FLUID MECHANICS

DEPARTMENT OF CIVIL ENGINEERING

ESC-CV 304 – FLUID MECHANICS

III SEMESTER

COURSE OBJECTIVE

1. To study processes and science of fluid and their properties.

2. To study pressure measuring devices and pressure diagram.

3. To apply basic principles in fluid flow problems.

4. To identify the losses in pipes.

COURSE OUTCOME

After successful completion of this course, students will be able to:

1. Study the basic properties of fluids and their behavior under application of various force systems.

2. Discuss the basic concepts and principles in fluid statics, fluid kinematics and fluid dynamics with their applications in fluid flow problems.

COURSE OUTCOME

3. Recognize the principles of continuity, momentum and energy as applied to fluid in motion.
4. Apply the equations to analyze problems by making proper assumptions and learn systematic engineering methods to solve practical fluid mechanics problems.

MODULE 1

Fluid properties and Pressure Measurement

- Properties of fluids.
- Viscosity
- Capillarity
- Compressibility
- Pressure.

Definitions

Fluid mechanics

It is the branch of science which deals with the behaviour of fluids at rest as well as in motion.

Fluid static

The study of fluid **at rest.**

Fluid Kinematics

The study of fluid in motion where **pressure forces are not considered.**

Fluid Dynamics

The study of fluids in motion where **pressure forces are considered.**

Pressure

The normal force a fluid exerts per unit surface area of contact.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} = \frac{F}{A} = N/m2$$

Mass Density /Specific Density

Density or mass density of a fluid is defined as the ratio of mass of fluid to its volume.

$$\rho = \frac{\text{Mass of fluid (kg)}}{\text{Volume of fluid (m}^3\text{)}} = \frac{M}{V}$$

Density of water = 1000 kg/m3

Specific Weight or Weight Density

Specific weight of a fluid is the ratio between the weight of a fluid to its volume.

$$w = \frac{\text{Weight of the fluid}}{\text{Volume of the fluid}} = \frac{W}{V} = \text{-----}(N/m3) \text{ or } KN/m3$$

$$w = \frac{(\text{Mass of the fluid } \times \text{ Acceleration due to gravity})}{\text{volume of the fluid}}$$

$$w = \frac{m \times g}{V} \quad \_ \ (m/v = \boldsymbol{\rho})$$

$$\color{red}{\mathbf{w = \rho \times g}}$$

Weight Density of water 9810 N

Specific volume

It is the volume per unit mass of the fluid.

$$\text{Specific volume} = \frac{\text{Volume of the fluid } (m^3)}{\text{Mass of the fluid (Kg)}} = \frac{v}{m}$$

$$V = \frac{1}{\rho} \quad \text{----}(m/v = \rho)$$

Specific Gravity / Relative Density

It is the ratio of density of a fluid to the (mass/weight) density of the standard fluid.

$$s = \frac{\text{Density of Liquid}}{\text{Density of water}} = \frac{\rho}{\rho_{std}} = \text{----- unit less}$$

The standard fluid for liquid is **water** and for gas it is **air**.

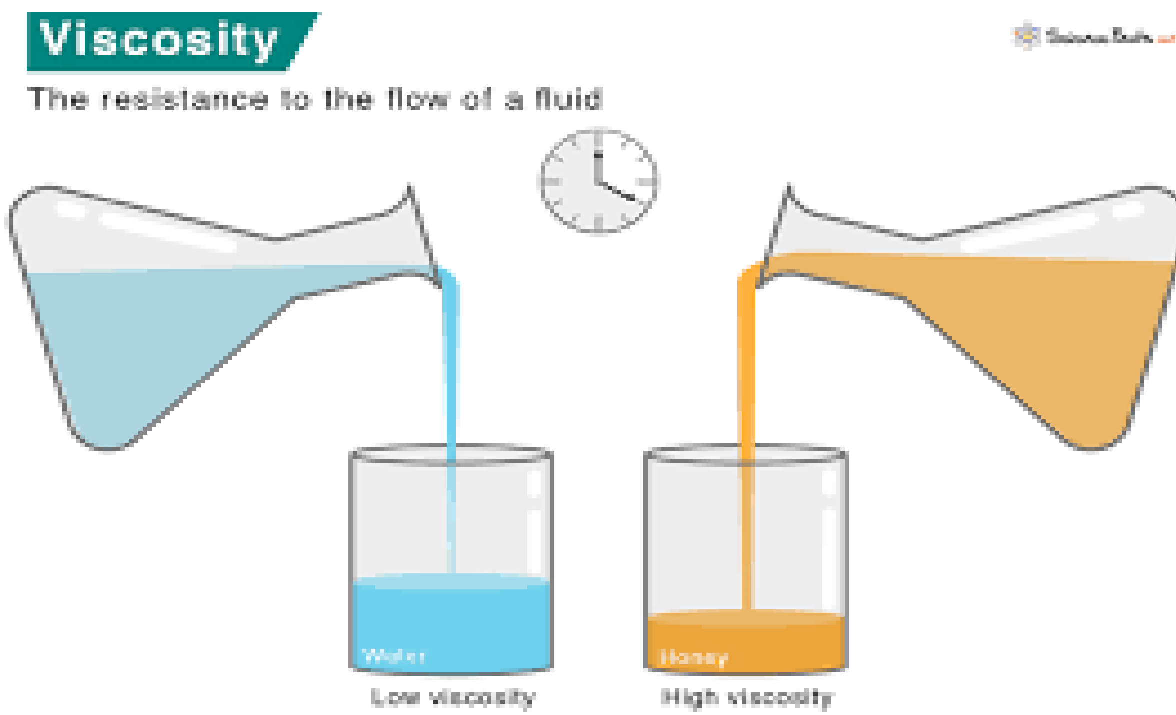
Specific Gravity of mercury is 13.6

Numericals

Viscosity /Dynamic Viscosity

Viscosity is defined as the property of a fluid which offers **resistance to flow or shear deformation or in other words reluctance of the fluid to flow.**

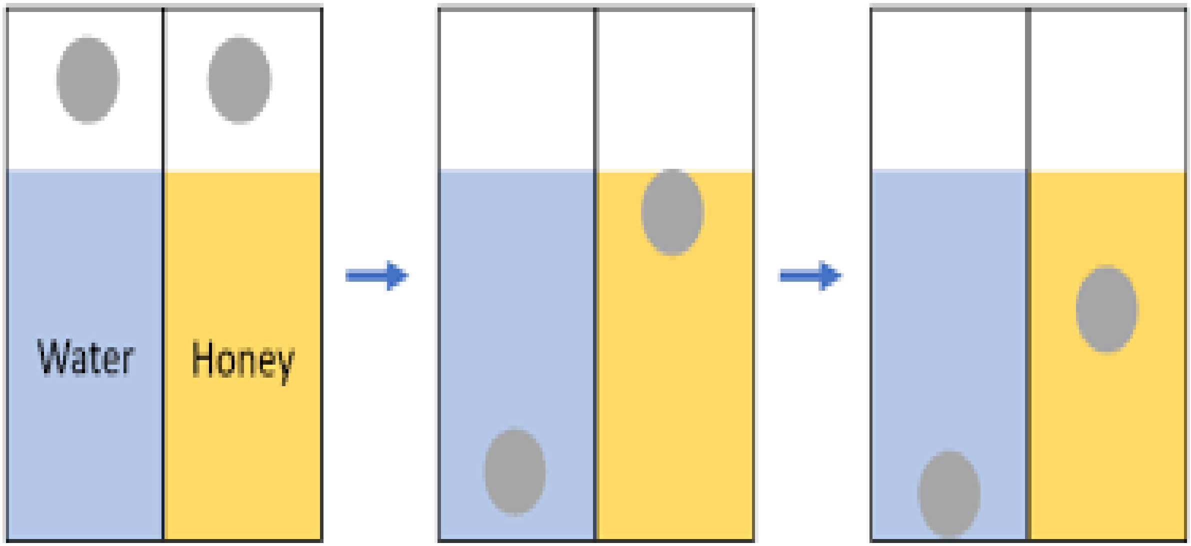
Viscous force is the force of resistance offered by a layer of fluid.



Viscosity

In case of liquid Viscosity is due to **cohesive force** between molecules of adjacent layers of liquid.

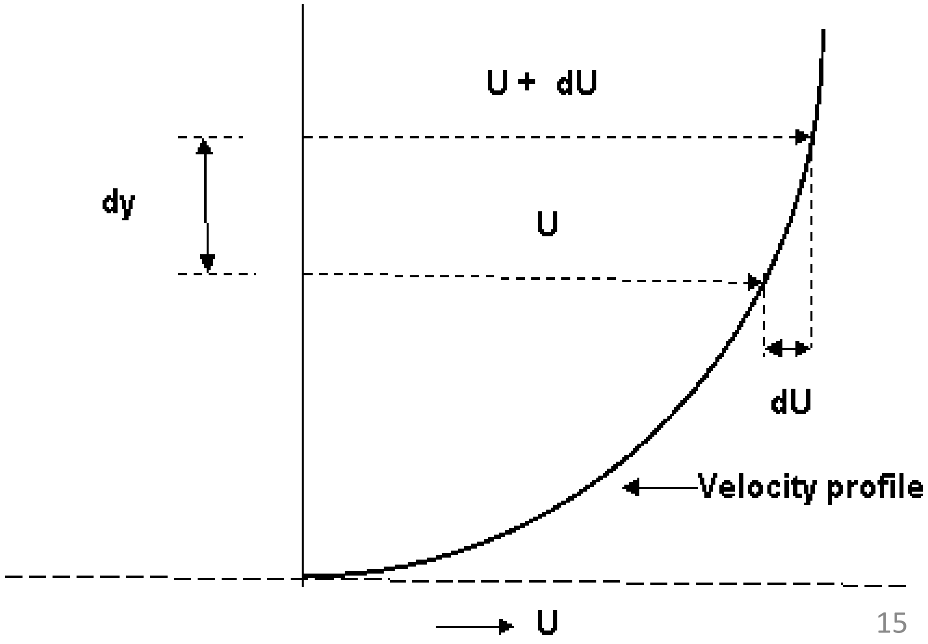
In case of gases **molecular activity** between adjacent layers is the cause of viscosity.



- Consider two layers of fluid at a distance “dy” apart with velocity of “U” and “U + dU”.
- Viscosity together with relative viscosity causes shear stress acting between fluid layers.
- Shear stress is proportional to the rate of change of velocity with respect to “y”.

$$\tau \propto \frac{du}{dy}$$

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



- **μ = Coefficient of dynamic viscosity or viscosity.**

$$\mu = \tau / (du/dy)$$

- Viscosity is also defined as the **shear stress required to produce unit rate of shear strain.**
- Units : SI system : N-s / m^2
- Note - If viscosity is given in the **poise it must be divided by 10 & 1 centipoise = 1/100 poise**

Newton's Law of Viscosity

It states that the shear stress (Ʈ) of a fluid element layer is directly proportional to the rate of shear strain.

Factors affecting the Viscosity

1. Pressure

Pressure has very less or no effect on viscosity

2. Temperature

- Effect of temperature on viscosity of liquids is due to cohesive action between molecules of adjacent layers. As the temperature increases cohesive force decreases & hence viscosity decreases.
- Effect of temperature on viscosity of is due to molecular activity between adjacent layers. As the temperature increases molecular activity increases & hence viscosity increases.

Viscosity

1. Dynamic Viscosity
2. Kinematic Viscosity

1. Dynamic Viscosity

It is the force needed (external) by the fluid to overcome its **own internal molecular friction** so that fluid will flow.

It is also called as absolute viscosity.

2. Kinematic Viscosity

Kinematic viscosity is defined as the ratio between the dynamic viscosity and density of fluid. Here no external force is required.

$$\gamma = \frac{\text{Viscosity}}{\text{Density}}$$

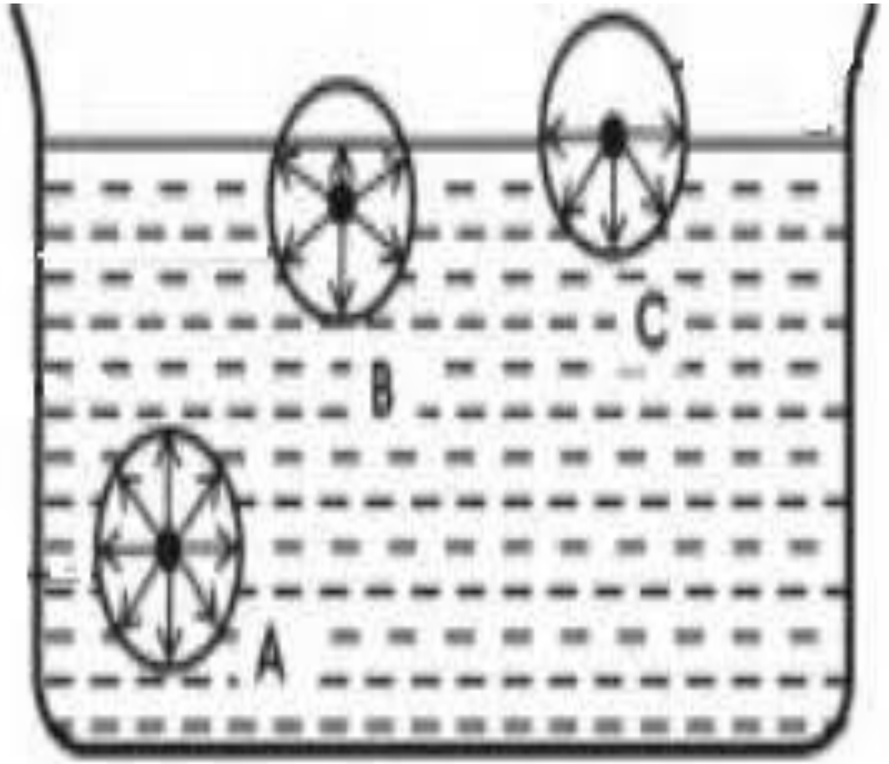
$$\gamma = \frac{\mu}{\rho}$$

Units : SI system : m^2/s

Surface Tension (6 Sigma):-

- It is defined as the property of liquid which enables it to resist tensile stress is called as surface tension.

Surface tension



Consider three molecules A, B and C in a liquid, such that molecule A is well inside the liquid, molecule B is close to the free surface and the molecule C is on the free surface.

The sphere of influence of the molecule A is completely inside the liquid, and hence it will be acted upon by equal forces in all directions and so net resultant force acting on it is **zero.**

For molecule B, near surface are unbalanced upward and downward direction forces. So net resultant force acting in downward direction

For the molecule C on the free surface of liquid subjected to only net resultant force acting in downward direction

So all the molecules on the free surface experiences downward force. So free surface of liquid act as a very thin layer under tension.

surface tension is defined as the tensile force acting on a free surface of liquid per unit length

Surface tension on liquid droplet

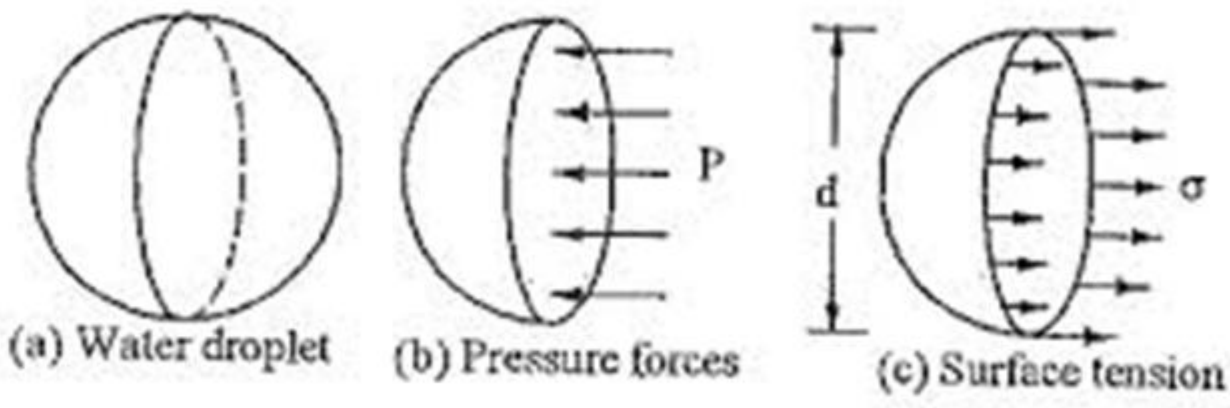


Fig 1.4 Forces on droplet.

$$P = \frac{4\sigma}{d}$$

Where P = Pressure in N/m^2

σ = Surface tension in N/m

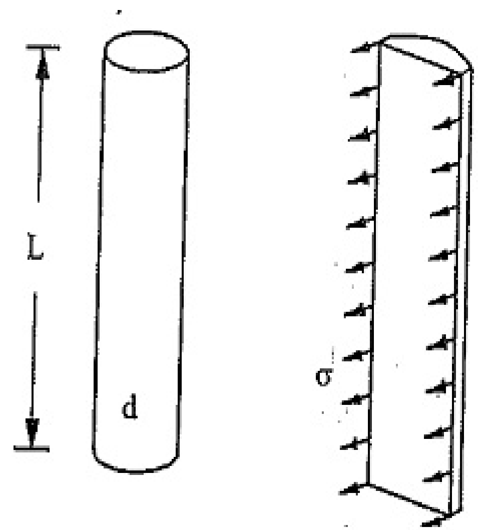
d = diameter of the liquid droplet

L = length of water jet

Surface tension on a hollow bubble

$$P = \frac{8\,\sigma}{d}$$

Surface tension on a liquid jet



$$P = \frac{2\sigma}{d}$$

Where P = Pressure in N/ m^2

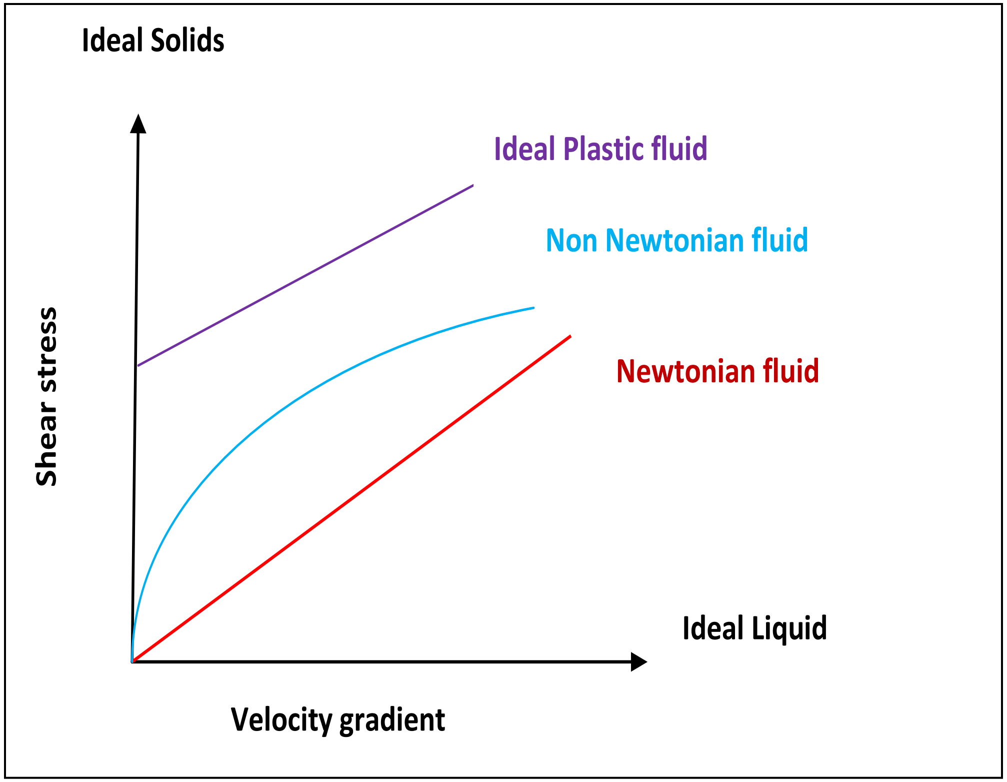
σ = Surface tension in N/m

d = diameter of the liquid droplet

L = length of water jet

Types of Fluids

- Ideal Fluid- Viscosity =shear stress =0
- Real Fluid – having some viscosity- kerosene, honey, petrol etc.
- Newtonian Fluid – all gases- air, water ,alcohol etc.
- Non Newtonian Fluid – tooth paste, gels, lubricants etc.



- **Ideal Fluid –**

A fluid which is incompressible and having no viscosity, is known as Ideal fluid.

- **Real Fluid:-**

A fluid which posses viscosity, known as real fluid.

- **Newtonion fluid:-**

A real fluid, in which the shear stress is directly proportional to the rate of shear strain in known as Newtonion fluid. e.g- Water

- **Non Newtonion fluid:-**

A real fluid, in which the shear stress is not proportional to the rate of shear strain in known as Newtonion fluid.e.g- Blood, paint,gel.

- **Ideal plastic fluid:-**

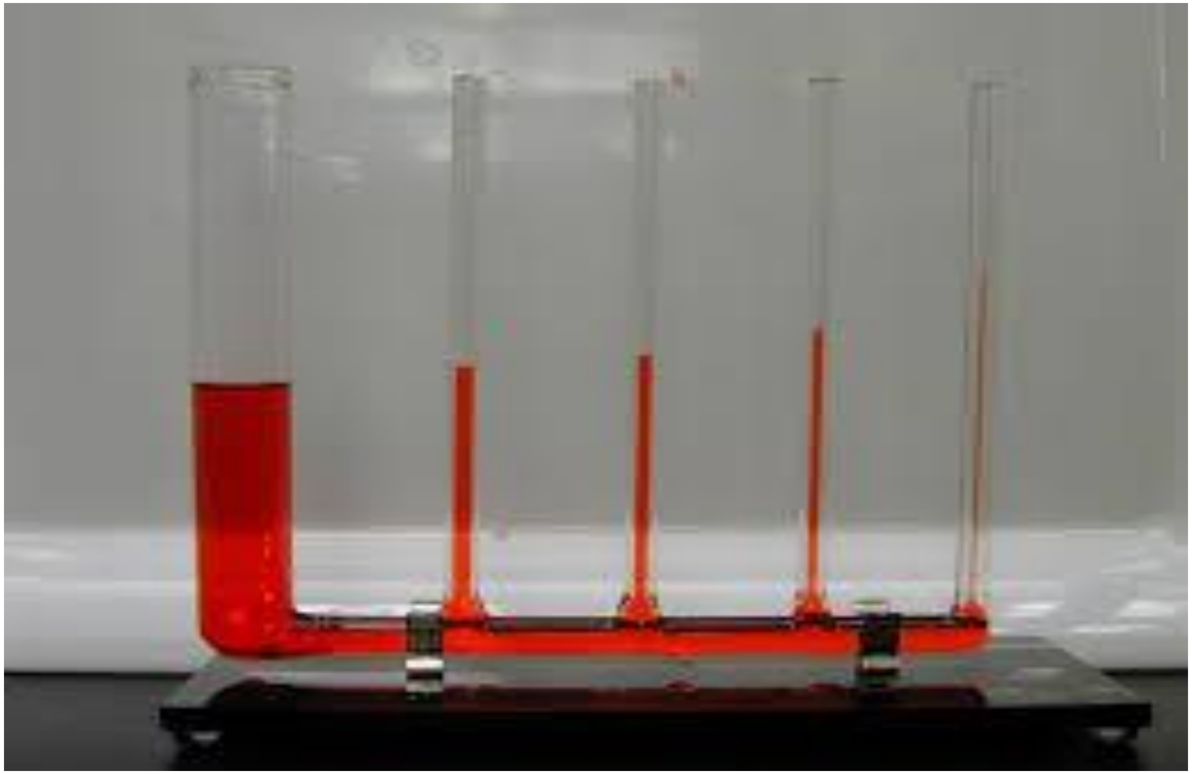
A fluid in which shear stress is more than the yield value and shear stress is proportional to the rate of shear strain is known as Ideal plastic fluid.

Properties of fluid

Ideal fluid	Real fluid
Ideal fluids have zero viscosity.	Viscosity exists.
Incompressible.	Can be compressible.
Infinite bulk modulus	Finite bulk modulus
No surface tension	Surface tension exists
Imaginary and do not exists in nature	Exists in nature

Capillarity

Capillarity is defined as the phenomenon of rise or fall of a **liquid surface in a small tube** relative to adjacent general level of liquid when the tube is held vertically in the liquid.



Capillarity

- Rise of liquid in the tube - **Capillary rise**
- Fall of liquid in the tube - **Capillary depression**

Factors affecting rise or fall

1.Denisty of liquid

2. Diameter of the tube

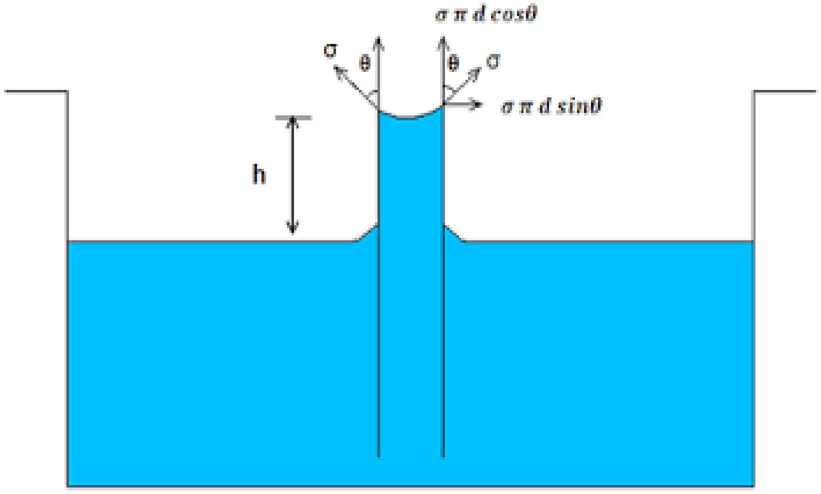
3.Surface tension of the liquid

Expression for Capillary rise

Under state of equilibrium weight of the liquid of height is balanced by the force at the surface of the liquid in the tube

Weight of liquid = **ρ x g x Area of tube x h**

$$= \rho \times g \times \frac{\pi}{4} d^2 \times h$$



Properties of fluid

- Vertical component of the tensile force **= $\sigma \times \pi d \cos\theta$**
- Equating two equations,
- The capillary rise is given as

$$h = \frac{4\sigma \cos\theta}{\rho \times g \times d}$$

- **θ = 0 for clean water and glass tube**

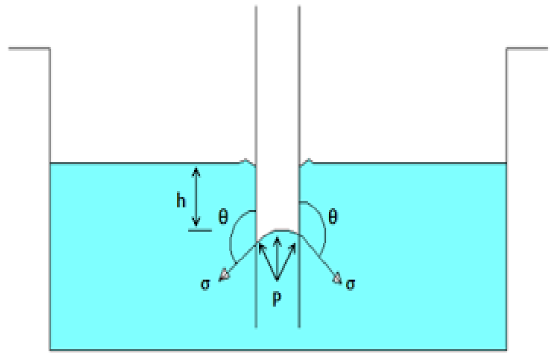
$$h = \frac{4\sigma}{\rho \times g \times d}$$

Where ρ= density;

σ= surface tension;

d = diameter of the tube

Expression for Capillary depression



If the glass tube is dipped in mercury the level of mercury in the tube is lower that the general level of the outside liquid.

The capillary depression is $h = -\dfrac{4\sigma \cos\theta}{\rho \times g \times d}$

θ = 128 ° for mercury and glass tube

Where ρ= density; σ= surface tension ;d = diameter of the tube

Image source :http://www.mechanicalbooster.com/2017/08/what-is-capillarity.html

Numerical

Pascal's law –

The Pascal's law states that the pressure or intensity of pressure at a point in a fluid at rest is same in all directions.

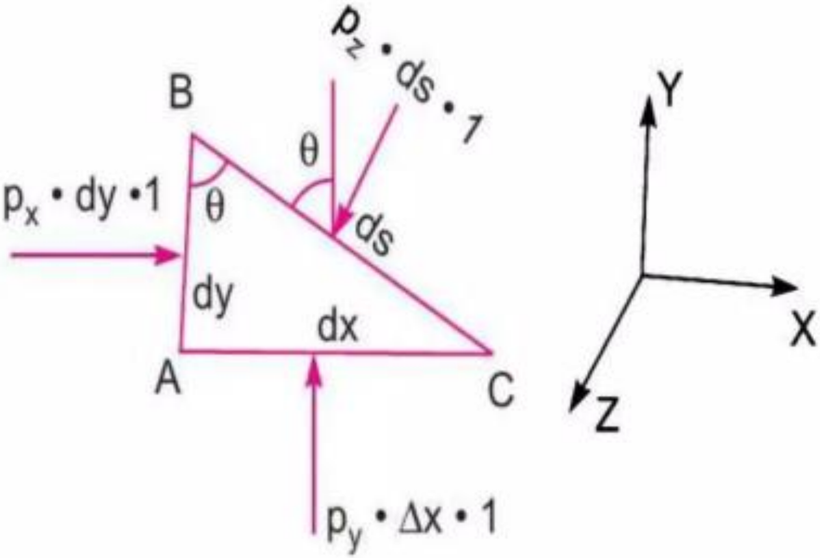
Applications

e.g – hydraulic lifts, hydraulic crane, hydraulic jacks, dam, braking system of motor etc.

Pascal's Law:

"Pressure or intensity of pressure at a point in a static fluid is equal in all directions".

$P_x = P_y = P_z$



Forces on a fluid element.

Hydrostatic law –

The Hydrostatic law states that the rate of increase of pressure in vertically downward direction must be equal to the weight density of fluid at that point.

Or

The hydrostatic law states that the rate of increase of pressure in a static fluid is equal to the fluid's specific weight at any given point

Pressure Variation in a fluid at rest:

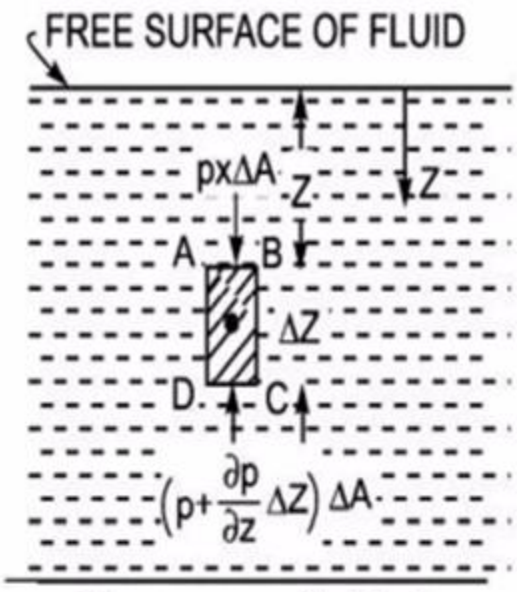
"Rate of increase of pressure in a vertical direction is equal to weight density of the fluid at that point". : Hydrostatic law

Let ΔA= Cross-sectional area of element

ΔZ = Height of fluid element

p = Pressure on face AB

Z = Distance of fluid element from free surface.



Forces on a fluid element.