Newton's Law of Viscosity:

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It states that the shear stress (τ) 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.

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

Fluids which obey the above relation are known as Newtonian fluids and fluids which do not obey is called non-newtonian fluids.

Variation of Viscosity with temperature:

Viscosity of liquid decreases with increase in temperature whereas the viscosity of gases increases. ~~with~~ This is due to cohesive force and molecular momentum transfer. In liquid, with rise in temp. reduces the cohesive force and in gas, it increases the molecular momentum transfer.

For liquids, $\boxed{\mu = \mu_0 \left(\frac{1}{1+\alpha t+\beta t^2}\right)}$

μ = Viscosity at $t^\circ C$, in poise
μ_0 = Viscosity at $0^\circ C$, in poise
α, β = Constants.

For water, $\mu_0 = 1.79 \times 10^{-3}$ poise
$\alpha = 0.03368$
$\beta = 0.000221$

For gas, $\boxed{\mu = \mu_0 + \alpha t - \beta t^2}$

For air, $\mu_0 = 0.000017$ poise $= 1.7 \times 10^{-5}$ poise
$\alpha = 5.6 \times 10^{-8}$
$\beta = 0.1189 \times 10^{-9}$

TYPES OF FLUIDS

no

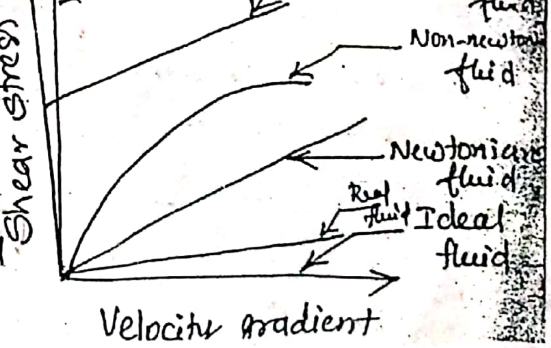
Ideal fluid: Incompressible, no viscosity

Real fluid: Viscosity Kerosene, Petrol, Castor oil

Newtonian fluid: Obeys Newton's law of viscosity
L water, air, emulsion

Non-newtonian fluid: Does not obey ,,
Slime, Flubber, Oobleck (suspension of starch in water)

Ideal Plastic fluid: which obeys newton's law and also shear stress > yield value.



∴ Torque = Force × r

$= 180.05 \times 0.2$

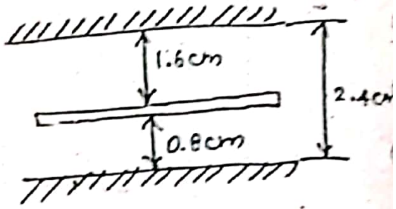
$= 360.10$ Nm

∴ Power $= \frac{2\pi NT}{60} = \frac{2 \times \pi \times 190 \times 36.01}{60}$

$=$ ~~764.86 W~~ 716.86W

1. Two large plane surfaces are 2.4 cm apart. The space between the surfaces is filled with glycerine. What force is required to drag a very thin plate of surface area 0.5 m^2 between two large plane surfaces at a speed of 0.6 m/s, if the thin plate is at a distance of 0.8 cm from one of the plane surfaces? Take the dynamic viscosity of glycerine = 8.10×10^{-1} NS/m^2.

Given Data:



Area of plate = A = 0.5 m^2

$du = 0.6$ m/s

$dy_1 = 0.8$ cm $= 8 \times 10^{-3}$ m

$dy_2 = 1.6$ cm $= 0.016$ m

$\mu = 8.10 \times 10^{-1}$

Solution

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

$$\frac{F_1}{A} = \mu \frac{du}{dy_1} = \frac{F_1}{A} = 8.10 \times 10^{-1} \times \frac{0.6}{0.8 \times 10^{-2}}$$

$$\therefore F_1 = 8.10 \times 10^{-1} \times \frac{0.6}{0.8 \times 10^{-2}} \times 0.5 = 30.38 \text{ N}$$

Similarly,

$$F_2 = 8.10 \times 10^{-1} \times \frac{0.6}{0.016} \times 0.5 = 15.19 \text{ N}$$

∴ Total force required $= 30.38 + 15.19 = 45.57$ N

THERMODYNAMIC PROPERTIES:

Gases are compressible fluids and hence thermodynamic properties play its part. Changes in pressure and temperature, the gases undergo changes. It is given by.

$$p\forall = RT$$

$\overline{\rho}$ 7

$= \boxed{\frac{p}{\rho} = RT}$ R – depends upon the particular gas. (Gas Constant)

Isothermal process:

Density change occurs at constant temp.

$\boxed{\frac{p}{\rho} = \text{constant}}$ $\boxed{p\forall = \text{Constant}}$

Adiabatic process:

Density change occurs with no heat exchange to and from the gas

$\boxed{\frac{p}{\rho^k} = \text{constant}}$ $\boxed{pV^k = c}$ k = Ratio of specific heat at constant pressure & constant vol. = 1.4 for air.

Universal Gas Constant

① ← $\boxed{p\forall = nMRT}$ M – ~~Mass of gas~~ $\frac{\text{Mass of the gas mole}}{\text{Mass of the hydrogen atom}}$

① ← $\boxed{p\forall = mRT}$ n – $\frac{\text{no. of moles}}{\text{volume of gas}}$

② ← $\boxed{m = n \times M}$ m – mass of gas in kg.

④ – $\boxed{M \times R}$ → Universal gas constant = 8314 $\frac{N\text{-}m}{kg\text{-mole}\ {}^\circ K}$

1. A gas weighs 16 N/m³ at 25°C and at an absolute pressure of 0.25 N/mm². Determine gas constant and density of the gas.

$\gamma = 16\ N/m^3$

$T = 25^\circ C = 25 + 273 = 298^\circ K$

$p = 0.25\ N/mm^2 = 0.25 \times 10^6\ N/m^2$

Solution

$p\forall = RT$

8. $\rho = \frac{16}{9.81} = 1.63\ kg/m^3$

$\forall = \frac{1}{1.63} = 0.61\ m^3/kg$

$R = \frac{p\forall}{T} = \frac{0.25 \times 10^6 \times 0.61}{298} = 514.68\ \frac{Nm}{kg\,K}$

$\frac{\frac{N}{m^2} \times \frac{m^3}{kg}}{K}$

$\frac{kg \times m/s^2 \times m}{kg\ \ K}$

0.3 N/mm² absolute pressure. The air is compressed ... Find (i) pressure inside the cylinder assuming isothermal process and (ii) pressure ~~and temperature~~ assuming adiabatic process. Take $k = 1.4$.

Given data

$V_1 = 0.6\ m^3$

$T = 50^\circ C = 273 + 50 = \cancel{293}\ 323\ ^\circ K$

$P_1 = 0.3 \times 10^6\ N/m^2$

$V_2 = 0.3\ m^3$

$k = 1.4$

$P_{2\,iso} = ?$ $\quad t_{adi} = ?$

$P_{2\,ad} = ?$

Solution:

$$\boxed{P_1 V_1 = P_2 V_2} \longrightarrow \text{Isothermal}$$

$$0.3 \times 10^6 \times 0.6 = P_2 \times 0.3$$

$$P_2 = 0.6 \times 10^6\ N/m^2$$

$$\boxed{P_1 V_1^k = P_2 V_2^k} \longrightarrow \text{adiabatic}$$

$$P_2 = \frac{0.3 \times 10^6\ (0.6)^{1.4}}{(0.3)^{1.4}} = \cancel{4.8 \times 10^6}\ 791.71 \times 10^3\ N/m^2 = 0.79 \times 10^6\ N/m^2$$

3. Calculate the pressure exerted by 5 kg of nitrogen gas at a temperature of 10°C if the volume is 0.4 m³. Molecular weight of nitrogen is 28. Assume, ideal gas laws are applicable.

Given data:

Mass of nitrogen = 5 kg = m

$T = 10^\circ C = 273 + 10 = 283^\circ K$

$V = 0.4\ m^3$

$M = 28.$

$P = ?$

Solution

$$PV = n \times M \times RT$$
$$= mRT$$

* Velocity gradient
* definite shape - reason - Cohesive force
* Cohesive force max 10^{-9} m

$$R = \frac{8.314}{28} = 296.93 \ \frac{N\text{-}m}{kg\,°K}$$

kg-mole K

$$\therefore p = \frac{5 \times 296.93 \times 283}{0.4} = 1.05 \times 10^6 \ N/m^2$$

$$= 1.05 \times N/mm^2$$

Compressibility & Bulk Modulus

$$\text{Bulk Modulus } (K) = \frac{\text{Compressive stress}}{\text{Volumetric strain}} = \frac{dp}{-\frac{dV}{V}} = -\frac{dp\,V}{dV} = K$$

$$\boxed{\text{Compressibility} = \frac{1}{K}}$$

$$= \frac{\text{change in pressure}}{\frac{\text{change in volume}}{\text{original volume}}}$$

Relationship between Bulk Modulus (K) and Pressure (p) for a Gas

We know that, (Isothermal)

$$pV = \text{Constant}$$

Differentiating this equation

$$p\,dV + V\,dp = 0$$

$$p\,dV = -V\,dp$$

$$p = \frac{-V\,dp}{dV}$$

$$\boxed{p = K}$$

Adiabatic

$$pV^k = \text{Constant}$$

Differentiating this equation,

$$p \cdot k\,V^{k-1} + V^k\,dp = 0$$

$$p\,k\,V^{k-1} =$$

$$\boxed{K = pk}$$

Determine the bulk modulus of elasticity of a liquid, if the pressure of the liquid is increased from $70\,N/cm^2$ to $130\,N/cm^2$. The volume of the liquid decreases by 0.15%.

Given data:

$$p_1 = 70\ N/cm^2 = 70 \times 10^4\ N/m^2$$

$$p_2 = 130\ N/cm^2 = 130 \times 10^4\ N/m^2$$

$$\frac{\text{change in volume}}{\text{original volume}} = \frac{0.15}{100}$$

$$\therefore K = \frac{(130-70) \times 100}{0.15} = 40 \times 10^3\ \frac{N}{m}$$

2. ~~10~~ What is the bulk modulus of elasticity of a liquid which is ~~converted~~ compressed in a cylinder from a volume of $0.0125\,m^3$ at $80\,N/cm^2$ pressure to a volume of $0.0124\,m^3$ at $150\,N/cm^2$ pressure? (18)

Given data:

$\forall_1 = 0.0125\,m^3$ (12)

$p_1 = 80\,N/cm^2 = 80 \times 10^4\,N/m^2$

$\forall_2 = 0.0124\,m^3$

Team2 $p_2 = 150\,N/cm^2 = 150 \times 10^4\,N/m^2$

$K = ?$

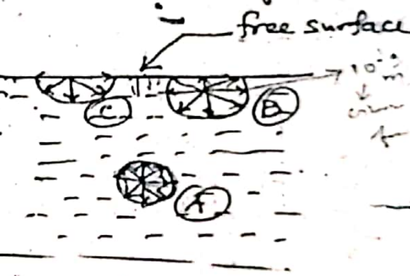
Solution

$$K = \frac{dp}{\frac{dv}{v}} = \frac{70}{\frac{1 \times 10^{-4}}{0.0125}} = 8750\,N/m^2$$

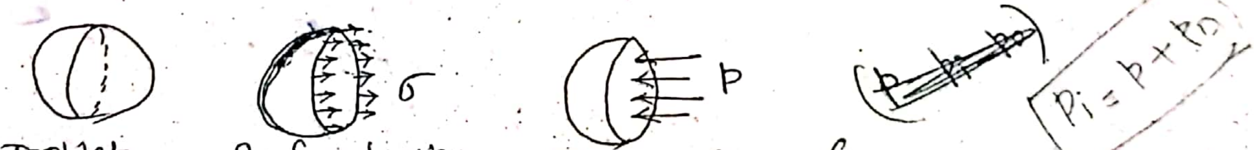
Surface Tension & Capillarity

Surface tension (σ): Defined as the tensile force acting on the surface of a liquid which is in contact with a gas or on the surface between two immiscible liquids such that the contact surface behaves like a membrane under tension.

$$\sigma = \frac{\text{Force}}{\text{unit length}} = \frac{\text{Surface energy}}{\text{Unit area}} = \frac{kgf}{m}$$



Surface tension on Liquid droplet



Droplet   Surface tension (tensile force)   Pressure forces. (in excess of the outside pressure intensity)

Tensile force $= \sigma \times \pi d$

Pressure force $= p \times \frac{\pi}{4} d^2$

Forces are equal and opposite ~~in~~ under equilibrium condition,

$$\sigma \times \pi d = p \times \frac{\pi}{4} d^2$$

$$\boxed{\sigma = \frac{pd}{4}}\ \frac{N}{m} \qquad \boxed{p = \frac{4\sigma}{d}}$$

E.g. Soap bubble in air

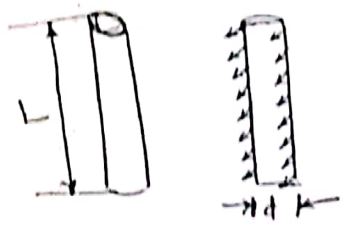
Tensile force $= 2 \times \sigma \times \pi d$ (on both sides) σ,

Pressure force $= p \times \frac{\pi}{4} d^2$

$\therefore \quad 2 \times \sigma \times \pi d = p \times \frac{\pi}{4} d^2$

$$\boxed{\sigma = \frac{pd}{8}} \qquad \boxed{p = \frac{8\sigma}{d}}$$

Surface tension on a liquid jet



Tensile force $= 2 \times L \times \sigma$

pressure force $= p \times L \times d$

$2 \times \cancel{L} \times \sigma = p \times \cancel{L} \times d$

$$\boxed{\sigma = \frac{pd}{2}} \qquad \boxed{p = \frac{2\sigma}{d}}$$

1. 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 data:

$\sigma = 0.0725$ N/m — Water droplet

$p = 0.02$ N/cm² $= 0.02 \times 10^4$ N/m²

$d = ?$

$p = \frac{4\sigma}{d} = \frac{4 \times 0.0725}{d} \quad \therefore d = \frac{4 \times 0.0725}{0.02 \times 10^4} =$

$= 0.00145$ m $= 1.45$ mm

~~What is the bulk modulus of elastic~~

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

Given data

$d = 40$ mm $= 40 \times 10^{-3}$ m

$p = 2.5$ N/m²

$\sigma = ?$

$\sigma = \frac{pd}{\cancel{4}8} = \frac{2.5 \times 40 \times 10^{-3}}{\cancel{4}8} = 0.0125 \frac{N}{m}$

...e pressure outside the droplet of [illegible] is 10.32 N/cm² (Atm. pressure). Calculate the pressure within the droplet if surface tension is given as 0.0725 N/m of water.

Given data

$P_o = 10.32 \times 10^4 \ N/m^2$ $\quad (\cancel{P_o + P_i = P})$ $\quad \boxed{P = P_i - P_o}$ $\quad$ 20

$\sigma = 0.0725$

$d = 0.04 mm = 0.04 \times 10^{-3} m$

We know that

$$\sigma = \frac{Pd}{4}$$

Team 4

$$P = \frac{\sigma \times 4}{d} = \frac{0.0725 \times 4}{0.04 \times 10^{-3}} = 7250 \ N/m^2$$

$$= 7250 \times 10^{-4} \ N/cm^2$$

$$P = 0.725 \ N/cm^2$$

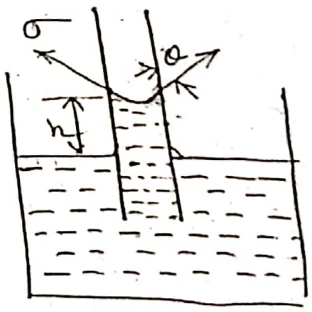
$$\therefore P_i = 10.32 + 0.725 = 11.045 \ N/cm^2$$

Capillarity:

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

The rise is known as capillary rise and fall is known as capillary depression. Unit is "mm"

It depends upon specific weight, dia of tube and surface tension of liquid



Expression:

Under state of equilibrium,

Weight of the liquid of height h in the tube = Surface tension

i.e $$\frac{\pi}{4} d^2 \times h \times \rho \times g = \sigma \times \pi d \times \cos\theta$$

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

$\boxed{\theta \text{ for water} = 0}$

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

1. Calculate the Capillary rise in a glass tube of 2.5 mm diameter when immersed vertically in (a) water and (b) mercury. Take $\sigma = 0.0725$ N/m for water and $\sigma = 0.52$ N/m for mercury in contact with air. The $S_m = 13.6$ (Specific gravity) $\theta = 130°$ (angle of contact)

Given data

$d = 2.5\,mm = 2.5 \times 10^{-3} m$

$\sigma_w = 0.0725$ N/m

$\sigma_m = 0.52$ N/m

$S_m = 13.6$

$\theta = 130°$

$h = ?$

Solution

$$h_w = \frac{4\sigma\cos\theta}{\rho \times g \times d} = \frac{4 \times 0.0725 \times 1}{1000 \times 9.81 \times 2.5 \times 10^{-3}} = 0.0118\,m = 11.8\,mm$$

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

$$S_m = \frac{\rho_m}{\rho_w} = \quad \rho_m = S_m \times \rho_w = 13.6 \times 1000$$

$$\therefore h_m = \frac{4 \times 0.52 \times \cos 130°}{13.6 \times 1000 \times 9.81 \times 2.5 \times 10^{-3}} = -4.008\,mm$$

2. Find out the min. size of glass tube that can be used to measure water level if the capillary rise in the tube is to be restricted to 2 mm. Consider the surface tension of water in contact with air as 0.073575 N/m.

Given data:

water

$h_w = 2mm = 2 \times 10^{-3} m$

$\sigma_w = 0.073575$ N/m

$d = ?$

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

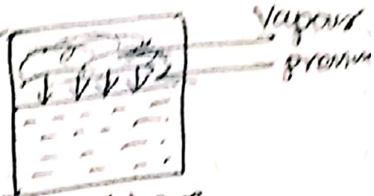
$$d = \frac{4\sigma\cos\theta}{\rho \times g \times h_w} = \frac{4 \times 0.073575 \times 1}{1000 \times 9.81 \times 2 \times 10^{-3}} = 0.015\,m$$

$$= 15\,mm$$

pour Pressure :

A change from liquid state to gaseous state is known as vapourization. It is because of continuous escape of the molecules through the free liquid surface.

If we decrease existing pressure to vapour pressure, boiling point of water decreases. This leads to cavitation.



cavitation.

In a flowing liquid in the system, if suppose pressure in the system falls below the vapour pressure, bubbles will form and later these bubbles will collapse and give rise to high ~~temp~~ pressure, which erodes and forms cavities in the piping system.

Note:

$$\boxed{\begin{array}{l} 1\ \text{mlitre} = 1000\ mm^3 \\ 1\ m^3 = 1000\ \text{litre} \end{array}}$$

Concepts of System:

A system is one which has a definite boundary. Herein fluid mechanics, it is defined as lump of fluid in space. Its a like a "fluid element". Mostly it may be triangular prism or a parallelopiped shape.

Types of system:

(1) Open system: mass and momentum enter and leave the System

(2) closed System : No transfer of above

(3) isolated system :

Control Volume:

An open system is also referred to as a control volume. It may be defined as an identified volume fixed in space. Boundaries around the control volume are known as control surfaces. They are expressed as ∂V and ∂S respectively. Rate of change of mass, momentum and energy across the control surfaces are known as mass flux, momentum flux and energy flux respectively.