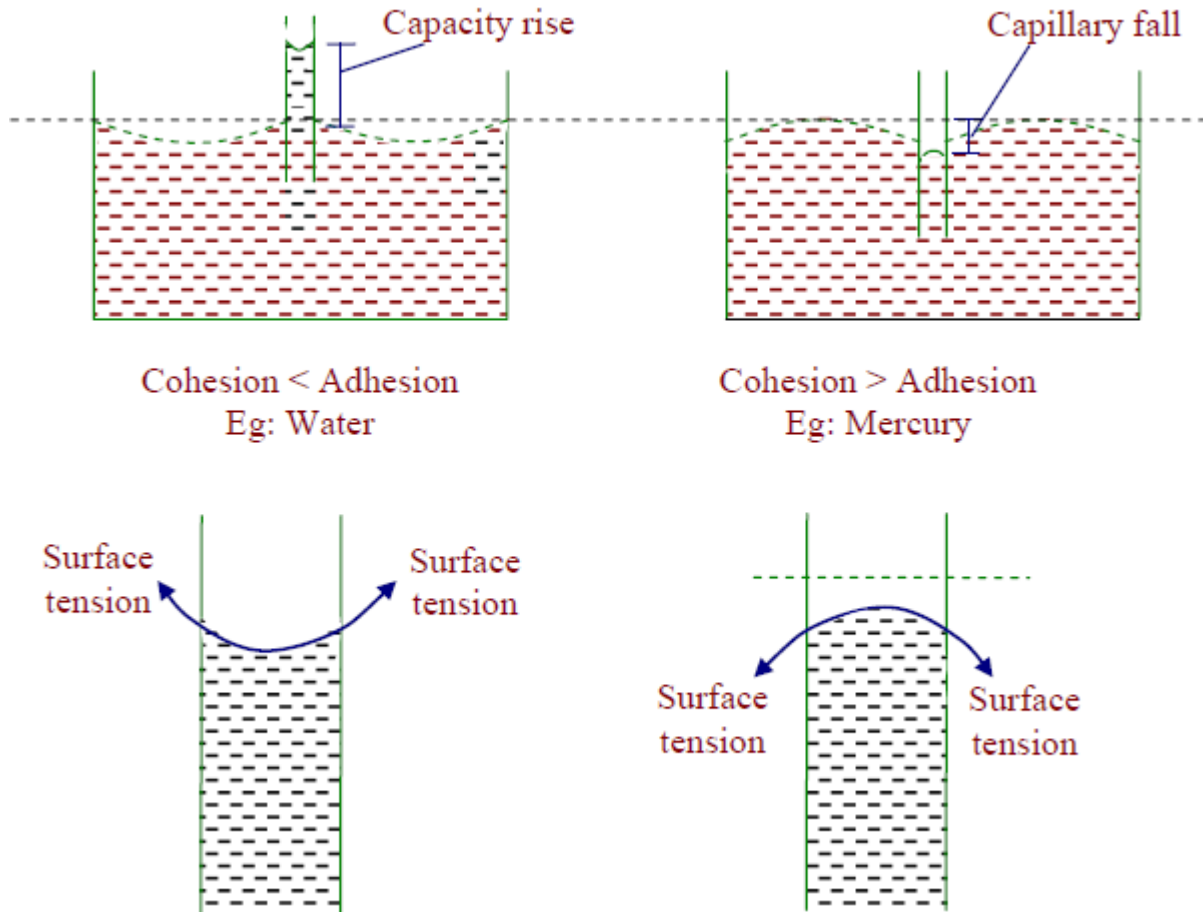Capillarity :

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. If cohesion is greater than adhesion then will be capillary fall or depression. The surface tensile force supports capillary rise or depression.

$$h = \frac{4\sigma \cos\theta}{\gamma D}$$

Figure 1.3.2 Capillarity

[Source: "https://en.wikiversity.org/wiki/Fluid_Mechanics_for_Mechanical_Engineers/fluid Properties"]

***Problem* 1 :** Capillary tube having an inside diameter 5mm is dipped in water at 20^0.

Determine the heat of water which will rise in tube. Take σ =0.0736N/m at 20^0 C.

$$h = \frac{4\sigma \cos\theta}{\gamma D}$$

$\theta = 0^0 \text{(assumed)}$

$$= \frac{4 \times 0.0736 \times \cos\theta}{9810 \times 5 \times 10^{-3}}$$

$\gamma = 9810 N/m^3$

$$h = 6 \times 10^{-3} m$$

***Problem* 2 :** Calculate capillary rise in a glass tube when immersed in Hg at 20⁰C.
Assume σ for Hg at 20⁰C as 0.51N/m. The diameter of the tube is 5mm. θ = 130⁰c.

$$h = \frac{4\sigma \cos\theta}{\gamma D}$$

$$S = \frac{\gamma}{\gamma_{Standard}}$$

$$13.6 = \frac{\gamma}{9810}$$

$$h = -1.965 \times 10^{-3} m$$

$$\gamma = 133.416 \text{ x } 10^3 \text{N}/\text{m}^3$$

-ve sign indicates capillary depression.

***Problem* 13:** Calculate the capillary effect in millimeters a glass tube of 4mm diameter, when immersed in (a) water (b) mercury. The temperature of the liquid is 20^0 C and the values of the surface tension of water and mercury at 20^0 C in contact with air are 0.073575 and 0.51 N/m respectively. The angle of contact for water is zero that for mercury 130^0. Take specific weight of water as 9790 N / m^3..

Given:

Diameter of tube $\Rightarrow$ d = 4 mm = $4 \times 10^{-3} m$

Capillary effect (rise or depression) $\Rightarrow h = \dfrac{4\sigma \cos \theta}{p \times g \times d}$

σ = Surface tension in kg f/m

θ = Angle of contact and p = density

Capillary effect for water

$\sigma = 0.073575 \ N/m, \quad \theta = 0^0$

$p = 998 \ kg/m^3 \ @ \ 20^0 c$

$h = \dfrac{4 \times 0.73575 \times Cos0^0}{998 \times 9.81 \times 4 \times 10^{-3}} = 7.51 \times 10^{-3} m$

= 7.51 mm.

Capillary effect for mercury:

$\sigma = 0.51 \ N/m, \qquad\qquad \theta = 130^0$

$p = sp \ gr \times 1000 = 13.6 \times 1000 = 13600 kg/m^3$

= - 2.46 mm.

-Ve indicates capillary depression.

1.Surface Tension:

Surface tension is defined as the tensile force acting on the surface of a liquid in contact with a gas or on the surface between two two immiscible liquids such that the contact surface behaves like a membrane under tension

Excess Pressure inside a Water Droplet:

Pressure inside a Liquid droplet: Liquid droplets tend to assume a spherical shape since a sphere has the smallest surface area per unit volume.

The pressure inside a drop of fluid can be calculated using a free-body diagram of a spherical shape of radius R cut in half, as shown in Figure below and the force developed around the edge of the cut sphere is $2\pi R\sigma$. This force must be balance with the difference between the internal pressure pi and the external pressure Δp acting on the circular area of the cut. Thus,

$$2\pi R\sigma = \Delta p \pi R^2$$

$$\Delta p = \left(p_{int\,ernal} - p_{external}\right) = \frac{2 \times \sigma}{R} = \frac{4 \times \sigma}{D}$$

Figure 1.3.3 Surface Tension inside a Water Droplet

[Source: "https://en.wikiversity.org/wiki/Fluid_Mechanics_for_Mechanical_Engineers/fluid Properties"]

The excess pressure within a Soap bubble:

The fact that air has to be blown into a drop of soap solution to make a bubble should suggest that the pressure within the bubble is greater than that outside. This is in fact the case: this excess pressure creates a force that is just balanced by the inward pull of the soap film of the bubble due to its surface tension.
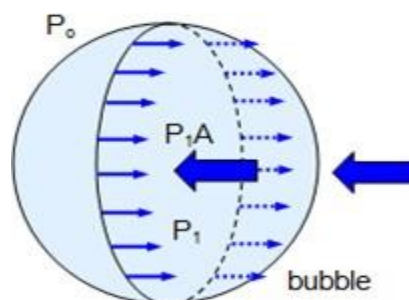
Figure 1.3.4 Surface Tension within a Soap bubble

[Source: "https://en.wikiversity.org/wiki/Fluid_Mechanics_for_Mechanical_Engineers/fluid Properties"]

Consider a soap bubble of radius r as shown in Figure 1. Let the external pressure be

P_o and the internal pressure P_1. The excess pressure ΔP within the bubble is therefore given by: Excess pressure $\Delta P = (P_1 - P_0)$

Consider the left-hand half of the bubble. The force acting from right to left due to the internal excess pressure can be shown to be PA, where A is the area of a section through the centre of the bubble. If the bubble is in equilibrium this force is balanced by a force due to surface tension acting from left to right. This force is $2 \times 2\pi r\sigma$ (the factor of 2 is necessary because the soap film has two sides) where 'σ' is the coefficient of surface tension of the soap film. Therefore

$2 \times 2\pi r\sigma = \Delta pA = \Delta p\pi r^2$ giving:

Excess pressure in a soap bubble (P) = $4\sigma/r$

2. Compressibility:

Compressibility is the reciprocal of the bulk modulus of elasticity, Kwhich is defined as the ratio of compressive stress to volumetric strain.

Bulk Modulus (K):

When a solid or fluid (liquid or gas) is subjected to a uniform pressure all over the surface, such that the shape remains the same, then there is a change in volume.

Then the ratio of normal stress to the volumetric strain within the elastic limits is called as Bulk modulus. This is denoted by K.

$$K = \frac{\text{Normal stress}}{\text{volumetric strain}}$$

$$K = \frac{F/A}{-\Delta V/V} = \frac{-pV}{\Delta V}$$

where p = increase in pressure; V = original volume; ΔV = change in volume

The negative sign shows that with increase in pressure p, the volume decreases by ΔV i.e. if p is positive, ΔV is negative. The reciprocal of bulk modulus is called compressibility.

$$C = Compressibility = \frac{1}{K} = \frac{\Delta V}{pV}$$

S.I. unit of compressibility is $N^{-1}m^2$ and C.G.S. unit is $dyne^{-1}\ cm^2$.

Problem 13: The surface tension of water in contact with air at 20°C is 0.0725 N/m. The pressure inside a droplet of water is to be 0.02 N/cm² greater than the outside pressure. Calculate the diameter of the droplet of water.

Given: Surface Tension of Water σ =0.0725 N/m, Δp= 0.02 N/cm² = 0.02×10⁻⁴ N/m²

Let 'D' be the diameter of jet

$$\Delta p = \frac{4\sigma}{D}$$

$$0.02 \times 10^{-4} = \frac{4 \times 0.0725}{D}$$

$$D = 0.00145m = 1.45mm$$

Problem 14: Find the surface tension in a soap bubble of 40mm diameter when inside pressure is 2.5 N/m² above the atmosphere.

Given: D = 40mm = 0.04 m, Δp = 2.5 N/m²

Let 'σ' be the surface tension of soap bubble

$$\Delta p = \frac{8\sigma}{D}$$

$$2.5 = \frac{4\sigma}{0.04}$$
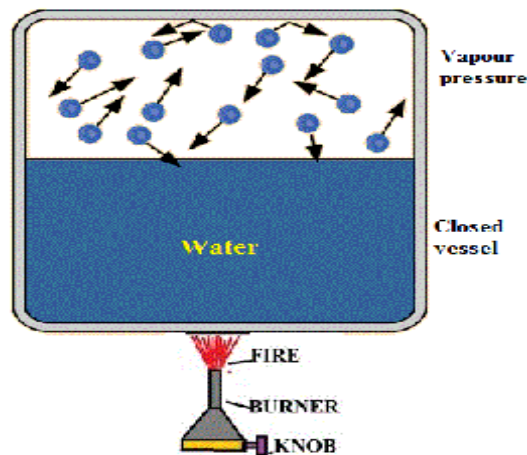
$$\sigma = 0.0125 \text{ N/m}$$

3. Vapour Pressure

Vapour pressure is a measure of the tendency of a material to change into the gaseous or vapour state, and it increases with temperature. The temperature at which the vapour pressure at the surface of a liquid becomes equal to the pressure exerted by the surroundings is called the boiling point of the liquid.

Vapor pressure is important to fluid flows because, in general, pressure in a flow decreases as velocity increases. This can lead to *cavitation*, which is generally destructive and undesirable. In particular, at high speeds the local pressure of a liquid sometimes drops below the vapor pressure of the liquid. In such a case, *cavitation* occurs. In other words, a "cavity" or bubble of vapor appears because the liquid vaporizes or boils at the location where the pressure dips below the local vapor pressure.

Cavitation is not desirable for several reasons. First, it causes noise (as the cavitation bubbles collapse when they migrate into regions of higher pressure). Second, it can lead to inefficiencies and reduction of heat transfer in pumps and turbines (turbo machines). Finally, the collapse of these cavitation bubbles causes pitting and corrosion of blades and other surfaces nearby. The left figure below shows a cavitating propeller in a water tunnel, and the right figure shows cavitation damage on a blade.

Figure 1.3.5 Vapour Pressure

[Source: "https://www.hkdivedi.com/2017/12/vapour-pressure-and-cavitation.html"]