Er. Iswor Rawat

Engineer

Hydraulics

Introduction

→ Hydraulics is the science that deals with the behaviour of fluid (liquid or gases) when subjected to a system of forces.

→ Under this sciences we discuss both the condition of fluids e.g. static & dynamic.

Fluid

→ Fluid means any substance that can flow.

→ Fluid are liquids & gases.

→ It has no definite shape of its own.

→ fluids deform continuously under the application of external stress (shear stress) as long as it is applied.

→ Example: Water, air, blood, Milk etc.

Real fluid	Ideal fluid
→ They have viscosity.	→ They do not have viscosity.
→ They have surface tension.	→ They do not have surface tension.
→ compressible.	→ Incompressible.
→ All existing fluids are real fluid.	→ Imaginary fluid, Not exist.
→ Density changes with change in pressure.	→ Density does not change with change in pressure.
→ Bulk modulus of elasticity finite	→ Bulk modulus of elasticity infinite

④ Specific Gravity (S)

→ Specific gravity (or relative density) is the ratio of wt. density of fluid to wt. density of standard fluids at standard temperature & pressure.

→ For liquid, standard fluid is taken water.

→ For gases, " " " " air.

→ $S = \frac{\text{Wt. density of liquid}}{\text{Wt. density of water}} = \frac{\rho}{\rho_w} = \frac{\gamma}{\gamma_w}$

∴ Density of any fluid, $\rho = S \times \rho_w$

∴ Sp. wt of any fluid, $\gamma = S \times \gamma_w$

→ Sp. gravity of water = 1 & sp. gravity of mercury = 13.6

→ If sp. gravity $S < 1$: Liquid is lighter then water.

→ If sp. gravity $S > 1$: Liquid is heavier then water.

→ $S = \frac{\text{Mass of certain volume of a fluid}}{\text{Mass of same volume of water at } 4^\circ C}$

⑤ Compressibility

→ Compressibility is the property of fluid due to which its volume changes by applying pressure.

→ $\text{Compressibility} = \frac{1}{\text{Bulk modulus of elasticity (K)}}$

→ $K = \frac{dp}{\frac{-dV}{V}} = \frac{\text{Change in pressure}}{-\text{Volumetric strain}}$

→ '−' sign means that volume decreases with increase in pressure.

→ Unit of K : N/m^2 (Pa) → Dimensions : $ML^{-1}T^{-2}$

⑥ Surface Tension (σ)

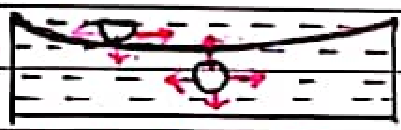
→ Surface tension is the force per unit length acting at the interface of liquid & air or at the interface of two immiscible (mix न हो) liquids.

→ Surface tension exists for liquids only.

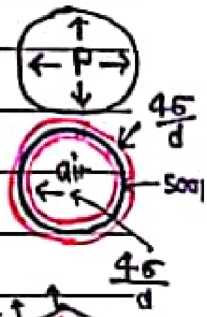
→ Due to surface tension, liquid drops become spherical.

→ Surface of liquid behaves like elastically stretched membrane.

→ Tensile force acting in the interface of a liquid & gas or two different immiscible liquids.



Internal pressure due to surface Tension



① Liquid Droplet

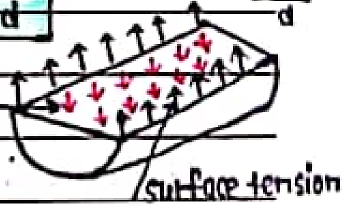
→ Internal pressure inside a liquid droplet $(P) = \frac{4\sigma}{d}$

② soap bubble

→ Internal pressure inside a soap bubble $(P) = \frac{8\sigma}{d}$

③ cylindrical jet of liquid

→ $P = \frac{2\sigma}{d}$



⑦ Capillarity

→ Capillarity is the rise or fall of liquid inside a tube of small diameter.

→ Capillary is a tube of diameter less then 6mm.

→ The unit of Capillarity is mm or cm.

→ It is caused by cohesion (surface tension) as well as adhesion.

* Cohesion force of attraction betn molecules of same liquid.

* Adhesion Force of attraction betn molecules of liquid & Solid boundary

→ When adhesion is more then cohesion, Capillary rise occurs. (eg: glass & water)

→ When cohesion is more then adhesion, Capillary fall occurs. (eg: glass & mercury)

→ Water wets the surface of glass.

→ Mercury does not wet surface of glass.

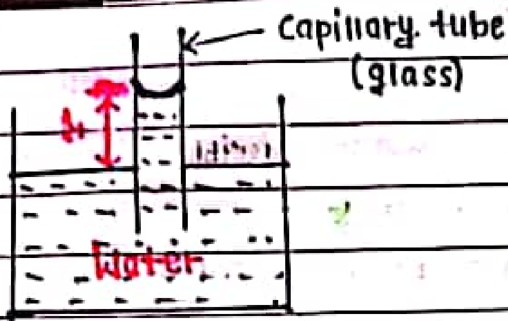


fig: Capillary rise

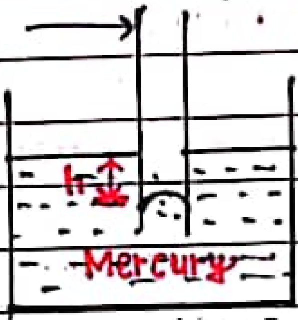


fig: Capillary fall

Expression for Capillary Rise & Fall

→ capillary rise or fall, $h = \frac{4\sigma\cos\theta}{\rho g d}$

Where; σ = Surface tension

θ = Angle of Contact = 0° for water

= 135° for mercury

ρ = density of liquid

d = diameter of tube

Factors Affecting Capillarity

① Capillarity ∝ Surface tension.

② Capillarity ∝ $1/\theta$

③ Capillarity ∝ $\frac{1}{\text{unit. wt of water}}$

④ Capillarity (h) ∝ $\frac{1}{\text{diameter of tube (d)}}$

⑧ Viscosity

→ Viscosity is the property of fluid due to which one layer of fluid opposes motion of another.

→ It is internal friction of fluid.

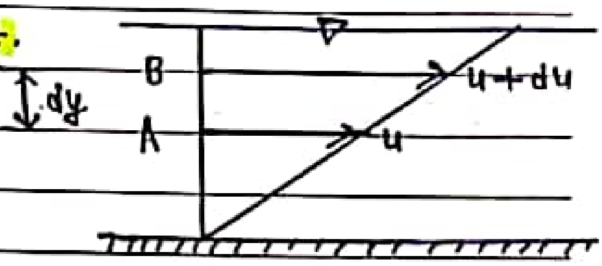
Newton's Law of Viscosity

→ It states that " Shear stress is directly proportional to velocity gradient."

→ Shear stress ∝ Velocity gradient.

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

or, $\tau = \mu \frac{du}{dy}$ ——— ①



Where: μ = Coefficient of dynamic viscosity.

Types

① Dynamic Viscosity / Viscosity (μ)

Unit of μ

① SI unit of μ

We have, $\tau = \mu \frac{dy}{dy}$ ⇒ $N/m^2 = \mu \frac{m/sec}{m}$

or, $N/m^2 = \mu/sec$ ∴ $\mu = N \times sec/m^2$

② C.G.S unit of u

→ Poise ∵ 1 Poise = 1 $\frac{dyne.sec}{cm^2}$ = 0.1 $\frac{N.sec}{m^2}$ = 0.1 X SI uni

→ 1 $Nsec/m^2$ = 10 poise → SI unix = 10 X C.G.S unit

③ MKS unit of μ

→ kg or kgf or kg force in place of Newton.

→ We know; 1 kg = 1 kgf = 9.81 $N sec/m^2$ = 9.81 X SI unit

→ MKS unit = 9.81 X SI unit = 9.81 X 10 X C.G.S unit = 98.1 X C.G.S unit
= 98.1 poise

② Kinematic Voscisity (ν)

$\nu = \frac{\text{Dynamic viscosity } (\mu)}{\text{density } (\rho)}$

Unit of ν

① SI unit of ν → m^2/sec

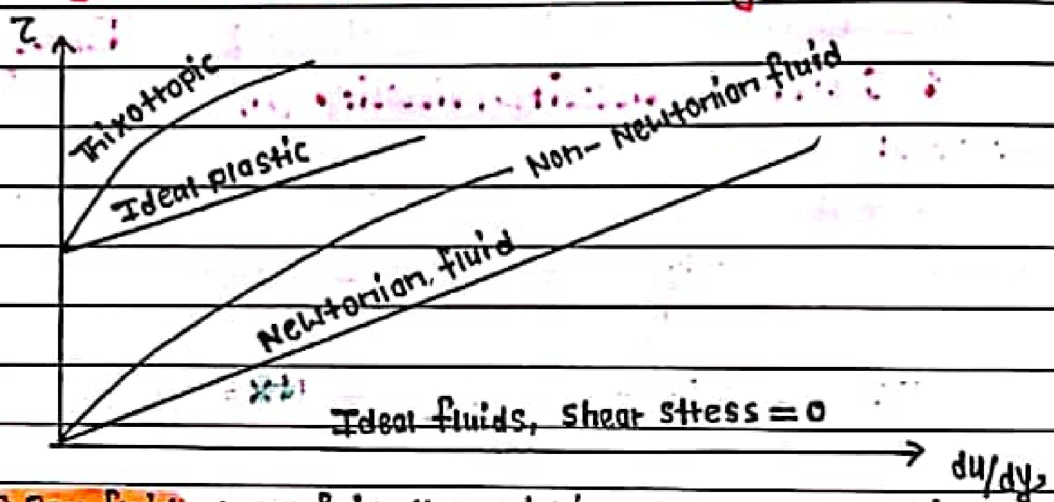
② C.G.S unit → stoke.

→ 1 stoke = $1 cm^2/sec = 10^{-4} m^2/sec$.

→ 1 centistoke = $\frac{1}{100}$ stoke = $\frac{1}{100} \times 10^{-4} m^2/sec$

$= 10^{-6} m^2/sec$

Types of fluid based on Viscosity



① Real fluid → All fluids that exist in nature have some viscosity.

② Ideal fluid → do not have viscosity.

③ Newtonian fluid → They obey newton's law of viscosity.

→ The fluid in which shear stress & velocity gradient have linear relation

→ Example: Water, air, kerosene etc.

④ Non-Newtoninan fluid → The fluid which donot obey newton's law of viscosity.

→ Shear stress & velocity gradient have non-linear relationship.

→ Example: Blood, concrete, sewage, tooth paste, mud, ink etc.

⑤ Ideal plastic → Ideal plastic have certain yield stress.

→ They show the linear relationship betn shear stress & velocity gradien

⑥ Thixotropic → The fluid, whose voscosity depends on dilution.

→ They show non-linear relationship betn shear stress & velocity gradien after yield stress has reached.

→ Example: Printer's ink

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Variation of viscosity with Temperature

→ Viscosity of liquid decrease with temperature.

→ Viscosity of gases increase with temperature.

Pressure

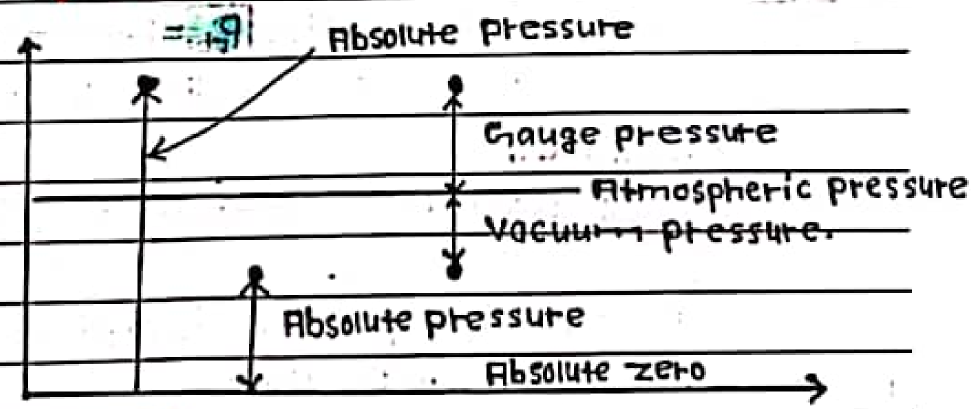
→ Pressure intensity is defined as the pressure force per unit are

→ The force acting on any surface due to pressure of fluid is called pressure force.

→ The direction of pressure intensity is normal to the surface on which it acts.

→ Mathematically, Pressure intensity $(P) = \frac{\text{Pressure force } (dF)}{\text{Area } (A)}$

Types of pressure



(1) Atmospheric pressure

→ The pressure exerted by atmosphere.

→ changes from place to place.

→ It is measured by barometer.

(2) Absolute zero or Absolute vacuum

→ The pressure at absolute vacuum is called absolute zero.

→ At a point where matter like solid, liquid, gas do not exists.

→ This is the lowest possible pressure.

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③ Gauge pressure

→ The pressure measured with respect to atmospheric pressure as datum is called gauge pressure.

→ Also called positive gauge pressure.

④ Vacuum pressure

→ The pressure measured with respect to datum as atmospheric pressure is called Vacuum pressure.

→ Vaccum pressure is also called negative gauge pressure.

→ Also called suction/Negative pressure.

⑤ Absolute pressure

→ The pressure measured with respect to zero absolute pressure or datum.

→ $P_{abs} = P_{atm} + P_{gauge}$

→ if gauge pressure is negative, $P_{abs} = P_{atm} - P_{vacuum}$

→ Numerical value, less, equal or more then atm pressure.

Pascal's Law

According to pascal's law, the pressure intensity at a point inside a liquid at rest is equal in all directions.

→ Also, it states that if a pressure is applied in a closed vessel, it transmits equally in all directions.

Mathematically; $P_x = P_y = P_z$ where; P_x, P_y, P_z = pressure intensity in x, y & z direction.

Pressure Measurement

① Manometers ② Mechanical Gauges

Manometers

→ pressure of fluid is measured by manometers.

→ Device used for pressure measurement.

Types of Manometers

1. Simple manometer
   1. Piezometer
   2. U-Shaped manometer
2. Differential manometer

① Piezometer

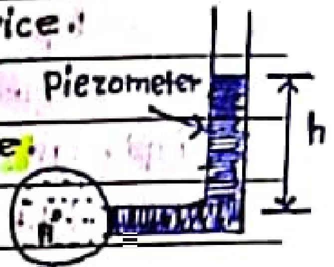
→ Simplest form of pressure measuring device.

→ It is used to measure gauge pressure.

→ It measure very low to moderate pressure.

→ It has a vertical tube connected to the container in which the pressure is needed.

→ The pressure head of the fluid column indicates the pressure of the container.



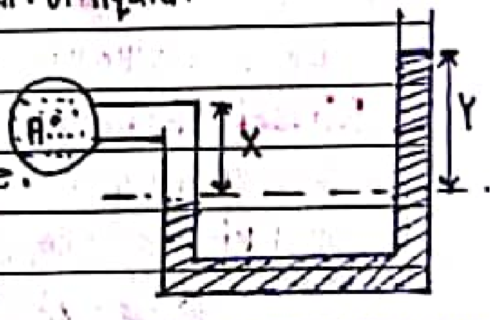
→ $P_A = Yh$ where; P_A = gauge pressure at point A within containe

Y = specific wt. of liquid.

Limitations of Piezometer

→ It can't measure gas pressure.

→ It cannot measure high pressure.



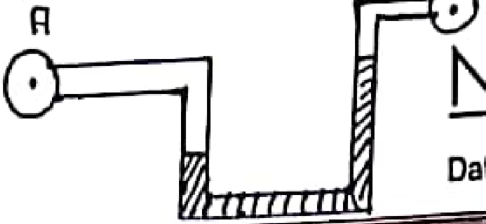
② U-Tube Manometer

→ It consists of a U-tube with one end connected to the pipe / contain whose pressure is to be measured & other end open to atmosphere.

→ The fluid in the U-tube manometer is usually different then the fluid in container.

③ Differential Manometer

→ The differential manometer is used to measure the pressure difference between two different pipes or two different points on the same pipe.



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④ Micromanometer

→ Used to measure low pressure with accuracy.

→ The manometer which can measure very small difference in pressure is called micromanometer.

Mechanical Gauges

→ mechanical gauges are the instruments used for measuring pressure by balancing the fluid column by spring or dead weight.

→ The commonly used mechanical gauges are.

* Diaphragm pressure gauge.
* Bourdon tube pressure gauge.
* Dead weight pressure gauge.
* Bellows pressure gauge.

Types of Energy of Flowing Liquid

① Pressure Energy

→ The energy possess by a fluid by virtue of its existing pressure is called pressure energy.

→ It is also known as elevation energy.

② Kinetic Energy

→ The energy possess by a fluid due to its motion (or velocity) is called kinetic energy.

→ $K \cdot E = \frac{1}{2} mv^2$

③ Potential Energy

→ The energy possess by a fluid due to its position above the datum is called potential / datum energy.

→ Potential energy = Mgh

Note:

ⓐ Total energy = pressure energy + K·E + P·E

ⓑ Total head = pressure head + K·H + P·H

ⓒ Specific energy = K·E + P·E

#: Hydro – Kinematics

→ The branch of science deals with motion of fluid without considering the force causing motion.

Hydro – Dynamics

→ The branch of science deals with motion of fluid with considering force causing motion.

→ The forces like elevations, kinetic & potential.

Bernoulli's Equations..

→ It states that, " Total energy in a flowing fluid is constant when fluid moves from one point to another point."

→ Based on the principle of conservation of energy.

→ It is derived from Euler's equation.

Assumption

→ Fluid is ideal.

→ fluid is incompressible.

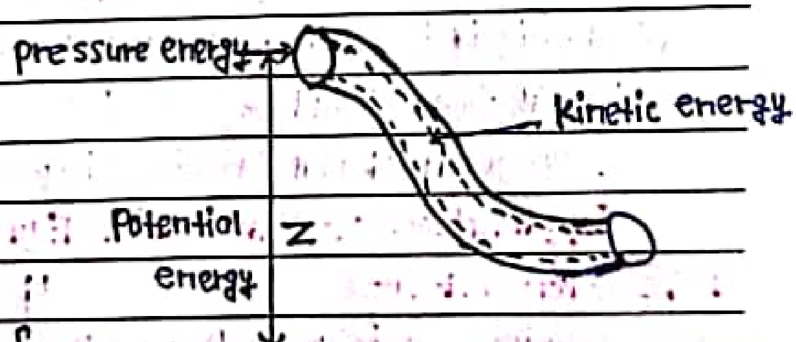
→ fluid is one – dimensional.

→ flow is steady.

→ flow is irrotational.

→ No loss of energy.

Derivation



From Euler eqn

$$\frac{dp}{\rho} + v\,dv + g\,dz = 0$$

Integrate;

$$\int \frac{dp}{\rho} + \int v\,dv + \int g\,dz = \int 0$$

or, $$\int \frac{P}{\rho} + \frac{V^2}{2} + gz$$

or, $$\boxed{\frac{P}{\rho g} + \frac{V^2}{2g} + z = \text{Constant}}$$

Where: $\frac{P}{\rho g}$ = pressure head / pressure energy per unit wt. $\because \gamma = \rho g$

$\frac{V^2}{2g}$ = Velocity head / velocity energy per unit wt.

Z = potential head / potential energy per unit wt.

$\therefore$ **Total head = pressure head + KH + PH**

Bernoulli's Modify eqn for Real Fluid

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_f$$

Where: h_f = head loss

Limitation of Bernoulli's Equation

→ The velocity of flow is not constant at every point of cross-secti

→ liquid is in motion, some K.E is converted into heat energy & part of energy loss due to shear force. → Total energy is not constan

→ The viscous drag comes into play, when a liquid is in motion. this has been neglected by bernoulli's.

→ if the liquid is flowing along a curved path, the energy due to centrifugal force should be taken into consideration.

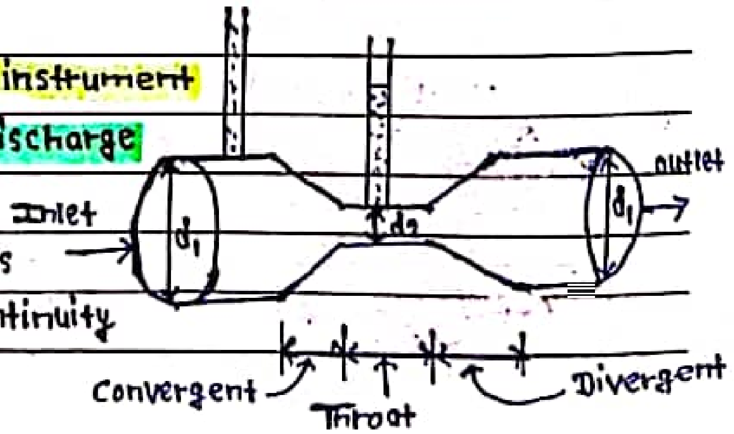
→ Not only gravitational force is acting on fluide.

Application of Bernoulli's Equation

① Venturimeter

→ Venturimeter is an instrument used for measuring the discharge or flow rate in the pipes.

→ Venturimeter works on the bernoulli's eqn, continuity



equation & manometric equation.

→ It consists of convergent section, divergent section & throat

Characteristics of Venturimeter

→ Diameter of inlet is equal to diameter of outlet

→ Divergent section is longer (3–4) times then convergent section (Length)

→ Converging part is less then diverging pipe.

→ Velocity at throat is greater then inlet/outlet.

→ Pressure at throat is less then inlet/outlet.

→ Discharge through Venturimeter, $Q = \frac{C_d a_1 a_2 \sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}}$

Where; C_d = coefficient of discharge. (0.95 – 0.99) generally 0.98

a_1 = area of inlet/outlet.

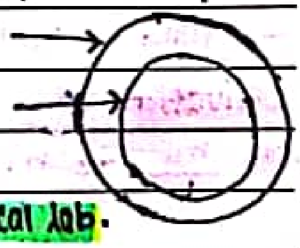
a_2 = " " throat

h = head difference

② Orifice Meter or plate

→ Orifice meter is an instrument used for measuring the discharge or rate of flow in the pipes.

→ Metallic plate of hollow circular inside it through which liquid flows is called orifice.



→ An orifice is fixed inside the pipe.

→ Diameter of pipe > Diameter of orifice.

→ Orifice meter can also be manufactured at local lab.

→ Orifice meter also works on the bernoulli's eq, continuity eqn & Manometric equation.

→ Which decrease flow area & increase velocity.

→ Discharge through orifice meter, $Q = \frac{C_d a_1 a_0 \sqrt{2gh}}{\sqrt{a_1^2 - a_0^2}}$

Where,

C_d = coefficient of discharge. (0.62 to 0.65) generally 0.62

a_1 = area of pipe a_0 = area of orifice.

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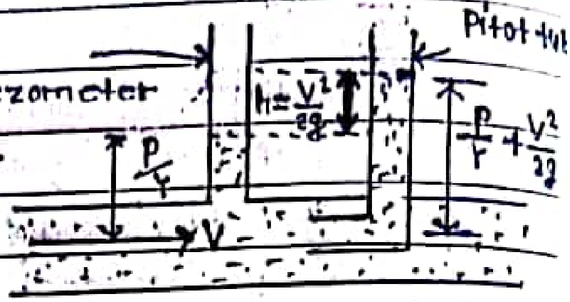
③ pitot Tube

→ It is the L-shape tube used to measure velocity of the fluid in open channel.

→ Kinetic head of water gets converted into pressure head.



→ $h = \frac{V^2}{2g}$ ∴ $V = \sqrt{2gh}$

→ Water rise in the pitot tube at more height then piezometer

→ Pitot tube is used to measure stagnation pressure.

Case-I When pitot tube nose is facing U/s, liquid will rise in the tube by $\frac{V^2}{2g}$.

Case-II When pitot tube nose is facing D/s, liquid level fall by $\frac{V^2}{2g}$.

Case-III When pitot tube is facing sideway, the liquid neither fall nor rise.

Continuity Equation

→ It states that, "the rate of mass per unit time flowing through one point to another point is always constant."

→ Continuity equation is based on "law of conservation of mass."

Assumption

→ fluid is ideal → flow is incompressible & one-dimensional

Derivation

or, $\frac{m_1}{t_1} = \frac{m_2}{t_2}$

or, $\frac{\rho_1 V_1}{t_1} = \frac{\rho_2 V_2}{t_2}$

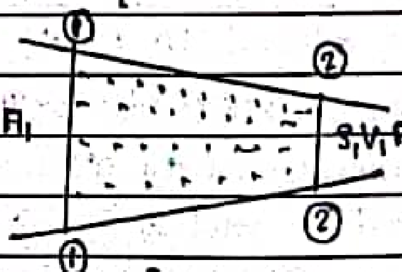


fig: fluid flowing through channel.

or, $\frac{\rho_1 A_1 L_1}{t_1} = \frac{\rho_2 A_2 L_2}{t_2}$

or, $\boxed{\rho_1 A_1 v_1 = \rho_2 A_2 v_2}$ → General eqn.

For ideal fluid ($\rho_1 = \rho_2$) ∴ $A_1 V_1 = A_2 V_2$

TEL, EGL & HGL

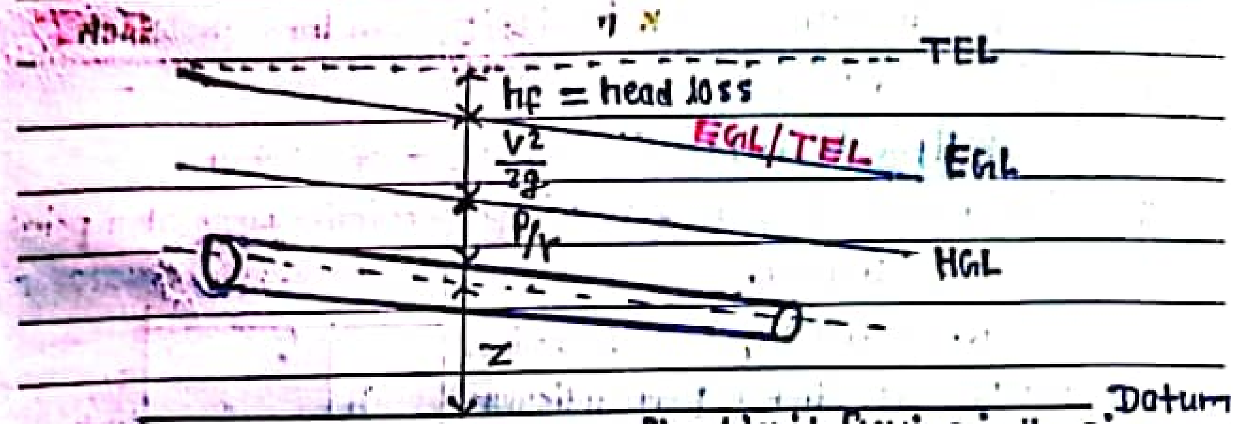


fig: Liquid flowing in the pipe.

Total Energy Line (TEL)

→ The line joining sum of static head, pressure head & kinematic head for an ideal fluid is called total energy line.

→ It is also called ideal total energy line.

Energy Gradient Line (EGL)

→ The line joining sum of static head, pressure head & kinematic head of fluid is called energy gradient line.

→ Energy gradient line slopping downwards.

Hydraulic Gradient Line (HGL)

→ The line joining sum of static head & pressure head of fluid is called hydraulic gradient line.

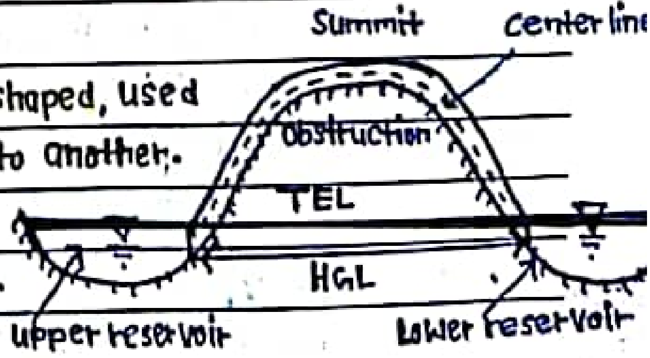
→ It is also called piezometric head.

Note: HGL in open channel flow lies at the flow surface.

→ Head loss = TEL − EGL

→ Velocity head/Kinematic head = EGL − HGL

→ pressure head = HGL − center line of pipe.



Syphon → It is inverted U-shaped, used to transfer liquid from one point to another.

→ In syphon pipe flow, HGL lies below the center line of conduit.

→ The pressure inside a siphon pipe is negative.

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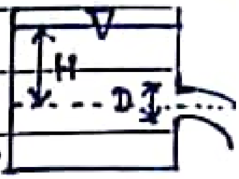
Types of Orifice

[A] Classification Based on head

① Small orifice

→ if the head of liquid is greater than five times diameter of orific

→ Head over orifice (H) > 5 × diam of orifice (D).



② Large orifice

→ the head of liquid is smaller then five times diameter of orifice.

[B] Classification Based on Shape

① Rectangular orifice

② square orifice

③ Circular orifice.

④ Triangular orifice.

⑤ Trapezoidal orifice.

→ Discharge of trapezoidal > rectangular > Circular > triangular.

[C] Classification Based on Discharge Condition.

① Freely discharging orifice.

→ The orifice is discharges in air or the orifice discharges under atmospheric pressure.

② Submerged orifice

→ The orifice is submerged in tail water or downstream water.

→ The pressure of water flowing through the orifice is more then atmospheric.

③ partially submerged orifice

→ A part of orifice is submerged in water & part is freely discharging.

[D] Classification Based on Shape of Upstream Edge of Orifice

① Sharp Edged orifice → The edge of orifice is sharp.

② Bell mouthed orifice → " " " " bell mouth shaped.

→ Bell mouthed orifice, better discharge coefficient & less head loss

Orifice

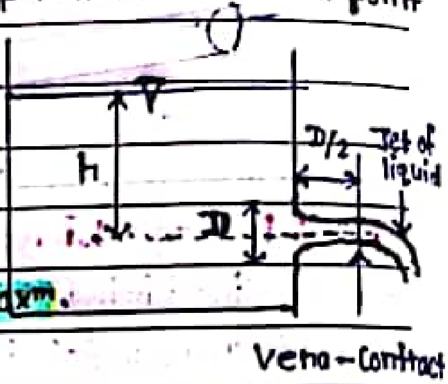
→ Small opening in the tank in side/bottom through which liquid flows is called orifice.

→ The flow through orifice forms a jet of water.

→ This jet of water goes on decreasing & minimum at a point called Vena-Contracta.

→ At Vena-contracta, the streamlines are parallel to each other & perpendicular to the section of orifice.

→ Area (jet of liquid) is min^m & Velocity of liquid max^m.



Hydraulic Coefficients of Orifice

① Coefficient of Velocity (C_v)

→ The ratio of actual velocity of jet of liquid at Vena-contracta to the theoretical velocity at orifice.

→ Mathematically; $C_v = \frac{\text{Actual Velocity of jet at Vena-contracta}}{\text{Theoretical Velocity at orifice}}$

→ Theoretical Velocity; $V_{th} = \sqrt{2gh}$

→ Value of C_v = 0·95 – 0·99, generally taken 0·97 – 0·98.

② Coefficient of Contraction (C_c)

→ The ratio of area of jet at Vena-Contracta to the area of orifice.

→ Mathematically; $C_c = \frac{\text{Area of jet at Vena-contracta}}{\text{Theoretical area at orifice}}$

→ Value of C_c = 0·61 – 0·69, generally taken as 0·64

③ Coefficient of Discharge (C_d)

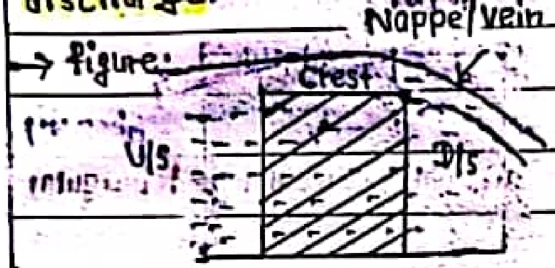
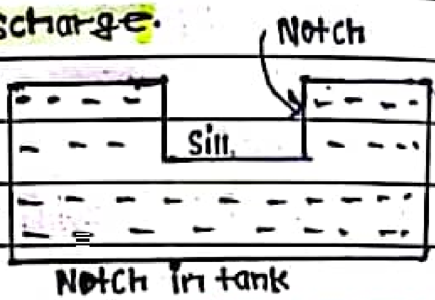
→ The ratio of actual discharge from the orifice to the theoretical discharge through orifice.

→ Mathematically, $C_d = \frac{\text{Actual discharge}}{\text{Theoretical discharge}}$

→ $C_d = C_c \times C_v$

→ Value of C_d = 0·61 – 0·65, generally taken as 0·62.

Weir & Notch

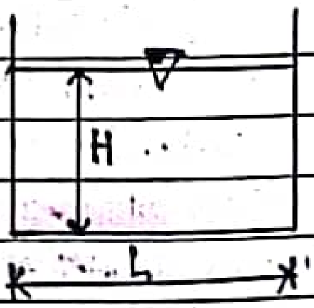
Weir	Notch
→ Made up of Concrete or masonary structure.	→ Made up of Metallic plate.
→ Liquid flows through the upper surface which is called Crest.	→ Liquid flows through the bottom of tank which is called Sill.
→ provided in open channel flow like; river, stream	→ provided in tanks.
→ Used to measure large discharge.	→ Used to measure small discharge.
→ figure: 	
→ Weir is a large structure.	→ Notch is a Small structure.

* Nappe/Vein : The sheet water flows through the weir/notch.

Classification of Weir/notch

[A] Based on shape of opening

① Rectangular weir/notch



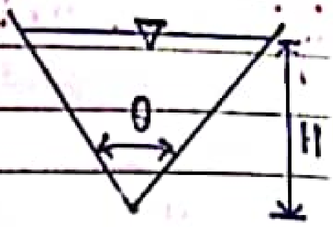
→ Nappe is rectangular in shape.

→ $q = \frac{2}{3} C_d L \sqrt{2g}\, H^{3/2}$

Where, C_d = Coefficient of discharge.
L = Length of Weir
H = Head over the Crest.

→ if 1% error in head measurement in rectangular Weir, the % error in discharge measurement = 1.5%.

② Triangular / V notch / Weir



→ Nappe of water is triangular.

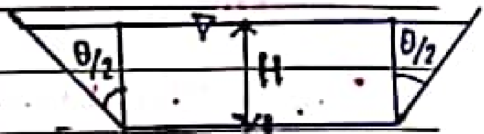
→ $Q = \frac{8}{15} C_d \tan\frac{\theta}{2} \cdot \sqrt{2g} \cdot H^{5/2}$

Where; θ = Angle of notch.

→ The optimum angle of right angular weir is θ = 90°

→ if 1 % error in head measurement, the % error in discharge measurement will be 2.5 %.

③ Trapezoidal weir / Notch



→ Combination of rectangular & triangular weir/notch.

→ $Q = \frac{2}{3} C_{d1} L \sqrt{2g}\, H^{3/2} + \frac{8}{15} C_{d2} \tan\frac{\theta}{2} \sqrt{2g}\, H^{5/2}$

Where; C_{d1} = Coefficient of discharge for rectangular portion.

C_{d2} = " " " " triangular portion.

④ Cipolletti weir / Notch

→ Special case of trapezoidal weir/notch.

→ Side slope 1H : 4V

→ θ/2 = 14.2°

→ The side slope angle of such weir/notch is 14.2 degrees with vertical

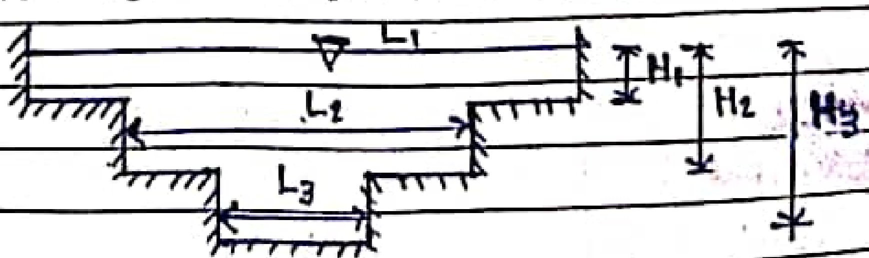
→ $Q = \frac{2}{3} C_d . L \sqrt{2g}\, H^{3/2}$

⑤ Stepped weir / Notch

→ It is a combination of rectangular weir/notches in series.

→ for lower discharge, the bottom notches are enough.

→ The top notches come into function when discharge increase.



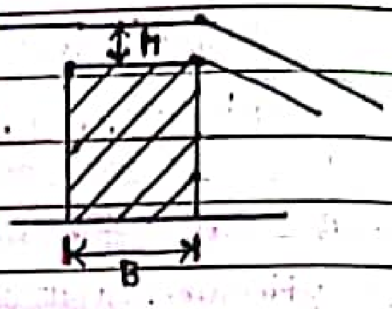
[B] Based on Width of Crest

① Narrow Crested Weir

→ $h > 2B$

Where: h = head of Water

B = Width of Weir



② Broad Crested Weir

→ $h < 2B$ → Discharge $q = 1.705 C_d L \sqrt{2g}\, H^{3/2}$

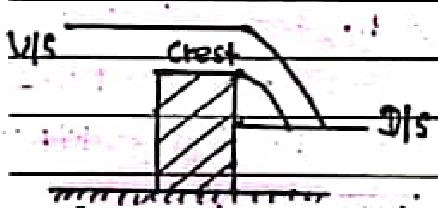
[C] Based on Submergence Condition

① Free / Unsubmerged Weir

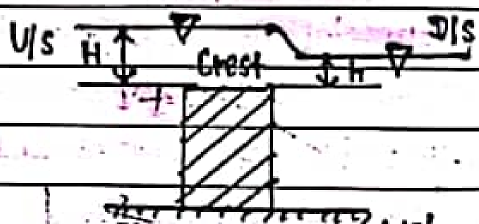
→ If the Water in the downstream channel is below the height of Crest, then it is called free Weir / notch.

② Submerged / Drowned Weir

→ If the Water in the D/S Channel is above the height of Crest then it is Called Submerged Weir / notch.



fig; Unsubmerged Weir



fig; Submerged Weir

Pipe flow & open channel flow

Pipe Flow

→ A fluid flowing in a Closed Conduit under pressure.

→ Maximum Velocity occurs at center of pipe.

→ flow occurs due to difference in pressure.

→ Liquid is not exposed in air.

→ Shear Stress is max^m at the both Side of Wall.

→ Example; full flows in pipes.

→ Reynold number is introduced to classify the types of flow.

Reynold Number

→ A non-dimensional number.

→ Reynold number $(Re) = \frac{\rho V D}{\mu}$

Where, ρ = density
V = Velocity
D = Diameter
μ = Viscosity

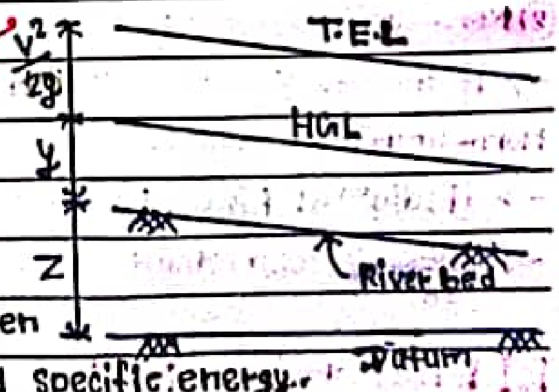
① $Re < 2{,}000$; laminar flow.
② $Re = 2000 - 4000$; transitional flow.
③ $Re > 4000$; turbulent flow.
→ Ratio of inertia force to viscous force.

$$Re = \frac{\text{Inertia force}}{\text{Viscous force}}$$

Open Channel flow

→ A fluid flow occurs due to gravity.
→ Maximum velocity occurs at a little distance below the top surf
→ Liquid is exposed in air.
→ Example; flow in river, canals, partial flow in sewer pipes.
→ Reynolds number is introduced to classify the type of flow.
① $Re < 500$; laminar flow
② $Re = 500 - 2000$; transitional flow
③ $Re > 2000$; turbulent flow.

Specific Energy



→ The total energy in a flowing liquid is: $z + y + \frac{V^2}{2g}$

→ When the datum surface is taken at bottom of river bed, then the energy at that point is called specific energy.

i.e. specific energy $= y + \frac{V^2}{2g}$

→ Also, specific energy is the sum of potential head & kinetic hea

Type of pipe Flow

[A] Based on Time

① Steady flow

→ If the flow parameter remain same with respect to time then it is called Steady flow. parameter: velocity, discharge, Pressure, density

→ i.e. $\frac{dv}{dt} = \text{constant}$

→ Flow through a pipe at constant rate/discharge.

② Unsteady flow

→ If the flow parameter changes with respect to time then it is called unsteady flow.

→ $\frac{dv}{dt} \neq \text{constant}$

→ Flow through a pipe at variable discharge, flow in a pipe during water hammer condition.

[B] Based on space

① Uniform flow

→ $\frac{dv}{dx} = \text{constant}$

→ if the flow parameter does not change with space (length) then it is called uniform flow. → if dia^m of pipe is constant.

② Non-uniform flow

→ if the flow parameter changes with space then it is called non-uniform flow.

→ if dia^m of pipe changes along it's length.

→ $\frac{dv}{dx} \neq \text{constant}$

[C] Based on Density

① Compressible flow

→ if the density (volume) of the fluid changes on applying pressure then it is called compressible flow.

→ All the gases follow the compressible flow.

② Incompressible flow

→ If the density of the fluid does not changes on applying pressure then it is called incompressible flow.

→ All the liquid flow the incompressible flow.

[D] Rotational & Irrotational flow

Rotational flow

→ The flow which rotates about its own axis is called rotational flow

→ eg: fluid in a rotating tank.

Non-rotational flow

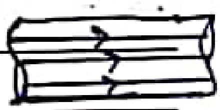
→ The flow which does not rotates about it's axis then it is called rotational flow.

→ eg: fluid in a pipe.

[E] Based on Reynold Number

① Laminar flow → Individual particle of fluid moves in St. way.

→ flow occurs in layer. → Also called Viscous flow.



→ Streamlines exist only in this type of flow

→ Re < 2,000 → Does not cross each other.

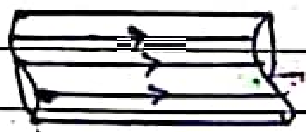
→ Example: flow of blood in the body, ground water flow, flow at small velocities.

② Transitional flow

→ Re = 2000 – 4000

③ Turbulent flow

→ fluid particle move in zig zag way.



→ Streamlines do not exist.

→ Re > 4000

→ Individual particle of fluid cross each other.

→ Example: flow through the water in pipe running full.

→ e.g. path taken by smoke coming out of chimney, movement of particles after dye is injected.

Note: If the flow is laminar, the path, stream & streak line are same

Critical Depth

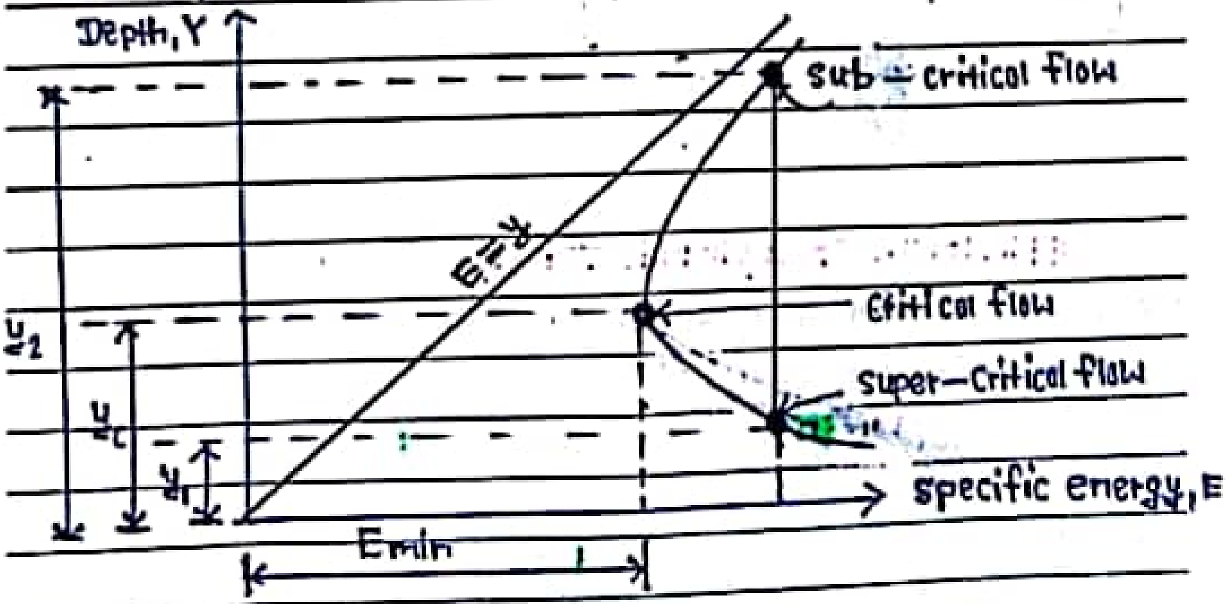
→ The depth when the flow is critical is called critical depth.

→ The depth at which specific depth(y) energy is minimum in the flow is called critical depth (y_c).

→ $$y_c = \left(\frac{q^2}{g}\right)^{1/3}$$

Where; q = discharge per unit width

g = Accleration due to gravity



Hydraulic Jump

→ The rise of water table, during the transformation of unstable shooting flow to stable streaming flow is known as hydraulic jump.

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→ Hydraulic jump is a rapidly varying non uniform flow in which the flow changes from super-critical to sub-critical.

→ The hydraulic jump forms on mild slope & horizontal floor.

→ This is also called positive surge or standing wave.

→ At hydraulic jump surplus energy is dissipated.

→ The depth before & after the jump formation are called sequent depths or conjugate depth.

→ The length of jump is equal to 5-7 times of (y_2-y_1)

Where ; y_1 = depth before jump formation.
y_2 = " after " "

① $$y_1 = \frac{y_2}{2}\left[\sqrt{8F_{r_2}^2+1}-1\right]$$

② $$y_2 = \frac{y_1}{2}\left[\sqrt{8F_{r_1}^2+1}-1\right]$$

Applications of Hydraulic Jump.

→ It is used for dissipation of energy (energy killing) of the water flowing over dam, barrage, weir & drop structures.

→ It is used for mixing of chemicals in industries.

→ It is also applicable to remove air from the water.

→ Maintains the high water level on the downstream side.

→ This high water level can be used for irrigation purposes.

Froude Number

→ It is the ratio of square root of inertia force of a flowing fluid to the gravitational force.

→ Used to determine the resistance of an object moving through a fluid.

→ It is denoted by Fr.

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→ Froude Number, $F_r = \sqrt{\frac{\text{Inertia force}}{\text{Gravitational force}}}$

① Sub-Critical flow

→ if $F_r < 1$

→ Also called streaming flow. tranquil → occurs on a mild slope.

② Critical flow

→ if $F_r = 1$

→ Sp. energy & sp. force are minimum at critical flow.

→ occurs on a critical slope.

③ Super Critical flow

→ if $F_r > 1$.

→ Also called shooting/rapid/torrential flow.

→ occure in a steep slope.

Characteristics of open channel flow

→ open channel flow have a free surface.

→ A free surface is subjected to atmospheric pressure.

→ Hydraulic gradient line is slightly higher (negligible). i.e. coincid with the free surface.

→ The driving force is the component of gravity along the flow direction.

→ The depth of flow, discharge, slope of channel bottom & of free surface are interdependent.

→ There may be different types of flow.

Head Loss

→ The loss of energy of flowing Water due to internal friction of flowing Water or other reasons is Called head loss.

[A] Major Head Loss

→ The loss of energy due to friction is called major head loss.

→ It is calculated by Darcy-Weisbach formula or manning's formula or Chezy formula.

① Darcy-Weisbach formula

*Darcy-Williams Formula

$$h_f = \frac{fLV^2}{2gd}$$

Where; h_f = head loss

f = friction factor = 4F (sometimes)

L = Length of channel

d = diameter of pipe

② Manning's Formula

→ Used for head loss Calculation in open channels.

→ $V = \frac{1}{n} R^{2/3} . S^{1/2}$

Where; S = energy slope or friction slope $= \frac{\text{head loss}}{\text{length}} = \frac{h_f}{L}$

$$\therefore h_f = \frac{V^2 n^2 L}{R^{4/3}}$$

③ Chezy's Formula

→ Used for Head loss Calculation in open channels.

→ $V = C\sqrt{RS}$ $\because S = \frac{h_f}{L}$

$$\therefore h_f = \frac{V^2 L}{C^2 R}$$

[B] Minor Head Loss

→ Minor head loss in pipes may be due to sudden expansion, sudden contraction, entry, exit, Valve, bend.

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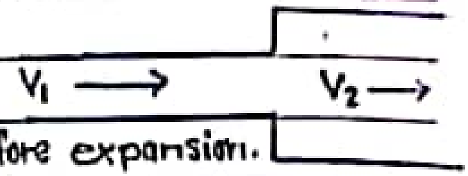
① Head loss due to sudden expansion:

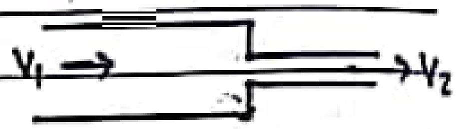
$$h_f = \frac{(V_1 - V_2)^2}{2g}$$



→ Where; V_1 = Velocity in small pipe before expansion.
V_2 = " " large " after "

② Head loss due to sudden Contraction

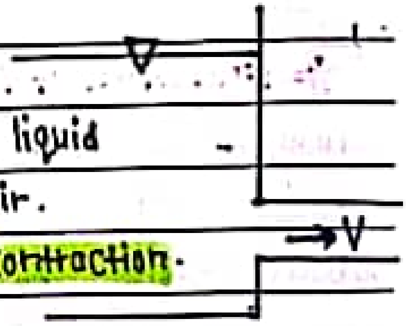
→ $h_f = \left(\frac{1}{C_c} - 1\right) \times \frac{V_2^2}{2g}$



Where; C_c = Coefficient of Contraction. generally; $C_c = 0.62$

$$\therefore h_f = \frac{0.5 V_2^2}{2g}$$

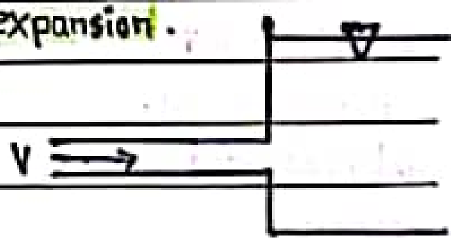
③ Entry Loss



→ The loss of energy which occurs when a liquid enters a pipe connected to tank or reservoir.
→ It is the extreme case of sudden contraction.
→ The entry loss is equal to $0.5\frac{V^2}{2g}$.

④ Exit Loss

→ It is the extreme case of sudden expansion.
→ The exit loss is equal to $\frac{V^2}{2g}$



⑤ Valve Loss

→ The loss of head due to valve is called valve loss.
→ $h_f = K\frac{V^2}{2g}$ Where: K = Coefficient of valve loss.

⑥ Bend Loss

→ The loss of head due to bend is called bend loss.
→ $h_f = K\frac{V^2}{2g}$, Where; K = Coefficient of bend loss, which depends on angle of bend.

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Factors Affecting Head Loss in pipe

Factors	Relation
1. flow rate	∝ Head loss
2. Pipe length	" "
3. Viscosity	" "
4. Roughness of pipe surface	" "
5. Scale deposits	" "
6. Friction factor	" "
7. fitting & bends	" "
8. Diameter	$\frac{1}{\text{Head loss}}$

Functions of Specific Instruments

1. Anemometer → measure wind speed & wind pressure.
2. Altimeter → measure altitude.
3. Bourdon-tube gauge → measuring the pressure of liquid & gases of all kinds.
4. Barometer → measure atmospheric pressure.
5. Hydrometer → Used to determine specific gravity.
6. Hygrometer → measure the humidity or amount of water vapour in the air.
7. Lactometer → check for purity of milk.
8. manometers → Measuring pressure against a volume of liquid
9. odometer → measuring the distance traveled by a vehicle.
10. Pyrometer → measure temperature remotely.
11. Pycnometer → Used to determine sp. gravity of cohesionless soil & water content.
12. Rotameters → Used to determine volumetric flow rates of fresh gas flows.
13. Thermometer → Used to measuring temperature.
14. Viscometer → measuring the viscosity of a fluid.

[F] One, Two & Three Dimensional Flow

One Dimensional Flow

→ Flow parameter such velocity is the function on one space co-ordinate & time. →eg; steady, uniform flow

Mathematically, $V = f(x, t)$.

→ The flow in pipes or canals of uniform cross section.

Two Dimensional Flow

→ Flow parameter such as velocity is the function of two space co-ordinate & time.

Mathematically; $V = f(x, y, t)$.

→ The flow in pipes or canals at expanding or contracting cross section.

Three Dimensional Flow.

→ Flow parameter such as velocity is the function of three space co-ordinate & time.

Mathematically; $V = f(x, y, z, t)$

→ The flow in rivers during flooding time.

Different Types of Flow Lines

 # Path Line → The path traced by a single fluid particle in motion over a period of time in a flow field is known as path line.

→ Path line can intersect themselves.

 # Stream Line → Stream line is an imaginary curve drawn through the flow field in such a way that the tangent to it at any point indicates the direction of velocity at that point.

→ Stream lines do not intersect each other.

→ The component of velocity perpendicular to a streamline is zero.

 # Streak Line → Streak line is a line made by a series of fluid particles through a fixed point in the flow field.

Note: The flow of fluid through the curved path is called vertex flow.

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Physical Properties of Fluids

① Density or mass Density (ρ)

→ Density is defined as mass per unit volume.

→ $\rho = \frac{\text{mass}}{\text{Volume}} = \frac{M}{V}$

→ Unit — SI system = kg/m^3

— CGS system = $\frac{gram}{cm^3}$ = g/cc

— Metric Gravitational system = $\frac{\text{Metric slug}}{m^3}$

→ 1 metric slug = 32.2 pound = 9.81 kg.

→ 1 gram/cc = 1000 kg/m^3

→ Density of water (ρ_w) = 1 g/cc = 1000 kg/m^3 (at 4°C)

→ Density of mercury (ρ_{Hg}) = 13600 kg/m^3 = 13.6 g/cc.

② Specific Weight / Unit Weight (γ)

→ specific weight is defined as weight per unit volume.

→ $\gamma = \frac{\text{weight}}{\text{Volume}} = \frac{Mg}{V} = \rho g$

→ Sp. wt. of water (γ_w) = $\rho_w \times g$ = 1000 × 9.81 = 9810 N/m^3

= 1000 kg/m^3

∵ 1 kg = 9.81 N

③ Specific Volume (V_s)

→ Specific Volume of fluid is defined as volume per unit mass.

→ $V_s = \frac{\text{Volume}}{\text{Mass}} = \frac{1}{\rho}$

→ We go down in a fluid mass like in oceans or reservoirs, the specific volume decrease.