جامعة التقنية والعلوم التطبيقية
University of Technology and Applied Sciences - Ibra

Department Of Mechanical Engineering

Fluids Mechanics-1 (MIME 2240)

Chapter-1
Introduction to Fluids Mechanics and Fluid Properties

Prepared by: Mr. Chethan G R

Ref: http://agrimoon.com/fluid-mechanics-pdf-book-free-download/

Classification of Fluid Flows

- There is a wide variety of fluid flow problems encountered in practice, and it is usually convenient to classify them on the basis of some common characteristics to make it feasible to study them in groups.

Viscous versus Inviscid Regions of Flow

- When two fluid layers move relative to each other, a friction force develops between them and the slower layer tries to slow down the faster layer.
- This internal resistance to flow is quantified by the fluid property *viscosity,* which is a measure of internal stickiness of the fluid.
- Viscosity is caused by cohesive forces between the molecules in liquids and by molecular collisions in gases.

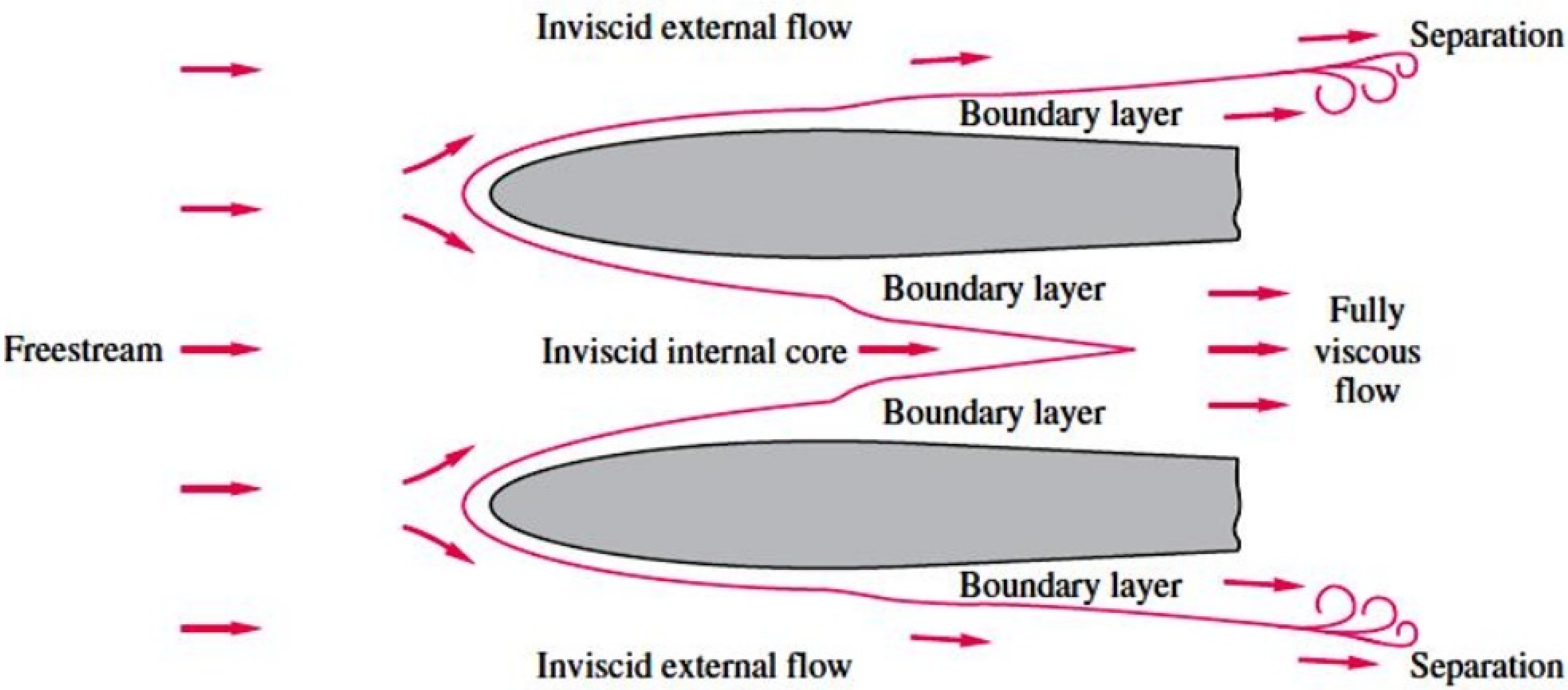
Classification of Fluid Flows

Viscous versus Inviscid Regions of Flow…

- There is no fluid with zero viscosity, and thus all fluid flows involve viscous effects to some degree.
- Flows in which the frictional effects are significant are called **viscous flows.**
- However, in many flows of practical interest, there are *regions (typically regions not close to solid surfaces)* where viscous forces are negligibly small compared to inertial or pressure forces.
- Neglecting the viscous terms in such **inviscid** flow regions greatly simplifies the analysis without much loss in accuracy.

Classification of Fluid Flows

Viscous versus Inviscid Regions of Flow



Classification of Fluid Flows

Internal versus External Flow

- A fluid flow is classified as being internal or external, depending on whether the fluid is forced to flow in a confined channel or over a surface.
- The flow of an unbounded fluid over a surface such as a plate, a wire, or a pipe is **external flow.**
- The flow in a pipe or duct is **internal flow** if the fluid is completely bounded by solid surfaces.
- Water flow in a pipe, for example, is internal flow, and airflow over a ball or over an exposed pipe during a windy day is external flow .

Classification of Fluid Flows

Compressible versus Incompressible Flow

- A flow is classified as being compressible or incompressible, depending on the level of variation of density during flow.
- Incompressibility is an approximation, and a flow is said to be **incompressible** if the density remains nearly constant throughout.
- Therefore, the volume of every portion of fluid remains unchanged over the course of its motion when the flow (or the fluid) is incompressible.
- The densities of liquids are essentially constant, and thus the flow of liquids is typically incompressible. Therefore, liquids are usually referred to as *incompressible substances*.

Classification of Fluid Flows

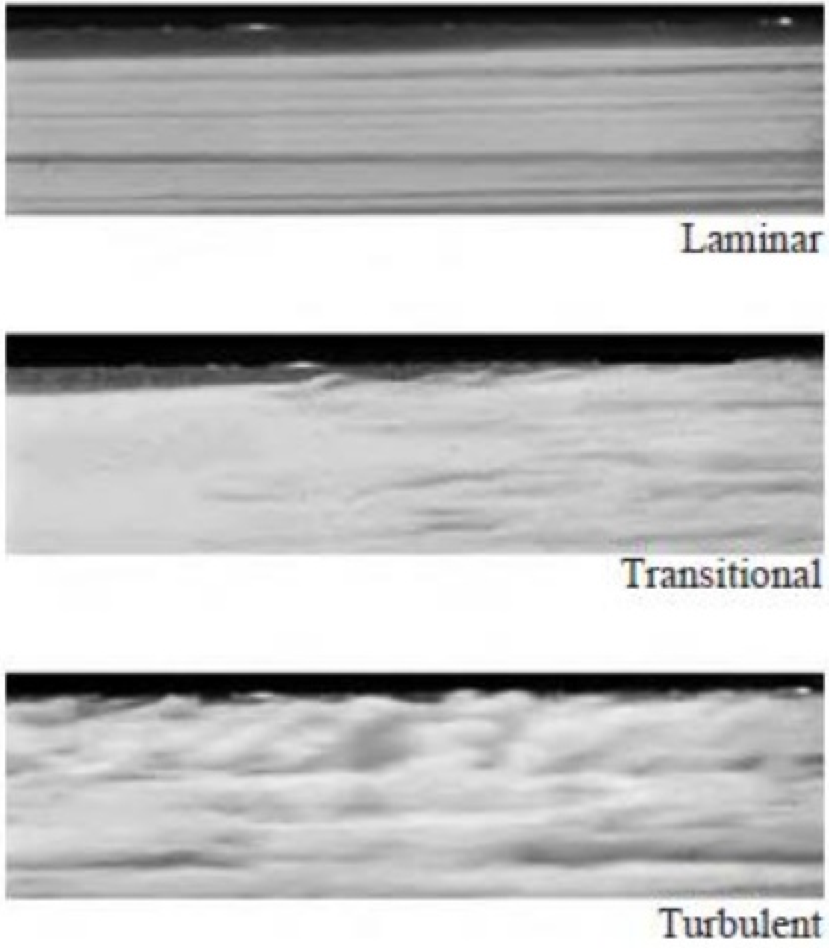
Compressible versus Incompressible Flow…

- A pressure of 210 atm, for example, causes the density of liquid water at 1 atm to change by just 1 percent.
- Gases, on the other hand, are highly compressible. A pressure change of just 0.01 atm, for example, causes a change of 1 percent in the density of atmospheric air.
- Gas flows can often be approximated as incompressible if the density changes are under about 5 percent.
- The compressibility effects of air can be neglected at speeds under about 100 m/s.

Classification of Fluid Flows

Laminar versus Turbulent Flow

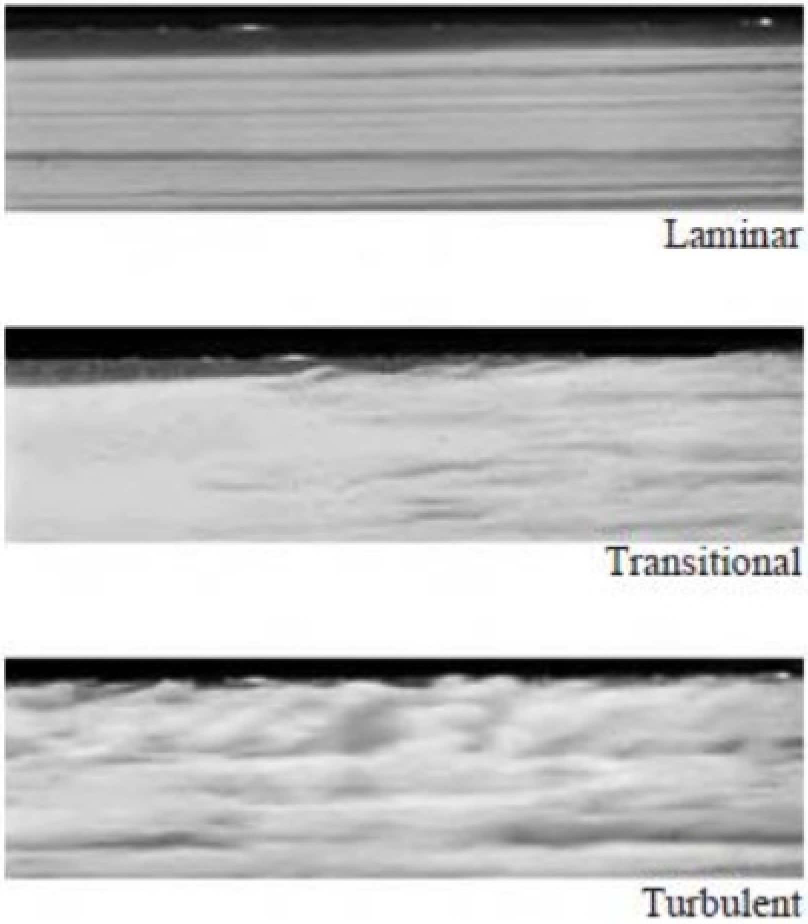
- Some flows are smooth and orderly while others are rather chaotic.
- The highly ordered fluid motion characterized by smooth layers of fluid is called **laminar.**
- The flow of high-viscosity fluids such as oils at low velocities is typically laminar.
- The highly disordered fluid motion that typically occurs at high velocities and is characterized by velocity fluctuations is called **turbulent .**



Classification of Fluid Flows

Laminar versus Turbulent Flow

- The flow of low-viscosity fluids such as air at high velocities is typically turbulent.
- A flow that alternates between being laminar and turbulent is called **transitional.**



Classification of Fluid Flows

Natural (or Unforced) versus Forced Flow

- A fluid flow is said to be natural or forced, depending on how the fluid motion is initiated.
- In **forced flow,** a fluid is forced to flow over a surface or in a pipe by external means such as a **pump or a fan**.
- In **natural flows,** any fluid motion is due to natural means such as the buoyancy effect, which manifests itself as the rise of the warmer (and thus lighter) fluid and the fall of cooler (and thus denser) fluid .
- In solar hot-water systems, for example, the thermosiphoning effect is commonly used to replace pumps by placing the water tank sufficiently above the solar collectors.

Classification of Fluid Flows

Steady versus Unsteady Flow

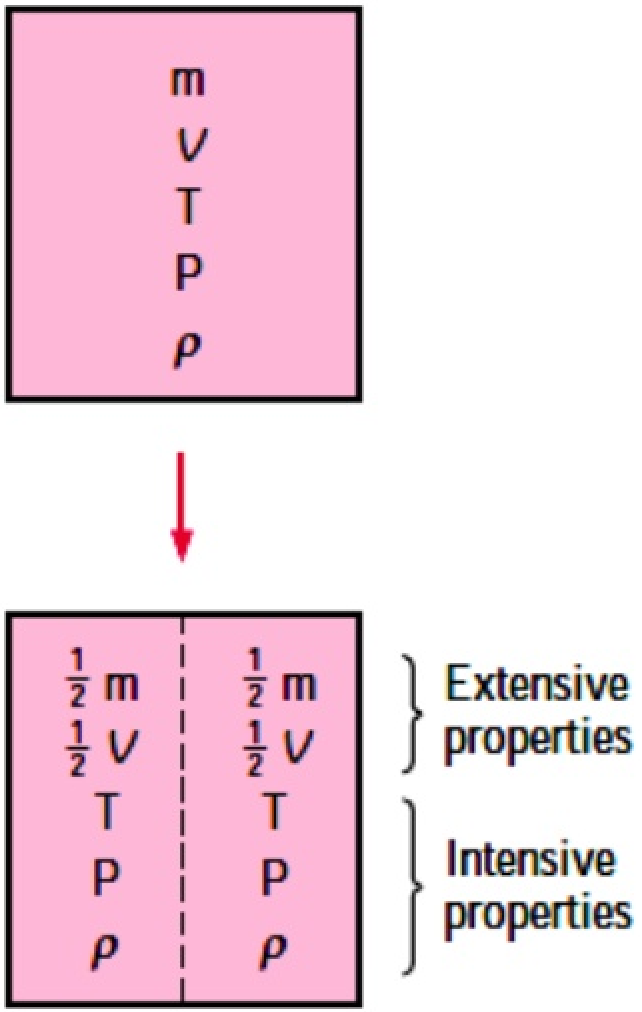
- The terms *steady and uniform are used frequently in engineering, and thus it* is important to have a clear understanding of their meanings.
- The term steady implies ***no change at a point with time*.**
- The opposite of steady is **unsteady.**
- The term **uniform** implies ***no change with location*** *over a specified* region.

Properties of Fluids

- Any characteristic of a system is called a **property.**
- Some familiar properties are pressure *P*, temperature T, volume V, and mass m.
- Other less familiar properties include viscosity, thermal conductivity, modulus of elasticity, thermal expansion coefficient, electric resistivity, and even velocity and elevation.
- Properties are considered to be either ***intensive or extensive***.
- ***Intensive*** properties are those that are independent of the mass of a system, such as temperature, pressure, and density.
- **Extensive** properties are those whose values depend on the size—or extent—of the system. Total mass, total volume *V*, and total momentum are some examples of extensive properties.

Properties of Fluids

- An easy way to determine whether a property is intensive or extensive is to divide the system into two equal parts with an imaginary partition.
- Each part will have the same value of intensive properties as the original system, but half the value of the extensive properties.



Properties of Fluids

Density or Mass Density

- Density or mass density of a fluid is defined as the ratio of the mass of a f1uid to its volume. Thus mass per unit volume of a fluid is called density. It is denoted the symbol ρ (rho). The unit of mass density in SI unit is kg per cubic meter, i.e ., kg/m^3.
- The density of liquids may be considered as constant while that of gases changes with the variation of pressure and temperature.
- Mathematically mass density is written as.

$$\rho = \frac{\text{Mass of fluid}}{\text{Volume of fluid}}$$

- The value of density of water is 1 gm/cm^3 or 1000 kg/m^3.

Properties of Fluids

Density or Mass Density

- The density of a substance, in general, depends on temperature and pressure.
- The density of most gases is proportional to pressure and inversely proportional to temperature.
- Liquids and solids, on the other hand, are essentially incompressible substances, and the variation of their density with pressure is usually negligible.

Properties of Fluids

Specific weight or Weight Density

- Specific weight or weight density of a fluid is the ratio between the weight of a fluid to its volume.
- Thus weight per unit volume of a fluid is called weight density and it is denoted by the symbol w.
- Mathematically,

$$w = \frac{\text{Weight of fluid}}{\text{Volume of fluid}} = \frac{\text{(Mass of fluid) x Acceleration due to gravity}}{\text{Volume of fluid}}$$

$$= \frac{\text{Mass of fluid x g}}{\text{Volume of fluid}}$$

$$= \rho \text{ x g}$$

$$w = \rho g$$

Properties of Fluids

Specific Volume

- Specific volume of a fluid is defined as the volume of a fluid occupied by a unit mass or volume per unit mass of a fluid is called specific volume.
- Mathematically, it is expressed as

$$\text{Specific volume} = \frac{\text{Volume of fluid}}{\text{Mass of fluid}} = \frac{1}{\frac{\text{Mass of fluid}}{\text{Volume}}} = \frac{1}{\rho}$$

- Thus specific volume is the reciprocal of mass density. It is expressed as m^3/kg.
- It is commonly applied to gases.

Properties of Fluids

Specific Gravity.

- Specific gravity is defined as the ratio of the weight density (or density) of a fluid to the weight density (or density) of a standard fluid.
- For liquids, the standard fluid is taken water and for gases, the standard fluid is taken air. Specific gravity is also called relative density. It is dimensionless quantity and is denoted by the symbol *S*.

$$S(\text{for liquids}) = \frac{\text{Weight density (density) of liquid}}{\text{Weight density (density) of water}}$$

$$S(\text{for gases}) = \frac{\text{Weight density (density) of gas}}{\text{Weight density (density) of air}}$$

$$\text{Thus weight density of a liquid} = S \text{ x Weight density of water}$$

$$= S \text{ x } 1000 \text{ x } 9.81 \text{ N/m}^3$$

$$\text{Thus density of a liquid} = S \text{ x Density of water}$$

$$= S \text{ x } 1000 \text{ kg/m}^3$$

Properties of Fluids

Specific Gravity.

- If the specific gravity of a fluid is known, then the density of the fluid will be equal to specific gravity of fluid multiplied by the density of water.
- For example the specific gravity of mercury is 13.6, hence density of mercury = 13.6 x 1000 = 13600 kg/m^3.

Specific gravities of some substances at 0°C

Substance	SG
Water	1.0
Blood	1.05
Seawater	1.025
Gasoline	0.7
Ethyl alcohol	0.79
Mercury	13.6
Wood	0.3–0.9
Gold	19.2
Bones	1.7–2.0
Ice	0.92
Air (at 1 atm)	0.0013

Properties of Fluids

Example 1.

Calculate the specific weight, density and specific gravity of one liter of a liquid which weighs 7 N.

Solution. Given :

$$\text{Volume} = 1 \text{ litre} = \frac{1}{1000}\,\text{m}^3 \quad \left(\because\ 1 \text{ litre} = \frac{1}{1000}\,\text{m}^3 \text{ or } 1 \text{ litre} = 1000 \text{ cm}^3\right)$$

$$\text{Weight} = 7 \text{ N}$$

(*i*) Specific weight (w)

$$= \frac{\text{Weight}}{\text{Volume}} = \frac{7\text{ N}}{\left(\frac{1}{1000}\right)\text{m}^3} = \mathbf{7000\ N/m^3.\ Ans.}$$

(*ii*) Density (ρ)

$$= \frac{w}{g} = \frac{7000}{9.81}\ \text{kg/m}^3 = \mathbf{713.5\ kg/m^3.\ Ans.}$$

(*iii*) Specific gravity

$$= \frac{\text{Density of liquid}}{\text{Density of water}} = \frac{713.5}{1000} \quad \{\because\ \text{Density of water} = 1000 \text{ kg/m}^3\}$$

$$= \mathbf{0.7135.\ Ans.}$$

Example 2. *Calculate the density, specific weight and weight of one liter of petrol of specific gravity = 0.7*

Solution. Given : Volume = 1 litre = $1 \times 1000 \text{ cm}^3 = \frac{1000}{10^6} \text{ m}^3 = 0.001 \text{ m}^3$

Sp. gravity $S = 0.7$

(*i*) *Density* (ρ)

Density (ρ) $= S \times 1000 \text{ kg/m}^3 = 0.7 \times 1000 =$ **700 kg/m³. Ans.**

(*ii*) *Specific weight* (*w*)

$$w = \rho \times g = 700 \times 9.81 \text{ N/m}^3 = \mathbf{6867 \text{ N/m}^3}.$$ **Ans.**

(*iii*) *Weight* (*W*)

We know that specific weight $= \frac{\text{Weight}}{\text{Volume}}$

or $w = \frac{W}{0.001}$ or $6867 = \frac{W}{0.001}$

$\therefore$ $W = 6867 \times 0.001 =$ **6.867 N. Ans.**

Properties of Fluids

Viscosity

- Viscosity is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid.
- When two layers of a fluid, a distance *'dy' apart move one* over the other at different velocities say u and u+ *du as shown in Fig. 1.1 , the viscosity together with* relative velocity causes a shear stress acting between the fluid layers:

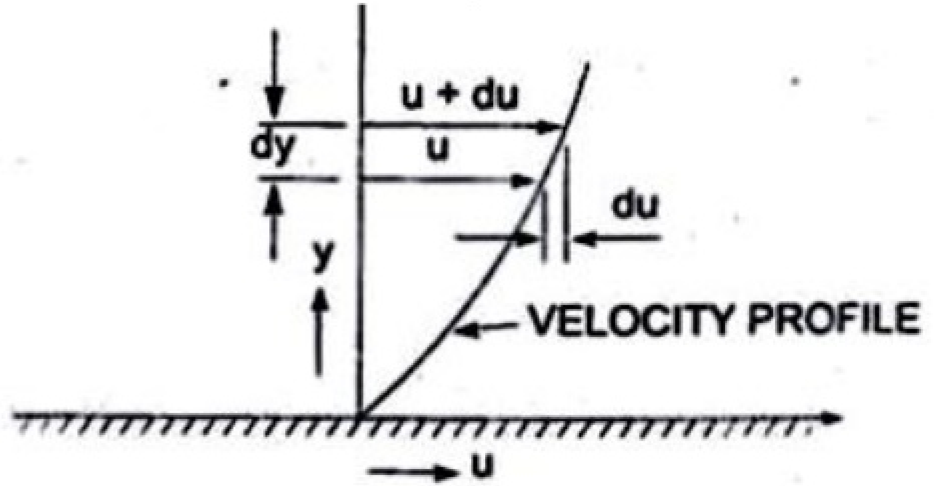


Fig. 1.1 *Velocity variation near a solid boundary.*

Properties of Fluids

Viscosity

- The top layer causes a shear stress on the adjacent lower layer while the lower layer causes a shear stress on the adjacent top layer.
- This shear stress is proportional to the rate of change of velocity with respect to *y*. *It is denoted by symbol* τ called Tau.
- Mathematically,

$$\tau \propto \frac{du}{dy}$$

- or

$$\tau = \mu \frac{du}{dy} \qquad (1.2)$$

Properties of Fluids

- where μ (called m*u*) *is the constant of proportionality and is known as the coefficient of dynamic viscosity* or only viscosity.
- $\frac{du}{dy}$ *represents the rate of shear strain or rate of shear deformation or velocity gradient.*
- *From equation (1.2) we have*

$$\mu = \frac{\tau}{\frac{du}{dy}} \qquad (1.3)$$

- Thus viscosity is also defined as the shear stress required to produce unit rate of shear strain.

Properties of Fluids

Unit of Viscosity.

- The unit of viscosity is obtained by putting the dimension of the quantities in equation (1.3)

$$\mu = \frac{\text{Shear stress}}{\dfrac{\text{Change of velocity}}{\text{Change of distance}}} = \frac{\text{Force/Area}}{\left(\dfrac{\text{Length}}{\text{Time}}\right) \times \dfrac{1}{\text{Length}}}$$

$$= \frac{\text{Force/(length)}^2}{\dfrac{1}{\text{Time}}} = \frac{\text{Force} \times \text{Time}}{(\text{Length})^2}$$

$$\text{SI unit of viscosity} = \frac{\text{Newton second}}{\text{m}^2} = \frac{\text{Ns}}{\text{m}^2}$$

Properties of Fluids

Kinematic Viscosity.

- It is defined as the ratio between the dynamic viscosity and density of fluid.lt is denoted by the Greek symbol (ν) called 'nu' . Thus, mathematically,

$$\nu = \frac{\text{Viscosity}}{\text{Density}} = \frac{\mu}{\rho}$$

- The SI unit of kinematic viscosity is m^2/s.

Newton's Law of Viscosity.

- It states that the shear stress (τ) on a fluid element layer is directly proportional to the rate of shear strain. The constant of proportionality is called the co-efficient viscosity. Mathematically, it is expressed as given by equation (1 . 2).

Properties of Fluids

- Fluids which obey the above relation are known as Newtonian fluids and the fluids which do not obey the above relation are called Non-newtonian fluids.

Variation of Viscosity with Temperature

- Temperature affects the viscosity.
- The viscosity of liquids decreases with the increase of temperature while the viscosity of gases increases with increase of temperature. This is due to reason that the viscous forces in a fluid are due to cohesive forces and *molecular momentum transfer.*
- *In liquids the cohesive forces predominates the molecular momentum* transfer due to closely packed molecules and with the increase in temperature, the cohesive forces decreases with the result of decreasing viscosity.

Properties of Fluids

- But in the case of gases the cohesive force are small and molecular momentum transfer predominates. With the increase in temperature, molecular momentum transfer increases and hence viscosity increases. The relation between viscosity and temperature for liquids and gases are:

(i) For liquids, $\mu = \mu_o \left(\frac{1}{1 + \alpha t + \beta t^2} \right)$

where μ = Viscosity of liquid at t°C, in poise $\quad 1 \text{ poise} = \frac{1}{10} \frac{Ns}{m^2}$

μ_o = Viscosity of liquid at $0^\circ C$, in poise

α, β = are constants for the liquid

For water, $\mu_o = 1.79 \times 10^{-3}$ poise, $\alpha = 0.03368$ and $\beta = 0.000221$

(ii) For a gas, $\mu = \mu_o + \alpha t - \beta t^2$

where for air $\mu_o = 0.000017$, $\alpha = 0.000000056$, $\beta = 0.1189 \times 10^{-9}$

Types of Fluids

1. Ideal Fluid. A fluid, which is incompressible and is having no viscosity, is known as an ideal fluid. Ideal fluid is only an imaginary fluid as all the fluids, which exist, have some viscosity.
2. Real fluid. A fluid, which possesses viscosity, is known as real fluid. All the fluids: in actual practice, are real fluids.
3. Newtonian Fluid. A real fluid, in which the shear stress is directly, proportional to the rate of shear strain (or velocity gradient), is known as a Newtonian fluid.
4. Non-Newtonian fluid. A real fluid, in which shear stress is not proportional to the rate of shear strain (or velocity gradient), known as a Non-Newtonian fluid.

Types of Fluids

5. Ideal Plastic Fluid.

A fluid, in which shear stress is more than the yield value and shear stress is proportional to the rate of shear strain (or velocity gradient), is known as ideal plastic fluid.

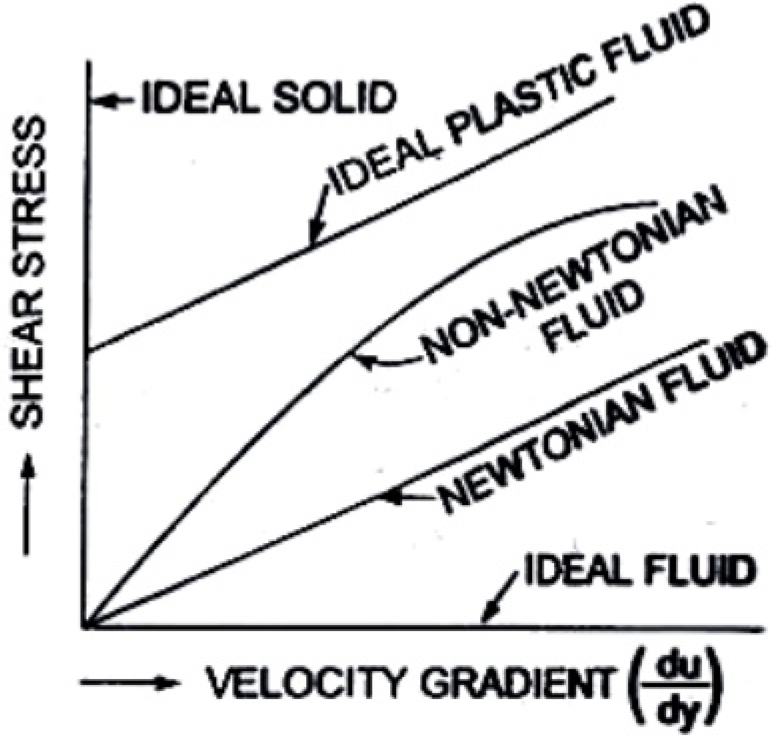


Fig. 1.2 *Types of fluids.*