VISCOSITY OF FLUIDS

Fluid:

→ Fluid is a phase/state of matter in which it flows. Fluids are subset of the phases of matter and include liquids, gases plasmas and to some extent plastic solids.

Viscosity:

→ "is the resistance to flow a fluid".

Main points:

→ The stronger the intermolecular forces of attraction, the more viscous is the fluid

→ When two adjacent liquid layers flow relative to each other, they offer resistance / internal friction This internal friction is called viscosity.

→ Viscosity causes part of K.E of fluid to convert into internal energy.

→ The numeric value of resistance to flow of fluid is called coefficient of viscosity η. It decreases with temprature.

Units:

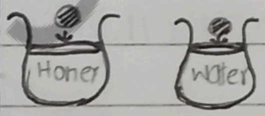
→ pascal second (Pas) SI

→ dyne second per square centimeter (dyne second) [given the name of poise (P)] most common unit (↑)

→ 1 Pas = 10 poise

→ 1 centipoise = 1 millipascal second

FUN WAY TO LEARN



Drop a stone in water and honey. You'll notice that stone reaches the bottom first in water container. It's because water is less viscous (offers less resistance) as compared to honey. :)

FLUID FRICTION | DRAG FORCE | STOKES LAW

FLUID FRICTION	DRAG FORCE	STOKES LAW
	definition	
↳ Fluid friction occurs when adjacent layers in a fluid are moving at different velocities.	↳ When an object moves through a fluid, the fluid exerts a retarding force on the object called drag force.	↳ The viscous drag force on a spherical object is expressed mathematically by a formula called stokes law.
	dependent on	
↳ Depends on the viscosity of the fluid. i.e., Blood offers more fluid friction than water.	↳ Depends on fluid's properties. • on size shape and orientation of object • speed of the object relative to the fluid.	↳ $F_D \propto \eta r v$ $\boxed{F_D = A\eta r v}$ hence depends on radius 'r', coefficient of viscosity eta 'η' and velocity of the **spherical object**. where $A = 6\pi$

mcq points :-

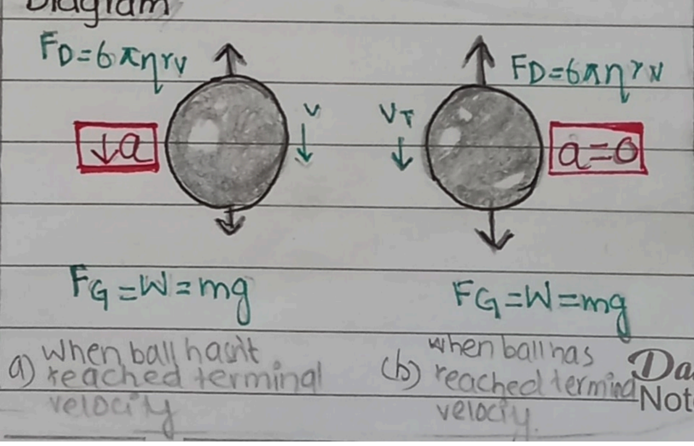
- ↳ The equation termed as stokes law was set forth by the British scientist Sir George G. Stokes in 1851
- ↳ Viscosity of the blood is 1.6×10^{-3} (outside the body) and 4.0×10^{-3} (at body temprature)
- ↳ Air has viscosity 1.8×10^{-5}
- ↳ Honey has viscosity 1.42.

TERMINAL VELOCITY :-

Definition:

→ The constant maximum velocity that is attained and maintained by an object while falling through a resistive medium is called terminal velocity V_T.

Diagram



Main points:

→ Terminal velocity is attained when 'acceleration' terminates i.e., acceleration reduces to 0.

→ At terminal velocity, weight of the body becomes equal to the drag force. → Depends on size, shape and orientation of object and viscosity of medium.

Mathematical explanation:

↳ F_{net} (acting on body falling through resistive medium) = F_G (weight) − F_D (drag) ··· (i)

• when the body hasn't attained 'v_t' (terminal velocity); eq (i) becomes

$$ma = mg - 6\pi\eta r v$$

• when the body has attained 'v_t' eq (i) becomes

$$m(0)_{\text{as a terminates}} = mg - 6\pi\eta r v_T$$

$$mg = 6\pi\eta r v_t$$

or $$\boxed{v_t = \frac{mg}{6\pi\eta r}}$$

For sphere, $$\boxed{v_T = \frac{2\rho g r^2}{9\eta}}$$

FUN FACTS:-

↳ A person reaches v_t after 12 seconds covering a distance of 450 meters.

↳ A paratrooper attains v_T twice; once before and once after opening the parachute.

Note: There's no single speed for terminal velocity.

FLUID FLOW:-

↳ laminar	↳ turbulent
Definition	
→ If every particle of the fluid that passes through a particular point, moves along exactly the same path as passed by the particles which have flown through that point earlier, the flow is said to be laminar.	→ A disordered and non-uniform flow of particles in whirlpool like paths is called turbulent flow.
Tends to occur at	
→ low speed, high viscosity	→ high speed, low viscosity.

area present

→ The area provided by the path is sufficient for particles to flow.

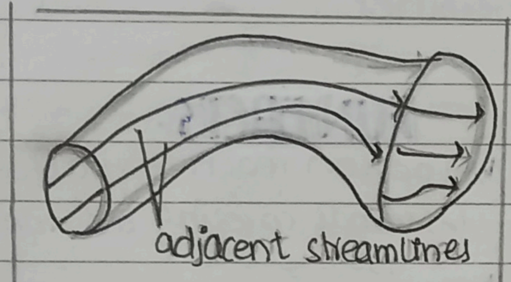
→ There are more particles required to pass through a path offering less area.

examples

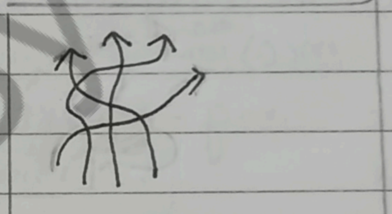
• Fluid flowing in a pipe having uniform cross-sectional area offering no height differences is an example of laminar flow.

rising smoke
blood flow in arteries
lava flow
oil transport in pipelines

diagram



△ streamline tube



△ chaotic turbulent path.

L. ideal fluid:

1. Has no viscosity, object flowing through it experiences no drag force.
2. Has a laminar flow. The velocity of fluid at each point remains constant
3. Isn't compressible, has constant density
4. Flow is irrotational; has no angular momentum.
5. It's temprature remains constant despite external conditions being applied

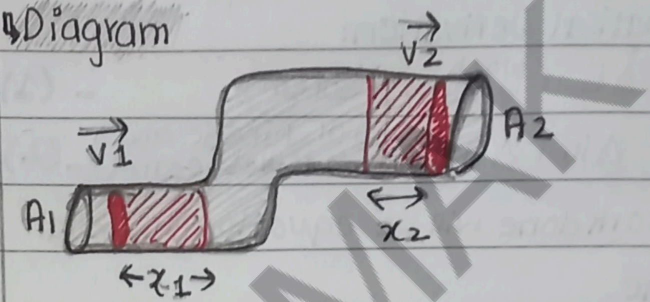
EQUATION OF CONTINUITY :-

Statement:

The product of cross sectional area and the speed of the fluid at any point along the pipe is constant.

→ $\boxed{A \propto \frac{1}{V\downarrow}}$, $\boxed{A\downarrow V\uparrow x\uparrow}$, $\boxed{A\uparrow V\uparrow x\downarrow}$

Diagram



Mathematical derivation:

[consider the fluid to be ideal]

$A_1V_1 = A_2V_2$; $AV = $ constant. (V=velocity, A=crosse-sectional area)

$\Delta m_1 = \Delta m_2 = \Delta m$ —①

$d_1 = d_2$ (density)

so $V_1 = V_2$; $d = \frac{m}{V}$

Density ⇒ $\rho = \frac{\Delta m}{\Delta V} \Rightarrow \Delta m = \rho \times \Delta V$ —②

Volume ⇒ $\Delta V = A\Delta x$ (volume = Area × height) —③

↳ $V = L \times B \times H$, $(L\times B = A)$, $V = A\times H$

Average speed ⇒ $\Delta x = v\Delta t$ $(S = vt)$ —④

[Now put equation (4) in 3]

$\Delta V = (A)(v\Delta t) \Rightarrow \Delta V = Av\Delta t$.

[putting equation (5) in eq (2)]

$\Delta m = \rho \times Av\Delta t$

$\boxed{\Delta m = \rho A v \Delta t}$, $\Delta m_1 = \rho A_1 V_1 \Delta t$

$\Delta m_2 = \rho A_2 V_2 \Delta t$

$\Delta m_1 = \Delta m_2$

$\cancel{\rho} A_1V_1\cancel{\Delta t} = \cancel{\rho} A_2V_2\cancel{\Delta t}$

$\boxed{A_1V_1 = A_2V_2}$

easy way to memorize:-
memorize it through the abreviation "DVA"

Equation of continuity shows law of conservation of mass.

BERNOULLI'S EQUATION :-

Statement:

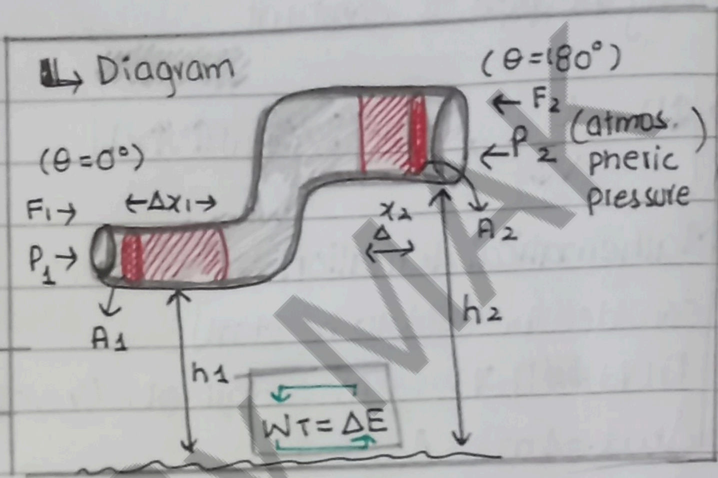
Bernoulli's equation that relates the pressure, flow speed and height for flow of an ideal fluid.

Mathematical Derivation:

$W = \Delta E$ (work energy theorem) – (1)

or $W = \Delta K + \Delta U$ (sum of kinetic and potential energies) – (2)

Total work done will be equal to individual work done.



for end 1;	for end 2;
$W_1 = F_1 \Delta x_1 \cos(0)$	$W_2 = F_2 \Delta x_2 \cos(180)$
$W_1 = F_1 \Delta x_1$ – (3)	$W_2 = -F_2 \Delta x_2$ – (4)

Pressure ⇒ $\left(P = \frac{F}{A}\right)(F = PA)$

For end 1 [Putting value of P_1, P_2]	For end 2
$W_1 = P_1 A_1 \Delta x_1$ – (5)	$W_2 = -P_2 A_2 \Delta x_2$ – (6)

Density ⇒ $\left(\rho = \frac{\Delta m}{\Delta V}, \Delta V = \frac{\Delta m}{\rho}\right)$

$\left(\frac{\Delta m}{\rho} = A \Delta x\right)$ $a \times H = V$

For end 1 [putting value of $A \Delta x$]	For end 2
$W_1 = P_1 \frac{\Delta m_1}{\rho}$ – (7)	$W_2 = -P_2 \frac{\Delta m_2}{\rho}$ – (8)

now we know that $W_t = W_1 + W_2$ – (9)

putting eq (7) and eq (8) in (9)

we get, $W = P_1 \frac{\Delta m_1}{\rho} - P_2 \frac{\Delta m_2}{\rho}$ – (10)

ΔK.E ⇒ $\Delta K = \frac{1}{2} \Delta m_2 v_2^2 - \frac{1}{2} \Delta m_1 v_1^2$ – (11)

ΔP.E ⇒ $\Delta U = \Delta m_2 g h_2 - \Delta m_1 g h_1$ – (12)

(10),

putting values from eq (11) and (12) in eq (2)

$$P_1 \frac{\Delta m_1}{\rho} - P_2 \frac{\Delta m_2}{\rho} = \frac{1}{2} \Delta m_2 v_2^2 - \frac{1}{2} \Delta m v_1^2 + \Delta m g h_2 - \Delta m g h_1$$

$[\Delta m = \Delta m_1 = \Delta m_2]$

$$P_1 \frac{\Delta m}{\rho} - P_2 \frac{\Delta m}{\rho} = \frac{1}{2} \Delta m v_2^2 - \frac{1}{2} \Delta m v_1^2 + \Delta m g h_2 - \Delta m g h_1$$

$$\frac{P_1 - P_2}{\rho} = \frac{1}{2} v_2^2 - \frac{1}{2} v_1^2 + g h_2 - g h_1$$

[bringing all the variables containing (1) on left and (2) on right]

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

or

$$\boxed{P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant.}}$$

Bernoulli's equation shows law of conservation of energy.

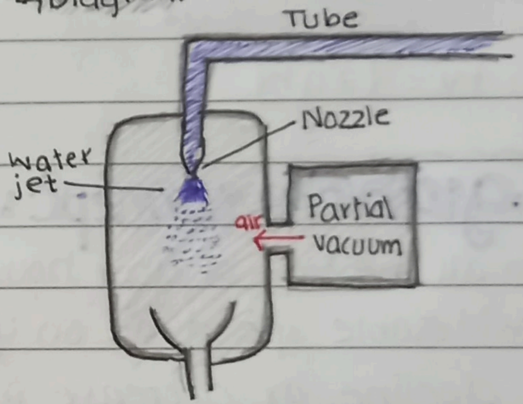
APPLICATIONS OF BERNOULLI'S EQUATION:-

a: filter pumps

Definition:

These are the devices which are used to transfer liquids from low pressure zones to high pressure zones. A filter pump is a device used to produce partial vaccuum in vessel attatched to it.

Diagram



Construction

- A tube with a jet (small opening) attatched to it
- A small vessel attatched to a larger one in which the water tube opens.

Working

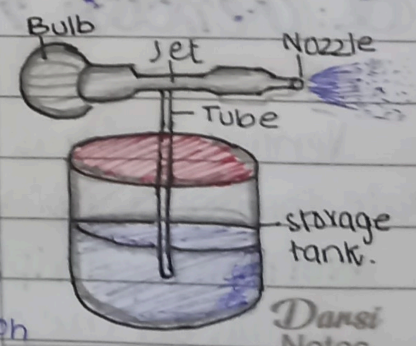
- as water reaches the jet, the speed of water increases as area (opening of tube i.e jet) decreases. $A \propto \frac{1}{v}$
- Increase in water's speed decreases the pressure around it. As a result air from the smaller vessel moves to the larger (i.e., motion from high to low concentration) $P \propto \frac{1}{v}$
- As a result, partial ~~pre~~ vaccuum or instantaneous vacuum is formed in the vessel.

b: atomizer

Definition:

A device for emitting water, perfume etc as fine spray

Diagram



Construction

- a bulb attatched to an open tube through a jet
- a storage tank

Working

- Bulb is squeezed which forces air out decreasing the air pressure above the tube
- water flows to lower concentration and is emitt as a fine spray.

Q: Torricelli's theorem (speed of efflux) [long q.s]

Statement:

'the speed of efflux is equal to the speed gained by fluid while falling through height 'h' under the action of gravity'.

efflux:

the flowing out of a substance.

Mathematical derivation of speed:

by bernoulli's equation; $P_1 + \frac{1}{2}\rho u_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$

putting values in eq (values from the cloud given below)

$$P + \frac{1}{2}\rho(0)^2 + \rho g h_1 = P + \frac{1}{2}\rho v^2 + \rho g h_2$$

$$\cancel{P} - \cancel{P} + \rho g h_1 - \rho g h_2 = \frac{1}{2}\rho v^2$$

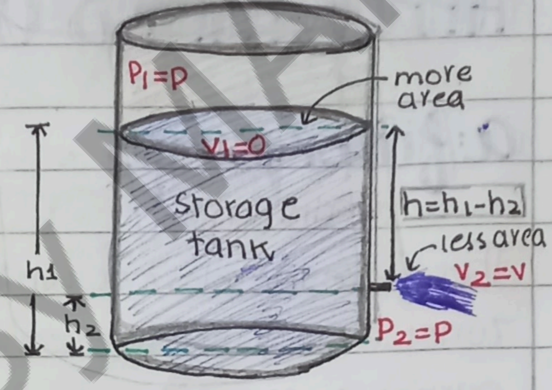
$$\rho g(h_1 - h_2) = \frac{1}{2}\rho v^2$$

$$\cancel{\rho} g(h) = \frac{1}{2}\cancel{\rho} v^2 ; \quad 2gh = v^2$$

$$\sqrt{2gh} = \sqrt{v^2}$$

$$\boxed{v = \sqrt{2gh}}$$

↳ Diagram



$h = h_1 - h_2$

$P_1 = P_2 = P$ [atmospheric]

$v_1 \neq v_2$

$v_1 = 0$, $v_2 = v$

↳ grab the concept:-

Open all the taps of your house, water will flow out of the taps with a considerable speed. go on your roof top and you'll notice that the decline or decrease in the water level of your water tanker is happening with almost negligible speed. consider this speed as v_1, it'll be zero (almost) and speed of water as it flows down the tap will be considerably high i.e. $v_2 = v$.

Q: venturi metre (flowmetre) [long q.s]

definition

Venturi meter is a device used to measure the flow speed or flow rate through a piping system.

working principle

It works on the principle of pressure difference between restricted and unrestricted flow regions.

'venturi meter basically measures pressure difference'.

Mathematical derivation:

end 1 end 2

$$P_1+\frac{1}{2}\rho v_1^2+\rho g h_1 = P_2+\frac{1}{2}\rho v_2^2+\rho g h_2$$

$$h_1 = h_2 = h$$

[To get pressure difference]

$$P_1-P_2=\frac{1}{2}\rho v_2^2-\frac{1}{2}\rho v_1^2+\cancel{\rho g h}-\cancel{\rho g h}$$

[By equation of continuity ; $A_1V_1 = A_2V_2$]

$$P_1-P_2=\frac{1}{2}\rho\left[\frac{A_1V_1}{A_2}\right]^2-\frac{1}{2}\rho v_1^2$$

$$=\frac{1}{2}\rho\left[\frac{A_1^2}{A_2^2}-1\right]v_1^2$$

$$v_1^2=(P_1-P_2)\div\frac{1}{2}\rho\left[A_1^2/A_2^2-1\right]$$

$$=(P_1-P_2)\times 2\div\left[\frac{\rho(A_1^2-A_2^2)}{A_2^2}\right]$$

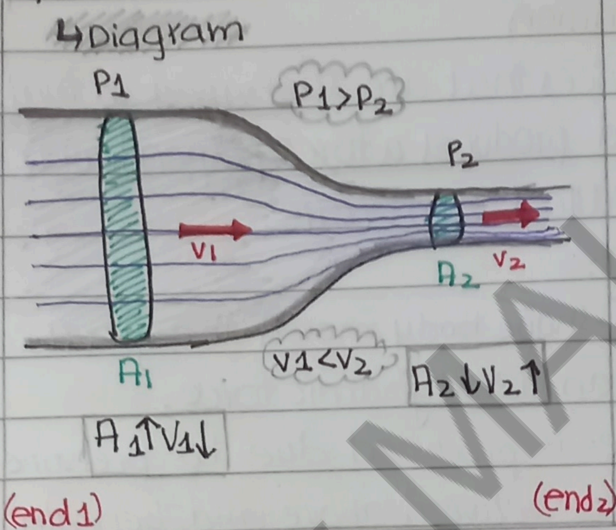
$$\sqrt{v_1^2}=\sqrt{\frac{2A_2^2(P_1-P_2)}{\rho(A_1^2-A_2^2)}} \Rightarrow V_1 = A_2\sqrt{\frac{2(P_1-P_2)}{\rho(A_1^2-A_2^2)}}$$

[we know that $(P_1-P_2)=\rho g h$]

$$V_1 = A_2\sqrt{\frac{2(\cancel{\rho}gh)}{\cancel{\rho}(A_1^2-A_2^2)}}$$

$$\boxed{V_1 = A_2\sqrt{\frac{2(gh)}{(A_1^2-A_2^2)}}}$$

↳ Diagram

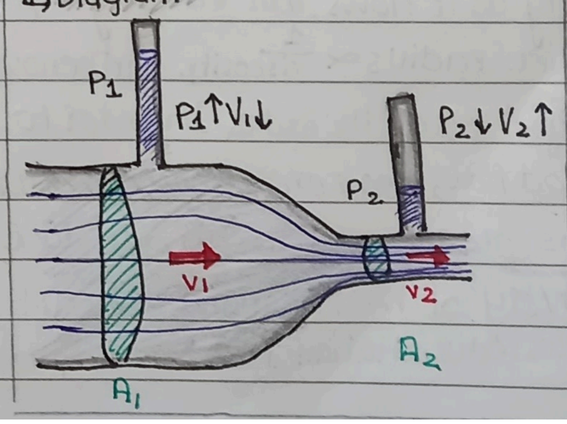


▲ wide and narrow sections of the tube.

way to convert venturi meter in a barometer

- connect two ~~to~~ calliberated tubes of same diameters at narrow and wide sections of the tube
- as $V_1<V_2$ and $P_1>P_2$, more water will rise up in the wide section tube as compared to the narrow section tube
- you can now easily note P_1 and P_2.

↳ Diagram



e: aerofoil

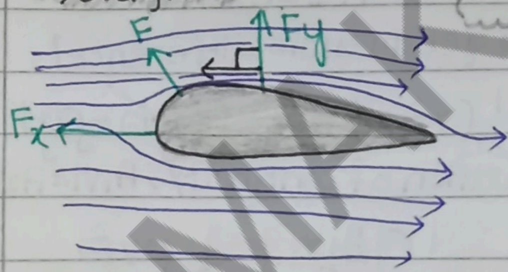
Definition

The devices that are so shaped so that the relative motion between it and the fluid produces a force perpendicular to the flow are called aerofoils.

Working:

- An airfoil-shape body moved through a fluid produces an aerodynamic force.
- This force is produced due to pressure difference between above and beneath sides of the aerofoil
- The component of this aerodynamic force which is perpendicular to the direction of motion is called lift (might be called upthrust).
- The component parallel to direction of motion is called drag.

↳ Diagram $\quad P \propto \frac{1}{v}$



above aerofoil:
- pressure less, - increased speed of fluid, - closer stream lines.

below aerofoil:
- more pressure, - less fluid speed
- spaced stream lines.

Uses:

- found in aeroplane wings, helicopters, sailboats, turbines etc.

B: Blood Flow

Definition: Blood flow means the quantity of blood that passes through a given point in the circulation in a given period. (at rest blood flow of an adult : 5000 mL/min)

Disorder:

Blood has viscosity as it flows. This viscosity depends on radius of arteries. $\text{radius} \propto \frac{1}{\text{viscosity}}$. Atherosclerosis (deposition of plague) reduces the radius. In order to maintain the blood flow, heart exerts more pressure. This can dislodge the plague and it can get stuck in a smaller artery of heart causing a heart attack. radius reduced to half increases the pressure by a factor of $2^4 = 16$

↳ diagram