Question Paper-2 with effect from 2019-20 (CBCS Scheme)

USN | | | | | | | | | | |

Fourth Semester B.E. Degree Examination

APPLIED HYDRAULICS

TIME: 03 Hours

Max. Marks: 100

Note:
01. Answer any **FIVE** full questions, choosing at least **ONE** question from each **MODULE**.
02. Assume suitable data , if required
03. Neat figurescarrieswcightage.

		Module -1	*Bloom's Taxonomy Level	Marks
Q.01	a	What is Dimensional Homogeneity?Identify whether following equations are dimensionally homogeneous or not i)$V= (\sqrt{2g\ H})$ ii)$V= C\sqrt{mi}$ iii)$H_f= fLV^2/2gD$ iv) $Q= 2/3\ C_d L\sqrt{2g}\ H^{3/2}$	L2/CO1/PO1	06
	b	Explain Rayleigh's method of Dimensional Analysis and also state what is the lacuna in this method .The Resisting force R of a supersonic plane during flight can be considered as dependent on the length of the aircraft l , velocity V, air viscosityμ , air density ρ , and bulk modulus of air K. Explain functionalrelation ship between these variables and the Resisting force.	L3/ CO1/PO2	09
	c	In 1 in 40 model of a spillway, the velocity and discharge are 2.5m/s and 3 m^3/s. Determine the corresponding velocity and Discharge in the prototype.	L2/ CO1/PO2	05
		OR		
Q.02	a	How do you select repeating Variables in Bucking ham π 's Theorem? Explain Geometric, Kinematic and Geometric similarities	L2/ CO1/PO2	06
	b	Explain following model laws and also state their applications i) Reynolds model Law ii) Froude model law	L2/ CO1/PO2	08
	c	Differentiate between stable and Unstable equilibrium with respect to submerged body. A rectangular barge is 5m long , 3m wide and 1.20 m high. The depth of immersion of the barge is 0.8m in sea water. If the centre of gravity is 0.6 m above the bottom of the barge, calculate the meta-centric height.	L2/ CO1/PO2	06
		Module-2		
Q. 03	a	Explain following types of flow in open channels i) Uniform and Non Uniform ii)Sub -critical and Super critical flow iii)Laminar and Turbulent flow	L2/CO2/PO1	06
	b	A trapezoidal channel has side slopes of 1 horizontal to 2 vertical and the side slope of the bed is 1in 2000.The area of the cross section is 40m^2. Find the dimensions of the section if it is most economical. Also find the discharge of this most economical section if C= 55.	L3/ CO2/PO2	06
	c	Find the discharge through a circular pipe of diameter 3.0m, if the depth of water in the pipe is 1.0 m and the pipe is laid at a slope of 1in 1000. Take C= 65	L3/ CO2/PO2	08
		OR		
Q.04	a	Derive Chezy's formula in open channel and also state the relation between Chezy's and manning 's equation	L2/ CO2/PO2	06
	b	Show that for the most economical Trapezoidal section i) Half the top width is equal to the one of the sloping side ii)Hydraulic mean depth is equal to half the depth of flow.	L3/ CO2/PO2	08
	c	The rate of flow of water through a circular channel of diameter 0.6m is 150 lit/sec . Find the slope of the bed of the channel for maximum velocity . Take C=60.	L3/ CO2/PO3	06

		Module-3		
Q. 05	a	What is Specific energy curve? Draw the specific energy curve, and hence derive expressions for critical depth and critical velocity	L2/ CO2/PO2	09
	b	A sluice gate discharges water in to a horizontal rectangular channel with a velocity of 10m/s and depth of flow of 1m. determine the depth of flow after the jump and consequent loss in total head.	L3/ CO2/PO2	06
	c	Find the slope of the free water surface in a rectangular channel of width 20m,having depth of flow 5m.The discharge through the channel is 50 m^3/s.The bed of the bed channel is having aslope of 1in 4500.Take the value of Chezy's constant C=60.	L3/ CO2/PO3	05
		OR		
Q. 06	a	The specific energy for a 5m wide rectangular channel is to be 4Nm/N. If the rate of flow of water through the channel is 20m^3/sec, determine the alternate depths of flow.	L3/CO3/PO2	06
	b	Derive the expression for depth of Hydraulic jump in terms of Upstream Froude Number.	L3/ CO3/PO1	08
	c	Draw the different water profiles for the following i) Mild ii) Critical and iii) Horizontal	L3/ CO3/PO3	06
		Module-4		
Q. 07	a	A jet of water of diameter 75mm moving with velocity of 30m/s , strikes a curved fixed plate tangentially at one end at an angle of 30 to the horizontal. The jet leaves the plate at an angle of 20^0 to the horizontal. Find the force exerted by the jet on the plate in the horizontal and vertical direction.	L2/ CO4/PO2	06
	b	Show that the efficiency of a free jet striking normally on a series of flat plates mounted on the periphery of a wheel can never exceed 50%.	L3/ CO4/PO2	06
	c	Draw the layout of a Hydro-electric power plant . Explain i) Hydraulic efficiency ii)Overall Efficiency	L2/ CO5/PO1	08
		OR		
Q. 08	a	A jet of water of diameter 7.5cm strikes a curved plate at its center with a velocity of 20m/s . The curved plate is moving with a velocity of 8m/s in the direction of the jet. The jet is deflected through an angle of 165^0. assuming the loss of energy due to impact is zero, calculate (1)Force exerted on the plate in the direction of jet, ii) Power of the jet, and (iii) Efficiency of the Jet	L4/ CO4/PO3	08
	b	How do you classify the turbines? With a sketch explain the parts of a Pelton turbine.	L2/CO5/PO1	06
	c	A Pelton wheel is to be designed for the specifications shown below-Shaft power= 11,772 KW: Head =380 meters: Speed= 750 r.p.m; Overall efficiency = 86%; Jet diameter is not to exceed one-sixth of the wheel diameter. Determine : (1)The wheel diameter 9 (ii) The number of jets required , and (iii)Diameter of the jet. Assume Co-efficient of velocity=0.985, Speed ratio = 0.45	L4/CO5/PO3	06
		Module-5		
Q. 09	a	Explain with a neat sketch components of Kaplan turbine	L2/CO5/PO1	06
	b	A water turbine has a velocity of 6m/s at the entrance to the draft tube anda velocity of 1.2m/s at the exit. For friction losses of 0.1 m an d a tail water 5m below the entrance to the draft tube, find the pressure head at the entrance.	L3/CO5/PO2	06
	c	A centrifugal pump is to discharge 0.118m^3/s at a speed of 1450 rpm against a head of 25m.The impeller diameter is 250mm , its width at outlet is 50mm and manometric efficiency is 75%. Compute the vane angle at the outer periphery of the impeller.	L3/CO5/PO2	08
		OR		

10	a	Explain with neat sketches working principle of Multistage Centrifugal Pumps for i)High Heads ii)For High Discharge	L2/CO5/PO1
	b	The diameters of an impeller of a centrifugal pump at inlet and outlet are 30cm and 60cm respectively. Determine the minimum starting speed of the pump if it works against a head of 30m.	L2/CO5/PO2
	c	A reaction turbine works at 450 rpm under a head of 120 meters . Its diameter at inlet is 120cm and the flow are is 0.4 m^2.The angles made by absolute and relative velocities at inlet are 20^0 and 60^0 respectively with the tangential velocity. Determine :i) The volume flow rate, (b)The power developed , and (c) Hydraulic efficiency.	L4/CO5/PO3

*Bloom's Taxonomy Level: Indicate as L1, L2, L3, L4, etc. It is also desirable to indicate the COs and POs t
attained by every bit of questions.

MODEL QUESTION PAPER. SOLUTIONS.

Fourth Semester B.E Applied Hydraulic (18CV43)

Q1. a. DIMENSIONAL HOMOGENEITY :-

Dimensional homogeneity means the dimensions of each terms in an equation on both sides are equal. Thus if the dimensions of each term on both sides of an equation are the same the equation is known as dimensionally homogeneous equation. The power of fundamental homogeneous dimensions (i.e L, M, T) on both sides of the equation will be identical for a dimensionally homogeneous equation. Such equations are independent of the system of units.

i) $V = \sqrt{2gH}$

Dimension of L.H.S $= V = \frac{L}{T} = LT^{-1}$

Dimension of R.H.S $= \sqrt{2gH} = \sqrt{\frac{L}{T^2} \times L} = \sqrt{\frac{L^2}{T^2}} = \frac{L}{T} = LT^{-1}$

$\therefore$ Equation $V = \sqrt{2gH}$ is dimensionally homogeneous.

ii) $V = C\sqrt{mi}$

Dimension of LHS $= V = \frac{L}{T} = LT^{-1}$

Dimension of RHS $= C\sqrt{mi} = \sqrt{L} = L^{\frac{1}{2}}$

$\therefore$ Equation $V = C\sqrt{mi}$ is non dimensionally non Homogeneous.

iii) $H_f = fLV^2/2gD$.

Dimension of LHS $= H_f = L$

Dimension of RHS $= fLV^2/2gD = \frac{L.(LT^{-1})^2}{LT^{-2}.L} = L$.

$\therefore$ Equation $H_f = fLV^2/2gD$ is Dimensionally Homogeneous.

iv). $Q = \frac{2}{3} cd\, L\sqrt{2g}\, H^{3/2}$

$Q = L^3T^{-1} = L\ \sqrt{LT^{-2}} \cdot (L)^{3/2}$

$\cancel{L}T^{-1} = \cancel{L}T^{-2}$ Its not a dimensionally Homogeneous Eq^n.

Q1.b. Rayleigh's Method of dimensional analysis :-

This method is used for determining the expression for a variable which depends upon maximum three or four variables only. If the number of independent variables becomes more than four, then it is very difficult to find the expression for the dependent variable.

Let X is a variable, which depends on X_1, X_2 & X_3 Variable. Then according to Rayleigh's method, X is function of X_1, X_2 & X_3 and mathematically it is written as

$X = f[X_1, X_2, X_3]$.

This can also be written as $X = K X_1^a \cdot X_2^b \cdot X_3^c$

where K is constant and a, b & c are arbitrary powers

The resisting force R depends upon

i) density, ρ (ii) Velocity V, (iii) viscosity μ

iv) length l (v) Bulk modulus, K.

$$R = A l^a \cdot V^b \cdot \mu^c \cdot \rho^d \cdot K^e \text{ ——— (i)}$$

where A is the non-dimensional constant.

Substituting the dimensions on both sides in the Eq^n (i)

$$MLT^{-2} = AL^a \cdot (LT^{-1})^b \cdot (ML^{-1}T^{-1})^c \cdot (ML^{-3})^d \cdot (ML^{-1}T^{-2})^e$$

Equating the powers of M, L, T on both sides.

Power of M, $1 = c + d + e$

Power of L, $1 = a + b - c - 3d - e$

Power of T, $-2 = -b - c - 2e$

∴ Express the values of a, b, and d in terms of c & e

Solving $d = 1 - c - e$

$b = 2 - c - 2e$

$a = 1 - b + c + 3d + e = 2 - c$.

Substituting these values in (i), we get

$$R = A\, l^{2-c} \cdot V^{2-c-2e} \cdot \mu^{c} \cdot \rho^{1-c-e} \cdot K^{e}$$

$$= A\, l^{2} \cdot V^{2} \cdot \rho\, (l^{-c}\, V^{-c}\, \mu^{c}\, \rho^{-c}) \cdot (V^{-2e}\, \rho^{-e}\, K^{e})$$

$$= A\, l^{2} V^{2} \rho \left(\frac{\mu}{\rho V L}\right)^{c} \cdot \left(\frac{K}{\rho V^{2}}\right)^{e}$$

$$\therefore \boxed{R = A \rho l^{2} V^{2} \phi\left[\left(\frac{\mu}{\rho V L}\right) \cdot \left(\frac{K}{\rho V^{2}}\right)\right]}$$

Q1.c Given :

Scale ratio of length, $L_r = 40$

Velocity in model, $V_m = 2.5$ m/s

Discharge in model, $Q_m = 3\ m^3/s$

Let V_p & Q_p are the velocity and discharge in prototype.

$\therefore$ Velocity ratio, $\frac{V_p}{V_m} = \sqrt{L_r} = \sqrt{40}$

$\therefore V_p = V_m \times \sqrt{40} = 2.5 \times \sqrt{40} = 15.81$ m/s.

Using discharge ratio

$$\frac{Q_p}{Q_m} = L_r^{2.5} = (40)^{2.5}$$

$$\therefore Q_p = Q_m \times 40^{2.5} = \cancel{2.5}\ 3 \times 40^{2.5} = 30357.86\ m^3/s$$

Q2.a Method of Selecting Repeating Variables :-

The number of repeating variables are equal to the number of fundamental dimensions of the problem. The choice of repeating variables is governed by the following considerations:-

1a. As far as possible, the dependent variable should not be selected as repeating variable.

2. The repeating variables should be choosen in such a way that one variable contains geometric property, other variable contains flow property and third variable contains fluid property.

3. The repeating variables selected should not form a dimensionless group.

4. The repeating variables together must have the same number of fundamental dimensions.

5. No two repeating variables should have the same dimensio

Geometric Similarity :- The geometric similarity is said to exist between the model and the prototype. The ratio of all corresponding linear dimension is the model & prototype are equal.

$$\frac{L_p}{L_m} = \frac{b_p}{b_m} = \frac{D_p}{D_m} = L_r$$

where L_r is called the scale ratio.

Kinematic Similarity :- Kinematic similarity means the similarity of motion between model and prototype. Thus kinematic similarity is said to exist between the model and the prototype if the ratios of the velocity & acceleration at the corresponding points in the model and at the corresponding points in the prototype are same.

$$\frac{V_{p_1}}{V_{m_1}} = \frac{V_{p_2}}{V_{m_2}} = V_r \quad \text{where } V_r \text{ is the velocity ratio.}$$

$$\frac{a_{p_1}}{a_{m_1}} = \frac{a_{p_2}}{a_{m_2}} = a_r \quad \text{where } a_r \text{ is the accel}^n \text{ ratio.}$$

Q2 b. Reynold's Model Law :-

Reynold number is the ratio of inertia force and viscous force, and hence fluid flow problems where viscous forces alone are predominent, the models are designed for dynamic similarity on Reynolds law, which states that the Reynold number for the model must be equal to the Reynold number for the prototype.

Let V_m = Velocity of fluid in model

ρ_m = Density of fluid " "

L_m = Length " "

μ_m = Viscosity in model,

& V_p, ρ_p, L_p & μ_p are the corresponding values of velocity density, linear dimension & viscosity of fluid in prototype according to Reynold's model law.

Then according to Reynold's model law,

$$[R_e]_m = [R_e]_p \quad \text{or} \quad \frac{\rho_m V_m L_m}{\mu_m} = \frac{\rho_p V_p L_p}{\mu_p}$$

$$\text{or} \quad \frac{\rho_p . V_p . L_p}{\rho_m . V_m . L_m} \times \frac{1}{\mu_p / \mu_m} = 1 \quad \text{or} \quad \frac{\rho_r . V_r . L_r}{\mu_r} = 1$$

Froude Model Law :-

Froude model law is the law in which the models are based on Froude number which means for dynamic similarity between the model and prototype, the Froude number for both of them should be equal.

Froude model law is applied in fluid flow problem like

1. Free Surface flows such as flow over Spillways, weirs, sluices, Channels etc.

2. Flow of jet from an orifice or nozzle
3. where waves are likely to be formed on surface
4. where fluids of different densities flow over one another

Let V_m & V_p = Velocity of fluid in model & prototype
L_m & L_p = Length of model & prototype
g_m & g_p = Accl^n due to gravity at a place where model is tested.

then according to froude model law

$$(F_e)_{model} = (F_e)_{prototype} \quad \text{or} \quad \frac{V_m}{\sqrt{g_m L_m}} = \frac{V_p}{\sqrt{g_p L_p}}$$

If the tests on the model are performed on the same place where prototype is to operate, then $g_m = g_p$

$$\frac{V_m}{\sqrt{L_m}} = \frac{V_p}{\sqrt{L_p}}$$

or
$$\frac{V_m}{V_p} \times \frac{1}{\sqrt{\frac{L_m}{L_p}}} = 1 \qquad \therefore \frac{V_p}{V_m} = \sqrt{\frac{L_p}{L_m}} = \sqrt{L_r}$$

where L_r = Scale ratio for length

$$\frac{V_p}{V_m} = V_r = \sqrt{L_r} = \text{Scale ratio for Velocity.}$$

Application of Reynold Model Law:-

i) Pipe flow

ii) Resistance experienced by sub-marines, airplanes, fully immersed bodies etc.

Q2.c. Stable Equilibrium :- When $W = F_B$ and point B is above G, the body is said to be in stable equilibrium

Unstable Equilibrium :- If $W = F_B$, but the Centre of buoyancy (B) is below centre of gravity (G) the body is in unstable equilibrium.

Given:-

Dimension of barge = $5 \times 3 \times 1.2$

Let Depth of immersion = 0.8m.

Sp. gravity = 0.6.

weight of barge = weight of water displaced.

$$600 \times 9.81 \times 5 \times 3 \times 1.2 = 1000 \times 9.81 \times 5 \times 3 \times \cancel{0.8}\, h$$

$$h = \frac{600 \times 9.81 \times 5 \times 3 \times 1.2}{1000 \times 9.81 \times 5 \times 3 \times \cancel{4}} = 0.58 \text{ m}.$$

Distance of centre of Buoyancy.

$$AB = \frac{h}{2} = \frac{0.58}{2} = 0.29 \text{ m}.$$

$$\& \quad AG = \frac{1.2}{2} = 0.6 \text{ m}.$$

$$\therefore BG = AG - AB = 0.6 - 0.29 = 0.31.$$

$$I = \frac{1}{12} \times \cancel{5} \times 3^3 = 11.25 \text{ m}^4.$$

$\forall$ = Volume of wood in water

$$= 5 \times 3 \times h = 5 \times 3 \times 0.58 = 8.7 \text{ m}^3$$

$$\therefore GM = 11.25 \times \frac{1}{8.7} - 0.31 = 0.98 \text{ m}.$$

Q3.a.

i) Uniform & Non uniform flow

If for a given length of the channel, the velocity of flow, depth of flow, slope of the channel & cross-section remain constant, the flow is said to be "uniform flow"

On the other hand, if for a given length of the channel the velocity of flow, depth of flow etc, do not remain constant, the flow is said to be "non-uniform flow"

$$\frac{\partial y}{\partial s} = 0, \quad \frac{\partial v}{\partial s} = 0 \quad \text{for uniform flow}$$

&

$$\frac{\partial y}{\partial s} \neq 0, \quad \frac{\partial v}{\partial s} \neq 0 \quad \text{for non-uniform flow.}$$

ii) Sub-critical & Super-critical flow :-

The flow in open channel is said to be sub-critical if the froude number (F_e) is less than 1.0

The flow in which $F_e > 1.0$ is called super critical flow

iii). Laminar & Turbulent flow :-

The flow in open channel is said to be laminar if the Reynold number (R_e) is less than 500 or 600.

If the Reynold number is more than 2000, the flow is said to be turbulent flow

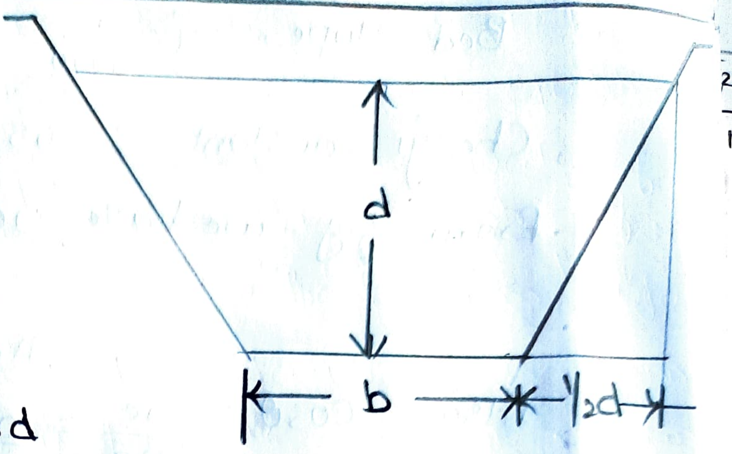
Q3.b. Given

Side slope $n = \frac{\text{Horizontal}}{\text{Vertical}} = \frac{1}{2}$

Bed slope $i = \frac{1}{2000}$

Area of section $A = 40\,m^2$

Chezy's Constant $C = 55$



$$\frac{b + 2nd}{2} = d\sqrt{n^2+1} \quad \text{(or)}$$

$$\frac{b + 2 \times 1/2 \times d}{2} = d\sqrt{(1/2)^2 + 1}$$

(or) $\frac{b+d}{2} = d\sqrt{1/4 + 1} = 1.118d$

(or) $b = 2 \times 1.118d - d = 1.236d$ —————— (i)

But area of trapezoidal section $A = \frac{b + (b + 2nd)}{2} \times d = (b+nd)d$

$= (1.236d + 1/2 d)d$

$= 1.736d^2$

But $A = 40\, m^2$

$\therefore\ 40 = 1.736d^2$

$\therefore\ d = \sqrt{\frac{40}{1.736}} = 4.80m$

Substituting the value of d in Eq^n (i), we get

$b = 1.236 \times 4.80 = 5.933m$

Discharge for most economical section.

$m = \frac{d}{2} = \frac{4.80}{2} = 2.40\, m$

$\therefore$ Discharge $Q = AC\sqrt{mi} = 40 \times 55 \times \sqrt{2.40 \times \frac{1}{2000}}$

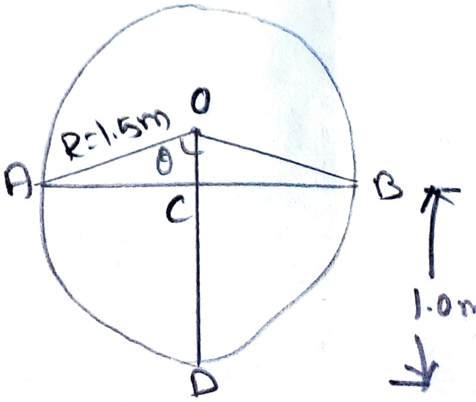
$Q = 76.21\, m^3/s$.

Q3.c Given:-

Dia. of pipe, $D = 3.0\, m$

$\therefore$ Radius $R = \frac{D}{2} = 1.5m$

Depth of water in pipe $= d = 1.0m$



Bed slope, $i = \frac{1}{1000}$

Chezy's constant $C = 65$

From fig we have $OC = OD - CD = R - 1.0$

$= 1.5 - 1.0 = 0.5m$

$AO = R = 1.5m$

Also $\cos\theta = \frac{OC}{AO} = \frac{0.5}{1.5} = \frac{1}{3}$

$\therefore \theta = 70.53^\circ = 70.53 \times \frac{\pi}{180} = 1.23$ radians.

wetted perimeter is given as

$P = 2R\theta = 2 \times 1.5 \times 1.23$

$= 3.69m$

wetted area is given as

$$A = R^2\left(\theta - \frac{\sin 2\theta}{2}\right) = 1.5^2\left(1.23 - \frac{\sin(2 \times 70.53^\circ)}{2}\right)$$

$$= 2.25\left[1.23 - \frac{\sin(141.08^\circ)}{2}\right] = 2.25\left[1.23 - \frac{\sin(180 - 141.08)}{2}\right]$$

$$= 2.25\left[1.23 - \frac{\sin 38.94^\circ}{2}\right] = 2.06\ m^2$$

$\therefore$ Hydraulic mean depth, $m = \frac{A}{P} = \frac{2.06}{3.69} = 0.5582$

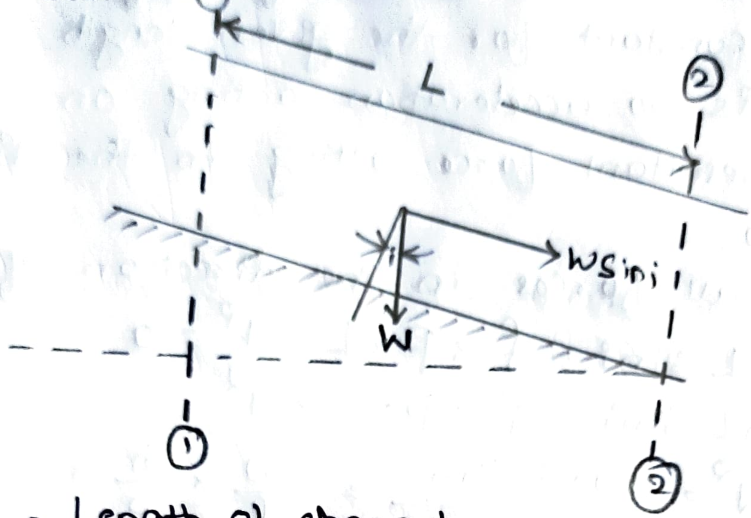
The discharge is given by. $Q = AC\sqrt{mi} =$

$$= 2.06 \times 65 \times \sqrt{0.5582 \times \frac{1}{2000}}$$

$Q = 3.16\ m^3/s$

Q4.a. Consider uniform flow of water in a channel. As the flow is uniform, it means the velocity, depth of flow & area of flow will be considered for a given length of the channel.

Consider sections 1-1 & 2-2.



Let
L = Length of channel
A = Area of flow of water
i = slope of the bed
V = Mean velocity of flow of water
P = Wetted perimeter of the cross-section
f = frictional resistance per unit velocity per unit area

The weight of water between sections 1-1 & 2-2

W = Specific weight of water × Volume of water

$= w \times A \times L$

Component of W along direction of flow $= W \times \sin i = wAL\sin i$

Frictional resistance against motion of water $= f \times$ Surface area $\times (\text{velocity})^n$

The value of n is found experimentally equal to 2 &

Surface area $= P \times L$

∴ Frictional resistance against motion $= f \times P \times L \times V^2$

The forces acting on the water between sections 1-1 & 2-2 are

1. Component of weight of water along the direction of flow,
2. Friction resistance against flow of water,
3. Pressure force at section 1-1,
4. Pressure force at section 2-2.

As the depths of water at the sections 1-1 and 2-2 are the same, the pressure forces on these two sections are same and acting in the opposite direction. Hence they cancel each other. In case of uniform flow, the velocity of flow is constant for the given length of the channel. Hence there is no acceleration acting on the water. Hence the resultant force acting in the direction of flow must be zero.

∴ Resolving all forces in the direction of flow, we get

$$w A L \sin i - f \times P \times L \times V^2 = 0$$

$$w A L \sin i = f \times P \times L \times V^2$$

$$V^2 = \frac{w A L \sin i}{f \times P \times L} = \frac{w}{f} \times \frac{A}{P} \times \sin i$$

or

$$V = \sqrt{\frac{w}{f}} \times \sqrt{\frac{A}{P} \times \sin i}$$

But

$$\frac{A}{P} = m$$

= hydraulic mean depth or hydraulic radius

$$\sqrt{\frac{w}{f}} = C = \text{Chezy's constant}$$

Substituting the values of $\frac{A}{P}$ and $\sqrt{\frac{w}{f}}$ in eq^n $V = C\sqrt{m \sin i}$

for small values of i, $\sin i \simeq \tan i \simeq i$ ∴ $V = C\sqrt{mi}$

∴ Discharge Q = Area × Velocity = $A \times V$

$$Q = AC\sqrt{mi}$$

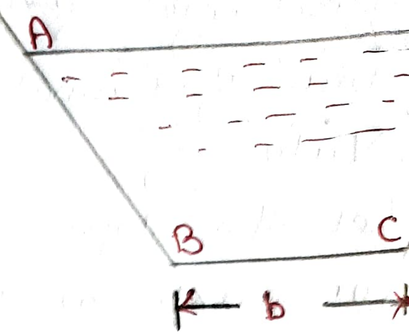
Q4.b. The trapezoidal section of a channel will be most economical, when its wetted perimeter is minimum. Consider a trapezoidal section of channel as shown in fig.

Let b = width of channel at bottom

d = depth of flow

θ = angle made by the side with horizontal

ii) The Side slope is given as 1 Vertical to n horizontal



$\therefore$ Area of flow $A = \dfrac{(BC + AD)}{2} \times d$

$= \dfrac{b + (b + 2nd)}{2} \times d$

$\therefore \dfrac{A}{d} = b + nd$

$\therefore b = \dfrac{A}{d} - nd$ ——————— (ii)

Now wetted perimeter $P = AB + BC + CD = BC + 2CD$

$= b + 2\sqrt{CE^2 + DE^2} = b + 2\sqrt{n^2 d^2 + d^2}$

$= b + 2d\sqrt{n^2+1}$

Substituting the value of b from eqn (ii) we get

$P = \dfrac{A}{d} - nd + 2d\sqrt{n^2+1}$ ——————— (iii)

For most economical Section, P should be minimum

$\therefore$ Differentiating eqn (iii) w.r.t d & Equating it to zero we get

$\dfrac{d}{d(d)}\left[\dfrac{A}{d} - nd + 2d\sqrt{n^2+1}\right] = 0$ or $-\dfrac{A}{d^2} - n + 2\sqrt{n^2+1}$

or $\dfrac{A}{d^2} + n = 2\sqrt{n^2+1}$

Substituting the value of A from eq (i) in the above

$\dfrac{(b+nd)d}{d^2} + n = 2\sqrt{n^2+1}$ or $\dfrac{b+nd}{d} + n = 2\sqrt{n^2+1}$

$\dfrac{b+2nd}{2}$ = Half of top width

and $d\sqrt{n^2+1}$ = CD = one of the sloping side.

iii) Hydraulic mean depth

Hydraulic mean depth, $m = \dfrac{A}{P}$

Value of A from (i), $A = (b+nd) \times d$

Value of P from (ii) $P = b + 2d\sqrt{n^2+1} = b + (b + 2nd)$

$= 2b + 2nd = 2(b+nd)$

$\therefore$ Hydraulic mean depth, $m = \dfrac{A}{P} = \dfrac{(b+nd)d}{2(b+nd)} = \dfrac{d}{2}$

Q4.c. Given:

Discharge $Q = 150$ lit/s $= 0.15\ m^3/s$

Dia. of channel $D = 0.6\,m$

Value of $C = 60$

Let the slope of the bed of channel for maximum Velocity $= i$

For maximum velocity through a circular channel, depth of flow is given by eq^n

$$d = 0.81 \times D = 0.81 \times 0.6 = 0.486\,m$$

and $\theta = 128^\circ 45'$ or $128.75 \times \frac{\pi}{180} = 2.247$ radians

hydraulic mean depth for maximum velocity.

$$m = 0.3 \times D = 0.3 \times 0.6 = 0.18\,m$$

wetted perimeter for circular pipe is given by

$$P = 2R\theta = D \times \theta = 0.6 \times 2.247 = 1.3482\,m$$

But $m = \frac{A}{P} = 0.18\,m$

$\therefore$ Area $A = 0.18 \times P = 0.18 \times 1.3482 = 0.2426\,m^2$

For discharge, using the relation

$$Q = AC\sqrt{mi} \quad \text{or} \quad 0.15 = 0.2426 \times 60 \times \sqrt{0.18 \times i}$$

$$= 6.175\sqrt{i}$$

$$\therefore i = \left(\frac{0.15}{6.175}\right)^2 = \frac{1}{1694.7}$$

$\therefore$ Bed slope is 1 in 1694.7.

Q5.a. Specific Energy curve :-

It is defined as the curve which shows the variation of specific energy with depth of flow. It is obtained as

$$E = h + \frac{V^2}{2g} = E_p + E_k.$$

where E_p = Potential energy of flow $= h$

E_k = Kinetic energy of flow $= \frac{V^2}{2g}$

$$\frac{d}{dh}\left[h + \frac{q^2}{2gh^2}\right] = 0 \quad \text{or} \quad 1 + \frac{q^2}{2g}\left(\frac{-2}{h^3}\right) = 0$$

or $$1 - \frac{q^2}{gh^3} = 0 \quad \text{or} \quad 1 = \frac{q^2}{gh^3} \quad \text{or} \quad h^3 = \frac{q^2}{g}$$

$$\therefore \quad h = \left(\frac{q^2}{g}\right)^{1/3}$$

But when Sp. Energy is minimum.

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

Critical Velocity (V_c) :-

The Velocity of flow at the critical depth is known as Critical Velocity. It is denoted by V_c

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

Taking cube to both side we get $h_c^3 = \frac{q^2}{g}$ or $gh_c^3 = q^2$

But q = Discharge per unit width $= \frac{Q}{b}$

$$= \frac{\text{Area} \times V}{b} = \frac{b \times h \times V}{b} = h \times V = h_c \times V_c$$

Substituting the value of q in (i)

$$\therefore \quad gh_c^3 = (h_c \times V_c)^2$$

or $$gh_c^3 = h_c^2 \times V_c^2 \quad \text{or} \quad gh_c = V_c^2$$

or $$V_c = \sqrt{g \times h_c}$$

Q5.b. Given :-

Velocity of flow before hydraulic jump, $V_1 = 10$ m/s.

Depth of flow before hydraulic jump, $d_1 = 1$m

Discharge per unit width $q = V_1 \times d_1 = 10 \times 1 = 10\ m^2/s$.

The depth of flow after jump is given by

$$d_2 = -\frac{d_1}{2} + \sqrt{\frac{d_1^2}{4} + \frac{2q^2}{gd_1}} = -\frac{1.0}{2} + \sqrt{\frac{1^2}{4} + \frac{2 \times 10^2}{9.81 \times 1}}$$

Consider a rectangular channel in which a steady but non-uniform flow is taking place.

Let Q = discharge through the channel,
b = width of the channel,
h = depth of flow, and
q = discharge per unit width

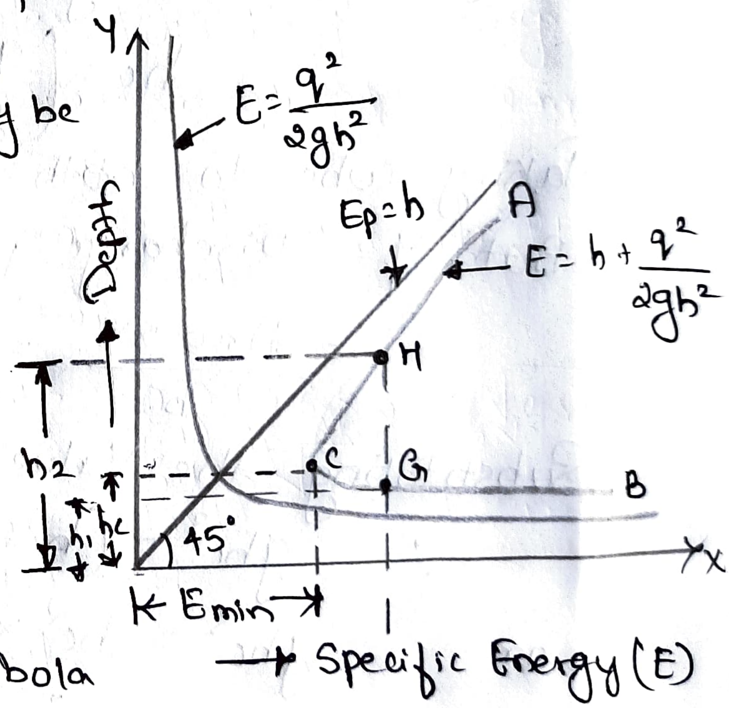
Then $q = \frac{Q}{\text{width}} = \frac{Q}{b}$ = constant

Velocity of flow, $V = \frac{\text{Discharge}}{\text{Area}} = \frac{Q}{b \times h} = \frac{q}{h}$

Substituting the values of V in Eq^n we get

$$E = h + \frac{q^2}{2gh^2} = E_p + E_K$$

The specific energy curve may be obtained by first drawing a curve for potential energy which will be a straight line passing through the origin, making an angle of 45° with the x-axis as show in fig. Then drawing another curve for K.E which will be a parabola



By combining these two curves, we can obtain the specific energy curve. In curve ACB denotes the specific energy curve

Critical Depth (h_c) :-

Critical depth is defined as that depth of flow of water at which the specific energy is minimum.

$\frac{dE}{dh} = 0$. where $E = h + \frac{q^2}{2gh^2}$

$= -0.50 + \sqrt{0.25 + 20.387} = 4.043\ m$

Loss in total head is given by

$$h_L = \frac{(d_2 - d_1)^3}{4 d_1 d_2} = \frac{(4.043 - 1.0)^3}{4 \times 1.0 \times 4.043} = 1.742\ m$$

Q5.c Given :-

Width of channel $b = 20\ m$

Depth of flow $h = 5\ m$

Discharge $Q = 50\ m^3/s$

Bed Slope $i_b = \frac{1}{4500} = 2.22 \times 10^{-4}$

Chezy's constant $C = 60$

$Q = V \times Area = C\sqrt{mi} \times A = AC\sqrt{mi}$

where A = Area of flow $= b \times h = 20 \times 5 = 100\ m^2$

m = hydraulic mean depth $= \frac{A}{P} = \frac{100}{b + 2h} = \frac{100}{20 + 2 \times 5} = \frac{100}{30} = \frac{10}{3}\ m$

$i = i_e$ = slope of Energy line

The slope of the Energy line :

$$50 = 100 \times 60 \times \sqrt{\frac{10}{3} \times i_e} = 10954.45\sqrt{i_e}$$

or $$i_e = \left(\frac{50}{10954.45}\right)^2 = 0.0000208$$

$$\frac{dh}{dx} = \frac{i_b - i_e}{1 - V^2/gh} = \frac{0.00025 - 0.0000208}{1 - \frac{V^2}{9.81 \times 5.0}}$$

$$V = \frac{Q}{Area} = \frac{50}{b \times h} = \frac{50}{20 \times 5} = 0.5$$

$$\frac{dh}{dh} = \frac{0.00025 - 0.0000208}{1 - \frac{0.5 \times 0.5}{9.81 \times 5.0}} = \frac{0.0002292}{0.9949} = 0.00023.$$

Q6.a. Given :-

width of channel $b = 5m$

Specific Energy $E = 4\ Nm/N = 4m$

Discharge, $Q = 20\ m^3/s$

$$E = h + \frac{V^2}{2g}\ ,\ \text{where } V = \frac{\text{Discharge}}{\text{Area}} = \frac{Q}{b \times h} = \frac{4}{h}$$

$$\therefore \text{Sp. Energy } E = h + \frac{V^2}{2g} = h + \left(\frac{4}{h}\right)^2 \times \frac{1}{2g} = h + \frac{8}{g \times h^2}$$

But $E = 4.0$.

Equating the two values $4 = h + \frac{8}{9.81 \times h^2} = h + \frac{0.8155}{h^2}$

$4h^2 = h^3 + 0.8155$ or $h^3 - 4h^3 + 0.8155 = 0$

This is a cubic Eq^n. Solving by trial & error we get

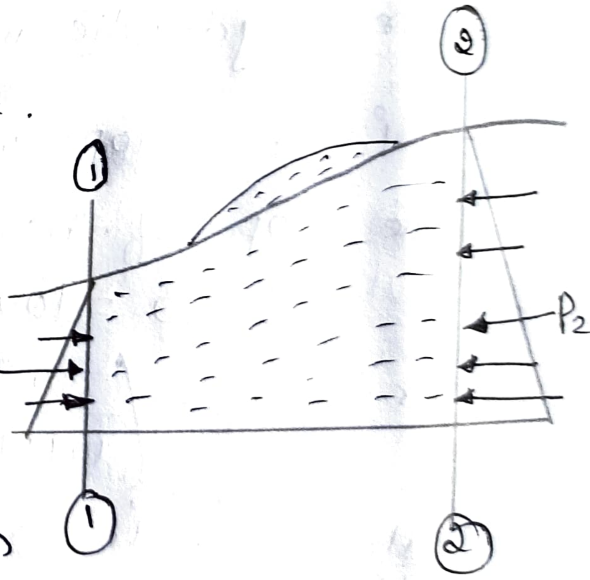
$h = 3.93m$ and $0.48m$.

Q6.b. Let d_1, d_2 = Depth of flow at 1-1 & 2-2.

V_1 & V_2 = Velocity of flow at 1-1 & 2-2

$\bar{Z}_1, \bar{Z}_2$ = Depth of centroid of area at Sectionat 1-1 & 2-2

A_1 & A_2 = Area of c/s at Sec^n 1-1 & 2 2



Let q = discharge per unit width

$= V_1 d_1 = V_2 d_2$

Now pr force P_1 on Section 1-1

$$= \rho g A_1 \bar{Z}_1 = \rho g \times d_1 \times 1 \times \frac{d_1}{2} = \frac{\rho g d_1^2}{2}.$$

Similarly pr force on Section 2-2

$$P_2 = \rho g A_2 \bar{Z}_2$$

$$= \rho g \times d_2 \times 1 \times \frac{d_2}{2} = \frac{\rho g d_2^2}{2}$$

The two roots of the Eq^n are $-\frac{d_1}{2} - \sqrt{\frac{d_1^2}{4} + \frac{2q^2}{gd_1}}$ & $-\frac{d_1}{2} + \sqrt{\frac{d_1^2}{4} + \frac{2q^2}{gd_1}}$

First root is not possible as it gives -ve depth. Hence

$$d_2 = -\frac{d_1}{2} + \sqrt{\frac{d_1^2}{4} + \frac{2q^2}{gd_1}}$$

$$= -\frac{d_1}{2} + \sqrt{\frac{d_1^2}{4} + \frac{2\times(V_1 d_1)^2}{gd_1}} \qquad (\because q_1 = V_1 d_1)$$

$$= -\frac{d_1}{2} + \sqrt{\frac{d_1^2}{4} + \frac{2V_1^2 d_1}{g}}$$

$\therefore$ Depth of Hydraulic jump $= (d_2 - d_1)$

$$(Fe) = \frac{V_1}{\sqrt{gd_1}}$$

Now the depth of flow after the hydraulic jump is d_2 & it given by equation.

$$d_2 = -\frac{d_1}{2} + \sqrt{\frac{d_1^2}{4} + \frac{2V_1^2 d_1}{g}} = -\frac{d_1}{2} + \sqrt{\frac{d_1^2}{4}\left(1 + \frac{8V_1^2}{gd_1}\right)}$$

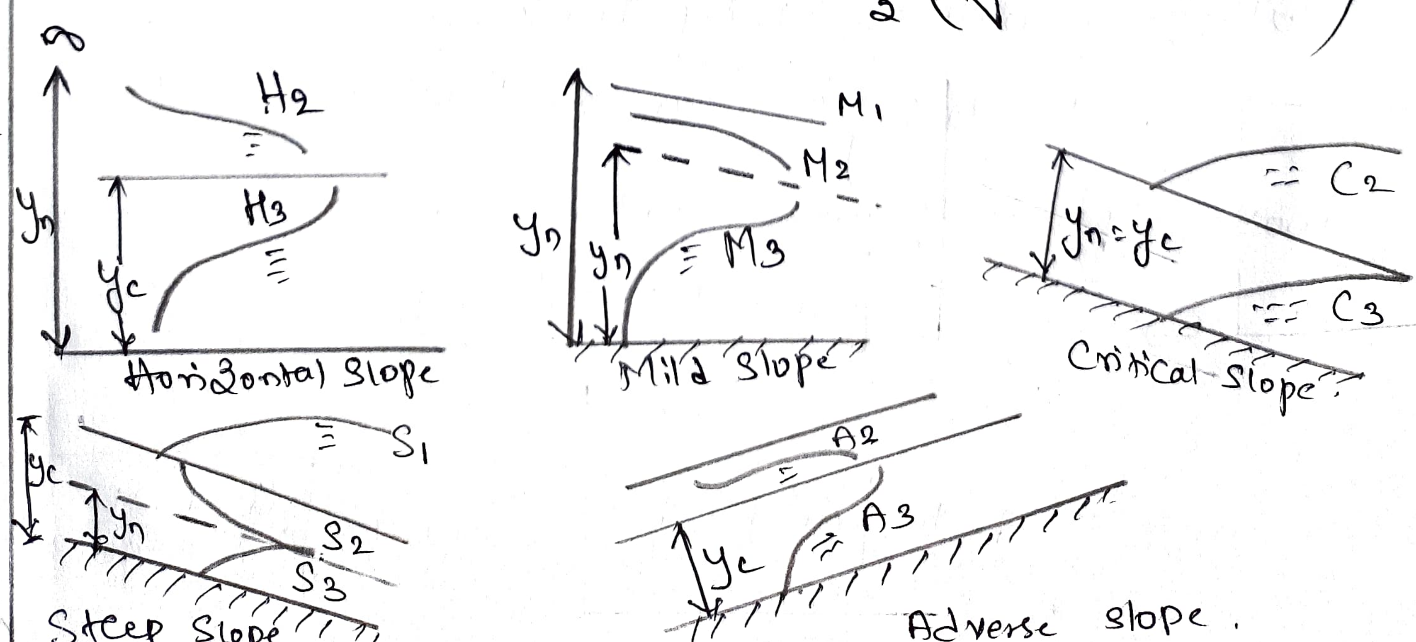
$$= -\frac{d_1}{2} + \frac{d_1}{2}\sqrt{1 + \frac{8V_1^2}{gd_1}}$$

But from Eq^n $(Fe)_1 = \frac{V_1}{\sqrt{gd_1}}$ or $(Fe)_1^2 = \frac{V_1^2}{gd_1}$

Substituting this value $d_2 = -\frac{d_1}{2} + \frac{d_1}{2}\sqrt{1+8(Fe)_1^2}$

$$= \frac{d_1}{2}\left(\sqrt{1+8(Fe)_1^2} - 1\right)$$

Q6.c



Net force acting on the mass of water b/w sec^n 1-1 & 2-2

$= P_2 - P_1$ $\quad$ $\because$ P_2 is greater than P_1 & d_2 is greater than d_1

$$= \frac{\rho g d_2^2}{2} - \frac{\rho g d_1^2}{2} = \frac{\rho g}{2}[d_2^2 - d_1^2]$$

$\therefore$ Rate of change of momentum in the direc^n of jet

$= \rho \times q \times 1 = \rho q \; m^3/s.$

Change of velocity $= (V_1 - V_2)$

$\therefore$ Rate of change of momentum $= \rho q (V_1 - V_2)$

or $\frac{\rho g}{2}(d_2^2 - d_1^2) = \rho q (V_1 - V_2)$

But from eq^n (i) $\quad V_1 = \frac{q}{d_1}$ & $V_2 = \frac{q}{d_2}$

$\therefore \frac{\rho g}{2}(d_2^2 - d_1^2) = \rho q \left(\frac{q}{d_1} - \frac{q}{d_2}\right)$

or $\frac{g}{2}(d_2 + d_1)(d_2 - d_1) = q^2\left(\frac{d_2 - d_1}{d_1 d_2}\right)$ $\quad (\div \text{ by } \rho)$

or $\frac{g}{2}(d_2 + d_1) = \frac{q^2}{d_1 d_2}$ $\quad (\div \text{ by } (d_2 - d_1))$

or $\frac{g}{2}(d_2 + d_1) = \frac{q^2}{d_1 d_2}$

$(d_2 + d_1) = \frac{2q^2}{g d_1 d_2}$

Multiplying both sides by d_2, we get

$d_2^2 + d_1 d_2 = \frac{2q^2}{g d_1}$ $\quad$ or $\quad d_2^2 + d_1 d_2 - \frac{2q^2}{g d_1} = 0$

above eq^n is quadratic eq^n in d_2.

$$\therefore d_2 = \frac{-d_1 \pm \sqrt{d_1^2 - 4 \times 1 \times \left(\frac{-2q^2}{g d_1}\right)}}{2 \times 1}$$

$$= \frac{-d_1 \pm \sqrt{d_1^2 + \frac{8q^2}{g d_1}}}{2} = -\frac{d_1}{2} \pm \sqrt{\frac{d_1^2}{4} + \frac{2q^2}{g d_1}}$$

Q7.a. Given :-

Diameter of the jet $\cdot d = 75mm = 0.075m$

$\therefore$ Area $\cdot$ $a = \frac{\pi}{4}(0.075)^2 = 0.004417m^2$

Velocity of jet $V = 30\ m/s$

Angle made by the jet at inlet tip with horizontal $\theta = 30°$

Angle made by the jet at outlet " " " $\phi = 20°$

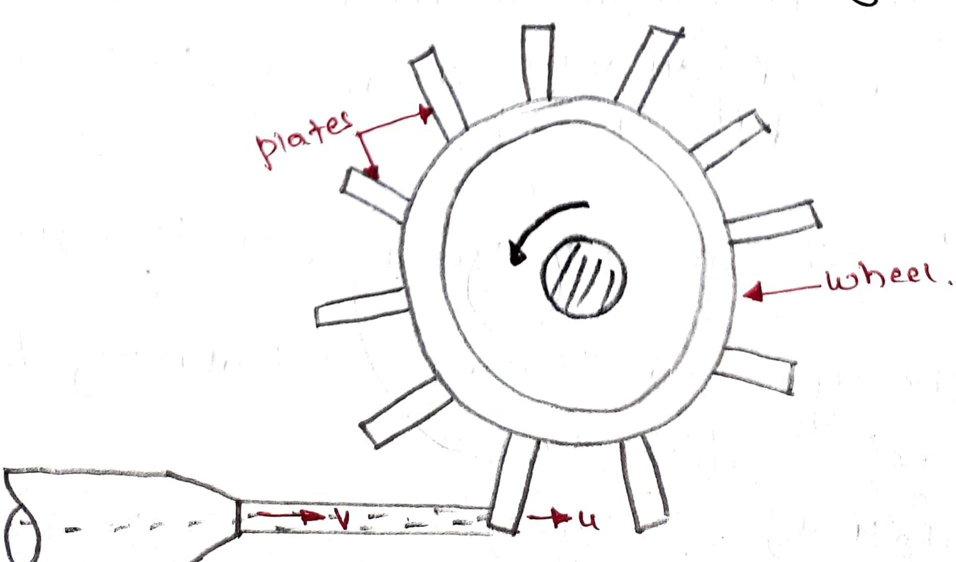
$F_x = \rho a v^2 [\cos\theta + \cos\phi]$

$F_x = 1000 \times 0.004417\ [\cos 30° + \cos 20°] \times 30^2 = 7178.2N$

& $F_y = \rho a V^2 [\sin\theta - \sin\phi] = 1000 \times 0.004417\ [\sin 30° - \sin 20°]$

$F_y = 628.13N.$

Q7.b The force exerted by a jet of water on a single moving plate is not practically feasible. This case is only a theoretical one. In actual practise, a large number of plates are mounted on the circumference of a wheel at a fixed distance apart. The jet strikes a plate & due to the force exerted by the jet on the plate, the wheel starts moving and the 2nd plate mounted on the wheel appears before the jet, which again exerts the force on the 2nd plate. The wheel starts moving at a constant speed.



Let V = Velocity of jet
d = Diameter of jet
a = Cross-sectional area of jet $= \pi/4\, d^2$
u = Velocity of vane.

Also the jet strikes the plate with a velocity $= (V-u)$

∴ The force exerted by the inlet jet in the direction of motion of plate.

$$F_x = \text{Mass per second}\,[\text{Initial velocity} - \text{final velocity}]$$
$$= \rho a V\,[(V-u)-0] = \rho a V\,[V-u]$$

Workdone by the jet on the series of plates per second

$= \text{force} \times \text{Distance per second in the direc}^n \text{ of force}$

$= F_x \times u = \rho a V\,[V-u] \times u$

Kinetic Energy of the jet per second

$= \frac{1}{2} m V^2 = \frac{1}{2}(\rho a V) \times V^2 = \frac{1}{2}\rho a V^3$

$$\therefore \text{Efficiency, } \eta = \frac{\text{Work done per second}}{\text{Kinetic Energy per second}} = \frac{\rho a V\,[V-u]\times u}{\frac{1}{2}\rho a V^3}$$

$$= \frac{2u\,[V-u]}{V^2}$$

Condition for maximum efficiency gives the value of the efficiency of the wheel. for a given jet velocity V, the efficiency will be maximum when

$$\frac{d\eta}{du} = 0 \quad \text{or} \quad \frac{d}{du}\left[\frac{2u(V-u)}{V^2}\right] = 0 \quad \text{or} \quad \frac{d}{du}\left[\frac{2uV - 2u^2}{V^2}\right] = 0$$

$$\text{or} \quad \frac{2V - 2\times 2u}{V^2} = 0 \quad \text{or} \quad 2V - 4u = 0 \quad \text{or} \quad V = \frac{4u}{2} = 2u \quad \text{or} \quad u = \frac{V}{2}$$

Maximum Efficiency :- Substituting the value of $V = 2u$ we get the max^m Efficiency as.

$$\eta_{max} = \frac{2u\,[2u-u]}{(2u)^2} = \frac{2u\times u}{2u\times 2u} = \frac{1}{2} = 0.5 \text{ or } 50\%$$

Let V = Velocity of jet
d = Diameter of jet
a = Cross-sectional area of jet. = $\pi/4\, d^2$
u = Velocity of vane.

Also the jet strikes the plate with a velocity $=(V-u)$

∴ The force exerted by the water jet in the direction of motion of plate.

F_x = Mass per second [Initial velocity − final velocity]

$= \rho a V[(V-u)-0] = \rho a V[V-u]$

Work done by the jet on the series of plates per second

= Force × Distance per second in the direcⁿ of force

$= F_x \times u = \rho a V[V-u]\times u$

Kinetic Energy of the jet per second

$= \frac{1}{2} m V^2 = \frac{1}{2}(\rho a V)\times V^2 = \frac{1}{2}\rho a V^3$

∴ Efficiency, $\eta = \frac{\text{Work done per second}}{\text{Kinetic Energy per second}} = \frac{\rho a V[V-u]\times u}{\frac{1}{2}\rho a V^3}$

$= \frac{2u[V-u]}{V^2}$

Condition for maximum Efficiency gives the value of the Efficiency of the wheel. for a given jet velocity V, the efficiency will be maximum when

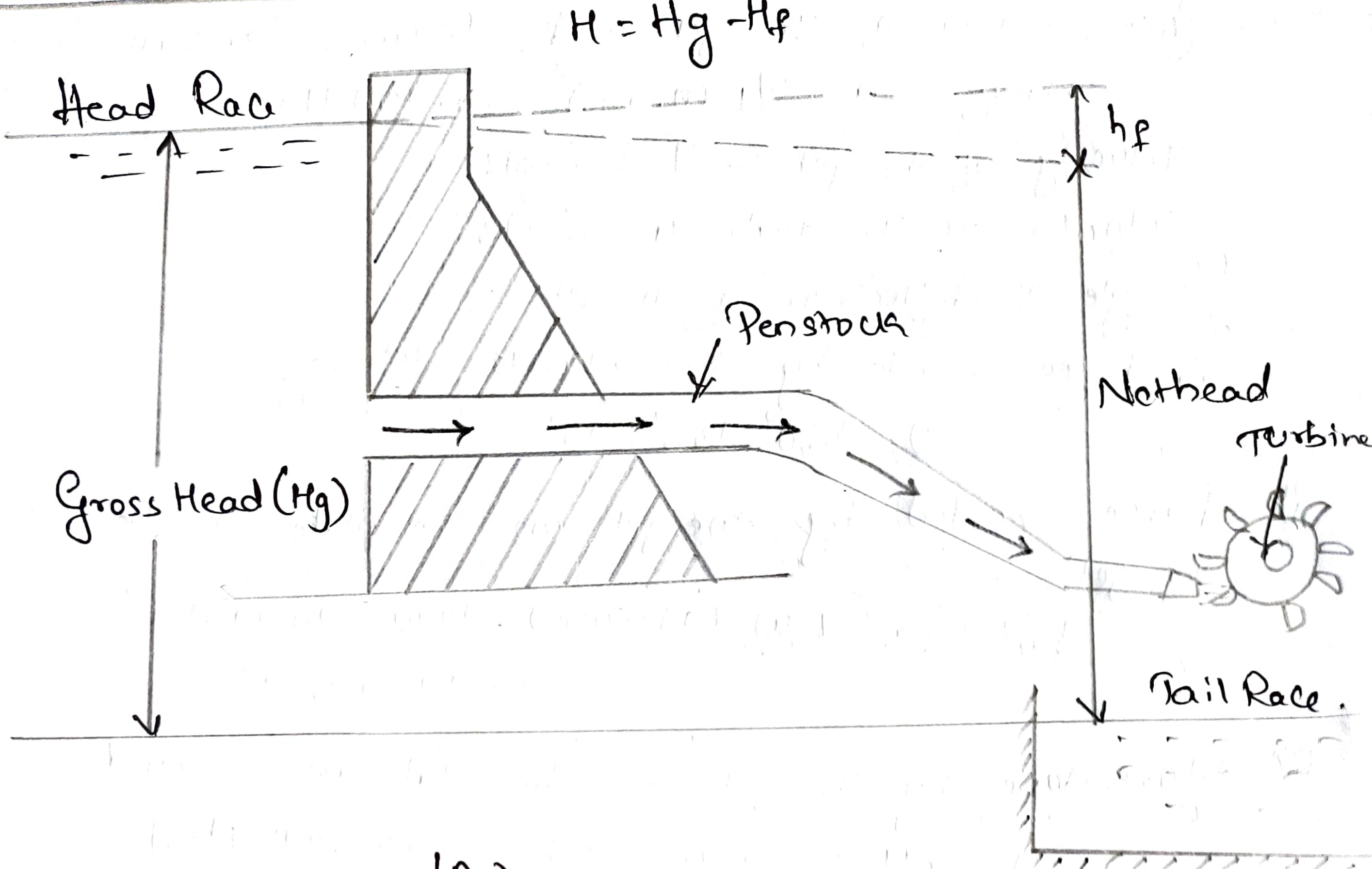
$\frac{d\eta}{du} = 0$ or $\frac{d}{du}\left[\frac{2u(V-u)}{V^2}\right] = 0$ or $\frac{d}{du}\left[\frac{2uV-2u^2}{V^2}\right] = 0$

or $\frac{2V-2\times 2u}{V^2} = 0$ or $2V-4u=0$ or $V = \frac{4u}{2} = 2u$ or $u = \frac{V}{2}$

Maximum Efficiency :- Substituting the value of $V = 2u$ we get the maxᵐ Efficiency as.

$\eta_{max} = \frac{2u[2u-u]}{(2u)^2} = \frac{2u\times u}{2u\times 2u} = \frac{1}{2} = 0.5$ or 50%

Q.7c.



Hydraulic Efficiency :- (η_h)

It is defined as the ratio of power given by water to the runner of a turbine to the power supplied by the water at the inlet of the turbine.

$$\eta_h = \frac{\text{Power delivered to runner}}{\text{Power Supplied at inlet}} = \frac{R.P}{W.P.}$$

where $R.p = \frac{W}{g} \frac{[V_{w_1} \pm V_{w_2}]}{1000}$ KW

$W.p = \frac{W \times H}{1000}$ KW.

Overall Efficiency (η_o) It is defined as the ratio of power available at the Shaft of the turbine to the power supplied by the water at the inlet of the turbine.

$$\eta_o = \frac{\text{Volume available at the Shaft of turbine}}{\text{Power Supplied at the inlet of the turbine}} = \frac{S.P}{W.P.}$$

Q8.a. Given:- Dia of the jet $= d = 7.5cm = 0.075\ m$

$\therefore$ Area $a = \pi/4\ (0.075)^2 = 0.004417$

Velocity of the jet, $V = 20\ m/s$

Velocity of the plate $u = 8\ m/s$

Angle of deflection of the jet $= 165°$

$\therefore$ Angle made by the relative velocity

$\theta = 180° - 165° = 15°$

i) Force exerted by the jet on the plate in the direction of the jet

$$F_x = \rho a (V-u)^2 (1+\cos\theta) = 1000 \times 0.004417\ (20-8)^2\ [1+\cos 15°]$$

$$= 1250.38\ N.$$

ii) Work done by the jet on the plate per second

$$= F_x \times u = 1250.38 \times 8 = 10003.04\ Nm/s$$

$\therefore$ Power of the jet $= \frac{10003.04}{1000} = 10\ kW$.

iii) Efficiency of the jet $= \frac{\text{output}}{\text{Input}} = \frac{\text{Work done by jet/sec}}{\text{K.E of jet/sec}}$

$$= \frac{1250.38 \times 8}{1/2(\rho a V) \times V^2} = \frac{1250.38 \times 8}{1/2 \times 1000 \times 0.004417 \times V^3}$$

$$= 0.564 = 56.4\ \%.$$

Q8.b. Classification of Hydraulic Turbines.

1. According to the type of energy at inlet

a. Impulse turbine & (b) Reaction turbine

2. According to the direction of flow through runner

a. Tangential flow (b) Radial flow (c) Axial flow

d. Mixed flow

Q8-c. Given:-

Shaft power $S.P = 11,772$ kW

Head $H = 380$ m

Speed $N = 750$ r.p.m

Overall Efficiency $\eta_o = 86\%$ or 0.86

Ratio of jet dia. to wheel dia $= \frac{d}{D} = \frac{1}{6}$

Co-Efficient of Velocity, $K_{v_1} = C_v = 0.985$

Speed ratio, $K_{u_1} = 0.45$

Velocity of jet, $V_1 = C_v\sqrt{2gH} = 0.985\sqrt{2\times 9.81\times 380} = 85.05$ m/s

The Velocity of wheel $u = u_1 = u_2$

$= \text{Speed ratio} \times \sqrt{2gH} = 0.45 \times \sqrt{2\times9.81\times380} = 38.85$ m/s

But $u = \frac{\pi DN}{60}$ $\therefore$ $38.85 = \frac{\pi DN}{60}$

or $D = \frac{60 \times 38.85}{\pi \times N} = \frac{60 \times 38.85}{\pi \times 750} = 0.989$ m.

But $\frac{d}{D} = \frac{1}{6}$

$\therefore$ Dia of jet $d = \frac{1}{6} \times D = \frac{0.989}{6} = 0.165$ m

Discharge of one jet q = Area of jet $\times$ Velocity of jet.

$= \frac{\pi}{4} d^2 \times V_1 = \frac{\pi}{4}(0.165) \times 85.05$ m³/s

$= 1.818$ m³/s

Now $\eta_o = \frac{S.P}{W.P} = \frac{11772}{\frac{\rho g \times Q \times H}{1000}}$

$0.86 = \frac{11772 \times 1000}{1000 \times 9.81 \times Q \times 380}$

$\therefore$ Total discharge $Q = \frac{11772 \times 1000}{1000 \times 9.81 \times 380 \times 0.86} = 3.672$ m³/s

$\therefore$ No. of jets $= \frac{\text{Total discharge}}{\text{Discharge of one jet}} = \frac{Q}{q} = \frac{3.675}{1.818} = 2$ jets.

3. According to the head at the inlet of turbine
a. High head turbine (b) Medium head turbine
c. Low head turbine

4. According to the specific speed of the turbine
a. Low specific speed turbine (b) Medium specific speed turbine
c. High specific speed turbine.

Parts of Pelton turbine :-

1. Nozzle & flow regulating arrangement.
2. Runner & buckets
3. Casing and
4. Breaking jet

1. Nozzle & flow regulating arrangement :- The amount of water striking the bucket of the runner is controlled by providing a spear in the nozzle. The spear is a conical needle which is operated either by a hand wheel or automatically in an axial direction depending upon the size of the unit.

2. Runner with Buckets:- It consists of a circular disc o the periphery of which a number of bucket evenly spaced are fixed.

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.

4. Breaking jet :- When the nozzle is completely closed by moving the spear in the forward direction, the amount of water striking the runner reduces to zero.

Q9.a If the water flows parallel to the axis of the rotation of the shaft, the turbine is known as axial flow turbine.

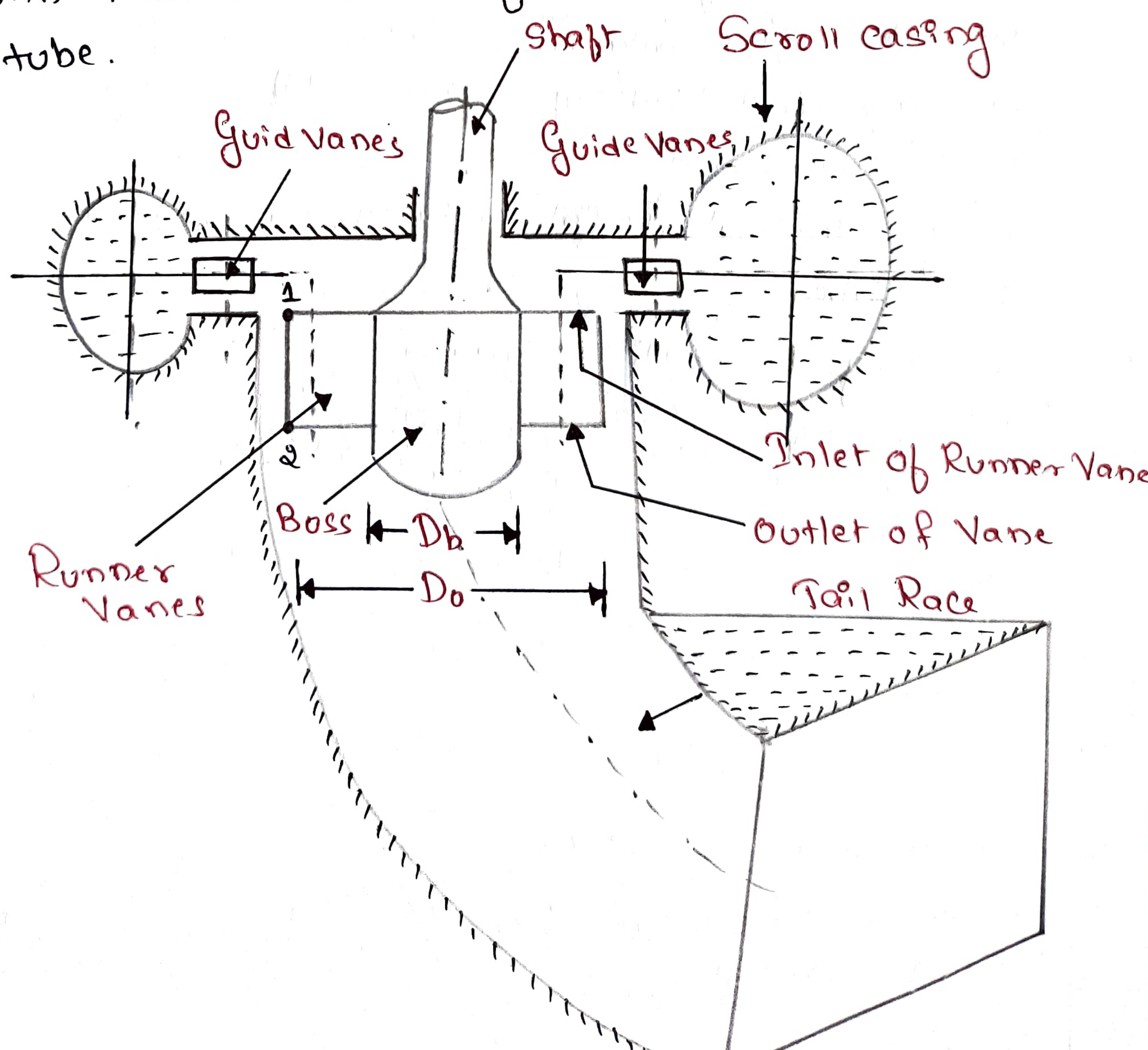
The following are the important type of axial flow reaction turbines:

1. Propeller Turbine (2) Kaplan turbine.

When the vanes are fixed to the hub and they are adjustable, the turbine is known as Kaplan turbine.

The main parts of a Kaplan turbine are:-

1. Scroll Casing
2. Guide Vanes mechanism
3. Hub with Vanes or runner of the turbine and
4. Draft tube.



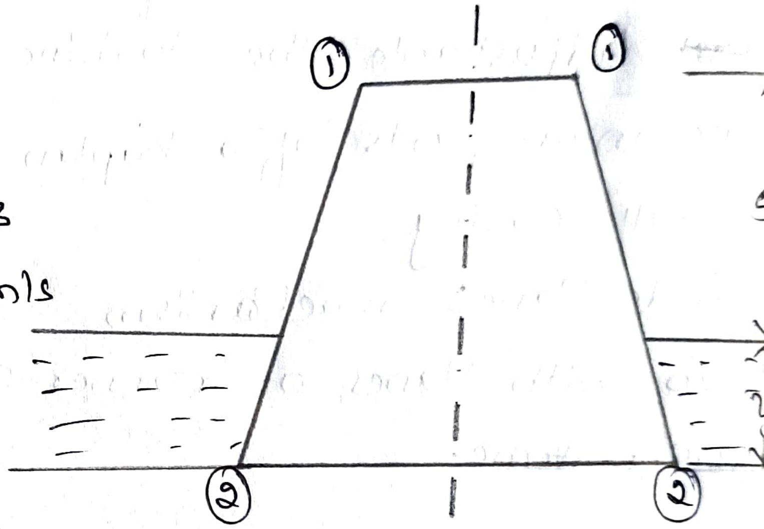
$$Q = \frac{\pi}{4}(D_o^2 - D_b^2) \times V_{f_1}$$

where D_o = Outer diameter of the runner

D_b = Diameter of hub and

V_{f_1} = Velocity of flow at inlet.

The inlet and outlet velocity triangles are drawn at Extreme Edge of the runner Vane. corresponding to point 1 and 2



Q9.b Given:-

Velocity at inlet $V_1 = 6$ m/s

Velocity at outlet $V_2 = 1.2$ m/s

Friction loss $h_f = 0.1$ m

Vertical height between tail race and inlet of draft tube = 5m

Let y = Vertical height between tail race and outlet draft tube.

Applying Bernoulli's Equation.

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

where $Z_1 = (5+y)$, $V_1 = 6$ m/s, $V_2 = 1.2$ m/s, $h_f = 0.1$

$\frac{P_2}{\rho g}$ = Atmospheric pressure head $+ y = \frac{P_a}{\rho g} + y$

$Z_2 = 0$

Substituting the Values, we get

$$\frac{P_1}{\rho g} + \frac{6^2}{2\times 9.81} + (5+y) = \left(\frac{P_a}{\rho g} + y\right) + \frac{1.2^2}{2\times 9.81} + 0 + 0.1$$

or $\frac{P_1}{\rho g} + 1.835 + 5 + y = \frac{P_a}{\rho g} + y + 0.0734 + 0.1$

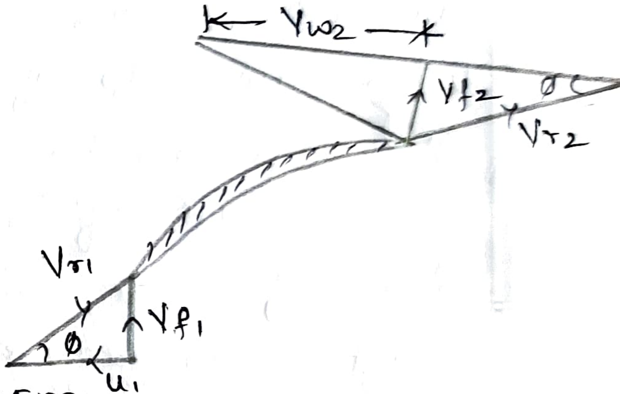
or $\frac{P_1}{\rho g} + 6.835 = \frac{P_a}{\rho g} + 0.1734.$

$\frac{P_a}{\rho g}$ = atmospheric pr. head is taken Zero.

$$\frac{P_1}{\rho g} + 6.835 = 0 + 0.1734$$

$$\therefore \frac{P_1}{\rho g} = -6.835 + 0.1734 = -6.6616 \text{ m}$$

Negative sign means vaccum pressure head.



Q9.c Given

Discharge $Q = 0.118 \text{ m}^3/\text{s}$

Speed $N = 1450$ r.p.m

Head $H_m = 25\text{m}$

Diameter at outlet, $D_2 = 250 \text{ mm} = 0.25\text{m}$

width at outlet, $B_2 = 50 \text{ mm} = 0.05\text{m}$

Manometric efficiency $\eta_{man} = 75\% = 0.75$

Let Vane angle at outlet $= \phi$

Tangential velocity of impeller at outlet

$$U_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.25 \times 1450}{60} = 18.98 \text{ m/s}.$$

Discharge is given by $Q = \pi D_2 B_2 \times V_{f2}$

$$V_{f2} = \frac{Q}{\pi D_2 B_2} = \frac{0.118}{\pi \times 0.25 \times 0.05} = 3.0 \text{ m/s}.$$

$$\eta_{man} = \frac{gH_m}{V_{w2} U_2} = \frac{9.81 \times 25}{V_{w2} \times 18.98}$$

$$\therefore V_{w2} = \frac{9.81 \times 25}{\eta_{man} \times 18.98} = \frac{9.81 \times 25}{0.75 \times 18.98} = 17.23.$$

from outlet Velocity triangle, we have

$$\tan\phi = \frac{V_{f_2}}{(u_2 - V_{w_2})} = \frac{3.0}{(18.98 - 17.23)} = 1.7143.$$

$$\therefore \phi = \tan^{-1} 1.7143 = 59.74^\circ \text{ or } 59^\circ 44'$$

Q10.a. Multistage Centrifugal Pumps for high heads.

The water from suction pipe enters the 1st impeller. at inlet and is discharged at outlet with increased pressure. The water with increased pressure from the outlet of the 1st impeller is taken to the inlet of the 2nd impeller with the help of a connecting pipe. At the outlet of the 2nd impeller, the pressure of water will be more than the pressure of water at the outlet of the 1st impeller. Thus if more impellers are mounted on the same shaft, the pressure at the outlet will be increased further.

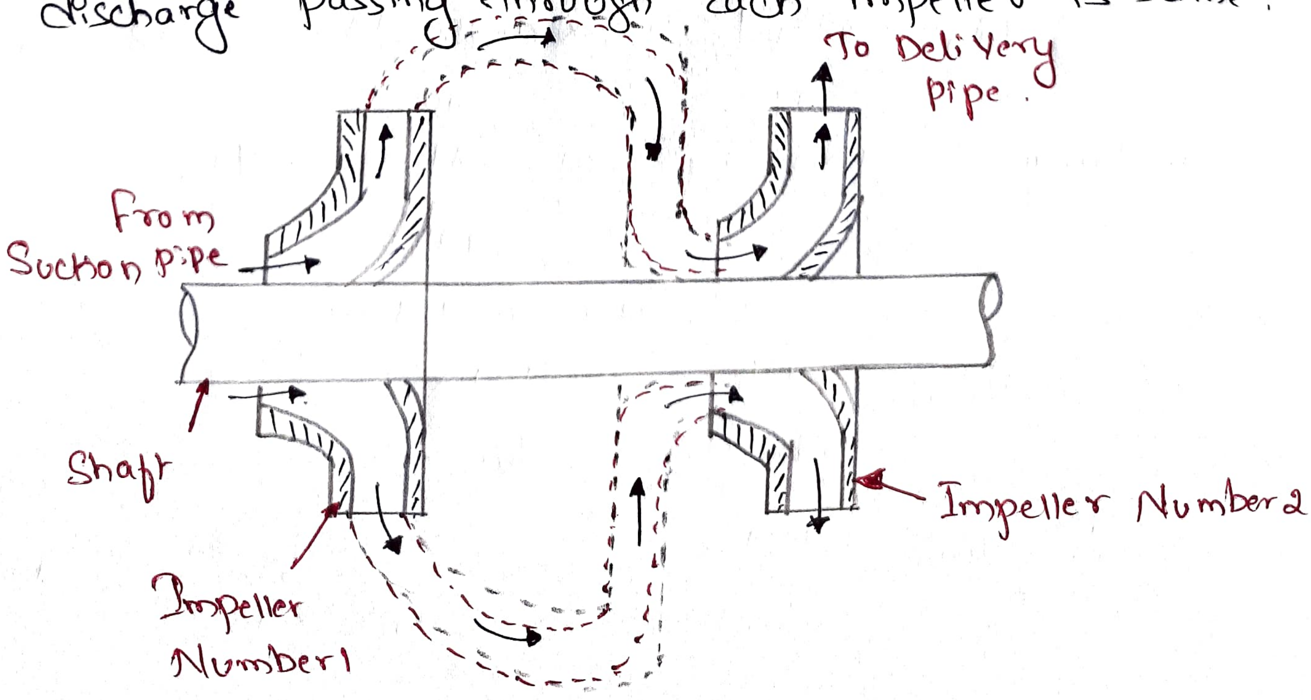
Let n = Number of identical impellers mounted on the same shaft

H_m = Head developed by each impeller

Then total head developed

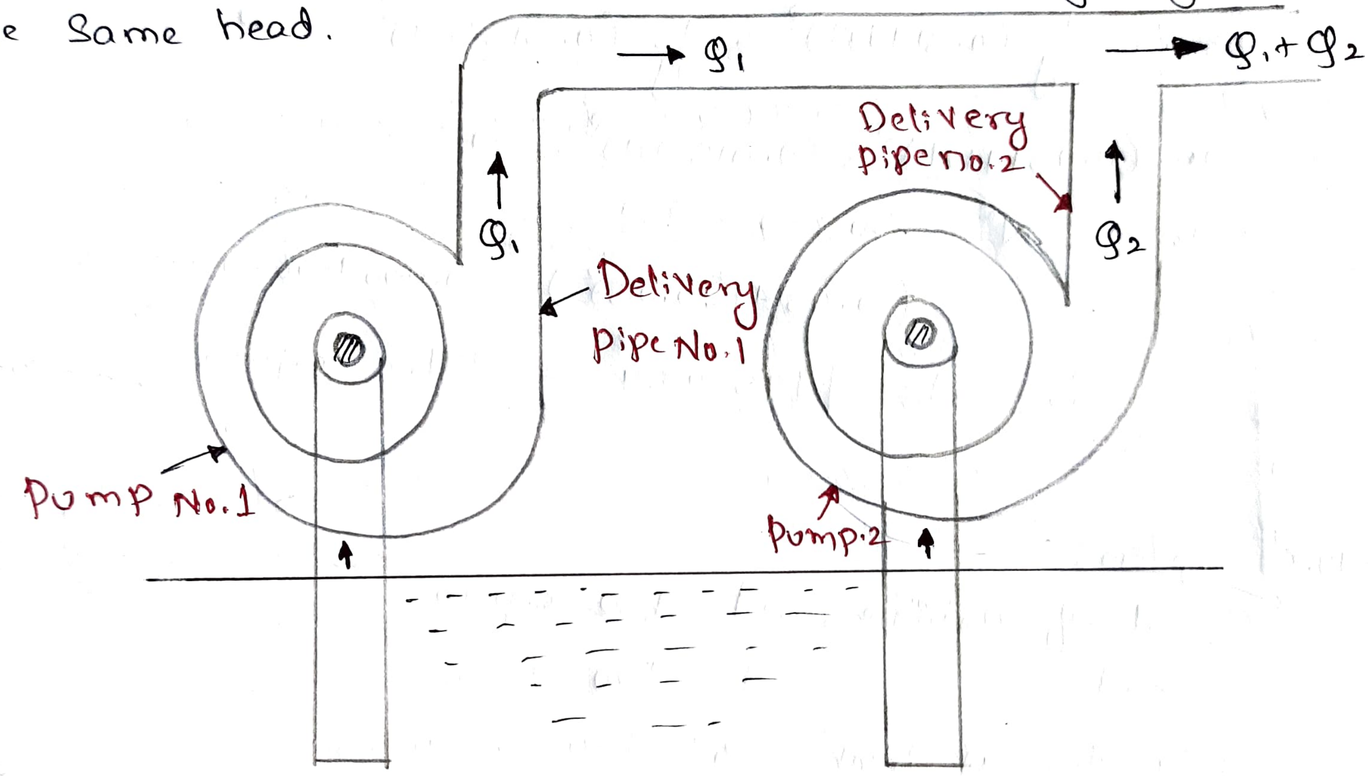
$= n \times H_m$

The discharge passing through each impeller is same.



* Multistage Centrifugal pumps for High Discharge.

For obtaining high discharge the pumps should be connected in parallel. Each of the pumps lifts the water from a common pump and discharge water to a common pipe to which the delivery pipes of each pump is connected. Each of the pump is working against the same head.



Let n = Number of identical pumps arranged in parallel

Q = Discharge from one pump.

∴ Total discharge $= n \times Q$.

Q10.b Given:-

Dia. of impeller at inlet, $D_1 = 30cm = 0.30m$

Dia. of impeller at outlet $D_2 = 60cm = 0.60m$.

Head, $H_m = 30cm$

Let the minimum starting speed $= N$

Using equation for minimum speed

$$\frac{u_2^2}{2g} - \frac{u_1^2}{2g} = H_m$$

where $u_2 = \dfrac{\pi \times D_2 \times N}{60} = \dfrac{\pi \times 0.6 \times N}{60} = 0.03141\,N$

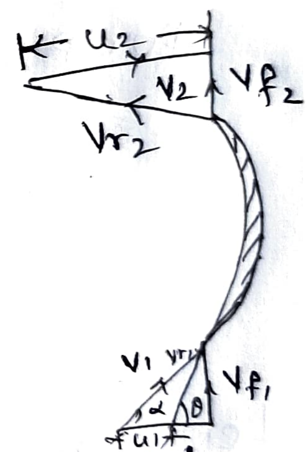
$u_1 = \dfrac{\pi \times D_1 \times N}{60} = \dfrac{\pi \times 0.3 \times N}{60} = 0.01577\,N.$

$\therefore \dfrac{1}{2g}(0.3141N)^2 - \dfrac{1}{2g}(0.01577N)^2 = 30$

or $(0.03141N)^2 - (0.01577N)^2 = 30 \times 2 \times g = 30 \times 2 \times 9.81$

Or $N^2 = \dfrac{30 \times 2 \times 9.81}{(0.03141^2 - 0.01577^2)} = \dfrac{588.6}{0.0009866 - 0.0002465} = 795297.9$

$\therefore N = \sqrt{795297.9} = 891.8$ r.p.m.



Q10.c Given:-

Speed of turbine, $N = 450$ r.p.m

Head $H = 120$ m

Diameter at inlet $D_1 = 120\,cm = 1.2\,m$

flow area $\pi D_1 \times B_1 = 0.4\,m^2$

Angle made by absolute velocity at inlet $\alpha = 20^\circ$

Angle made by the relative velocity at inlet $\theta = 60^\circ$.

whirl at outlet $V_{w_2} = 0$.

Tangential velocity of the turbine at inlet,

$u_1 = \dfrac{\pi D_1 N}{60} = \dfrac{\pi \times 1.2 \times 450}{60} = 28.27$ m/s.

From inlet velocity triangle,

$\tan\alpha = \dfrac{V_{f_1}}{V_{w_1}}$ or $\tan 20^\circ = \dfrac{V_{f_1}}{V_{w_1}}$ or $\dfrac{V_{f_1}}{V_{w_1}} = \tan 20^\circ = 0.364$

$V_{f_1} = 0.364\,V_{w_1}$

Also $\tan\theta = \dfrac{V_{f_1}}{V_{w_1} - u_1} = \dfrac{0.364\,V_{w_1}}{V_{w_1} - 28.27}$. $\quad (\because V_{f_1} = 0.364 V_{w_1})$

or $\frac{0.364 V_{w1}}{V_{w1} - 28.27} = \tan\theta = \tan 60^\circ = 1.732$

$\therefore$ $0.364 V_{w1} = 1.732 (V_{w1} - 28.27) = 1.732 V_{w1} - 48.96.$

or $(1.732 - 0.364) V_{w1} = 48.96$

$\therefore$ $V_{w1} = \frac{48.96}{(1.732 - 0.364)} = 35.789 = 35.79 \text{ m/s}.$

$V_{f1} = 0.364 \times V_{w1} = 0.364 \times 35.79 = 13.027 \text{ m/s}.$

Volume flow rate is $Q = \pi D_1 B_1 \times V_{f1}$

But $\pi D_1 \times B_1 = 0.4 \text{ m}^2$

$Q = 0.4 \times 13.027 = 5.211 \text{ m}^3/\text{s}.$

Work done per sec on the turbine is.

$= \rho Q [V_{w1} u_1]$

$= 1000 \times 5.211 [35.79 \times 28.27] = 5272402 \text{ Nm/s}.$

$\therefore$ Power developed in kW $= \frac{\text{Work done per second}}{1000}$

$= \frac{5272402}{1000} = 5272.402 \text{ kW}.$

The hydraulic efficiency is

$\eta_h = \frac{V_{w1} u_1}{gH} = \frac{35.79 \times 28.27}{9.81 \times 120} = 0.85 = 85.95\%$