1.0 A REVIEW OF FLUIDMECHANICS

Fluid Mechanics: This can be defined as the branch of Engineering-science that deals with the behaviour of fluid under the conditions of rest and motion. This can be divided into three parts, viz: Statics, Kinematics and dynamics.

1.1 TERMINOLOGIES:

(i) Statics: The study of incompressible fluids under static conditions is called hydrostatics, while the study of compressible (fluids) static gases is called aerostatics.

(ii) Kinematics: This deals with velocities, accelerations and patterns of flow only, without considering the forces or energy that bring about the velocity and acceleration.

(iii) Dynamics: It deals with the relations between velocities, accelerations of fluid with the forces or energy causing them.

(iv) Fluid: A fluid is a substance which offers no resistance to shear deformation and will continue to deform when subjected to shear stresses. It has no definite shape of its own, but assumes the shape of the containing vessel.

Fluid can be classified into:

A. (i) Liquid, (ii) Gases, and (iii) Vapour.

B. (i) Ideal fluids, and (ii) Real fluids.

(v) Liquid: It is a fluid which possesses a definite volume (which slightly with temperature and pressure); liquid is relatively incompressible and has a high specific mass.

(vi) Gases: They are readily compressible and possesses no definite volume. They have a very low specific mass.

(vii) Vapour: It is a gas whose temperatures and pressure are such that it is very near the liquid state (e.g. steam).

(viii) Ideal fluids: A perfect or an ideal fluid is one which has no viscosity and surface tensions but only has pressure force whether at rest or in motion and it is incompressible.

The internal forces on any internal section are normal to the section even when the fluid is in motion. Since there is no tangential force, an ideal fluid helps to simplify mathematical analysis.

(ix) Real fluids: These otherwise called actual or practical fluids. They have viscosity. Surface tension, shear stresses or tangential stresses are present whenever the fluid is in motion and are compressible.

(x) Continuum: A continuous and homogeneous medium is called continuum. From the continuum point of View, the overall properties and behaviour of fluid can be studied without regard for its atomic and molecular structure.

Some Important Properties of Fluid:

(xi) Density: This otherwise called mass density or specific mass of a liquid, and can be defined as the mass per unit volume ($^m/_v$) at a standard temperature and pressure, measured in kg/m^3.

$$\text{i.e. } \rho(roh)\ \rho = \frac{m}{r}\left({}^{kg}/_{m^3}\right).$$

(xii) Weight density: This is the otherwise known as specific weight; it is defined as the weight per unit volume at the standard temperature and pressure. It is denoted by w.

$$\mathrm{W} = \rho g \left({}^{KN}/_{m^3}\right).$$

(xiii) Specific Gravity: This is the ratio of the specific weight of a standard fluid. It has no unit. Specific weight = $\frac{Specific\ \ weight\ of\ liquid}{Specific\ weight\ of\ pure\ water}$

(xiv) Viscosity: This may be defined as the property of fluid which determined its resistance to shearing stresses. It is a measure of the internal fluid friction which causes resistance to flow. This is primarily due to cohesion and molecular momentum exchange between fluid layers.

Shear stress, $\tau \propto \frac{du}{dy}$

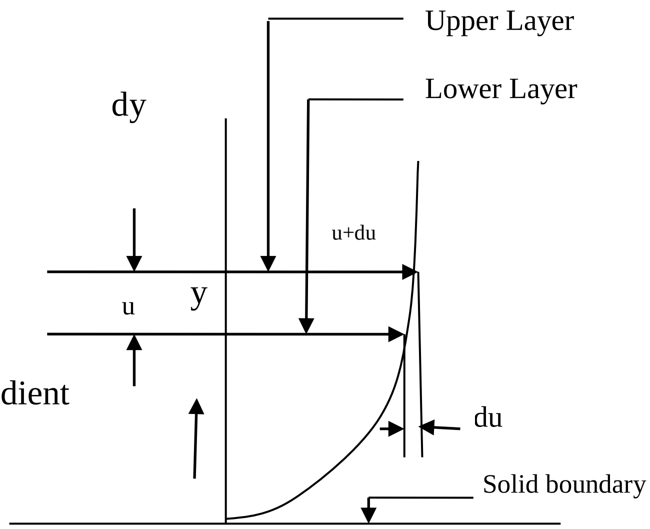
τ is called Tau.

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

U is coefficient of dynamic viscosity

$\frac{du}{dy}$ is rate of shear stress or velocity gradient

τ is shear stress



Thus viscosity, N is the shear stress required to produce unit rate of shear strain.

Unit of viscosity: N.S/m^2 $\left[\mu = \frac{force/area}{(length/time)\times\frac{1}{length}}\right]$

(xv) Kinematic Viscosity: It is defined as the ratio between the dynamic viscosity and density of fluid. It is denoted by V (called nv)

Mathematically, V $=\frac{Viscosity}{Density} = \frac{\mu}{\rho}\left(m^3/_s\right)$.

Kinematic viscosity is also known as stoke (= Cm^2/sec)

1 stoke = 10^{-4} $m^3/_s$.

(xvi) Newton's Law of Viscosity: This law 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 of viscosity.

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

The fluids which obey this law are known as Newtonian fluids. In these type of fluids,

μ does not change with rate of deformation

Examples of Newtonian fluid are: Water, kerosene, e.t.c.

(xvii) Non-Newtonian Fluids: these are fluids which do not follow the linear relationship between shear stress and rate of deformation.

Such fluids as solutions, Suspensions or Sherries, mud flows, polymer solutions, blood, etc. are examples.

(xviii) Plastic fluids: Theses are non-Newtonian fluids and the initial yield stress has to be exceeded to cause a continuous deformation.

(i) In Ideal fluid, $\tau = 0$

(ii) In Newtonian, $\tau = \mu \frac{du}{dy}$

(iii) In non – Newtonian, $\tau = \mu \left[\frac{du}{dy}\right]^n$ if n is less than unity, they are pseudo – plastics, examples: paper pulp, ruber suspension paints, but if n is greater than unity, they are dilatants. Examples are: Butter, Printing ink.

1.2 Compressibility and Bulk Modulus

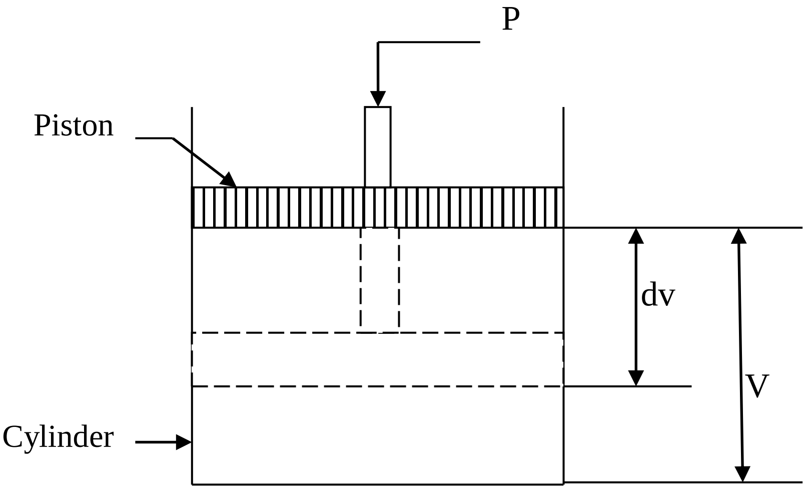
(i) Compressibility: The property by virtue of which fluid undergoes a change in volume under the action of external pressure is known as compressibility.

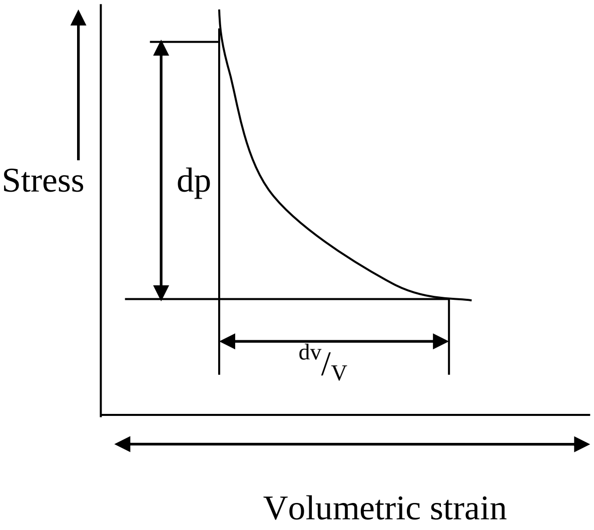
This decreases with increase in pressure of fluid, as the volume modules increases with the increase in pressure.

The variation in volume of water, with variation of pressure is so small that for all practical purposes it is neglected, and water is considered as incompressible fluid. However, in the case of flow of water through pipes with sudden or large changes in pressure such as in water hammer, the compressibility cannot be neglected.

The compressibility in fluid mechanics is considered mainly when the velocity of flow is high enough reaching 20% of speed of sound in the medium.

(ii) Bulk Modulus of Elasticity: This is defined as the ratio of compressive stress to volumetric strain. Compressibility is the reciprocal of bulk modulus of elasticity.





V = Volume of gas enclosed in the cylinder, and

P = pressure of gas, when the volume is V.

= $\frac{P}{A}$, where A is the area of cross-section of the cylinder.

When the pressure is increased to P+dp, the Volume of gas decreases from V to V-dv.

Therefore, Volumetric decrease in volume with increase in pressure.

∴ Bulk modulus, K = $\frac{dp\ (increase\ of\ pressure)}{-dv/_{V}(volumetric\ strain)}$

i.e. K = $\frac{dp}{-dv/_{V}}$

Compressibility = $1/_{K}$.

NOTE:

The bulk modulus, K is not constant but increased with increase in pressure; because when a fluid mass is compressed, its molecules become close and resistance to further compression increases e.g., K increases.

However, in gases, pressure and temperature are inter-related and as temperature increases, pressure also increases. Therefore, an increase in the value is K.

1.3 FLUID KINEMATICS

Fluid kinematics is a branch of fluid mechanics which deals with the study of velocity and acceleration of the particles of fluids in motion and their distribution in space without considering any force or energy involved.

(i) Description of Fluid Motion

The motion of fluid particles may be described by the following methods:

- **(a)** Langrangian method
- **(b)** Eulerian method

(a) Langrangian method: This method, the observer concentrates on the movement of a single particle. The path taken by the particles and the changes in its velocity and acceleration are studied.

In the Cartesian system, the position of the fluid particle in space (x, y, z) at anytime from its position (a, b, c) at time t = O shall be given as:

$$x = f_1 (a, b, c, t)$$

$$y = f_2 (a, b, c, t)$$

$$z = f_3 (a, b, c, t)$$

Velocity components: $U = \frac{\partial x}{\partial t},\ V = \frac{\partial y}{\partial t},\ w = \frac{\partial z}{\partial t}$

Acceleration components: $a_x = \frac{\partial^2 x}{\partial t^2},\ a_y = \frac{\partial^2 y}{\partial t^2},\ a_z = \frac{\partial^2 z}{\partial t^2}$

Resultant Velocity, $\boldsymbol{V} = \sqrt{u^2 + v^2 + w^2}$

Resultant Acceleration **a** $= \sqrt{a_x^2 + a_y^2 + a_z^2}$

(b) Eulerian Method: In this method the observer concentrates on a point in the fluid system. Velocity, acceleration and other characteristics of the fluid at that particular point are studied.

The Velocity at any point (x, y, z) can be written as:

$u = f_1\ (x, y, z, t)$

$v = f_2\ (x, y, z, t)$

$w = f_3\ (x, y, z, t)$

The components of acceleration of the fluid can be worked out by partial differentiation as follows:

$$du = \frac{\partial u}{\partial x}.dx + \frac{\partial u}{\partial y}.dy + \frac{\partial u}{\partial z}.dz + \frac{\partial u}{\partial t}.dt$$

$$a_x = \frac{\partial u}{\partial t} = \left[\frac{\partial u}{\partial x}.\frac{\partial x}{\partial t} + \frac{\partial u}{\partial y}.\frac{\partial y}{\partial t} + \frac{\partial u}{\partial z}.\frac{\partial z}{\partial t}\right] + \frac{\partial u}{\partial t}.dt$$

$$a_x = \left(U\frac{\partial u}{\partial x} + V\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) + \frac{\partial u}{\partial t}$$

Similarly,

$$a_y = \frac{\partial v}{\partial t} = \left(U\frac{\partial u}{\partial x} + V\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) + \frac{\partial u}{\partial t}$$

$$a_z = \frac{\partial w}{\partial t} = \left(U\frac{\partial u}{\partial x} + V\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) + \frac{\partial w}{\partial t}$$

Resultant Velocity, $\boldsymbol{V} = \sqrt{u^2 + v^2 + w^2}$

Resultant acceleration, **a** =$\sqrt{a_x^2 + a_y^2 + a_z^2}$

In vector motion,

Velocity vector: *V=ui+vj+wk*

1.4 TYPES OF FLUID FLOW

(i) **Steady Flow**: In this type of flow, the fluid characteristics like velocity, pressure, density etc., at a point do not change with time.

Mathematically, we have:

$$\left(\frac{\partial u}{\partial t}\right)_{x_o,y_o,z_o} = 0, \left(\frac{\partial v}{\partial t}\right)_{x_o,y_o,z_o} = 0, \left(\frac{\partial w}{\partial t}\right)_{x_o,y_o,z_o} = 0$$

$$\left(\frac{\partial p}{\partial t}\right)_{x_o,y_o,z_o} = 0, \left(\frac{\partial \rho}{\partial t}\right)_{x_o,y_o,z_o} = 0, etc.$$

Where $(x_o, y_o, z_o)$is a fixed pointed in a fluid field where these variables are being measured w.r.t. time.

(ii) **Unsteady Flow:** It is the type of flow in which the velocity; pressure or density at a point change w.r.t. time.

Mathematically, we have:

$$\left(\frac{\partial u}{\partial t}\right)_{x_o,y_o,z_o} \neq 0, \left(\frac{\partial v}{\partial t}\right)_{x_o,y_o,z_o} \neq 0, \left(\frac{\partial w}{\partial t}\right)_{x_o,y_o,z_o} \neq 0.$$

$$\left(\frac{\partial p}{\partial t}\right)_{x_o,y_o,z_o} \neq 0, \left(\frac{\partial \rho}{\partial t}\right)_{x_o,y_o,z_o} \neq 0, etc.$$

(iii) **Uniform Flow:** the type of flow, in which the velocity of fluid at any given time does not change with respect to space, is called uniform flow.

Mathematically, we have: $\left(\frac{\partial u}{\partial t}\right)_{t=constant} = O$

Where, d_v= change in velocity, and

d_s= displacement in any direction.

Example, is a flow through a straight prismatic conduct (i.e. flow through straight pipe of constant diameter)

(iv) **Non-Uniform Flow:** It is the type of flow in which the velocity at any given time changes with respect to space.

Mathematically**,** $\left(\frac{\partial v}{\partial s}\right)_{t=constant} \neq O.$

Examples, (i) Flow through a non-prismatic conduct,

(i) Flow around a uniform diameter pipe-bend or a canal bend.

(v) **One Dimensional Flow:** It is that type of flow in which the flow parameter such as velocity is a function of time and one space co-ordinate only.

Mathematically, U= f(x), v = o and w = o

Where u, v, and w are velocity components, in x, y and z direction respectively.

Example is a flow in a pipe where average flow parameters are considered for analysis.

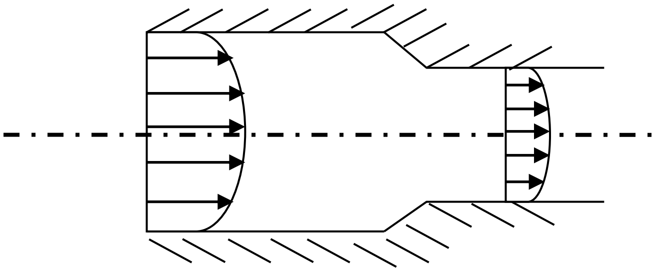
(vi) **Two Dimensional Flow**: The flow in which the velocity is a function of time and two rectangular space co-ordinates are involved is called two dimensional flow.

Mathematically, $u = f_1 (x, y, z)$

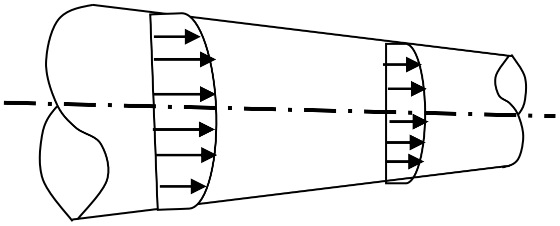
$v = f_2 (x, y, z)$

$w = f_3 (x, y, z)$

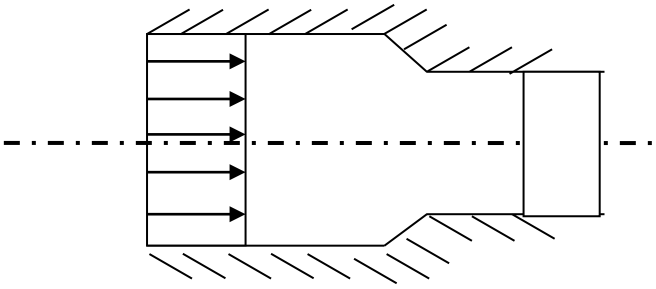
Examples: flow between parallel plates of infinite extent.



Two dimensional flow



Three dimensional flow



One dimensional flow

(vii) **Three Dimensional Flow:** The flow in which the velocity is a function of time and three mutually perpendicular directions.

Examples: (i) Flow in a converging or diverging pipe or channel.

(ii) Flow in a prismatic open channel in which the width and the water depth are of the same order of magnitude

(viii) **Rotational Flow:** This occurs when the fluid particles while moving the direction of flow rotate about their mass centres.

Flow near the solid boundaries is rotational.

Example is motion of liquid in a rotating tank.

(ix) **Irrotational Flow:** A flow is said to be irrotational if the fluid particles while moving in the direction of flow do not rotate about their mass centres.

Example of irrotational flow is the flow above a drain hole of a stationary tank or wash basic.

* Note: if the flow is irrotatonal as well as steady, it is known as potential flow.

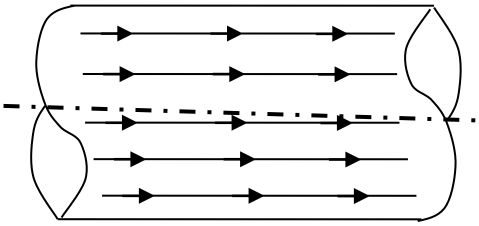
(x) **Laminar Flow:** A laminar flow, is the one in which paths taken by the individual particles do not cross one another and move along well defined paths. It is also called stream-line flow or viscous flow.

Examples: (i) Flow through a capillary tube

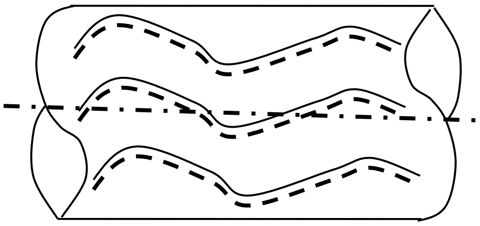
(ii) Flow of blood in veins and arteries.

(iii) Ground water flow.

(xi) **Turbulent Flow:** A turbulent flow is that in which fluid particles move in a zig-zag way. Examples: high velocity flow in a conduct of large size.



Laminar flow



Turbulent flow

(xii) **Compressible Flow:** It is that type of flow in which the density of fluid, (ρ) changes from point to point i.e the density is not constant for this flow.

Mathematically, $\rho \neq$ constant.

(xiii) **Incompressible Flow:** It is the type where the density of fluid is constant for the fluid flow: this is generally common to liquid.

Mathematically, $\rho =$ constant.