NMDC DAV POYTECHNIC DANTEWADA

04 SEMESTER MECHANICAL

INDEX- FLUID MECHANICS & HYDRAULIC MACHINES CLASS NOTES

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UNIT/CHAPTER - 01

Fundamental of fluid flow (तरल प्रवाह के आधार)

Fluid → A fluid is a substance which is capable of flowing or moving under the action of shear force. (जिसमें बहने की क्षमता हो।)

Ex → Liquids, Gaseous, Vapour etc.

* When the fluid is in static condition (रुका हुआ हो / स्थिर हो) than there is no shear force.

Types of fluid →

① Ideal fluid (आदर्श तरल) → किसी fluid को Ideal fluid तभी कहा जा सकता है जब वह Non-Viscous तथा Incompressible हो। (Hypothetical / मानक / काल्पनिक)

$\tau = \mu \, du/dy$ (μ = dynamic viscosity / viscosity = 0)

$\boxed{\tau = 0}$ → shear stress zero.

② Real or Practical Fluid (व्यवहारिक तरल) → All the fluids available in the world are real & Practical fluids which contains viscosity, surface tension etc. fluid properties.

Types of real fluids →

ⓐ Compressible fluid → (संपीड्य तरल) → इस प्रकार के तरलों को compress किया जा सकता है; जिससे fluid के Density और आयतन में परिवर्तन आ जाता है।

Ex → Gas, Vapour.

(b) Incompressible fluid / असम्पीड्य तरल → ऐसे fluid जिनकी Density या Volume सभी परिस्थितियों में (Compress) करने पर भी परिवर्तित नहीं होते हैं, उन्हे Incompressible fluid कहा जाता है।

Ex→ Liquid.

$$\left[\begin{array}{l} \text{Density} \rightarrow \rho = \frac{m}{V} \leftarrow \frac{\text{mass}}{\text{Volume}} \\ m = \text{constant}, \\ \text{If } \rho = \text{constant} = V \end{array}\right]$$

↓

$$\rho_1 = \rho_2 = \text{Constant or } V_1 = V_2 = \text{Constant.}$$

⇒ Fluid Properties (तरल गुण) →

① Density / Mass Density / घनत्व → (ρ) → It is the ratio of mass of the fluid to its volume.

$$\rho = \frac{m}{V} \rightarrow \frac{Kg}{m^3} \text{ (unit)}$$

⇒ $\rho_{H_2O} = 1000 \ Kg/m^3$ (जल का घनत्व = ρ_{H_2O})

$T\uparrow = \rho\downarrow$ but $P\uparrow = \rho\uparrow$

② Specific Weight / Weight Density / आपेक्षिक भार → (w) → It is the ratio of Weight of the fluid to its volume.

→ $w = \frac{W}{V}$ (N/m^3) ← unit

$$w = \frac{mg}{V} = \rho g$$

$$\boxed{w = \frac{W}{V} = \rho g}$$

⇒ $w_{H_2O} = \rho_{H_2O} \cdot g = 1000 \times 9.81 = 9810 \ N/m^3$

(2)

(3) Specific Gravity/specific density/relative density | आपेक्षिक भार | आपेक्षिक घनत्व → It is the ratio of density of fluid to the density of standard fluid.

→ For Liquid → standard fluid is water (H_2O).
→ For Gases → standard fluid is Hydrogen or air.

$$S = \frac{\rho_{fluid}}{\rho_{st.fluid}} = \frac{\rho}{\rho_{H_2O}} \quad [\text{NO unit}]$$

* $\rho_{H_2O} = 1000\ Kg/m^3$ at $4°c$

$$\boxed{\rho = S \times 1000}$$

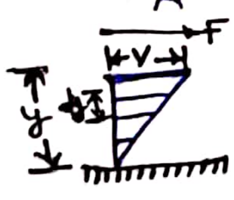
(4) Visosity / Dynamic viscosity | गतिक श्यानता → It is the Internal resistance offered by one layer of fluid to the other layer.

from Newton's Law of Viscosity → $\boxed{\tau = \mu \frac{du}{dy}}$ ← for all velocity Profile

τ = shear stress,
$\frac{du}{dy}$ = velocity gradient, μ = dynamic viscosity.

For linear velocity Profile → $\tau = \mu \frac{V}{y}$ & $\tau = F/A$

than $\frac{F}{A} = \mu \frac{V}{y}$ ⇒ $\boxed{F = \frac{\mu A V}{y}}$ ⇒ $\mu = \frac{Fy}{AV}$



$$\mu = \frac{N \times m}{m^2 \times m/s} = \frac{N\,s}{m^2} = Pa\text{-}S$$

so, unit of dynamic viscosity → $\boxed{\mu = \frac{N\,S}{m^2} = Pa-S = \frac{Kg}{m-s}}$ ← S.I. unit S

$\boxed{\frac{g}{cm-s} = \text{Poise}}$ In C.G.S. ←

1 Pa-S = 10 Poise ← Conversion

⑤ Kinematic viscosity / निरपेक्ष गतिक श्यानता → In fluid Mechanics the term $\frac{\mu}{\rho}$ appears frequently & for convience this term is known as Kinematic Viscosity.

$$\boxed{\nu = \frac{\mu}{\rho}} \rightarrow \nu = \frac{Kg/m\text{-}s}{Kg/m^3} = \frac{m^2}{s} \rightarrow \text{In S.I. units}$$

→ In C.G.S. System = $\frac{cm^2}{s}$ → called stoke.

➔ **Types of flow** → Fluid flow is analysed by Langrangian Approach or Eularian approach.

① Steady & Unsteady flow (अपरिवर्ती और परिवर्ती प्रवाह)

→ A flow is said to be steady flow if the fluid properties donot vary with respect to time at any given section, otherwise the flow is unsteady.

steady flow → $dv/dt = 0 =$ constant or $d\rho/dt = 0$

for unsteady flow → $\frac{dv}{dt} \neq 0 \neq$ constant or $d\rho/dt \neq 0$

② Uniform & Non-uniform flow → A flow is said to be uniform flow if the velocity remains constant at different sections at any given instant time, otherwise the flow is Non-uniform.

⇒ for uniform flow → (समान प्रवाह) → $\frac{dv}{ds} = 0$

⇒ for Non-uniform flow (असमान प्रवाह) → $\frac{dv}{ds} \neq 0$

(ds = different sections)

③ Laminar & Turbulant flow (स्तरीय एवं विक्षुब्ध प्रवाह) → In Laminar flow, fluid Particles move in the form of Layers with one layer sliding over the another Layer. Its also called viscous flow and it is occured at low velocity.

When fluid Particles move in highly disorganised manner leading to rapid mixing of Particles than the flow is called turbulant flow and it is occured at high velocities.

Stream-Line (धारारेखीय प्रवाह) → जब कोई fluid flow में एक fluid molecule जिस Path को follow करें तथा बाकी के सारे fluid molecules भी उसी Path से ही flow हो रहे हो, तब उसे Stream Line flow कहा जाता है। तथा इस Path/Way/मार्ग को stream line या धारा रेखा कहते हैं।

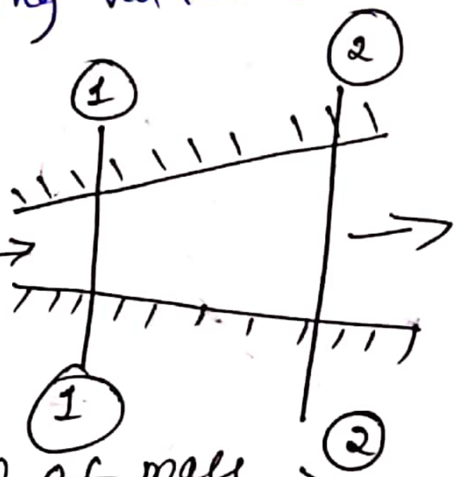
⇒ Continuity Equation (सांतत्य समीकरण) → The Equation based on the Principle of conservation of mass is called continuity equation.

by this Principle, the quantity of fluid flowing per second at any section is constant.

Let, V_1 = Average velocity at cross-section at 1-1
ρ_1 = Density at Section 1-1
A_1 = Area of pipe at section 1-1
and V_2, ρ_2, A_2 are corrosponding values at section 2-2,

→ Rate of flow at section 1-1 = $\rho_1 \times A_1 \times V_1$

→ Rate of flow at 2-2 = $\rho_2 \times A_2 \times V_2$



According to Law of Conservation of mass →
Rate of flow at Section 1-1 = Rate of flow at 2-2

$$\rho_1 \times A_1 \times V_1 = \rho_2 \times A_2 \times V_2$$

↑ Continuity eqn for Compressible & Incompressible fluids.

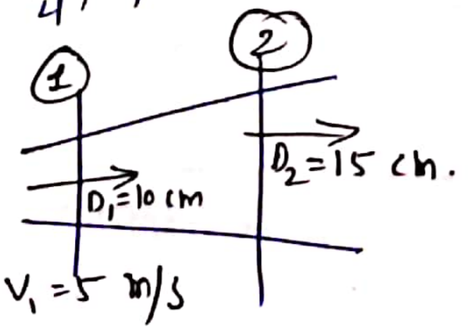
→ for Compressible flow → $\rho_1 = \rho_2$

$$A_1 V_1 = A_2 V_2 = A_3 V_3 = \ldots\ldots$$

↑ For Liquids only.

Que) 1 → The diameters of a pipe at the sections 1 and 2 are 10 cm and 15 cm respectively. Find the discharge through the Pipe if the velocity of water flowing through the Pipe at section 1 is 5 m/s. Determine velocity at 2.

Ans → Given→ $D_1 = 10$ cm $= 0.1$ m., $A_1 = \frac{\pi}{4} \times D_1^2 = 0.00786\ m^2$
$V_1 = 5$ m/s,
$D_2 = 15$ cm $= 0.15$ m,
$A_2 = \frac{\pi}{4} \times D_2^2 = 0.01767 m^2$.



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(1) Discharge through pipe, $Q_1 = A_1 V_1 = 0.00786 \times 5 = 0.0393\ m^3/s$

(2) velocity (V_2) at section 2, → $A_1 V_1 = A_2 V_2$

$$V_2 = \frac{A_1 V_1}{A_2} = \frac{0.00786}{0.01767} \times 5 = 2.22\ m/s.$$

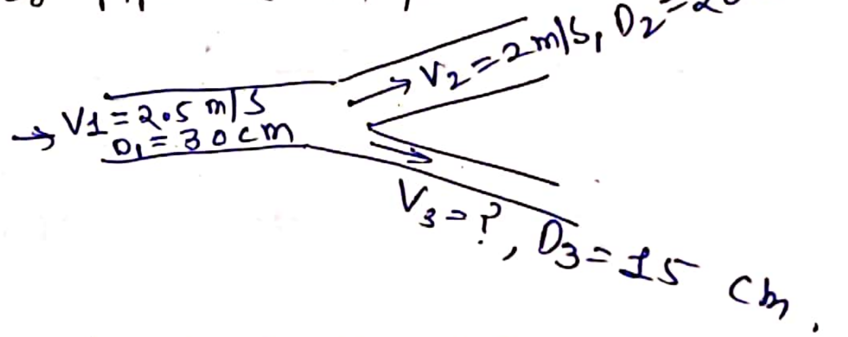
Que A 30 cm diameter pipe, conveying water, branches into two pipes of diameters 20 cm and 15 cm respectively, If the average velocity in 30 cm pipe is 2.5 m/s. find the discharge in this pipe. Also determine the velocity in 15 cm pipe if the average velocity in 20 cm diameter pipe is 2 m/s.

Ans → $D_1 = 30\ cm = 0.3\ m$

$A_1 = \frac{\pi}{4} D_1^2 = 0.07068\ m^2$

$V_1 = 2.5\ m/s$

$D_2 = 20\ cm = 0.2\ m$



$A_2 = \frac{\pi}{4} \times D_2^2 = 0.0314\ m^2$, $V_2 = 2\ m/s$, $D_3 = 15\ cm = 0.15\ m$,

$A_3 = \pi/4 \times D_3^2 = 0.01767\ m^2$

from, question we know, $\boxed{Q_1 = Q_2 + Q_3}$ ---- (1)

(1) Discharge $Q_1 = A_1 V_1 = 0.07068 \times 2.5 = 0.1767\ m^3/s.$

(2) $V_3 = ?$ → $Q_2 = A_2 V_2 = 0.0314 \times 2.0 = 0.0628\ m^3/s$

from eq.(1) → $0.1767 = 0.0628 + Q_3$

$Q_3 = 0.1767 - 0.0628 = 0.1139 \ m^3/s$

$\Rightarrow Q_3 = A_3 \times V_3 \Rightarrow V_3 = Q_3 / A_3 = \frac{0.1139}{0.01767}$

$\boxed{V_3 = 6.44 \ m/s}$ Answer.

Que 3 → Calculate Specific Weight, density and specific gravity of one litre of a liquid which weighs 7N.

Ans → Given, Volume = 1 litre = $10^{-3} \ m^3$

Weight = 7 N

① Specific gravity = $\frac{\text{Density of fluid}}{\text{Standard fluid}}$

$\therefore$ density (ρ) $= \frac{m}{V} = \frac{W/g}{V} = \frac{7}{9.81 \times 10^{-3}}$

② $\rho = \frac{7000}{9.81} = 713.5 \ Kg/m^3$

So, $S = \frac{713.5}{1000} = 0.7135$

③ Specific weight (w) $= \frac{\text{Weight}}{\text{Volume}} = \frac{7}{10^{-3}} = 7000 \ N/m^3$

Que 4 → Determine the Intensity of Shear of an oil having Viscosity = 1 Poise. The oil is used for lubricating the clearance between a shaft of diameter 10 cm and its journal bearing. The clearance is 1.5 mm and shaft rotates at 150 rpm.

Ans 4 ∴ Given, $\mu = 1$ poise $= 0.1$ Pa-s

$D = 10$ cm $= 0.1$ m,

$dy = 1.5$ mm $= 1.5 \times 10^{-3}$ m $\Rightarrow 0.0015$ m

$N = 150$ rpm.,

Tangential Speed $\Rightarrow u = \frac{\pi D N}{60} = \frac{\pi \times 0.1 \times 150}{60} = 0.785$ m/s

$du = u - 0 = u$

we Know, $\tau = \mu \frac{du}{dy} = 0.1 \times \frac{0.785}{0.0015} = 52.3$ N/m²

Qu #5 ⇒ Find Kinematic viscosity of an oil having density 981 Kg/m³. The shear stress at a point in oil is 0.2452 N/m² and velocity gradient at the point is 0.2 per second.

Ans → $\rho = 981$, $\tau = 0.2452$, $du/dy = 0.2$ s

we Know, $\tau = \mu \, du/dy$

$0.2452 = \mu \times 0.2 \Rightarrow \mu = 1.226$ Pa-s

& $\nu = \frac{\mu}{\rho} = \frac{1.226}{981} = 0.00125$ m²/s

$\nu = 12.5$ cm²/s or 12.5 stoke.

Ans.

Qu 6 → Determine Specific gravity of a fluid having Viscosity 0.05 poise and Kinematic viscosity 0.035 stokes.

Ans → Given, $\mu = 0.05$ Poise $= 0.005$ Pa-s

$\nu = 0.035$ Stokes $= 0.035 \times 10^{-4}$ m²/s

$\therefore \nu = \frac{\mu}{\rho} \Rightarrow \rho = \frac{\mu}{\nu} = \frac{0.005}{0.035 \times 10^{-4}} = 1428.5$ Kg/m³

$\therefore S = \frac{\rho_f}{\rho_{st.fluid}} = \frac{1428.5}{1000} = 1.43$ Ans.

Qu 7 → Determine Viscosity of a liquid having Kinematic viscosity 6 stokes and specific gravity 1.9.

Ans → $\nu = 6$ Stokes $= 6 \times 10^{-4}$ m²/s

$S = 1.9$

Density → $\rho = S \times \rho_{st.fluid} = 1.9 \times 1000 = 1900$ Kg/m³

$\therefore$ Kinematic Viscosity, $\nu = \frac{\mu}{\rho}$

$6 \times 10^{-4} = \frac{\mu}{1900}$

$\mu = 6 \times 10^{-4} \times 1900$

$\mu = 1.14$ Pa-s or 11.4 Poise.

Ans.

Chapter No. – 08

Water Turbines (जल टरबाइन)

Turbines are defined as the hydraulic machines which convert hydraulic Energy into mechanical Energy. This mechanical Energy is converted into Electrical Energy through an electric generator.

The electric Power obtained from water is called Hydroelectric Power.

Classification of Water Turbines (जल टर्बाइनों का वर्गीकरण) →

① On the basis of Hydraulic Action on the Runner (रनर पर जल की ड्रबिक क्रिया के आधार पर) →

(a) Impulse or velocity turbine (आवेग या वेग टरबाइन)
(b) Reaction or Pressure turbine (रिएक्शन या दाब टरबाइन)

② On the basis of Head of Water (जल शीर्ष के आधार पर) →

(a) High head Turbine (उच्च शीर्ष टरबाइन) (* Pelton)
(b) Medium Head Turbine (मध्यम शीर्ष टरबाइन) (* Francis)
(c) Low Head Turbine (निम्न शीर्ष टरबाइन) (* Kaplan)

③ On the basis of Specific Speed (विशिष्ट गति के आधार पर) →

(a) High Speed Turbine (उच्च वेग टरबाइन) (* Kaplan)
(b) Medium Speed Turbine (मध्यम वेग टरबाइन) (* Francis)
(c) Low Speed Turbine (निम्न वेग टरबाइन) (* Pelton)

(4) On the basis of Inventor's Name (आविष्कारक के नाम पर) →

(a) Pelton wheel Turbine (पेल्टन व्हील टरबाइन)
(b) Francis Turbine (फ्रांसिस टरबाइन)
(c) Kaplan Turbine (कप्लान टरबाइन)

(5) On the basis of direction of flow (प्रवाह की दिशा के आधार पर) →

(a) Tangential flow turbine (स्पर्श रेखीय टरबाइन)
(b) Radial flow Turbine (त्रिज्या प्रवाह टरबाइन)
(c) Axial flow Turbine (अक्षीय प्रवाह टरबाइन)
(d) mixed flow Turbine (मिश्रित प्रवाह टरबाइन)

⇒ **Impulse (आवेग) Turbine** → If at the Inlet of the turbine, the Energy available is only Kinetic Energy, the turbine is Known as Impulse turbine.

इस टरबाइन में जल की धारा को नॉजल से प्रवाहित किया जाता है तो Pressure Energy, Kinetic Energy ($A_1V_1 = A_2V_2$) में परिवर्तित हो जाती है तथा टरबाइन के प्रवेश पर केवल Kinetic Energy available होती है।

Ex ⇒ Pelton wheel Turbine.

⇒ **Reaction (रिएक्शन टरबाइन)** → If at the Inlet of the Turbine, the Water Possesses Kinetic Energy as well as Pressure Energy, The turbine is Known as reaction Turbine.

जिस टरबाइन में द्रव की सम्पूर्ण ऊर्जा गतिज ऊर्जा में परिवर्तित नहीं होती है; जिसमें कुछ कार्य गतिज (velocity) तथा कुछ कार्य दाब ऊर्जा (Pressure Energy) के रूप में प्रवेश करती है उसे Reaction Turbine कहते हैं। (Ex ⇒ Kaplan turbine)

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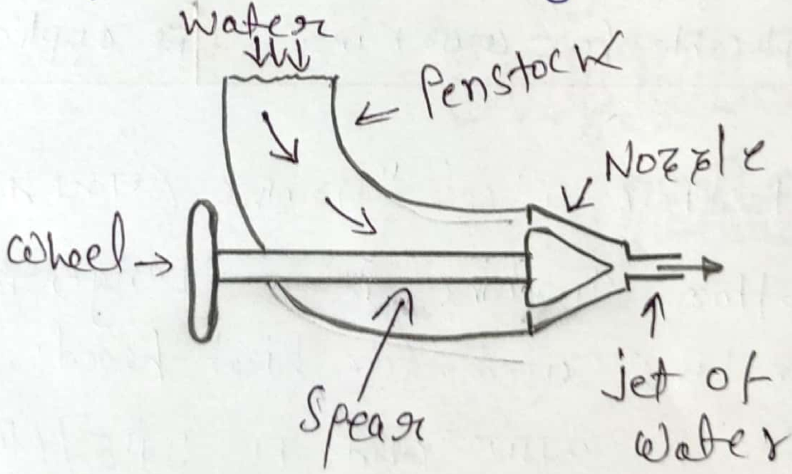
Impulse Turbine	Reaction Turbine
(1) Inlet में केवल Kinetic energy available होती है।	Inlet में Kinetic तथा Pressure Energy दोनों Available होते हैं।
(2) outlet में Fluid velocity 0 होती है।	outlet में Water velocity High तथा Pressure Low होता है।
(3) Open to Atmosphere होता है।	close to Atmosphere होता है।
(4) Suitable for High head	Suitable for Low & Medium head.
(5) Low efficiency Compared to reaction Turbine	High efficiency Compared to Impulse Turbine
(6) Low quantity of water is applicable for working.	sufficient quantity of water is applicable for working.

⇒ Pelton wheel Turbine (पेल्टन व्हील टरबाइन) ⇒

Pelton Turbine is a tangential flow Impulse Turbine used for high heads and Low specific Speed. अगर जल का प्रवाह/flow Turbine के runner के साथ Tangent बनाते हुए होता है तो उसे pelton Tangential turbine कहते हैं।

Figure shows the Layout of a hydroelectric Power plant in which the turbine is Pelton wheel. The water from the reservoir flows through the Penstock. At the outlet a nozzle is is fitted. Nozzle converts the Pressure Energy of water into Kinetic Energy (velocity). from Nozzle water comes out in the form of a jet and strikes buckets/vanes/blades. The main Parts of Pelton turbine →

① Nozzle and flow regulating Arrangement →
The amount of water striking the buckets of the runner is controlled by Providing a Spear in the Nozzle. The Spear is a conical needle which is operated by a hand wheel or automatically. when the Spear is pushed forward into the nozzle the amount of water striking the runner is reduced. On the other hand, if spear pushed back, the amount of water striking the runner increases.



② Runner with buckets → Runner एक Circular disk होता है जिसकी Periphery में कई Buckets evenly space में fixed होते हैं। Bucket का shape एक Double Hemispherical cup या Bowl की तरह होता है। Nozzle से Water jet इन Buckets से Impact करती है, Impact angle 160° to 170° होती है। Cast Iron, Stainless steel से Buckets बनाए जाते हैं।

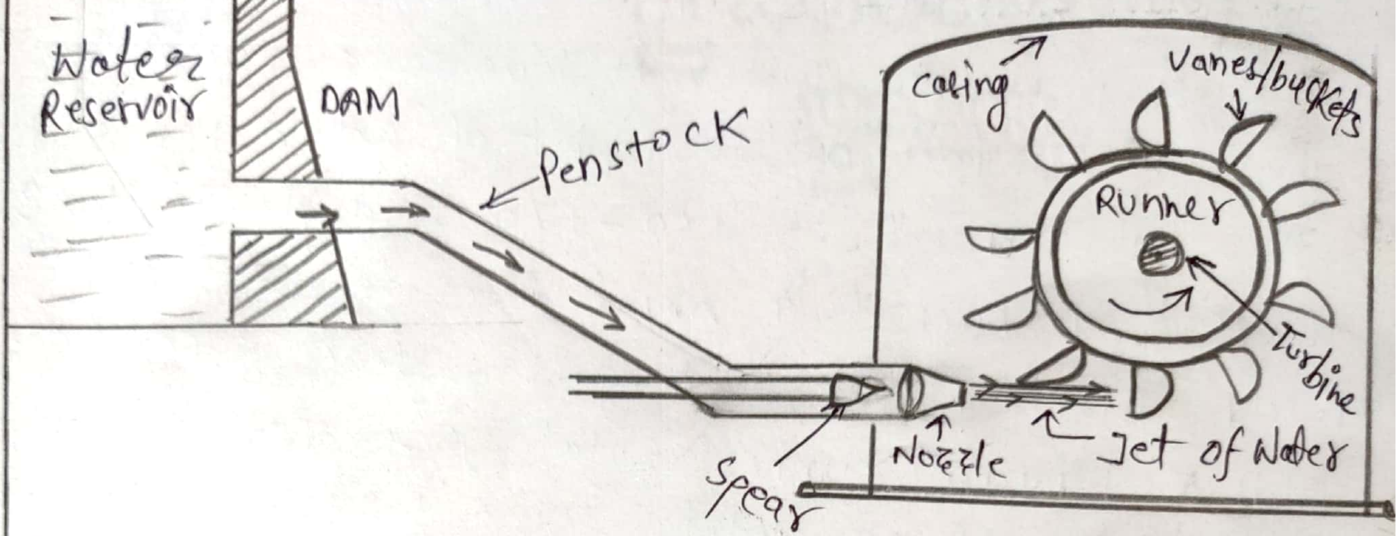


fig → Pelton turbine in hydroelectric Power plant

(3) Casing → The function of the casing is to Prevent the Splashing of the Water and to discharge Water to tail race. It also acts as Safeguard against accidents. It is made of Cast iron or fabricated steel plates. Casing doesnot Perform hydraulic function.

(4) Breaking jet → when the nozzle is completely closed by moving spear in the forward direction, The amount of Water striking the runner reduces to zero. But runner due to Inertia goes on revolving for a long time. To stop runner in short time, a small nozzle is provided which directs the jet of water on the back of vanes. This jet of

water is called breaking jet.

Working → जब water को High head से penstock की द्वारा छोड़ा जाता है तो वो Nozzle से flow होती है। Nozzle water की kinetic energy को Increase कर देता है जिसे outlet पे Jet of water कहते हैं। यह Jet Bucket से 160°-170° के angle पर strike करती है। Bucket पे Axial force generate होता है, जिसके कारण Runner पर tangential force generate होता है। जिससे runner rotate होने लगता है तथा Turbine shaft भी rotate होता है। इस shaft rotation को ही shaft work/Turbine work/Mechanical work कहते हैं। Turbine से generator को couple कर Mechanical energy को Electrical Energy में convert किया जाता है।

Francis Turbine → Francis turbine एक Inward radial flow reaction turbine है। Radial flow Turbine ऐसे Turbine को कहते हैं जिसमें पानी radial direction में flow होता है। Water radially outward से Inward या Inward to outward flow हो सकता है; तब direction के कारण इसे Inward या outward radial flow turbine कहते हैं। इस Turbine में runner और casing को water से completely fill किया जाता है।

Main Parts →

(1) Casing → Penstock से Water casing में प्रवेश करता है। Casing Spiral Shape में होता है जिसका cross-section area gradually decrease होता है। casing runner को completely cover करता है। Casing की इस बनावट के कारण runner के अंदर water constant velocity से Travel करता है।

(2) Guide-Mechanism → यह एक stationary circular wheel होता है जो runner को चारो तरफ से surround किए हुए होता है। stationary guide vanes, guide mechanism में fix होते हैं। Guide Vanes Water को इस तरह से Guide करता है कि Water बिना shock के vanes से टकराते हैं। इस कारण Water की Kinetic Energy बिना loss के vanes से strike करती है।

(3) Runner → Runner एक circular wheel होता है, जिस पर radial curved vanes fix होते हैं। यह cast Iron, Stainless steel etc. का बना होता है।

(4) Draft-tube → Reaction turbine के exit में Pressure atmospheric Pressure से कम होता है। Water अपने आप tail race से बाहर निकल नहीं पाता है। Draft tube Gradually Increasing area का tube होता

है, Area बढ़ने से Velocity कम होती है तथा Pressure Increase होता है। जब Pressure, Atmospheric Pressure से ज्यादा होती है तब water अपने आप बाहर चला जाता है।

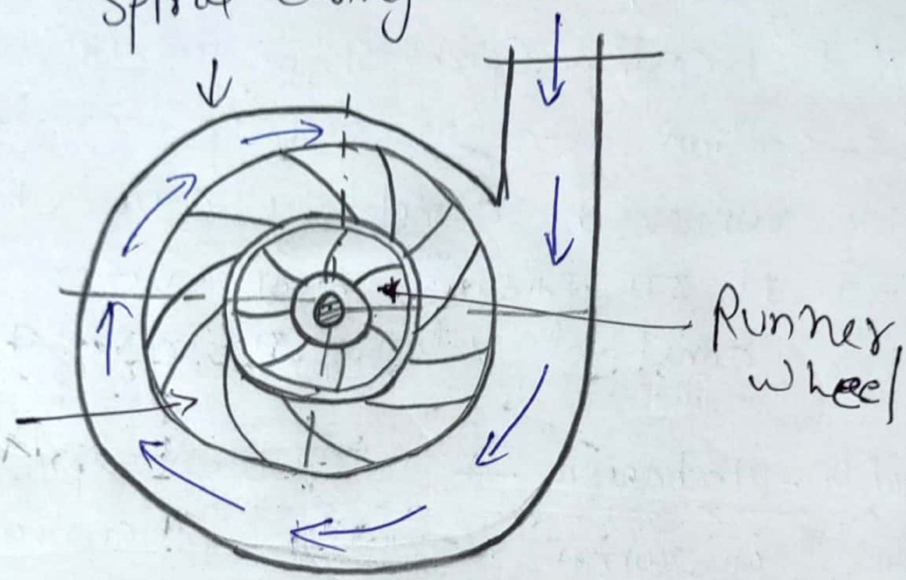
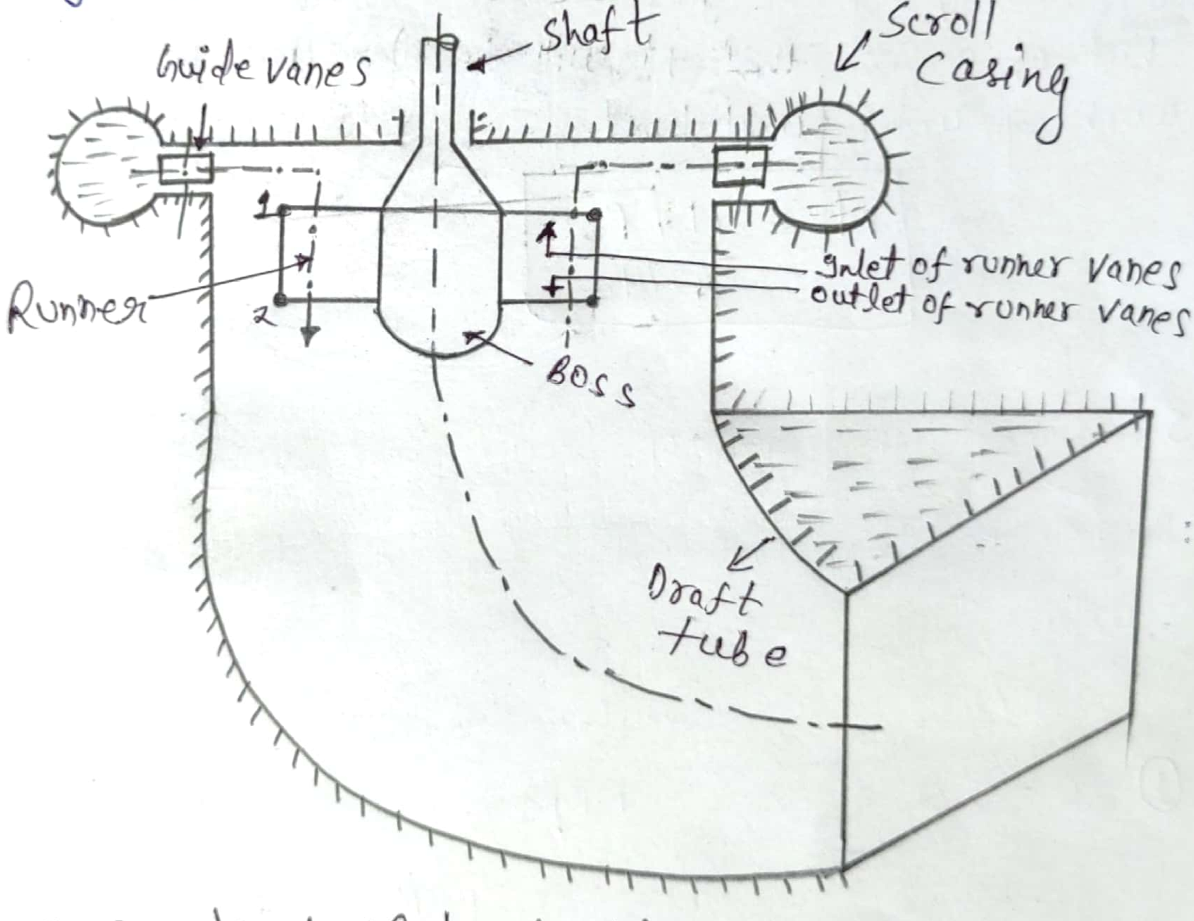


fig. → Francis turbine

Kaplan-Turbine → अगर जल का प्रवाह Shaft-axis rotation के Parallel होता है तब Turbine को Axial flow turbine कहते हैं। Kaplan Turbine is a Axial flow reaction turbine. Kaplan turbine में shaft Verticle होता है। Shaft के Lower end को Large बनाया जाता है जिसें Hub या Boss कहा जाता है। Turbine blades को Hub में Fix किया जाता है। Mainly Axial flow turbine is of two types →

(1) Propeller Turbine (2) Kaplan Turbine

जब Vanes hub में fixed होते है तथा Not adjustable होता है तो उसे Propeller turbine कहते हैं। But जब Vanes को hub में fix किया जाता है तथा Vanes adjustable होते हैं तब उसे Kaplan turbine कहते हैं। इस Turbine को design Austrian Engineer V Kaplan ने किया था।



Main components of Kaplan turbine →
① Scroll casing (सर्पिल आवरण)
② Guide Vanes Mechanism ③ Draft Tube.
④ Hub with Vanes or runner of the turbine.

Penstock से water scroll casing में आता है, scroll casing से water guide vanes के द्वारा 90° का कोण बनाते

हुए runner vanes पर Impact होता है। Vanes के rotate होने पर Hub/shaft भी rotate होता है तथा हमें Work output/shaft power/Turbine Power की प्राप्ति होती है। Draft-tube की सहायता से water को Tail race में exit कर दिया जाता है।

Specific Speed (N_s) → It is defined as the speed of a turbine which is identical in shape, geometrical dimensions, blade angles etc. with the actual turbine but of a size that it will develop unit power when working under unit head.

$$N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

Selection & Significance of Specific Speed → Specific speed plays an important role for selecting the type of turbine.

SN	Specific Speed	Type
①	0 - 50 RPM	→ Pelton wheel.
②	51 - 225 RPM	→ Francis Turbine.
③	255 - 860 RPM	→ Kaplan Turbine.

Que → A turbine is to operate under a head of 25 m at 200 rpm. The discharge is 09 cumec. If the efficiency is 90%, determine →

① Specific Speed ② Power generated ③ Type of turbine.

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Ans → Given, $H = 25$ m., $N = 200$ rpm, $Q = 9$ cumec $= 9\ m^3/s$,
$\eta_o = 90\% = 0.9$.

Now using relation, $\eta_o = \frac{\text{Power developed}}{\text{Water Power}}$

$$\eta_o = \frac{P}{\frac{\rho g Q H}{1000}} \Rightarrow P = \eta_o \times \frac{\rho g Q H}{1000} = \frac{0.9 \times 1000 \times 9.81 \times 9 \times 25}{1000}$$

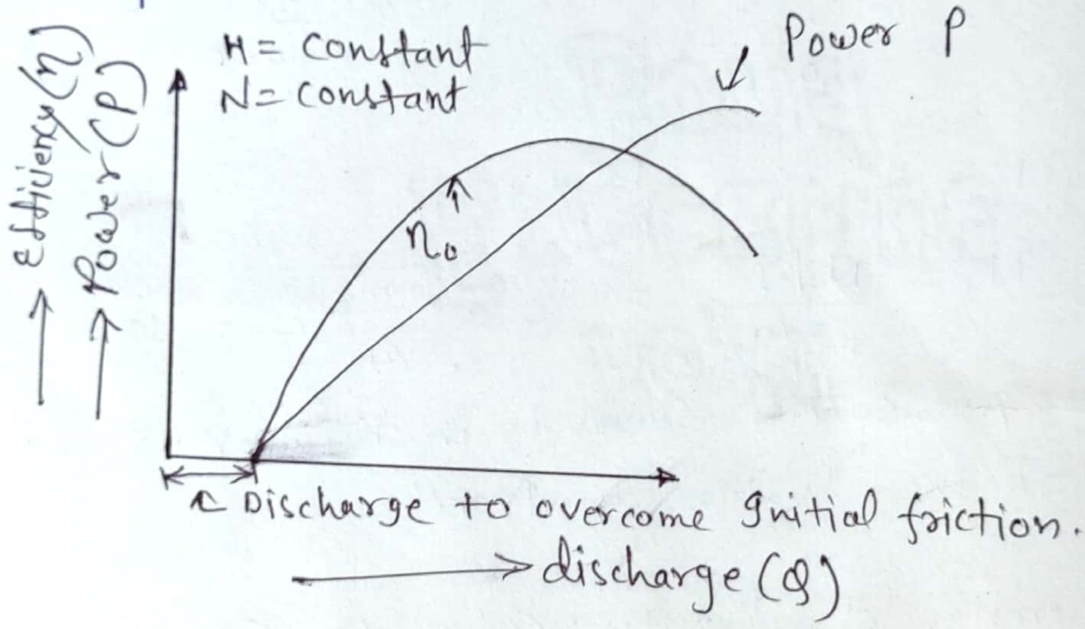
(1) $P = 1986.5$ Kw.

(2) $$N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{200 \times \sqrt{1986.5}}{25^{5/4}} = 159.46 \text{ RPM}$$

(3) As specific speed is in between 51 to 225, so the Turbine is Francis.

Operating characteristic Curves or Constant Speed Curves → Generally Turbines में Head constant होता है। Operating characteristic curve तब Draw किया जाता है जब किसी Turbine की speed constant होती है। Mainly 03 Independent Parameters होते हैं:- (1) N (Speed) (2) H (Head) (3) Discharge (Q). Operating characteristic curve में N & H Constant हो जाते हैं तथा Power (P) and efficiency (η) curves

With respect Q (discharge) plott करते है।
Power curves turbines के ~~लिए~~ origin से pass नहीं होता है क्योंकि certain amount of discharge के बाद ही Power Produced होता है। कुछ Power Initial friction को overcome करने मे भी Expense हो जाता है। Power के बाद ही efficiency calculate किया जाता है अतः Efficiency भी origin से Pass नहीं होता है।



Chapter No.-09

Pump (Centrifugal & Jet)

Pump → ऐसी Hydraulic machines जो Mechanical Energy को Hydraulic Energy में convert करती है, उसे Pump कहते हैं।

⇒ **Centrifugal Pump (अपकेन्द्री पम्प)** → Centrifugal Pump एक Hydraulic machine है जो Centrifugal force के द्वारा fluid के Pressure को rise करती है। फिर इस High Pressure fluid को High head तक deliver किया जाता है।

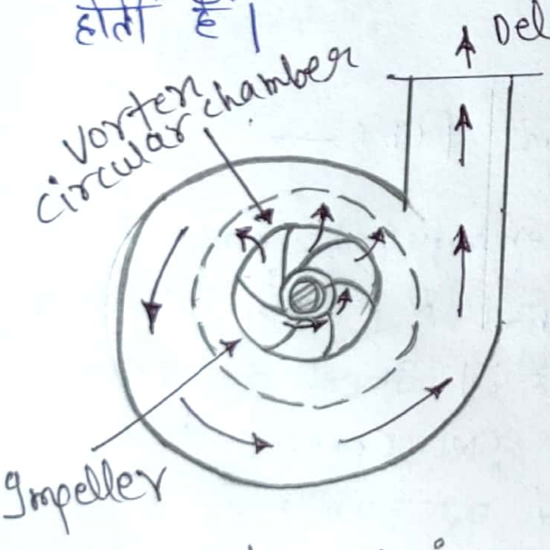
Main parts of the Centrifugal Pump →

① **Impeller (आंतरनोदक)** → Centrifugal Pump के rotating part को Impeller कहते हैं। इसमें curved vanes की series लगी होती है। Impeller तथा electric motor एक ही shaft द्वारा connected होते हैं, जिस कारण motor के घूमने पर Impeller भी घूमता है।

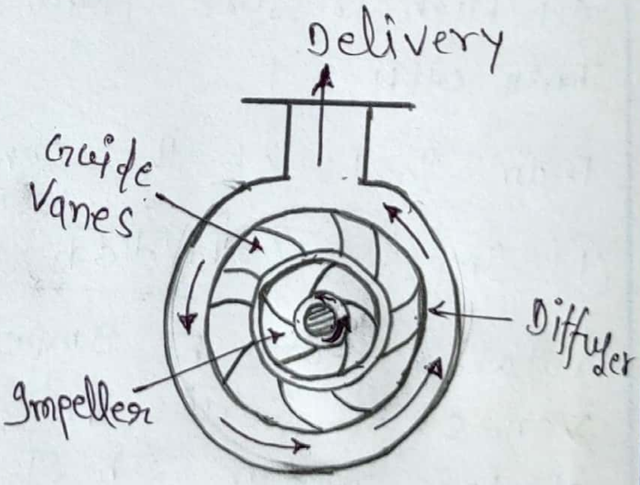
② **Casing (आवरण)** → Centrifugal Pump की casing reaction turbine की तरह ही होती है। यह एक air tight passage होता है जो Impeller

को Surround किए हुए रहता है। इसका design ऐसा होता है कि जब Impeller के outlet से water exit होता है तो यह water की Kinetic Energy को Pressure Energy में convert कर देता है। यह मुख्यतः 03 types का होता है।

ⓐ Vortex Casing → यह एक Circular chamber को Consist करता है तथा यह chamber, Casing और Impeller के मध्य होता है। Impeller के outlet से निकला जल पहले Circular Chamber (Vortex room) में आता है फिर casing मे Transfer होता है। Vortex room में eddies formation (भँवर या जलावर्त) reduce होता है जिससे Energy loss कम होता है तथा Pump की Efficiency बढ़ जाती है। Volute casing की अपेक्षा Vortex Casing में Pump efficiency ज्यादा होती है।



ⓐ Vortex Casing



ⓑ Casing with Guide blades.

ⓑ Casing with Guide blades → इस casing में Impeller को series of guide blades mechanism से surround कर देते हैं, तथा इसे Diffuser कहते हैं। Guide vanes इस तरह से Design होते हैं कि Impeller outlet से निकला water guide vanes में without shock

Enter करता है। Guide Vanes water की velocity को कम करके Pressure Energy को Increase करता है। फिर यह Pressurised water casing मे transfer हो जाता है।

ⓒ Volute casing → Volute casing spiral shape का gradually increasing area का casing होता है। Area increase होने से velocity कम होती है तथा Pressure Energy increase होती है। इस casing मे eddies formation (भँवर) होता है जिस कारण Pump की efficiency slightly कम हो जाती है।

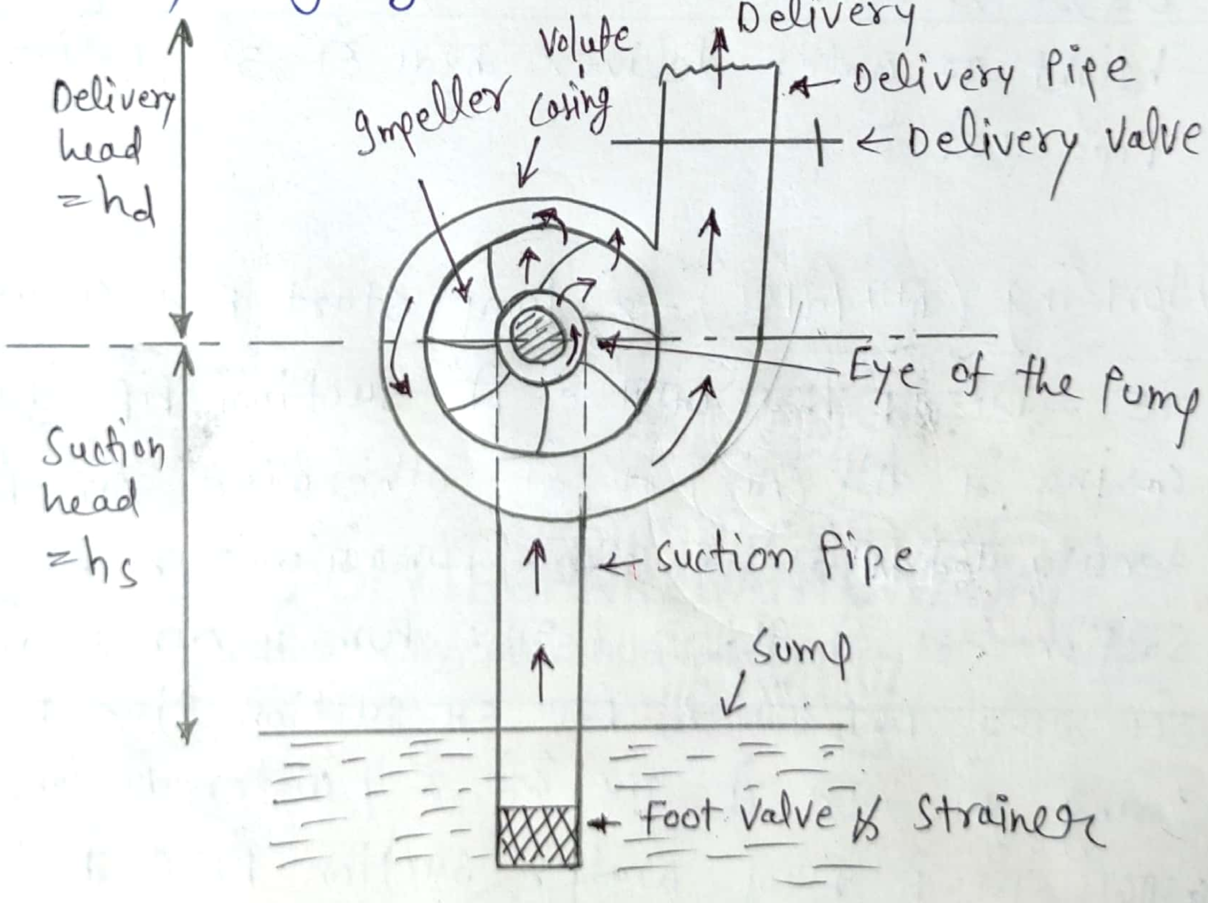


fig → Centrifugal Pump with Volute Casing.

③ Suction Pipe with a foot Valve & a Strainer →
एक Pipe जिसका एक End Pump के Inlet पे तथा दूसरा End Water Sump से connected हो, उसे Suction Pipe कहते हैं। Suction Pipe के Lower End में एक Foot valve और एक strainer attach होता है। Foot valve Non-returning या one way type valve होता है, जिसमें पानी Inlet हो सकता है परंतु Exit नही हो सकता है। Strainer (छलनी) का work होता है कि जल मे मौजूद Waste को strain कर देता है।

④ Delivery Pipe → एक Pipe जिसका एक End Pump Outlet से connected हो तथा दूसरा End Required height पर water deliver करता हो, उसे Delivery Pipe कहते हैं।

Working (कार्यविधि) → Pump start करने से पहले यह सुनिश्चित किया जाता है कि suction Pipe तथा casing मे वायु (Air) न हो, otherwise Air की density बहुत कम होने के कारण Pump में water का Suction नहीं हो पाता है। अगर Pump मे Air है तो उसे बाहर निकालने के लिए हम suction pipe तथा Casing को जल से भर देते हैं। Water की density ज्यादा होने के कारण water suction Pipe से होते हुए Impeller मे पहुँचता है। Water suction की यह Method Priming कहलाती है।

Pump start करने पर electric motor start हो जाता है तथा

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Same shaft में होने के कारण Impeller भी Run होता है। Impeller के centre जिसे Eye of the Pump भी कहा जाता है वहाँ Suction Create होता है। जिस कारण Water Sump level से suction pipe के through Impeller में Entry करता है। Impeller के rotation के कारण Centrifugal force generate होता है तथा water की Kinetic Energy बढ़ जाती है। फिर यह water casing मे प्रवेश करता है जहाँ Increasing Area होने के कारण Water की Kinetic Energy Pressure Energy में convert होती है तथा High Pressure water Delivery Pipe से होते हुए Declared head में पहुँच जाता है।

Efficiency → 50–85%

Advantage – Less Space, High speed, High head, Low Maintenance.

Limitation – Priming Problem, Less efficiency

Application – tube wells, drainage, feed water in boilers, Public water distribution system, Petrol Pump, Fire Centre etc.

Classification of Centrifugal Pump (वर्गीकरण) →

(1) On the Basis of working head (कार्यकारी शीर्ष के आधार पर) → (a) High head Pump
(b) Low head Pump
(c) Medium head Pump

(2) On the basis of Specific Speed → (a) High Specific Speed pump (b) Medium speed Pump (c) Low Speed Pump.

(3) On the basis of Impeller (आंतरनोदक के आधार पर) →
(a) open Impeller Pump (b) closed Impeller Pump
(c) semi-open Impeller (अर्द्ध खुला आंतरनोदक).

(4) On the basis of flow from Impeller (आंतरनोदक से प्रवाह के आधार पर) →
(a) Axial flow pump (अक्षीय प्रवाह पम्प)
(b) Radial flow Pump (त्रिज्यीय प्रवाह पम्प)
(c) Mixed flow Pump (मिक्सड / मिश्रित प्रवाह पम्प).

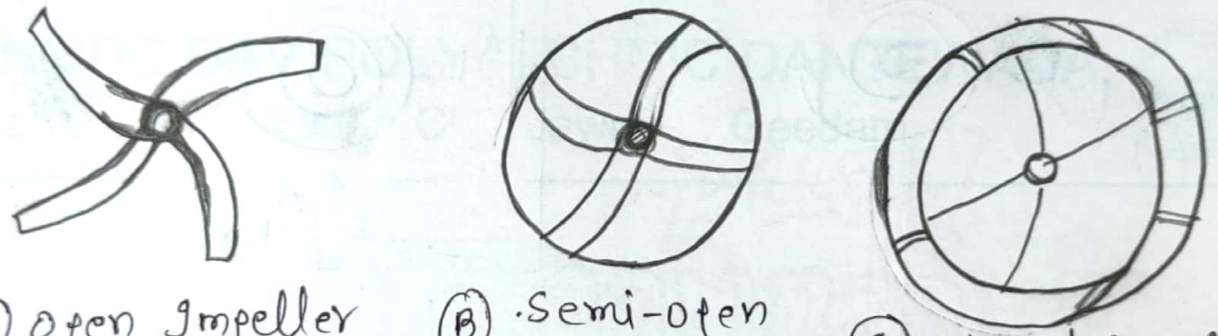
Types of Impeller (आंतरनोदक के प्रकार) →

(1) Open Impeller (खुला आंतरनोदक) → यह Impeller खुला होता है। इसमें Blades/Vanes लगे होते हैं, यह किसी फूल की Pallets (पंखुड़ियों) के समान दिखता है। इसका Application वहाँ होता है जहाँ water में Silica content हो या Heavy water हो।

(2) Semi open Impeller → जब open Impeller को किसी plate में fix कर दिया जाता है, जिससे Impeller के एक side plate तथा दूसरे side पर

Impeller open हो तो इसे semi open Impeller कहा जाता है।

(c) closed Impeller → जब Impeller के दोनों side पर plate fixed कर दिया जाता है तथा Impeller दोनों side से closed हो जाता है तो इसे closed Impeller कहते हैं।



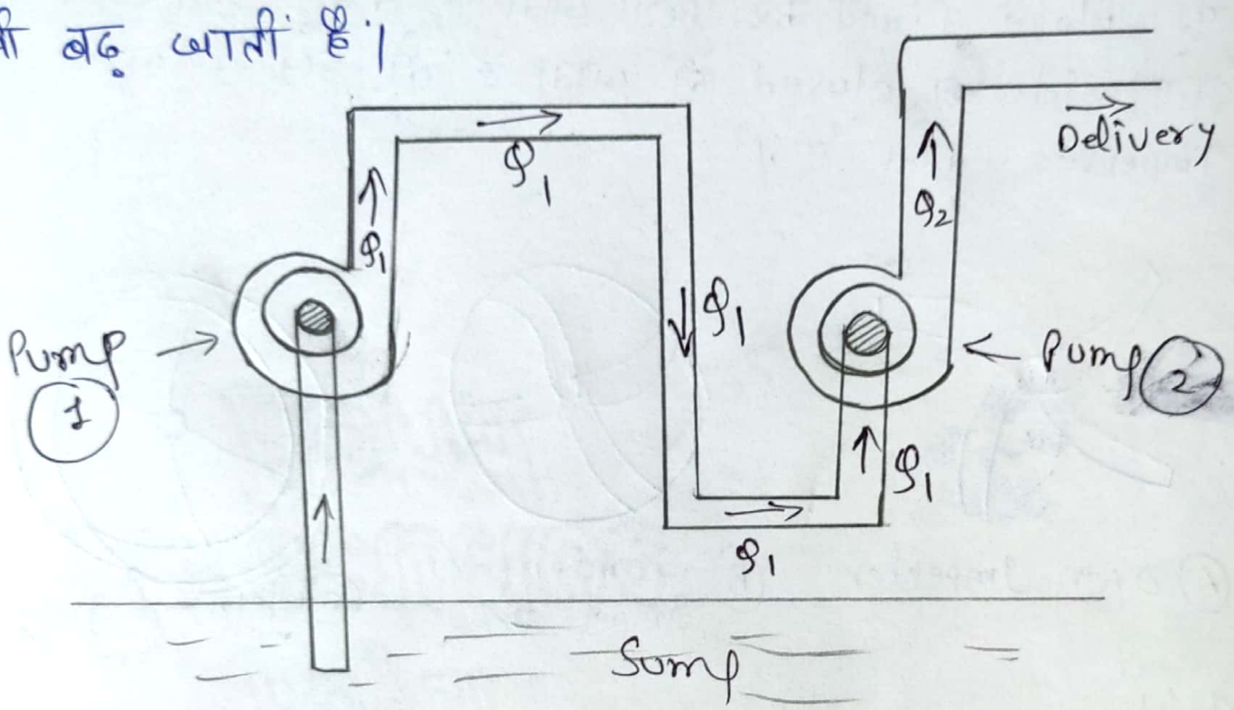
(A) open Impeller (B) Semi-open Impeller. (C) closed Impeller

Multistage - Centrifugal Pump (बहुचरण) → जब किसी centrifugal pump में Two or more than two Impellers को mount किया जाता है तो इसे Multistage centrifugal Pump कहते हैं।

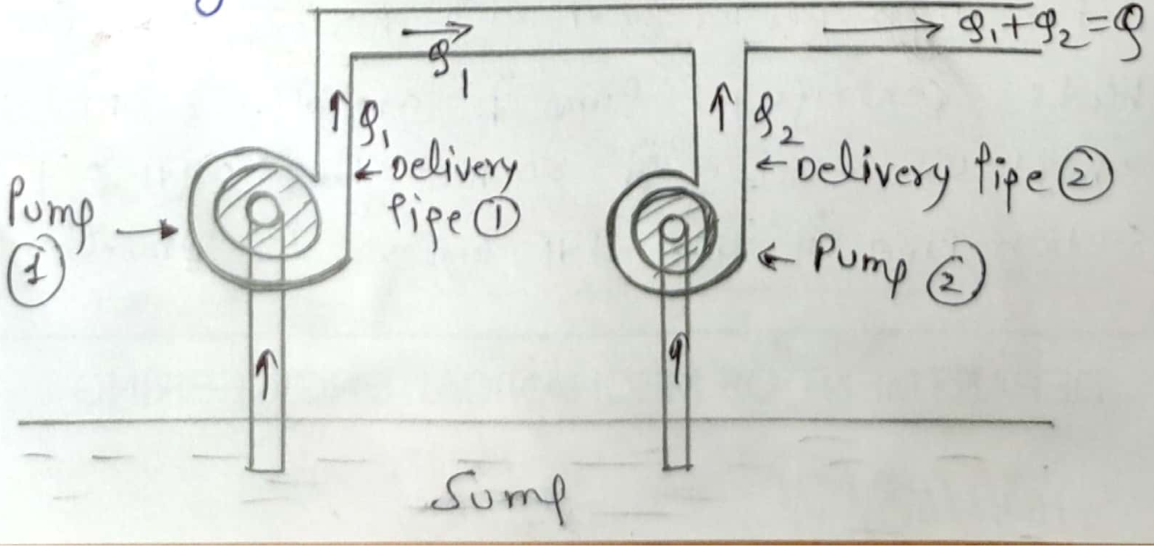
Types of Multistage centrifugal pump →

(1) For High head (उच्च शीर्ष के लिए) → for High heads, centrifugal pump के Impellers को same shaft पर series में connect किया जाता है।
suction pipe से आने वाला water 1st Impeller से

Pressurize होकर discharge होता है। First Impeller का outlet Connection second Impeller के Input से होता है। Second Impeller के outlet से निकलने वाली water की Pressure, 1st Impeller से निकले water से ज्यादा होती है। अगर same shaft में No. of Impeller बढ़ाए जाए तो Delivery Pressure को rise किया जा सकता है तथा उसी ratio में Head delivery भी बढ़ जाती है।



(2) For High Discharge (उच्च निस्सरण या ज्यादा प्रवाह के लिए) → High discharge के लिए Pumps को Parallely connect किया जाता है। सारे Pump एक common Pipe में discharge delivery देते हैं जिससे Exit में High discharge obtain होता है।



Cavitation (कोटरण) → जब किसी भी Hydraulic Machines में Liquid Pressure की value Liquid की Vapour Pressure से कम हो जाती है तो cavitation formation start होता है। Cavitation में Liquid में Vapour bubbles (जल बुलबुले) form होते हैं तथा जब यह bubbles high Pressure region में आते हैं तो burst हो जाते हैं। जब यह bubbles collapse होते हैं तो Noise and Vibration generate करते हैं तथा Metallic Surface में Pitting (क्षरण) Action होते हैं। इस कारण surface Damage हो जाता है। cavitation से Hydraulic machines की Efficiency भी कम हो जाती है।

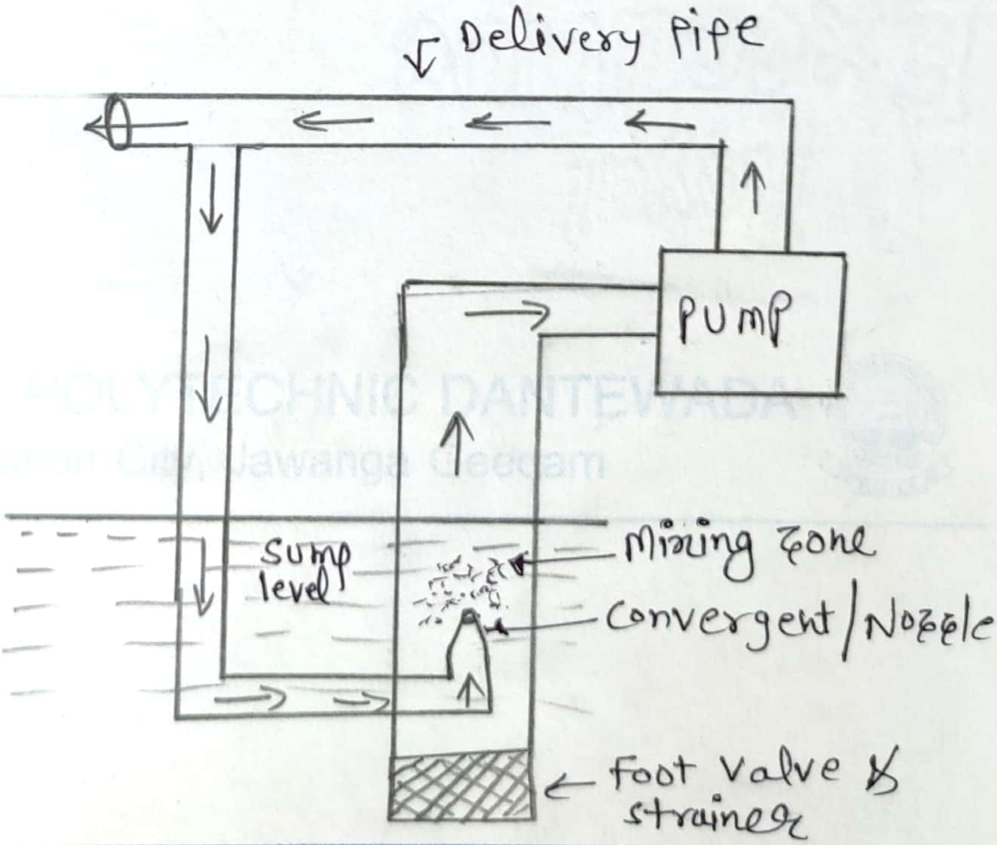
(1) Turbine – cavitation reaction turbine में होता है। Runner के outlet या draft tube के inlet पर Cavitation होता है।

(2) Pump – Centrifugal Pump में Impeller inlet में Liquid Vapour, vapour pressure से कम हो जाती है।

Specific Speed of Pump (पम्प की विशिष्ट गति) →

The Specific Speed of a Pump is defined as the speed of a geometrically Similar Pump which would deliver one m^3 Liquid per second ($1\ m^3/s$) against a head of one meter.

⇒ Jet pump (जेट पम्प) → Jet pump Simply एक Pipe होता है जिसके एक End पर convergent (▷) shape होता है या End पर एक convergent लगा होता है। जब water को Pipe से flow किया जाता है तथा water convergent से होकर गुजरती है तब Decreasing Area के कारण fluid का Pressure, Kinetic Energy में convert होने लगता है। convergent या Nozzle fluid की Kinetic Energy (speed) को increase कर देती है। जिसके कारण fluid का Pressure कम हो जाता है तथा suction condition generate हो जाती है। suction के कारण fluid sump level से lift होने लगता है।

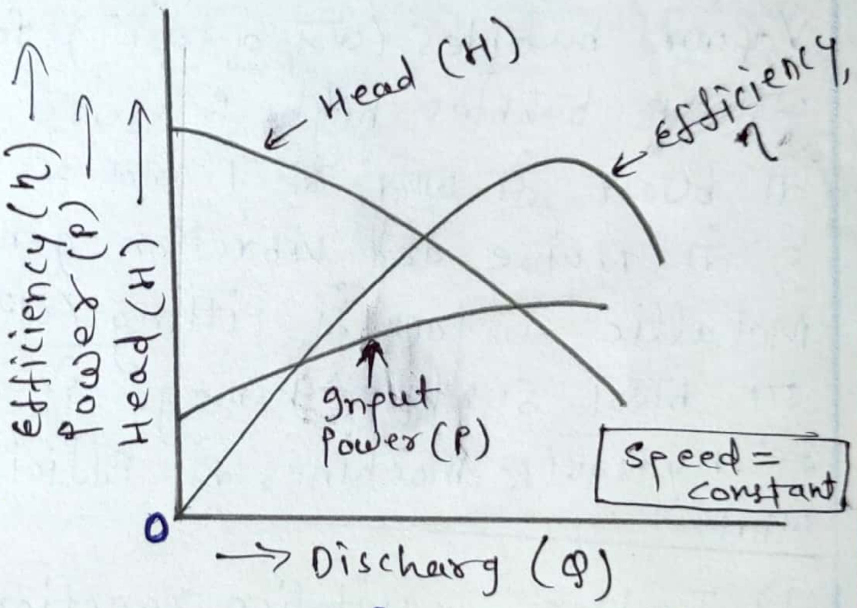


किसी पम्प की विशिष्ट गति, ज्यामितीय रूप से समानुपाती पम्प की speed होती है जो 1 m head पर 1 m³/s का discharge प्रवाहित करता है।

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}}$$

Operating Characteristic Curves for Pump →

for constant speed, जब हम Efficiency, Power तथा Head of the pump को discharge के respect में curve plot करते हैं तो उसे Operating Characteristic Curves कहते हैं।



① Input Power curve origin 0 से न शुरू होकर कुछ lift लेकर y-axis से start होता है, क्योंकि Discharge 0 होने पर भी static friction/Mechanical loss को overcome करने के लिए कुछ power की आवश्यकता होती है।

② Efficiency curve, discharge के According vary करता है।

③ Head curve Maximum तब होता है जब discharge zero होता है। Discharge के rise होने पर Head का Low होना common (स्वभाविक) है।

Jet Pump की construction Easy होती है तथा इसमे कोई moving Part नहीं होता है।

Advantage → ① Light weight ② Easy stallation ③ Low Maintenance ④ used for dirty water or mud water erection from bore well. ⑤ used as Propulsion system in Marine Systems. ⑥ In Jet Engines for thrust

Disadvantages → ① Low efficiency 20% to 30%. ② High Running cost. ③ * compressed air is required to run the pump.

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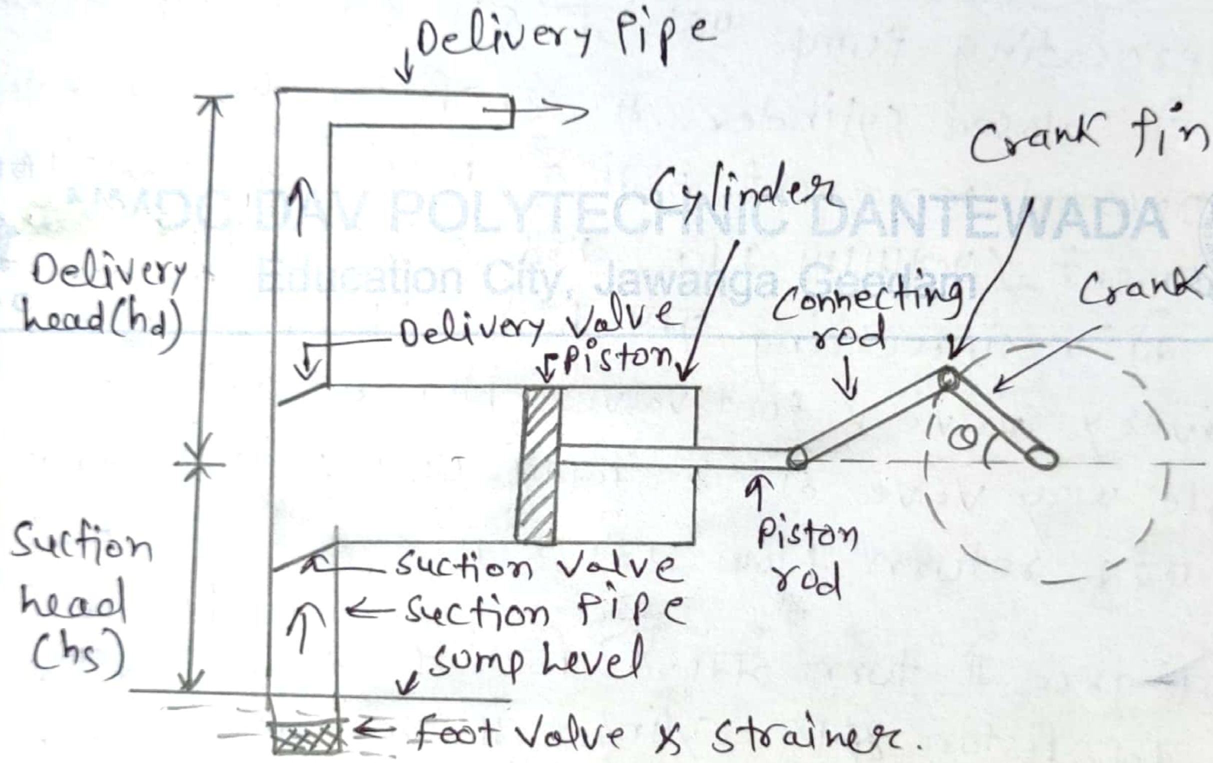
Chapter No. - 10

Pumps (Submersible & Reciprocating).

⇒ Reciprocating Pump (प्रत्यागामी पम्प) →



जब Mechanical Energy को Hydraulic Energy मे convert करने के लिए fluid को suction Pipe द्वारा cylinder मे compress करके या Piston द्वारा Axial thrust लगाकर किया जाता है तो ऐसे Pump को Reciprocating Pump कहते है।

Main parts of reciprocating Pump →

① A cylinder with piston, Piston rod & Crank.
② suction pipe
③ Delivery pipe
④ Delivery valve
⑤ suction valve.

Working (कार्यविधि) → चित्र में एक single acting reciprocating pump प्रदर्शित है। इस reciprocating पम्प में closed cylinder में एक Piston backward & Forward movement करता है जिसे reciprocating movement (प्रत्यागामी गति) कहते हैं, इसी कारण पम्प को reciprocating पम्प कहते हैं। suction valve, Delivery valve & foot valve Non returning या single way valve होते हैं जिनसे पानी गुजर तो सकता है परंतु return flow नहीं होता है।

जब Crank 0° से 180° में turn लेता है जिसे 1 stroke कहते हैं, तब Piston द्वारा cylinder में vaccume (निर्वात) उत्पन्न होता है तथा fluid sump level से suction Pipe से होते हुए cylinder में पहुँच जाता है। जब पिस्टन 180° to 0° crank angle के कारण Right to left movement करता है तो piston Axial thrust fluid पर लगाती है जिससे fluid का Hydraulic Pressure बढ़ जाता है। इस समय suction valve बंद रहता है तथा Delivery valve खुल जाता है। High Pressure fluid delivery valve द्वारा निर्धारित स्थान पर पहुँच जाता है। यह Process बार-बार होता है जिससे flow continue होता है।

Discharge (q) = $\frac{ALN}{60}$

L = Length of stroke = $2 \times r$ (r = crank radius)

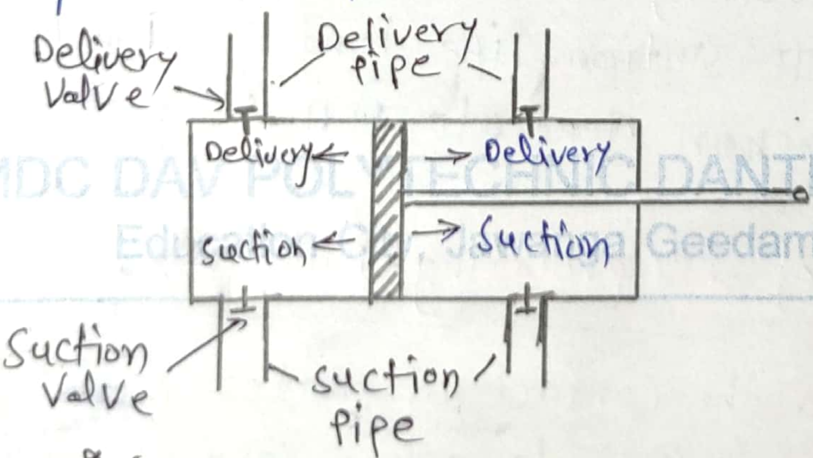
N = rpm of crank

A = cross-section Area of cylinder.

Power (P) ⇒ $\frac{\rho g ALN (h_s + h_d)}{60000}$ Kw.

Application → ① well से fluid/oil आदि निकालने के लिए ② Boilers में fluid feeding के लिए।
③ Vehicle servicing centre में washing के लिए।

Double Acting reciprocating Pump → इस पम्प मे पम्प cylinder के दोनों तरफ suction valve, Delivery valve, suction pipe तथा Delivery pipe होता है।



इस पम्प में जब Piston backward motion करता है तो एक तरफ vaccum के कारण suction होता है परंतु

दूसरी तरफ Delivery Stroke work करता है। अर्थात Piston के 02 stroke में दोनो तरफ Suction तथा Delivery Simultaneously होता है। बाकी सारा Process तथा Structure Single acting Pump के समान ही होती है।

इस पम्प की efficiency Single acting Pump के तुलना में Double होती है।

Slip → Slip is defined as the difference between theoretical discharge & actual discharge of the Pump.

$$S = Q_{th} - Q_{act}$$

Negative Slip → जब Actual discharge theoretical discharge से ज्यादा हो जाता है तो उसे Negative होने के कारण Negative Slip कहा जाता है।

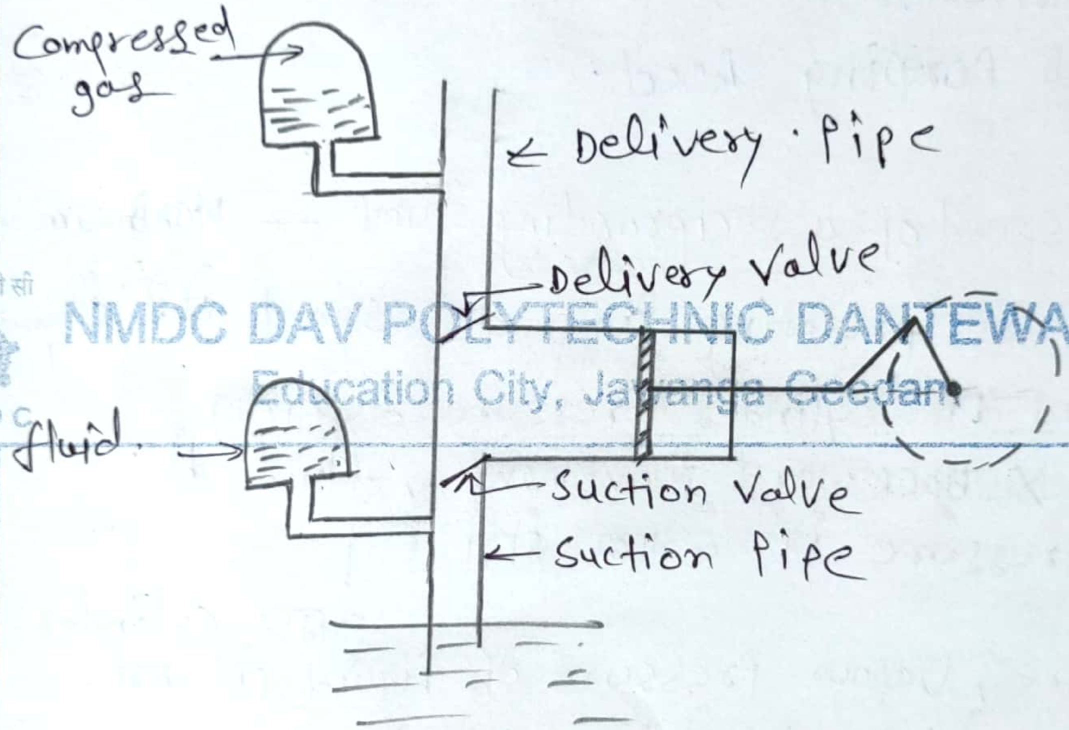
जब पम्प की running Speed ज्यादा है, Delivery Pipe Small हो तथा Suction Pipe long हो तब Negative Slip phenomenon generate होता है।

Classification of reciprocating Pump →

① According to the Contact of Water (जल स्पर्श के आधार पर) → ① Single acting ② Double acting

② According to the No. of Cylinders →
① Single Cylinder Pump ② Double Cylinder Pump
③ Triple Cylinder Pump.

→ Air Vessel → Air Vessel एक closed chamber होता है जिसके Top portion पर compressed air तथा Bottom portion पर fluid store हो जाता है।



Air Vessel chamber के नीचे एक opening होती है जिससे इसे suction pipe तथा Delivery Pipe से connect किया जाता है। जब suction या Delivery Pipe में fluid flow ज्यादा होता है तब कुछ fluid इस vessel में store होता है तथा compressed air और ज्यादा compress हो जाती है। जब fluid flow कम होता है तब Air vessel से fluid out होकर Suction तथा Delivery Pipe में चले जाता है। अतः Pump में flow की continuity को बनाए रखने के लिए Air vessel का उपयोग किया जाता है।

Selection of the Pump → किसी पम्प का selection निम्न Parameters को ध्यान मे रखकर किया जाता है।

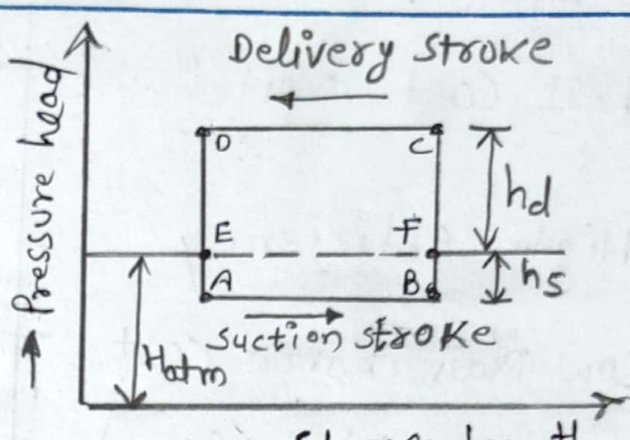
1. Capacity of Pump
2. Initial cost or capital (प्रारंभिक लागत)
3. Maintenance cost
4. Position or place of pump
5. Total Pumping head.

Maximum speed of a reciprocating Pump → Maximum speed of reciprocating Pump वह speed होती है, जिस speed तक cylinder pressure during forward & Backward movement, fluid के Vapour pressure से ज्यादा होती है।

अगर cylinder मे pressure, Vapour pressure of Liquid से कम हो जाती है तो Liquid मे घुली हुई gases बाहर आ जाती है तथा cavitation phenomenon generate हो जाता है।

Indicator-diagram → Indicator diagram of Pump वह है कि for one revolution of crank, Pressure head in cylinder और Piston द्वारा stroke के समय तय की गयी दूरी के मध्य बनाया जाता है।

h_s = suction head
h_d = Delivery head
H_{atm} = Atmospheric Pressure head.



Indicator diagram से यह पता चलता है कि suction stroke के समय cylinder pressure, atmospheric pressure से कम होती है तथा Delivery stroke के समय cylinder pressure, atmospheric pressure से ज्यादा होती है।

Suction stroke = Line A-B

Atmospheric pressure head = E-F

Delivery stroke = DC

एक complete revolution में cylinder के pressure head को A-B-C-D-A diagram द्वारा दर्शाते हैं। यह Ideal Indicator diagram कहलाता है।

→ Difference between centrifugal and Reciprocating pump →

centrifugal pump	Reciprocating pump
① Discharge – continuous & smooth	Discharge – fluctuating & pulsating

Centrifugal Pump	Reciprocating pump
(2) used for large quantity of liquid.	used for small quantity of liquid only.
(3) Less cost capital.	High cost (4 times more than centrifugal pump.
(4) High efficiency	Low efficiency.
(5) Low Maintenance cost	High Maintenance cost.
(6) runs at high speed.	runs at low speed.
(7) Low head & High discharge use	High head & low discharge use

⇒ Submersible Pump → सबमर्सिबल पम्प एक vertical shaft centrifugal pump होता है। इस पम्प को एक electric motor से जोड़ देते हैं तथा Motor से coupled होने के कारण जब electric supply प्रदान करने पर यह Pump rotate होने लगता है। shaft के support के लिए Nickel या रबर की bearing use की जाती है।

यह पम्प Hermetically sealed (पूरी तरह से pack/बंद) होता है। क्योंकि इसे fluid में डुबाया जाता है अतः इसे water proof बनाने के लिए पूरी तरीके से बंद किया जाता है।

Working →
Basically यह Multistage Centrifugal Pump है, परंतु इसमें vertical shaft होता है। इसकी कार्यविधि Centrifugal Pump के समान ही होती है।

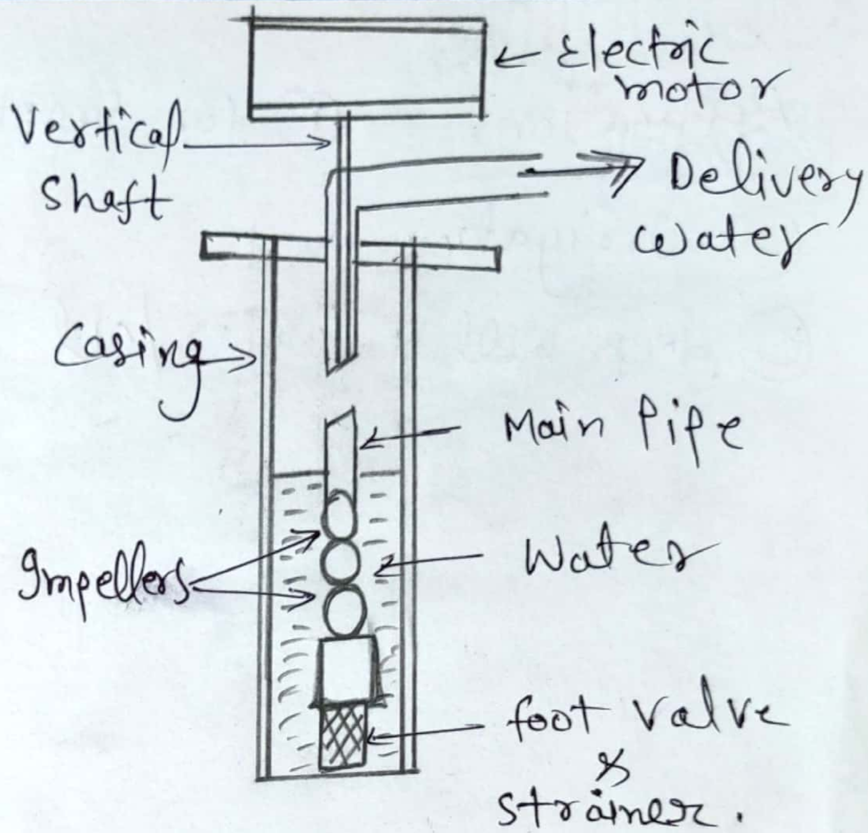


fig → Submersible Pump

Installation → Generally इस पम्प का use deep well (गहरे कुओं) या जमीन से पानी निकालने के लिए use होता है। Submersible pump को chain Mechanism द्वारा एक Extra (अतिरिक्त) Pipe द्वारा जल में पहुँचाया जाता है। पम्प का Impeller, 3 m. Suction Pipe, foot valve & strainer जल में डूबे होते हैं। ऐसे wires द्वारा wiring

की जाती है जो long lasting होता है, क्योंकि इस पम्प को deep wells में use किया जाता है अतः maintenance कठिन हो जाता है।

Applications → ① for supply drinking water

② Irrigation में।

③ deep well से water/oil निकालने के लिए।

Chapter No. - 02

Pressure & Its Measurement

(दाब एवं इसका मापन)

Pressure → Pressure is Normal force per unit area. Pressure is compressive in nature.

$$P = F/A$$

unit → Pressure = N/m^2 or Pascal (Pa)

1 MPa = 10^6 Pa, 1 GPa = 10^9 Pa

1 MPa = 1 N/mm^2, 1 bar = 10^5 Pa

Atmospheric pressure, P_{atm} = 1.013 bar
≈ 1 bar.

Intensity of Pressure → किसी Liquid द्वारा किसी surface के unit area ($1\ m^2$) पर लगाने वाला कुल बल, Intensity of Pressure कहलाता है। इसे p से denote करते हैं।

$$p = F/A \quad (\because \text{where } A = \text{unit area})$$

Pressure-head (दाब-शीर्ष) → जब किसी Liquid के Pressure को उसकी height द्वारा show करते हैं तो उसे Pressure head कहते हैं।

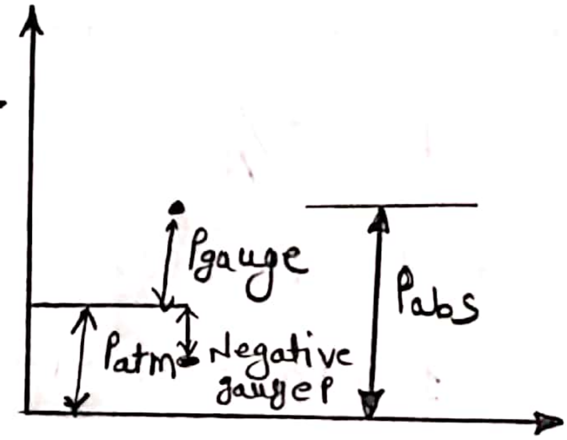
अर्थात $h = \frac{P}{\omega}$ or $\frac{P}{\rho g}$

or $\boxed{P = \rho g h}$

ρ = density of fluid.
g = gravity.
h = height of fluid.

classification →

① **Atmospheric Pressure (P_{atm})** →
The Pressure Exerted by the environmental mass is called Atmospheric Pressure (P_{atm}).



② **gauge-Pressure (P_{gauge})** → The Pressure measured relative to atmospheric Pressure is Known as gauge Pressure.

अगर gauge Pressure, Patm से ज्यादा हो तो positive gauge Pressure कहते हैं, अगर gauge Pressure, Patm से कम हो तो Negative gauge Pressure या Vaccum Pressure कहते हैं।

③ **Absolute Pressure (P_{abs})** → (निरपेक्ष दाब)
The Pressure measured with respect to ZERO pressure is Known as absolute Pressure.

$$\boxed{P_{abs} = P_{gauge} + P_{atm}}$$

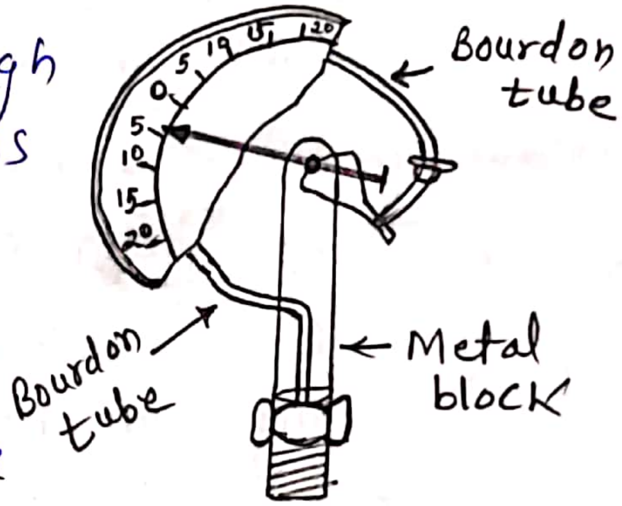
Pressure gauges → Pressure gauges ऐसे devices होते हैं जिनका उपयोग Pressure measurement के लिए होता है। इन्हे Mechanical gauges या Mechanical Pressure gauges भी कहते हैं। Pressure measure करने के लिए Fluid column की balancing की जाती है; जिसके लिए Spring या Dead weight का उपयोग किया जाता है।

Common - Pressure gauges →

1. Diaphragm Pressure gauge.
2. Bourdon tube Pressure gauge.
3. Dead weight Pressure gauge.
4. Bellows Pressure gauge.

2) Bourdon tube Pressure gauge → बॉर्डन ट्यूब Pressure gauge से Atmospheric Pressure के ऊपर तथा नीचे दोनों तरफ के Pressure को measure किया जाता है। इसमे एक circular tube का उपयोग होता है जिसका एक End open तथा एक End close होता है। close End flexible होता है जो Move कर सकता है तथा open End को fix रखा जाता है।

Atmospheric pressure पर tube चित्र में दर्शाए अनुसार सामान्य स्थिति में होता है।
परंतु Pressure Low या High होने पर यह tube compress & expand होता है।
जिसके अनुसार dial gauge reading show करता है जो कि उस fluid के Pressure को दर्शाती है।



→ Manometer → Manometers ऐसे device होते हैं जिनसे Pressure measure किया जाता है तथा Pressure measurement के लिए fluid column की balancing की जाती है।

→ Manometers दो Types के होते हैं →

① Simple Manometer (साधारण Manometer) → Eg. Piezometer, U-tube Manometer.
→ किसी एक point पर Pressure Measure करते हैं।

② Differential Manometer → Eg. U-tube differential manometer. इन Manometers द्वारा 02 points के बीच Pressure difference को Measure करते हैं।

⇒ Piezometer → Piezometer ऐसा device होता है जो दोनों End से open होता है। इसका एक End उस Point से connect किया जाता है जिसका Pressure Measure करता हो तथा दूसरा End Atmosphere में open होता है।

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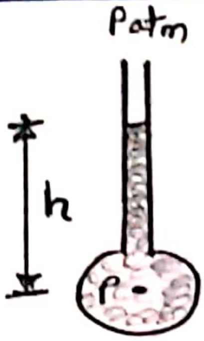
Pressure $P = \rho \times g \times h$ N/m^2

h = height of the liquid.

Application → used to finding out liquid moderate pressure.



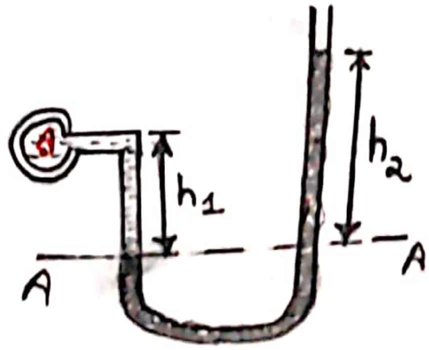
⇒ U-tube Manometer → इस Manometer में glass या plastic के tube को U shape में bent करते हैं। इस Tube का एक सिरा उस point पर connect करते हैं जहाँ का pressure measure करते हैं तथा दूसरा end Atmosphere में open होता है। U-tube Manometer में Balancing के लिए generally Mercury (पारा) जिसकी specific gravity 13.6 होती है, भरी होती है या ऐसा liquid जिसकी specific gravity High होती है comparing to जिस liquid का pressure measure करता है।

Case ① → for gauge Pressure →

Let A वह Point है जिसका Pressure find करना है। suppose यह P है।

A–A = datum or reference line

h_1 = height of light liquid above datum line.



h_2 = height of heavy liquid above datum line.
S_1 = specific gravity of light liquid.
S_2 = specific gravity of Heavy Liquid.
ρ_1 = density of light liquid.
ρ_2 = density of heavy liquid.

We know that, gauge Pressure $= \rho g h$
→ downward direction में यह Positive (बढ़ता) है।
→ upward direction में यह Negative (घटता) है।

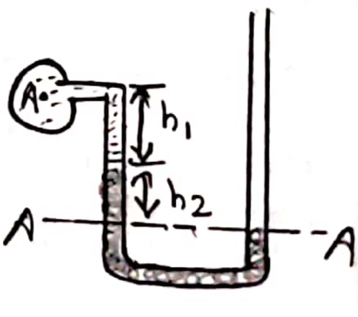
So, Pressure at A →

$$P_A + \rho_1 g h_1 - \rho_2 g h_2 = 0$$

$$\boxed{P_A = \rho_2 g h_2 - \rho_1 g h_1}$$

Case ② → for Vaccum Pressure →

Pressure at A,



→ $P_A + \rho_1 g h_1 + \rho_2 g h_2 = 0$

→ $P_A = -\rho_1 g h_1 - \rho_2 g h_2$

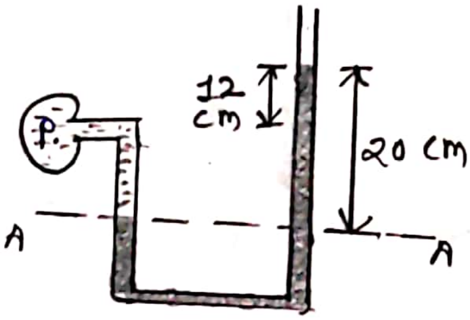
→ $P_A = -(\rho_1 g h_1 + \rho_2 g h_2)$

Qu → The right limb of a simple U tube Manometer containing mercury is open to the atmosphere while the left limb is connected to a pipe in which specific gravity of 0.9 fluid is flowing. The centre of the pipe is 12 cm below the level of mercury in the right limb. Find fluid pressure

Scanned with CamScanner

if the difference of mercury level in two limbs is 20 cm.

Ans → Given,



→ Pipe fluid, $S_1 = 0.9$

density, $\rho_1 = S_1 \times 1000$

$\rho_1 = 900 \ kg/m^3$

→ Mercury, $S_2 = 13.6$, $\rho_2 = S_2 \times 1000 = 13600 \ kg/m^2$

→ $h_2 = 20 \ cm = 0.2 \ m$.

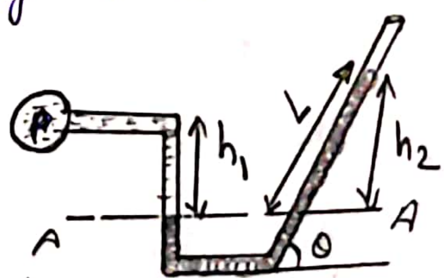
→ $h_1 = 20 - 12 = 8 \ cm = 0.08 \ m$.

Let P = Pressure of fluid in Pipe

→ $P + \rho_1 g h_1 - \rho_2 g h_2 = 0$

→ $P + 900 \times 9.81 \times 0.08 - 13600 \times 9.81 \times 0.2$ ⇒ P ⇒ $25977 \ N/m^2$

⇒ **Inclined Manometer** → This manometer is more sensitive, Due to Inclination the distance moved by the heavy liquid in the right limb will be more.



L = length of heavy liquid in right Limb from AA.

θ = Inclination of right limb with horizontal.

h_2 = vertical height of right limb from Horizontal.

So, Pressure P,

$$P + \rho_1 g h_1 - \rho_2 g h_2 = 0$$

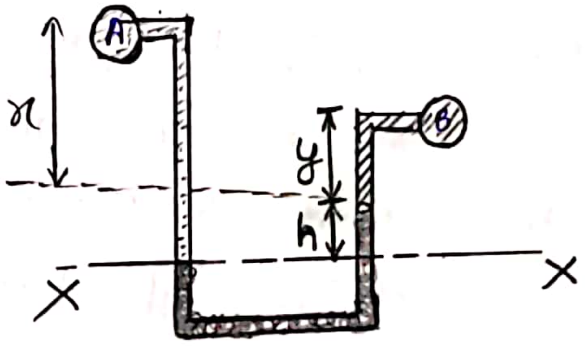
$$P = \rho_2 g h_2 - \rho_1 g h_1$$

& $\sin\theta = \frac{h_2}{L}$ or $h_2 = L\sin\theta$

So $\boxed{P = \rho_2 g L \sin\theta - \rho_1 g h_1}$

→ U-tube differential Manometer →

A & B दो different point हैं, जिनमें different specific gravity का liquid है। यह point differential Manometer से connected है।



Let Pressure at A = P_A,
Pressure at B = P_B,

→ h = difference of mercury level.
y = distance of B from mercury level.
x = distance of A from mercury level.
ρ_1 = density of liquid at A
ρ_2 = density of liquid at B
ρ_g = density of mercury or heavy liquid.

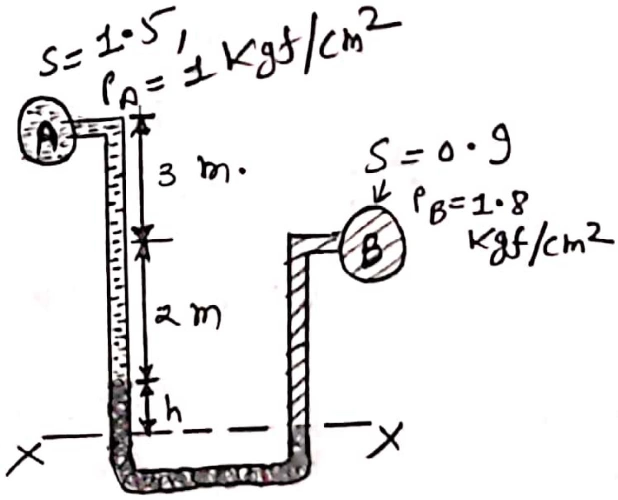
→ Reference line X-X लेने पर,

$$P_A + \rho_1 g(x+h) - \rho_g g h - \rho_2 g y - P_B = 0$$

$$P_A - P_B = \rho_g g h + \rho_2 g y - \rho_1 g x - \rho_1 g h$$

$$\boxed{P_A - P_B = gh(\rho_g - \rho_1) + \rho_2 g y - \rho_1 g x}$$

Q4) A differential Manometer is connected at the two point A & B of two pipes shown in figure. The Pipe A contains a Liquid of Specific gravity 1.5 while pipe B contains a liquid of specific gravity = 0.9. The pressure at A and B are 1 Kgf/cm² and 1.80 Kgf/cm² respectively. find the difference in mercury level in the differential Manometer.



Ans →

→ $S_1 = 1.5$, $\rho_1 = 1500\ Kg/m^3$

$P_A = 1\ Kgf/cm^2 = 9.81\ N/cm^2$

$P_A = 9.81 \times 10^4\ N/m^2$

→ $S_2 = 0.9$, $\rho_2 = 900\ Kg/m^3$,

$P_B = 1.8 \times 9.81 \times 10^4\ N/m^2$

→ Mercury → $S_m = 13.6$, $\rho_m = 13600\ Kg/m^3$

→ $h = ?$

P_A = Pressure at A.

P_B = Pressure at B.

$\rightarrow P_A + \rho_1 g \times 5 + S_M g \times h - \rho_2 g (h+2) - P_B = 0$

$\rightarrow 9.81 \times 10^4 + 1500 \times 9.81 \times 5 + 13600 \times 9.81 \times h - 900 \times 9.81 (h+2) - 1.8 \times 9.81 \times 10^4 = 0$

$\rightarrow 98100 + 73575 + 133416 h - 8829 h - 17658 - 176580 = 0$

$\rightarrow -22563 + 124587 h = 0$

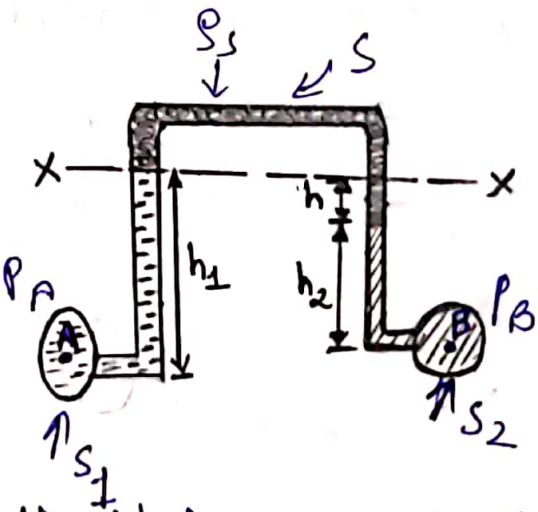
$\rightarrow h = \frac{22563}{124587} = 0.181 \text{ m} = 18.1 \text{ cm.}$ Ans.

→ Inverted U-tube differential Manometer →

It is just opposite to U-tube differential Manometer. इसमे एक Inverted (उल्टा) U tube होता है, जिसके दोनो सिरे उन points पर connect किए जाते हैं जिनके मध्य Pressure difference find करना होता है।

$P_A - \rho_1 g h_1 + \rho_s g h + \rho_2 g h_2 - P_B = 0$

$$P_A - P_B = \rho_1 g h_1 - \rho_2 g h_2 - \rho_s g h$$



* Imps ⇒ ① Upward (ऊपर) जाने पर Liquid Pressure Negative (कम) होता है तथा downward जाने पर Positive (ज्यादा) होता है।

② $h_1 S_1 = h_2 S_2$ → liquid height & specific gravity का Product हमेशा Constant होता है।

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Chapter No.-03

Hydro-statics (द्रव-स्थैतिकी)

जब fluid rest condition मे होता है तब किसी Element पर fluid behaviour की study को Hydro-statics कहते है।

Total Pressure or Hydrostatic force → जब static fluid द्वारा किसी plane or curved surface पर force Exert किया जाता है तो उसे Total pressure या Hydrostatic force कहते है।

$$F = wA\bar{x} = \rho g A\bar{x}$$

F = Hydrostatic force

$\bar{x}$ = distance of centre of gravity G from free surface of fluid.

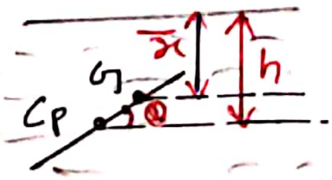
Centre of Pressure (Cp) → वह point जिस पर Total Pressure act करता है, Centre of Pressure कहलाता है।

$$h = \bar{x} + \frac{I_G}{A\bar{x}} \sin^2\theta$$

θ = Inclination angle.

h = Distance of Cp from free Surface

I_G = Moment of inertia about centroidal axis.



SN	Case	F (Hydrostatic force)	Inclination angle (θ)	Centre of Pressure (Cp)
①	Inclined	$wA\bar{x}$	θ	$h = \bar{x} + \frac{I_G}{A\bar{x}} \times \sin^2\theta$
②	Vertical	$wA\bar{x}$	$\theta = 90°$	$h = \bar{x} + \frac{I_G}{A\bar{x}}$
③	Horizontal	$wA\bar{x}$	$\theta = 0°$	$h = \bar{x}$

SN	Case	Centre of gravity from base	Area	MI about C.G.	MI about base
①	Rectangle	$h/2$	$b \times h$	$\frac{bh^3}{12}$	$\frac{bh^3}{3}$
②	Traingle	$h/3$ (from base)	$\frac{1}{2} \times b \times h$	$bh^3/36$	$\frac{bh^3}{12}$
③	circle	$d/2$	$\frac{\pi d^2}{4}$	$\frac{\pi d^4}{64}$	$\frac{\pi d^4}{64}$

Que) A rectangular plane surface is 2 m wide and 3 m deep. It lies in vertical plane in water. Determine the total Pressure and position of Centre of Pressure on the plane surface when its upper edge is horizontal and

ⓐ co-incides with water surface

ⓑ 2.5 m below the free water surface.

Ans → Given, $b = 2$ m,

$d = 3$ m,

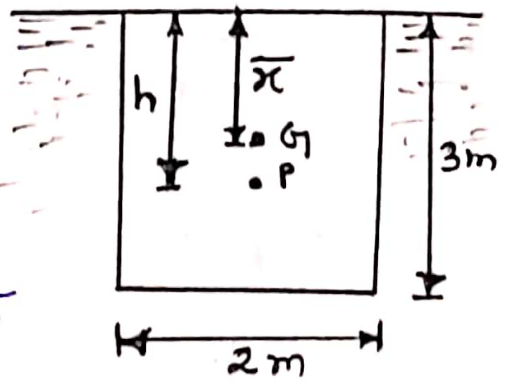
(a) upper edge coincides with water surface →

Area $a = 3 \times 2 = 6\ m^2$,

ρ of water $= 1000\ Kg/m^3$,

$g = 9.81\ m/s^2$,

$\bar{x} = \frac{3}{2} = 1.5\ m$.



$F = \rho g a \bar{x} = 1000 \times 9.81 \times 6 \times 1.5$

$F = 88290\ N.$

→ $I_G = \frac{bh^3}{12} = \frac{2 \times 3^3}{12} = \frac{54}{12} = 4.5\ m^4$

C_p position, $h = \bar{x} + \frac{I_G}{A\bar{x}} \times \sin^2\theta$

element is vertical, $\theta = 90^\circ$

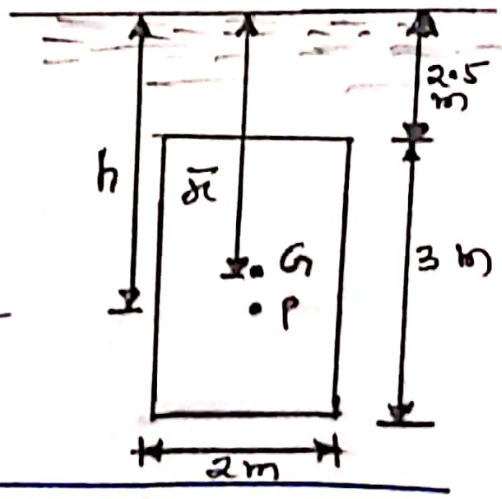
$h = \bar{x} + \frac{I_G}{A\bar{x}} \times \sin 90^\circ = 1.5 + \frac{4.5}{6 \times 1.5} \times 1 = 2\ m.$ Ans.

(b) Upper edge is 2.5 m below water surface →

$\bar{x} = 2.5 + 3/2 = 4\ m.$

$F = \rho g A\bar{x} = 1000 \times 9.81 \times 6 \times 4$

$F = 235440\ N$

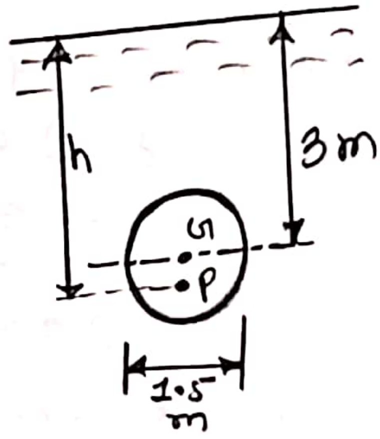


$h = \bar{x} + \frac{I_G}{A\bar{x}} \times \sin\theta$

$h = 4 + \frac{4.5}{6 \times 4} \times 1 = 4 + 0.1875$

$h = 4.1875$

Qu → Determine total pressure on a circular plate of diameter 1.5 m which is placed vertically in water in such a way that the centre of plate is 3 m below the free surface of water. Find the position of centre of pressure also.



Answer → Given,

diameter of plate,

$d = 1.5\ m$

$\therefore$ Area $= \frac{\pi}{4}(1.5)^2 = 1.767\ m^2$

$\bar{x} = 3\ m$

Moment of Inertia, $I_G = \frac{\pi d^4}{64}$

$I_G = \frac{\pi \times 1.5^4}{64} = 0.2485\ m^4$

→ Hydrostatic force / Total pressure,

$F = \rho g A \bar{x}$

$F = 1000 \times 9.81 \times 1.767 \times 3$

→ $F = 52002.8\ N$

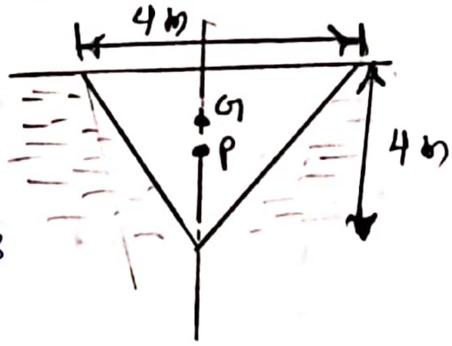
→ Position of centre of pressure,

$h = \bar{x} + \frac{I_G}{A\bar{x}} \times \sin^2\theta$

$h = 3 + \frac{0.2485}{1.767 \times 3} \times 1$ ($\sin 90^\circ = 1$)

$h = 3.0468\ m.$

Que) Determine Total pressure and Centre of Pressure on an traingular plate of base 4 m and altitude 4 m, when it is immersed vertically in an oil of specific gravity 0.9. The base of the plate coincides with the free surface of oil.



Ans → base $b = 4$ m,
height $h = 4$ m,
$S = 0.9$, $\rho = 0.9 \times 1000$ Kg/m³

⇒ $\bar{x} = \frac{h}{3} = \frac{4}{3} = 1.33$ m.,

⇒ $I_G = \frac{bh^3}{36} = \frac{4 \times 4^3}{36} = 7.11$ m⁴, area $= \frac{b \times h}{2} = 8$ m²,

→ $F = \rho g A \bar{x} = 900 \times 9.81 \times 8 \times 1.33 = 9597.6$ N Ans.

→ $h = \bar{x} + \frac{I_G}{A\bar{x}} \sin^2\theta = 1.33 + \frac{7.11}{8 \times 1.33} \times 1$

($\sin 90° = 1$)

→ $h = 0.6667 + 1.33$

→ $h = 1.99$

Buoyancy → (उत्प्लावन) → जब किसी body को fluid मे immersed/submerged (डुबाया) जाता है Partially या completely, उस समय Fluid द्वारा Exerted Net vertical upward force को buoyant force (उत्प्लावन बल) कहते है तथा fluid की यह Property buoyancy कहलाती है।

→ Archimedis Principle "The buoyant force is equal to weight of the fluid displaced"

$$\boxed{F_B = W_{fd} = W_b = \rho_f g V_f = \rho_b g V_b}$$

- F_B = buoyant force, W_{fd} = Weight of fluid displaced,
- W_b = weight of body, ρ_f = density of fluid,
- V_f = volume of fluid, ρ_b = density of body
- V_b = volume of body.

we know, weight density $\omega = \dfrac{W\,(\text{Weight})}{\text{Volume}}$

$$\boxed{W = \omega V = \rho g V}$$

$\Rightarrow \rho_f g V_f = \rho_b g V_b \Rightarrow \rho_f \times A \times H = \rho_b \times A \times d$

$$\boxed{\rho_f H = \rho_f d}$$ ← Principle of floation.

→ H = height ; d = diameter or distance or depth of immersion.

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Centre of buoyancy (उत्प्लावन केन्द्र) → यह वह point होता है जिस पर buoyancy force act करती है।

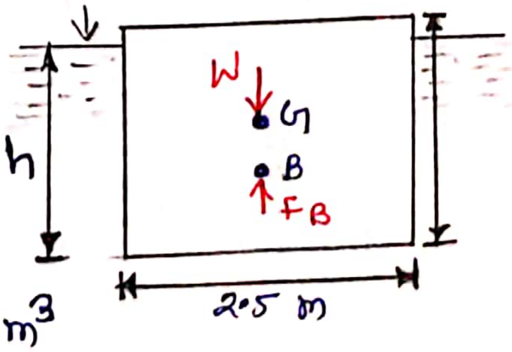
→ This will act at the centre of gravity of displaced volume.

(fluid में कोई element का वह भाग जो submerged है उसके centre of gravity में buoyancy force act करती है। अगर body 4 m height तक submerged है तो यह 4/2 = 2 m. पर Act करेगी)

→ $h = \frac{\text{depth of immersion}}{2}$ (centre of buoyancy को B से denote करते हैं)

Qu. Find the volume of water displaced & position of centre of buoyancy for a wooden block of width 2.5 m and depth 1.5 m, when it floats horizontally in water. The density of wooden block is 650 kg/m³ and its length is 6.0 m.?

Ans → width, b = 2.5 m,
height, h = 1.5 m,
Length, L = 6.0 m,



Volume of body = 2.5 × 1.5 × 6 = 22.5 m³ density of block, $\rho_b = 650\ kg/m^3$

$\therefore$ weight of body, $W = \rho_b \times g \times V_b = 650 \times 9.81 \times 22.5$

$$\boxed{W = 143471\ N}$$

& weight of the body = Weight of the fluid displaced.

$$143471 = \rho_f \times g \times V_f = 1000 \times 9.81 \times V_f$$

$$\boxed{V_f = 14.625\ m^3}$$

- Position of Centre of buoyancy →

- $V_f = 14.625$
- $2.5 \times 6 \times h = 14.625$, $h = 0.975\ m$.
- Centre of buoyancy, $h = \frac{0.975}{2} = 0.4875\ m$

Ans.

Qu → A stone weighs 392.4 N in air & 196.2 N in water. Compute volume of stone & its specific gravity ?

Ans → Given, stone - Weight in air = 392.4 N
Weight in water = 196.2 N

for equilibrium →

→ weight of water displaced = Weight in air − Weight in water

→ $W_f = 392.4 - 196.2 = 196.2$

→ $W_f = \rho_f g V_f = 1000 \times 9.81 \times V_f$

→ $V_f = \frac{196.2}{1000 \times 9.81} = 2 \times 10^{-2} = 0.02\ m^3$

$\Rightarrow$ V_f = Volume of stone, $V_b = 0.02\ m^3 = 2\times10^4\ cm^3$ Ans

Specific gravity of stone $\rightarrow$ $m = \frac{W}{g} = \frac{392.4}{9.81} = 40\ kg.$

$$\text{density} = \frac{m}{V} = \frac{40}{0.02} = 2000\ Kg/m^3$$

$$S = \frac{\text{density of element}}{\text{density of fluid}} = \frac{2000}{1000} = 2.0 \quad \text{Ans.}$$

Qu $\Rightarrow$ A body of dimensions $1.5\ m \times 1.0\ m \times 2\ m$, weighs 1962 N in water. Find its weight in air. what will be its specific gravity?

Ans $\rightarrow$ Volume of body $= 1.5\times1\times2 = 3.0\ m^3$,

weight in water = 1962 N.

$\rightarrow$ weight of fluid displaced $\Rightarrow W_{fd} = \rho_f \times g \times V_f$

Volume of body = volume of fluid displaced,

$\rightarrow$ $W_f = 1000\times9.81\times3 = 29430\ N$

$\rightarrow$ Weight in air − Weight in water $= W_f$

$\rightarrow$ $W_{air} - 29430 = 1962$, $\boxed{W_{air} = 31392\ N}$

→ Mass = $\frac{W}{g} = \frac{31392}{9.81} = 3200$ Kg.

→ $\rho = m/V = \frac{3200}{3} = 1066.67$,

∴ Specific gravity of body = $\frac{1066.67}{1000} = 1.067$ Ans

⇒ **Metacentre (आप्लव केन्द्र)** → It is defined as the point about which a body starts oscillating when the body is tilted by small angle.

→ यह ऐसा point है जिसके about element oscillating (आवर्ती गति) motion करता है, जब body को small angle पर displace करके छोड़ा जाता है।

Metacentric height (MG) → The distance between Metacentre of a floating body and the Centre of gravity of body is called meta centric height.

MG = G (centre of gravity) & M (metacentre) के बीच की दूरी आप्लव केन्द्र की ऊँचाई कहलाती है।

* for Stable Equilibrium → MG = +ve (BM>BG)
for Unstable Equilibrium → MG = −ve (BM<BG)
for Neutral Equilibrium → MG = 0 (BM=BG)

$$GM = BM - BG = \frac{I_{min}}{V} - BG$$

∴ $I = I_{xx}$ or I_{yy} which is minimum, V = volume of immersed
= From top view

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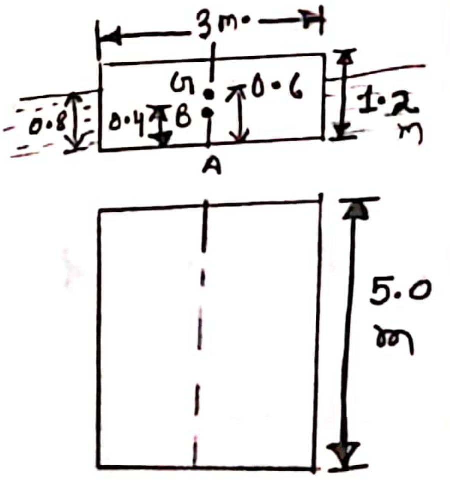
Education City, Jawanga Geedam

Que A rectangular Pontoon is 5 m long, 3 m wide and 1.20 m high. The depth of immersion of the Pontoon is 0.80 m in sea water. If Centre of gravity is 0.6 m above the bottom of the Pontoon, determine metacentric height. The density for sea water is 1025 Kg/m^3.

Answer → Dimension of Pontoon = $5 \times 3 \times 1.2$

depth of immersion, $d = 0.8$ m.



distance, $AG = 0.6$ m,

$AB = \frac{1}{2} \times$ depth of immersion

$AB = \frac{1}{2} \times 0.8 = 0.4$,

Density of sea water = 1025 Kg/m^3

Metacentric height,

$$GM = \frac{I_{min}}{V} - BG$$

$$I_{min} = \frac{bh^3}{12} \text{ or } \frac{hb^3}{12} = \frac{1}{12} \times 5 \times 3^3 = 11.25 \text{ m}^4$$

$$\text{Volume} = 3 \times 5 \times 0.8 = 12 \text{ m}^3$$

$$BG = AG - AB = 0.6 - 0.4 = 0.2$$

$$GM = \frac{11.25}{12} - 0.2 = 0.7375 \text{ m}.$$

→ GM is +ve, BM > BG it means body is in stable equillibrium.

Qu → A uniform body of size 3 m long × 2 m wide × 1 m deep floats in water. What is the weight of the body if depth of immersion is 0.8 m? Determine metacentric height?

Ans → Given :

Dimension of body $= 3 \times 2 \times 1 = 6\ m^3$

Depth of immersion $= 0.8\ m$.

① Weight of body, W → Weight of water displaced.

$$W = \rho g V$$

$$W = 1000 \times 9.81 \times 3 \times 2 \times 0.8$$

$$W = 47088\ N.$$

② Metacentric height, GM → $\frac{I}{V} - BG$

$$I = \frac{1}{12} \times 3 \times 2^3 = \frac{3 \times 2^3}{12} = 2.0\ m^4.$$

Volume of body in water $= 3 \times 2 \times 0.8 = 4.8\ m^3$

$$BG = AG - AB = \frac{1}{2} - \frac{0.8}{2} = 0.1$$

$$GM = \frac{2}{4.8} - 0.1 = 0.3167\ m \quad \text{Ans.}$$

Q4) A solid cylinder of diameter 4 m has a height of 3 metres. Find the metacentric height of the cylinder when it is floating in water with its axial vertical. The sp. gravity of the cylinder = 0.6.

Ans → Given, $d = 4.0\ m$,

Height of cylinder ; $h = 3.0\ m$,

Sp. gravity of Cylinder = 0.6.

Depth of Immersion, d $\quad S_1 h_1 = S_2 h_2$

$$1 \times h_1 = 0.6 \times 3$$

$$h_1 = 1.8 \text{ m}.$$

So, $AB = \frac{1.8}{2} = 0.9 \text{ m}$,

$AG = \frac{3}{2} = 1.5 \text{ m}$,

$BG = AG - AB = 1.5 - 0.9 = 0.6 \text{ m}.$

$\Rightarrow GM = \frac{I}{V} - BG$

$I = \frac{\pi d^4}{64} = \frac{\pi \times (4.0)^4}{64} = 12.6$

$\rightarrow$ Volume $= \frac{\pi d^2}{4} \times h_d = \pi/4 \times 4^2 \times 1.8 = 22.62$

$\rightarrow GM = \frac{\pi/64 \times (4)^4}{\frac{\pi}{4} \times 4^2 \times 1.8} - 0.6 = \frac{12.6}{22.62} - 0.6 \Rightarrow -0.05$

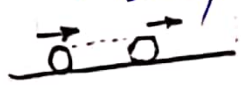
$\Rightarrow$ −ve Sign means that metacentre (M) is below centre of gravity, so body is in unstable equillibrium.

Types of Equillibrium →

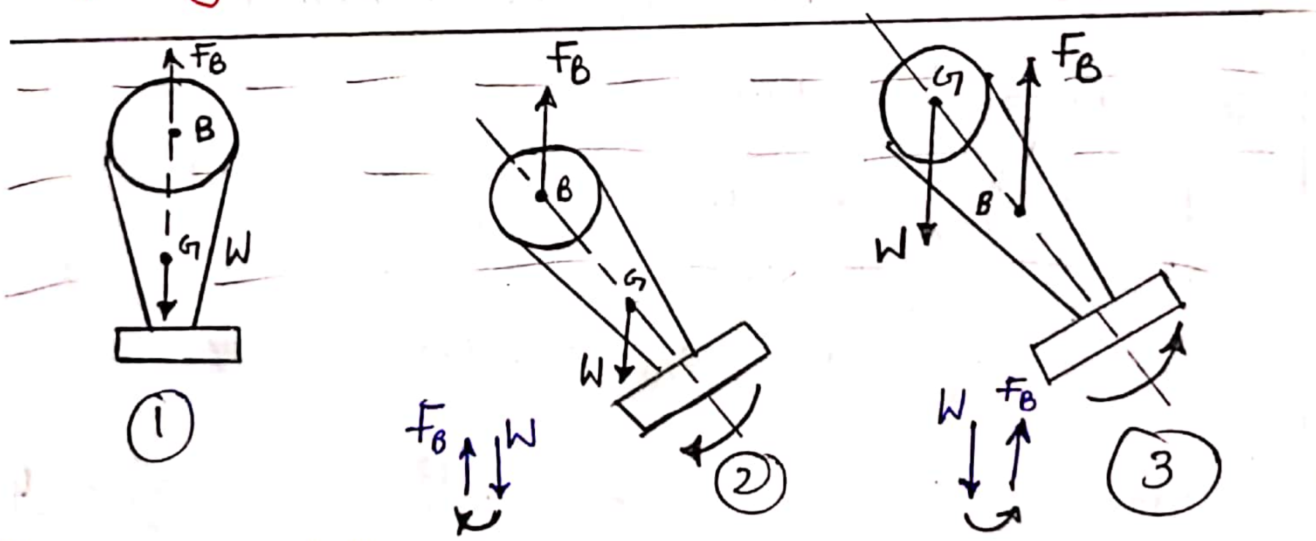
1. Stable Equillibrium → when body is in always orginal position.

2. Unstable Equillibrium → Body deflected away from original position.

3. Neutral Equillibrium → Body movement dependent to Force applied.



Stability or Equillibrium conditions for completely submerged bodies →



For a completely submerged body →

(2) Stable Eq. → Exist when Centre of buoyancy is above the Centre of gravity.

(3) Unstable Eq. → Exit when centre of buoyancy is below the Centre of gravity.

(1) Neutral Eq. → Exist when centre of gravity & Centre of buoyancy coincide.

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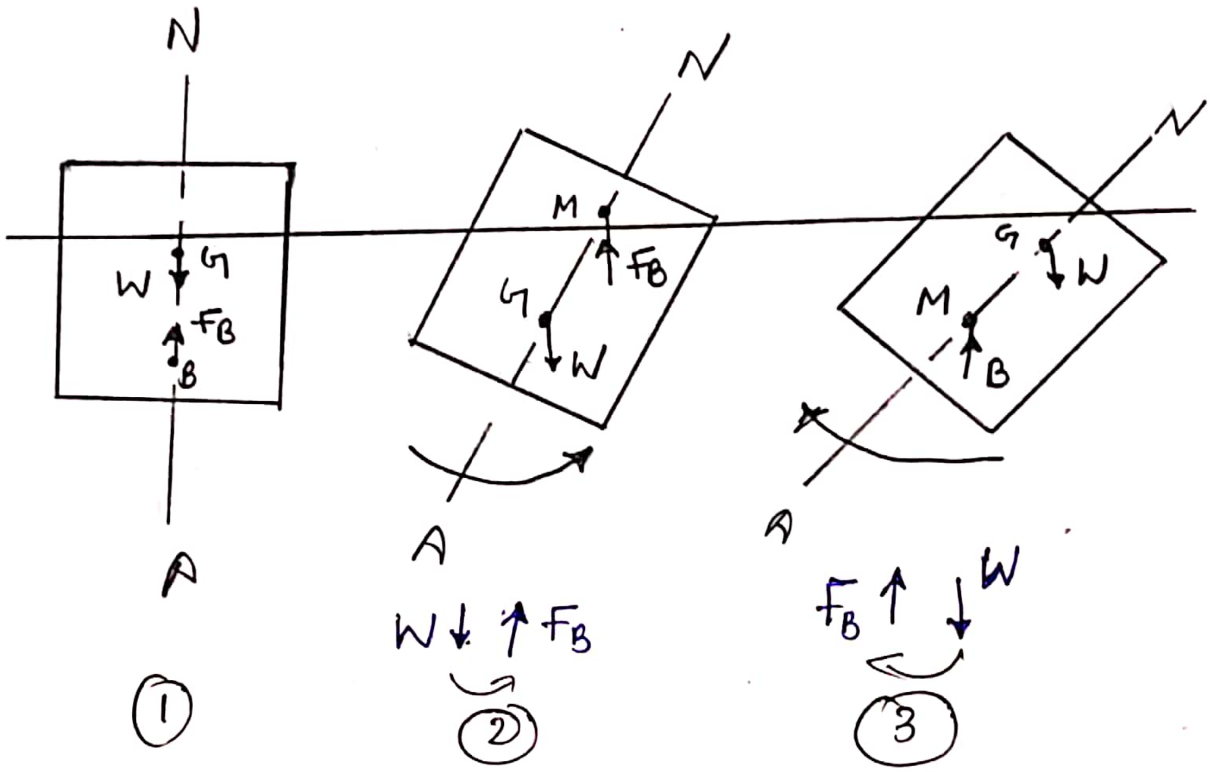
→ Stability Conditions for Partially submerged or floating bodies –



For a floating body →

① Neutral Eq. – Exist when centre of gravity & Metacentre coincide.

② Stable Eq. – Exist when Centre of gravity is the metacentre.

③ Unstable Eq. → Exist when Centre of gravity is the metacentre.

Chapter No.-04

Basic Equation of fluid flow
(तरल प्रवाह के मौलिक समीकरण)

forms of Energy →

(1) potential / static Energy / स्थैतिक ऊर्जा → Energy due to the position of Energy.

$$P.E. = mgh$$ also called datum energy.

(2) Kinetic energy (गतिज ऊर्जा) → Energy due to the velocity of object.

$$K.E. = \frac{1}{2}mv^2$$

(3) Pressure Energy (दाब ऊर्जा) → Energy due to the Pressure applied.

$$\text{Pressure Energy} = P/\omega$$

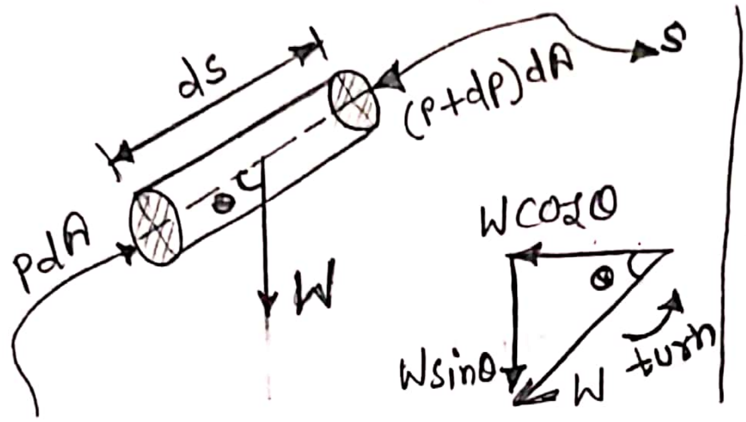
ω = specific weight या weight density

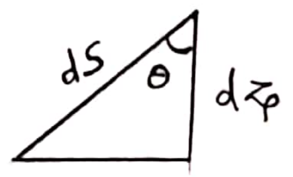
Total Energy = P.E. + K.E. + Pressure Energy.

$$H = mgh + \frac{1}{2}mv^2 + P/\omega$$

Bernoullies Eqⁿ → Euler's Eqⁿ – Law of Conservation of **Energy** → based on Newton's 2nd Law.

Assumptions → ① Non-Viscous flow ② Steady flow ③ Incompressible flow.





→ $\cos\theta = dz/ds$
→ $dz = ds\cos\theta$

A cylindrical element of cross-section dA & length ds is placed in a stream line (s). The forces in the element are →

① Pressure force pdA in the direction of flow.
② Pressure force (p+dp)dA opposite to the direction of flow.
③ Weight of the element → $W = mg$ & $m = W/g$

→ $W = \omega \times V = \rho g V = \rho \times g \times dA \times ds$

ω = weight density, ρ = density, V = volume.

→ $\Sigma F_{Net} = m \times a_s$

∵ a_s = acceleration in the direction of s.

$a_s = V \times \frac{dV}{ds}$

So, $pdA - (p+dp)\,dA - \rho g\, dA\, ds \cos\theta = \rho\, dA\, ds \left(V\frac{dV}{ds}\right)$

$\Rightarrow -dA\,dp - \rho g\, dz\, dA = \rho\, dA\, ds \left(V\, dV/ds\right)$

$\Rightarrow -dp - \rho g\, dz = \rho\, dV \times V$

$\Rightarrow dp + \rho g dz + \rho v dv = 0$

$\Rightarrow \boxed{\frac{dp}{\rho} + g dz + v dv = 0}$ ← Euler's Equation.

After Integration →

$$\int dp/\rho + \int g dz + \int v dv = \text{Constant}.$$

$$\boxed{\frac{p}{\rho} + gz + \frac{v^2}{2} = \text{Constant}}$$ ← Bernoullies Equation.

Statement of bernoullies equation / theorem →

" In a steady, Incompressible, Non-viscous flow along a stream line sum of Pressure Energy, Kinetic energy & potential Energy is constant."

→ $\frac{p}{\rho} + \frac{V^2}{2} + gz$ = constant. → $\frac{\text{Energy}}{\text{mass}}$

→ $\frac{p}{\rho g} + \frac{V^2}{2g} + z$ = Constant → $\frac{\text{Energy}}{\text{mass} \times g}$

→ $P/\omega + \frac{V^2}{2g} + z$ = Constant → $\frac{\text{Energy}}{\text{weight}}$

P/ω — Pressure head; $\frac{V^2}{2g}$ — Velocity or Kinetic energy head; z — Datum or P.E. head.

→ $(P/\omega + z)$ → Piezometric head.

Q.3) Water is flowing through a pipe of 5 cm diameter under a pressure of 29.43 N/cm² (gauge) and with mean velocity of 2.0 m/s. Find the total head or total energy per unit weight of the water at a cross-section, which is 5 m above datum line.

Ans → Given, diameter of pipe = 5 cm = 0.05 m,

Pressure, $P = 29.43\ N/cm^2 = 29.43 \times 10^4\ N/m^2$

velocity, $v = 2.0\ m/s$

Datum head, $z = 5\ m$.

Total head = pressure head + Kinetic head + datum head.

$$\text{Pressure head} = \frac{P}{\rho g} = \frac{29.43 \times 10^4}{1000 \times 9.81} = 30\ m$$

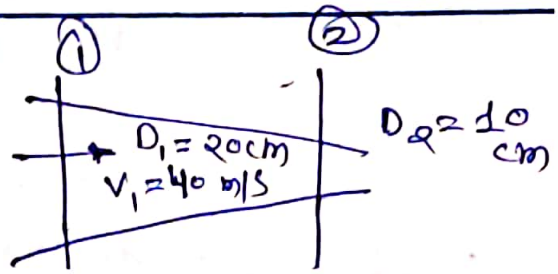
$$\text{Kinetic head} = v^2/2g = \frac{2 \times 2}{2 \times 9.81} = 0.204\ m.$$

$\therefore$ Total head $= 30 + 0.204 + 5 = 35.204\ m.$ Ans.

Q.4) A pipe, through which water is flowing is having diameters, 20 cm and 10 cm at the cross-sections 1 & 2 respectively. The velocity of water at section 1 is given 4 m/s. Find velocity head at sections 1 & 2 and also rate of discharge?

Ans → Given,

$D_1 = 20\ cm = 0.2\ m$,



∴ Area, $A_1 = \frac{\pi}{4} D_1^2 = 0.0314\ m^2$,

$V_1 = 4.0\ m/s$

$D_2 = 0.1\ m$

$A_2 = \pi/4\,(0.1)^2 = 0.00785\ m^2$.

① velocity head at Section 1 $= \frac{V_1^2}{2g} = 0.815\ m$

② velocity head at section 2 $= \frac{V_2^2}{2g}$.

from continuity eqn →

$A_1V_1 = A_2V_2 \Rightarrow V_2 = \frac{A_1V_1}{A_2} = \frac{0.0314 \times 4}{0.00785} = 16\ m/s$

velocity head $= \frac{16 \times 16}{2 \times 9.81} = 13.047\ m$ Ans.

③ Rate of discharge, $Q = A_1V_1$ or A_2V_2

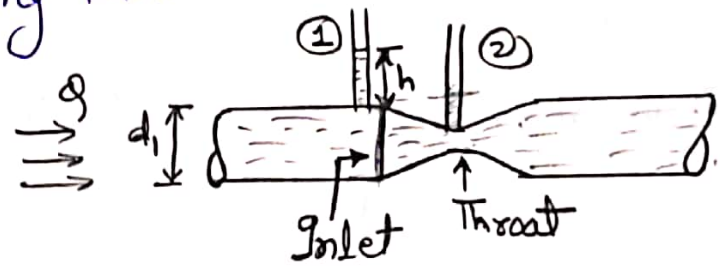
$Q = 0.0314 \times 4 = 0.1256\ m^3/s$

$Q = 125.6$ litres/s $(1\ m^3 = 1000$ Litres$)$

* Practical Applications of bernoullie's Equation →

Bernoullie's Equation का application following measuring devices मे होता है ⇒ (1) Venturimeter (2) orifice-meter (3) Pitot-tube.

Venturimeter → Venturimeter का उपयोग rate of fluid flow or discharge measuring के लिए use होता है। इसमे 03 part होते है → (1) A short converging part (2) Throat (3) Diverging Part.



Principle (सिद्धांत) → Venturimeter एक gradually converging & diverging device है। किसी study, one dimensional, Incompressible flow मे Area reduce होने पर velocity Increase होता है (Continuity Eqn i.e. $A_1V_1 = A_2V_2$) जिसके कारण Pressure decrease हो जाता है (bernoullie's Eqn → Total head = Pressure head + datum head + velocity head) तथा Pressure difference के कारण Manometric fluid deflection होता है तथा इस deflection को find out करने पर discharge find किया जाता है।

from figure when applied bernoullies equation to section 1 & 2 →

$$\frac{P_1}{w} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{w} + \frac{V_2^2}{2g} + Z_2$$

If Pipe is horizontal, $z_1 = z_2$

$$\frac{P_1}{w} - \frac{P_2}{w} = \frac{V_2^2 - V_1^2}{2g} = h$$

h = difference of pressure head or difference of velocity head.

$$\rightarrow h = \frac{V_2^2 - V_1^2}{2g} \Rightarrow V_2^2 - V_1^2 = 2gh$$

$$\rightarrow Q = A_1V_1 = A_2V_2 \Rightarrow V_1 = \frac{Q}{A_1}, V_2 = Q/A_2$$

$$\rightarrow \frac{Q^2}{A_2^2} - \frac{Q^2}{A_1^2} = 2gh$$

$$\Rightarrow Q^2\left(\frac{A_1^2 - A_2^2}{A_1^2 \cdot A_2^2}\right) = 2gh$$

$$\Rightarrow Q = \frac{A_1 \cdot A_2 \sqrt{2gh}}{\sqrt{A_1^2 - A_2^2}}$$

→ इस calculation में हमने Losses को count नहीं किया अतः यह theoretical discharge है।

$$\boxed{Q_{th} = \frac{A_1 \cdot A_2 \sqrt{2gh}}{\sqrt{A_1^2 - A_2^2}}}$$

A_1 & A_2 = Area at section 1 & throat 2.

where:

$$\rightarrow h = \frac{P_1 - P_2}{w} = \frac{V_2^2 - V_1^2}{2g}$$

$$\rightarrow h = x\left[\frac{S_h}{S_o} - 1\right]$$

$$\rightarrow h = x\left[1 - \frac{S_L}{S_o}\right]$$

S_h = Specific gravity of heavy Liquid

S_o = Specific gravity of liquid flowing in Pipe

S_L = Specific gravity of Lighter Liquid

x = manometer reading or difference of Liquid level.

&

$$Q_{act} = C_d \times \frac{a_1 a_2 \sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}}$$

or

$$Q_{act} = C_d \times Q_{th}$$

here Q_{act} = Actual discharge

C_d = coefficient of discharge.

$$C_d = \frac{Q_{act}}{Q_{th}}$$

Qu: A horizontal Venturimeter with Inlet & throat diameters 30 cm and 15 cm respectively is used to measure the flow of water. The reading of differential Manometer connected to the inlet and the throat is 20 cm of mercury. Determine rate of flow. Take $C_d = 0.98$.

Ans → Given, dia at Inlet, $d_1 = 30$ cm

∴ Area at Inlet, $a_1 = \frac{\pi}{4} d_1^2 = \frac{\pi}{4} \times 0.3^2 = 0.071\ m^2$

∴ Area at outlet, $a_2 = \frac{\pi}{4} \times d_2^2 = \frac{\pi}{4} \times 0.15^2 = 0.0177\ m^2$

∴ $C_d = 0.98$

$x = 20$ cm. $= 0.2$

So, $h = x\left[\frac{S_h}{S_0} - 1\right] = 0.2\left[\frac{13.6}{1} - 1\right] = 2.52$ m.

So, discharge $Q = C_d \times \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh}$

$$Q = 0.98 \times \frac{0.071 \times 0.0177}{\sqrt{(0.071)^2 - (0.0177)^2}} \times \sqrt{2 \times 9.81 \times 2.52}$$

$Q = 0.126\ m^3/s$ or 126 Lit/s

[∵ $1\ m^3 = 1000$ Lit] Ans.

Que) A horizontal venturimeter with Inlet diameter 20 cm and throat diameter 10 cm is used to measure the flow of water. The Pressure at Inlet is 17.658 N/cm² and the vaccum Pressure at the throat is 30 cm of mercury. find discharge if $C_d = 0.98$.

Ans → Given, $d_1 = 20\,cm = 0.2\,m$

$$a_1 = \frac{\pi}{4} \times 0.2^2 = 0.0314\ m^2$$

& throat diameter = 10 cm = 0.1 m,

$$a_2 = \frac{\pi}{4} \times 0.1^2 = 0.0079\ m^2$$

→ $P_1 = 17.568\ N/cm^2 = 17.568 \times 10^4\ N/m^2$

$$\frac{P_1}{\rho g} = \frac{17.568 \times 10^4}{9.81 \times 1000} = 18\ m \text{ of Water}$$

→ $\frac{P_2}{\rho g} \Rightarrow -0.3$ m of mercy $= 0.3 \times 13.6$

$\Rightarrow -4.08$ m of Water (Vaccum Pressure)

→ $h = \frac{P_1}{\rho g} - \frac{P_2}{\rho g} = 18 - (-4.08) = 22.08$ m of Water

$$Q = C_d \times \frac{a_1 a_2 \times \sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}}$$

$$Q = 0.98 \times \frac{0.0314 \times 0.0079 \times \sqrt{2 \times 9.81 \times 22.08}}{\sqrt{(0.0314)^2 - (0.0079)^2}}$$

$Q = 0.165\ m^3/s$

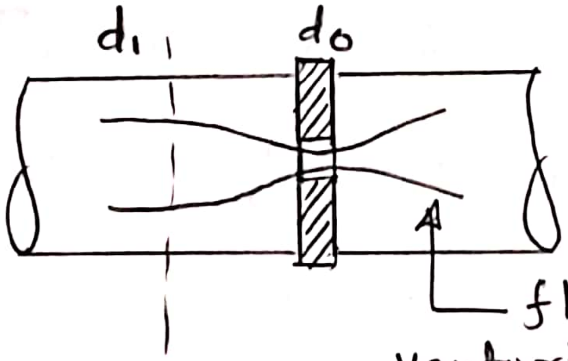
$Q \Rightarrow 165$ lit/s

Ans.

→ **Orifice-meter** → It is used for finding out discharge and is based on the same principle of venturimeter.

Orifice or throat diameter $= d_o$

$$Q_{act} = \frac{C_d \times a_1 a_0 \sqrt{2gh}}{\sqrt{a_1^2 - a_0^2}} = Q_{th} \times C_d$$



flow follow venturimeter pattern

यह discharge findout करने के लिए सबसे cheapest instrument है। It consists of a flat circular plate which has circular small hole called orifice.

Que An orifice meter with orifice diameter 15 cm is inserted in a pipe of 30 cm diameter. The Pressure difference of manometer gives reading of 50 cm of mercury. Find the rate of flow of oil of sp. gr. 0.9 when coefficient of discharge of orifice meter is 0.64.

Ans → Dia of orifice, $d_o = 15\ cm = 0.15\ m$

$$a_o = \frac{\pi}{4} \times 0.15^2 = 0.0177\ m^2$$

dia of Pipe, $d_1 = 30\ cm$

$$\therefore\ a_1 = \frac{\pi}{4} \times 0.3^2 = 0.071\ m^2$$

→ $x = 50\ cm = 0.5\ m$, $C_d = 0.64$

→ differential head $= x\left[\frac{S_h}{S_o} - 1\right]$

$$h = 0.5\left[\frac{13.6}{0.9} - 1\right]$$

$$h = 7.05\ m$$

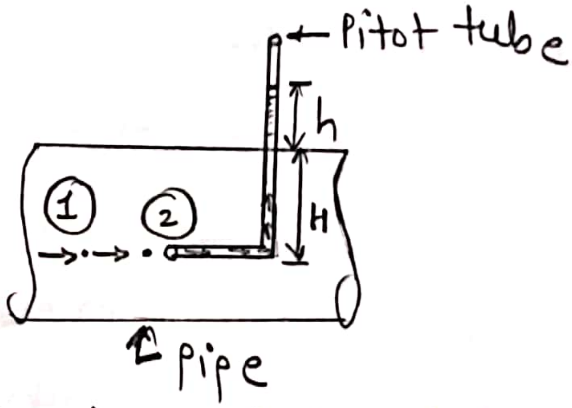
→ $$q = C_d \times \frac{a_o a_1 \sqrt{2gh}}{\sqrt{a_o^2 - a_1^2}}$$

$$q = 0.64 \times \frac{0.0177 \times 0.15 \times \sqrt{2 \times 9.81 \times 7.05}}{\sqrt{0.0177^2 - 0.071^2}}$$

$$q = 0.1374\ m^3/s$$

$$q = 137.4\ lit/s.$$

→ **Pitot tube** → It is a device used for measuring the velocity of flow at any point in a pipe or a channel. Pitot tube consist a glass tube bent at right angles.



It is based on the Principle that if velocity of flow at a point becomes zero, the pressure energy increased due to conversion of Kinetic energy into pressure energy.

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

Actual velocity, $V_{act} = C_v \sqrt{2gh} = C_v \times V_{th}$

C_v = Coefficient of velocity

$$C_v = \frac{V_{act}}{V_{th}}$$

d) Dynamic head = Stagnation head − Static head

Dynamic head $= \frac{V_1^2}{2g} = h$

Static head $= P_1/w$

Stagnation head $= \frac{P_2}{w}$

Que find the velocity of flow of an oil through a pipe, when the difference of mercury level in a differential U-tube manometer connected to the two tappings of the pitot tube is 100 mm. Take coefficient of pitot tube 0.98 and sp. gravity of oil = 0.8.

Ans → $x = 100\ mm = 0.1\ m$, $S_o = 0.8$,
$S_m = 13.6 = S_h$, $C_v = 0.98$

→ $h = x\left[\frac{S_h}{S_o} - 1\right] = 0.1\left[\frac{13.6}{0.8} - 1\right] = 1.6\ m$

→ velocity of flow, $V = C_v\sqrt{2gh}$

$V = 0.98\sqrt{2 \times 9.81 \times 1.6}$

$V = 5.49\ m/s$.

Q4 → A Pitot tube is used to measure the velocity of water in Pipe. The stagnation pressure head is 6m and static pressure head is 5 m. Calculate the velocity of flow assuming the coefficient of tube equal to 0.98.

Ans → Given, stagnation Pressure head = 6 m.

$h_s = 6$ m

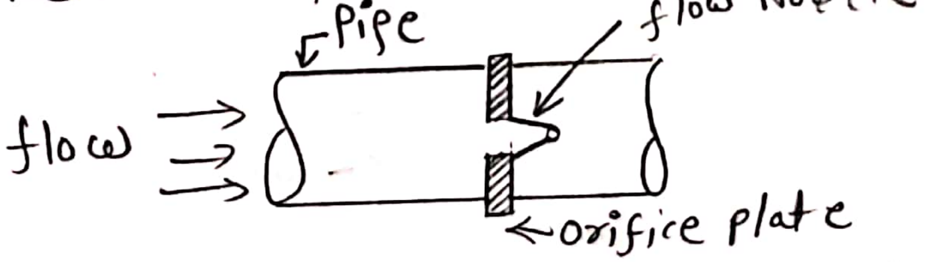
Static Pressure head = 5 m.

$h = 6 - 5 = 1$ m.

Velocity of flow, $V = C_v\sqrt{2gh} = 0.98\sqrt{2\times 9.81\times 1}$

$V = 4.34$ m/s.

→ flow Nozzle (प्रवाह नॉजल) → Nozzle एक convergent shape का device होता है जो fluid की Kinetic energy को increase करता है। Orifice plate के orifice पर Nozzle को fix किया जाता है तब उसे प्रवाह Nozzle कहते हैं। Area reduce होने के कारण Kinetic Energy increase हो जाती है।



Chapter No.- 05

Flow through orifices & Mouthpieces
(छारकों तथा मुखिकाओं से प्रवाह)

Orifice (छारक) → orifice is a small opening of any cross-section (such as circular, traingular, rectangular etc.) on the side or bottom of a tank, through which fluid is flowing.

classification of orifices →

① According to size →

ⓐ Large orifice → If the head of liquid is less than five times the depth of orifice.

ⓑ Small orifice → If the head of liquid is more than five times the depth of orifice.

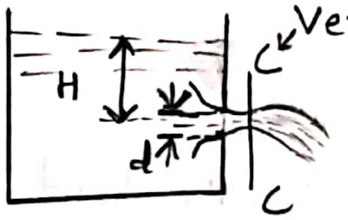
* Head measurement orifice के centre से करते हैं।

② According to the cross-sectional area →
ⓐ circular orifice ⓑ Traingular orifice
ⓒ Rectangular orifice ⓓ square orifice.

③ According to the shape → ⓐ sharp Edged orifice
ⓑ Bell mouthed orifice

④ Depending upon nature of discharge →
ⓐ Free discharging orifice
ⓑ Drowned or submerged orifice (Partially या पूरी डूबी orifice)

Vena contracta or throat or जेट संकोच → Vena contracta जेट की वह section है जहाँ Jet area Minimum होती है। Generally if orifice diameter d हो तो vena contracta orifice से d/2 distance पर होती है, but orifice के size, available water head भी vena contracta find out करने के लिए responsible होते है।



⇒ **Mouthpiece (मुखिका)** → Mouthpiece is a short length of pipe which is 02 to 03 times of its diameter in length, fitted in a tank or vessel containing the fluid.

* Mouthpiece और orifice दोनों ही discharge measuring के लिए use किए जाते है।

classification →

① on the basis of position →
ⓐ External Mouthpiece → जब mouthpiece को tank या vessel में Externally (बाहर की तरफ) fix किया जाता है।

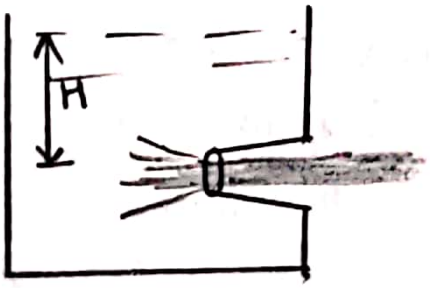
(b) Internal Mouthpiece → जब Mouthpiece को pipe में Internal direction में fix किया जाता है।

(2) According to shapes → (a) cylindrical mouthpiece (b) convergent mouthpiece (c) convergent-divergent mouthpiece.

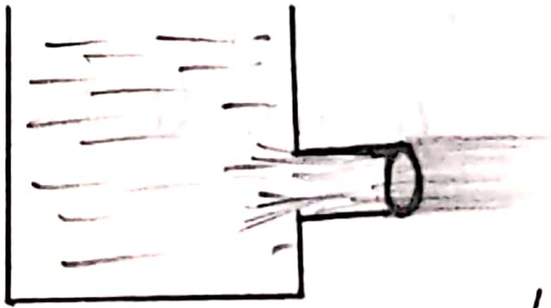
(3) According to the Nature of discharge →

(a) Mouthpieces running full → If the jet after contraction, expands & fills the whole mouthpiece is known as running full.

(b) Mouthpieces running free → If the jet of liquid after contraction doesnot touch the sides of the mouthpiece.



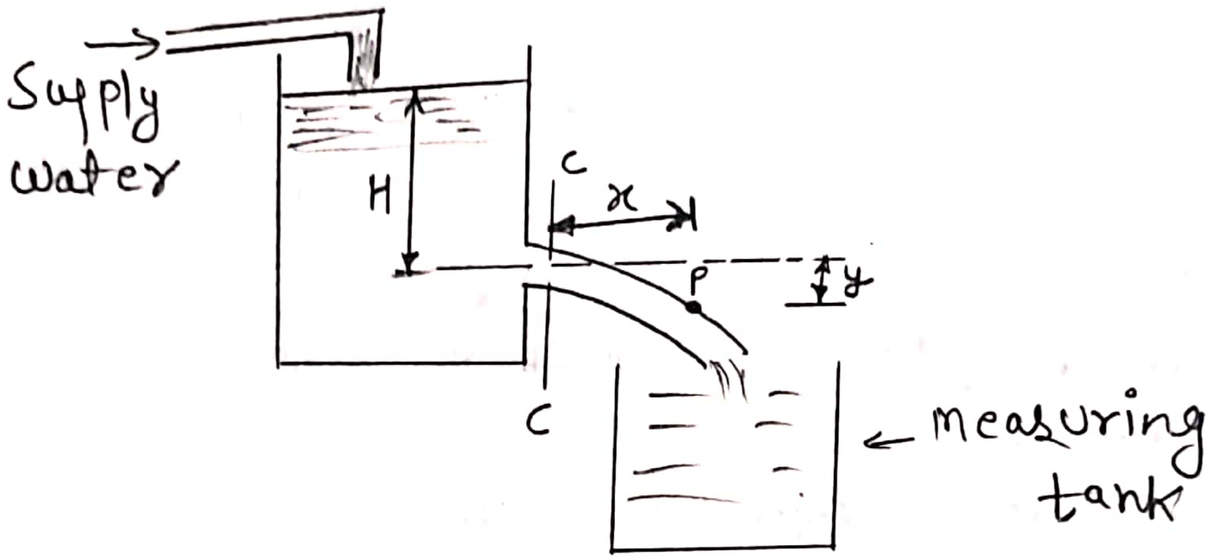
(a) Internal / convergent / running free mouthpiece.



(b) External / cylindrical / running full Mouthpiece.

Hydraulic-coefficients → Experimental determination →

(1) Determination of coefficient of discharge →



Constant Head H से एक orifice द्वारा Continuous water flow हो रहा है। Water को एक Measuring tank में collect करते हैं t time तक, फिर collected water की height को Measuring tank में measure करते हैं।

Actual discharge $Q = \dfrac{\text{Area of Measuring tank} \times \text{Height of water in Measuring tank}}{\text{Time } (t)}$

∴ Theoretical discharge = area of orifice × $\sqrt{2gh}$

$$C_d = \frac{Q_{act}}{Q_{th}} = \frac{Q}{a \times \sqrt{2gH}}$$

(2) Determination of Coefficient of Velocity (Cv) →

Let C-C = Vena Contracta of jet

Consider a liquid particle P and takes the position at P along the jet in time 't'

Let x = horizontal distance travelled by P at time t

y = vertical distance between P & C-C

V = Actual velocity of jet.

→ distance $x = V \times t$ ---- ①

Vertical distance $y = \frac{1}{2} g t^2$.

$$y = \frac{1}{2} g \times \left(\frac{x}{V}\right)^2 = \frac{1}{2} g \frac{x^2}{V^2}$$

$$\rightarrow V^2 = \frac{g x^2}{2y} \quad \text{or} \quad V = \sqrt{\frac{g x^2}{2y}}$$

& Theoretical velocity $V_{th} = \sqrt{2gh}$

∴ Coefficient of velocity, $C_v = \frac{V}{V_{th}} = \frac{\sqrt{\frac{g x^2}{2y}}}{\sqrt{2gh}}$

$$C_v = \sqrt{\frac{g x^2}{2y} \times \frac{1}{2gh}} = \sqrt{\frac{x^2}{4yh}} = \frac{x}{\sqrt{4yH}}$$

(3) Determination of coefficient of contraction (C_c)

→ We know $C_d = C_v \times C_c$

$$C_c = \frac{C_d}{C_v}$$

—×—

* $C_c = \frac{\text{area of Jet at Vena Contracta}}{\text{area of orifice}} = \frac{a_c}{a}$

Que A Jet of water, issuing from a sharp-edged Vertical office Under a constant head of 10 cm at a certain point, has the horizontal and Vertical co-ordinates measured from the vena-Contracta as 20.0 cm and 10.5 cm respectively. find Value of C_v, also find the value of C_c if $C_d = 0.60$.

Ans → Given, $H = 10$ cm, $x = 20$ cm, $y = 10.5$ cm,

$C_d = 0.6$.

$$C_v = \frac{x}{\sqrt{4yH}} = \frac{20}{\sqrt{4 \times 10.5 \times 10}} = \frac{20}{20.493}$$

$$C_v = 0.9759 = 0.976$$

$$\& \; C_c = \frac{C_d}{C_v} = \frac{0.6}{0.976} = 0.6147$$

Ans

Qu.) The head of water over an orifice of diameter 40 mm is 10 m. find actual discharge and actual velocity of the jet at vena-contracta. Take $C_d = 0.6$ & $C_v = 0.98$

Ans → Given, $H = 10\,m$, $d = 40\,mm = 0.04\,m$.

$\therefore$ Area; $a = \frac{\pi}{4} \times (0.04)^2 = 0.001256\,m^2$

$C_d = 0.6$, $C_v = 0.98$

(i) $\frac{\text{Actual discharge}}{\text{Theoretical discharge}} = 0.6$

$Q_{th} = V_{th} \times$ Area of orifice $= \sqrt{2gh} \times 0.001256$

$Q_{th} = 0.01758\ m^2/s$

$\therefore$ Actual discharge $= 0.6 \times$ Theoretical discharge

$= 0.6 \times 0.1758 = 0.01054\ m^3/s$

(ii) $C_v = \frac{\text{Actual velocity}}{\text{Theoretical velocity}}$

Actual velocity $= C_v \times V_{th} = 0.98 \times 14$

$= 13.72\ m/s$ Ans.

Qu.) The head of water over an orifice of diameter 100 mm is 10 m. The water coming out from orifice is collected in a circular tank of diameter 1.5 m. The rise of water level in this tank is 4.3 m horizontal & 0.5 m vertical. find the coefficients, Cd, Cv & Cc. tank require 25 sec to fill 1 m head.

Ans → Given, Head = 10 m

dia of orifice ⇒ $d = 100\ mm = 0.1\ m$.

∴ Area of orifice, $a = \pi/4 \times (0.1)^2 = 0.007853\ m^2$.

Dia of measuring tank, $D = 1.5\ m$

∴ Area, $A = \pi/4 \times 1.5^2 = 1.767\ m^2$

∴ $h = 1\ m$, $t = 25$ seconds, $x = 4.3\ m$,

$y = 0.5\ m$.

→ $V_{th} = \sqrt{2gH} = \sqrt{2 \times 9.81 \times 10} = 14\ m/s$

→ $Q_{th} = V_{th} \times$ Area of orifice $= 14 \times 0.007854$

$Q_{th} = 0.1099\ m^3/s$

→ $Q_{act} = \frac{A \times h}{t} = \frac{1.767 \times 1}{25} = 0.07068$

∴ $C_d = \frac{Q}{Q_{th}} = \frac{0.07068}{0.1099} = 0.643$

& $C_v = \frac{x}{\sqrt{4yH}} = \frac{4.3}{\sqrt{4 \times 0.5 \times 10}} = \frac{4.3}{4.472} = 0.96$

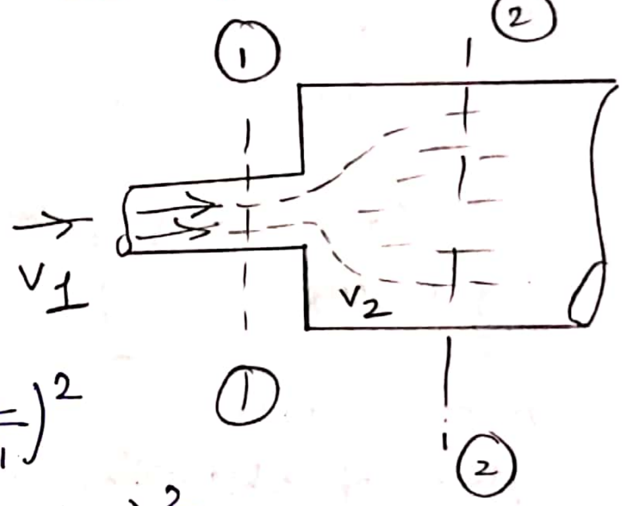
C_c is given by, $C_c = \frac{C_d}{C_v} = \frac{0.643}{0.96} = 0.669$ Ans

Minor Losses (Head) → The loss of head due to change in velocity of fluid in magnitude or direction is called minor loss of Energy.

Types of Minor Losses →

(1) Head loss due to sudden enlargement → (विस्तार होने पर)

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



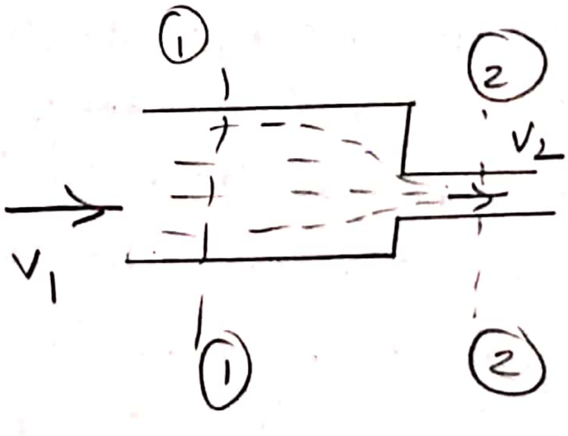
We know,

$$A_1V_1 = A_2V_2$$

so, $h_L = \frac{V_1^2}{2g}\left(1 - \frac{V_2}{V_1}\right)^2$

or $h_L = \frac{V_1^2}{2g}\left(1 - A_1/A_2\right)^2$

(2) Head loss due to sudden contraction (संकुचन होने पर) →



Coefficient of Contraction = $\frac{\text{Area of vena contracta}}{\text{area at orifice}}$

$$C_c = \frac{a_c}{a_2}$$

& $a_c V_c = a_2 V_2$ or $\dfrac{a_c}{a_2} = \dfrac{V_2}{V_c} = C_c$

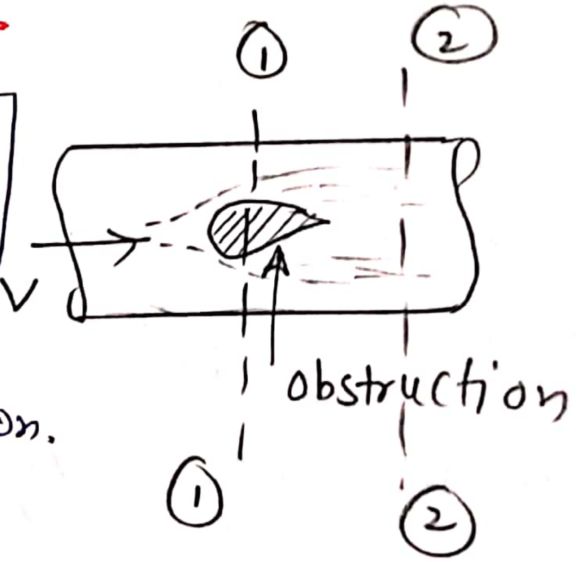
$$h_L = \frac{(V_1 - V_2)^2}{2g} = \frac{V_2^2}{2g}\left(\frac{V_c}{V_2} - 1\right)^2$$

$$\boxed{h_L = \frac{V_2^2}{2g}\left(\frac{1}{C_c} - 1\right)^2} \rightarrow \text{If } C_c \text{ is given.}$$

$$\boxed{h_L = \frac{0.5\, V_2^2}{2g}} \rightarrow \text{If } C_c \text{ is not given}$$

③ head loss due to obstruction in Pipe (पाइप में बाधा की स्थिति पर) →

$$\boxed{h_L = \frac{V^2}{2g}\left(\frac{A_2}{C_c(A_2 - A_1)} - 1\right)^2}$$



A_2 = Area of Pipe

A_1 = Area of obstruction.

Qu → The rate of flow of water through a horizontal Pipe is 0.25 m³/s. The diameter of the Pipe which is 200 mm is suddenly Enlarged to 400 mm. The Pressure Intensity in Smaller Pipe is 11.772 N/cm², Determine.

(i) Loss of head due to sudden Enlargement

(ii) Pressure intensity in large Pipe.

(iii) Power loss due to Enlargement.

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Ans → Given, discharge $Q = 0.25\ m^3/s$

→ dia of smaller pipe, $d_1 = 200mm = 0.2m$

→ $A_1 = \pi/4 \times 0.2^2 = 0.03141\ m^2$

→ dia of large pipe, $D_2 = 400\ mm = 0.4\ m$

→ $A_2 = \pi/4 \times 0.4^2 = 0.12566\ m^2$

→ Pressure in small pipe, $P_1 = 11.772\ N/cm^2$

$P_1 = 11.772 \times 10^4\ N/m^2$

→ velocity → $V_1 = Q/A_1 = \frac{0.25}{0.3141} = 7.96\ m/s$

$V_2 = Q/A_2 = \frac{0.25}{0.12566} = 1.99\ m/s$

(1) Sudden enlargement head loss →

$$h_{le} = \frac{V_1 - V_2^2}{2g} = 1.816\ m \quad \text{Ans.}$$

(2) Intensity of pressure at large pipe (P_2) →

from bernoullie's equation →

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

and $z_1 = z_2$

$$\frac{P_2}{\rho g} = \frac{P_1}{\rho g} + \frac{V_1^2}{2g} - \frac{V_2^2}{2g} - h_{le}$$

$$\frac{P_2}{\rho g} = \frac{11.772 \times 10^4}{1000 \times 9.81} + \frac{7.96^2}{2 \times 9.81} - \frac{1.99^2}{2 \times 9.81} - 1.816$$

$$\frac{P_2}{\rho g} = 13.21 \text{ m}$$

$$P_2 = 13.21 \times 1000 \times 9.81 = 12.96 \times 10^4 \text{ N/m}^2$$

$$P_2 = 12.96 \text{ N/cm}^2.$$

(3) Power loss → $P = \frac{\rho g Q h}{1000} = \frac{1000 \times 9.81 \times 0.25 \times 1.816}{1000}$

$$\boxed{P = 4.453 \text{ KW}}$$ Ans.

Qu → A horizontal pipe of diameter 500 mm is suddenly contracted to a diameter of 250 mm. The pressure intensities in the large and smaller pipe is given as 13.734 N/cm² and 11.772 N/cm² respectively. If discharge is 300 litres/s. Find coefficient of contraction.

Ans → Given, $D_1 = 500 \text{ mm} = 0.5 \text{ m}$, $A_1 = 0.1963 \text{ m}^2$

$D_2 = 250 \text{ mm} = 0.25 \text{ m}$, $A_2 = 0.04908 \text{ m}^2$

$P_1 = 13.734 \times 10^4 \text{ N/m}^2$

$P_2 = 11.772 \times 10^4 \text{ N/m}^2$

$Q = 300 \text{ liter/s} = 0.3 \text{ m/s}$.

→ for finding C_c, we required head loss due to sudden contraction i.e. h_{Lc},

$Q = A_1 V_1 = A_2 V_2 \Rightarrow V_1 = Q/A_1 = 1.528 \text{ m/s}$

$V_2 = Q/A_2 = 6.112 \text{ m/s}$

from bernoullie's equation →

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

$$\rightarrow \frac{13.734 \times 10^4}{9.81 \times 1000} + \frac{1.528^2}{2 \times 9.81} = \frac{11.772 \times 10^4}{9.81 \times 1000} + \frac{(6.112)^2}{2 \times 9.81} + h_c$$

$(\because z_1 = z_2)$

$$\rightarrow 14 + 0.119 = 12 + 1.904 + h_c$$

$$\boxed{h_c = 0.215 \text{ m}}$$

&

$$h_c = \frac{V_2^2}{2g}\left[\frac{1}{C_c} - 1\right]^2 = \frac{6.112^2}{2 \times 9.81}\left[\frac{1}{C_c} - 1\right]^2$$

$$\rightarrow \left(\frac{1}{C_c} - 1\right)^2 = \frac{0.215 \times 2 \times 9.81}{6.112^2} = 0.1129$$

$$\rightarrow \frac{1}{C_c} - 1 = \sqrt{0.1129} = 0.336$$

$$\rightarrow \frac{1}{C_c} = 1.336$$

$$\rightarrow C_c = \frac{1}{1.336} = 0.748$$

Ans.

Qu) Water is flowing through a horizontal pipe of diameter 200 mm at a velocity of 3 m/s. A circular solid plate of diameter 150 mm is placed in the pipe to obstruct the flow. Find head loss due to sudden obstruction in pipe if $C_c = 0.62$.

Ans → Given, $D_1 = 200\,mm = 0.2\,m$, $A_1 = 0.03141\,m^2$

$V = 3\,m/s$

dia of obstruction, $d_2 = 150\,mm = 0.15\,m$

$A_2 = \pi/4 \times 0.15^2 = 0.01767\,m^2$

$C_c = 0.62$

We know head loss due to obstruction →

$$h_{Lo} = \frac{V^2}{2g}\left[\frac{A_1}{C_c(A_1 - A_2)} - 1\right]^2$$

$$h_{Lo} = \frac{3^2}{2 \times 9.81}\left[\frac{0.03141}{0.62(0.03141 - 0.01767)} - 1\right]^2$$

$$\boxed{h_{Lo} = 1.311\,m}$$

Ans.

→ Torricell's theorem → "किसी vessel में भरे Fluid की velocity जब वह vessel के किसी hole से discharge होता है, यह velocity vessel में available fluid head से small hole तक fluid के गिरने की velocity के बराबर होती है।

$$\boxed{V_2 = \sqrt{2gh}}$$ ← Torricell's equation.

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Flow through Large orifices → Consider a large rectangle orifice in one side of the tank discharging freely into atmosphere under a constant head.

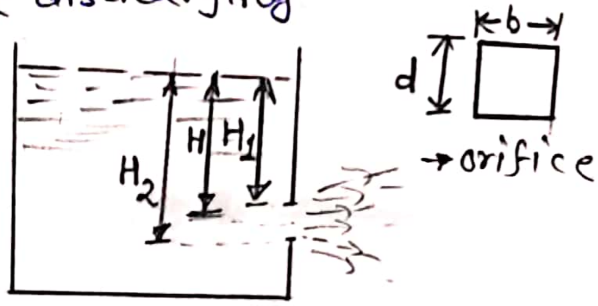


fig → Large rectangle orifice

H_1 = height of liquid above top edge of orifice.

H_2 = height of liquid above bottom edge of orifice.

b = breadth of orifice

d = depth of orifice $= H_2 - H_1$

Cd = coefficient of discharge.

$$Q = \frac{2}{3} C_d \times b \sqrt{2g} \left[H_2^{3/2} - H_1^{3/2} \right]$$

Qu → Find the discharge through a rectangular orifice 2.0 m wide and 1.5 m deep fitted to a water tank. The water level in the tank is 3.0 m above the top edge of the orifice. Take $C_d = 0.62$

Ans → Given, width of orifice ⇒ $b = 2.0$ m

Depth of orifice ⇒ $d = 1.5$ m.

Height of water above top edge of the orifice, $H_1 = 3$ m.

Height of water above bottom edge of orifice, $H_2 = H_1 + d = 3 + 1.5 = 4.5$ m.

$C_d = 0.62$

→ Discharge $Q = \frac{2}{3} C_d \times b \times \sqrt{2g} \left(H_2^{3/2} - H_1^{3/2}\right)$

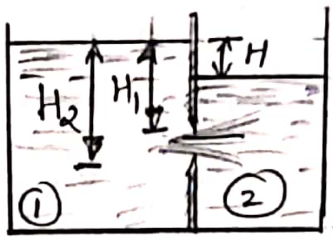
$Q = \frac{2}{3} \times 0.62 \times 2 \times \sqrt{2 \times 9.81} \left(4.5^{3/2} - 3^{1.5}\right)$

$Q = 15.917$ m³/s.

→ Discharge through fully submerged orifice →

$Q = C_d \times \text{Area} \times \text{velocity}$

$Q = C_d \times b \times d \times \sqrt{2gH}$



$$Q = C_d \times b (H_2 - H_1) \times \sqrt{2gH}$$

Qu → Find the discharge through a fully submerged orifice of width 2 m, if the difference of water levels on both sides of orifice be 50 cm. The height of water from top & bottom of the orifice are 2.5 m and 2.75 m respectively. Take $C_d = 0.6$.

Ans → Given, $b = 2$ m, $H = 50$ cm $= 0.5$ m.

$H_1 = 2.5$ m, $H_2 = 2.75$ m, $C_d = 0.6$

→ $Q = C_d \times b \times (H_2 - H_1) \times \sqrt{2gH}$

$Q = 0.6 \times 2 \times (2.75 - 2.5) \times \sqrt{2 \times 9.81 \times 0.5}$ m³/s

$Q = 0.9396$ m³/s.

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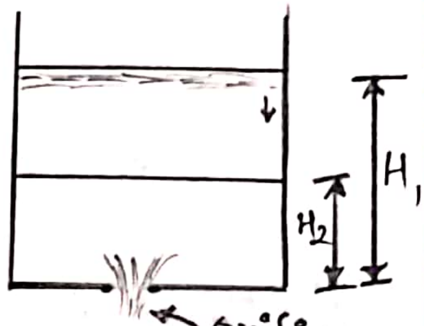
→ Time of Emptying A tank through An orifice At its bottom →

$$T = \frac{2A\sqrt{H_1 - H_2}}{C_d \times a \times \sqrt{2g}}$$ ← for some head.



for Emptying the tank completely,
$H_2 = 0$.

$$T = \frac{2A\sqrt{H_1}}{C_d \times a \times \sqrt{2g}}$$

A = Area of tank
a = Area of orifice

Que) A circular tank of diameter 4 m contains water upto a height of 5 m. The tank is provided with an orifice of diameter 0.5 m at bottom. Find the time taken by water (i) to fall from 5m to 2 m (ii) for emptying the tank. Take $C_d = 0.6$.

Ans) $D = 4$ m, $A = \pi/4 \times 4^2 = 12.566\ m^2$
$d = 0.5$ m, $a = \pi/4 \times 0.5^2 = 0.1963$
$H_1 = 5$ m,

(i) for 5 m to 2m → $T = \frac{2A\sqrt{H_1 - H_2}}{C_d \times a\sqrt{2g}} = \frac{2 \times 12.566 \times \sqrt{5-2}}{0.6 \times 0.1963 \times \sqrt{2 \times 9.81}}$

$T = 39.58$ seconds

(2) for 5m to 0m → $T = \frac{2A\sqrt{H_1}}{C_d \times a \times \sqrt{2g}} = 107.7$ Sec.

Q → find the discharge through a totally drowned Orifice 2.0 m wide & 1 m deep. If the difference of water levels on both the sides of orifice be 3 m. Take $C_d = 0.62$,

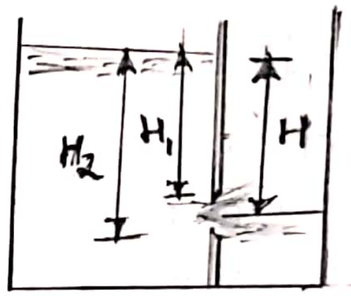
Ans → Given, $b = 2$ m, $d = 1$ m, $H = 3$ m, $C_d = 0.62$

$$Q = C_d \times Area \times \sqrt{2gH} = C_d \times b \times d \times \sqrt{2gH}$$

$$Q = 0.62 \times 2 \times 1 \times \sqrt{2 \times 9.81 \times 3} = 9.513 \text{ m}^3/\text{s}.$$

→ Discharge through Partially Sub-merged orifice →

$$Q = C_d \times b \times (H_2 - H) \times \sqrt{2gH} + \frac{2}{3} C_d \times b \times \sqrt{2g}\left(H_2^{3/2} - H^{3/2}\right)$$



Que → A rectangluar Orifice of 2 m width and 1.2 m deep is fitted in one Side of the ~~orifice~~ tank, while on the one Side of orifice the water level is 3 m above the top edge of orifice, other side water level is 0.5 m below its top edge. Calculate discharge by Orifice if $C_d = 0.64$.

Ans → Width, $b = 2$ m, $d = 1.2$ m, $H_1 = 3$ m,
difference of water level on both sides, $H = 3 + 0.5$
$H = 3.5$ m.

Height of water from bottom edge, $H_2 = H_1 + d$
$= 3 + 1.2$
$= 4.2$ m.

→ $Q = 12.5329 \text{ m}^3/\text{s}$. Ans.

Chapter No. - 06

Flow through Pipes (नलों में प्रवाह)

Reynolds Number (Re) → It is the ratio of Inertia force to viscous force.

$$Re = \frac{\rho V L}{\mu} \text{ or } \frac{VL}{\nu}$$

(If required L changes to d)

if $Re < 2000$ → Laminar flow

$Re > 4000$ → Turbulent flow

$2000 < Re < 4000$ = Transition phase.

Major Loss (Head loss) → The loss of head or energy due to friction in a pipe is known as major loss. It can be found by →

① Darcy-Weisbach formula →

$$h_f = \frac{4 f L V^2}{2 g d}$$

&

$$F = 4f$$

h_f = head loss by friction

L = pipe length

V = velocity of flow

d = pipe diameter

f = coefficient of friction

F = friction factor.

$$f = \frac{16}{Re}, \text{ if } Re < 2000$$

$$f = \frac{0.079}{Re^{1/4}}, \text{ if } Re > 2000$$

$$h_L = \frac{fLQ^2}{3D^5}$$

⇓

Darcy Weisbach formula in discharge form

f = coefficient of friction

② Chezy's formula →

$$V = c\sqrt{mi}$$

c = chezy's constant

m = hydraulic mean depth, v = velocity of flow

i = hydraulic slope

$$i = \frac{h_f}{L}$$

& $m = \frac{Area}{Perimeter} = \frac{\pi/4 \, D^2}{\pi D} = D/4$

& $c = \sqrt{\frac{2g}{f}} = \sqrt{2g/f}$ → f = coefficient of friction.

Que) find the head loss due to friction in a pipe of diameter 300 mm and length 50m, through which water is flowing at a velocity of 3 m/s using (i) Darcy formula ② chezy's formula for c=60. (Take ν = 0.01 stoke)

Ans → given, d = 300 mm = 0.3 m

L = 50 m, V = 3 m/s, c = 60

ν = 0.01 stoke = 0.01 cm^2/s = 0.01×10^{-4} m^2/s

① Darcy Weisbach formula →

$$h_f = \frac{4fLV^2}{2gd}$$

[f depends to reynolds No.]

$$Re = \frac{V \times d}{\nu} = \frac{3 \times 0.3}{0.01 \times 10^{-4}} = 9 \times 10^5$$

So, $f = \frac{0.079}{Re^{1/4}} = \frac{0.079}{(9 \times 10^5)^{1/4}} = 0.00256$

$\therefore$ Head lost, $h_f = \frac{4fLV^2}{2gd} = \frac{4 \times 0.00256 \times 50 \times 3^2}{0.3 \times 2.0 \times 9.81}$

$$h_f = 0.7828 \text{ m.}$$

(ii) Chezy's formula is $V = C\sqrt{mi}$

where $C = 60$, $m = d/4 = 0.3/4 = 0.075$ m.

$\therefore 3 = 60 \times \sqrt{0.075 \times i}$

$i = \left(\frac{3}{60}\right)^2 \times \frac{1}{0.075} = 0.0333$

& $\frac{h_f}{L} = i$ so, $\frac{h_f}{50} = 0.0333$

$h_f = 50 \times 0.0333 = 1.665$ m. Ans.

Qu. Find the diameter of a pipe of length 2000 m when the rate of flow of water through the pipe is 200 litres/s & the head lost due to friction is 4 m. Take the value of $C = 50$ in Chezy's formulae.

Ans → Given, $L = 2000$ m, $Q = 200$ lit/s $= 0.2$ m³/s

$h_f = 4$ m, $C = 50$

→ discharge Q = Area (A) × Velocity (V)

$$V = Q/A = \frac{Q}{\frac{\pi}{4}d^2} = \frac{4Q}{\pi d^2} = \frac{0.8}{\pi d^2}$$

→ Hydraulic mean depth, $m = d/4$

$$\rightarrow i = \frac{h_f}{L} = \frac{4}{2000} = 0.002$$

We know, $V = C\sqrt{mi}$ (Chezy's constant)

$$\Rightarrow \frac{0.8}{\pi d^2} = 50 \times \sqrt{d/4 \times 0.002}$$

$$\Rightarrow \frac{0.8}{\pi d^2 \times 50} = \sqrt{d/4 \times 0.002}$$

$$\Rightarrow \left(\frac{0.8}{\pi d^2 \times 50}\right)^2 = d/4 \times 0.002$$

$$\Rightarrow d^5 = 0.0518$$

$$\Rightarrow d = 0.553 \text{ m} = 553 \text{ mm}.$$

Ans.

Q4) A crude oil of Kinematic viscosity 0.4 stoke is flowing through a pipe of diameter 300 mm at the rate of 300 litres per sec. Find the head lost due to friction for a length of 50 m of pipe.

Answer → Given, $\nu = 0.4$ Stokes $= 0.4\ cm^2/s = 0.4 \times 10^{-4}\ m^2/s$

$d = 300\ mm = 0.3\ m$, $Q = 300\ lit/s = 0.3\ m^3/s$.

→ Length of pipe, $L = 50\ m$.

→ velocity of flow, $V = Q/Area = \frac{0.3}{\pi/4 \times 0.3^2} = 4.24\ m/s$

∴ Reynolds no., $Re = \frac{V \times d}{\nu} = \frac{4.24 \times 0.3}{0.4 \times 10^{-4}} = 3.18 \times 10^4$

⇒ Re is between, 4000 – 100000, so,

$$f = \frac{0.079}{(Re)^{1/4}} = \frac{0.079}{(3.18 \times 10^4)^{1/4}} = 0.00591$$

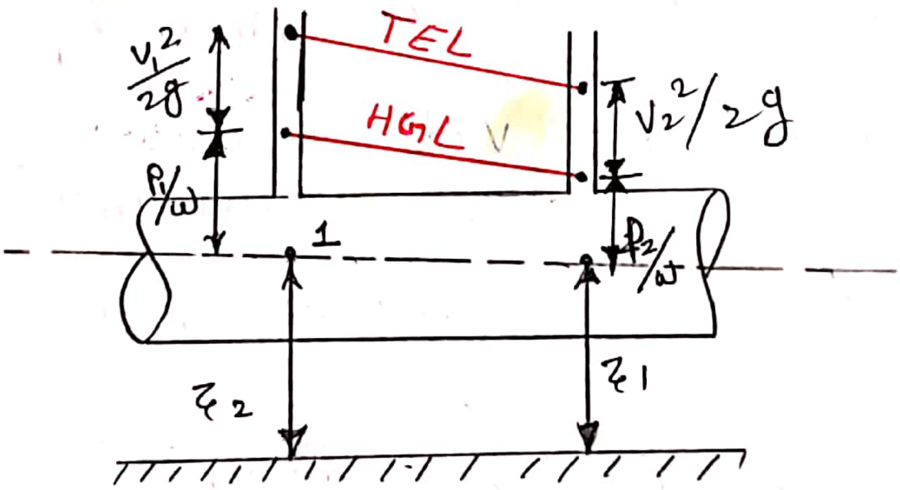
$$\therefore h_f = \frac{4fLV^2}{2gd} = \frac{4 \times 0.00591 \times 50 \times 4.24^2}{0.3 \times 2 \times 9.81}$$

$$\boxed{h_f = 3.61\ m.}$$

Ans.

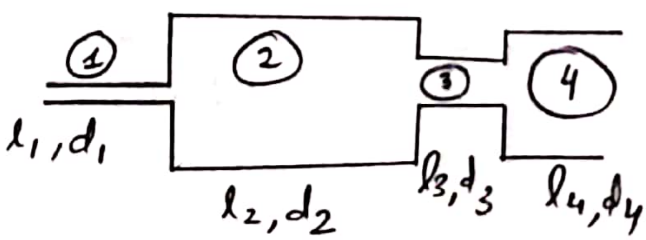
→ **Hydraulic gradient line** → The line which joins Piezometric head i.e. Pressure head & datum head ($P/\omega + z$) at various points known as hydraulic gradient line (HGL).

→ **Total Energy line (TEL)** → The line which joins Total energy ($P/\omega + z + v^2/2g$) i.e. Pressure head, Kinetic head & Potential head at various points in a flow called Total Energy line.



→ HGL may rise or fall but TEL always fall until the external energy input supplied.

⇒ **Pipes in Series** →



Discharge → $Q_1 = Q_2 = Q_3 = Q$ (Same in every pipe)

Total head loss → $h_L = h_{L_1} + h_{L_2} + h_{L_3}$ (Sum of all)

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Pipe in series or compound pipes are defined as the pipes of different lengths and different diameters connected in series to form a pipe. (shown in fig.)

$$h_L = h_{L_1} + h_{L_2} + h_{L_3}$$

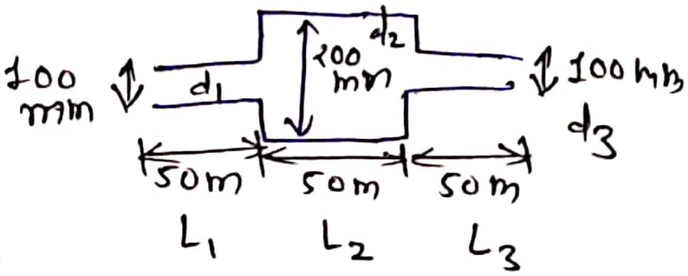
$$\Rightarrow h_L = \frac{4 f_1 L_1 V_1^2}{d_1 \times 2g} + \frac{4 f_2 L_2 V_2^2}{d_2 \times 2g} + \frac{4 f_3 L_3 V_3^2}{d_3 \times 2g}$$

if $f_1 = f_2 = f_3 = f$, then,

$$h_L = \frac{4f}{2g}\left[\frac{L_1 V_1^2}{d_1} + \frac{L_2 V_2^2}{d_2} + \frac{L_3 V_3^2}{d_3}\right]$$

Q4) 150m Long Horizontal Pipe से water 1.5 m/s की velocity से Exit हो रहा है। पाइप के 50m mid portion का diameter 200 mm तथा Remaining 02 parts का diameter 100 mm है। Find the total head if $f = 0.005$ for all pipes.

Ans → $L_1 = 50$ m, $L_2 = 50$ m, $L_3 = 50$ m, $d_1 = 0.1$ m, $d_2 = 0.2$ m, $d_3 = 0.1$ m,



Suppose, $Q = Q_1 = Q_2 = Q_3$

$\rightarrow A_1 V_1 = A_2 V_2 = A_3 V_3$

$\rightarrow \frac{\pi}{4} \times (0.1)^2 \times V_1 = \pi/4 \times (0.2)^2 \times V_2 = \frac{\pi}{4} \times 0.1^2 \times V_3$

$\rightarrow V_1 = V_3 = 1.5 \text{ m/s}, \; V_2 = 0.375 \text{ m/s}$

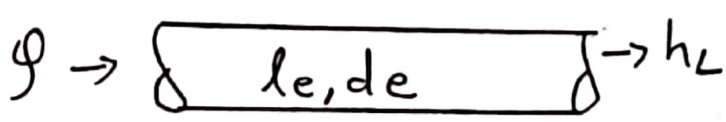
$$\rightarrow h_f = \frac{4 f L_1 V_1^2}{2 g d_1} + \frac{4 f L_2 V_2^2}{2 g d_2} + \frac{4 f l_3 V_3^2}{2 g d_3}$$

$$\rightarrow h_f = \frac{4 f L}{2 g} \left[\frac{V_1^2}{d_1} + \frac{V_2^2}{d_2} + \frac{V_3^2}{d_3} \right]$$

$$\rightarrow h_f = \frac{4 \times 0.0005 \times 50}{2 \times 9.81} \left[\frac{1.5^2}{0.1} + \frac{0.375^2}{0.2} + \frac{1.5^2}{0.1} \right]$$

$\rightarrow h_f = 0.232$ m.

$\Rightarrow$ **Equivalent Pipe** $\rightarrow$ A pipe of constant diameter is said to be equivalent pipe to a compound pipe when it carries same discharge and same losses.



We know $h_L = \frac{4 f L V^2}{2 g d} = \frac{f L Q^2}{3 d^5}$

$\rightarrow$ friction factor (f) & discharge (Q) same for all.

So, $\Rightarrow h_L = h_{L_1} + h_{L_2} + h_{L_3} \Rightarrow$ sum of all of compound pipe.

$$\rightarrow \frac{f l_e Q^2}{03 d_e^5} = \frac{f L_1 Q^2}{03 d_1^5} + \frac{f L_2 Q^2}{03 d_2^5} + \frac{f L_3 Q^2}{03 d_3^5}$$

$$\boxed{\frac{L_e}{d_e^5} = \frac{l_1}{d_1^5} + \frac{l_2}{d_2^5} + \frac{l_3}{d_3^5}}$$

Qu → 8 Km. Long compound pipe is made by 04 different pipes. Diameters of the pipes are 100 mm, 200mm, 250 mm & 300 mm and lengths are 1 km, 2 Km, 1.5 Km & 3.5 Km. Find the diameter of Equivalent Pipe.

Ans →

$l_1 = 1$ Km	$d_1 = 0.1$ m
$l_2 = 2$ Km	$d_2 = 0.2$ m
$l_3 = 1.5$ Km	$d_3 = 0.25$ m
$l_4 = 3.5$ Km	$d_4 = 0.3$ m
$l_e = 8$ Km	$d_e = ?$

$$\rightarrow l_e/d^5 = l_1/d_1^5 + l_2/d_2^5 + l_3/d_3^5 + l_4/d_4^5$$

$$\rightarrow \frac{8000}{d^5} = \frac{1000}{(0.1)^5} + \frac{2000}{(0.2)^5} + \frac{1500}{(0.25)^5} + \frac{3500}{(0.3)^5}$$

$d^5 = (7.3 \times 10^{-5})$

$d = \sqrt[5]{7.3 \times 10^{-5}} = 0.15\ m$

$$d = 0.15\ m = 150\ mm.$$

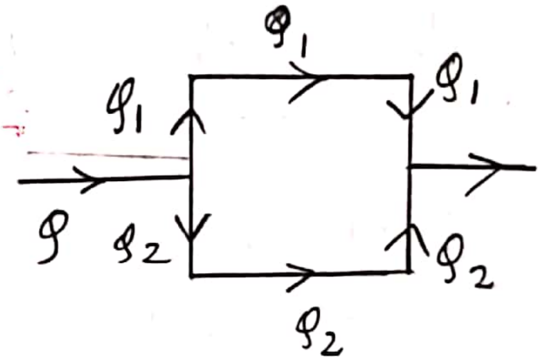
Parallel Pipes or Pipes in Parallel →

Total discharge,

$Q = Q_1 + Q_2 + \ldots$

&

Head loss $\Rightarrow h_L = h_{L_1} = h_{L_2}$



Qu → A main pipe divides into two parallel pipes which again forms one pipe. The length & diameter for the for first parallel pipe are 2000m and 1.0 m respectively, while the length and diameter of 2nd parallel pipe are 2000m and 0.8 m. Find discharge in each parallel pipe, if total flow in the main is 3 m³/s. The coefficient of friction for each parallel pipe is same and equal to 0.005.

Ans → Given, $L_1 = 2000\ m$, $d_1 = 1\ m$, $L_2 = 2000\ m$,

$d_2 = 0.8\ m$, $Q = 3\ m^3/s = Q_1 + Q_2$

$f_1 = f_2 = f = 0.005$

Q_1 = discharge of Pipe 1

Q_2 = discharge of Pipe 2

$\rightarrow h_{f_1} = h_{f_2}$

$\rightarrow \frac{4 f_1 L_1 V_1^2}{2 g d_1} = \frac{4 f_2 L_2 V_2^2}{2 g d_2}$

$\rightarrow \frac{2000 \times V_1^2}{1} = \frac{2000 \times V_2^2}{0.8}$

$\rightarrow V_1^2 = \frac{V_2^2}{0.8} \Rightarrow V_1 = \frac{V_2}{\sqrt{0.8}} = \frac{V_2}{0.894}$

$\rightarrow Q_1 = \pi/4 \, d_1^2 \times V_1 = \pi/4 \times 1^2 \times \frac{V_2}{0.894} = 0.88 \, V_2$

$\rightarrow Q_2 = \pi/4 \times d_2^2 \times V_2 = \pi/4 \times 0.8^2 \times V_2 = 0.5 \, V_2$

$\rightarrow Q_1 + Q_2 = Q$

$\rightarrow 0.88 \, V_2 + 0.5 \, V_2 = 3$

$\rightarrow 1.38 \, V_2 = 3$

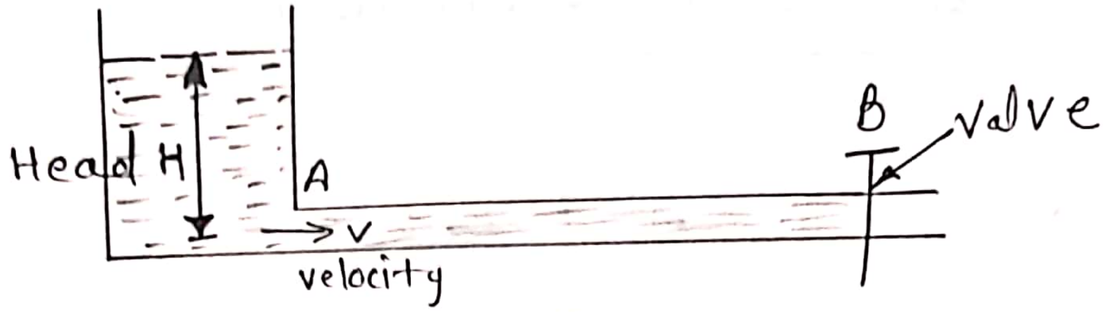
$\rightarrow V_2 = 2.17 \text{ m/s}$

$\rightarrow V_1 = \frac{V_2}{0.894} = \frac{2.17}{0.894} = 2.43 \text{ m/s}$

$\rightarrow Q_1 = 0.88 \, V_2 = 0.88 \times 2.17 = 1.91 \text{ m}^3/\text{s}$

$\rightarrow Q_2 = 3 - 1.91 = 1.09 \text{ m}^3/\text{s}$ Ans.

Water hammer (जल आघात) →



एक Long Pipe AB figure में shown है, यह Pipe एक tank से connected है जिसमें water head (H) pipe के centre से लिया गया है। Pipe के दूसरे End पर एक Valve flow regulate करने के लिए Provided है। जब valve completely open होता है तब water velocity v से pipe में बहता है। अब अगर Valve को suddenly closed किया जाता है तो water का momentum destroy हो जाएगा तथा High Pressure wave generate होगी। यह High Pressure wave पूरे pipe में transmit होगी तथा wave की velocity, velocity of sound wave के बराबर होगी। इस wave के कारण noise generation होता है जिसे Knocking कहते हैं। यह High Pressure wave pipe walls में Hammering effect generate करती है, इसलिए इसे water hammer कहते हैं।

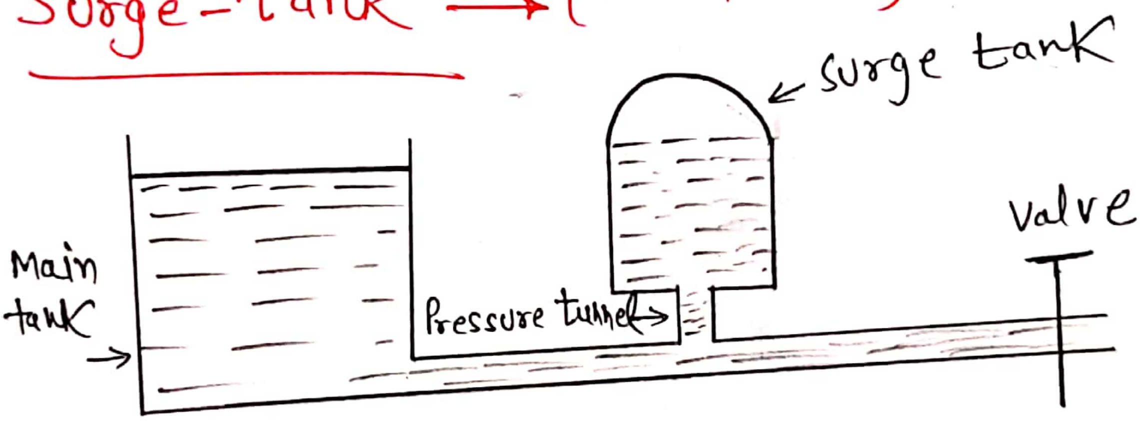
→ Intensity of Pressure wave depend करती है →

(1) Length of pipe (2) Time taken to close valve
(3) velocity of flow (4) elastic properties of Materials

Water hammer को reduce करने के तरीके →

1. Valve को Gradually close करना चाहिए। Sudden close नहीं करना चाहिए।
2. Non-return valve use करना चाहिए।
3. Surge Tank Provide करना चाहिए।

Surge-tank → (प्रोत्कर्ष टंकी)



किसी पाइप लाइन मे जब valve को suddenly close किया जाता है तो Water hammer के कारण High Pressure waves generate होते है जिनसे Pipe के फटने का fear होता है। Water hammer से बचने के लिए surge tank का use किया जाता है। जब valve बंद की जाती है तो Pipeline में मौजूद water surge tank में चला जाता है तथा High Pressure waves create नहीं होते है। अतः Surge tank एक water storage tank है जिसे किसी Penstock या Pipeline में fit किया जाता है तथा Valve बंद करने पर Extra flow of water इस tank में जमा हो जाता है जिसे जरूरत पड़ने पर यूज किया जा सकता है।

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Chapter No. - 07

Impact of Jets (जेटों का संघट्ट)

जब Water Nozzle से High velocity से बाहर आता है तो उसे Jet कहते हैं। यह Jet जब किसी plate या object से टकराता है तो उसे Impact of jets कहते हैं। Impact से Jet की Kinetic Energy object में transferr हो जाती है। Impact of jet के द्वारा turbine के rotor को घुमाया जाता है।

→ force Exerted by the Jet on Stationary plate →

① On Stationary Vertical plate → $F_x = \rho a v^2$ ← flat plate

v = velocity of jet, d = diameter of jet, a = area of jet.

② On stationary Inclined Flate plate →

$F_x = \rho a v^2 \sin^2\theta$ → In the direction of flow/jet

$F_y = \rho a v^2 \sin\theta$ ← In the direction Perpendicular to flow.

(3) force Exerted on a Stationary Curved Plate →

$$F_x = \rho a v^2 (1+\cos\theta)$$

$$F_y = -\rho a v^2 \sin\theta$$

-ve sign means force is acting downward. In this, angle of deflection = $(180-\theta)$.

Qu.) Water is flowing through a pipe at the End of which a nozzle is fitted. The diameter of the nozzle is 100 mm and head of water at the Centre of nozzle is 100 m. Find force Exerted by jet of water on fixed vertical plate. The Coefficient of velocity is given as 0.95.

Ans → $d = 100\,mm = 0.1\,m$, $H = 100\,m$, $C_v = 0.95$

Area of nozzle, $a = \pi/4\,(0.1)^2 = 0.007854\,m^2$

Theoretical velocity of jet, $V_{th} = \sqrt{2gH} = \sqrt{2 \times 9.81 \times 100}$

$V_{th} = 44.294\,m/s$

But, $C_V = \dfrac{\text{Actual velocity}}{\text{Theoretical Velocity}}$.

$V = C_V \times V_{th} = 0.95 \times 44.3 = 42.08\,m/s$

Force Exerted ⇒ $F = \rho a v^2 = 1000 \times 0.007854 \times 42.08^2$

$= 13907.2\,N$

$= 13.9\,KN$

Que) A jet of water of diameter 75 mm moving with a velocity of 25 m/s strikes a fixed plate in such a way that the angle between the jet and plate is 60°. Find the force exerted by the jet on the plate ⇒ (i) in the direction normal to plate (ii) in the direction of the jet. ?

Ans → $d = 75\ mm = 0.075\ m$,

$\therefore a = \pi/4\, d^2 = \pi/4 \times 0.75^2 = 0.004417\ m^2$

Velocity of jet, $V = 25\ m/s$

$\theta = 60°$

(i) The force exerted by jet in the direction of flow →

$F_x = \rho a v^2 \sin\theta = 1000 \times 0.004417 \times 25^2 \times \sin^2 60°$

$F_x = 2070.4\ N.$

(ii) Force exerted by jet opposite / normal to flow →

$F_y = \rho a v^2 \sin\theta = 1000 \times 0.004417 \times 25^2 \times \sin 60°$

$F_y = 2390.7\ N$

Ans.

Qu) A jet of water of diameter 50 mm moving with a velocity of 40 m/s, strikes a curved fixed symmetrical plate. Find force exerted by the jet of water in the direction of jet, If the jet is deflected through an angle of 120° at the outlet of the curved plate. ?

Ans → Given, diameter $d = 50\ mm = 0.05\ m$,

∴ Area, $a = \pi/4 \times (0.05)^2 = 0.001963\ m^2$.

Velocity of jet, $V = 40\ m/s$

Angle of deflection $\Rightarrow 180° - \theta = 120°$

$\theta = 180° - 120° = 60°$

→ force, $F_x = \rho a v^2 (1 + \cos\theta) = 1000 \times 0.001963 \times 40^2 \times (1 + \cos 60°)$

$$\boxed{F_x = 4711.15\ N}$$ ← Ans

⇒ force Exerted by jet on moving plates →

① Flate vertical plate →

$$\boxed{F_x = \rho a (V - u)^2}$$ ← In the direction of flow (unit Newton)

$$\boxed{\text{Work-done}, \ W = F_x \times u}$$ → unit (Nm/s or J/s = W)

V = Velocity of jet (absolute)

a = cross-section area of jet

u = Velocity of flate plate

② Force on Inclined moving plate →

$$F_n = \rho a (V-u)^2 \sin\theta$$

$$F_x = F_n \times \sin\theta = \rho a (V-u)^2 \sin^2\theta \quad \leftarrow \text{Newton}$$

$$F_y = F_n \cos\theta = \rho a (V-u)^2 \sin\theta \cos\theta \quad \leftarrow \text{Newton}$$

Work-done, $W = F_x \times u = \rho a (V-u)^2 \sin^2\theta \times u$ ← J/s or Nm/s or W

③ Force on Curved moving plate →

$$F_x = \rho a (V-u)^2 (1+\cos\theta)$$

$$W = F_x \times u$$ [θ ⇒ Angle of deflection (180 − θ)]

Que A Nozzle of 50 mm diameter delivers a stream of water at 20 m/s perpendicular to a plate that moves away from the jet at 5 m/s. find ① Force on plate ② work-done ③ the efficiency of jet.

Ans → $d = 50\ mm = 0.05\ m$, $a = \pi/4 \times 0.05^2 = 0.0019635\ m^2$

$V = 20\ m/s$, $u = 5\ m/s$.

(i) Force $F_x = \rho a (V-u)^2 = 1000 \times 0.0019635 \times (20-5)^2$

$F_x = 441.78$ N

(ii) Work done, $W = F_x \times u = 441.78 \times 5 = 2208.9$ Nm/s

(iii) Efficiency, $\eta = \frac{\text{Output}}{\text{Input}} = \frac{\text{Work done/s}}{\text{Kinetic Energy/s}}$

$$\eta = \frac{F_x \times u}{\frac{1}{2} m V^2} = \frac{F_x \times u}{\frac{1}{2}(\rho A V) \times V^2} \Rightarrow \frac{2208.9}{\frac{1}{2}(1000 \times 0.0019635 \times 20) \times 20^2}$$

($m = \rho A V$)

$$\eta = \frac{2208.9}{6540} = 0.3377 = 33.77\%$$

Qu → A jet of water of diameter 7.5 cm strikes a curved plate at its centre with a velocity of 20 m/s. The curved plate is moving with a velocity of 8 m/s in the direction of jet. The jet is deflected through an angle of 165°. Find: ① Force exerted in the direction of jet ② Power of jet ③ Efficiency of jet.

Ans → $d = 7.5$ cm $= 0.075$ m, $a = \pi/4 \times (0.075)^2$

$a = 0.004417$

velocity, $V = 20$ m/s, $u = 8$ m/s

Angle of deflection of jet, $= 165°$

$\theta = 180 - 165° = 15°$

(i) Force Exerted, $F_x = \rho a (V-u)^2 (1+\cos\theta)$

$= 1000 \times 0.004417 \times (20-8)^2 \times [1+\cos 15^\circ] = 1250.38\ N$

(ii) Work done,

$W = F_x \times u = 1250.38 \times 8$

$W = 10003.04\ Nm/s$ or W

Work done or power = 10 KW

(iii) $\eta = \frac{\text{output}}{\text{Input}} = \frac{\text{work done by Jet/sec}}{\text{K.E. of Jet } (\frac{1}{2}mV^2)}$

$= \frac{1250.38 \times 8}{\frac{1}{2}(\rho AV) \times V^2}$ $(m = \rho AV)$

$= \frac{1250.38 \times 8}{\frac{1}{2} \times 1000 \times 0.004417 \times 20^3} = 0.564$

$= 56.4\%$

Ans.

Work-done by Pelton runner →

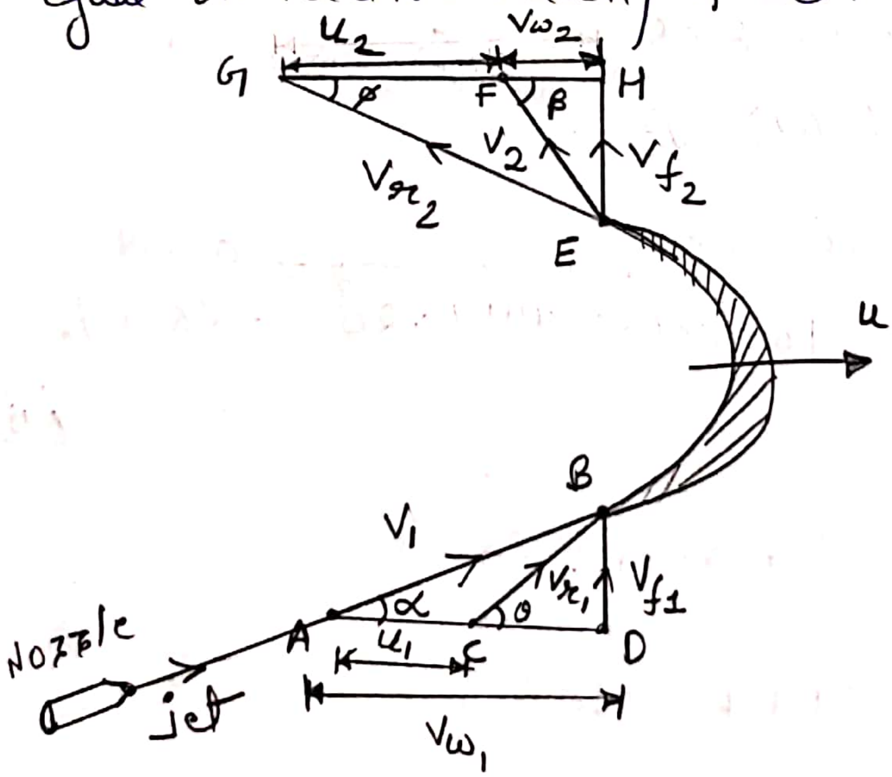
$F = \rho (V-u)(1+K\cos\theta)$

$W = \rho (V-u)(1+K\cos\theta) \times u$

$$K = \frac{V_{r_2}}{V_{r_1}}$$ [V_{r_2} = relative velocity at Exit
V_{r_1} = relative velocity at entry]

⇒ Forces Exerted to unsymmetrical moving curved plate by jet when Tangentially Strikes

⇒ figure shows a jet of water striking a moving curved plate tangentially at one of its tips. As jet strikes tangentially, the loss of energy will zero. plate velocity is Equal to relative velocity of jet.



V_1 = Velocity of jet at Inlet.
V_2 = —— " —— outlet.
u_1 = velocity of plate at Inlet. (plate = vane)
u_2 = —— " —— outlet.

V_{r_1} = Relative velocity of jet & plate at Inlet.

V_{r_2} = ——— " ——————— " ——— outlet.

V_{f_1} = velocity of flow at Inlet.

V_{f_2} = ——— " ——————— outlet.

V_{w_1} = velocity of whirl at Inlet.

V_{w_2} = ——— " ——————— at outlet.

α = Guide blade angle = angle between direction of jet and direction of motion of plate at Inlet.

θ = Vane angle at Inlet = angle made by the (V_{r_1}) relative velocity with direction of motion of plate.

β = Angle made by velocity V_2 with direction of motion of plate at outlet.

ϕ = Vane angle at outlet = Angle made by relative velocity (V_{r_2}) with direction of motion of plate at outlet.

→ Triangles ABD & EGH are called velocity triangles at Inlet & outlet.

→ if vane is smooth & velocity is equal at Inlet & velocity than, $u_1 = u_2 = u$ & $V_{r_1} = V_{r_2}$.

→ Force Exerted by jet ⇒

$F_x = \rho a V_{r_1} (V_{w_1} + V_{w_2})$ [if $\beta < 90°$ or acute angle]

$F_x = \rho a V_{r_1} (V_{w_1})$ [if $\beta = 90°$, than $V_{w_2} = 0$]

$F_x = \rho a V_{r_1} (V_{w_1} - V_{w_2})$ [if $\beta > 90°$ or obtuse angle]

⇒ Work-done/s → $W = F_x \times u$ ← by Jet on vane

$W = \frac{1}{g}(V_{w_1} \pm V_{w_2}) \times u$ ← Per unit weight of fluid striking per second on vane

⇒ Efficiency, $\eta = \frac{\text{output}}{\text{Input}} = \frac{\text{Work done/sec}}{\text{Initial K.E./second of jet}}$

$$\eta = \frac{W}{\frac{1}{2} m V_1^2} = \frac{W}{\frac{1}{2}(\rho a V_1) \times V_1^2}$$

Que: A jet of water having a velocity of 20 m/s strikes a curved vane, which is moving with a velocity of 10 m/s. The jet makes an angle of 20° with direction of motion of vane at inlet and leaves at angle of 130° to direction of motion of vane at outlet. Calculate:

① Vane angle ② Work done per second per unit weight of water striking the vane per second.

Given,

→ Velocity of jet, $V_1 = 20 m/s$

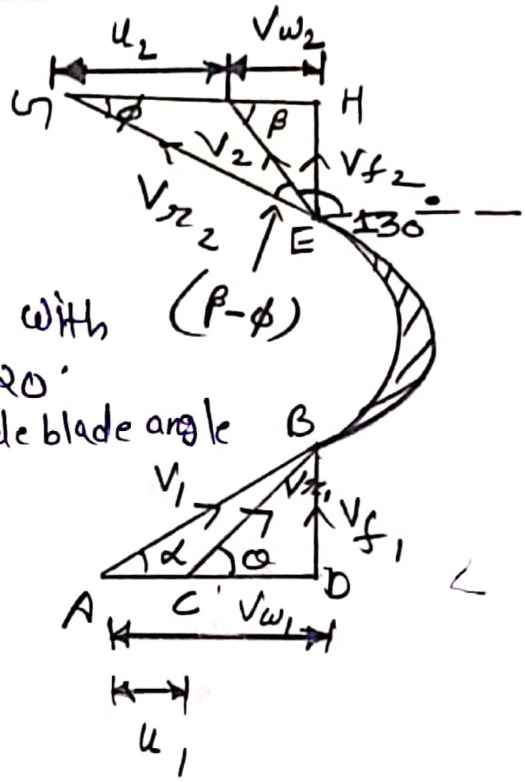
→ Velocity of Vane, $u_1 = 10 m/s$

→ Angle made by Jet at Inlet with direction of motion of Vane, $\alpha = 20°$

α = Guide blade angle

→ Angle made by leaving jet = 130°

$\beta = 180° - 130° = 50°$



→ $u_1 = u_2 = 10 m/s$,

$V_{r_1} = V_{r_2}$

① Vane angles, θ & ϕ →

$$\tan\theta = \frac{BD}{CD} = \frac{V_{f_1}}{AD - AC} = \frac{V_{f_1}}{V_{w_1} - u_1}$$

where, $V_{f_1} = V_1 \sin\alpha = 20 \times \sin 20° = 6.84 \ m/s$

$V_{w_1} = V_1 \cos\alpha = 20 \times \cos 20° = 18.8 \ m/s$

$$\tan\theta = \frac{6.84}{18.8 - 10} = 0.778 \text{ or } \boxed{\theta = 37.9°}$$

from $\Delta ABC \Rightarrow$

$$\sin\theta = \frac{V_{f_1}}{V_{r_1}} \quad \text{or} \quad V_{r_1} = \frac{V_{f_1}}{\sin\theta} = \frac{6.84}{\sin(37.9)}$$

$$V_{r_1} = 11.14$$

& $V_{r_1} = V_{r_2} = 11.14$ m/s

from Δ EFG, by Sine rule,

$$\Rightarrow \frac{V_{r_2}}{\sin(180-\beta)} = \frac{u_2}{\sin(\beta-\phi)}$$

$$\Rightarrow \frac{11.14}{\sin 50^\circ} = \frac{10}{\sin(50^\circ-\phi)} \quad (\because \beta = 50^\circ \text{ \& } \sin(180-\beta) = \sin\beta)$$

$$\Rightarrow \phi = 6.56^\circ$$

(ii) Work-done per second per unit weight of the water striking the vane per second $\Rightarrow$

$$W = \frac{1}{g}(V_{w_1} + V_{w_2}) \times u$$

$\Rightarrow V_{w_2} = GH - GF = V_{r_2}\cos\phi - u_2 = 11.14 \times \cos 6.56^\circ - 10.$

$\rightarrow V_{w_2} = 1.067$ m/s

then $W = \frac{1}{9.81}[18.794 + 1.067] \times 10 = 20.24$ Nm/N

Ans.