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Lecture (2)

Compressible and Incompressible Fluids

Fluid mechanics deals with both incompressible and compressible fluids, that is, with liquids and gases of either constant or variable density. Although there is no such thing in reality as an incompressible fluid, we use this term where the change in density with pressure is so small as to be negligible. This is usually the case with liquids. We may also consider gases to be incompressible when the pressure variation is small compared with the absolute pressure. Ordinarily we consider liquids to be incompressible fluids, yet sound waves, which are really pressure waves, travel through them. This is evidence of the elasticity of liquids. In problems involving water hammer we must consider the compressibility of the liquid.

The flow of air in a ventilating system is a case where we may treat a gas as incompressible, for the pressure variation is so small that the change in density is of no importance. But for a gas or steam flowing at high velocity through a long pipeline, the drop in pressure may be so great that we cannot ignore the change in density. For an airplane flying at speeds below (100 m/s), we may consider the air to be of constant density. But as an object moving through the air approaches the velocity of sound, which is of the order of (1200 km/h) depending on temperature, the pressure and density of the air adjacent to the body become materially different from those of the air at some distance away, and we must then treat the air as a compressible fluid.

Compressibility of Liquids

The compressibility (change in volume due to change in pressure) of a liquid is inversely proportional to its ***volume modulus of elasticity*, also known as the *bulk modulus***. This modulus is defined as

$$(K) = E_v = -v\frac{dp}{dv} = -\left(\frac{v}{dv}\right)dp$$

where v = specific volume and p= pressure. As v/dv is a dimensionless ratio, the units of Ev and p are identical. The bulk modulus is analogous to the modulus of elasticity for solids; however, for fluids it is defined on a volume basis rather than in terms of the familiar one-dimensional stress–strain relation for solid bodies. The bulk modulus is a property of the fluid and for liquids is a function of temperature and pressure. At any temperature we see that the value of Ev increases continuously with pressure, but at any one pressure the value of Ev is a maximum at about 120°F (50°C). Thus water has a minimum compressibility at about 120°F (50°C). By rearranging the definition of Ev, as an approximation we may use for the case of a fixed mass of liquid at constant temperature

$$\frac{\Delta v}{v} \approx -\frac{\Delta p}{E_v}$$

$$\frac{v_2 - v_1}{v_1} \approx -\frac{p_2 - p_1}{E_v}$$

where Ev is the mean value of the modulus for the pressure range and the subscripts 1 and 2 refer to the before and after conditions.

س/ اثبت ان $\left(K = \rho \frac{dp}{d\rho}\right)$

solution:- $\rho = \frac{m}{V} \Rightarrow d\rho = d\left(\frac{m}{V}\right) \Rightarrow d\rho = m\, d\left(\frac{1}{V}\right) \Rightarrow d\rho = m * -\frac{dv}{V^2}$

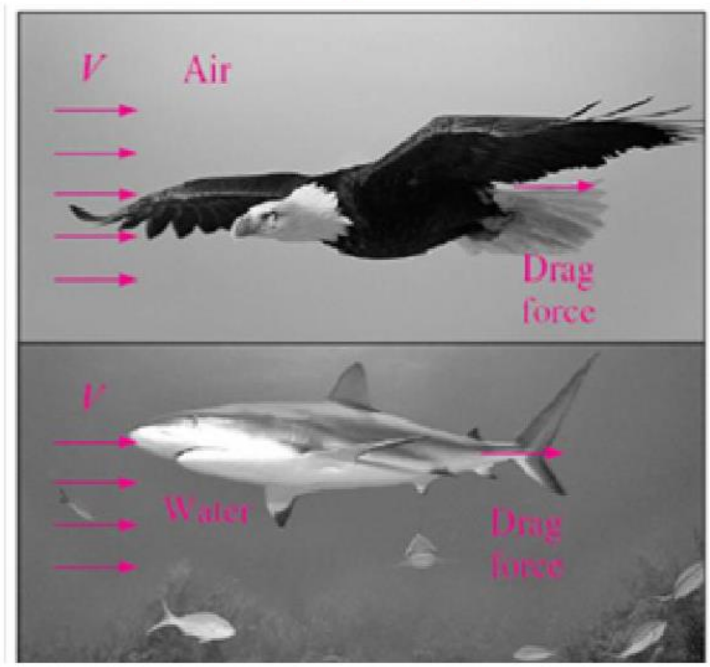
$d\rho = \frac{m}{V} * -\frac{dv}{V} \Rightarrow d\rho = \rho * -\frac{dv}{V} \Rightarrow \frac{d\rho}{\rho} = -\frac{dv}{V}$ — $-\frac{dv}{V}$ نعوض عنها في (K)

$K = \frac{dP}{\frac{d\rho}{\rho}} \quad \therefore \quad K = \rho \frac{dP}{d\rho}$

VISCOSITY

Is a measure of the resistance of a fluid which is being deformed by either shear stress or tensile stress. In everyday terms (and for fluids only), viscosity is "thickness" or "internal friction". Thus, water is "thin", having a lower viscosity, while honey is "thick", having a higher viscosity. Put simply, the less viscous the fluid is, the greater its ease of movement (fluidity). Viscosity escribes a fluid's internal resistance to flow and may be thought of as a measure of fluid friction. For example, high-viscosity felsic magma will create a tall, steep stratovolcano, because it cannot flow far before it cools, while low-viscosity mafic lava will create a wide, shallow sloped shield volcano. All real fluids (except super fluids) have some resistance to stress and therefore are viscous, but a fluid which has no resistance to shear stress is known as an ideal fluid or inviscid fluid.

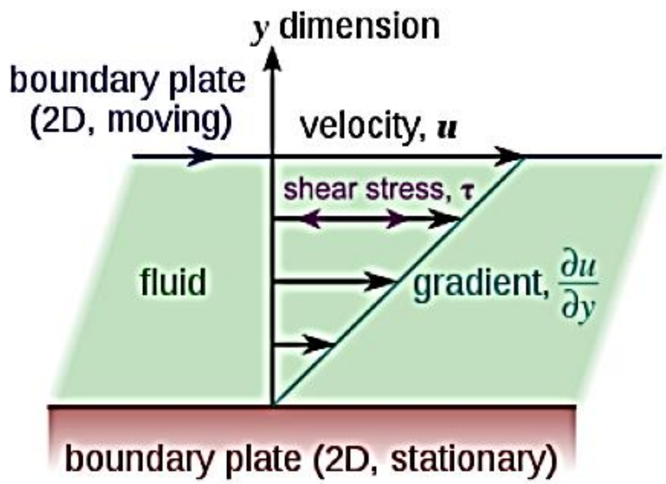
NOTE: **ideal fluids** don't have (compressibility, viscosity, surface tension)



In general, in any flow, layers move at different velocities and the fluid's viscosity arises from the shear stress between the layers that ultimately oppose any applied force. The relationship between the shear stress and the velocity gradient can be obtained by considering two plates closely spaced at a distance y, and separated by a homogeneous substance. Assuming that the plates are very large, with a large area A, such that edge effects may be ignored, and that the lower plate is fixed, let a force F be applied to the upper plate. If this force causes the substance between the plates to undergo shear flow with a velocity gradient *u* (as opposed to just shearing elastically until the shear stress in the substance balances the applied force), the substance is called a fluid. The applied force is proportional to the area and velocity gradient in the

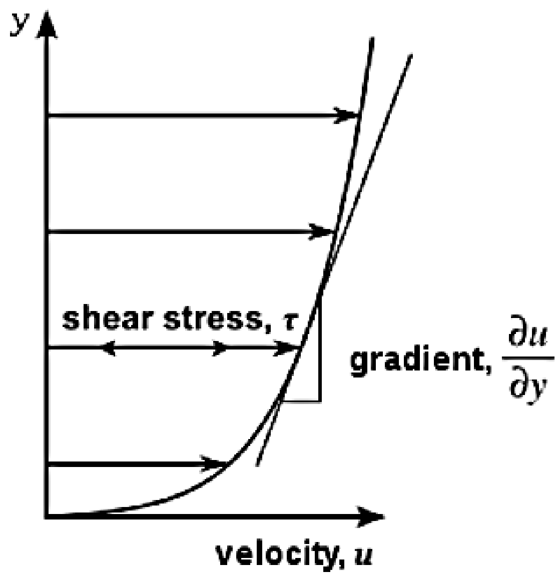
fluid and inversely proportional to the distance between the plates. Combining these three relations results in the equation: $F = \mu A \frac{u}{y}$

where μ is the proportionality factor called *viscosity*.



This equation can be expressed in terms of shear stress. $\tau = \frac{F}{A}$

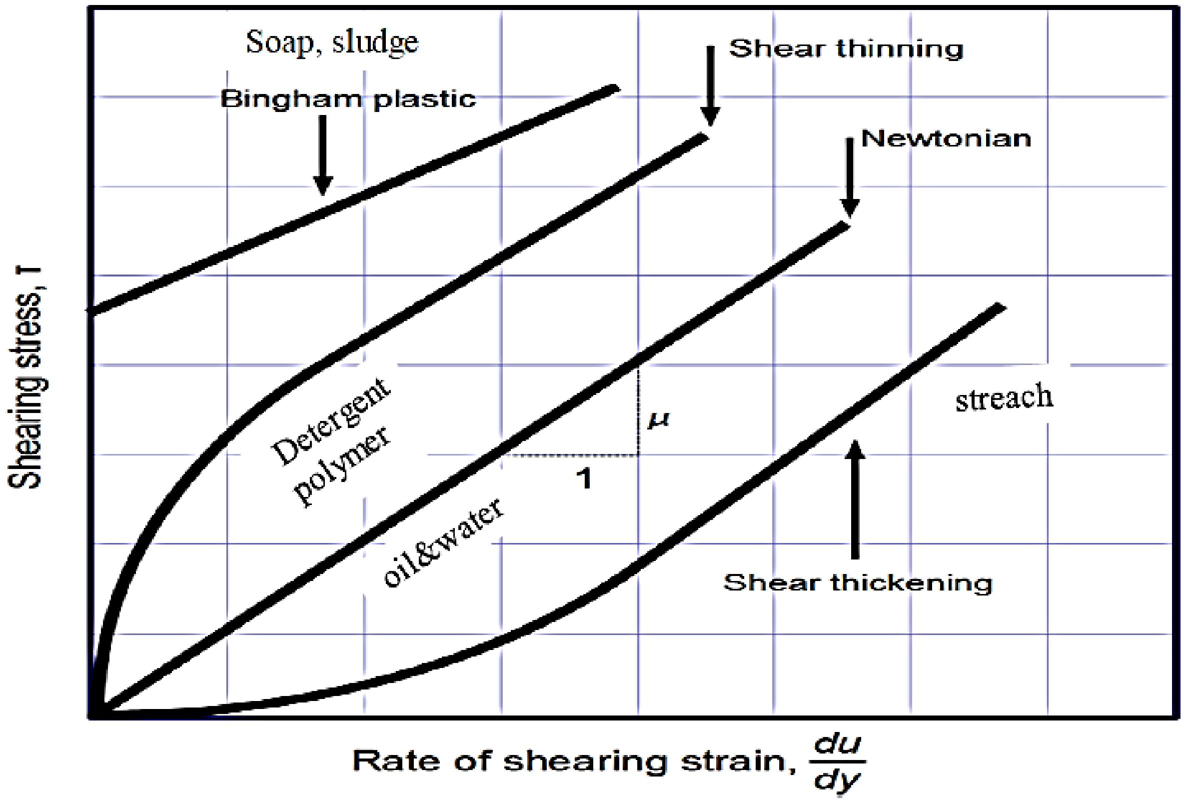
Thus as expressed in differential form by Isaac Newton for straight, parallel and uniform flow, the shear stress between layers is proportional to the velocity gradient in the direction perpendicular to the layers:



Laminar shear, the non-constant gradient, is a result of the geometry the fluid is flowing through (e.g. a pipe).

$$\tau = \mu \frac{\partial u}{\partial y}$$

Hence, through this method, the relation between the shear stress and the velocity gradient can be obtained. Note that the *rate of shear deformation* is $\frac{u}{y}$ which can be also written as a *shear velocity*, $\frac{du}{dy}$



Viscosity coefficients can be defined in two ways:

• Dynamic viscosity, also absolute viscosity, the more usual one (typical units Pa·s, Poise, P);

• Kinematic viscosity is the dynamic viscosity divided by the density (typical units m2/s, Stokes, St).

Intensive and Extensive Properties

Thermodynamic properties can be divided into two general classes, intensive

and extensive properties. An intensive property is independent of the amount of mass. The value of an extensive property varies directly with the mass. Thus, if a quantity of matter in a given state is divided into two equal parts, each part will have the same value of intensive property as the original and half the value of the extensive property.