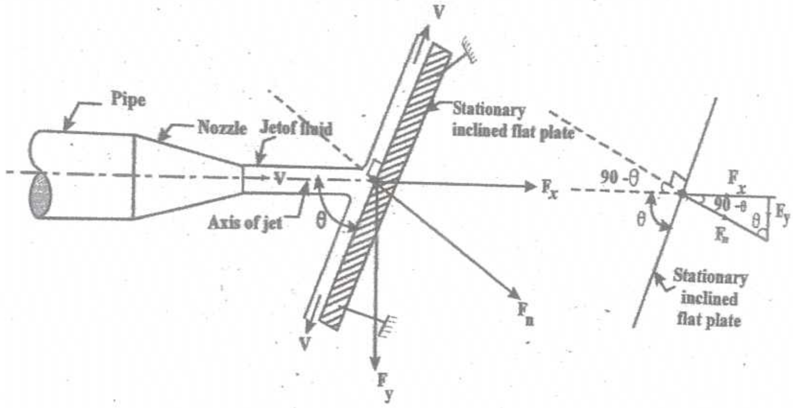
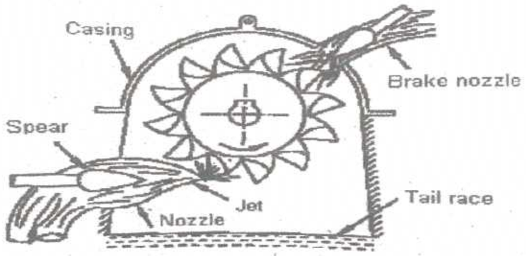
SCORING INDICATORS

CODE : TED(15) 6022 HYDRAULIC MACHINES

Qn No.	Scoring indicators	Split up score	Total Score
	PART - A		
I.1	➤ When a high velocity water jet impinges on a solid smooth surface, it exerts a force on the surface known as Impact of jets. ➤ This force can be evaluated by Newton's II law of motion.	1+1	2
I.2	➤ The process of controlling or keeping the speed of a turbine as constant is known as governing of a turbine.	2	2
I.3	➤ Tangential flow turbines ➤ Radial flow turbines ➤ Axial flow turbines ➤ Mixed flow turbines	0.5 X 4	2
I.4	➤ The power of a turbine working under a unit head is known as unit power ➤ Unit power $P_u = P/H^{3/2}$	1+1	2
I.5	➤ The difference between Theoretical discharge and actual discharge is called slip of a pump.	2	2
	PART - B		
II.1	 Figure Shows a jet issuing from a nozzle impinges on a smooth flat plate inclined at an angle θ to the direction of the jet. Component of the jet velocity, in the direction normal to the plate is V sinθ before the impact And zero after the impact. Applying impulse-momentum principle Normal force on the plate is F_n = Mass of jet striking per second(Velocity before striking – Velocity after striking) $= \rho AV (V\sin\theta - 0)$ $= \rho AV^2 \sin\theta$ This force can be resolved into two components, one in the direction of the jet and other normal to the direction of flow. Force exerted by the jet in the direction of flow $F_x = F_n \cos (90 - \theta)$ $= F_n \sin\theta$	Figure (3) + Derivation (3)	6

	$=\rho AV^2 \sin^2 \theta$ Force exerted by the jet in the direction normal to the flow $F_y = F_n \cos\theta$ $= \rho AV^2 \sin\theta \cos\theta$ $= \frac{1}{2} \rho AV^2 \sin 2\theta$		
II.2	H=25 m $F_x = 1.12$ kN $C_v = 0.9$ Velocity $V = C_v \sqrt{2gH}$ $= 0.9 \times \sqrt{2 X 9.81 X 25}$ $= 19.93$ m/s Diameter of the jet , $d = \sqrt{\frac{4 X F}{\rho X \pi X V^2}}$ $= \sqrt{\frac{4 X 1.12 X 1000}{1000 X \pi X 19.93^2}}$ $= 0.0599$ m	Velocity (3)(Equation 2marks answer 1 mark) + Diameter (3) (Equation 2marks answer 1 mark)	6
II.3	 In an impulse turbine, Potential energy possessed by the water is first converted into kinetic energy by expanding it through a nozzle. Water discharged from the nozzle strikes on the series of suitably shaped blades or buckets fixed around the rim of a wheel. Change in velocity results in change in momentum leads to the rotation of blades and wheel. Thus mechanical energy is created from available hydraulic energy. Pressure of water is atmospheric from inlet to outlet of the turbine. No draft tube is required.	Fig 3 + explanation 3	6

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II.4	(see table below)	6 X 1	6

Impulse turbine	Reaction turbine
1. All the available hydraulic energy is converted into kinetic energy by an efficient nozzle.	1. Only the portion of the hydraulic energy is converted into kinetic energy before the water enters the turbine runner.
2. The jet of water impinges on the buckets with kinetic energy	2. The water passes over the moving vanes with potential or pressure energy
3. Pressure of water is atmospheric from inlet to the outlet of the turbine.	3. Pressure of water is not uniform thruoghout but varies from maximum to mimimum as it passes through the vanes.The pressure is negative(below atmospheric pressure) at the outlet end of the turbine.
4. The wheel must not run full. Air has free access between the vanes and wheel. The water may be admitted over the part of the circumference or over the whole circumference.	4. The wheel is always run full of water. Water flows into the wheel throughout its circumference.
5. The jet of water impinges from the nozzle strikes the buckets fixed to the periphery of the wheel.	5. The water is guided to the moving vanes at a proper angle by the guide vanes
6. All the vanes are not in action.Only the vanes infront of the nozzle are in action.	6. All the vanes are in action.
7. An air tight casing is not essential	7. An air tight casing is essential
8. This turbine is placed above tail race	8. This turbine is placed submerged below the tail race
9. It is possible to regulate the flow without loss.	9. Flow regulation is always accompanied by loss of energy.
10. It does not require draft tube.	10. It always require draft tube.
11 Workdone is entirely due to change in kinetic energy.	11 .Workdone is due to change in pressure and velocity.
12. Turbine components are easily accessible.	12. Turbine components are not easly accessible.
13. Relative velocity changes only slightly. Such change in velocity is due to friction only.	13. Relative velocity changes considerably due to centrifugal action.
14 These are comparatively small in size and run at high speeds.	14. These turbines are large in size and runs at relatively low speeds.
15. These are suitable for high heads.	15. These are suitable for low heads.

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<tr>
<td>II.5</td>
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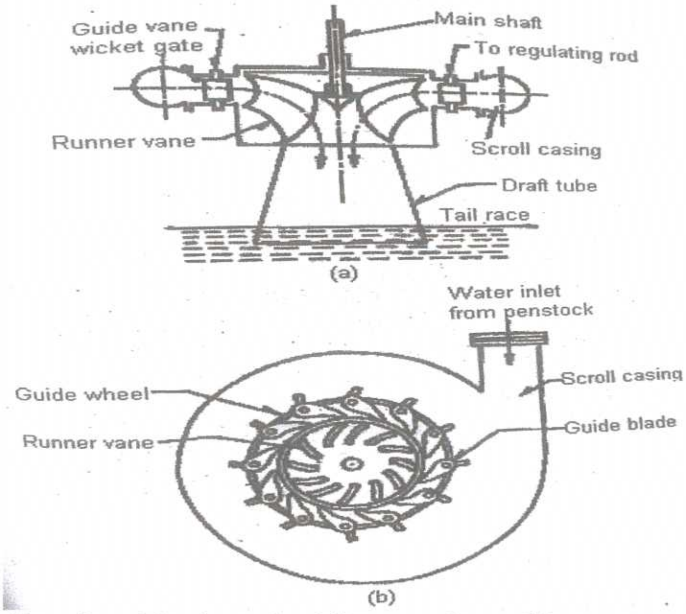
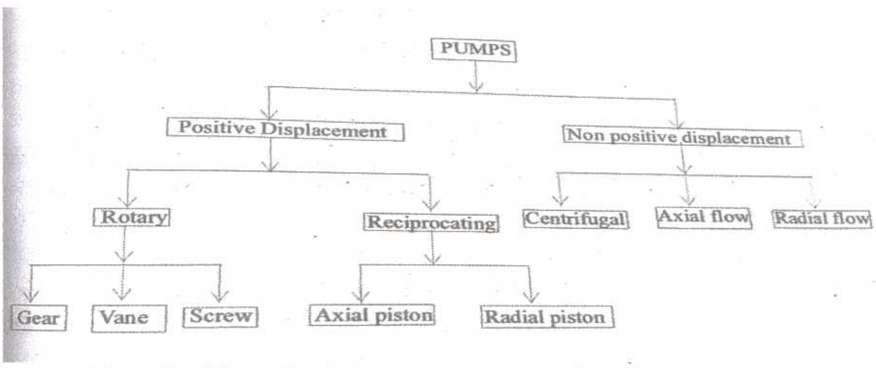


Modern Francis turbine is a mixed flow reaction turbine.
There is a difference of pressure between the guide vanes and the runner which is called reaction pressure and is responsible for the motion of the runner. Pressure energy is gradually converted into kinetic energy while water is flowing through the vanes. Pressure at the outlet of runner is lower than that of the inlet. Water is discharged to the tail race through draft tube.
</td>
<td>Fig 3 +
explanation
3</td>
<td>6</td>
</tr>
<tr>
<td>II.6</td>
<td>


Non Positive displacement pumps:- In these pumps pressure produced is proportional to the rotor speed. These pumps are used for low pressure and high volume flow applications.

Positive displacement pumps:- These pumps produce flow proportional to their displacement and rotor speed. Output flow is constant.
</td>
<td>Classification
4
+
Explanation
2</td>
<td>6</td>
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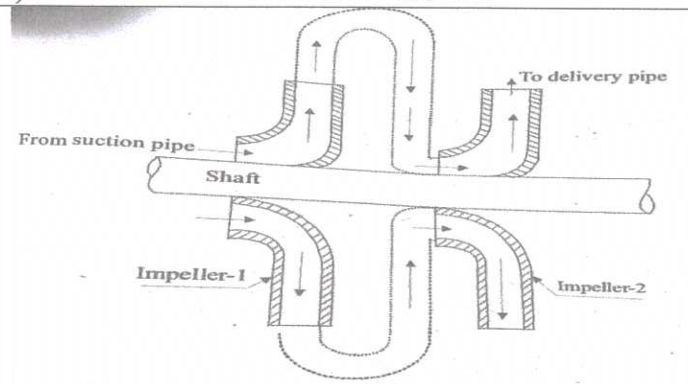
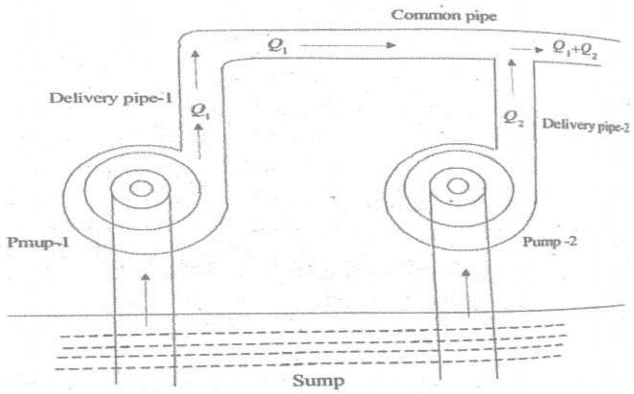
II.7



Multistage pump with impeller in series



Pumps in parallel

- **For getting high heads** a number of impellers are connected in series. At the outlet of the second impeller, pressure of water will be more than the pressure of water at the outlet of the first impeller. Total head = No. of impeller X Head developed by each impeller.
- **For getting high discharge** pumps should be connected in parallel. Each pump lifts water from common sump and discharges to a common pipe. Each pump working against the same head. Total discharge = No of pumps X Discharge from one pump.

➢

Figure 4 + explanation 2

6

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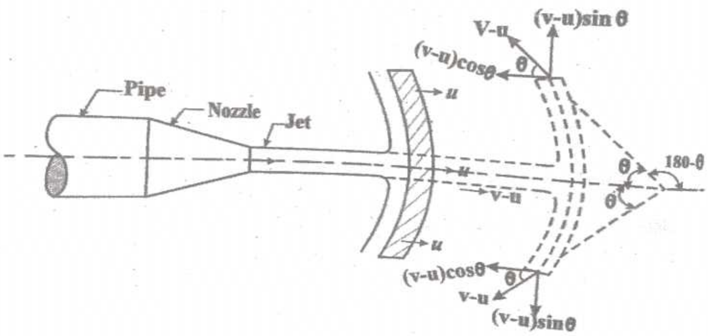
<table>
<tr><td colspan="4">PART - C</td></tr>
<tr><td colspan="4">UNIT - I</td></tr>
<tr><td>III.a</td><td>


V = Velocity of water jet m/s.
a = Cross-sectional area of jet.
u= Velocity of plate in the direction of jet.
θ = Angle made by relative velocity at the outlet.

Mass of fluid striking the vane per second = Density X Area of jet X Velocity with which the jet strikes the plate.

$m = \rho a(V-u)$
Force exerted by the jet of fluid on the moving curved plate in the direction of the jet
F_x = Mass of fluid striking/ second X (Initial velocity in the direction of jet – Final velocity in the direction of jet)
$= \rho a(V-u)[(V-u) - {}^{-}(V-u)\cos\theta]$

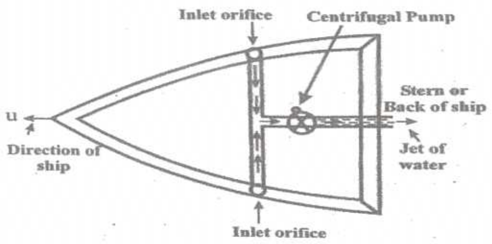
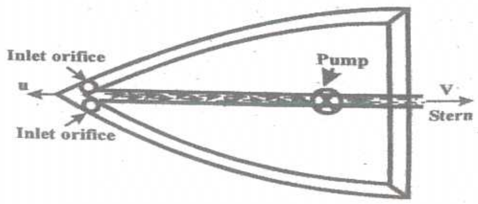
$= \rho a(V-u)^2\,[1+\cos\theta]$

Work done by the jet on the plate = F_x X Distance travelled/second in the direction of jet.

$W = F_x \times u$

$= \rho a(V-u)^2\,[1+\cos\theta] \times u$
Work done/sec is also the power developed.
</td><td>Fig 4
+
Derivation 4</td><td>8</td></tr>
<tr><td>III.b</td><td>
Dia d = 0.1 m
Velocity V = 15m/s
Velocity of plate = 5m/s
Force exerted by the jet on a fixed flat vertical plate,

$F_x = \rho a V^2$
$= \rho \times \frac{\pi}{4} \times (0.1)^2 \times 15^2$
$= 1767.15$ N
</td><td>Equations 3
+
Calculation 4</td><td>7</td></tr>
</table>

	Force exerted by the jet on a moving plate $F_x = \rho a(V-u)^2$ $= \rho \times \frac{\pi}{4} \times (0.1)^2 \times (15-5)^2$ $= 785.4$ N Work done/sec OR Power developed by the jet $P = F_x \times u$ $= 785.4 \times 5$ $= 3927$ W		
OR			
IV.a	 (a) Inlet orifices are at right angles.  (b) Inlet orifices facing the direction of ship. The ships carry pumps, which take water from its surroundings. This water is discharged by forcing through the orifice at the back of the ship. The efficiency of ship depends upon the the direction of the inlet orifice. 1. Inlet orifices at right angles to the direction of its motion. (AMID – Water is drawn at the middle of the ship) 2. Inlet orifices faces the direction of motion. Ship is steered through the water due to reaction of the force of the jet.	Fig4 + Explanation 2	6

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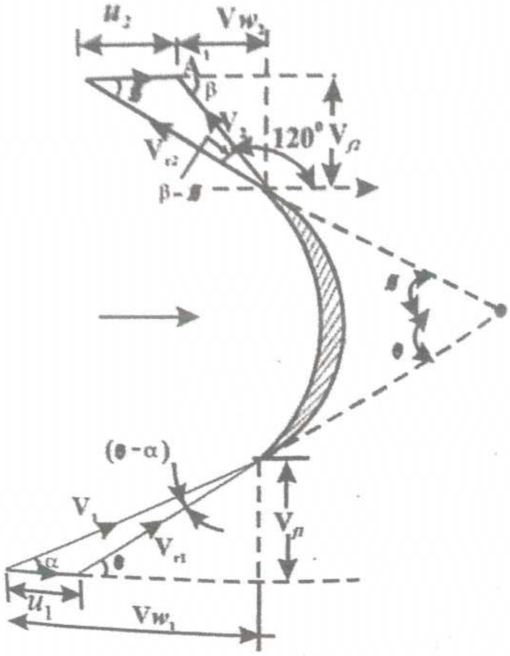
<table>
<tr><td>IV.b</td><td>


$V_1 = 30$ m/s $u_1 = u_2 = 15$ m/s
Angle $\alpha = 30^0$
Angle made by the absolute velocity with the direction of motion of the vane at exit, $\beta = 180 - 120 = 60^0$
Velocity of whirl at entrance, $V_{w1} = V_1 \cos\alpha = 30 \cos 30$
$= 25.98$ m/s
Velocity of flow at entrance, $V_{f1} = V_1 \sin\alpha = 30 \sin 30$
$= 15$ m/s

From inlet velocity triangle, $\tan\theta = \frac{V_{f1}}{V_{w1}-u_1}$
$\theta = \tan^{-1}\left(\frac{V_{f1}}{V_{w1}-u_1}\right)$
$= \tan^{-1}\frac{15}{25.98-15}$
$= 53.8^0$
Applying sine rule at inlet velocity triangle
$\frac{V_1}{\sin(180-\theta)} = \frac{u_1}{\sin(\theta-\alpha)} = \frac{V_{r1}}{\sin\alpha}$
$\frac{30}{\sin(180-53.8)} = \frac{15}{\sin(53.8-30)} = \frac{V_{r1}}{\sin 30}$
Relative velocity $V_{r1} = \frac{30 \sin 30}{\sin(180-53.8)}$
$= 18.59$ m/s
</td><td>Triangle 4
+
Angles 3
+
Work done 2</td><td>9</td></tr>
</table>

Relative velocity at exit = $V_{r2} = V_{r1} = 18.59$ m/s

Applying sine rule at outlet velocity triangle

$$\frac{V_2}{\sin \emptyset} = \frac{u_2}{\sin(\beta - \emptyset)} = \frac{V_{r2}}{\sin(180 - \beta)}$$

$$\frac{V_2}{\sin \emptyset} = \frac{15}{\sin(60 - \emptyset)} = \frac{18.59}{\sin(180 - 60)}$$

$$\sin(60 - \phi) = \frac{15 \sin(180-60)}{18.59}$$

$$\phi = 15.67^0$$

Velocity of whirl at exit $V_{w2} = V_{r2} \cos\phi - u_2$

$= 18.59 \cos 15.67 - 15$

$= 2.9$ m/s

Work done/ kilogram of water = $[V_{w1} \pm V_{w2}]\, u_1$

$= [25.98 + 2.9] X 15$

$= 433.2$ Nm/s

UNIT – II			
V.a	• The hydraulic machine which converts hydraulic energy or power into mechanical energy is called hydraulic turbine or water turbine. Hydraulic turbines may be classified according to the following factors: (i) According to the nature of energy possessed by water at inlet (a) Impulse turbines, and (b) Reaction turbines (ii) According to the direction of flow of water through runner (a) Tangential flow turbines (b) Radial flow turbines (c) Axial flow turbines, and (d) Mixed flow turbines. (iii) According to the head and quantity of water available at the inlet (a) High head turbine (b) Medium head turbines, and (c) Low head turbines (iv) According to the disposition of shaft (a) Horizontal shaft turbine, and (b) Vertical shaft turbine (v) According to the name of the originator (a) Pelton wheel (b) Francis turbine (c) Kaplan turbine, etc . (vi) According to the specific speed of the turbine (a) Low specific speed turbine (b) Medium specific speed turbine, and (c) High specific speed turbine.	Definition 1 + Classification 6	7
V.b	No. of jets = 2 Head, H = 50 m Poer , P = 90 kW Overall efficiency η_o = 90% = 0.9 Overall efficiency $\eta_o = \frac{P}{\rho g Q H}$ Discharge through the wheel, $Q = \frac{P}{\rho g \eta_o H}$ $= \frac{90 X 1000}{1000 X 9.81 X 0.9 X 50}$ = 0.2039 m^3/s Velocity of jet $V = C_v\sqrt{2gH}$ $= 0.96 X \sqrt{2 X 9.81 X 50}$ = 30.0681 m/s Discharge through the jet, Q = Area of jets X Velocity of jet $=(\pi d^2 n X V)/4$	Equations 3X2=6 + Calculation 2	8

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Diameter of the nozzle jet, d = $\sqrt{\frac{4Q}{\pi\, n\, V}}$

$= \sqrt{\frac{4 X 0.2039}{\pi X 2 X 30.0681}}$

= **0.0657 m**

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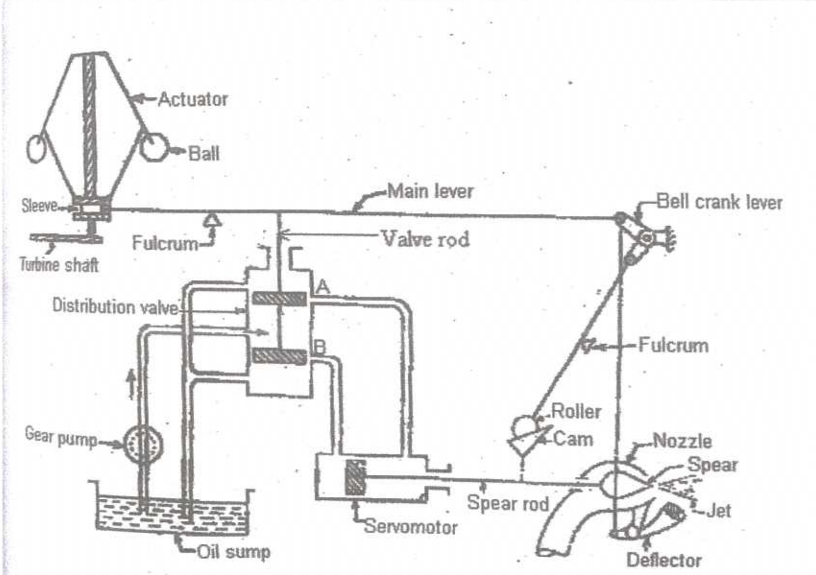
<tr><td colspan="4">OR</td></tr>
<tr><td>VI.a</td><td>



At normal load the ports A and B are closed, Oil supplied by the gear pump remains in the middle portion of the distribution valve and thus gears of the pump go on rotating without developing further pressure.

As the load on the turbine decreases, speed increases correspondingly. Actuator speed increases and balls fly off. Sleeve moves upward, the lever rod inclined and the bell crank lever moves downward. When bell crank lever moves downwards, the jet deflector will operate and divert whole or part of the jet away from the buckets. With the downward movement of the bell crank lever, the roller on the cam rises.

When the lever rod inclined then sleeve control valve rod is pushed down in the distribution valve. Port B opens and A still closed. As soon as B opens, the oil from the middle port of the distribution valve goes to the servo motor on the left side of the piston. This oil of high pressure forces the piston to move towards right side, thus forcing the spear to reduce the area of jet and hence the rate of flow. The spear occupies its final position, jet deflector occupies its original position and doesn't obstruct jet as the speed again becomes normal.

</td><td>Fig 5
+
Explanation
4</td><td>9</td></tr>
</table>

When the load on the turbine increases, the speed reduces. This causes the fly balls of the actuator to come down and thus sleeve also move downwards causing the lever rod to move upward and to open port A to the right side of the piston. The piston moves towards the left, causing the spear to move away from the nozzle and increases the area of flow, and increases the discharge. In this case deflector moves up but the deflector plate is not able to obstruct the jet at normal speed.

As soon as the speed becomes normal, the actuator balls occupy normal position and port A and B closed.

VI.b

Power developed P =12 MW
Net Head H = 300 m
Overall efficiency η_o = 80% = 0.8

Overall efficiency, $\eta_o = \frac{P}{\rho g Q H}$

Discharge through the wheel, $Q = \frac{P}{\rho g \eta_o H}$

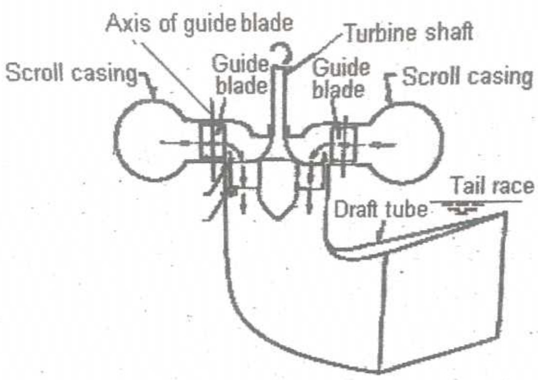
$= \frac{12 X 1000}{9.81 X 300 X 0.8}$

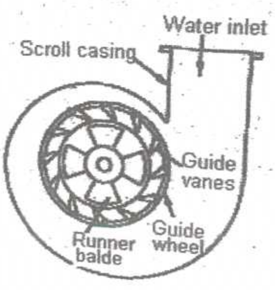
$= 5.0968$ m^3/s

Equation 3 + Calculation 3 — 6

UNIT - III

VII.a





Kaplan Turbine is a parallel flow turbine in which flow from the inlet to the outlet is perfectly parallel to the shaft of the turbine. The number of

Fig 4 + Explanation 3 — 7

	blades is only 3 to 6 and 8 in exceptional cases. Water strikes the blades axially. Turbine blades are adjustable. If it is fixed, known as propeller turbine. In a Kaplan turbine less contact surface with water and frictional resistance is less. A single Kaplan turbine can produce an output of 30 MW. Specific speed of the turbine is between 260 – 860 rpm.		
VII.b	Working Head = 20 m Power P = 20000 kW Efficiency η_o = 86% = 0.86 Speed ratio, K_u = 2 Flow ratio, K_f = 0.6 Hub diameter of wheel , $D_b = 0.35\ D_o$ Speed Ratio, $K_u = \frac{u}{\sqrt{2gH}}$ Peripheral velocity of the wheel, $u = K_u\sqrt{2gH}$ $= 2\ X\ \sqrt{2\ X\ 9.81\ X\ 20}$ = 39.62 m/s Flow ratio, $K_f = \frac{V_f}{\sqrt{2gH}}$ $V_f = K_f\sqrt{2gH} = 0.6 \text{ x } \sqrt{2\ X\ 9\ 81\ X\ 20}$ = 11.89 m/s Overall efficiency = $\eta_o = \frac{P}{\rho gQH}$ Discharge, $Q = \frac{P}{\rho gH\eta_o} = \frac{20000}{1\ X\ 9.81\ X\ 20\ X\ 0.86}$ = 118.53 m^3/s Discharge , Q = Area of Flow X Velocity of Flow $= (\pi/4)(D_o^2 - D_b^2)\ X\ V_f$ From the equation, $118.53 = \frac{\pi}{4}\ X\ (D_o^2 - (0.35\ D_o)^2)\ X\ 11.89$ Diameter of the turbine runner = $D_o = \sqrt{\frac{4\ X\ 118.53}{\pi\ X\ (1-0.35^2)X\ 11.89}}$ = 3.8 m Diameter of the runner boss, $D_b = 0.35\ D_o$ = 0.35 X 3.8 = 1.33 m Peripheral velocity of turbine, $u = \frac{\pi D_o N}{60}$ Speed of turbine runner, $N = \frac{60\ u}{\pi D_o} = \frac{60\ X\ 39.62}{\pi\ X 3.8}$ = 199.13 rpm.	Diameter 6 (equ 3 + calculation 3) + Speed 2	8

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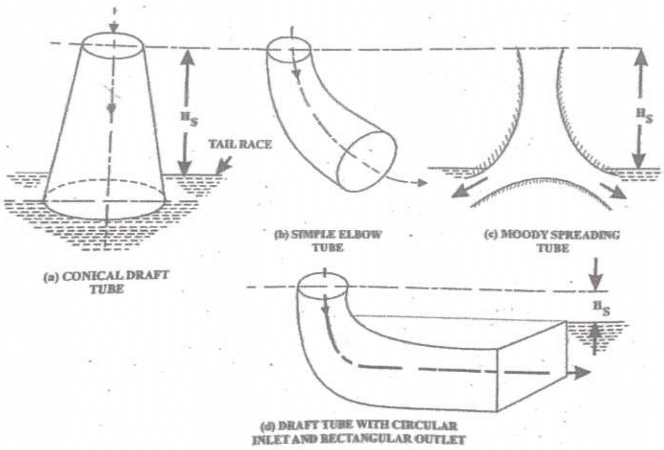
OR

VIII.a	**S.No** **Range of specific speed (in SI units)** **Type of turbine selected** 1. Less than 30 — Single jet pelton wheel 2. 30 - 50 — Multi-jet pelton wheel 3. 50 - 260 — Francis turbine 4. 260 - 860 — Kaplan turbine ***(ii) Selection based on head of water.*** Selection based on head of water is based on experience and observational factors only. Following table shows the type of turbine, to be used, for corresponding head of water. **S.No** **Head of turbine in m** **Type of turbine selected** 1. Less than 15 — Kaplan turbine 2. 30 - 60 — Kaplan turbine or Francis turbine (Preferably Kaplan turbine) 3. 60 - 150 — Francis turbine or Kaplan turbine (Preferably Francis turbine) 4. 150-240 — Francis turbine or Pelton wheel (Preferably Francis turbine) 5. 240 – 300 — Pelton wheel or Francis Turbine (preferably Pelton wheel) 6. Above 300 — Pelton wheel Turbine	Speed 4 + Head 3	7

<table>
<tr>
<td>VIII.b</td>
<td>The following are the important types of draft tubes which are commonly used :
(i) Conical draft tubes.
(ii) Spreading draft tubes.
(iii) Simple elbow draft tubes.
(iv) Elbow draft tube with ciecular inlet and rectangular outlet.



Conical Draft tube :- Outlet is always under the water level. Angle of divergence shouldn't be more than 9 to 10 degrees. It shold be long enough to reduce velocity at outlet to be about 1m/s. Submerged by nearly 1m in the tail race. Its efficiency is around 90%. Most suitable for Francis turbine.
Spreading draft tubes or hydraucone draft tubes :- Designed by Moody. Reduces whirling action. Efficiency is approximately 85%.
Simple elbow draft tube:- This requires lesser excavation for the installation. Efficiency is about 60%.
Elbow draft tube with circular inlet and rectangular outlet:- This has circular cross-section at the top and rectangular cross section at outlet. It recovers more kinetic head at outlet. It is generally used with Kaplan turbine and has an efficiency of about 70%.</td>
<td>Fig 4
+
Explanation
4</td>
<td>8</td>
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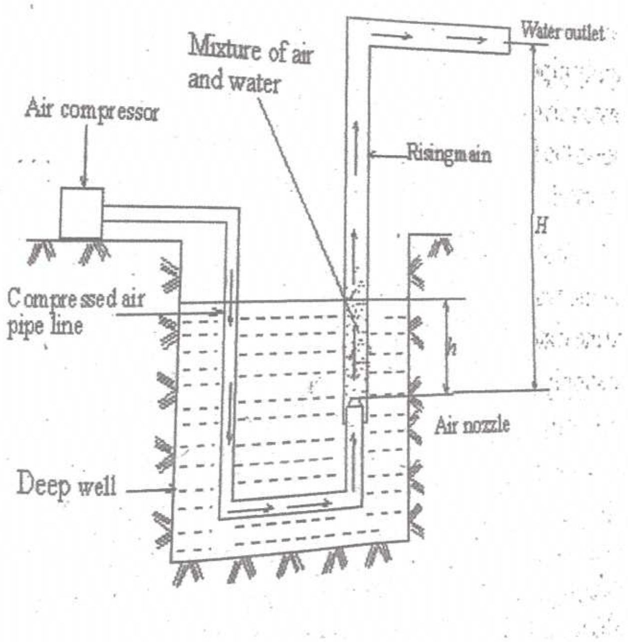
IX.a	**Cavitation:-** When the pressure of the flowing fluid is less than its vapour pressure, the fluid starts boiling and vapour bubbles are formed.When these vapour bubbles moves towards a zone of high pressure, they condense and finally collapse. Sudden collapsing of these vapour bubbles may create a very high pressure as high as 101 bar, there by a tremendous shock (pitting action) on the adjacent wall. The ultimate effect may be the break-down of the machine itself due to severe pitting and erosion of blade surface in region of cavitation. This phenomenon is called cavitation. Harmful effects are • Damage on vanes • Reduced head, power and efficiency • Noise and vibration Following factors aid the cavitation. • High runner speed • Restricted suction • Too high specific speed • Too high temperature of the flowing liquid **Priming-**The entire operation of completely filling suction pipe, casing and a portion of delivery pipe upto delivery valve with liquid to be pumped is called Priming. It is done to remove the entrapped air in the pump.if air is present sufficient pressure cannot be developed. Pressure generated by the impeller is directly proportional to the density of fluid. If the impeller is running in air, negligible pressure is generated because of low density of air hence no water is lifted by the pump. During priming delivery valve is kept closed. For small pumps priming is done by pouring water directly in the pump casing through a funnel provided at the top of the casing. Larger pumps are primed by evacuating the casing and suction pipe by a vaccum pump or steam ejector. In self priming pumps certain features are provided in construction for automatic priming.	Cavitation 4 + Priming 3	7
IX.b	Discharge, Q = 0.03 m^3/s Head, H = 20 m Length of pipe, l = 80 m Diameter of pipe, d = 0.1m Overall efficiency, η_o = 72% = 0.72 Co- efficient of friction = 0.01 Cross- sectional area of the pipe, a =$(\pi/4)d^2 = (\pi/4)(0.1)^2$ = 0.007854 m^2 Velocity of water flowing through the pipe,V = (Q/a) = (0.03/0.007854) = 3.82 m/s Manometric head of the pump, $H_m = H + h_f + \frac{V^2}{2g} = H + \frac{4flV^2}{2gd} + \frac{V^2}{2g}$ $= 20 + \frac{4 X 0.01 X 80 X 3.82^2}{2 x 9.81 X 0.1} + \frac{3.82^2}{2 X 9.81}$ = 44.54 m Power required to the centrifugal pump, $P = \frac{\rho g Q H_m}{\eta_o}$	Manometric head 4 (Equ 2+calcul 2) + Power 4(Equ 2+calcul 2)	8

$$= \frac{9.81 \times 0.03 \times 44.54}{0.72}$$

$= 18.21$ kW

OR

X.a	 An air lift pump is a simple pumping device used to lift water from a deep well or sump by utilizing the compressed air. It consists of an air compressor and an air pipe line fitted with nozzle at the one end and an open vertical delivery pipe or raising main encloses the nozzle. The compressed air is introduced at the bottom of the rising main and it issues from a set of air nozzles in the form of a fine spray. The air mixes with the rising main and reduces the density of air – water mixture. As soon as the pressure of the column of air-water mixture in the rising main of height H becomes less than the pressure due to the height of water column 'h' in the deep well, the water begins to flow at the outlet of the rising main. The flow rate depends upon the density of mixture in the rising main/delivery pipe. An air lift pump doesn't require a prime mover and it can pump water with solid particles without any damage to the system. The efficiency of pump varies from 20 to 40%.	Fig 4 + Explanation 3	7

X.b	Speed of pump, N = 60 rpm Dia of cylinder, D = 0.15 m Stroke length, L = 0.3 m Static head, $H_s = h_s + h_d$ =20 m Actual discharge, Q_{act} = 10 lps = 0.01 m^3/s Area of piston $A = (\pi/4)D^2 = (\pi/4) X (0.15)^2 = 0.01767\ m^2$ Theoretical discharge, $Q_{th} = \frac{2LAN}{60} = \frac{2 X 0.3 X 0.01767 X 60}{60} = 0.0106\ m^3/s$ Slip of the pump = Q_{th} - Q_{act} = 0.0106 – 0.01 = 0.0006 m^3/s Co- efficient of discharge, $C_d = \frac{Actual\ discharge}{Theoretical\ discharge} = \frac{Q_{act}}{Q_{th}}$ $= \frac{0.01}{0.0106} = 0.94$ Theoretical power required to drive the pump, $P = \rho g Q(h_s+h_d)$ = 9.81 X 0.0106 X 20 = 2.08 kW.	~~4~~ 4 x 1 (equation 1 + Calculation 4 x 1) ~~X 4~~	8