5. MECHANICAL PROPERTIES OF FLUIDS

Density and Relative Density

Density If we hold cubes of equal volume of different solids such as wood, aluminium, lead, etc. we notice immediately that lead has a higher density than wood or aluminium.

$$\text{Density} = \frac{mass}{volume}$$

The SI unit of density is kilogram per metre cubed. Density of water is 1,000 kg/m^3 (or 1 g/cm^3). The densities of some of the common substances are listed in the following table.

Substance	Density in kg/m^3
Alcohol	790
Aluminium	2,700
Copper	8,900
Gold	19,300
Lead	11,300
Mercury	13,600
Platinum	21,500
Steel (varies)	7,800
Turpentine	870
Water	1,000
Wood (varies)	700

Relative Density The relative density (RD) of a substance is the ratio of the density of the substance to the density of water. Relative density has no unit. From the table of densities we find that the RD of mercury is 13.6 and that of turpentine 0.87.

Pressure

Pressure is defined as force acting per unit area.

$$\text{Pressure} = \frac{force}{area}$$

The SI unit of pressure is newton per metre square or **pascal**.

To illustrate the difference between pressure and force, consider two identical bricks of equal weight. One brick stands on its side and the other on its end. Both bricks exert the same force on the ground but the upright brick exerts greater pressure against the ground due to its smaller area of contact.

It is much easier to cut find with a sharp knife than with a blunt one. In the case of sharp knife the blade makes such as small area of contract with the fruit that the pressure below it is very high and easily cuts the fruit.

The pin used on a drawing-board has a broad head and a pointed tip. When force is applied on the head, the pressure exerted on the tip, due to its small area, is so large that it pierces the board.

Pressure in Liquids A diver experiences pressure in the water due to the weight of water above him. The pressure at any point in a liquid acts in all directions. The pressure P at a depth h in a liquid of density p is given by the relation.

$$P = hpg$$

Where g is the acceleration due to gravity.

Since the pressure of water increase with depth, the bottom of a dam is made much thicker than the top.

The pressure and hence speed of water obtained from the ground floor tap is much higher than that from the top floor tap.

Transmission of Liquid Pressure The pressure exerted on an enclosed liquid at one place is transmitted equally throughout the liquid. Hydraulic presses, hydraulic brakes, hydraulic door closers, etc. are application of this principle.

Atmosphere Pressure The air surroundings the earth is pressure not only atmosphere. Air has weight and therefore exerts pressure not only on the earth's surface but on all objects on the earth. In fact, human beings and other animals are living at the bottom of an ocean of air which exerts enormous pressure. This pressure is not felt because the blood exerts a slightly higher pressure from inside. At high altitudes where atmospheric pressure is less nose bleedings may occur due to the greater pressure of blood.

It is due to the pressure of the atmosphere that ink rises in the tube of a fountain pen, or liquid rises a syringe when the piston is pulled.

One is able to have cold drink using a straw-pipe due to atmosphere pressure. When the air from the pipe is sucked, the atmosphere pressure pushes the liquid up in the pipe.

In an aircraft flying at high altitude, normal atmospheric pressure is maintained by the use of air pumps, if this were not done, the crew and passengers would experience difficulty in breathing and consequently face dangers.

Atmospheric pressure is measured with an instrument called the **barometer**. Accurate measurement of atmospheric pressure in laboratories is made with a Fortin's barometer which is an improved form of simple mercury barometer. A small portable barometer, called the aneroid barometer does not use any liquid.

Since atmosphere pressure varies with altitudes, a barometer can be used for determining altitudes. An aneroid barometer calibrated for determining altitude is called an altimeter. Barometers are also used for weather forecasting. If the barometric height falls suddenly, it indicates the coming of a storm. A gradual fall in the barometric height indicates the possibilities of rain. A gradual increase in the barometric height indicates fair weather.

Surface Tension

A molecule at A is pulled equally in all directions by the cohesion of liquid molecules all around it. A molecule at B is pulled by the liquid molecules around it, but since it is near the surface there are more liquid molecules below it than above it, so the downward force of attraction is greater than the upward force of attraction. The molecule at C, which is at the surface of the liquid, has no liquid molecules above it, and has a strong downward pull, unbalanced by an equal upward pull as in the case of the molecule at A. We see therefore that there is an unbalanced force tending to pull the surface molecules toward the interior of the liquid and to keep the free surface of the liquid as small as possible. The tendency of a liquid surface to contract and occupy the minimum area possible is called surface tension. When a force acts on a liquid surface and distorts it, the force of attraction between the liquid molecules i.e. the cohesion of the liquid molecules exerts a counter balancing force which tends to restore the original surface.

Surface tension accounts for many interesting phenomena. Small droplets of liquid tend to be spherical shape requires the smallest surface area. The pull on the surface of a liquid produces the effect of a thin skin covering it. Small insects are often observed to walk or run on the surface of water. A needle can be made to float on the surface, even though the needle may be nearly ten times as dense as water.

Surface tension is affected by temperature. It is reduced as the temperature rises. Impurities in solution also bring about a reduction of surface tension. So do modern synthetic detergents. As a result they greatly increase the wetting ability of water. Many materials that are not wet at all by pure water become soaked when a small quantity of detergent is dissolved in the liquid. A duck can swim easily because its feathers are not wet by water. If it tries to swim in water to which detergent has been added, its feathers will becomes soaked and it will drown if not rescued. Antiseptics under for cuts and other punctures of human flesh should have a low surface tension, as well as good germ-killing ability. If the surface tension were high, not all the damaged surface would be wet by the liquid. Alcohol and most other antiseptics have a low surface tension.

Capillarity

A capillary tube is one with a very fine bore, 'capilla' being the Latin word for 'hair'. When such a tube is placed in water, the water will rise up the tube. The thinner the bore of the tube the greater the height to which the water rises. If a capillary tube is placed in mercury, the mercury falls in the tube, and the depression of the mercury is greater in narrow tubes that it is in wider tubes.

The elevation or depression of liquids in narrow tubes, (tubes of very fine bore) is called capillarity.

The rise of water in a capillary tube can be explained in the following way. Since the adhesion of water to glass is greater than the cohesion of water molecules, the water sticks to the glass, and this produces a curved concave surface. Surface tension tends to contract this surface and the water rises as the surface contracts till it loses its curve and is level. Adhesion again results in water sticking to the glass which further curves the surface. The effect of surface tension which contracts the surface again raises the water. Thus the water gradually crawls up the tube due to the effects of both adhesion and surface tension. The water will continue to rise until the combined effect of the forces of adhesion and surface tension is balanced by the force of gravity (i.e. the weight of the water column).

Bearing in mind that in the case of mercury, the force of cohesion between the mercury molecules is greater than the force of adhesion of mercury for glass, explains the depression of mercury in capillary tubes.

Capillarity is of considerable practical importance. Plants grow in soil only because capillarity makes it possible for water to be drawn up through the fine spaces between the grains of the soil to the roots of the plant. Cloth absorbs water by capillary action. Oil is drawn up the wick of a lamp by capillarity, and blotting paper absorbs ink by capillarity.

Osmosis

Certain substances are porous to one material, but not to another. For example, water will diffuse through a thin slice of potato, but sugar molecules will not. A membrane of this sort is called a semipermeable membrane. The selective diffusion through such a membrane is known as osmosis. Osmosis plays an important part in carrying liquids through plants, and in the absorption of food and disposal of waste by cells in plants and animals. It explains how food passes through the walls of intestines, and also explains in part how sap is forced to the top of a tree.

Viscosity

If you stir some water in a glass with a spoon and then stop stirring the water continues to swirl more and more slowly until comes to rest. If you had stirred honey or treacle instead of water, it would have come to rest much more quickly internal friction in treacle or honey is greater than internal friction, or resistance to motion, in water. Treacle is more viscous than water; it has greater viscosity. The viscosity of a fluid is the property it possesses of resisting the movement of its various parts. Viscosity is the internal friction of a fluid.

The viscosity of a gas, however, increases as the temperature increases. The reason is that in the case of a gas the diffusion of gas molecules from one moving layer of gas to another determines the viscosity of that gas. Since the rate of diffusion molecular speed, the viscosity of a gas becomes greater as it temperatures rises.

Upthrust

If a block of wood is held below the surface of water and then released, it immediately rises to the surface. The block rises because it experiences an upward force or upthrust (or buoyant force) due to water. Like liquids, gases also exert upthrust on objects inside them.

Archimedes' Principles This principle states that when a body is wholly or partially immersed in a fluid, it experience an upthrust equal to the weight of the fluid displaced.

When an object is immersed in a fluid, two forces act on it: (i) the weight of the object acting downward, and (ii) upthrust acting upward. It is due to upthrust that objects apparently weigh less when immersed in fluids.

An angler pulling a fish out of water experiences the sudden increase in the weight of the fish as soon as it is out of water.

It requires relatively less efforts to lift a larger boulder off the bottom of river bed as long as the boulder is under water. Once the same boulder is out of the water, considerably greater effort is required to lift it.

The relative values of the weight and upthrust determine whether an object will sink in a liquid or float in it. If the weight of the immersed object is greater than the upthrust, the object will sink. If the weight is equal to the upthrust, the object remains at any level like a fish. If the upthrust is greater than the weight of the immersed object it will float to the surface.

It can easily be shown that an object will sink in a liquid if its density is more than that of the liquid. If the density of the object is less than that of the liquid, it will float on it.

Law of Floatation When a block of wood is placed in water in sinks until the weight of water displaced is just equal to its own weight. When this happens the block floats. This example illustrates the law of floatation, which states: A floating body displaces its own weight of the fluid in which it floats.

Archimedes' principles and law of floatation can explain several phenomena.

An iron nail sinks in water whereas a ship made of iron and steel floats. This is due to the fact that a ship is hollow and contains air and, therefore, its density is less than that of water.

A ship sinks in water to a level such that the weight of the displaced water equals its own weight. Since the density of sea water is more than that of river water, a ship sinks less in sea water. It is for this reason that a ship rises a little when it enters a sea from a river.

It is because of the higher density of sea water that it is easier to swim in the sea.

A submarine has large ballast tanks. Are filled with water the average density of the submarine becomes more than that of water and it can dive easily. When the submarine is ready to surface, compressed air is forced into the ballast tanks forcing the water out, thus reducing the density of the submarine which can then rise.

A solid chunk of iron will sink in the water but float in mercury because the density of iron is more than that of water but less than that of mercury.

A balloon filled with a light gas, such as hydrogen, rises because the average density of the balloon and the gas is less than that of air. The balloon cannot rise indefinite altitude. At a certain height, where the density of air is equal to the average density of the balloon, it ceases to rise and drifts sideways with the wind.

Ice, being less dense than water, floats in it with one tenth of its volume above the surface. When ice melts it contracts by as much of its volume as was above the surface and, therefore, the level of water remains unchanged.

Hydrometer

A hydrometer is an instrument used for measurement the density or relative density of liquids. It is based on the principle of floatation. A special type of hydrometer is used to measure the density of acid in a car battery. Another special type of a hydrometer called **lactometer** is used for testing milk by measuring its density.

Bernoulli's Principle–Fluids in Motion. For continuous flow of liquid through a pipeline of non-uniform cross-section, the velocity of the liquid is greater in the narrower parts of the pipe. Bernoulli (1654-1705) observed a very interesting phenomenon. He found that in a liquid flow (this also holds for gas flow), the pressure is lower in the region where the flow is faster. This is called Bernoulli's principle. We may also state it in the following way.

When the speed of fluid (liquid or gas) in a pipeline increases, the pressure decreases and conversely when the speed of a fluid decreases, the pressure increases.

The jet water pump, which is often used to pump water out of basements, works on Bernoulli's principle. Bernoulli's principle also explains why two speedboats moving parallel and close to each other are likely to the pulled together and collide. As the boats move forward, water is funneled into the narrow region between them. The relative speed between the water and the boats is greater in this narrow region than if there were more space between the boats. As a result, there is a decrease in pressure of the water between the boats, and the greater pressure of the water upon the outer sides pushes the boats together.