Density Measurement

Definition

- It is defined as the mass (m) per unit volume (v) .

  $\rho = m/v$

  The unit of density is kg/m3

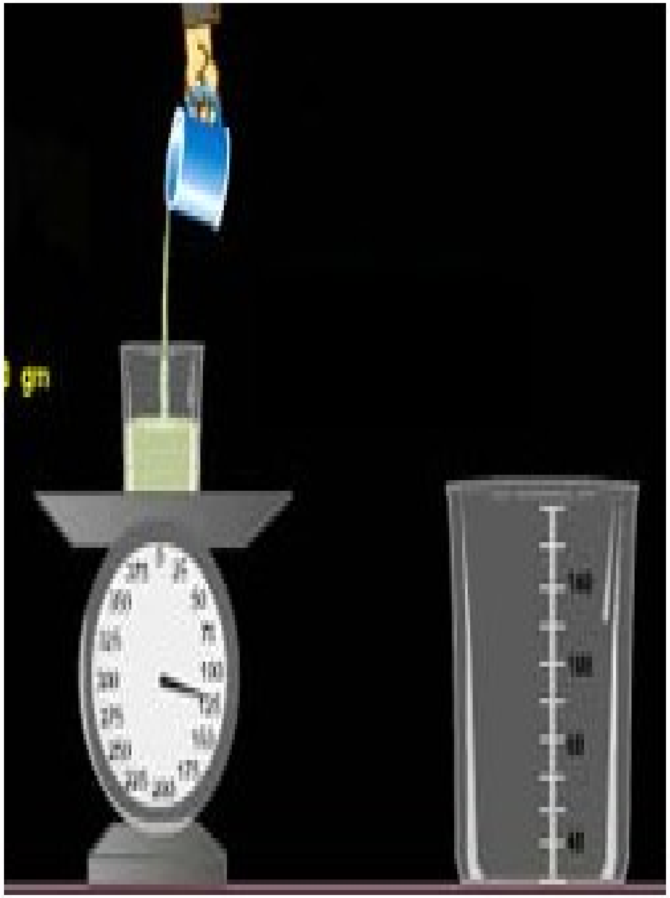

Fig 1

- Volume is measured with a graduated jar
- Mass is measured with weighing machine
- By knowing volume and mass density can be measured

Necessity of measurement of density

- Density measurement is necessary in chemical industries where the determination of concentration of a solution or mixture is based on density.
- In flow measurements while converting the volumetric flow rate into the mass flow rate, the density of a substance should be known.

Types of densitometers

- Densitometer is a device used to measure the density of a given sample
- There are three types of densitometers
- They are :
    - Displacement type densitometers
    - Fluid dynamic type densitometers
    - Capacitance type densitometers

Displacement Type Densitometer

Operation

- It mainly consists of float and chain
- The test liquid will flow through the transparent chamber from bottom to top.
- When the density of the fluid increases a buoyant force increases in the test liquid.
- The increase in the force would cause the flow to rise.

Displacement type densitometer

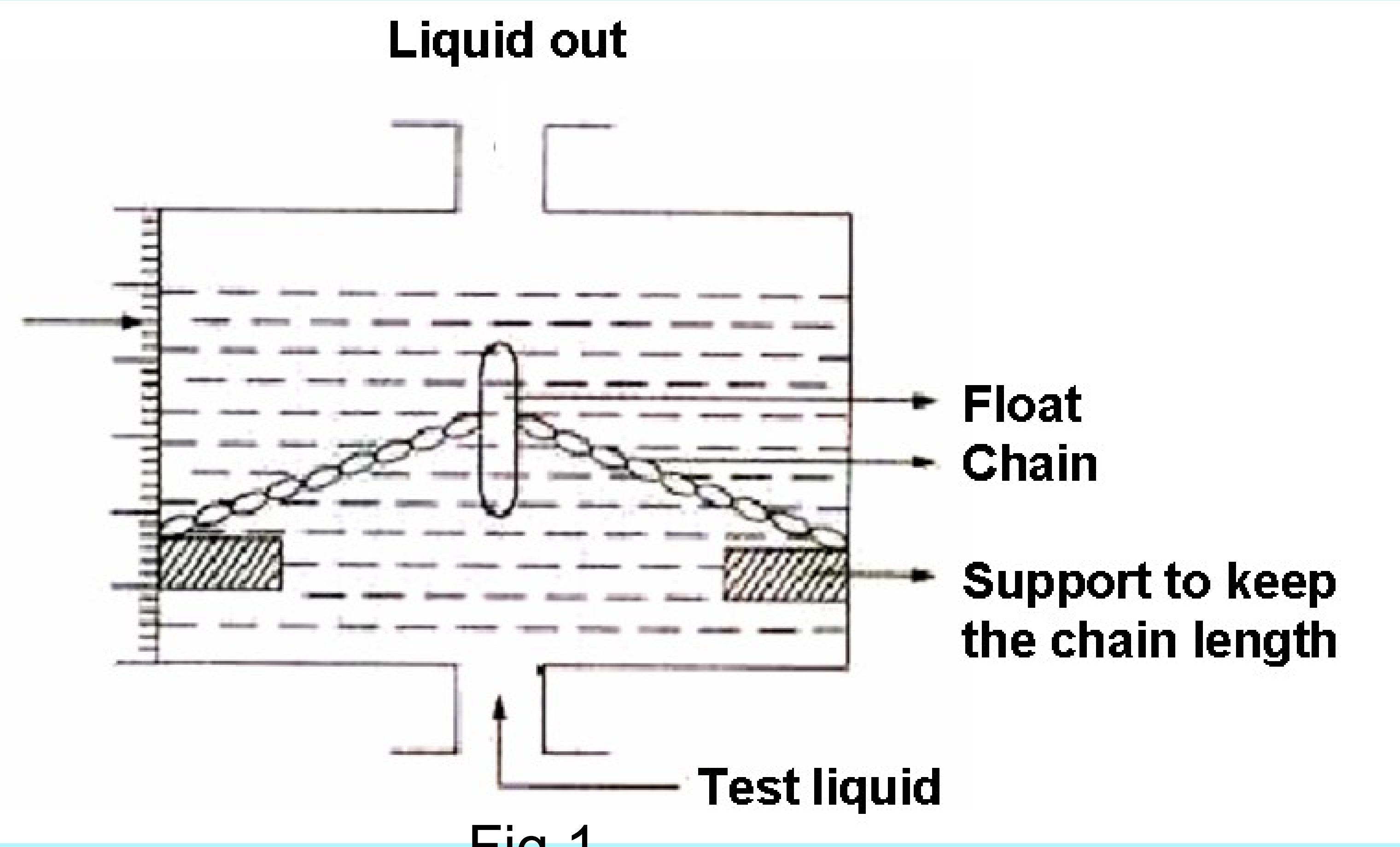

Fig 1

Operation

- As the float rises it will take up a greater portion of the chain.
- When the density of test liquid decreases the float comes down.
- A greater portion of the chain weight is taken up by the supports.

Operation

- The float moves according to the density of the test fluid.
- The position of the float can be seen through transparent chamber in which the measurement is carried out.
- The new float position is a function of the density.

Fluid Dynamic type Densitometer

Fluid dynamic type densitometer

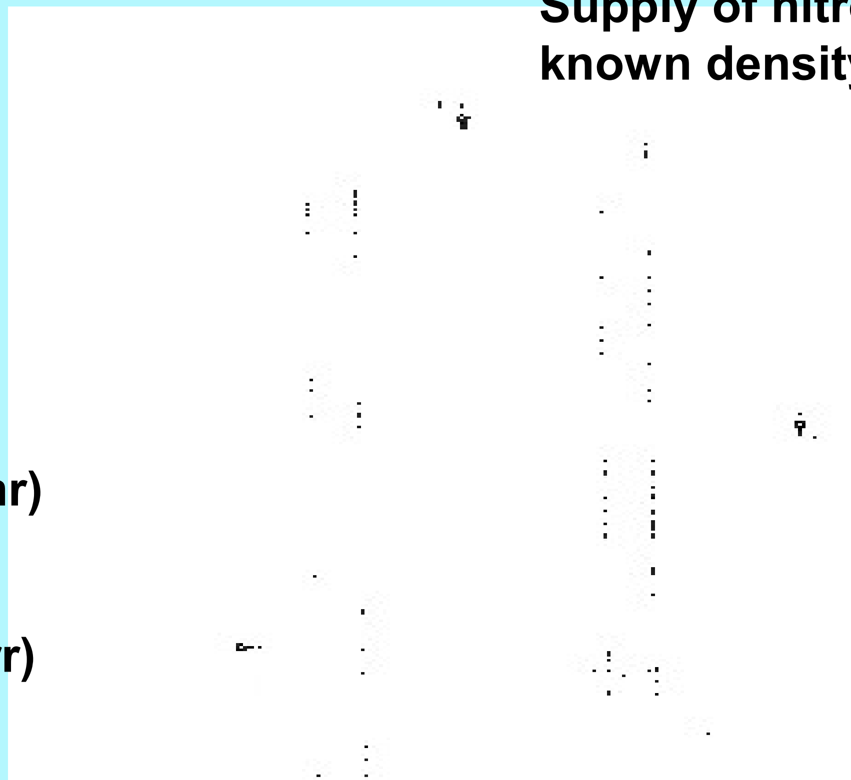

Fig 1

Operation

- It is used to measure the densities of gases and liquids.
- It mainly consists of two chambers
  - Reference chamber
  - Measuring chamber

Reference chamber:

- The reference chamber consists of
  - Supply nozzle (Nr)
  - Receiver port (Rr)
  - A small outlet port

- This chamber is filled with suitable supply of nitrogen at known density such that the reference pressure (Pr) serves as a reference value at the receiver port.

Measuring Chamber

- The measuring chamber consists of
  - Inlet
  - Outlet
  - Supply Nozzle (Nm)
  - Receiver port (Rm)
- This chamber is placed into directly adjacent to reference chamber

- The measuring fluid or gas is pumped through the inlet and this chamber also receives the nitrogen with known density
- The differential pressure between the receiving port and measuring port is a measure of the density of unknown sample

Capacitance type densitometer

Capacitance type densitometer

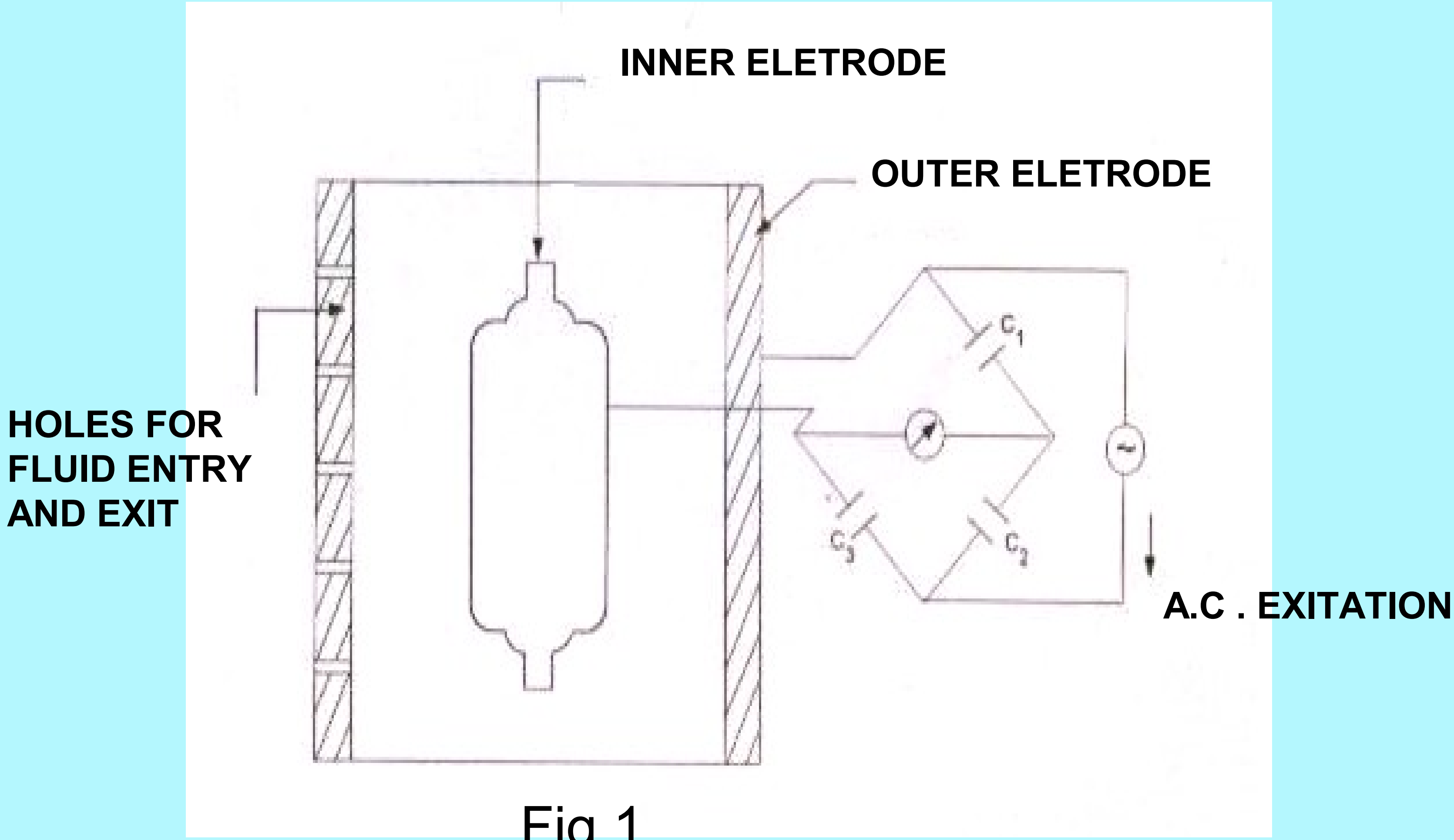

Fig 1

Capacitance type densitometer

- It mainly consists of two concentric cylinders
- The sample whose density is to be measured is placed between these two cylinders
- These cylinders acts as two parallel plates of a capacitor and the sample acts as the dielectric between the plates

- The two cylinders are connected to one arm of a bridge circuit and the outer cylinder consists of holes for fluid entry and exit

- The bridge circuit measures the capacitance between the two cylinders

- The capacitance is proportional to dielectric constant which is in turn is proportional to the density of the fluid

Density and Viscocity Measurement

Introduction

- It is a measure of the fluidity of the liquid or the gas
- Many fluids undergo continuous deformation with the application of shearing stress
- This shear force produces a flow
- If the force-flow relation is linear then the fluid is said to be Newtonian

- For non Newtonian fluids the relation is not only non-linear but changes from material to material
- When continuous deformation occurs the fluid tries to oppose this with frictional resistance
- This resistance is measured in terms of consistency

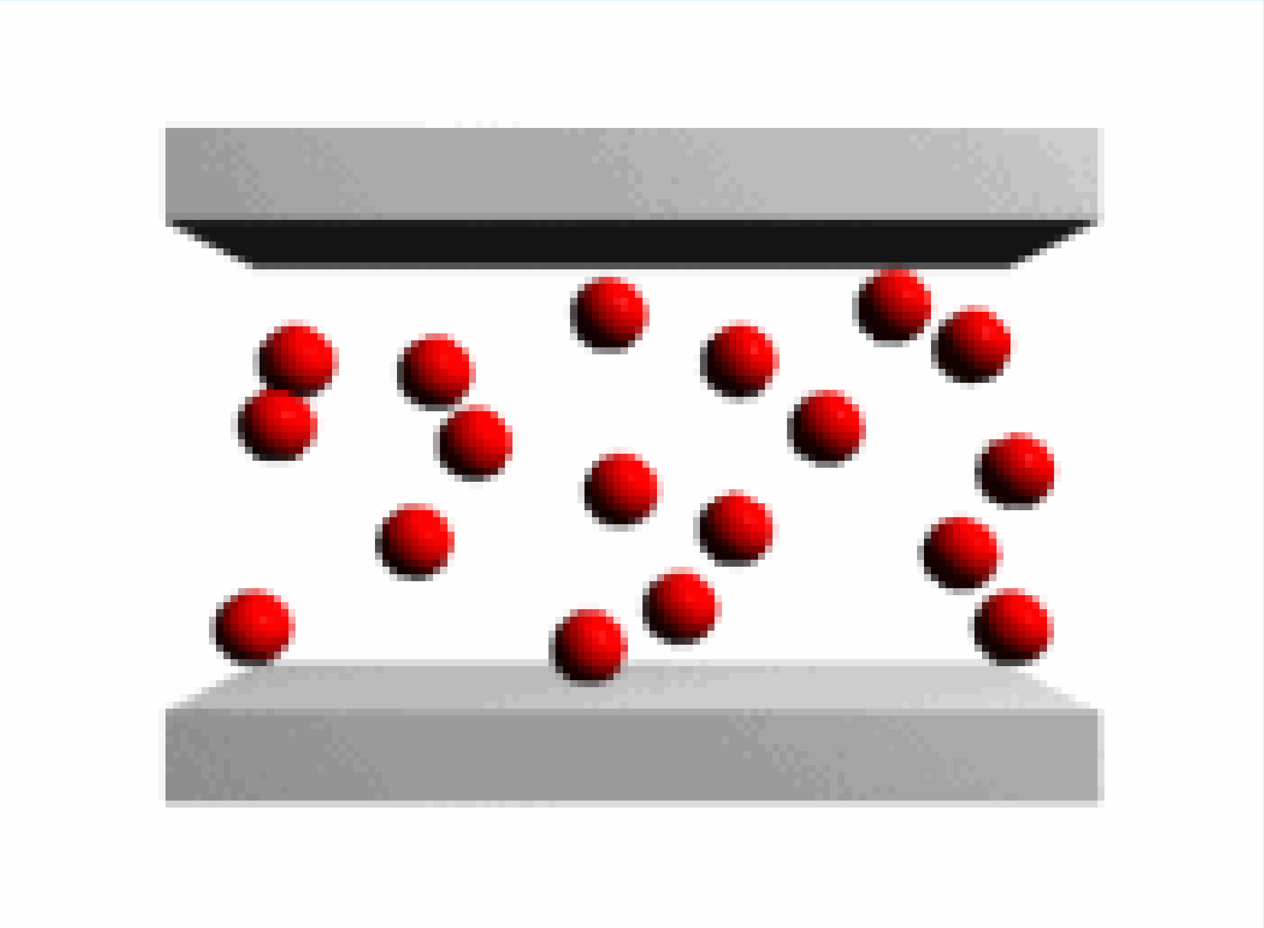

Fig.1

Definition:

- Consistency of Newtonian fluids is called" Viscosity"

- It is often formulated as the ratio of shear stress to shear rate

$$\mu = \frac{S}{(dv / dz)}$$

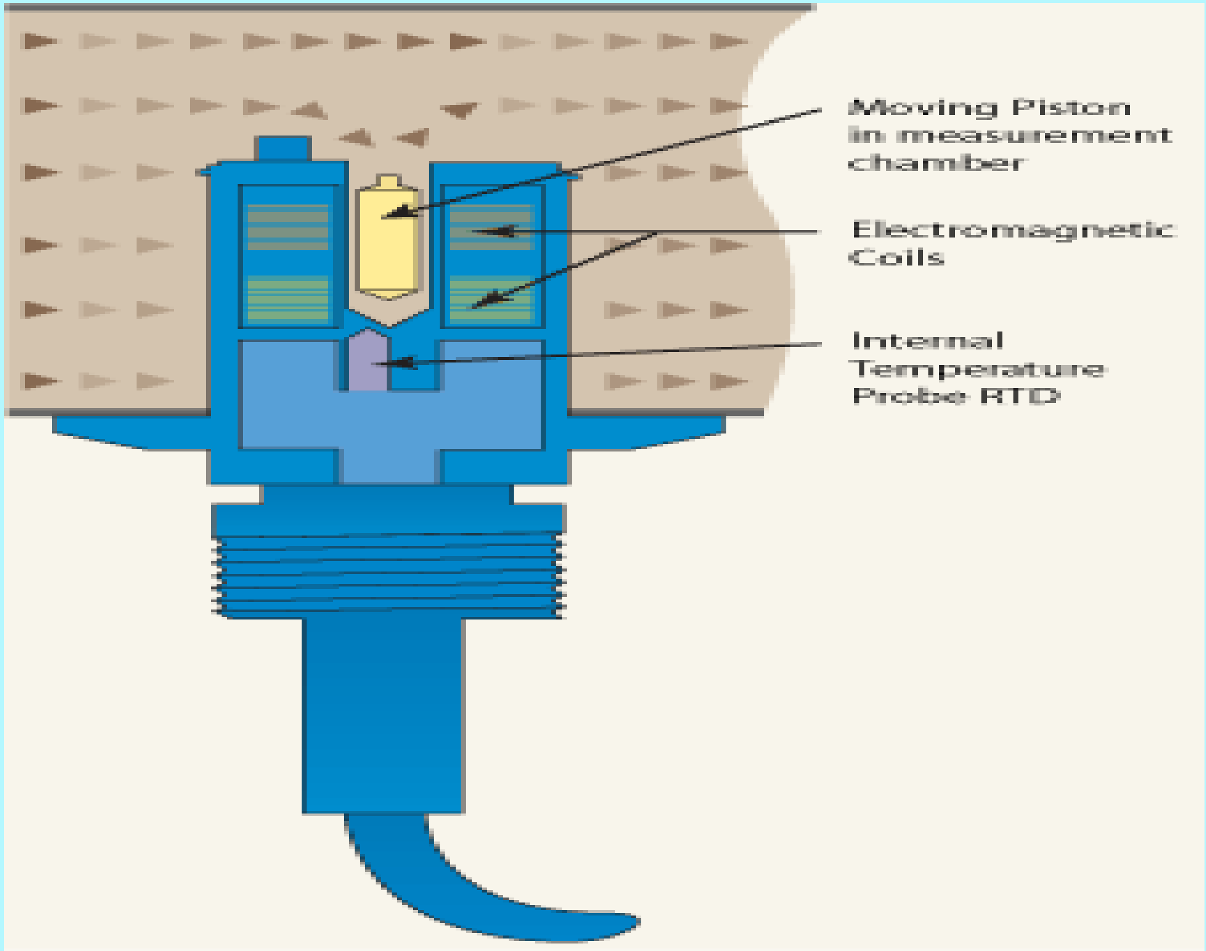
Moving Piston
in measurement
chamber
Electromagnetic
Coils
Internal
Temperature
Probe RTD

Fig 3

Where

- S is the shear stress
- dv/dz is the velocity gradient

The unit of viscosity is Newton-Sec/m2 = 10 poise

Fluidity is the reciprocal of viscosity units are

rhe = 1/poise

Kinemetic viscosity (υ)

- It is the ratio of absolute viscosity to density of the fluid in

$$\upsilon = \mu / \rho$$

cm2/sec, or stokes

Specific viscosity

- It is the ratio of absolute viscosity of the fluid to the absolute viscosity of the standard fluid at the same temperature.

$$\mu_s = \mu / \mu_{st}$$

Relative viscosity (μ_R)

- It is the ratio of the absolute viscosity of the fluid at a given temperature to the absolute viscosity of a standard fluid at 20^0c.
- Viscosity index (I_v)
- It is an emperical number that indicates the effect of changes of temperature on viscosity of the fluid

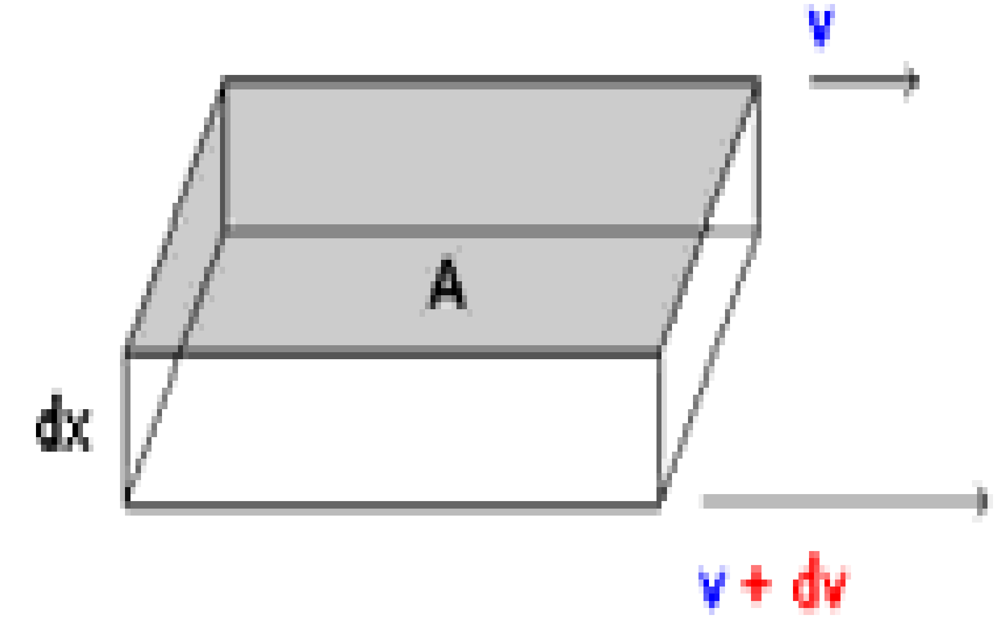

Fig 4

Necessity:

- Measurement of viscosity of lubricating oils, fuels, paints is taken into consideration before their use

Lubricating oils :-

- Lubricating should be sufficiently viscous so that they are not squeezed out from the bearings
- Further they should not be too viscous to increase the resistance to the motion between the moving parts.

Paints :-

- In paint spraying the viscosity of paint should be maintained with certain limits
- Hence the measurement of viscosity is necessary in process industries

Types of viscometer

- There are mainly three types of viscometers used in measurement viscosity.
- They are:
  - Capillary tube viscometer
  - Falling ball viscometer
  - Rotating concentric cylinder viscometer

Capillary Tube Viscometer

Capillary Tube Viscometer

Flow in

Liquid vessel

Constant head (h)

Liquid

Flow

Capillary tube

L

Overflow

Measuring jar

Fig1

Capillary Tube Viscometer

- It mainly consists of a
  - Liquid vessel
  - Capillary tube
  - Measuring jar

Flow in
Liquid vessel
Constant head (h)
Liquid
Flow
Capillary tube
Overflow
Measuring jar

- The measuring jar is used to collect the specified volume of sample liquid
- The constant pressure head or hydrostatic head of fluid causes the liquid flow through the capillary tube

- The discharge rate (Q) can be easily calculated by using measuring jar and stop watch

$$Q = \frac{\text{Volume of liquid collected in the measuring jar}}{\text{Time taken to collect the liquid in the measuring jar}}$$

If the flow is laminar, the discharge rate (Q) is given by

$$Q = \frac{\pi D4 \Delta P}{128 \mu L}$$

Where

Q = Volume of the liquid passing through the tube per second

L = Length of the capillary tube

D = Diameter of the capillary tube

μ = Coefficient of viscosity

ΔP = pressure drop across the ends of the tube

$\Delta P = \rho \, g \, h$

Where ρ = Density of the fluid

g = Acceleration due to gravity

h = constant head

$$Q = \frac{\pi D4 \rho g \, h}{128 \mu L}$$

$$\mu = \frac{\pi D4 \, \rho g \, h}{128 Q L}$$

- In the above equation the diameter of Capillary tube is raised to fourth power
- Hence it is essential to measure it as accurately as possible
- By using traveling microscope the diameter of the capillary tube can be measured accurately
- Capillary tube viscometer can be used as a flow metering device if the viscosity of the liquid is known

Advantages

- Simple in construction
- No maintenance required
- Easy to use

Disadvantage

- The main disadvantage of this viscometer is that it is not suitable for unclean fluids as the dirt or grit tends to clog the capillary tube

Applications

- They can be used as secondary standards for the calibration of other type of viscometers
- They are used in the refineries to measure the viscosity of petroleum products

Falling Ball Viscometer

Falling ball Viscometer

- Falling ball Viscometer is a device used to calculate the coefficient of viscosity (μ) of a given sample

Falling Ball Viscometer

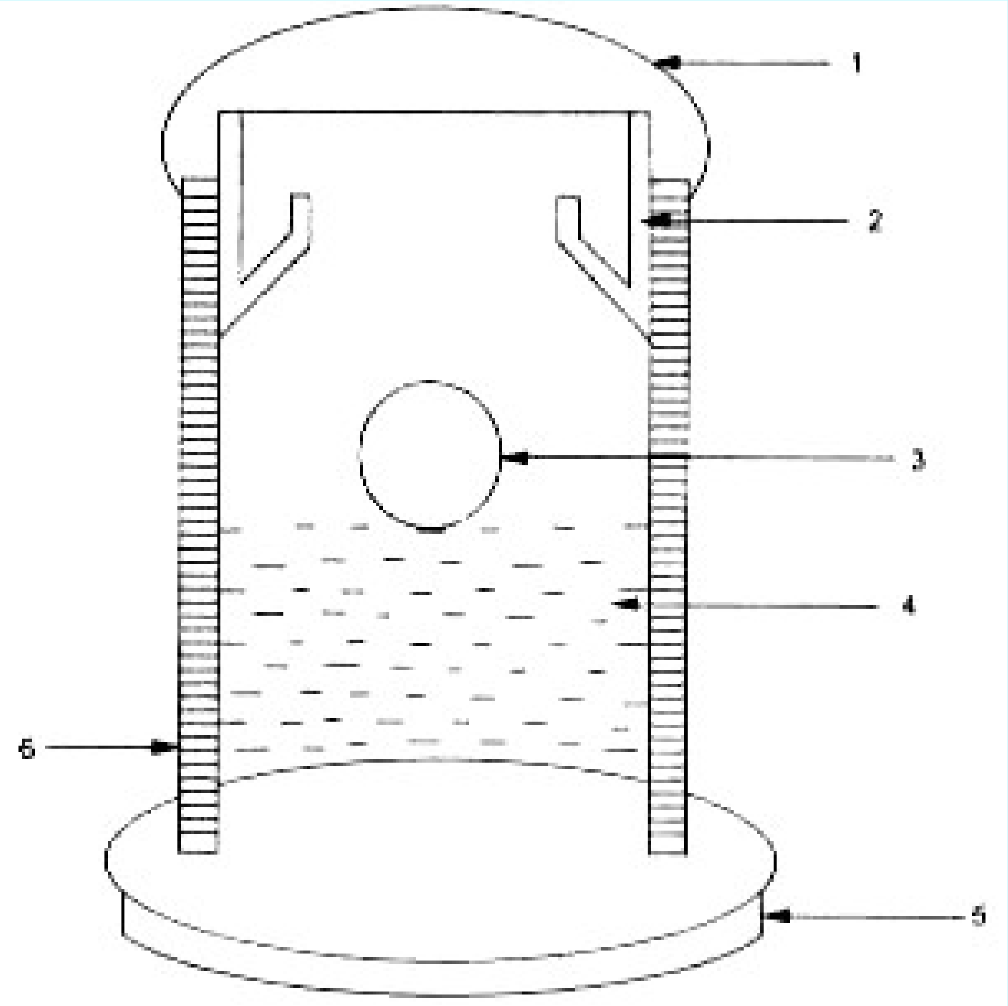

Fig 1

1. Cap
2. Capillary tube
3. Steel ball
4. Liquid whose viscosity is to be measured
5. Base
6. Marking denoting falling ball distance to be timed

Falling ball viscometer-Principle of operation

- It consists of essentially a precision glass tube of 200 mm length
- A perfectly smooth steel ball freely released from the rest into the test liquid under gravitational force
- The ball obtains a maximum terminal velocity, when upward and downward forces acting on it which are equal

- The following forces act on the ball
  - Weight of ball (w)
  - Upward force (f_l)
  - Viscous force (F)

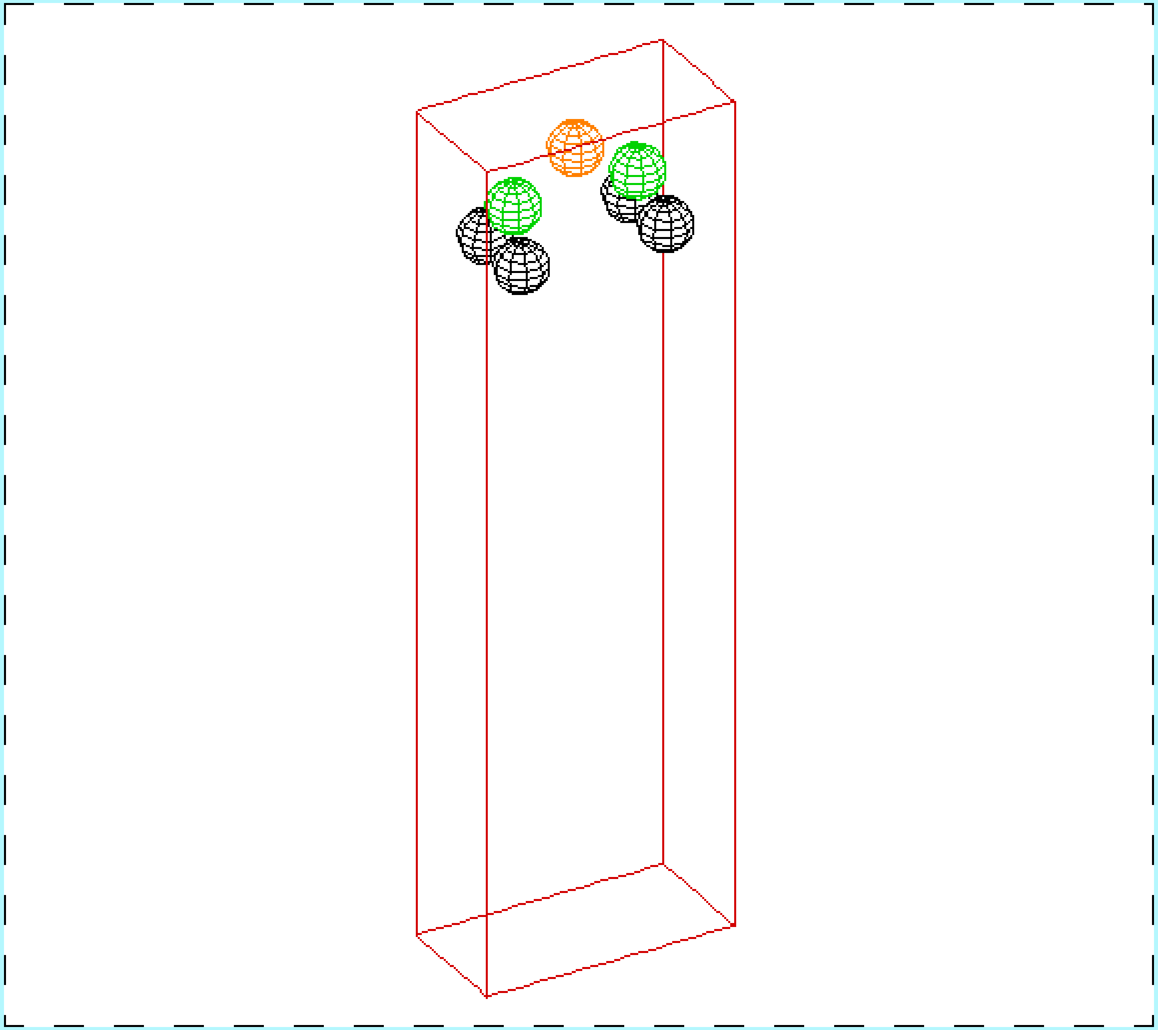

Fig 2

- Weight of the ball that acts vertically downward

  i.e. $w = 4/3\ \pi\ r3\ \rho_b\ g$

- Where r = Radius of ball

  ρ_b = Density of ball

  g = Acceleration due to gravity

Upward force (f_l) of the fluid due to buoyancy

i.e. $F_l = 4/3\ \pi\ r3\rho_l g$

Where ρ_l = Density of the liquid whose viscosity is to be measured

Viscous force (F) in upward direction

i.e. $F = 6\pi\mu r\, v$

Where μ = Coefficient of viscosity

V = Constant velocity with which the ball moves through the liquid

In equilibrium condition the upward forces are equal to downward forces

$$F_l + F = W$$

$$F = W - F_l$$

$$6\pi\mu rv = 4/3\ \pi 3\rho_b g - 4/3\ \pi\ r3\rho_l\ g$$

$$= 4/3\ \pi r3g\ (\rho_b - \rho_l)$$

$$\mu = [4/3\ \pi\ r3g\ (\rho_b - \rho_l)]\ /\ 6rv$$

$$=[2/9\ r2g(\rho_b - \rho_l)]\ /V$$

- The terminal velocity (V) can be calculated by measuring the timing of the fall of the ball and the distance between the markings on the glass tube
- V= Distance / Time
- By measuring the density of ball (ρ_b), density of liquid (ρ_l), radius of the ball (r) and knowing terminal velocity (V) the coefficient of viscosity (μ) can be calculated

Rotating Viscometer

Rotating concentric cylinder viscometer

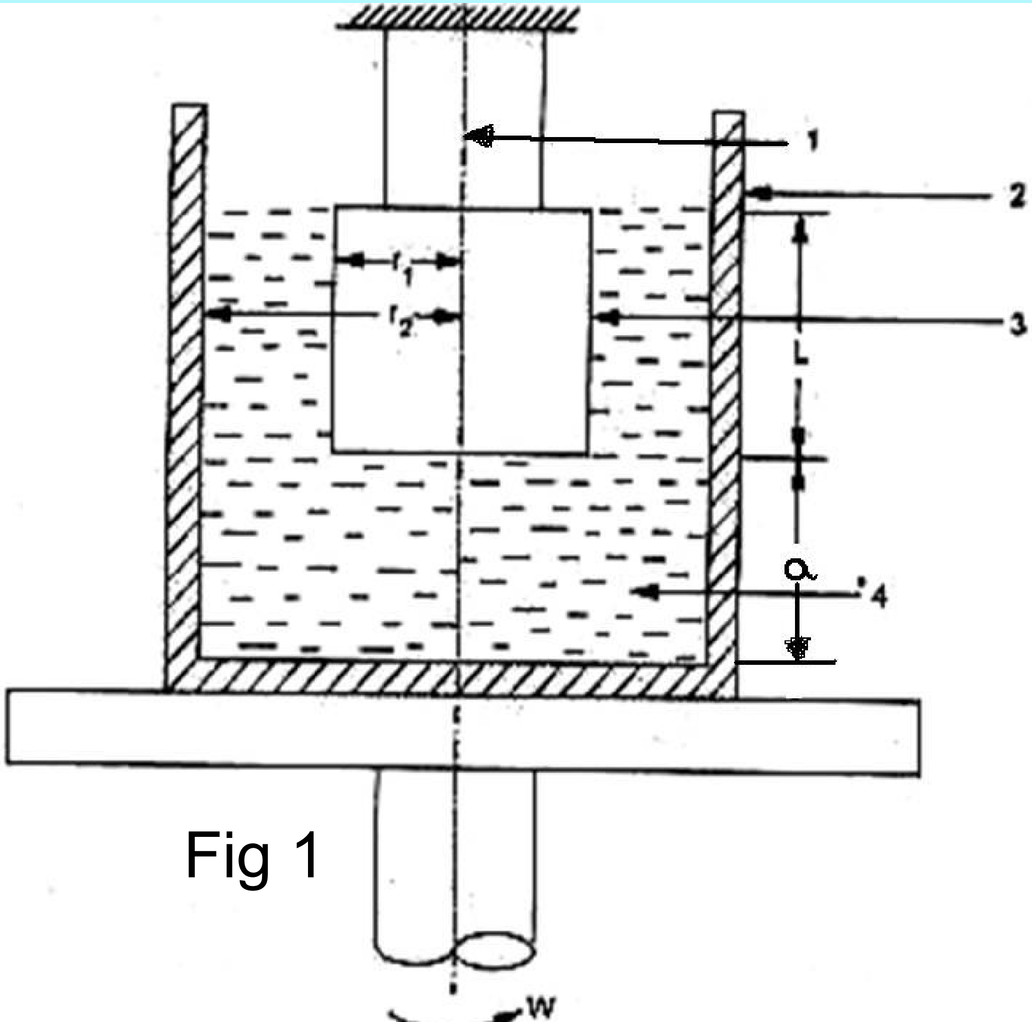

Fig 1

1. **Fixed end torsion wire**
2. **Rotating cylinder**
3. **Stationary cylinder**
4. **Liquid under test**

Rotating Concentric Cylinder Type Viscometer

- It consists of two concentric cylinders, inner cylinder and outer cylinder
- The outer cylinder is rotated at a constant angular speed and the inner cylinder is stationary
- A small annular space contains the fluid whose viscosity is to be measured
- The viscous drag due to the fluid between the cylinders produce a torque on the inner cylinder

- If the annular space $(r_2 - r_1)$ is sufficiently small in comparison to the radius of the inner cylinder, then a torque produced on vertical side of the inner cylinder
- The relation between coefficient viscosity and torque is given by

$$\mu = [T_1(r_2 - r_1)] / (2\pi w r_1^2 r_2 L)$$

$$T_1 = [\mu 2\pi w r_1^2 r_2 L] \div (r_2 - r_1)$$

- When the annular space ‘a’ is very small then additional viscous drag torque is produced on the inner cylinder due to bottom disk
- The relationship between coefficient of viscosity and the torque is given by

$$\mu = (2T_2a) \div (\Pi\ wr_1^4)$$

$$T_2 = (\mu\pi wr_1^4) \div 2a$$

- The total torque produced on inner cylinder is $T = T_1 + T_2$

$$= \frac{\mu 2\pi w r12r24}{(r2 - r1)} + \frac{\mu\pi w r14}{2a}$$

$$= \mu\pi w r12 \left(\frac{2r2L}{(r2 - r1)} + \frac{r12}{2a} \right)$$

- The coefficient of viscosity

$$\mu = \frac{T}{\pi r12w \left(\dfrac{2r2L}{r2 - r1} + \dfrac{r12}{2a} \right)}$$