Chapter One

Introduction to Fluid Mechanics

A fluid is a substance that continually deforms (flows) because the weak internal forces between the atoms, fluid can change its shape according to the container has it and can do that under an applied shear force even the force is very small.

Fluids are consisting of liquids, gases and some states of solid such are the plastic or elastic states.

Fluid mechanics is the study of fluids and the forces acting on them. (Fluids include liquids, gases, and plasmas). It is a branch of continuum mechanics, a subject that models matter without using the information that it is made out of atoms

Fluid mechanics can be divided into the categories:

1. Fluid statics: the study of fluids at rest.
2. Fluid kinematics: the study of fluids in motion.
3. Fluid dynamics (kinetic): the study of the effect of forces on fluid motion.

Fluids can be classified in too many ways according to certain fluid properties. Fluids are Newtonian and Non-Newtonian depending of the relation between the shear stress and the strain-rate. If the relation is linear started from the origin, then it is Newtonian Fluid such as water, oil, air, but if it is non-linear or linear but does not start from the origin, then these fluids are called as Non-Newtonian Fluids such as the polymer melts, pastes, and heavy liquids.

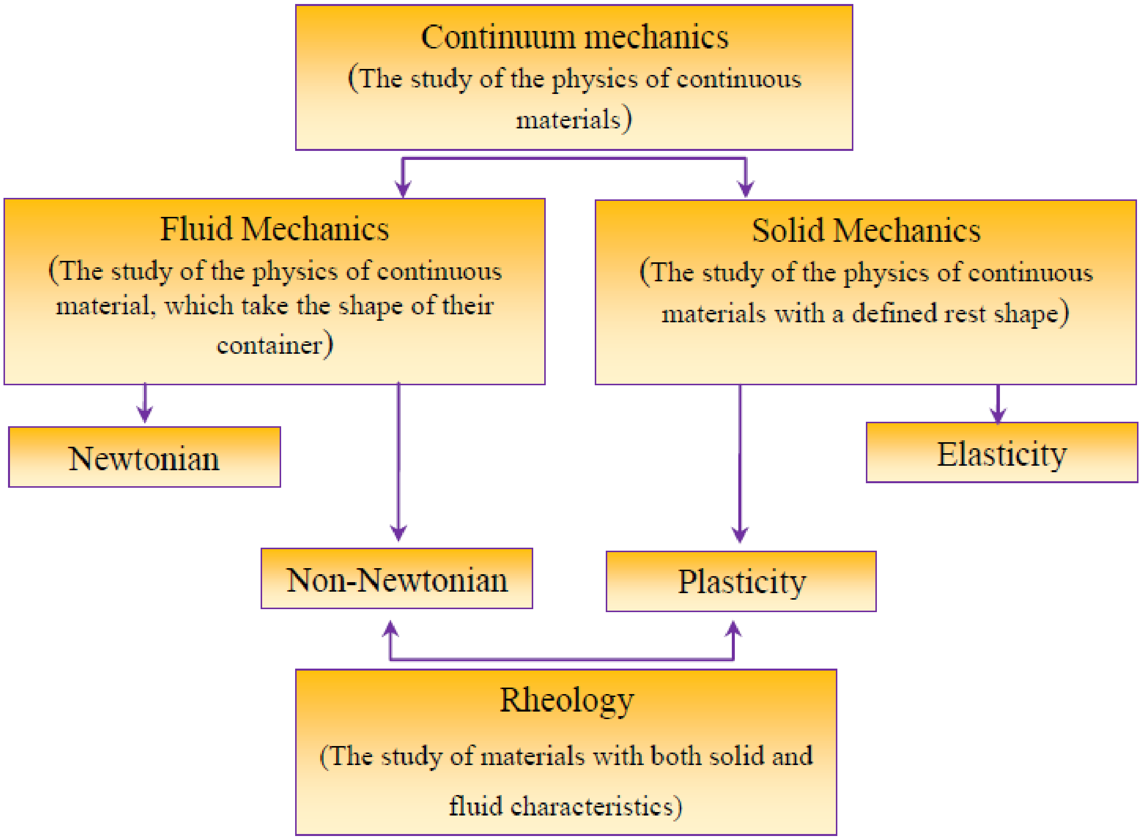


Figure 1: Fluids classification

Definitions

Some of definitions are useful to understand the fluids importance and their applications.

1. Density:

A) Density or Mass density: It is defined as the ratio of mass and volume of the container.

$\rho = m/V$ [kg/m^3 or lbm/ft^3]

B) Weight Density: It is defined as the ratio of mass and volume of the container.

$\gamma = W/V$ [N/m^3 or lb/ft^3]

C) Specific gravity: It is the ratio of density or weight density of a fluid to that for water.

$$S = \frac{\rho}{\rho_w} = \frac{\gamma}{\gamma_w} \qquad Dimensionless$$

2. Viscosity and kinematic viscosity

When a fluid flows, the upper layer will slide over the lower one. The disability of the flow is generated by a resistance to the sliding, this resistance is called the viscosity and denoted by μ. It could be found by applying the newton law, which is:

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

If the viscosity (absolut or dynamic) [μ] is divied by the fluid density (ρ), it will be called as kinematic viscosity (v) as:

$$v = \frac{\mu}{\rho} \qquad [m^2/s]$$

Important viscosity units:

For viscosity: 1 P = 100 cP and 1 cP= 10^{-3} Pa . s

For Kinematic viscosity: 1 St = 100 cSt and 1 cSt = 10^{-6} m^2/s

Where: P is Poise and St is Stoke

Question to all students: How did we know that 1 cSt=10^{-6} m^2/s

Answer: $\mu = 10^{-3}$ N s/m^2 $\rho = 10^3$ kg/m^3 then $\nu = 10^{-6}$ m^2/s

Question: Prove that the kinematic viscosity units are m^2/s

Answer: $v=\mu/\rho=(N.s/m^2)/(kg/m^3)=(kg.m/s^2.\ s/m^2)/(kg/m^3) = m^2/s$

Note 1) : Pa.s = 10 P and $m^2/s = 10^4$ St

Note 2) : The viscosity decrease as the temperature of the liquid increase. For example, the viscosity of the liquid water is given by:

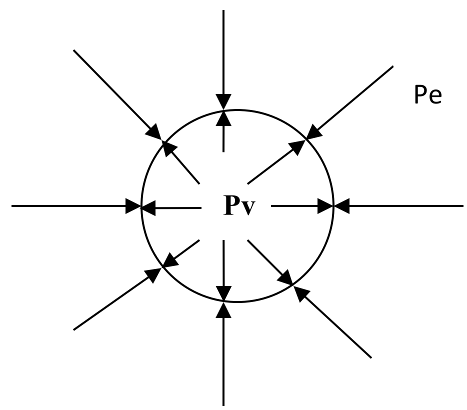
$$\frac{1}{\mu} = 2.1482\left[(T-a) + \sqrt{8078.4 + (T-a)^2}\right] - 120 \quad \text{where } a=8.1435$$

3. Pressure: It is defined as the weight of fluid per unit area and its unit [Pa or N/m^2 and psi or lb_f/in^2], there many types of pressure can be met in fluid study, are:

a) vapor pressure:

It is the magnitude of pressure at which the vapor or the bubbles appear. It is useful to predict the cavitation phynomena in the pump suction.

Note: If the external pressure less than the vapor pressure, the bubbles appear.



b) gage pressure (Pg): the differential increament of the pressure of the fluid at certain point or the reading of the gage that uses to measure the pressure.

c) Atmoshperic pressure (Patm): The pressure of the free surface without any external effects. (Note: Patm=10^5 Pa)

d) absolute pressure (Pa): The real pressure of the fluid at certain point or the total value of pressure. Note: Pa=Patm + Pg

e) Vacuum pressure: Or Evaculate pressure, when the applied pressure is less than the atmosphere or the pressure of a space without gas or air.

4. Surface tension (σ):

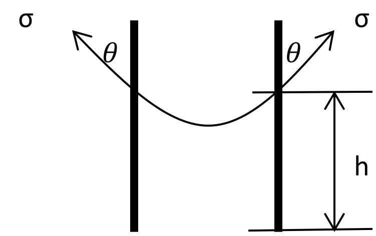
It is the tensile forces of the atoms on the upper surface of fluid; it helps to generate good attraction between the bodies and the fluid at the surface. Solids have also a surface tension but it is too high and this appears significantly in the reinforced polymer composites as an example. In the capillary tube, this force is easy to derive according to the equilibrium laws, as in the following:

$$\sum F_y = 0$$

$F_\sigma - F_w = 0$

$\sigma \, Cos\,\theta \times \pi\, d - \frac{\pi}{4}\, d^2 \times h \times \gamma$

$\sigma = \frac{\gamma d h}{4\, Cos\theta}$



Note: Surface tension reduces as fluid temperature increases, in other words $\sigma \propto \frac{1}{T}$

Ex: Find the height to which ethyl alcohol will rise in a glass capillary tube of 0.127 mm diameter? (ρ=790 kg/m^3 , σ=0.0227 N/m and θ=0)

Sol. We have $\sigma = \frac{\gamma d h}{4\, Cos\theta}$ so that $0.0227 = \frac{790 \times 9.81 \times 0.127 \times h}{4 \cos 0}$

and then h=0.00923 m or 9.23 mm

Question to all students: which one is more reasonable?

Answer: 9.23 mm is measureable and recognize more than 0.00923 m

5. Compressibility (Ep**):** It is a measure of fluid state if it has the ability to press or not and it is the ratio of the increment of the fluid pressure (ΔP) to the fluid volume strain (ΔV/V)

$Ep = \frac{\Delta P}{\Delta V / V}$ Ep > 5% for compressible flow

6. Velocity (v): it is one of the most important property of the fluid which can identify the fluid at rest or motion (flow of fluid).

A) Fluid at Rest or Fluid Mechanics

It is the case of no motion might be happened to the fluid. Many applications may encountered such as the water behind a dam, Boats, and manometers applications.