FLUID DYNAMICS

MAT 401

UNIT 1

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Fluid Dynamics

- Fluid dynamics is a branch of science that is concerned with the study of the *motion of fluids or that of bodies in contact with fluids*.
- Fluids are classified as *liquids* and *gases*.
- Liquids are compressible under the action of *heavy forces* whereas gases are easily compressible and expand to fill any closed space.
- In fluid dynamics, the study of the *individual molecule* is neither necessary nor appropriate from the point of view of the use of mathematical methods.
- Fluid to be *continuously distributed* in a given space.

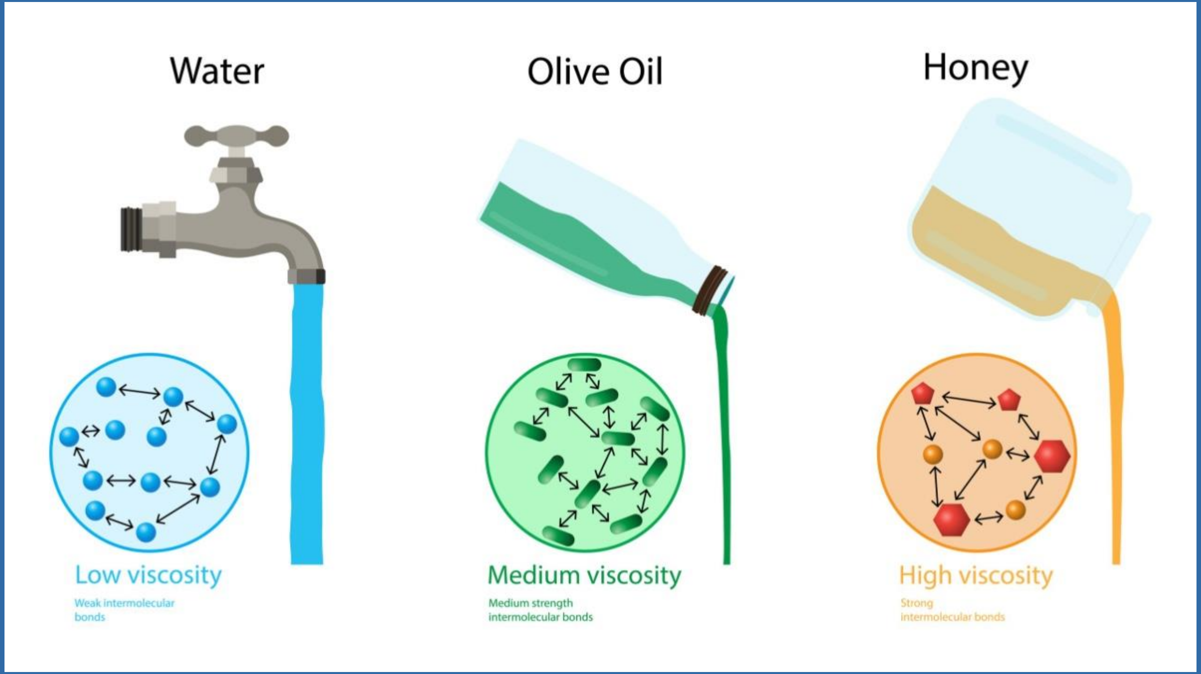
Real and Ideal Fluids

- A fluid is said to be *real (viscous)* when normal as well as shearing stress exist. On the other hand, a fluid is said to be *ideal* (non-viscous, *perfect, inviscid, frictionless)* when it does not exert any shearing stress, whether at rest or in motion.
- The pressure exerted by an inviscid fluid on any surface is always *along the normal* to the surface at that point.
- Due to shearing stress a viscous fluid produces resistance to the body moving through it as well as between the particles of the fluid itself.
- Water and air are treated *inviscid fluids* whereas syrup and heavy oil are treated as *viscous fluids*.

Viscosity

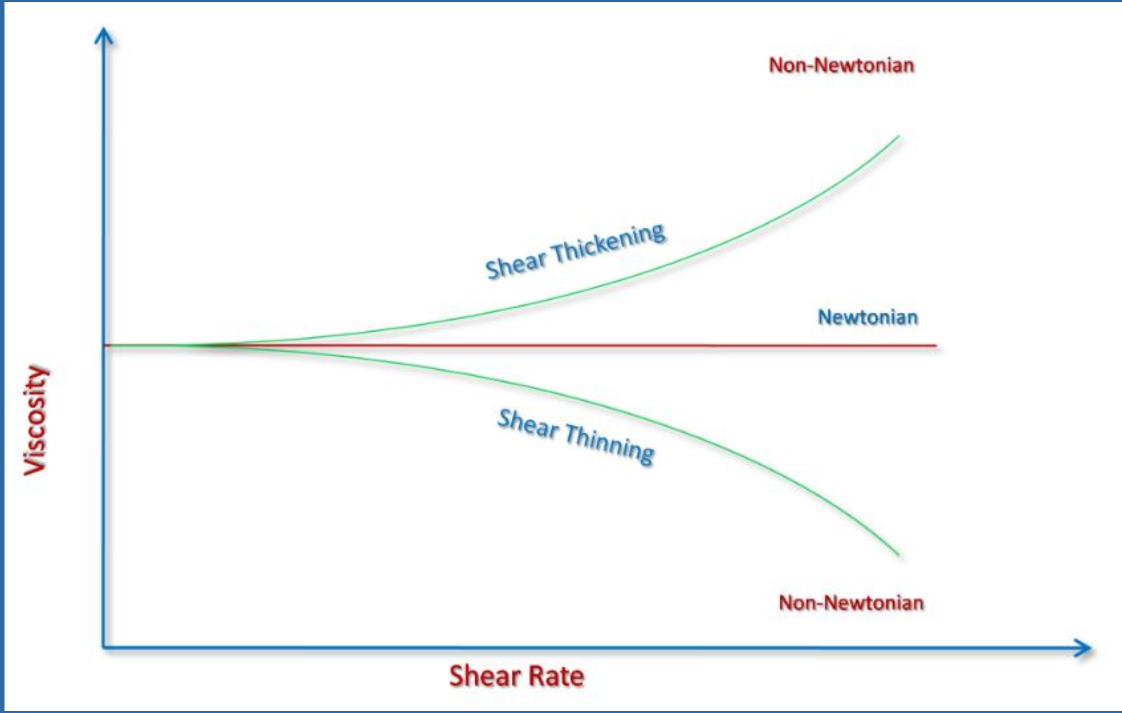
- It is the *internal friction* between the particles of the fluid which offers resistance to the deformation of the fluid.
- The friction is in the form of *tangential* and *shearing forces* (stresses).
- Fluids with such property are called *viscous or real* fluids and those not having this property are called *inviscid or ideal or perfect fluids*.
- All fluids are *real*, but in many cases, when the rates of variation of fluid velocity with distances are small, viscous effects may be ignored.
- Body force per unit area at every point of surface of an ideal fluid act along the *normal to the surface* at that point.

- Ideal fluid *does not exert* any shearing stress. Thus, viscosity of a fluid is that property by virtue of which it is able to offer *resistance to shearing stress*.
- It is a kind of molecular *frictional resistance*.



Newtonian and Non-Newtonian Fluids

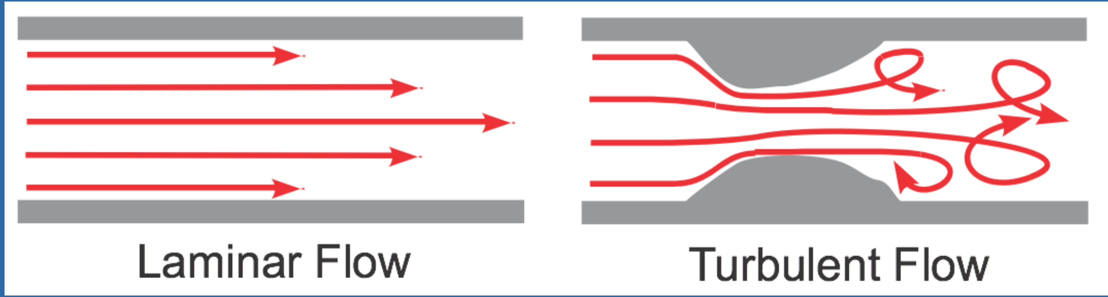
- Newtonian fluids are named after **Sir Issac Newton** (1642 - 1726) who described the flow behavior of fluids with a simple linear relationship between *shear stress and shear rate*.
- The *ratio* of shear stress to shear rate is a *constant*, for a given temperature and pressure, and is defined as the *viscosity or coefficient of viscosity*.
- This relationship is known as *Newton's Law of Viscosity*, where the *proportionality constant* η is the viscosity of the fluid.
- *Newtonian fluids* obey Newton’s law of viscosity. The viscosity is independent of the shear rate. *Non-Newtonian fluids* do not follow Newton’s law and, thus, their viscosity is not constant and is dependent on the shear rate.


Non-Newtonian
Shear Thickening
Newtonian
Shear Thinning
Non-Newtonian
Viscosity
Shear Rate

Some Important Types of Flows

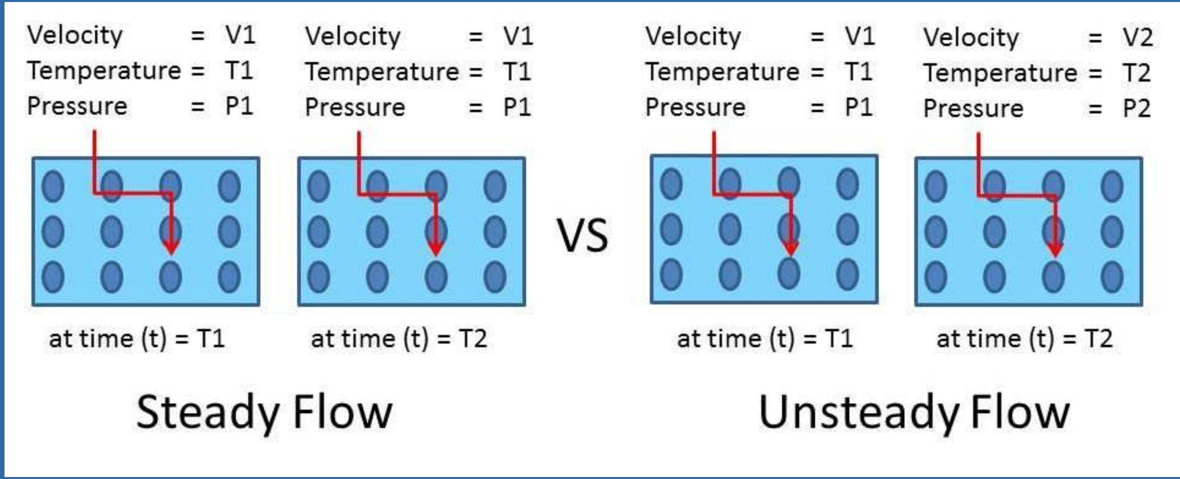
Laminar and Turbulent Flows

- A flow, in which each fluid particle *traces out a definite curve* and the curves traced out by any two different fluid particles *do not intersect*, is said to be *laminar*.
- On the other hand, a flow, in which each fluid particle *does not traces out a definite curve* and the curves traced out by fluid particles *intersect*, is said to be *turbulent*.



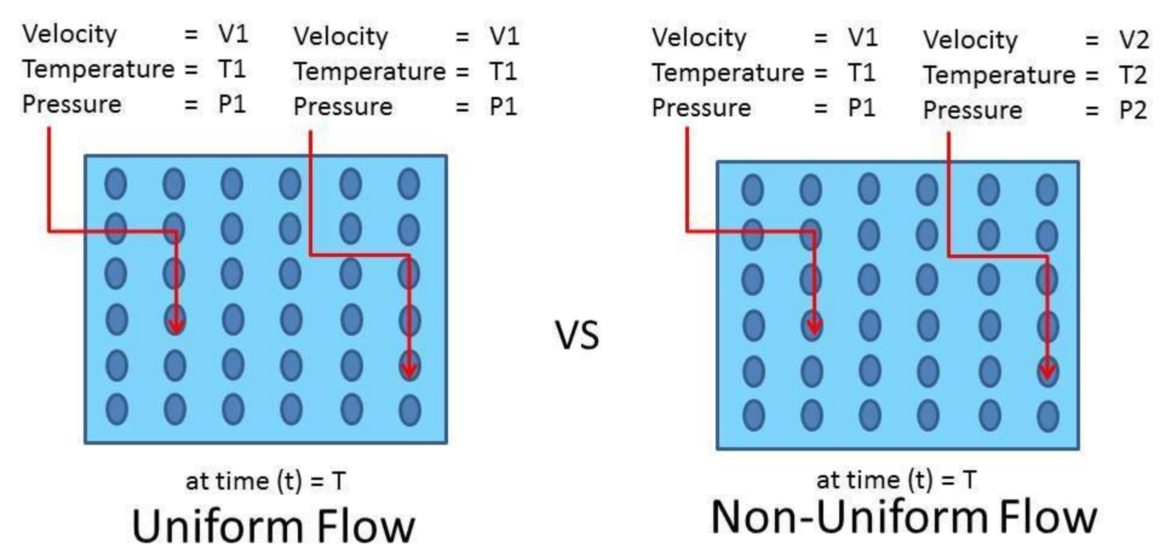
Steady and Unsteady Flows

- A flow, in which properties and conditions associated with the motion of the fluid are *independent of the time* so that the flow pattern remains unchanged with the time, is said to be *steady*.
- On the other hand, a flow, in which properties and conditions associated with the motion of the fluid *depend on the time* so that the flow pattern varies with time, is said to be *unsteady*.



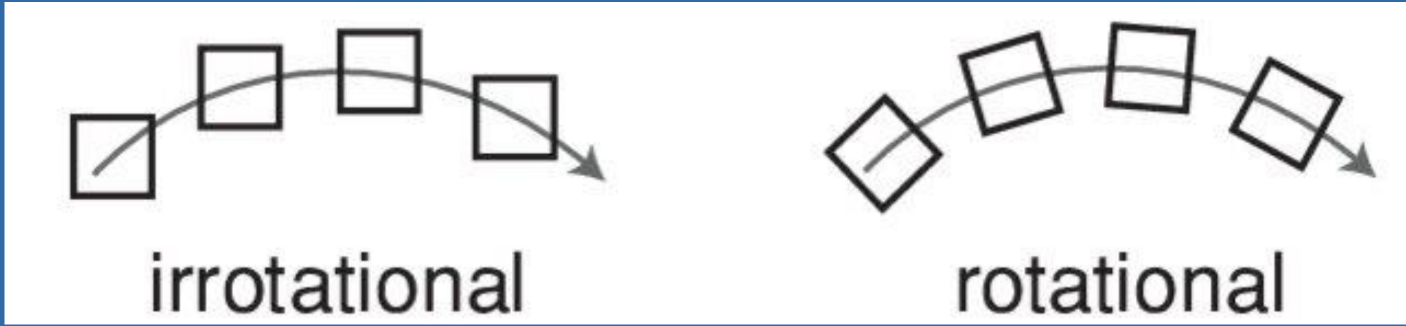
Uniform and Non-uniform Flows

- A flow, in which the fluid particles possess *equal velocities* at each section of the channel or pipe is called *uniform*.
- On the other hand, a flow, in which the fluid particles possess *different velocities* at each section of the channel or pipe is called *non-uniform*.



Rotational and Irrotational Flows

- A flow, in which the fluid particles go on *rotating about their own axes*, while flowing, is said to be *rotational*.
- On the other hand, a flow in which the fluid particles *do not rotate about their own axes*, while flowing is said to be *irrotational*.

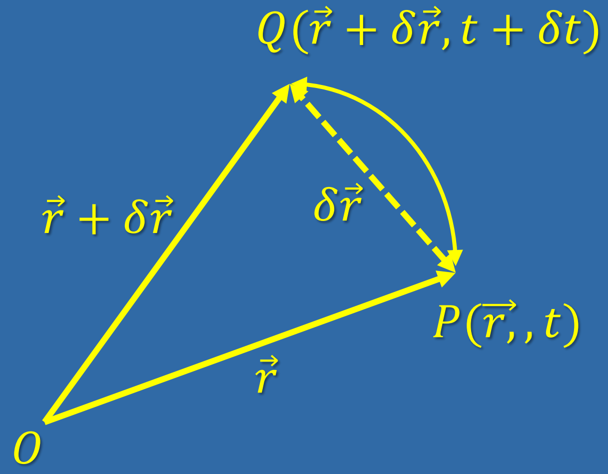


Barotropic Flow

- The flow is said to be *barotropic* when the pressure is a function of density.

Velocity of Fluid at a Point

Let us suppose that at time t, a fluid particle is at the point P having position vector $\vec{r}$ $(i.e.\ \overrightarrow{OP} = \vec{r})$ and at time $t + dt$ the same particle has reached at point Q having position vector $\vec{r} + \delta\vec{r}$. The particle velocity $\vec{q}$ at point P is



$$\vec{q} = \lim_{\delta t \to 0} \frac{(\vec{r} + \delta\vec{r}) - \vec{r}}{\delta t} = \lim_{\delta t \to 0} \frac{\delta\vec{r}}{\delta t} = \frac{d\vec{r}}{dt}$$

where the limit is assumed to exist uniquely. Clearly $\vec{q}$ is in general dependent on both $\vec{r}$ and t, so we may write $\vec{q} = \vec{q}(\vec{r}, t) = \vec{q}(x, y, z, t)$ where $\vec{r} = x\hat{\imath} + y\hat{\jmath} + z\hat{k}$ as the coordinate of P is (x, y, z).

Let, $\vec{q} = u\hat{\imath} + v\hat{\jmath} + w\hat{k}$, where u, v, w are velocity components along x, y, z directions respectively.

Again, $\vec{q} = \frac{d\vec{r}}{dt} = \frac{d}{dt}\left(x\hat{\imath} + y\hat{\jmath} + z\hat{k}\right) = \frac{dx}{dt}\hat{\imath} + \frac{dy}{dt}\hat{\jmath} + \frac{dz}{dt}\hat{k}$

Therefore, $$u = \frac{dx}{dt},\ v = \frac{dy}{dt},\ w = \frac{dz}{dt}$$

Remarks. **(i)** A point where $\vec{q} = 0$, is called a *stagnation point*.

(ii) When the flow is such that the velocity at each point is independent of time i.e. the flow pattern is same at each instant, then the motion is termed as *steady motion*, otherwise it is *unsteady*.