Measurement and Industrial Instrumentation

ME 3225

Credit: 3.00

Measurement of Viscosity and Pressure

Presented By

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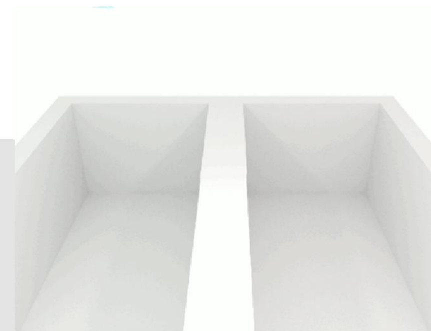


Viscosity

- Informally, viscosity is the quantity that describes a fluid's resistance to flow.
- Fluids resist the relative motion of immersed objects through them as well as to the motion of layers with differing velocities within them.
- Formally, viscosity (represented by the symbol μ "miu") is the ratio of the shearing stress ($\tau = F/A$) to the velocity gradient ($\partial u/\partial y$) in a fluid.

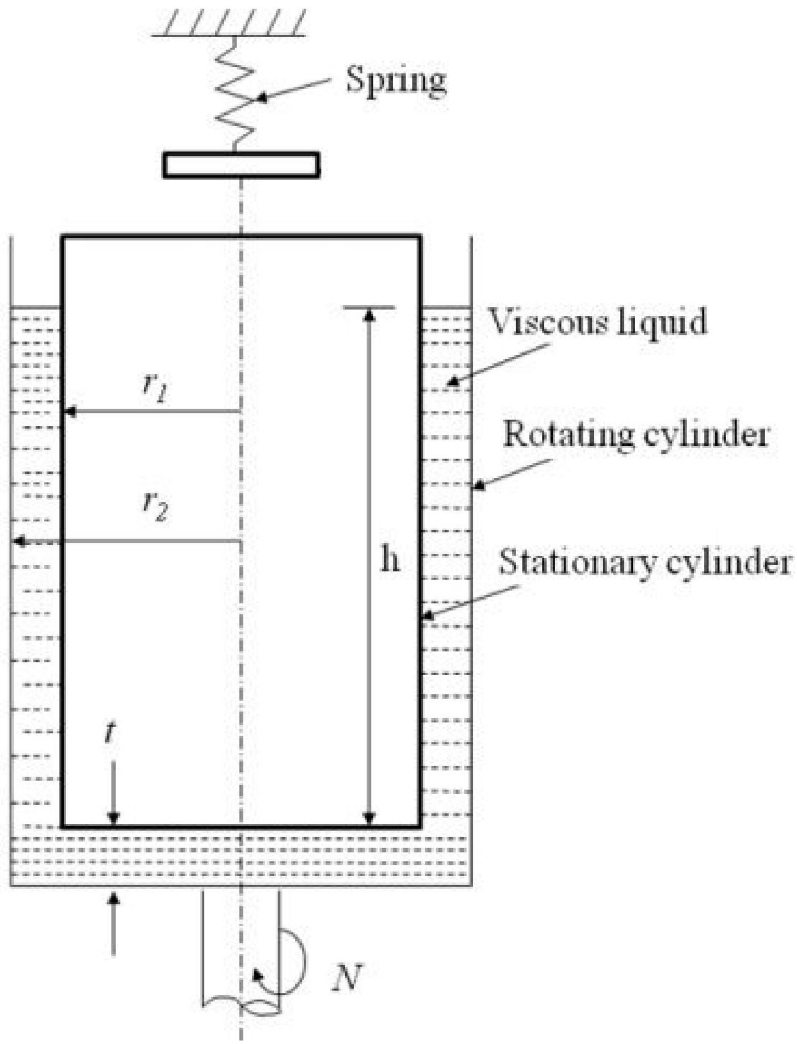
$$\tau = \mu \frac{\partial u}{\partial y}$$

- The more usual form of this relationship, called Newton's equation, states that the resulting shear of a fluid is directly proportional to the velocity gradient between the layers of fluid

Measurement of Viscosity

- The device used for measurement of viscosity is known as *viscometer* and it uses the basic laws of laminar flow.
- The principles of measurement of some commonly used viscometers are discussed here:
  - Rotating Cylinder Viscometer
  - Falling Sphere Viscometer
  - Capillary Tube Viscometer
  - Saybolt and Redwood Viscometer

Rotating Cylinder Viscometer



Rotating Cylinder Viscometer

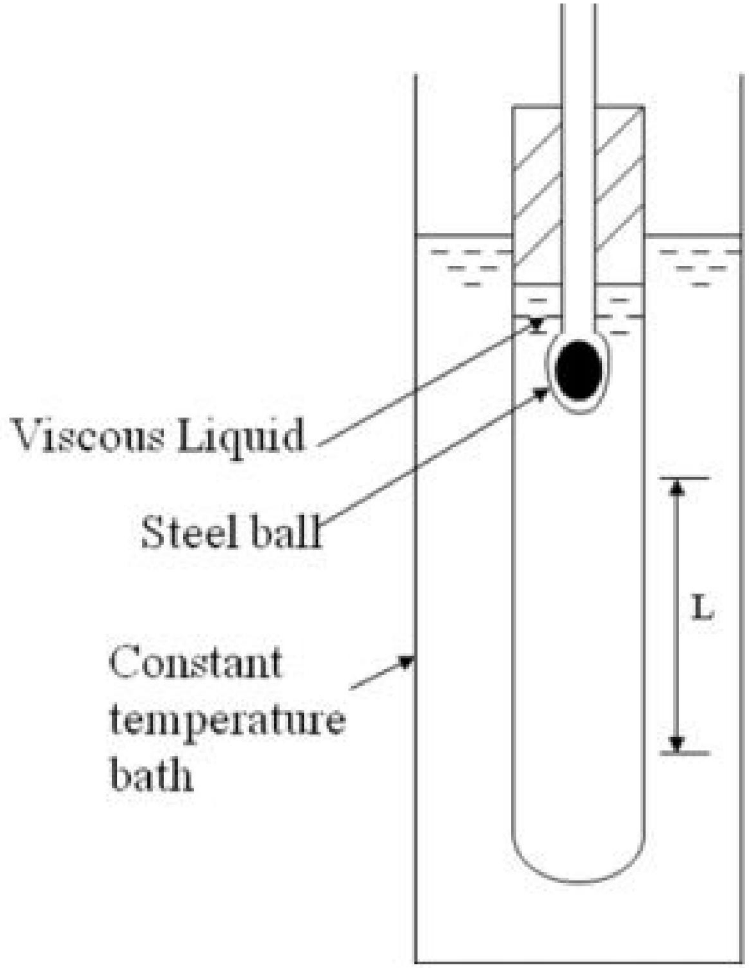
- It consists of two co-axial cylinders suspended co-axially as shown in the figure. The narrow annular space between the cylinders is filled with a liquid for which the viscosity needs to be measured.
- The outer cylinder has the provision to rotate while the inner cylinder is a fixed one and has the provision to measure the torque(T) and angular rotation.
- When the outer cylinder rotates, the torque is transmitted to the inner stationary member through the thin liquid film formed between the cylinders. Let r_1 and r_2 be the radii of inner and outer cylinders, h be the depth of immersion in the inner cylinder in the liquid and $t = r_2 - r_2$ is the annular gap between the cylinders.
- Considering N as the speed of rotation of the cylinder in rpm, one can obtain viscosity as:

$$\mu = \frac{T}{CN}$$

Here, C is a constant quantity for a given viscometer

Rotating Cylinder Viscometer

Falling Sphere Viscometer



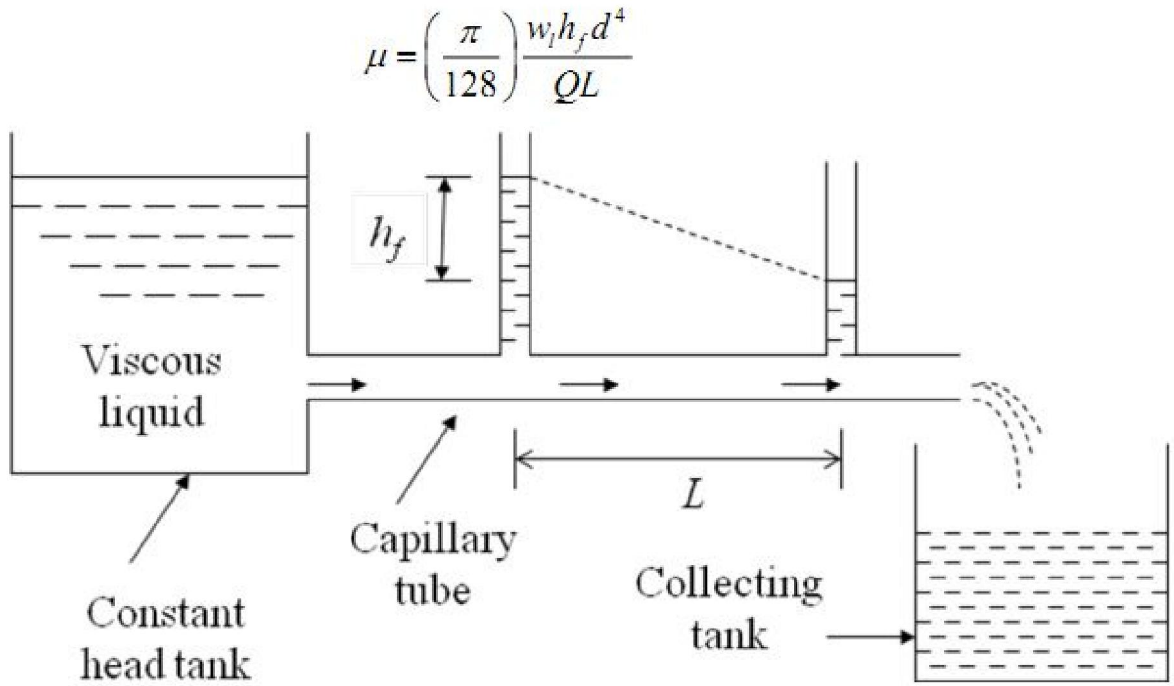
Falling Sphere Viscometer

- It consists of a long container of constant area filled with a liquid whose viscosity has to be measured. Since the viscosity depends strongly with the temperature, so this container is kept in a constant temperature bath as shown in figure.
- A perfectly smooth spherical ball is allowed to fall vertically through the liquid by virtue of its own weight (W) . The ball will accelerate inside the liquid, until the net downward force is zero i.e. the submerged weight of the ball (F_B) is equal to the resisting force (F_R) given by Stokes' law.
- After this point, the ball will move at steady velocity which is known as *terminal velocity*. If w_l and w_s are the specific weights of the liquid and the ball, respectively and the spherical ball has the diameter D that moves at constant fall velocity V in a fluid having viscosity μ then

$$\mu = \frac{D^2}{18V}(w_s - w_l) \text{ where } V = \frac{L}{t}$$

- The constant fall velocity can be calculated by measuring the time (t) taken by the ball to fall through a distance (L) .

Capillary Tube Viscometer

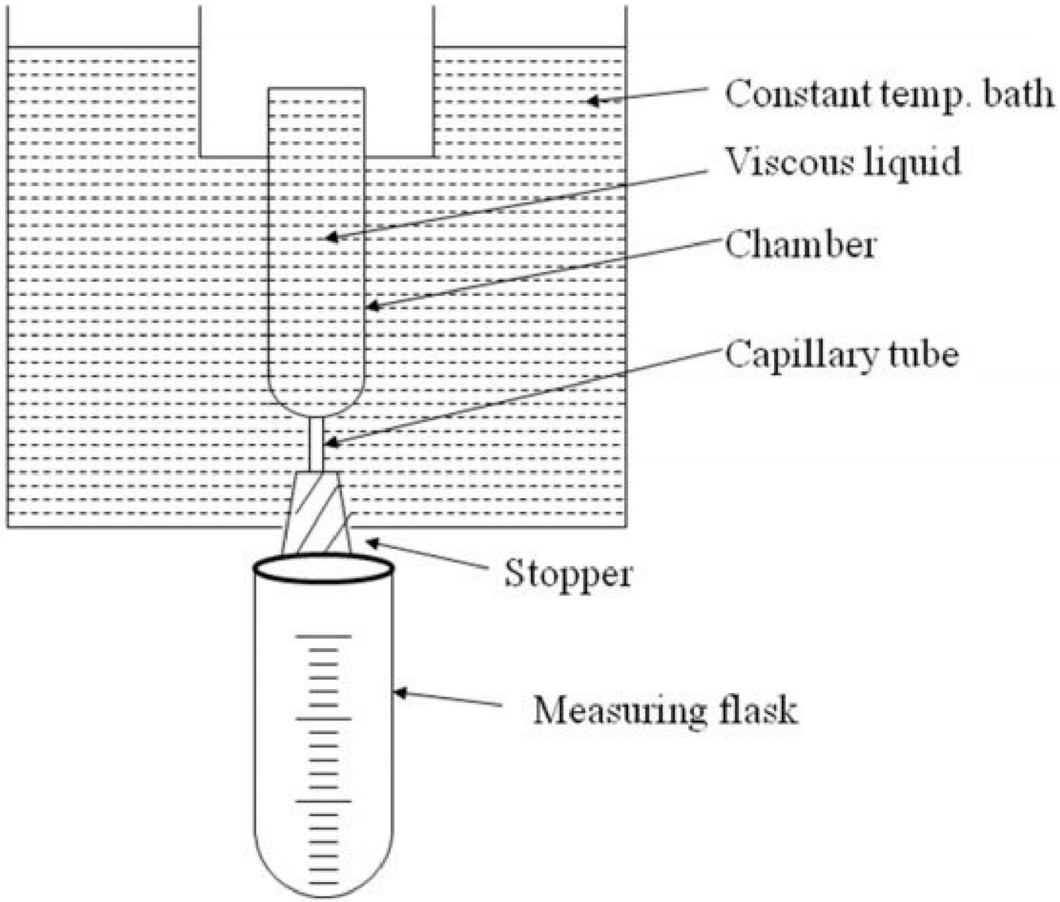


Capillary Tube Viscometer

- In capillary tube method, the viscosity of a liquid is calculated by measuring the pressure difference for a given length of the capillary tube. This type of viscometer is based on laminar flow through a circular pipe.
- It has a circular tube attached horizontally to a vessel filled with a liquid whose viscosity has to be measured. Suitable head (h_f) is provided to the liquid so that it can flow freely through the capillary tube of certain length (L) into a collection tank as shown in figure. The flow rate (Q) of the liquid having specific weight w_l can be measured through the volume flow rate in the tank.
- The Hagen-Poiseuille equation for laminar flow can be applied to calculate the viscosity (μ) of the liquid

$$\mu = \left(\frac{\pi}{128}\right)\frac{w_l h_f d^4}{QL}$$

Say-bolt Viscometer

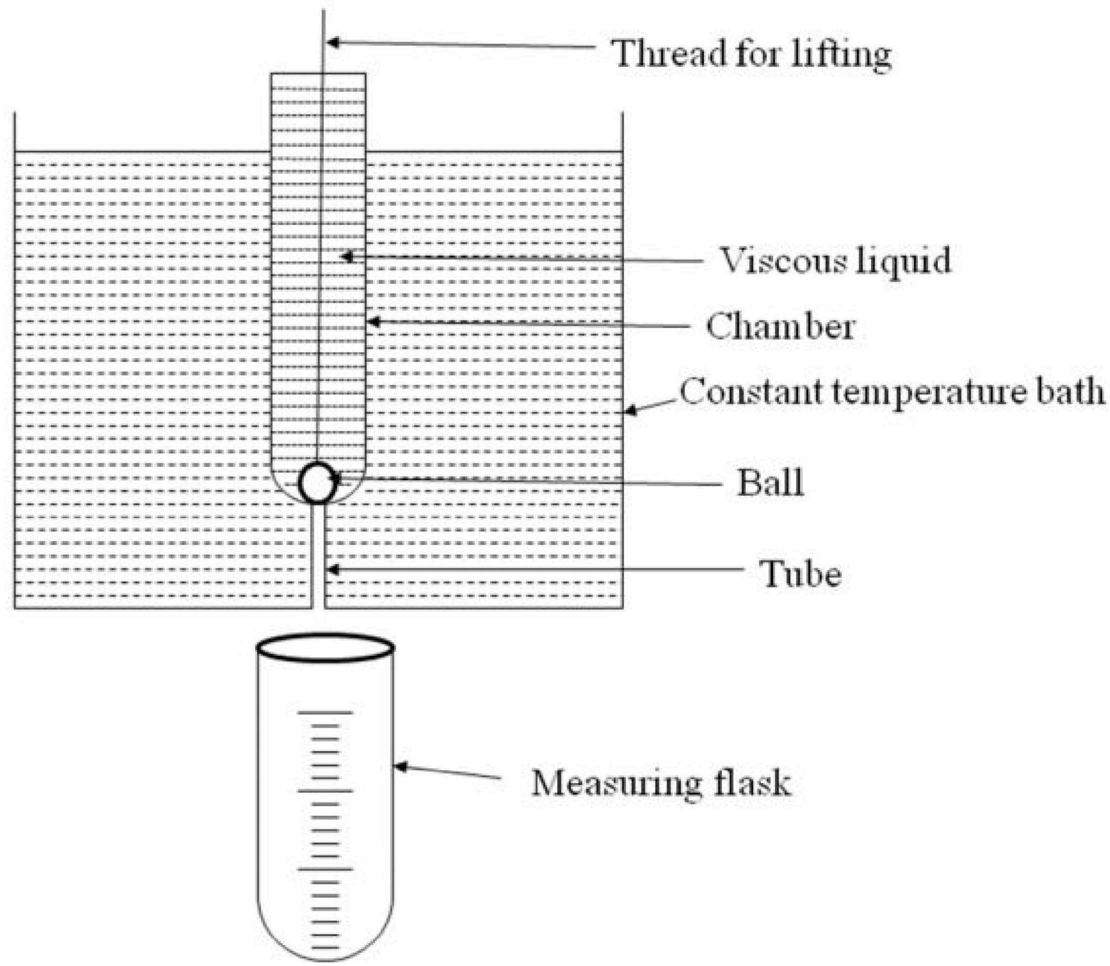


Say-bolt Viscometer

- The Say-bolt viscometer has a vertical cylindrical chamber filled with liquid whose viscosity is to be measured (Figure).
- It is surrounded by a constant temperature bath and a capillary tube (length 12mm and diameter 1.75mm) is attached vertically at the bottom of the chamber.
- For measurement of viscosity, the stopper at the bottom of the tube is removed and time for 60ml of liquid to flow is noted which is named as Say-bolt seconds.
- For calculation purpose of kinematic viscosity (ν), the simplified expression is obtained as below;

$$\nu = \frac{\mu}{\rho} = 0.002t - \frac{1.8}{t};\ \text{where, } \nu \text{ in Stokes and } t \text{ in seconds}$$

Redwood Viscometer



Redwood Viscometer

- A Redwood viscometer works on the same principle of Say-bolt viscometer.
- Here, the stopper is replaced with an orifice and Redwood seconds is defined for collection of 50ml of liquid to flow out of orifice.
- Similar expressions can be written for Redwood viscometer. In general, both the viscometers are used to compare the viscosities of different liquid.
- So, the value of viscosity of the liquid may be obtained by comparison with value of time for the liquid of known viscosity.

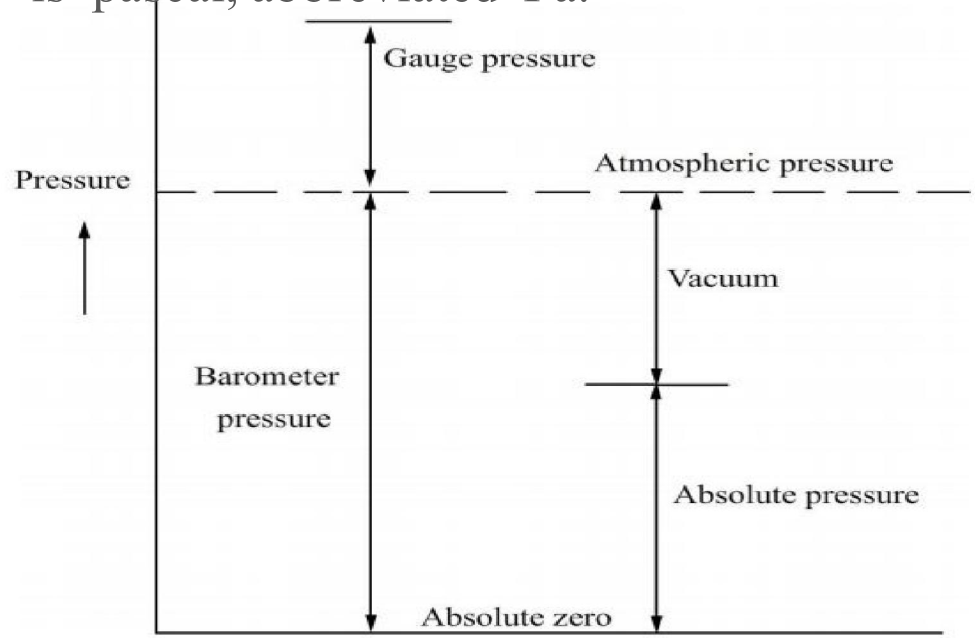
Pressure

- Pressure is defined as a ratio between a force and a unit area, perpendicular to the direction of that force, on which the force acts. Mathematically this definition is expressed as:

$$P = \frac{F}{A}$$

where p – pressure, F – normal force, A – area.

- The primary unit of pressure in the International System of Units (SI) is pascal, abbreviated Pa.



Gauge Pressure Vs Absolute Pressure

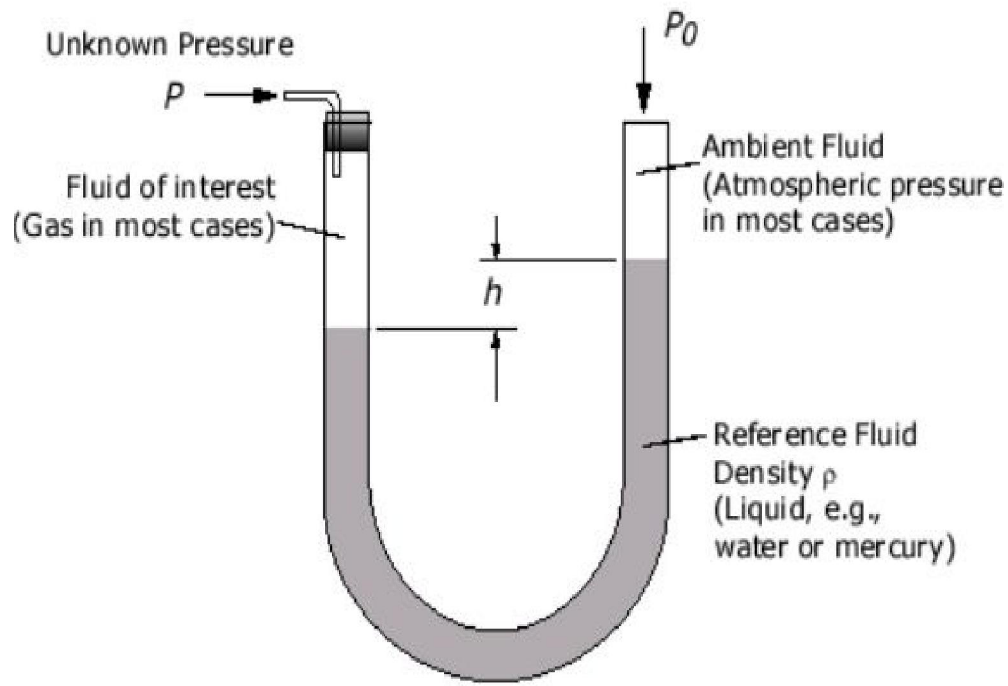
- In most cases pressure measurement devices actually measure pressure difference (either between two areas or between the measured area and reference level), not absolute pressure.
- One commonly used reference level is the standardized atmospheric pressure. Two types of standard pressure values are commonly used:
- p = 100,000 Pa – according to standard conditions for temperature and pressure (STP) as defined by International Union of Pure and Applied Chemistry (IUPAC)
- p = 101,325 Pa - according to e.g. National Institute of Standards and Technology (NIST).

Pressure Measuring Devices

- Manometer
- Bourdon tube pressure gauge
- A dead weight tester
- Diaphragm gauges
- Bellow gauges to measure gauge pressure
- Bellow gauge to measure differential pressure
- Cylindrical type pressure cell
- Bridgman pressure gauge
- McLeod vacuum gauge
- Thermal conductivity gauges
- Pirani gauge
- Ionization gauge

Manometer

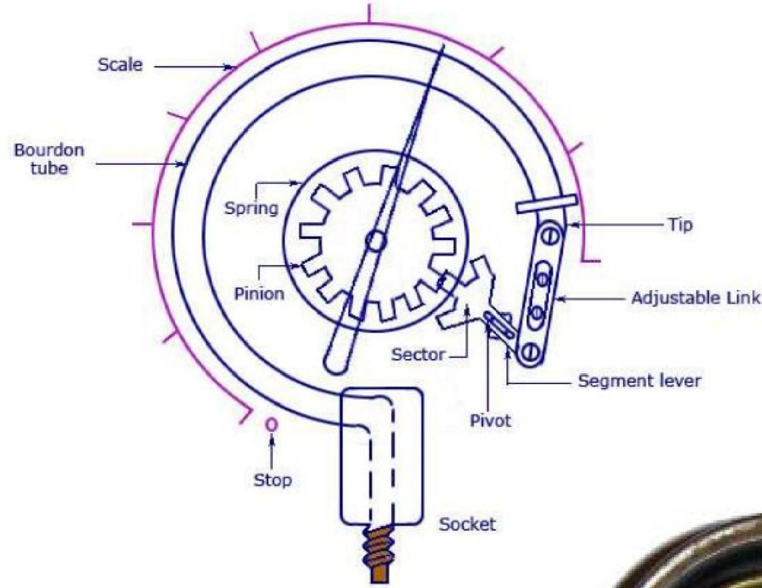
- Simple Manometers - A simple manometer is one which consists of a glass tube, whose one end is connected to a point where pressure is to be measured and the other end is open to atmosphere.
- U Tube manometer



Gage Pressure $\Delta P = P - P_0 = \rho g h$

How U Tube manometer works: Self Study

Bourdon Tube Pressure Gauge



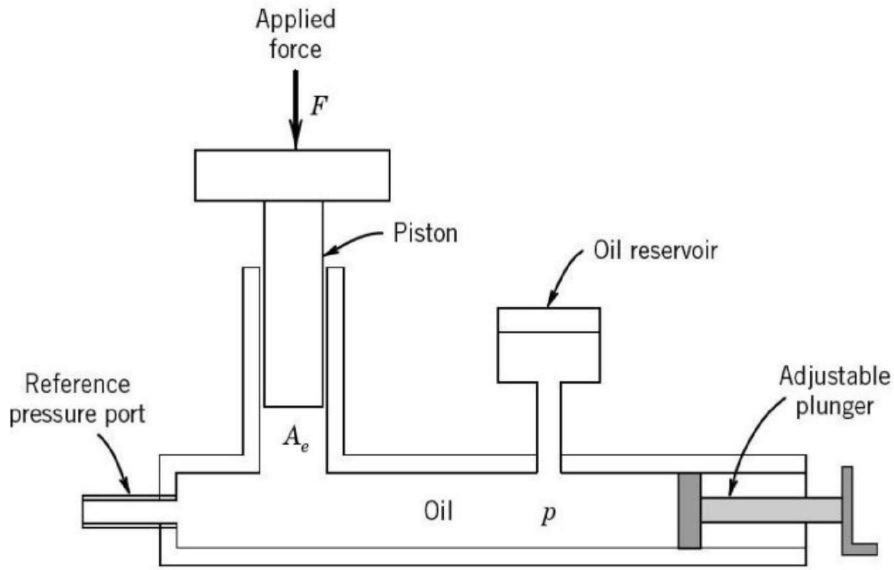
Bourdon Tube Pressure Gauge

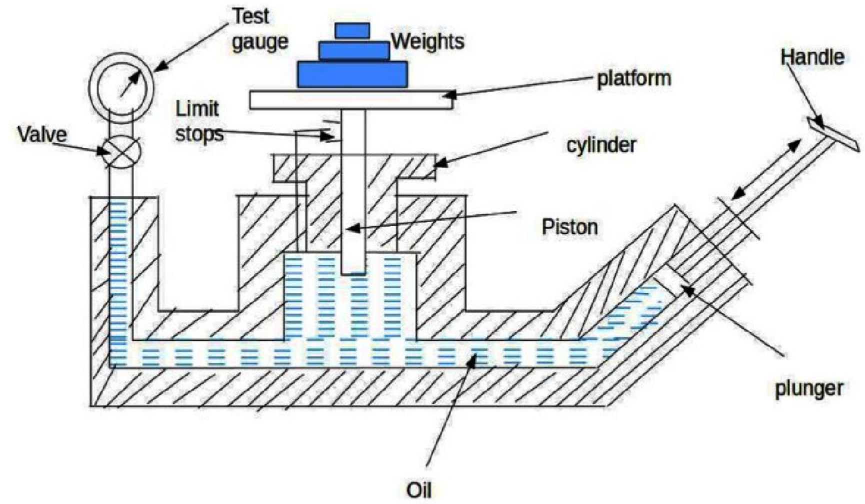
- The bourdon tube works on a simple principle that a bent tube will change its shape .
- As pressure is applied internally, the tube straightens and returns to its original form when the pressure is released .
- The tip of the tube moves with the internal pressure change and is easily converted with a pointer onto a scale.

Bourdon Tube Pressure Gauge

Dead Weight Tester

(Calibration Of Pressure Measuring Device)





Dead Weight Tester

(Calibration Of Pressure Measuring Device)

- The dead weight tester is basically a pressure producing (pressure measuring) device.
- It is used to calibrate pressure gauges.
- The dead weight tester apparatus consists of a chamber which is filled with oil free of impurities and a piston - cylinder combination is fitted above the chamber as shown in diagram.
- The top portion of the piston is attached with a platform to carry weights. A plunger with a handle has been provided to vary the pressure of oil in the chamber.
- The pressure gauge to be tested is fitted at an appropriate plate.

$$p = \frac{F}{A_e} + \sum \text{errors}$$

$$P*A = Mg + F$$
$$P = (Mg + F)/A$$

Thank You