ENE 206 – Fluid Mechanics

WEEK 1

Definition:

- **What is solid?**

  Solid is a state of matter with very strong intermolecular attractions forces so that the relative position of the molecules are rather fixed.

- **What is fluid?**

  Fluid is a state of matter with weaker intermolecular attractions forces than fluids so that the relative position of the molecules can change.

➢ The fluid can be classified in to two groups namely liquids and gaseous depending upon the magnitudes of their intermolecular attraction forces. Liquid is a state of matter with medium intermolecular attraction forces which allow the molecules to quite freely change their relative positions, whilst gas is a state of matter with very weak intermolecular attraction forces which allow the molecules to freely move in their domain.

- **The continuum postulate**

  In most of the fluid flow problems, the overall behavior of the fluid is considered as a continuous material and the detailed molecular structure of the fluid can be replaced by a continuum so that one can deal with the fluid on a macroscopic scale. The continuum postulate is required in that case and assumes that the molecular mean free path is very small compared to some significant characteristic linear dimension of the flow field. For this purpose, the Knudsen number is defined and for the continuum postulate, this number is less than approximately 0.01.

- **The continuum properties**

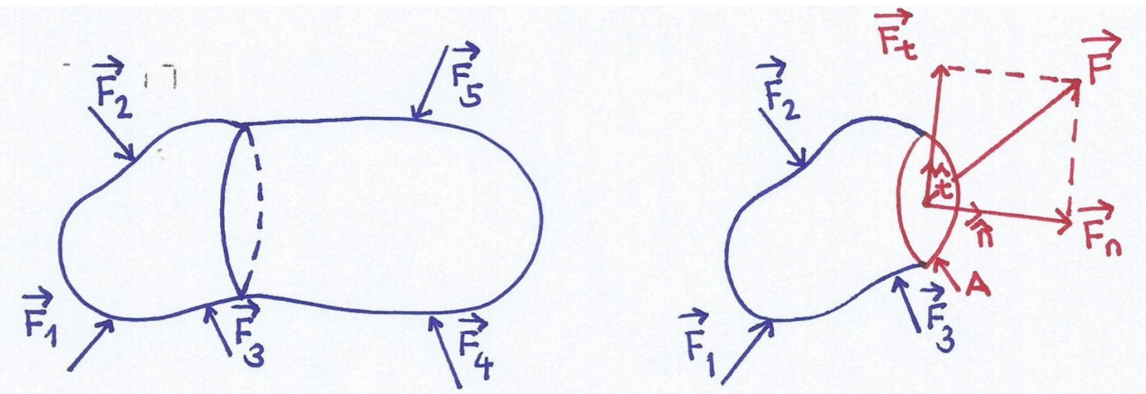
➢ **Mass density:** For a homogeneous fluid domain, the average mass density is defined as the mass per unit volume and defined as $\rho = \frac{m}{V}$, where ρ is the density, m is the mass and V is the volume. In SI, its unit is kg/m^3.

➢ **Specific gravity:** It is defined a ratio of the density of any fluid, ρ to the density of the water, ρ_w and is defined as $s_g = \frac{\rho}{\rho_w}$

- **Specific weight:** It can be obtained by multiplying the density of the fluid, ρ by the local gravitational acceleration, g and defined as $\gamma = \rho g$. This signifies the force exerted by the gravitational fluid on a unit volume of the fluid.

- **Fluid velocity:** The average velocity of the fluid, $\vec{V}$ contained in a limiting volume surrounding a point in the flow domain can be obtained by dividing the total momentum contained in that volume by the total mass inside the volume. This volume around the point ie required to satisfy "continuum postulate". In SI, its unit is m/s and is represented by a vector quantity.

- **Forces acting on a body of fluid:** The external forces acting on a fluid element can be classifies into two group forces: a) **Surface forces** which may have any orientation with respect to the surfaces as normal forces acting normal to the fluid surface and tangential or shear forces acting parallel to the fluid surface and b) **Body forces** which are distributed over the entire volume of the fluid. Both types of forces are very important as sources of fluid statics or motion and are analyzed well to successfully describe the fluid flow. A fluid body which is in equilibrium under the action of a few external forces is shown in Figure 1.1a. When this fluid body is cut with a plane, the external forces are balanced by the internal forces over the body surface as shown in Figure 1.1b. The internal resultant force, $\vec{F}$ is the sources of the stress the fluid body experiences and is decomposed in to its components as $\vec{F} = F_n \hat{n} + F_t \hat{t}$, where F_n and F_t are the normal and tangential components of the force, $\vec{F}$ respectively, and $\hat{n}$ and $\hat{t}$ are the unit vectors in the normal and tangential directions, respectively. The SI unit of the force is Newtons (N).



(a) (b)

Figure 1.1. External and internal forces acting on a fluid body

- **Stress:**

  a) The normal stress, σ is defined as $\sigma = \dfrac{F_n}{A}$;

b) The shear stress, τ is defined as $\tau = \frac{F_t}{A}$

In SI, the unit of stress is newtons per square metre (N/m^2) or pascals (Pa).

- **Pressure:** It is the normal component of the force acting on area divided by the same area. It has the same magnitude as the normal stress, but opposite in direction. For a fluid at rest, the pressure is the same in all directions. In SI, the pressure unit is newtons per square metre (N/m^2) or pascals (Pa).

- **Viscosity:** It is the measure of resistance of a fluid to shear force or angular deformation which is represented by the velocity gradient in a normal direction to the fluid flow. Every fluid has a viscosity as can not resist a shear stress when it is at rest. In SI, it has units of Ns/m^2 or Pa.s.
Figure 1.2 clearly signifies the continual deformation of a fluid body restricted between two parallel plates and gives a good example of viscous motion.

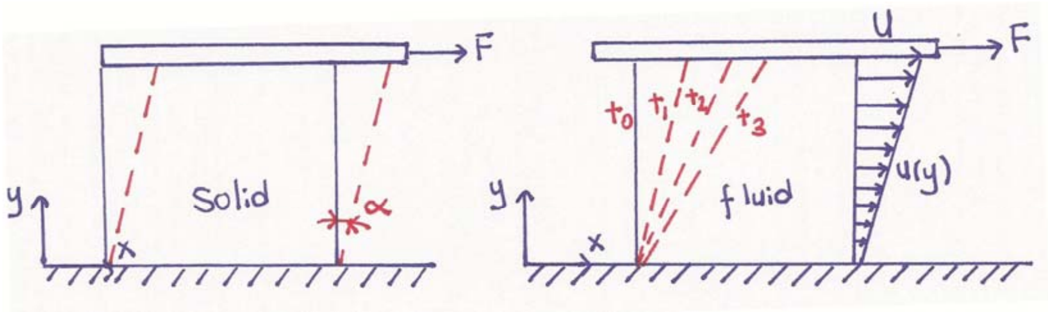


Figure 1.2. Solid and fluid bodies under the action of a constant tangential force

a) Here, α is know as the shear strain within the elastic limit, the shear stress, $\tau = \frac{F_t}{A}$ is directly proportional to the shear strain by Hooke's Law as $\tau = G\alpha$, where G is the modulus of elasticity in shear.

b) Newton's Law of Viscosity for a fluid flow in the x-direction simply assumes that the shear stress, τ is directly proportional to the velocity gradient, $\frac{\partial u}{\partial y}$, and the coefficient of proportionality is known as the absolute of dynamic viscosity, μ as $\tau = \mu \frac{\partial u}{\partial y}$.

c) A fluid can not sustain a shear force when it is at rest, but it deforms continuously under the action of this force, no matter how small it is.

d) It is experimental fact that the fluid particles which have a contact with a solid surface must possess the velocity of that surface (no-slip condition).

e) The general relation between the shear stress and the shear strain can be given by the power laws as $\tau = A\left(\frac{\partial u}{\partial y}\right)^n + B$ where A and B are the constants which depend on the type of the fluid. The fluids can be classified according to the behavior of their viscosity, and generally decomposed into two groups a) Inviscid fluid which has zero viscosity (ideal fluid) and b) viscous flow (real fluid) which have different viscosity values and is also classified into two groups as Newtonian and non-Newtonian fluid. All fluids are viscous however, for simplicity, fluids can be considered to be inviscid for easy analytical treatment of the fluid flow problem. Depending on the values of *A*, *B*, and *n* in the general equation, the real fluids have different viscosity behavior.

f) The kinematic viscosity, v as the ratio of the absolute viscosity to the mass density and is defined as $v = \frac{\mu}{\rho}$. In SI, its unit is m^2/s.

g) The viscosity is subject to change depending on temperature and pressure of the fluid. For a liquid,, viscosity value decreases as the temperature increases, while for a gas, it decreases as the temperature increases.

- **Surface tension:** Surface tension always exits whenever there is a discontinuity in the density. It depends on the contacting substances and on temperature and pressure. The cohesive forces among liquid molecules are responsible for the phenomenon of surface tension. These forces hold the molecules of a liquid together as intermolecular attraction forces. The magnitude of these forces is very small however, they enable the liquid to withstand small tensile forces. The forces of attraction between two molecules of two different liquids which do not mix, between liquid molecules and the solid boundary containing the liquid or between liquid molecules and the gas molecules are also known adhesion. In SI, the unit of surface tension is N/m. A surface of contact between a liquid and a gas is known as **free surface**.

References

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