5. **The flow rate**

   5.1. **Volumetric flow rate [symbol: Q]**

   It is the volume of fluid transferred per unit time.

   $\boxed{Q = u\,A}$ where A: is the cross sectional area of flow normal to the flow direction. The common units used for volumetric flow is (m^3/s), (cm^3/s), (ft^3/s).

   5.2. **Mass flow rate [symbol: $\dot{m}$]**

   It is the mass of fluid transferred per unit time. $\boxed{\dot{m} = Q\,\rho = u\,A\,\rho}$

   The common units used for volumetric flow is (kg/s), (g/s), (lb/s).

   5.3. **Mass flux or (mass velocity) [symbol: G]**

   It is the mass flow rate per unit area of flow, $\boxed{G = \frac{\dot{m}}{A} = u\,\rho}$

   The common units used for mass flux is (kg/m2.s), (g/cm2.s), (lb/ft2.s).

6. **Ideal fluid**

   An ideal fluid is one that is incompressible It is a fluid, and having no viscosity (μ = 0). Ideal fluid is only an imaginary fluid since all the fluids, which exist, have some viscosity.

7. **Real fluid**

   A fluid, which possesses viscosity, is known as real fluid. All the fluids, an actual practice, are real fluids.

1.4 Important Laws

1. **Law of conservation of mass**

   “ The mass can neither be created nor destroyed, and it can not be created from nothing”

2. **Law of conservation of energy**

   “ The energy can neither be created nor destroyed, though it can be transformed from one form into another”

   Newton’s Laws of Motion

   Newton has formulated three law of motion, which are the basic postulates or assumption on which the whole system of dynamics is based.

3. **Newton’s first laws of motion**

   “Every body continues in its state of rest or of uniform motion in a straight line, unless it is acted upon by some external forces”

4. **Newton’s second laws of motion**

   “The rate of change in momentum is directly proportional to the impressed force and takes place in the same direction in which the force acts”[momentum = mass × velocity]

5. **Newton’s third laws of motion**

   “To every action, there is always an equal and opposite reaction”

6. First law of thermodynamics

"Although energy assumes many forms, the total quantity of energy is constant, and when energy disappears in one form it appears simultaneously in other forms"

1.5 Flow Patterns

The nature of fluid flow is a function of the fluid physical properties, the geometry of the container, and the fluid flow rate. The flow can be characterized either as **Laminar** or as **Turbulent** flow.

Laminar flow is also called "viscous or streamline flow". In this type of flow layers of fluid move relative to each other without any intermixing.

Turbulent flow in this flow, there is irregular random movement of fluid in directions transverse to the main flow.

1.6 Newton's Law of Viscosity and Momentum Transfer

Consider two parallel plates of area (A), distance (dz) apart shown in Figure (1). The space between the plates is filled with a fluid. The lower plate travels with a velocity (u) and the upper plate with a velocity (u-du). The small difference in velocity (du) between the plates results in a resisting force (F) acting over the plate area (A) due to viscous frictional effects in the fluid.

Thus the force (F) must apply to the lower plate to maintain the difference in velocity (du) between the two plates. The force per unit area (F/A) is known as the shear stress (τ).

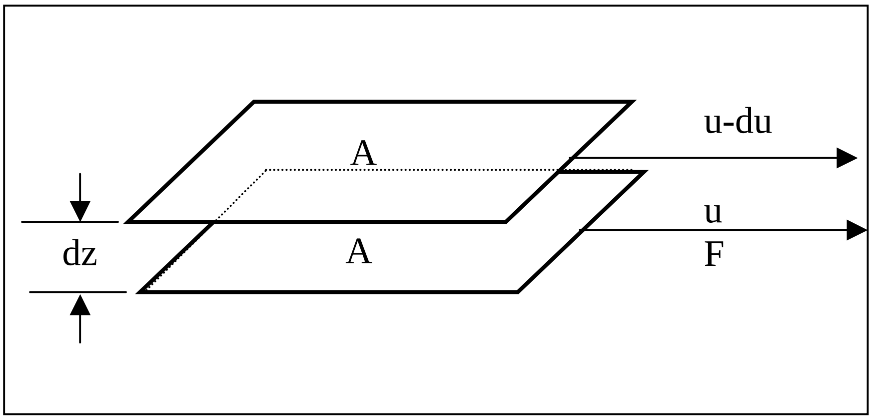

Figure (1) Shear between two plates

Newton's law of viscosity states that:

$$\tau \propto -\frac{du}{dz} \Rightarrow \tau = -\mu \frac{du}{dz}$$

Fluids, which obey this equation, are called "Newtonian Fluids" and Fluids, don't obey this equation, are called "non-Newtonian Fluids".

Note: Newton's law of viscosity holds for Newtonian fluids in laminar flow.

Momentum (shear stress) transfers through the fluid from the region of high velocities to region of low velocities, and the rate of momentum transfer increase with increasing the viscosity of fluids.

1.7 Newtonian and non-Newtonian fluids

The plot of shear stress (τ) against shear rate ($\dot{\gamma} \equiv \frac{du}{dz}$) is different in Newtonian fluids than that in non-Newtonian fluids as shown in Figure (2).

For Newtonian fluids the plot give a straight line from the origin but for non-Newtonian fluids the plot gives different relations than that of Newtonian some of these relations are given in Figure (2).

A- Newtonian fluids

B- non-Newtonian (pseudoplastic)

C- non-Newtonian (dilatant)

D- non-Newtonian (Bingham)

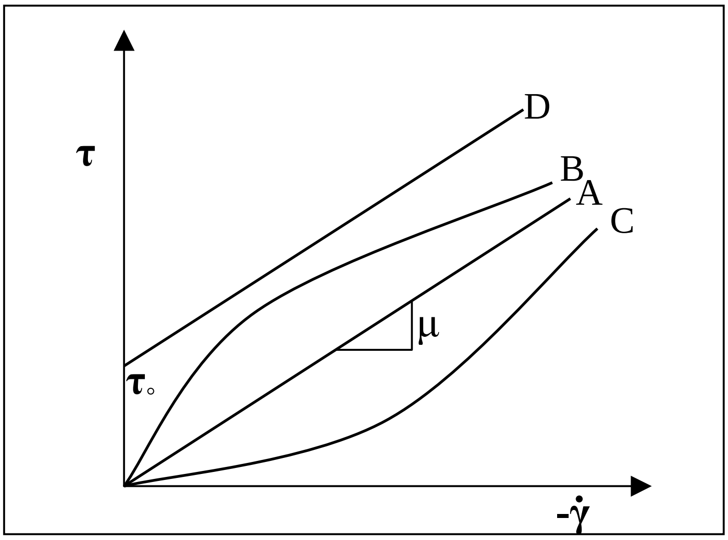

Figure (2): Shear stress (τ) against shear rate ($-\dot{\gamma} \equiv -\frac{du}{dz}$)

Example -1.1-

One liter of certain oil weighs 0.8 kg, calculate the specific weight, density, specific volume, and specific gravity of it.

Solution:

$$sp.wt. = \frac{\text{Weight of fluid}}{\text{Volume of fluid}} = \frac{(0.8kg)(9.81m/s^2)}{1x10^{-3}m^3} = 7848\frac{N}{m^3}$$

$$\rho = \frac{(0.8kg)}{1x10^{-3}m^3} = 800\frac{kg}{m^3} \qquad \upsilon = \frac{1}{\rho} = 1.25x10^{-3}\frac{m^3}{kg}$$

$$sp.gr. = \frac{\rho_{\text{liquid}}}{\rho_{\text{water}}} = \frac{800kg/m^3}{1000kg/m^3} = 0.8$$

Example -1.2-

Determine the specific gravity of a fluid having viscosity of 4.0 c.poice and kinematic viscosity of 3.6 c.stokes.

Solution:

$$\mu = 4c.p\frac{poice}{100c.p} = 0.04\,poise = 0.04\frac{g}{cm.s} \qquad \nu = 3.6c.s\frac{stoke}{100c.s} = 0.036stoke = 0.04\frac{cm^2}{s}$$

$$\nu = \frac{\mu}{\rho} \Rightarrow \rho = \frac{\mu}{\nu} = \frac{0.04\frac{g}{cm.s}}{0.036cm^2/s} = 1.1111\frac{g}{cc} \qquad \Rightarrow \rho = 1111.1\frac{kg}{m^3} \qquad \Rightarrow sp.gr. = 1.1111$$