MECHANICAL PROPERTIES OF FLUIDS.

Fluid is a substance which can flow
— liquids & gases are fluids.

* liquid has a definite volume and a free surface on its own while gas can expand to occupy all the space available to it.
* The atoms / molecules are arranged in a random manner in a fluid.
* As fluids don't have a definite shape, it has no shear modulus of elasticity but it can withstand a force in a direction perpendicular to its surface — it has Bulk modulus of elasticity.

PRESSURE:

The pressure at a point on a surface is the thrust (force) acting normally per unit area at that point. $P = F/A$

S.I unit Nm^{-2} or Pascal (Pa).

Applications based on concept of pressure.

(i) Railway tracks are laid on wooden / concrete sleepers — This spreads force due to the weight of the train on a large area and hence reduces the pressure considerably. This in turn, prevents the yielding of the ground under the weight of the train.

(ii) A sharp pin pierces the skin of a human easily while a trickster can lie on a bed of nails which eventually spreads the weight of the person evenly on all the nails hence brings no ~~harm~~ injuries.

PASCAL'S LAW :

(i) The pressure exerted at any point on enclosed liquid is transmitted equally in al directions.

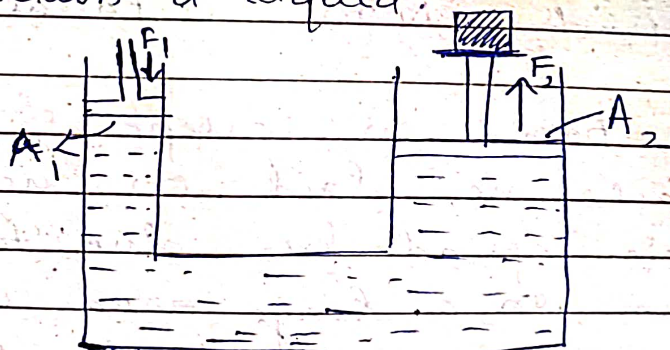
(ii) A change in pressure applied to an enclosed incompressible fluid is transmitted undiminished to every point of the fluid and walls of the vessel.

(iii)

Applications of Pascal's Law :

Hydraulic Lift : Hydraulic lift is an application of Pascal's Law which is used to lift heavy objects. It is also called force multiplier.

It consists of 2 cylinders C_1 and C_2 connected to each other by a pipe. The cylinders are fitted with water tight frictionless pistons of different cross-sectional areas. The cylinders and pipe contains a liquid.



Suppose a force F_1 is applied on the smaller piston of cross-sectional area A_1. Then, pressure exerted on the liquid

$$P = F_1/A_1$$

According to Pascal's Law, the same pressure P is also transmitted to the larger piston of cross-sectional area A_2.

~~A_2~~ $A_2 > A_1$

∴ Force on the loaded end (larger piston)

$$F_2 = P \times A_2$$

$$= \frac{F_1}{A_1} \times A_2 = \frac{A_2}{A_1} \times F_1$$

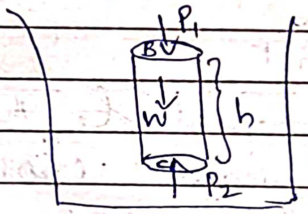
As $A_2 > A_1$ therefore $F_2 > F_1$

Hence by making the ratio A_2/A_1 large, very heavy loads can be lifted by the application of small force.

* Another application of pascal's Law is hydraulic brakes in automobiles.

Variation of fluid pressure with depth

Consider a liquid at rest in a container. Imagine a cylindrical column of liquid of cross-sectional area 'A' and height 'h'. Let P_1 and P_2 be the pressure at two points B and C resp.



As the liquid cylinder is in equilibrium

Net upward force = Net downward force.

Upward forces ~~are~~ on the bottom of the cylinder, $F_2 = P_2 \times A$

Net Downward force = weight of the liquid cylinder + downward force on the top of cylinder.

$$= Mxg + P_1 A$$

$$= Ah\rho g + P_1 A$$

$$\therefore P_2 A = Ah\rho g + P_1 A$$

$$P_2 = P_1 + h\rho g.$$

If the point 'B' is shifted to ~~top~~ the liquid surface, then P_1 can be replaced by atmospheric pressure and $P_2 = P$

Then $P = P_a + h\rho g$.

* $\&\ P - P_a = h\rho g$

* The liquid pressure is the same at all points at the same horizontal level or at same depth.
* Pressure at any pt. inside the liquid depends on depth h.
* The actual pressure P at a depth 'h' below the liquid surface open to the atmosphere is greater than the atmospheric pressure by an amount $h\rho g$. The excess pressure $P - P_a$ is called gauge pressure.
* Pressure does not depend on the shape of the vessel (ie does not depend on cross-sectional area) ~~or~~ –

Atmospheric pressure at a point is equal to the force/wt exerted by air column of unit cross-sectional area extending from that point to the top of atmosphere. At sea level it is 1.013×10^5 Pa.

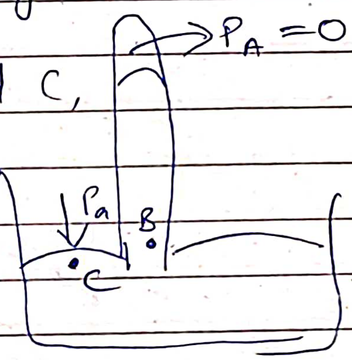
$$1\ \text{atm} = 1.013 \times 10^5\ \text{Pa}.$$

Mercury Barometer

E. Toricelli was the first to design a method for measuring atmospheric pressure.

A 1m long glass tube closed at one end

is filled with Mercury. After closing the end of the tube with thumb, it is inverted into a trough containing Mercury. As the thumb is removed, the mercury level in the tube falls down a little & comes to rest at a height of 76 cm above the lev. mercury level in the dish.



Consider two points B and C, pressure at these points are equal which is equal to atmospheric pressure. If h is the height of Mercury column, ρ its density then

$$P_B = P_A + h\rho g$$

$P_A = 0$ because space above mercury in the tube is almost vacuum.

$$\therefore P_B = h\rho g$$

$$\therefore P_B = \text{atm. pr.} = 1.013 \times 10^5 \text{ Pa} = 1\text{atm}$$
(after subs. values for $h\rho g$).

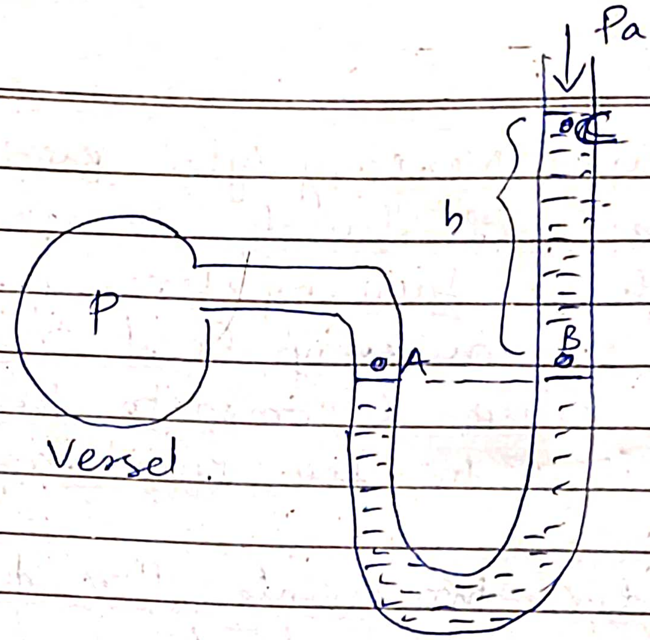
For a mercury barometer, $h = 76$ cm. (At sea level)

It is seen that the Hg level in the barometer has a height of 76cm at sea level.

Open Tube Manometer :

It is a simple device used to measure the pressure of a gas enclosed in a vessel. It consists of a U-tube containing some liquid. One end of the tube is open to the atmosphere & the other end connected to the vessel.

The total pressure P of the gas is equal to the pressure at A.



Manometer.

* ∴ $P = P_A = P_C + h\rho g = P_{atm} + h\rho g$

h = BC, diff. in the levels of the liquid in 2 arms & ρ is the density of ~~press~~ liquid

* $P_g = P - P_a = h\rho g$ where P is the actual pr at a point & P_a → atm. pressure and P_g → gauge pr. Many devices measure the gauge pr. directly (tyre pr. gauge, sphygmomanometer etc).

Height of Atmosphere

Assume density of air to be uniform & variations of 'g' with height is neglected then

pressure exerted by height 'h' of air column = Pressure exerted by 0.76 m of Hg.

$h\rho g = 1.013 \times 10^5$ Pa

$h = \frac{1.013 \times 10^5}{\rho g} \approx 8$ km.

(Practically, both ρ and g decrease with height, so atmosphere extends with decreasing pressure beyond 100 km)

Different units of Pressure

SI unit $N m^{-2}$ or Pa.

1 atm = 1.013×10^5 Pa

In meteorology, the atm. pr. is measured in bar and millibar.

1 bar = 10^5 Pa

1 milliBar = 10^{-3} bar = 100 Pa.

It is also measured in Torr

1 Torr = 1 mm of Hg.

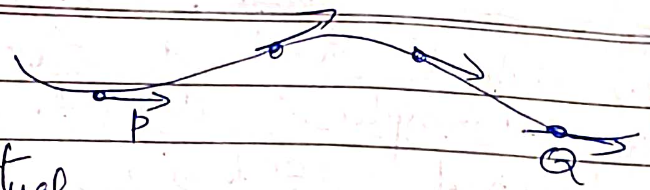
∴ 1 atm = 1.013 bar = 760 tor.

(The blood pressure is measured in mm of Hg. When the heart contracts to pump blood — pressure of blood in major arteries is 120 mm of Hg — systolic pressure. When heart expands the blood pressure is 80 mm of Hg — diastolic pressure).

Stream line flow and Turbulent Flow:

Stream line flow — when a liquid flows such that each particle of the liquid passing a given point moves along the same path and has same velocity as its predecessor, the flow is called stream line flow or steady flow ie. velocity of each particle (along a particular path) remains constant with time. Each particle follows a smooth path, & their paths donot cross each other.

When a liquid flows, the path taken by a particle — flow line.



The actual path taken by a fluid particle (curved or straight) under steady flow — Stream line. It is defined as a ~~direct~~ curve whose tangent at any point is in the direction of the fluid velocity at that point.

Tube of flow : A bundle of stream lines forming a tubular region — tube of flow.

Turbulent flow - when the liquid velocity exceeds a certain limiting value, called critical velocity, the liquid flow path and velocity of liquid particles change continuously. This is called turbulent flow.

Properties of stream lines:

* No 2 stream lines can cross each other. if they do so, the fluid particle at the point of intersection will have 2 directions of flow - which is not steady flow.

* The tangent at any point on the stream line gives the direction of fluid particle at that point.

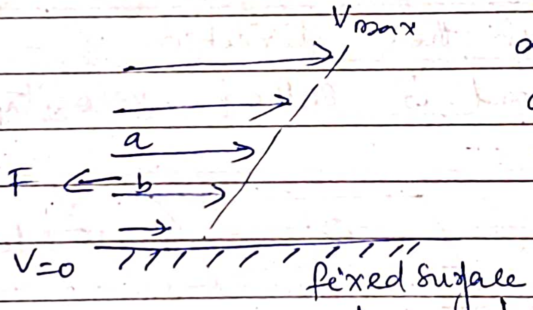
* Greater the no. of stream lines passing normally thru' a section of fluid, larger is the fluid velocity at that section.

LAMINAR FLOW: when the velocity of a fluid is less than its critical velocity, the liquid flows steadily. Each layer of the liquid slides over the other layer. ∴ such a flow is called laminar flow. When a viscous liquid flows through a pipe, the velocity layer along the axis is max, the velocity decreases towards the walls & becomes zero for the layer in contact with the pipe.

Viscosity

Viscosity is the property of fluid by virtue of which an internal force of friction comes into play when a fluid is in motion which opposes the relative motion b/w its different layers. This viscous force / drag acts tangentially on the layers of the fluid in motion.

Consider any two adjacent layers a and b as we move towards the axis of a pipe.



The upper layer 'a' tend to accelerat the lower layer 'b' while the lower layer tends to retard the upper layer 'a'. Due to this, a backward tangential force F — viscous drag comes into play which tends to destroy the relative motion.

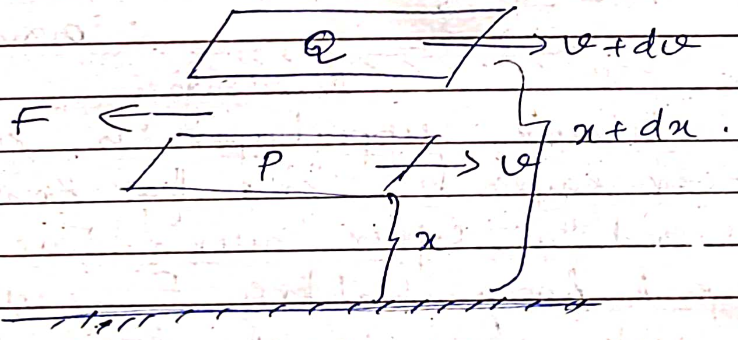
* Eg: when we stir a liquid in a beaker with a spoon, it starts rotating in co-axial cylindrical layers and when we stop stirring, the speed of diff. layers

The internal frictional forces b/w diff. liquid layers — viscous forces and this property of a liquid is viscosity. Actual reason for viscosity is intermolecular forces / van der waals force — which is inversely prop to 7th power of inter molecular distance b/w them.

gradually decreases & water comes to
This happens because viscous force
b/w the layers oppose their relative mot
* when we pour honey in to vessel through a funnel, it trickles down slowly as it is more viscous.
* Cloud particles fall down very slowly due to viscosity of air & hence seen floa in the sky.

Coefficient of viscosity

Suppose a liquid is flowing steadily in parallel layers on a fixed horizontal surface. Consider 2 layers P and Q at distances x and $x+dx$ from the surface and moving with velocities v and $v+dv$ resp. Then dv/dx is the rate of change of velocity with distance in the direction of increasing distance and is called velocity gradient.



A viscous force is acting tangentially b/w the 2 layers which is

a) proportional to the area A of the layers in contact ie $F \propto A$.

b) proportional to the velocity gradient dv/dx b/w the 2 layers.

$$F \propto \frac{dv}{dx}.$$

combining,

$$F \propto A\frac{dv}{dx}$$

$$F = -\eta A \frac{dv}{dx}.$$

where η is the coeff. of viscosity of the liquid. It depends on the nature of the liquid and gives a measure of its viscosity (-ve sign indicates that viscous force acts opp. to the motion of the liquid.)

If $A = 1$, $\frac{dv}{dx} = 1$ then

$F = \eta$

Hence Coeff. of viscosity of a liquid may be defined as the tangential viscous force required to maintain a unit velocity gradient b/w the parallel layers each of unit area.

Dimensions of η.

$$\eta = F/A \cdot \frac{dx}{dv} = \frac{[MLT^{-2}][L]}{[L^2][LT^{-1}]}$$

$$= [ML^{-1}T^{-1}].$$

S.I unit of η is Nsm^{-2} or $kg\,m^{-1}s^{-1}$ & is called poiseuilli

c.g.s unit is called Poise

& 1 poiseuilli = 10 poise.

[c.g.s unit 1 poise = 1 dyne s cm^{-2}

(decapoise) 1 Poiseuilli = 1 N s m^{-2}

$= 10^5$ dyne × s × $(10^2 cm)^{-2}$

$= 10$ dyne s cm^{-2}

$= 10$ poise]

"optional"

Points of difference b/w viscous force & frictional force

* Viscous Force	* Frictional Force
(i) It is directly prop. to area of layers in contact	(i) It is independent of surfaces in contact
(ii) directly prop. to the relative velocity b/w liq. layers	(ii) It is independent of relative velocity
(iii) It is independent of normal reaction b/w 2 liq. layers	(iii) It is directly prop. to the normal reaction b/w surfaces in contact.

Practical applications of knowledge of η

(i) knowledge of η & its variation with temp. helps us to select a suitable lubricant for a given machine in diff. seasons.

(ii) Liquids of high η are used as buffers at railway stations.

(iii) The phenomenon of viscosity plays an impt. role in the circulation of blood thru' arteries and veins.

Dependence on temp. & Pr.

* viscosity of a liquid decreases with increase in temp but in the case of gases, viscosity increase with increase in temp. (In the case of gases, the viscosity is due to the diffusion of molecules from one moving layer to the another and rate of diffusion is directly prop. to the sq. root. of its absolute temp, ∴ $\eta \propto \sqrt{T}$ for gases.)

* Except water, viscosity of liquids increase

*

with increase in pressure. In case of water, viscosity decreases with increase in pressure for first few hundred atm of pressure. In case of gases, it is independent of pressure.

- Stokes Law and Terminal velocity

Viscous drag on a body falling thru' a fluid: When a body falls through a viscous fluid, the layer in contact with the body moves with its velocity while layer far away from the body can be considered at rest. Hence there is relative motion b/w diff. layers of fluid. As a result, the body experiences a viscous force which tends to retard its motion. This is given by Stoke's Law. According to Stoke's Law, the backward viscous force acting on a small spherical body with uniform velocity v thru' a fluid of coeff. of viscosity η is given by

$$F = 6\pi\eta r v.$$ ($r \rightarrow$ radius of the spherical body)

Terminal velocity:

When a small spherical body falls thru' a viscous medium, the viscous force experienced by it is given by

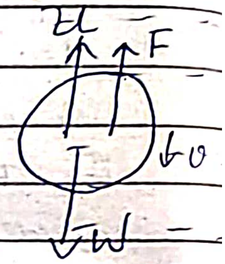
$F = 6\pi\eta r v$. This force will tend to retard its motion. As the velocity of the body increases, F also increases. A stage is reached, when the weight of the body becomes just equal to the upthrust & viscous force. Then no net force acts on the body & it begins to move with a const velocity.

*

The max. constant velocity acquired b[y a] body while falling through a viscous medi[um] is called it terminal velocity.

Consider a spherical body of radi[us] 'r' falling thru a viscous medium of densi[ty σ] and coeff. of viscosity η. Let ρ be the densit[y] of the body.

Forces acting on the body are.



(i) Weight of the body acting downward

$$W = mg = \frac{4}{3}\pi r^3 \rho g$$

(ii) Upthrust equal to weight of liquid displaced

$$U = \frac{4}{3}\pi r^3 \sigma g$$

(iii) Viscous force acting upward,

$$F = 6\pi\eta r v$$

when the body attains terminal velocity v,

$$U + F = W$$

$$\frac{4}{3}\pi r^3 \sigma + 6\pi\eta r v = \frac{4}{3}\pi r^3 \rho$$

$$\therefore v = \frac{2}{9} \cdot \frac{r^2(\rho - \sigma)g}{\eta}$$

* v is directly prop. to square of radius of the body. That is why bigger rain drops fall with a larger velocity compared to smaller rain drops.

* $v \propto (\rho - \sigma)$ i.e. diff. of densities of the body and fluid.

*

→ If $\rho > \sigma$, body will attain terminal velocity in the downward direction

→ If $\rho < \sigma$, the v will be negative, ie the body will raise through the fluid. That is why, air bubble in a liquid and clouds in the sky are seen to move in upward direction.

→ If $\rho = \sigma$, body will remain suspended in the fluid.

* $v \propto \frac{1}{\eta}$, more viscous fluid, the smaller the terminal velocity attained by a body.

* v is independent of the height through which a body is dropped.

Critical velocity

It is that limiting value of its velocity of flow upto which the flow is streamlined and above which the flow become turbulent.

$$v_c = \frac{K\eta}{\rho D}$$ where K is a dimensionless constant.

η → coeff. of viscosity of liquid

ρ → density of liq.

D → Diameter of tube.

Reynold's Number: It is a dimensionless number whose value decides the nature of flow of a liquid through a pipe.

$$R_e = \frac{\rho v D}{\eta}$$

* Flow is laminar if R_e is b/w 0 and 1000 (or < 1000)
* Flow is turbulent if R_e is > 2000
* Flow is unstable if R_e is b/w 1000 and 2000 ie ~~flow~~ it may change from laminar to turbulent or vice versa

*

→ As $V_c = \frac{K\eta}{\rho D}$

Flow of liquids of high η and low ρ thru' narrow pipes tend to be streamlined. Also liquids with low η and high ρ thru' broad pipes tend to be turbulent as V_c is v. small for them.

Equation of Continuity

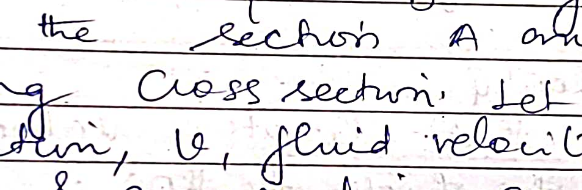
Step the proof

Consider a non-viscous and incompressible liquid flowing steadily b/w the section A and B of a pipe of varying cross section. Let a_1 be the area of cross section, v_1 fluid velocity, ρ_1 fluid density at A; & corresponding quantities at B be a_2, v_2, ρ_2.

Mass of fluid that flow thru' A in time Δt,

$$m_1 = a_1 v_1 \Delta t \rho_1$$ [Here length = vel. × time)

$$m_2 = a_2 v_2 \Delta t \rho_2$$



By Conservation of mass, $m_1 = m_2$

ie $a_1 v_1 \Delta t \rho_1 = a_2 v_2 \Delta t \rho_2$

As the fluid is assumed to be incompressible $\rho_1 = \rho_2$

$$a_1 v_1 = a_2 v_2.$$

an incompressible ... in streamlined motion, ... through a tube and the product of cross-sectional area of the tube and the velocity of ~~flow is the same at~~ every point in the tube.

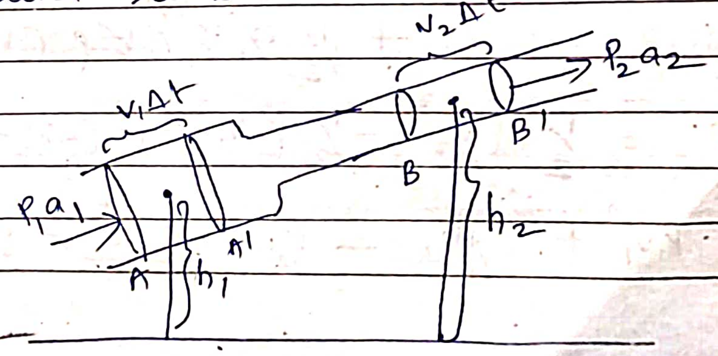
or av = Constant.

* Equation of continuity is a special case of law of conservation of mass.
* It shows that $v \propto \frac{1}{a}$ ie the liquid velocity at any section of a pipe is inversely prop. to its area of c.s.
* This explains why deep water run slowly. As the depth in a river or stream available to its increases, the area of c.s. its velocity flow increases. Consequently, with eqn of decreases in accordance continuity.
* The water gushes out thru' your fingers when you try to close the mouth of a tap with your palm.

* BERNOULLI'S PRINCIPLE

Bernoulli's principle states that the sum of pressure energy, K.E and P.E energy per unit volume of an incompressible, non-viscous fluid in a stream lined, irrotational flow remains constant.

Consider a non-viscous and incompressible fluid flowing steadily b/w the sections A & B of a pipe of varying c-s. Let a_1 be the area of c.s. at A, v_1 — fluid velocity, P_1 — fluid pressure and h_1 mean height above the ground level.



The corresponding quantities at B be, a_2, v_2, P_2 and h_2 resp.

As fluid is incompressible $\rho_1 = \rho_2 = \rho$.

Acc to eqn. of continuity,

$$a_1 V_1 = a_2 V_2 .$$

$$\left[m = a_1 V_1 \Delta t = a_2 V_2 \Delta t \right.$$

∴ change in K.E of the fluid

K.E at B − K.E at A.

$$= \frac{1}{2} m (V_2^2 - V_1^2) = \frac{1}{2} a_1 v_1 \Delta t \rho (V_2^2 - V_1^2)$$

change in P.E of the fluid

$$= P.E \text{ at } B - P.E \text{ at } A.$$

$$= mg(h_2 - h_1) = a_1 V_1 \Delta t \rho g (h_2 - h_1)$$

Net work done on the fluid

$$= W.D. \text{ at } A - W.D \text{ at } B$$

$$= P_1 a_1 v_1 \Delta t - P_2 a_2 v_2 \Delta t$$

$$= a_1 v_1 \Delta t (P_1 - P_2)$$

By law of conservation of energy,

Net W.D. on the fluid = change in K.E + change in P.E

$$a_1 v_1 \Delta t (P_1 - P_2) = a_1 V_1 \Delta t \rho g (h_2 - h_1) + \frac{1}{2} a_1 V_1 \Delta t \rho (V_2^2 - V_1^2)$$

$$P_1 - P_2 = \frac{1}{2} \rho V_2^2 - \frac{1}{2} \rho V_1^2 + \rho g h_2 - \rho g h_1$$

$$P_1 + \frac{1}{2} \rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2} \rho V_2^2 + \rho g h_2$$

or $P + \frac{1}{2}\rho v^2 + \rho gh = \text{Const}$

Hence proved

It is also stated as the sum of pressure head, velocity head & gravitational head remains const in the stream line flow of an ideal fluid. Pressure head → $P/\rho g$

velocity head → $\frac{1}{2}\frac{v^2}{g}$

and h → grav. head.

Limitations

* As we have assumed the fluid to be ideal one, in reality we need to take into account the W.D against viscous drag.
* Here elastic nature of fluids is not taken into account.
* Applicable to streamline flow of fluid.
* ~~It is also assumed that~~

→ when flow is horizontal i.e the fluid flows thru' a horizontal pipe, then there is no gravitational head (level diff.)

i.e $h_1 = h_2$

$$\therefore P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

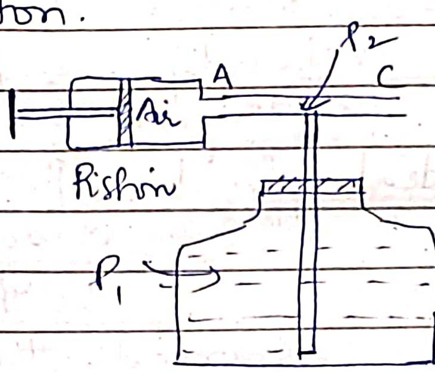
$$\text{or } P + \frac{1}{2}\rho v^2$$

which shows that if P increases, V decreases and vice-versa.

Applications

(i) Sprayer / Atomizer – Used to spray the liquid in a bottle in the form of tiny drops. It consists of a bottle B containing liquid which has vertical tube T as shown in the fig. The upper end of tube T is connected in the narrower part of another horizontal tube AC.

The narrower ~~end~~ part has a fine bore at its end C, while its other end A is fitted with a piston.



when the piston of the tube is pushed inward, a steam of air emerges out from C. The velocity of air in the narrow region AC is large due to which pressure P_2 is ~~less~~ reduced. As P_2 is less than atm pressure P_1 in the bottle, the atm. pr. exerting on the liquid surface forces the liquid to enter into the tube T, where it mixes with air and comes out as a fine spray.

(ii) Blowing off the ~~tiled~~ roof of tinned roofing sheets during storm

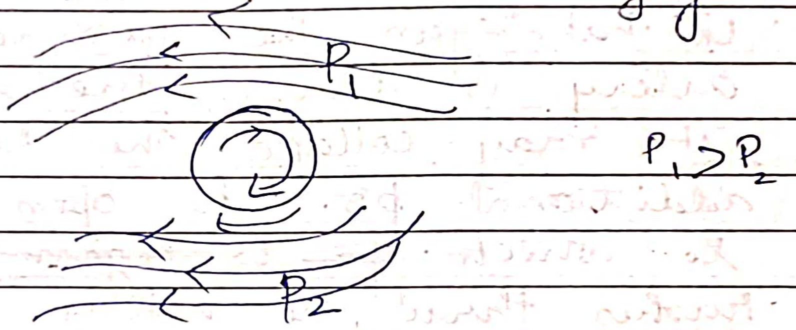
This is because when wind blows with a high velocity over a light roof, the pr. above the roof decrease acc. to Bernoulli's theorem. The pressure below the roof is the atm. pr. which is v. large. Due to this pr. diff, the roof gets lifted in the upward direction and are blown off.

(iii) when a fast moving train ~~approaches~~ passes by a railway platform, can cause a risk of pulling a ~~people~~ person towards the track if he is standing too close to the track. This is because when the train passes with high speed, the pressure b/w the person & train gets reduced where as the air behind him is still the atm. pr. Due to this pr. diff., he may be pushed towards the track.

(iv) Curved path of a spinning ball — MAGNUS EFFECT

When a cricket ball is thrown horizontally, it follows a parabolic path. But if the same ball is thrown spinning, then the ball follows a sharp curved path

When a spinning ball moves forward with large speed, then it drags air along with it as shown in the fig.



The layer of air adjacent to the upper part of the ball moves in the opposite direction while the layers close to the lower part of the ball moves in the same direction of spin (clockwise spin). Due to this, layers of air above the ball gets retarded while those below the ball gets accelerated. Due to this difference of velocities of air layers, the pressure above the ball increases while that below the ball decreases. This pr. difference cause a resultant force in the downward direction which provides the necessary centripetal force due to which it follows a sharp curved path. This dynamic lift due to spinning is called 'Magnus Effect'.

$R = \rho l / A$ $R \propto \frac{1}{r^2}$

(v) Flow of blood in the Heart and Cause Heart attack

Due to accumulation of fat (cholesterol) in the inner walls of artery, they get constricted. In order to drive blood thru' this small area, greater ~~speed~~ demand of blood is required to function properly. Due to this the speed of flow of blood in the arteries increases which lowers the pressure in that region. The pressure outside the artery is larger, due to which it may collapse. The heart exerts additional pr. to open the artery, due to which ~~pr. is again reduced~~ blood rushes thru' the artery, here by reducing the pr. again and which results in a Heart attack.

~~Note~~

SURFACE TENSION :

* The behaviour of liquids is controlled not only by gravitational force (weight) but some other force also acts between the surfaces in contact.
* All liquids have free surfaces which behaves as stretched membrane & tends to have min. surface area.
* The property by virtue of which the free surface of a liquid at rest behaves like a stretched membrane is called surface tension which is the tendency of a liquid to reduce its surface area. (A liquid stays together because of attraction b/w the molecules).

→ force of attraction b/w molecules is called intermolecular forces

→ they are of v. short range – ie 10^{-9} m

Cohesive force – force of attraction acting b/w molecules of same substance. [cohesive forces are strongest in solids – hence the shape & weakest in liquids & weakest in gases)

Adhesive force – Force of attraction acting b/w the molecules of different substances. [water sticks to the walls of container, bricks are joined thru' cement, woods joined by strong glues are few examples of these forces.) This force is different for different pairs of substances.

* Water wets glass surface while Mercury does not.

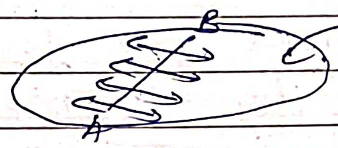
when a glass rod is dipped in water, water drops cling with it & wets it. This is due to the fact that force of adhesion b/w water molecules and glass molecules is greater than cohesive forces b/w water molecules. Mercury does not wet glass because force of cohesion is larger that force of ~~cohe~~ adhesion.

→ The free surface of a liquid is always in a state of tension & hence has a tendency to contract naturally.

→ It always acts parallel to the surface.

→ Surface tension of a liquid is measured as the force per unit length of a line imagined to be drawn tangentially on the liquid surface at rest, which acts ⊥r to this line on its either side.

~~and~~



$$T = F/l$$

S.I unit Nm^{-1}

→ T is independent of size or shape of liquid surface.

→ T depends on the temp. as well as medium on the other side of surface.

T decreases with increase in temp.

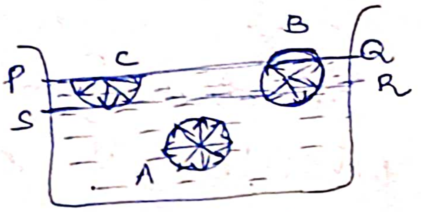
→ It is scalar quantity (no particular direction).

→ Greater T indicates smaller surface area

→ The surface of the liquid itself experiences a net downward attractive force of tension. whenever it is required to move a molecule from the interior of the liquid to the surface, an amount of work has to be done on it against the

Molecular range : Max. distance upto which a molecule can exert force of attraction on other molecules : ($\sim 10^{-9}$m).

Sphere of influence - A sphere drawn around a molecule as centre and with a radius equal to the molecular range. (this molecule attracts all other molecules lying in its sphere of influence).



Molecular theory of S.T

PQRS → surface film.

→ A is inside the liquid, so attracted equally in all directions by molecules in its sphere of influence

→ B → its sphere of influence lies partly outside so experiences less upward force & more downward force

→ C → 1/2 of its sphere of influence inside & half outside - Due to net downward force - P.E of of such molecules is higher than those lying well inside the liquid.

→ for stability - P.E needs to be min → which indicates no. of molecules on the surface film should be min.

→ Thus it tends to acquire min. surface area or the free surface of a liquid at rest behaves like a stretched membrane.

Illustrations of S.T

(i) A greased needle can be supported on water surface The floating needle causes a little depression ~~which acts~~ along which surface tension acts (along the curved surface of depression) The vertical components

of surface tension support the weight of the
needle.

(ii) Rain drops are generally spherical in shape
as they tend to minimise their S.A. & the S.A
of a sphere is min. for a given volume. But larger
drops of liquid are flattened because force of
surface tension is outweighed by the weight of
the drop. [to keep centre of gravity as low as
possible, it shifts to a lower position — so
P.E is min.]

(iii) A piece of Camphor dances on water surface
→ Due to its irregular shape, the camphor
piece dissolves more rapidly at some regions.
The surface tension is reduced at these regions
and as the force of S.T. reduces by different
amounts at different region points, a resultant
force acts on it which makes it unstable on
the water surface.

(iv) Oil spreads on cold water but remains as a drop
on hot water. This is because surface tension of oil
is less than that of cold water but it is greater than that
of hot water.

Surface Energy:

The free surface of a liquid possess
min surface area due to surface tension. To
increase the surface area, molecules have to be
brought from the interior to the surface. Work
has to be done against forces of attraction. This

work done is stored as the P.E of the molecules on the surface. So the molecules at the surface have extra energy compared to the molecules in the interior.

The extra energy possessed by the molecules of surface film of unit area compared to the molecules in the interior is called surface energy. It is equal to the work done in increasing the area of the surface film by unit amount.

$$S.E = \frac{W.D}{\text{Increase in } S.A}$$

It is also defined as the P.E. per unit area of the liquid surface.

[excess P.E or W.D. is stored in the newly formed surface. Besides this, there is cooling due to increase in the area of the film. To keep its temp. const, heat flows into the liq. surface from the surroundings & is added to the P.E energy of the surface. So the molecules at the surface have some additional energy].

S.T. of a liquid is the amt. of W.D. in increasing the surface area of a liquid film by unit amount at const. temp. or S.T. is the surface energy/unit area of the liquid interface.

$$S.T = \frac{\text{Work done}}{\text{Increase in area}}$$

or $W.D = \sigma \times \Delta a$.

Factors affecting the surface Tension

(i) Effect of Temperature : S.T. decreases with increase in temperature.

(ii) Effect of solute : S.T. varies with concentrations of solutions. If the solute is easily soluble, then S.T of liquid increases. (Eg: Salt in water → S.T increases]. If the solute is less soluble, S.T decreases [detergent in water → S.T. decreases.

(iii) Effect of contamination : dust, grease / oil present on the surface of water, S.T. reduces.

Angle of Contact :

The angle b/w the tangent to the liquid surface and the tangent to the solid surface inside the liquid at the pt. of contact → angle of contact.

* It depends on the nature of ~~solid~~ liquid & solid in contact

* increases with increase in temp. of liquid.

* Value of angle of contact is acute ($\theta < 90^\circ$) for those liquids which wet the walls of solid (water & glass) and have a meniscus concave upwards. The ∠le of contact is obtuse ($\theta > 90^\circ$) for the liquids which do not wet the solid (mercury and glass) and have meniscus convex upward.

$\theta = 0^\circ$ for pure water in contact with glass plate.