MODULE-I

BASICS OF FLUID MECHANICS

CONTENTS

- Fundamental Concepts
- Branches of Mechanics
- Properties of fluids
- Vapour pressure
- Viscosity
- Newton’s law of viscosity
- Kinematic viscosity
- surface tension
- Capillarity
- Pressure and its measurements
- Pascal s law
- Manometers

Objectives:

- To have a working knowledge of basic properties of fluids and its effects with examples.
- To understand the continuum effects.
- To study pressure measuring devices
- To understand the basic flow characteristics.
- To Calculate the forces exerted by a fluid at rest on submerged surfaces
- Understand the forces of buoyancy.
- To know the velocity changes and energy transfer in fluid flows

INTRODUCTION

Fundamental Concepts

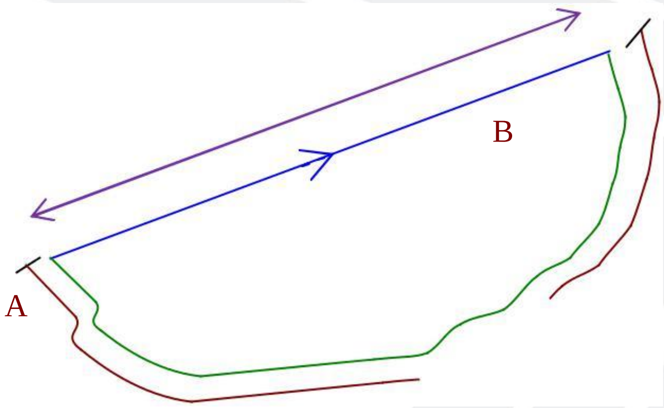
- **Mechanics:** Deals with action of forces on bodies at rest or in motion.

- **State of rest and Motion:** They are relative and depend on the frame of reference. If the position with reference to frame of reference is fixed with time, then the body is said to be in a state of rest. Otherwise, it is said to be in a state of motion.

- **Scalar and heater quantities:** Quantities which require only magnitude to represent them are called scalar quantities. Quantities which acquire magnitudes and direction to represent them are called vector quantities.

  Eg: Mass, time internal, Distance travelled etc

- **Displacement and Distance**



Velocity and Speed: Rate of displacement is called velocity and Rate and distance travelled is called Speed. Unit: m/s

Acceleration: Rate of change of velocity is called acceleration. Negative acceleration is called retardation.

Momentum: The capacity of a body to impart motion to other bodies is called momentum.
The momentum of a moving body is measured by the product of mass and velocity the moving body

Momentum = Mass x Velocity Unit: Kgm/s

Newton's first law of motion: Everybody continues to be in its state of rest or uniform motion unless compelled by an external agency.

Inertia: It is the inherent property the body to retain its state of rest or uniform motion.

Force: It is an external agency which overcomes or tends to overcome the inertia of a body.

Newton's second law of motion: The rate of change of momentum of a body is directly proportional to the magnitudes of the applied force and takes place in the direction of the applied force.

Matter: Anything which possesses mass and requires space to occupy is called matter.

States of the matter:

Matter can exist in the following states

- Solid state.
- Fluid state.

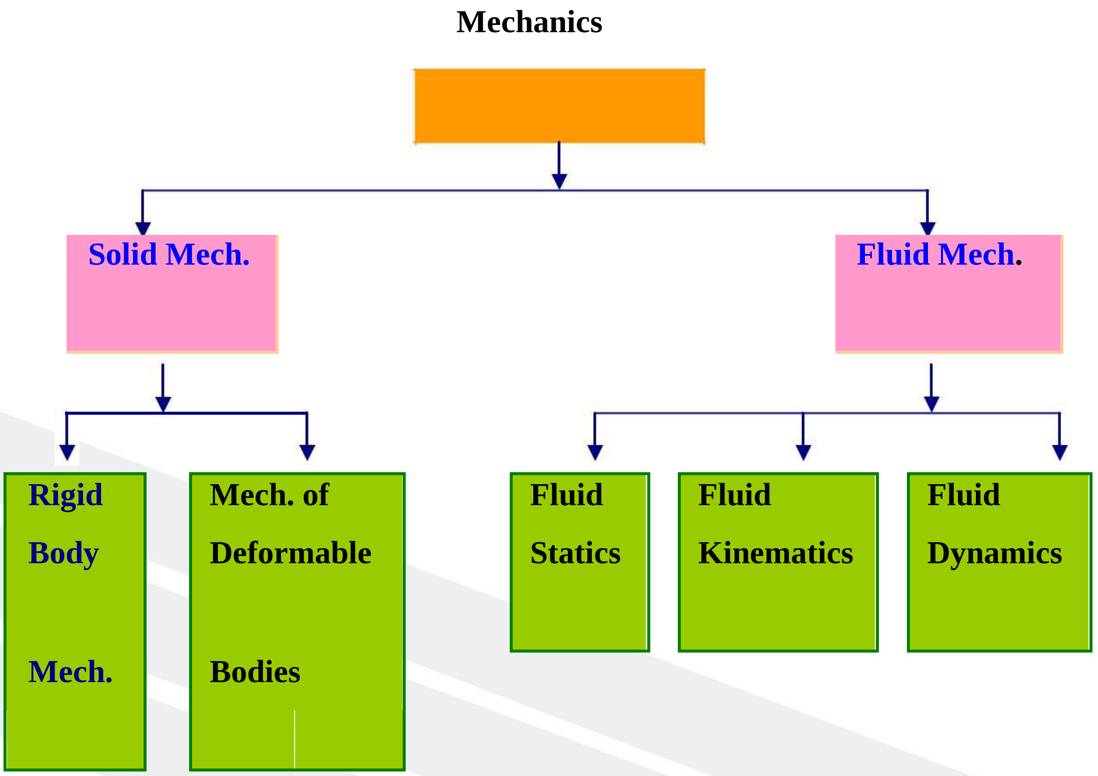
Solid state: In the case of solids intermolecular force is very large and hence molecules are not free to move. Solids exhibit definite shape and volume. Solids undergo certain amounts of deformation and then attain state of equilibrium when subjected to tensile, compressive and shear forces.

Fluid State: Liquids and gases together are called fluids. In case of liquids Intermolecular force is comparatively small. Therefore, liquids exhibit definite volume. But they assume the shape of the container. Liquids offer very little resistance against tensile force.

In the case of gases, the intermolecular force is very small. Therefore, the molecules are free to move along any direction. Therefore, gases will occupy or assume the shape as well as the volume of the container.

Gases offer little resistance against compressive forces. Therefore, gases are called compressible fluids. When subjected to shear force gases undergo continuous or prolonged angular deformation or shear strain. This property of gas is called flow of gases. Any substance which exhibits the property of flow is called fluid. Therefore, gases are also considered as fluids.

Branches of Mechanics:



- Fluid Statics deals with the action of forces on fluids at rest or in equilibrium.
- Fluid Kinematics deals with geometry of motion of fluids without considering the cause of motion.
- Fluid dynamics deals with the motion of fluids considering the cause of motion

Properties Of Fluids

Mass density or Specific mass (ρ)

Mass density or specific mass is the mass per unit volume of the fluid.

Unit: kg/m^3 or kgm^3

With the increase in temperature volume of fluid increases and hence mass density decreases.

Weight density or Specific weight (γ)

Weight density or Specific weight of a fluid is the weight per unit volume.

Unit: N/m^3 or Nm^{-3}.

Specific gravity or Relative density (S)

It is the ratio of specific weight of the fluid to the specific weight of a standard fluid.

Unit: It is a dimensionless quantity and has no unit.

Specific volume (∀): It is the volume per unit mass of the fluid.

Unit: m^3/kg

As the temperature increases volume increases and hence specific volume increases. As the pressure increases volume decreases and hence specific volume decreases.

Vapour pressure

The process by which the molecules of the liquid go out of its surface in the form of vapour is called Vaporization.

There are two ways of causing Vaporization.

a) By increasing the temperature of the liquid to its boiling point.
b) By reducing the pressure above the surface of the liquid to a value less than Vapour pressure of the liquid.

Importance of Vapour Pressure:

1. In case of Hydraulic turbines sometimes pressure goes below the vapour pressure of the liquid. This leads to vaporization and formation of bubbles of liquid. When bubbles are carried to high Pressure zone they get busted leaving partial vacuum. Surrounding liquid enters this space with very high velocity exerting large force on the part of the machinery. This phenomenon is called cavitations. Turbines are designed such that there are no cavitations.
2. In Carburetors and sprayers vapors of liquid are created by reducing the pressure below vapour pressure of the liquid. Unit of Vapour Pressure: N/m^2

Viscosity:

Viscosity is the property by virtue of which fluid offers resistance against the flow or shear deformation. In other words, it is the reluctance of the fluid to flow. Viscous force is that force of resistance offered by a layer of fluid for the motion of another layer over it.

<u>Velocity gradient or rate of shear strain:</u>

It is the difference in velocity per unit distance between any two layers. If the velocity profile is linear then velocity gradient is given by du/dy

Effect of Pressure on Viscosity of fluids:

Pressure has very little or no effect on the viscosity of fluids.

Effect of Temperature on Viscosity of fluids:

Effect of temperature on viscosity of liquids:

Viscosity of liquids is due to cohesive force between the molecules of adjacent layers.

As the temperature increases cohesive force decreases and hence viscosity decreases.

Effect of temperature on viscosity of gases*:*

Viscosity of gases is due to molecular activity between adjacent layers.

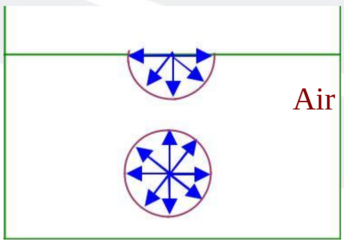
As the temperature increases molecular activity increases and hence viscosity increases.

Kinematic Viscosity:

It is the ratio of dynamic viscosity of the fluid to its mass density.SI Unit of Kinematic Viscosity is m^2 / s.

NOTE: Unit of kinematics viscosity in CGS system is cm^2/s and is called stoke. If the value of KV is given in stoke, multiply it by 10^{-4} to convert it into m^2/s.

Surface Tension:



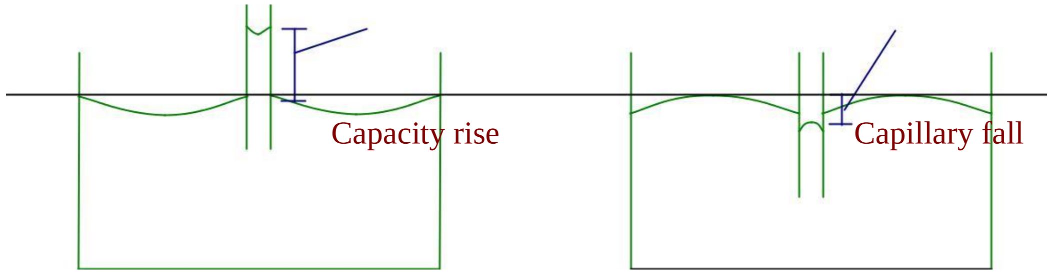
Surface tension is due to cohesion between the molecules of liquid and weak adhesion between the molecules on the exposed surface of the liquid and molecules of air

A molecule inside the surface gets attracted by equal forces from the surrounding molecules whereas a molecule on the surface gets attracted by the molecule below it. Since there are no molecules above it, it experiences an unbalanced vertically downward force. Due to this entire surface of the liquid expose of to air will have a tendency to move in ward and hence the surface will be under tension. The property of the liquid surface to offer resistance against tension is called surface tension.

Consequences of Surface tension:

- Liquid surface supports small loads.
- Formation of spherical droplets of liquid
- Formation of spherical bubbles of liquid
- Formation of cylindrical jet of liquids.

Any liquid between contact surfaces attains curved surface as shown in figure. The curved surface of the liquid is called Meniscus. If adhesion is more than cohesion, then the meniscus will be concave. If cohesion is greater than adhesion meniscus will be convex.

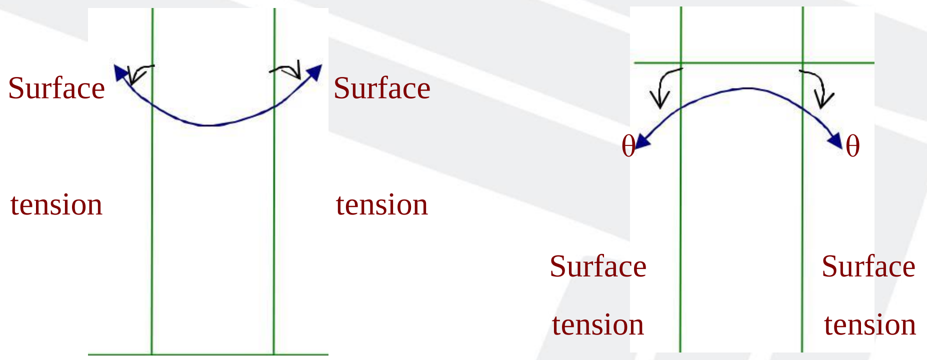


Cohesion< Adhesion — Eg: Water

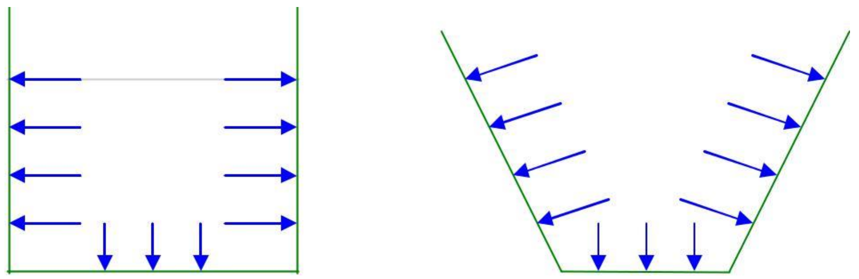
Cohesion > Adhesion — Eg: Mercury

Capillarity is the phenomena by which liquids will rise or fall in a tube of small diameter dipped in them. Capillarity is due to cohesion / adhesion and surface tension of liquids. If adhesion is more than cohesion then there will be capillary rise.

Angle of contact:



PRESSURE AND ITS MEASUREMENTS:



Fluid is a state of matter which exhibits the property of flow. When a certain mass of fluids is held in static equilibrium by confining it within solid boundaries, it exerts force along direction Perpendicular to the boundary in contact. This force is called fluid pressure.

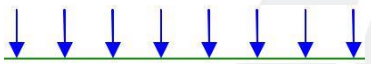
Pressure distribution:

It is the variation of pressure over the boundary in contact with the fluid. There are two types of pressure distribution.

a) Uniform Pressure distribution.

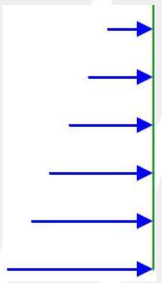
b) Non-Uniform Pressure distribution.

Uniform Pressure distribution:



If the force exerted by the fluid is same at all the points of contact boundary then the pressure distribution is said to be uniform.

Non –Uniform Pressure distribution



PASCAL 'S LAW

Statement: Intensity of pressure at a point in a static mass of fluid is same along the directions.

Proof

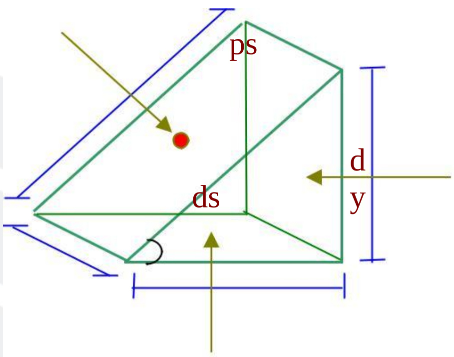


Figure shows intensity of pressure and force along different directions. The system of forces should be in equilibrium. $\therefore$ Fx = 0

$- p_x\, dy.dz + p_s\, ds\, dz \cos(90^0) = 0$
$p_s\, ds \sin\theta = p_x\, dy$

$p_s\, dy = p_x\, dy$

$p_s = p_x$

$\therefore$ Fy=0

$- p_s\, ds.dz \cos\theta + p_y\, dx\, dz = 0$
$p_y\, dx = p_s\, ds \cos\theta$

$p_y\, dx = p_s\, dx$
$p_y = p_s$

$\therefore \mathbf{p_x = p_y = p_z}$

Intensity of pressure at a point is same along all the directions.

Manometers:

Manometers are broadly classified into

a) Simple Manometers
b) Differential Manometers.

a) Simple Manometers

Simple monometers are used to measure intensity of pressure at a point. They are connected to the point at which the intensity of pressure is required. Such a point is called gauge point.

b) Differential Manometers

Differential manometers are used to measure the pressure difference between two points. They are connected to the two points between which the intensity of pressure is required.

Fluid Statics

CONTENTS

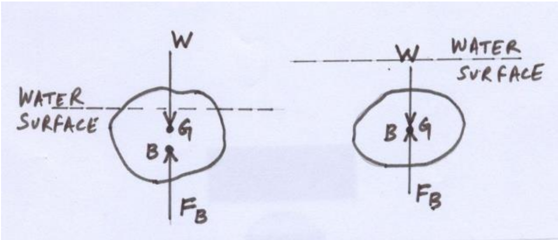
- **Definition of Buoyancy**
- **Centre of Buoyancy**
- **Archimedes principle**
- **Stability**
- **Metacentric height.**

Concept of Buoyancy

When a body is either wholly or partially immersed in a fluid, the hydrostatic lift due to the net vertical component of the hydrostatic pressure forces experienced by the body is called the “Buoyant Force” and the phenomenon is called “Buoyancy”.

The Buoyancy is an upward force exerted by the fluid on the body when the body is immersed in a fluid or floating on a fluid. This upward force is equal to the weight of the fluid displaced by the body.

Center Of Buoyancy



(a) Floating Body (b) Submerged Body

Fig. Center of Buoyancy

Center of Buoyancy is a point through which the force of buoyancy is supposed to act. As the force of buoyancy is a vertical force and is equal to the weight of the fluid displaced by the body, the Center of Buoyancy will be the center of the fluid displaced.

ARCHIMEDES PRINCIPLE

The Buoyant Force (F_B) is equal to the weight of the liquid displaced by the submerged body and acts vertically upwards through the centered of the displaced volume. Net weight of the submerged body = Actual weight – Buoyant force.

STABILITY

Stable conditions of the floating body can be achieved, under certain conditions even though (G) is above (B). When a floating body undergoes angular displacement about the horizontal position, the shape of the immersed volume changes and so, the Center of Buoyancy moves relative to the body.

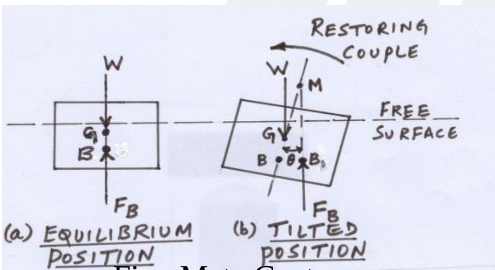


Fig. Meta Center

Fig. (a) Shows equilibrium position; (G) is above (B), F_B and W are co-linear. Fig. (b) shows the situation after the body has undergone a small angular displacement (θ) with respect to the vertical axis. (G) Remains unchanged relative to the body. (B) is the Center of Buoyancy (Centroid of the Immersed Volume) and it moves towards the right to the new position [B_1]. The new line of action of the buoyant force through [B_1] which is always vertical intersects the axis BG (old vertical line through [B] and [G]) at [M]. For small angles of (θ), point [M] is practically constant and is known as Meta Center.

Meta Center [M] is a point of intersection of the lines of action of Buoyant Force before and after heel. The distance between Center of Gravity and Meta Center (GM) is called Meta-Centric Height. The distance [BM] is known as Meta-Centric Radius.

Meta-Centric Heights

Consider a floating object as shown. It is given a small tilt angle (θ) from the initial state. Increase in the volume of displacement on the right hand side displaces the Center of Buoyancy from (B) to (B_1)

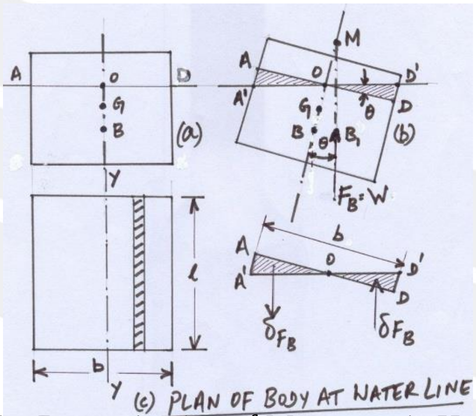


Fig. Determination of Meta-centric Height.

The shift in the center of Buoyancy results in the Restoring Couple = W (BM tan θ); Since F_B= W; W=Weight of the body= Buoyant force= F_B

This is the moment caused by the movement of the Center of Buoyancy from (B) to (B_1)
Volume of the liquid displaced by the object remains same.

Area AOA^1=Area DOD^1

Weight of the wedge AOA^1 (which emerges out) =Weight of the wedge DOD^1 (that was submerged)

Let (l) and (b) be the length and breadth of the object. . Weight of each wedge shaped portion of the liquid

W(BM) tan θ=w(I_{YY}) tan θ; Since W=wV, where V=volume of liquid displaced by the object,

wV(BM) tan θ=w I_{YY} tan θ

Therefore,BM= ($I_{YY/}$ V) and GM = BM-BG= ($I_{YY/}$ V) - BG

Where BM = [Second moment of the area of the plane of flotation about the centroidal axis perpendicular to the plane of rotation / Immersed Volume]

Out Comes

1. Identify and calculate the key fluid properties used in the analysis of fluid behavior.
2. To know the uses of manometers and its types
3. Concepts of hydrostatic law and Pascal's law

Exercise

1. Define the basic properties of fluids along with SI units
2. Define vapour pressure and cavitations
3. Establish relationship among absolute, atmospheric and gauge pressure.
4. Derive an expression for hydrostatic law

Further Reading

- **Fluid Mechanics,** John F.Douglas, Janul and M.Gasiosek and john A.Swaffield, Pearson Education Asia, 5th ed., 2006
- **Fluid Mechanics and Fluid Power Engineering**, Kumar.D.S, Kataria and Sons., 2004
- **Fluid Mechanics** -. Merle C. Potter, Elaine P.Scott. Cengage learning

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