a tap.
- 📖 Birds to drink water from ponds.

- ☞ A vessel to be filled slightly above the brim.
- ☞ Dust particles and needle to float on the surface of liquids.
- ☞ Capillary rise and depression in thin-bored tubes.

Capillarity or meniscus effect

When a tube of small diameter called capillary tube is inserted in to a container of liquid, the level will rise or fall within the tube depending up on the relative magnitudes of the cohesion of the liquid and the adhesion of the liquid to the wall of the containing vessel. Liquids rise in tubes they wet (adhesion > cohesion) and fall in tubes they do not wet (cohesion > adhesion) see the following figure.

The phenomenon of rise and fall of liquid in a capillary tube is known as capillarity. Capillarity is important in capillary tubes, monometer or open pores in the soil. (Tubes ≤ 10 mm diameter).

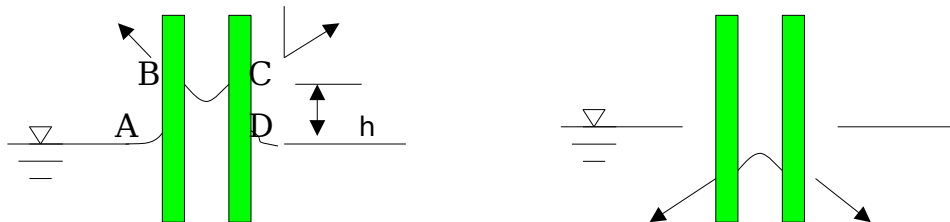


Fig1.4. A) Rise of column of liquid for wetting liquid b) depression of column for non-wetting liquid.

The magnitude of the capillary rise (or depression), h , is determined by the balance of adhesive force between the liquid and solid surface and the weight of the liquid column above (or below) the liquid free surface.

For Fig a The gravitational force on the column of liquid elevated must be supported by surface tension acting around the periphery of the tube.

$$\therefore \sum F_y = 0$$

Component of forces due to surface tension = weight of volume (ABCD) $\rightarrow$ neglecting pressure forces.

$$\Rightarrow h = \frac{4\sigma \cos \theta}{\rho g d} = \frac{4\sigma \cos \theta}{\gamma d} \quad h = \frac{4\sigma \cos \theta}{\gamma d}$$

It is to be noted that for $0 \leq \theta \leq 90^\circ$ h is positive (concave meniscus and capillary rise) and that for $90 \leq \theta \leq 180^\circ$ h is negative (convex meniscus and capillary depression).

- 📖 For pure water and clean glass $\theta = 0^\circ$
- 📖 σ for water = 0.0735 N/m

In case of liquid drop or inside a jet, the action of surface tension is to increase the internal pressure
For a liquid droplet

Considering force balance on a hemispherical drop, it is possible to equate the change in pressure (which is trying to blow apart the two hemispheres) and the surface tension σ (which is trying to pull them together). See the following figure

$$\text{Therefore, } \Delta p \pi d^2/4 = \sigma \pi d$$

$$\Delta p = 4\sigma/d$$

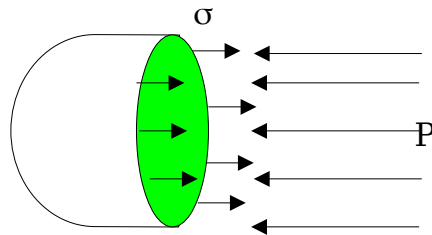


Fig1.5. Pressure in a sphere due to surface tension

Exercise:

Similarly show that $\Delta p = 2\sigma/d$ and $8\sigma/d$ for jet of water and soap bubble respectively.

Vapor pressure

The vapor pressure of a liquid is the (generally small) pressure at which the liquid vaporizes or boils as it changes from the liquid to the gaseous or vapor state. The vapor pressure is strongly dependent on temperature. Water boils at atmospheric pressure when the temperature is 100°C and at higher elevations the atmospheric pressure is less; hence, water evaporates at temperatures lower than 100°C . This property usually has no effect on a fluid flow; however, if a flowing liquid experiences a pressure at any point, which lowers the pressure locally to the vapor pressure for that temperature, then this vaporization, will take place. In problems involving siphoning, the result of pressure reduction to the vapor point will be to break the siphon and interrupt the flow. In other cases the flow will continue, altered in form, as the phenomenon of cavitation occurs. Cavitation is the rapid formation and collapse of small vapor bubbles, which

are not only disruptive, but are also frequently destructive as well. This subject will be treated more fully in other courses.

3 Illustrative Exercise

1. The density of a substance is 2.94 g/cm^3 . What is it's
 - a) Specific gravity
 - b) Specific volume
 - c) Specific weight
2. Two liquids of specific gravities 1.25 and 0.75 and volumes of 0.01 and 0.006m^3 respectively are mixed. If the bulk of the liquid shrinks by 1% on mixing, calculate the density and specific gravity of the mixture.
3. A reservoir contains a two-component mixture of water and sediment. The water density is ρ_w and the density of the sediment particles is ρ_s . Assuming complete mixing find the density of the mixture, ρ_m , if the mass fraction of the sediment is ω_s .
4. For $K=2.2\text{GPa}$ (bulk modulus of elasticity of water), what pressure is required to reduce its volume by 0.5%?
5. Eight kilometers below the surface of the ocean the pressure is 82Mpa . Determine the density of the seawater at this depth if the density at the surface is 1025kg/m^3 and the average bulk modulus of elasticity is 2.3GPa .

6. If the velocity distribution over a plate is given by $v = \frac{2}{3}y - y^2$ in which v is the velocity in m/s at a distance y meters above the plate, determine the shear stress at $y=0$ and $y=0.15$ m. Take $\nu=1.015 \times 10^{-3} \text{m}^2/\text{s}$ and $s=0.85$.
7. A lubricated shaft of 200mm radius rotates inside a concentric sleeve bearing of 205mm radius. Determine the viscosity of the fluid, which fills the space between the sleeve and the shaft if a torque of 1.5N.m is required to maintain an angular velocity of 120rpm. take length of sleeve as 450mm.
8. A large movable plate is located between two large fixed plates as shown in fig. below. Two Newtonian fluids having the viscosities indicated are contained between the plates Determine the magnitude and direction of the shearing stresses that act on the fixed walls when the moving plate has a velocity of 4m/s as shown. Assume that the velocity distribution between the plates is linear.
9. Classify the substance that has the following rates of deformation and corresponding shear stresses:
- | | | | | | |
|------------------------|---|-----|-----|-----|-----|
| $Dv/dy, \text{s}^{-1}$ | 0 | 0.3 | 0.6 | 0.9 | 1.2 |
| τ, KPa | 0 | 2 | 4 | 6 | 8 |
10. A small circular jet of mercury 0.1mm in diameter issues from an opening. What is the pressure difference between the inside and outside of the jet at 20°C.
11. The diameter of two glass limbs of a differential U tube manometer was found to be 2mm and 3mm respectively. The tube is kept vertically and partially filled with water of surface tension 0.0735N/m and zero contact angle. Calculate the difference in levels of water in the two limbs caused by surface tension effect.

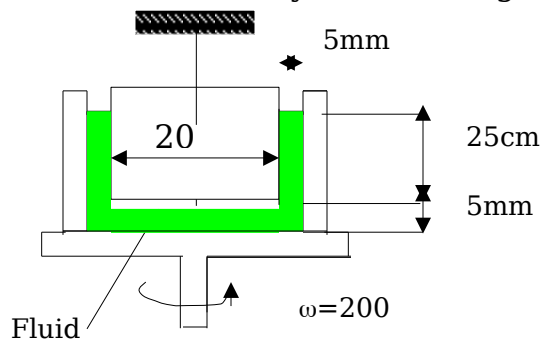
Assignment-I on Fluid Properties

1. Three different types of liquids having volumes V_1 , V_2 and V_3 and specific gravities S_1 , S_2 and S_3 respectively are mixed. If the bulk of the liquid shrinks by 1% on mixing, express the specific gravity of the mixture in terms of volumes and relative densities.
2. The variation in the density of water, ρ , with temperature, T , in the range $20^\circ\text{C} \leq T \leq 50^\circ\text{C}$ is given in the following table.

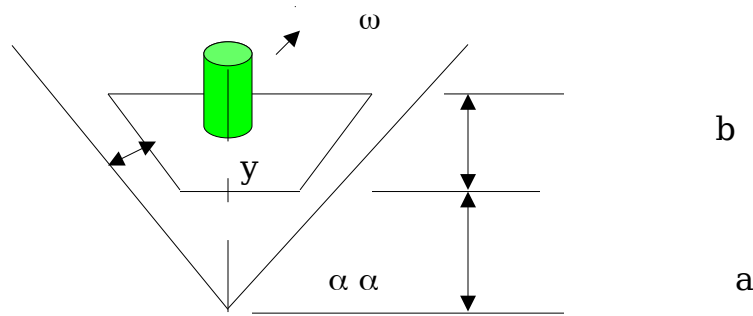
Density (kg/m ³)	998.2	997.1	995.7	994.1	992.2	990.2	988.1
Temperature (°C)	20	25	30	35	40	45	50

Use these data to determine an empirical equation of the form $\rho = C_1 + C_2 T + C_3 T^2$ which can be used to predict the density over the range indicated. Compare the predicted values with the data given. What is the density of water at 37.5°C? **Hint: Use Q- Regression.**

- A steel container expands in volume 1% when the pressure within it is increased by 70Mpa. At standard pressure, it holds 8kg of water; $\rho = 1000 \text{ kg/m}^3$. For $K = 2.05 \text{ GPa}$, when it is filled, how many kilograms of water must be added to increase the pressure to 70Mpa (gage)?
- A 196.2N cubical block, having 20 cm edge, slides down an inclined plane making an angle of 20° with the horizontal on which there is a thin film of oil having a viscosity of $2.16 \times 10^{-3} \text{ Ns/m}^2$. What terminal velocity will the block attain, if the film thickness is estimated to be 0.025mm?
- A very large thin plate is centered in a gap of width 6cm with different oils of unknown viscosities above and below, the viscosity of one being twice that of the other. When the plate is pulled at a velocity of 30cm/sec, the resulting force on one square meter of plate due to viscous shear on both sides is 29.4N. Assuming viscous flow and neglecting all end effects, calculate viscosities of the oils in poise.
- The side and bottom space of two concentric cylinders is filled with fluid. The outer cylinder is rotated at a speed of 200 rpm and a torque of 2.5N-m is required to maintain this speed. The inner cylinder, which is suspended by a torsion wire, will remain stationary. Neglecting end effects, determine the fluid viscosity. (See the figure).



- In the figure, oil of viscosity μ fills the small gap of thickness y . Determine an expression for the torque T required to rotate the truncated cone at a constant speed ω . Neglect fluid stress exerted on the circular bottom.



8. Classify the following substances, and find the viscosities and yield stresses if they have.

$dv/dy, s^{-1}$	0	1	2	3
τ, kpa	0	2	3	5

(a)

(b)

$dv/dy, s^{-1}$	0	2	3	5
τ, Kpa	0	4	6	10

(c)

(d)

9. Calculate the maximum capillary rise of water to be expected
- In a vertical glass tube 1mm in diameter.
 - In between two concentric glass tubes of radii 4 and 5mm.
- Take $\sigma = 0.0735 \text{ N/m}$
- In between two vertical, parallel, clean glass plates spaced a distance of 2mm apart.
10. What force is necessary to lift a thin wire ring 2.5cm in diameter from a water surface at 20°C ? Surface tension at 20°C is 0.0718 N/m . Neglect the weight of