CHEMICAL ENGINEERING DEPARTMENT

NIT SRINAGAR

SUBJECT : PROCESS FLUID MECHANICS
(3 Sem)

UNIT –I

Course No – ChBC-33

Credit 4

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INTRODUCTION TO PROCESS FLUID MECHANICS

Objective : To Present The Fundamental Insights Of Fluids And Their Static And Dynamic Behaviours And Fluid Machineries , etc.

SYLLABUS

Introduction : Units and Dimensions , Fluid Properties,Concepts of consecutive relations, Newtonian and Non –Newtonian fluids. Fluid Statics: Fluid forces and Pressure measurement . Dimensional Analysis and Similitude. Kinematics of flow, Velocity fields, Streamline , etc. Stream function , Potential function, Rotational and Irrotational flows. Laminar and Turbulent flows. Flow in pipes , Frictional losses in pipes, Equation of Continuity, Equation of motion .Euler's equation .Bernoulli's theorem and its application to blowers ,pumps, compressors and turbines .Flow past immersed body ,drag and fluidized bed. Flow measuring instruments, Pitot tube ,Orifice ,Venturimeter ,Wet gas meter, Notches, Pumps and Compressors ,Characteristics , Applications and Specifications of umps,blowers ,compressors and turbines. Navier –stokes equation.

TOPICS COVERED :

- DEFINATION OF FLUID MECHANICS
- CHARACTERISTICS OF FLUIDS / DEFINATION OF A FLUID
- BASIC LAWS GOVERNING THE FLUID MOTION
- APPLICATION OF FLUID MECHANICS
- SCOPE OF FLUID MECHANICS
- UNITS AND DIMENSIONS
- FLUID PROPERTIES

- **THERMODYNAMIC PROPERTIES OF A FLUID**
- **NEWTON'S LAW OF VISCOSITY**
- **GAS LAWS : THERMODYNAMIC RELATIONS**
- **TYPES OF FLUIDS**
- **FLUID STATICS**
- **DERIVATIONS**
- **PRESSURE MEASUREMENT**

DEFINATION OF FLUID MECHANICS

Fluid mechanics is that branch of science which deals with the behaviour of the fluids (liquids or gases) at rest as well, as in motion and the subsequent effects of the fluid upon the boundaries, which may be either solid surfaces or interfaces with other fluids. This branch of science deals with static, kinematic and dynamic aspects of fluids.

Study of fluids at rest is termed as static .The study of fluids in motion where pressure forces are called fluid kinematics and when pressure forces are also considered for fluids in motion that branch of science is called fluid dynamics.

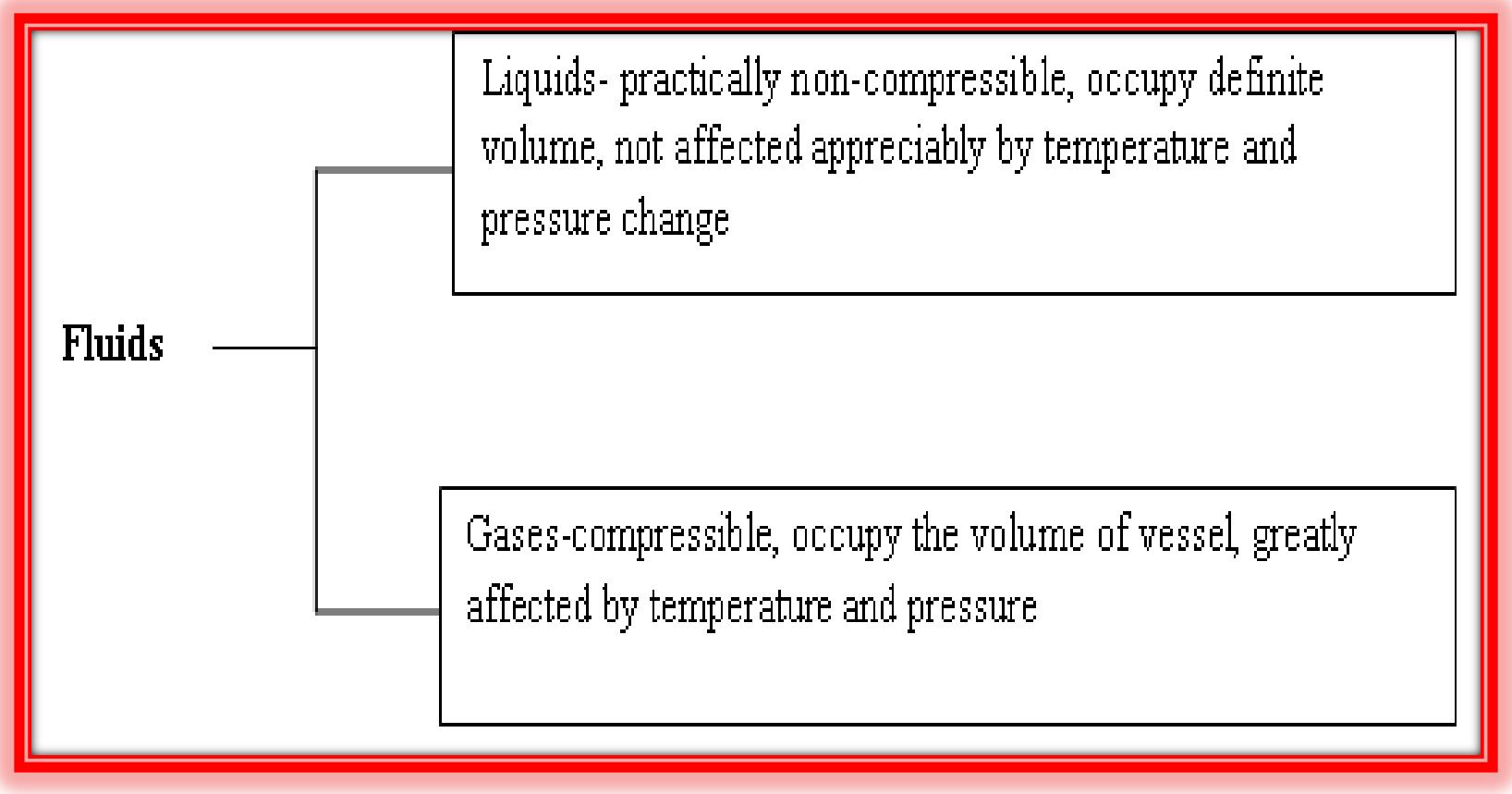
THE CHARACTERISTICS OF FLUIDS / DEFINATION OF A FLUID :

A fluid is defined as a substance that deforms continuously whilst acted upon by any force tangential to the area on which it acts. Such a force is termed a shear force, and the ratio of the shear force to the area on which it acts is known as the shear stress. Hence when a fluid is at rest neither shear forces nor shear stresses exist in it.

Fluids may be sub-divided into –

a) Liquids

b) Gases.


Fluids
Liquids- practically non-compressible, occupy definite volume, not affected appreciably by temperature and pressure change
Gases-compressible, occupy the volume of vessel, greatly affected by temperature and pressure

Liquids : Liquids , being composed of relatively close-packed molecules with strong cohesive forces, tends to retain its volume. Free-surface flows are dominated by gravitational effects. A fixed amount of a liquid has a definite volume which varies only slightly with temperature and pressure. Liquids are difficult to compress . Liquids have greater densities than gas. As a consequence, when considering forces and pressures that occur in fluid mechanics, the weight of a liquid has an important role to play.

Gas: Since gas molecules are widely spaced with negligible cohesive forces, a gas is free to expand until it encounters confining walls. A gas has no definite volume, and when left to itself without confinement, a gas forms an atmosphere which is essentially hydrostatic . A fixed amount of a gas, by itself in a closed container, will always expand until its volume equals that of the container. Only then can it be in equilibrium. Gases can be compressed easily therefore compressible in nature.

Fluids On The Basis Of Molecular Structure :

In a liquid, although the forces of attraction between molecules cause it to hold together, the molecules can move past one another and find new neighbours. Thus a force applied to an unconfined liquid causes the molecules to slip past one another until the force is removed. A gas, on the other hand, with its molecules much farther apart, offers much less resistance to compression.

Fluids as Continuum : We regard the fluid as a continuum, that is a continuous distribution of matter with no empty space. This assumption is normally justifiable because the number of molecules involved in the situation is so vast and the distances between them are so small.

Mechanics Of Fluids : The mechanics of fluids is the field of study in which the fundamental principles of general mechanics are applied to liquids and gases. These principles are those of the conservation of matter, the conservation of energy and Newton's laws of motion.

BASIC LAWS GOVERNING THE FLUID MOTION

The Basic laws which are applicable to any fluid are –

- The Conservation Of Mass
- Newtons Second Law Of Motion
- Principle Of Angular Momentum
- The First Law Of Thermodynamics
- The Second Law Of Thermodynamics.

APPLICATION OF FLUID MECHANICS

- To learn the behaviour of fluid under various conditions in order to design the system for handling of fluids in different plants. Fluid mechanics is a branch of Engineering Science, the knowledge of which is needed in the design of:
- Water supply and treatment system
- Pumps used for handling of different fluids
- Ships, submarines, aeroplanes, Automobiles
- Storage tanks (milk silo, tankers, feed tanks, balance tanks etc.)
- Piping systems for various utilities, pipefitting & valves, flow meters
- Measuring instrument
- Cleaning-In-Place (CIP) systems for optimum performance
- Heat transfer behaviour in processing equipments (such as HTST pasteurizers, spray dryers etc.)

SCOPE OF FLUID MECHANICS

- Used in the design of canal ,levee and dam systems .
- Design of pumps, compressors and piping and ducting used in the water and air conditioning systems of homes and businesses .
- Piping systems in chemical plants , aerodynamics of automobiles and sub and supersonic airplanes.
- The development of many different flow measurement devices such as gas pump meters.
- It also plays a crucial role in environmental and energy issues ,biomechanics ,sports, as an smart fluids.

UNITS AND DIMENSIONS

DIMENSION - It describes the measurable qualities or characteristics of an object such as all physical quantities ; length ,time ,mass and temperature are referred to as dimensions. All measurable quantities are divided into two groups –

a)Primary quantities- Refer to a group of dimensions from which all others can be formed as primary quantities.

b)Secondary quantities – Those quantities whose dimensions are expressible in terms of the dimensions of the primary quantities.

UNITS – A unit is an accepted standard for measuring the dimension or quality. These are the arbitrary names assigned to the primary dimensions adopted as standards for measurement . eg –primary dimension of length may be measured in units of meters, feet,yards or miles.

a) Systems of dimensions - We have three basic systems of dimensions :

a)Mass [M] , length [L] ,time [t] ,temperature [T]

b) Force [F] , length [L] , time [t] , temperature [T]

c) Force [F] ,mass [M] , length [L] ,time [t] , temperature [T]

In a) force is a secondary dimension and the constant of proportionalty in Newton ‘s second law is dimensionless. In b) mass is a secondary dimension and in c) force and mass are primary dimensions.

Primary dimensions in SI and BG (BRITISH GRAVITATIONAL) systems

Primary dimension	SI unit	BG unit	Conversion factor
Mass {M}	Kilogram (kg)	Slug	1 slug = 14.5939 kg
Length {L}	Meter (m)	Foot (ft)	1 ft = 0.3048 m
Time {T}	Second (s)	Second (s)	1 s = 1 s
Temperature {Θ}	Kelvin (K)	Rankine (°R)	1 K = 1.8°R

Secondary Dimensions in Fluid Mechanics

Secondary dimension	SI unit	BG unit	Conversion factor
Area $\{L^2\}$	m^2	ft^2	$1\ m^2 = 10.764\ ft^2$
Volume $\{L^3\}$	m^3	ft^3	$1\ m^3 = 35.315\ ft^3$
Velocity $\{LT^{-1}\}$	m/s	ft/s	1 ft/s = 0.3048 m/s
Acceleration $\{LT^{-2}\}$	m/s^2	ft/s^2	$1\ ft/s^2 = 0.3048\ m/s^2$
Pressure or stress $\{ML^{-1}T^{-2}\}$	$Pa = N/m^2$	lbf/ft^2	$1\ lbf/ft^2 = 47.88\ Pa$
Angular velocity $\{T^{-1}\}$	s^{-1}	s^{-1}	$1\ s^{-1} = 1\ s^{-1}$
Energy, heat, work $\{ML^2T^{-2}\}$	$J = N \cdot m$	$ft \cdot lbf$	$1\ ft \cdot lbf = 1.3558\ J$
Power $\{ML^2T^{-3}\}$	$W = J/s$	$ft \cdot lbf/s$	$1\ ft \cdot lbf/s = 1.3558\ W$
Density $\{ML^{-3}\}$	kg/m^3	$slugs/ft^3$	$1\ slug/ft^3 = 515.4\ kg/m^3$
Viscosity $\{ML^{-1}T^{-1}\}$	$kg/(m \cdot s)$	$slugs/(ft \cdot s)$	$1\ slug/(ft \cdot s) = 47.88\ kg/(m \cdot s)$
Specific heat $\{L^2T^{-2}\Theta^{-1}\}$	$m^2/(s^2 \cdot K)$	$ft^2/(s^2 \cdot {}^\circ R)$	$1\ m^2/(s^2 \cdot K) = 5.980\ ft^2/(s^2 \cdot {}^\circ R)$

FLUID PROPERTIES

- Viscosity
- Vapor pressure
- Compressibility and bulk modulus
- Surface Tension
- Capillarity
- Specific weight or weight density
- Specific volume
- Specific gravity
- Kinematic viscosity

THERMODYNAMIC PROPERTIES OF A FLUID

- Pressure *p*
- Density
- Temperature *T*
- Four other thermodynamic properties become important when work, heat, and energy balances are treated :
- Internal energy *e*
- Enthalpy *h*
- Entropy *s*
- Specific heats *cp* and *cv*
- In addition, friction and heat conduction effects are governed by the two so-called transport properties:
- Coefficient of viscosity
- Thermal conductivity *k*

NEWTON'S LAW OF VISCOSITY

It states that shear stress 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 .

$$\tau = \mu dv/dy$$

where τ = **Shear stress**

μ = **Viscosity of fluid**

dv/dy = shear rate, rate of strain or velocity gradient

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

TYPES OF FLUIDS

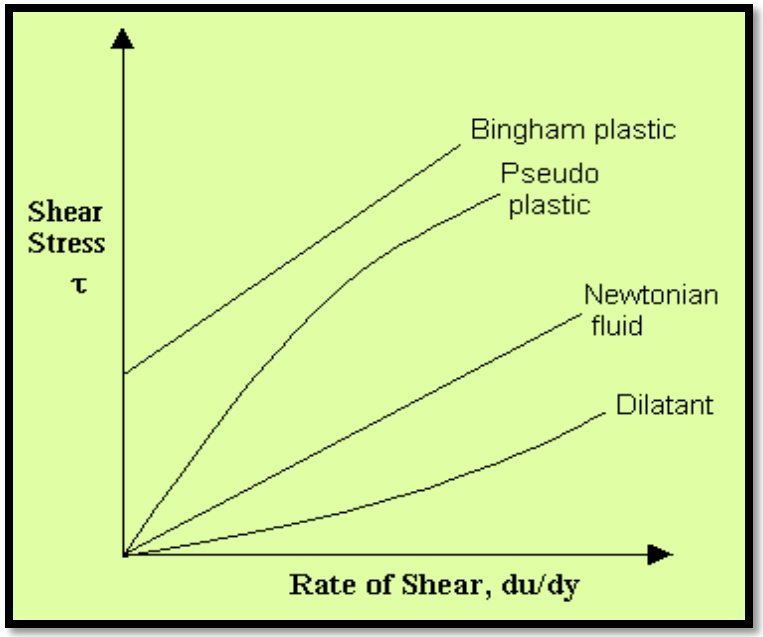
a) NEWTONIAN FLUIDS :

Fluids which obey the Newton's law of viscosity are called as Newtonian fluids.

All gases and most liquids which have simpler molecular formula and low molecular weight such as water, benzene, ethyl alcohol, CCl_4, hexane and most solutions of simple molecules are Newtonian fluids.

b) NON-NEWTONIAN FLUIDS :

Fluids which do not obey the Newton's law of viscosity are called as non-newtonian fluids. Generally non-Newtonian fluids are complex mixtures: slurries, pastes, gels, polymer solutions etc.,



GAS LAWS : THERMODYNAMIC RELATIONS :

- Dimension Of R
- Isothermal Process
- Adiabatic Process
- Universal Gas Constant

VARIOUS NON-NEWTONIAN BEHAVIORS:

I) TIME-INDEPENDENT BEHAVIORS:

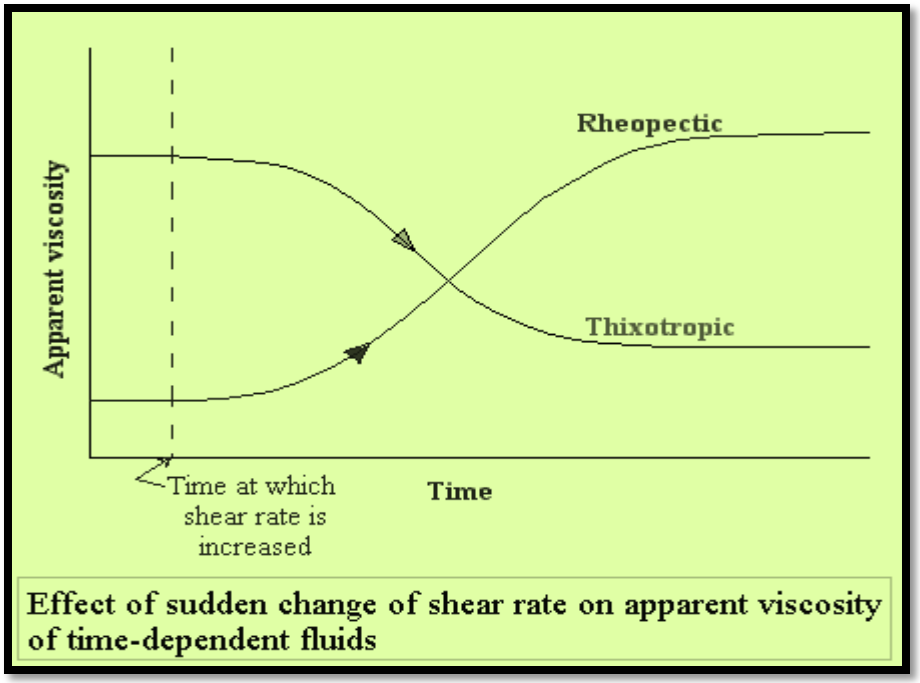
Properties are independent of time under shear.

a)Bingham-plastic: Resist a small shear stress but flow easily under larger shear stresses. e.g. tooth-paste, jellies, and some slurries.

b)Pseudo-plastic: Most non-Newtonian fluids fall into this group. Viscosity decreases with increasing velocity gradient. e.g. polymer solutions, blood. Pseudoplastic fluids are also called as Shear thinning fluids. At low shear rates(du/dy) the shear thinning fluid is more viscous than the Newtonian fluid, and at high shear rates it is less viscous.

c)Dilatant fluids: Viscosity increases with increasing velocity gradient. They are uncommon, but suspensions of starch and sand behave in this way. Dilatant fluids are also called as shear thickening fluids.

II) TIME DEPENDENT BEHAVIORS:



Effect of sudden change of shear rate on apparent viscosity of time-dependent fluids

These are those which are dependent upon duration of shear.

a)Thixotropic fluids: For which the dynamic viscosity decreases with the time for which shearing forces are applied. e.g. thixotropic jelly paints.

b)Rheopectic fluids: Dynamic viscosity increases with the time for which shearing forces are applied. e.g. gypsum suspension in water.

c) Visco-elastic fluids: Some fluids have elastic properties, which allow them to spring back when a shear force is released. e.g. egg white.

FLUID STATICS

Fluid statics : It is the study of a fluid at rest .It includes situations where fluids are either actually at rest or undergo uniform acceleration in a container or rotate as a solid mass. There is no shear force present as the fluid particles do not move with respect to one another.

A fluid element or mass is essentially acted upon by two types of forces :

a) Body forces : Such forces on fluid elements are caused by agencies like gravitational ,electric and magnetic fields. Magnitude of these forces is proportional to the mass of the fluid.

b) Surface forces : These represent the action of the surrounding fluid on the element under consideration through direct contact. These forces are due to surface stresses like pressure and shear.

DERIVATIONS TO STUDY

- To Calculate Fluid pressure at a point
- Pascal's law for pressure at a point in fluid
- Variation of pressure with elevation
- Pressure variation in a fluid at rest (Hydrostatic law)
- Absolute ,Gauge ,Vacuum Pressure Calculation .

PRESSURE MEASUREMENT

Fluid Pressure :

In a stationary fluid the pressure is exerted equally in all directions and is referred to as the static pressure. In a moving fluid, the static pressure is exerted on any plane parallel to the direction of motion.

When the static pressure in a moving fluid is to be determined, the measuring surface must be parallel to the direction of flow so that no kinetic energy is converted into pressure energy at the surface. If the fluid is flowing in a circular pipe the measuring surface must be perpendicular to the radial direction at any point.

The pressure of a fluid is measured by following devices-

- **Manometers**
- **Mechanical gauges**

MANOMETERS

Devices used for measuring a pressure at a point in a fluid by balancing the column of the fluid by the same or another column of the fluid. It is a somewhat more complicated device for measuring fluid pressure consists of a bent tube containing one or more liquid of different specific gravities. In using a manometer, generally a known pressure (which may be atmospheric) is applied to one end of the manometer tube and the unknown pressure to be determined is applied to the other end.

In some cases, however, the difference between pressure at ends of the manometer tube is desired rather than the actual pressure at the either end. A manometer to determine this differential pressure is known as *differential pressure manometer*.

These are divided into :

- Simple
- Differential

SIMPLE MANOMETER

These are of following types :

a) Piezometer

b) U tube type manometer- for gauge and vacuum pressure

c) Single column manometer –vertical and inclined

DIFFERENTIAL MANOMETER

These are of following types :

a)U tube type differential manometer

b) Inverted u tube type differential manometer

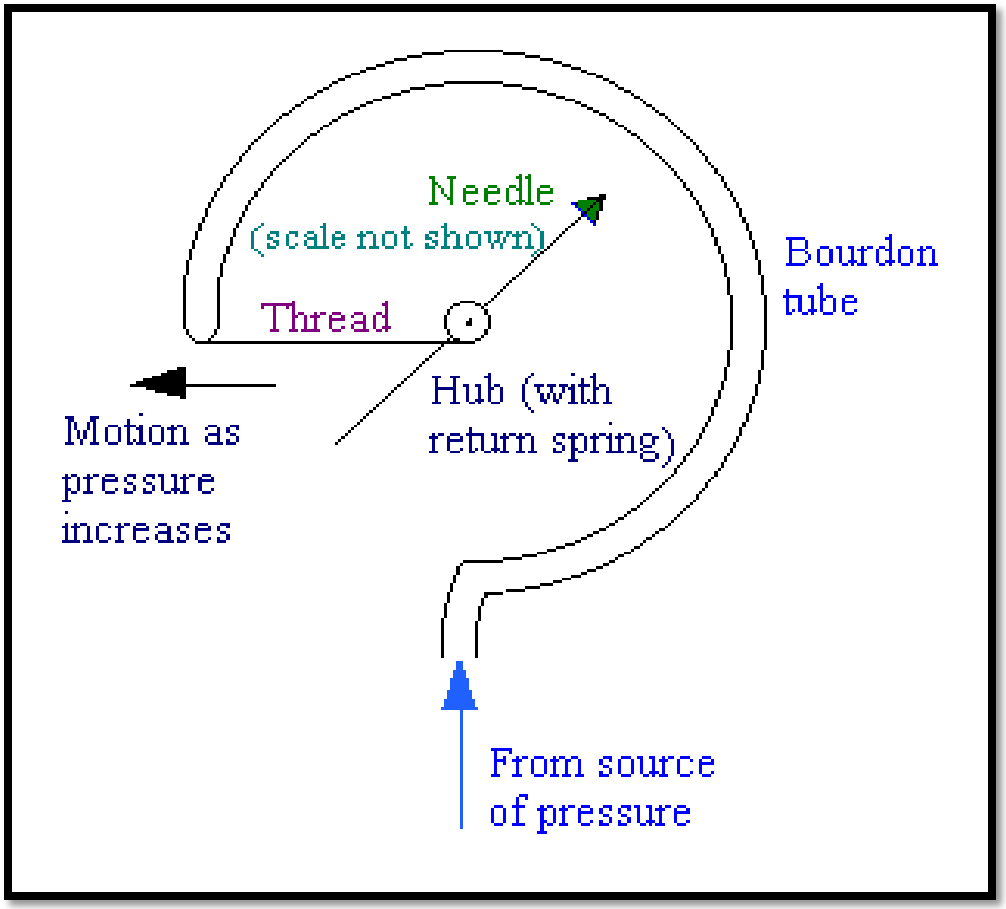
MECHANICAL GAUGES

Devices used for measuring the pressure of the fluid column by the spring or dead weight . Commonly used are :

- **Diaphragm Pressure Gauge**
- **Bourdon Tube Pressure Gauge**
- **Dead Weight Pressure Gauge**
- **Bellows Pressure Gauge**

PRESSURE GAUGES

Eg. Bourdon Gauge:



The pressure to be measured is applied to a curved tube, oval in cross section. Pressure applied to the tube tends to cause the tube to straighten out, and the deflection of the end of the tube is communicated through a system of levers to a recording needle. This gauge is widely used for steam and compressed gases. The pressure indicated is the difference between that communicated by the system to the external (ambient) pressure, and is usually referred to as the gauge pressure.

MANOMETERS - ADVANTAGES AND LIMITATIONS

- The manometer in its various forms is an extremely useful type of pressure measuring instrument, but suffers from a number of limitations.
- While it can be adapted to measure very small pressure differences, it can not be used conveniently for large pressure differences - although it is possible to connect a number of manometers in series and to use mercury as the manometric fluid to improve the range. (limitation)
- A manometer does not have to be calibrated against any standard; the pressure difference can be calculated from first principles. (Advantage)

- Some liquids are unsuitable for use because they do not form well-defined menisci. Surface tension can also cause errors due to capillary rise; this can be avoided if the diameters of the tubes are sufficiently large - preferably not less than 15 mm diameter. (limitation)
- A major disadvantage of the manometer is its slow response, which makes it unsuitable for measuring fluctuating pressures.(limitation)
- It is essential that the pipes connecting the manometer to the pipe or vessel containing the liquid under pressure should be filled with this liquid and there should be no air bubbles in the liquid.

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THANK YOU