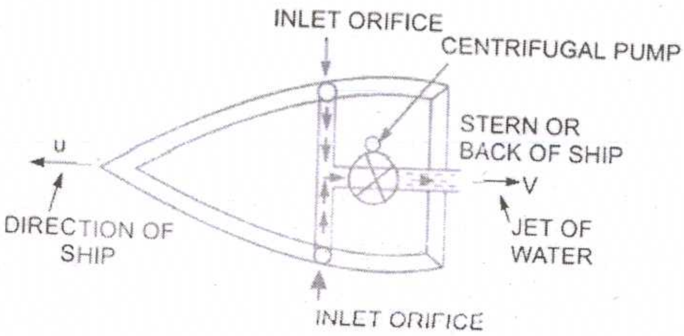
REVISION:2015

COURSE TITLE:HYDRAULIC MACHINES **COURSE CODE:6022**

Q. No.	SCORING INDICATOR	SPLIT UP SCORE	SUB TOTAL	TOTAL
	PART-A (Answer all questions)			
1	The force exerted by the jet on a plate which may be stationary or moving is called impact of jet	2	2	
2	a) Nozzle b) Spear c) Runner d) Buckets e) Casing f) Breaking jet	Any 4 4×0.5	2	
3	The difference between water level at the reservoir (head race) and the water level at the tail race is known as gross head or total head	2	2	
4	Unit power is the power developed by a turbine, working under a unit head $$P_U = \frac{P}{H^{\frac{3}{2}}}$$ Where, P = Power developed by the turbine (in kW) under a head of H	2	2	10
5	1. To obtain continuous supply of liquid at uniform rate 2. To save the power required to drive the pump 3. To run the pump at high speed without separation	Any 2	2	
	PART-B (Answer any 5 questions)			30
1		Fig.3	6	
	Jet propulsion is the propulsion of an object in one direction, produced by ejecting a jet of fluid in the opposite direction By the application of the jet propulsion principle a ship is driven through water. A jet of water which is discharged at the back of (stern) of the ship exerts a propulsive force on the ship. The ship carries centrifugal pumps which draw water from the surrounding sea. This water is discharged through the orifice provided at the back of the ship in the form of a jet. The reaction of the jet coming out at the back of the ship propels the ship in the opposite direction of the jet	3		

2.	Diameter of jet, d = 3 cm = 0.03m Velocity of jet, V = 10 m/s Weight of plate, W = 98.1 N Area of jet, $A = \frac{\pi}{4}d^2 = \frac{\pi}{4}(0.03)^2$ $= 0.0007065 m^2$ The angle through which the plate will swing is calculated by using equation, $\sin\theta = \frac{\rho A V^2}{W}$ $= \frac{1000X0.0007065X10^2}{98.1}$ = 0.72 $\theta = \sin^{-1}(0.72)$ $\theta = 46.06^0$	2 2 2	6	
3.	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 turbine (b) Radial flow turbine (c) Axial flow turbine (d) Mixed flow turbine 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) High specific speed turbine (b) Medium specific speed turbine (c) Low specific speed turbine.	Any 3 example 3×2	6	
4	A draft tube is a pipe or passage of gradually increasing cross sectional area which connects the runner exit to the tail race. It may be made of cast or plate steel or concrete. It must be air tight and under all conditions of operations its lower end must be submerged below the level of water in the tail race. A draft tube has the following functions to perform: 1. It permits a negative head to be established at the outlet of the runner and thereby increase the net head on the turbine. The turbine may be placed above the tail race without any loss of net head and hence turbine may be inspected properly. 2. It converts a large proportion of kinetic energy rejected at the outlet of the turbine into useful pressure energy. Without the draft tube, the kinetic energy rejected at the outlet of the turbine will go waste to the tail race	2 2 2	6	

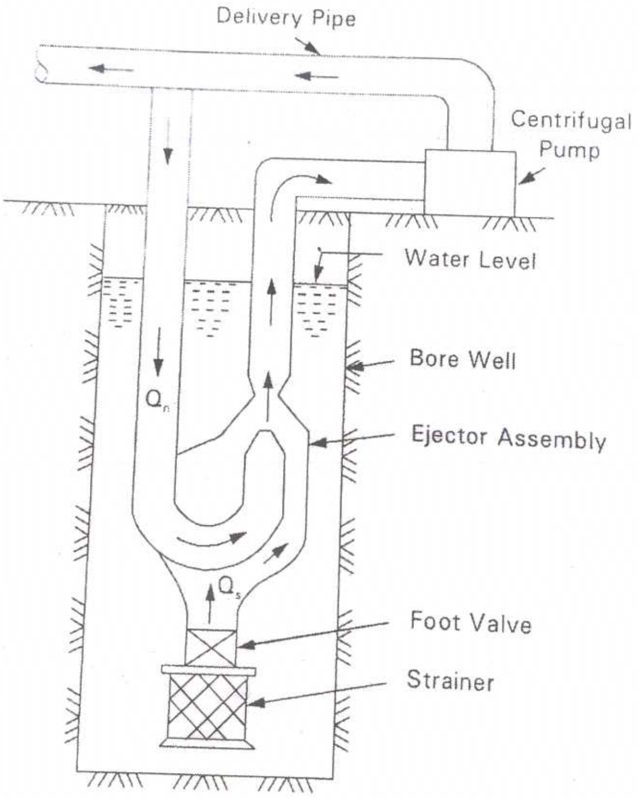
5	<table><tr><th>Francis turbine</th><th>Kaplan turbine</th></tr><tr><td>Radially inward or mixed flow turbine</td><td>Purely axial flow turbine</td></tr><tr><td>Runner vanes are not adjustable</td><td>Runner vanes are adjustable</td></tr><tr><td>Correct disposition of the guide and moving vanes are obtained at full load only</td><td>Correct disposition of the guide or moving vanes are obtained at any load</td></tr><tr><td>Runner blades range 16 to 24 in number</td><td>Runner blades may be 3 to 8</td></tr><tr><td>Medium head (60-250m)</td><td>Low head (upto 30m)</td></tr><tr><td>Medium flow rate</td><td>Large flow rate</td></tr><tr><td>Ordinary governor is used</td><td>Heavy duty governor is used</td></tr></table>	(4X 1.5) points	6	
6.	**Slip** The actual discharge (Q_{act}) of a pump is less than the theoretical discharge (Q_{th}) due to leakage. The difference between the theoretical discharge and actual discharge is called the slip of the pump. $$\text{Slip} = Q_{th} - Q_{act}$$	3	6	
	Significance of negative slip In most of the reciprocating pumps Q_{act} is less than Q_{th}, in such a case the value of C_d is less than unity and the slip of the pump is positive. However in some cases Q_{act} may be more than Q_{th}, in such a case C_d is more than unity and the slip will be negative. It occurs when there is direct connection between the suction and delivery sides before the end of suction stroke. This happens if the momentum of liquid in the suction pipe is large enough to open the delivery valve before the beginning of delivery stroke. The negative slip is possible in case of pumps having long suction pipe and a short delivery pipe, especially when these are operating at high speeds.	3		
7	A jet pump consists of conventional radial flow pump with jet nozzle at the suction end. The working of jet pump is as follows: • The suction side is completely filled with water and the pump is started • A stream of high pressure water from the delivery pipe is allowed to flow through the suction jet nozzle. The pressure energy of water is converted into kinetic energy due to which a local drop in the pressure takes place. Due to this pressure drop			

suction is created and water is sucked from the bore well. This action ensures a considerably large supply of low pressure water

- When the streams with different velocities mix (in the mixing zone), some pressure rise takes place in the mixing zone.
- After the mixing zone, there is a diverging section where further rise of pressure occurs due to decrease in velocity

3

6



Jet Pump

Fig.3

PART-C

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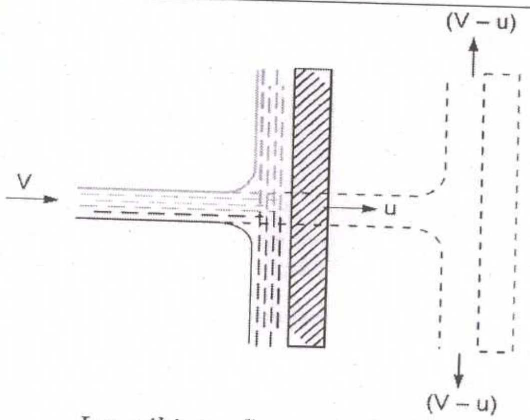
III.a



Jet striking a flat vertical moving plate.

Fig.2

Fig. shows a jet of water striking a flat vertical

	plate moving with a uniform velocity away from the jet. Let V = Velocity of the jet a = area of cross section of the jet u = velocity of the flat plate In this case, the jet does not strike the plate with a velocity V, but it strikes with a relative velocity, which is equal to the absolute velocity of jet of water minus the velocity of the plate. Hence relative velocity of the jet with respect to the plate $= (V-u)$ Mass of water striking the plate per second $= \rho \times$ Area of jet $\times$ velocity with which jet strikes the plate $= \rho a \times [V-u]$ Force exerted by the jet on the moving plate in the direction of jet F_x = Mass of water striking per sec $\times$[Initial velocity with which water strikes - Final velocity] $= \rho a(V-u)[(V-u)-0]$ $= \rho a(V-u)^2$ In this case, the work will be done by the jet on the plate, as plate is moving. For the stationary plates, the work done is zero. Work done per second by the jet on the plate, $= \text{Force} \times \frac{\text{Distance in the direction of force}}{\text{Time}}$ $= F_x \times u$ $\mathbf{= \rho a(V-u)^2 \times u}$	6	8	
III.b	Diameter of jet, $d = 80\text{mm} = 0.08\text{m}$ Area of jet, $A = \frac{\pi}{4}d^2 = \frac{\pi}{4}(0.08)^2$ $= 0.005024\text{m}^2$ Velocity of jet, $V = 30$ m/s Angle between jet and plate, $\theta = 60^0$ 1. Force exerted by the jet on the plate in the direction normal to the plate (F_N) $F_N = \rho AV^2 \sin\theta)$ $F_N = 1000 \times 0.005024 \times 30^2 \sin 60$ $\mathbf{F_N = 3915.8\ N}$ 2. Force exerted by the jet on the plate in the direction of jet (F_x)	4 3	7	

	$F_x = \rho A V^2 \sin^2\theta$ $F_x = 1000 \times 0.005024 \times 30^2 \sin^2 60$ **F_x = 3391.2 N**			
IV.a	Diameter of jet, d = 8 cm = 0.08m Area of jet, $A = \frac{\pi}{4} d^2 = \frac{\pi}{4}(0.08)^2$ $= 0.005024 m^2$ Velocity of jet, V = 25 m/s Velocity of plate, u = 25 m/s Angle of deflection of the jet = 165^0 Angle made by the relative velocity at the outlet of the plate, $\theta = 180 - 165^0 = 15^0$ 3. Force exerted by the jet on the plate in the direction of jet $F_x = \rho A (V-u)^2 (1+\cos\theta)$ $F_x = 1000 \times 0.005024 (25-8)^2 (1 + \cos 15)$ **F_x = 2854.39 N** 4. Work done by the jet on the plate per second $= F_x \times u$ = 2854.39 × 8 = 22835 Nm/s **Power of the jet = 22835 W** = 22.835 kW 5. Efficiency of the jet, $\eta = \frac{\text{Output}}{\text{Input}}$ $= \frac{\text{Work done by jet per second}}{\text{Kinetic energy of jet per second}}$ Kinetic energy of jet per second $= \frac{1}{2}(\rho A V) V^2$ $= \frac{1}{2}(1000 \times 0.005024 \times 25) 25^2$ = 39250 W $\eta = \frac{22835}{39250}$ **η = 58.17%**	3 3 2	8	
IV.b	The force exerted by a single moving plate is not practically feasible. In actual practice a large number of plates are mounted on the circumference of a wheel at a fixed distance apart as shown in figure. The jet strikes a plate and due to force exerted by the jet on the plate, the wheel starts moving and the second plate mounted on the			

wheel appears before the jet, which again exerts the force on the second plate. Thus each plate appears successively before the jet and the jet exerts force on each plate. The wheel starts moving at constant speed.

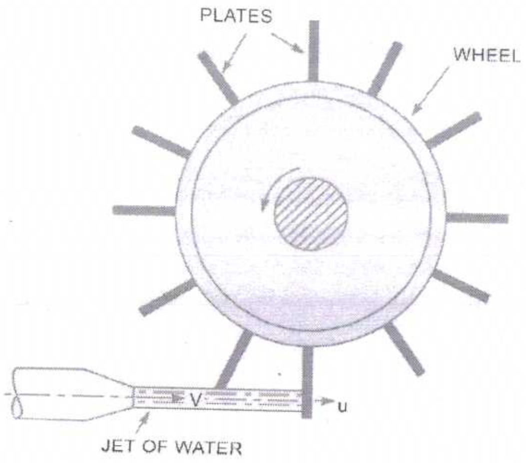


Fig.3

7

Let V = velocity of jet
D = Diameter of jet
a = Cross-sectional area of jet
u = Velocity of vane

The mass of water coming out from the nozzle per second is always in contact with the plates are considered.
Hence mass of water per second striking the series of plates = ρaV
The jet strikes the plate with a velocity = (V-u)
After striking the jet moves tangential to the plate and hence the velocity component in the direction of motion of plate is equal to zero.

The force exerted by the jet in the direction of motion of plate,

F_x = Mass per second[Initial velocity- Final velocity]

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

$\mathbf{F_x = \rho aV[V-u]}$

Work done by the jet on the series of plates per second
= Force × Distance per second on the direction of force
= Fx × u

Work done by the jet = $\rho aV[V-u] \times u$

Kinetic energy of the jet per second

$$= \frac{1}{2}mV^2 = \frac{1}{2}(\rho aV) \times V^2$$

$$= \frac{1}{2}\rho aV^3$$

4

Efficiency ,

$$\eta = \frac{\text{Work done per second}}{\text{Kinetic energy per second}}$$

	$\eta = \frac{\rho aV[V-u] \times u}{\frac{1}{2}\rho aV^3}$ $\eta = \frac{2u[V-u]}{V^2}$			
V.a	Number of jets , $n = 2$ Diameter of jet, $d = 200\ mm = 0.2m$ Area of jet, $a = \frac{\pi}{4}d^2 = \frac{\pi}{4}(0.2)^2$ $= 0.0314m^2$ Shaft power , $P = 15000\ kW = 15 \times 10^6\ W$ Net head , $H = 400m$ Co-efficient of velocity, $C_V = 0.97$ Velocity of each jet , $V_1 = C_V\sqrt{2gH}$ $= 0.97\sqrt{2 \times 9.81 \times 400}$ $= 85.93\ m/s$ Discharge of each jet, $q = aV_1$ $= 0.314 \times 85.93$ $= 2.698\ m^3/s$ Total discharge, $Q = nq$ $= 2 \times 2.698$ $= 5.396\ m^3/s$ Overall efficiency $\eta = \frac{P}{\rho gQH} \times 100$ $= \frac{15 \times 10^6}{1000 \times 9.81 \times 5.396 \times 400} \times 100$ **$\eta = 70.84\%$**	4 4	8	
V.b	**Hydraulic efficiency (η_h)** It is defined as the ratio of power given by water to the runner of a turbine (R.P.) to the power supplied by the water at the inlet of the turbine (W.P.) $\eta_h = \frac{\text{Power delivered to runner}}{\text{Power supplied at inlet}}$ $\eta_h = \frac{R.P.}{W.P.}$ **Mechanical efficiency (η_{mech})** It is defined as the ratio of power available at the shaft of a turbine (S.P.) to the power delivered to the runner (R.P.) $\eta_{mech} = \frac{\text{Power available at the shaft of the turbine}}{\text{Power delivered by water to the runner}}$	2 2	7	

$$\eta_{mech} = \frac{S.P.}{R.P.}$$

Overall efficiency (η_o)

It is defined as the ratio power available at the shaft of a turbine (S.P.) to the power supplied by the water at the inlet of the turbine (W.P.)

$$\eta_o = \frac{\text{Power available at the shaft of the turbine}}{\text{Power delivered by water to the runner}}$$

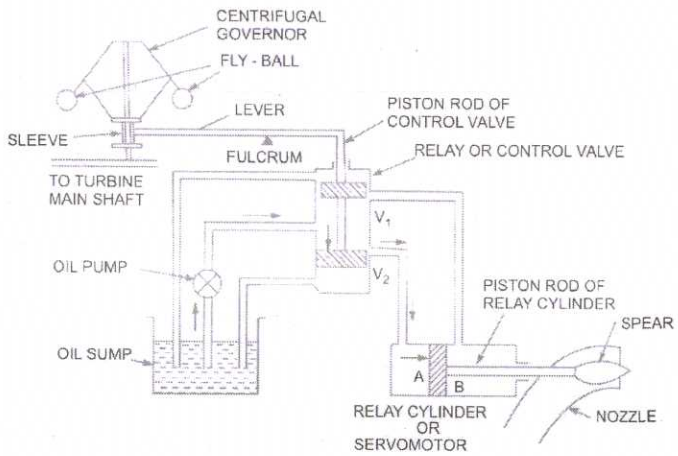
$$\eta_o = \frac{S.P.}{W.P.}$$

$$\eta_o = \frac{S.P.}{R.P.} \times \frac{R.P.}{W.P.}$$

$$\eta_o = \eta_{mech} \times \eta_h$$

3

VI.a



Governing of Pelton turbine.

Fig.5

8

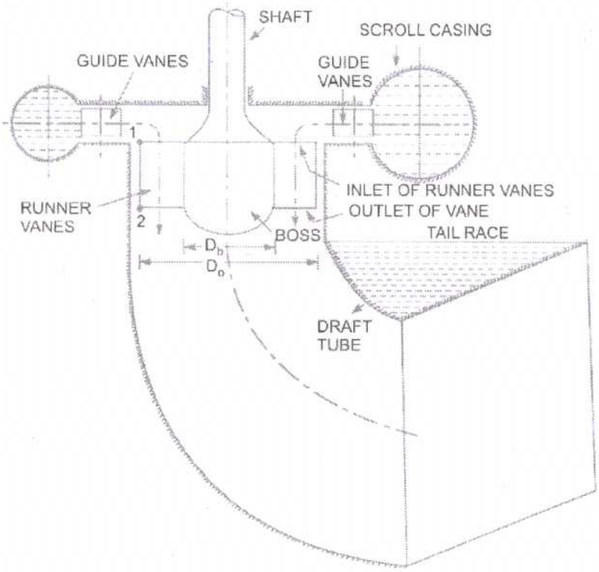
Governing of impulse turbine is done by means of oil pressure governor which consist of the following parts

1. Oil sump
2. Gear pump (oil pump)
3. The servomotor (relay cylinder)
4. The control valve
5. Centrifugal governor
6. Pipes connecting oil sump with control valve and control valve with servomotor
7. Spear rod or needle

Figure shows the position of the piston, control valve, and fly-balls of the centrifugal governor, when the turbine is running at the normal speed.

When the load on the generator decreases the speed of the generator increases. This increases the speed of the turbine beyond the normal speed. The centrifugal governor which is connected to the turbine main shaft,

	will be rotating at an increased speed. Due to increase in the speed of the centrifugal governor, the fly-balls move upward due to the increased centrifugal force on them. Due to the upward movement of the fly-balls, the sleeve will also move upward. A horizontal lever supported over a fulcrum and the piston od of the control valve moves downward. This closes the valve V_1 and opens the valve V_2. The oil, pumped from the oil pump to the control valve under pressure will flow through the valve V_2 to the servomotor and will exert force on the face A of the piston of the relay cylinder. The Piston along with piston rod and spear will move towards right. This decrease of area of flow will reduce the rate of flow of water to the turbine which consequently produces the speed of the turbine. When the speed of the turbine becomes normal, the fly-balls, sleeve, lever and Piston rod of control valve come to its normal position as shown in figure When the load on the generator increases, the speed of the generator and hence of the turbine decreases. The speed of the centrifugal governor also decreases and hence centrifugal force acting on the fly-balls also reduces. This brings the fly-balls in the downward direction. Due to this, the sleeve moves downward and the lever turns about the fulcrum, moving the piston rod of the control valve in the upward direction. This closes the valve V_2 and opens the valve V_1.The oil under pressure from the control valve, will move through valve V_1 to the Servomotor and will exert a force on the face B of the Piston. This will move the piston along with the piston rod and spear towards left, increasing the area of flow of water at the outlet of the nozzle. This will increase the rate of flow of water to the turbine and consequently the speed of the turbine will also increase, till the speed of the turbine becomes normal.	3		
VI.b	Shaft power , $P = 3.85MW$ $= 3.85\times10^6$ W Net head , $H = 220m$ Discharge, $Q = 2000$ lps $= 2\ m^3/s$ Overall efficiency $\eta = \frac{P}{\rho g Q H} \times 100$ $= \frac{3.85 \times 10^6}{1000 \times 9.81 \times 2 \times 220} \times 100$ **$\eta = 89.19\%$**	7	7	

VII.a	 *Main components of Kaplan turbine.* Kaplan turbine is an axial flow reaction turbine. This turbine is suitable where a large quantity of water at low head is available. The main parts of the Kaplan turbine are : 1. Scroll casing 2. Guide vane mechanism 3. Hub with vanes or runner of the turbine 4. Draft tube Figure shows the main parts of Kaplan turbine. The runner of a Kaplan turbine consists of a hub fixed to the shaft. On the hub adjustable vanes are fixed. The water from the penstock enters the scroll casing and then moves to the guide vanes; the water turns through 90^0 and flows axially through the runner as shown in figure. The runner of a Kaplan turbine has 4 to 6 blades and it closely resembles a ship's propeller.	Fig.5 3	8	

<table>
<tr>
<td>VII.b</td>
<td>Specific speed is defined as the speed of a turbine which is identical in shape, geometrical dimensions, blade angles, gate openings etc., with the actual turbine but of such a size that it will develop unit power when working under unit head

Specific speed plays an important role for selecting the type of the turbine. Also the performance of the turbine can be predicted by knowing the specific speed of the turbine</td>
<td>2</td>
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<tr>
<td></td>
<td>1. If the runner of high specific speed is used for a given head and unit power output, the overall cost of installation is lower. The selection of too high specific speed reaction runner would reduce the size of the runner to such an extent that the discharge velocity of water into the throat of draft tube would be excessive. This is objectionable because a vacuum may be created in the extreme case.
2. The runner of too high specific speed with high available head increases the cost of turbine on account of high mechanical strength required.
3. The runner of too low specific speed with low available head increases the cost of generator due to the low turbine speed.
4. An increase in specific speed of turbine is accompanied by lower maximum efficiency and greater depth of excavation of the draft tube. In choosing a high specific speed turbine, an increase in cost of excavation of foundation and draft tube should be considered in addition to the efficiency.</td>
<td>3</td>
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<td>The type of turbine for different specific speed is given in the table

<table>
<tr><th>Specific speed (SI unit)</th><th>Types of turbine</th></tr>
<tr><td>8.5 to 30</td><td>Pelton wheel with single jet</td></tr>
<tr><td>30 to 50</td><td>Pelton wheel with two or more jets</td></tr>
<tr><td>51 to 250</td><td>Francis turbine</td></tr>
<tr><td>255 to 860</td><td>Kaplan or Propeller turbine</td></tr>
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<tr>
<td>VIII. a</td>
<td>Net head , $H = 30m$
Discharge, $Q = 10\ m^3/s$
Speed, $N = 300\ rpm$
Overall efficiency, $\eta = 90\% = 0.9$
Overall efficiency
$$\eta = \frac{P}{\rho g Q H}$$</td>
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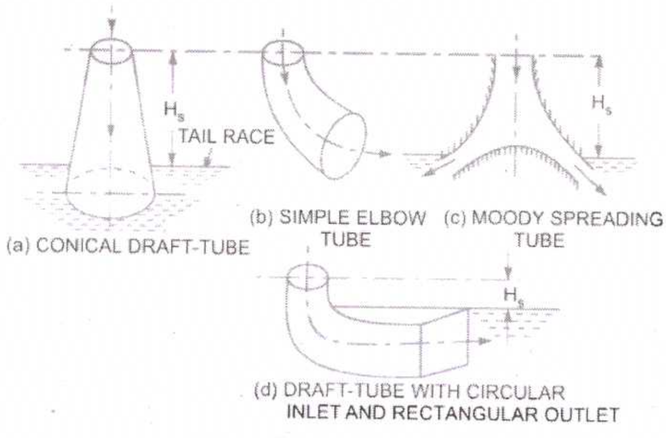
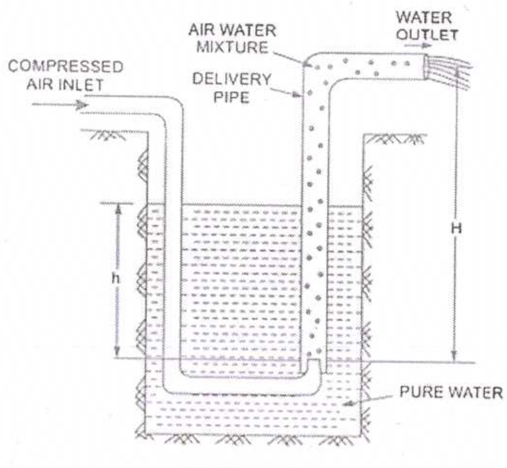
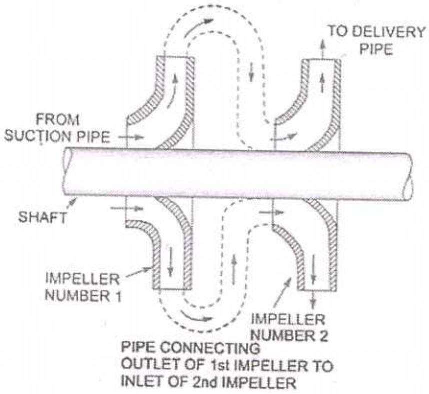
</table>

	1. Power generated by the turbine, $P = \eta \rho g Q H$ $P = 0.9 \times 1000 \times 9.81 \times 10 \times 30$ $= 2648700 W$ $= 2648.7 kW$ **P = 2.6487 MW**	3	8	
	2. Specific speed of the turbine(N_S), $N_s = \frac{N\sqrt{P}}{H^{\frac{5}{4}}}$ $N_s = \frac{300\sqrt{2648.7}}{30^{\frac{5}{4}}}$ **N_S = 219.9 rpm**	3		
	3. Type of the turbine: **As the specific speed lies between 51 to 250 the turbine is Francis turbine**	2		
VIII. b	 *Types of draft-tubes.*	Fig.4		
	Conical draft tube: Takes the form of the frustum of a cone with central angle less than 8^0 so as to prevent the possibility of flow separation. This draft tube has an efficiency of about 90% and is generally employed for low speed and vertical shaft turbines **Simple elbow tube:** It finds application where the length of the shaft has to be minimum so as to cut short the volume of excavation. Because of bend there is a loss of head and so the elbow type draft tube has a low efficiency of the order of 60% **Moody spreading tube:** It is provided with a central core of conical shape which reduces whirling action of discharge water. The draft tube has an efficiency of 85% and is suited particularly for	3	7	

	helical flows which occur when the water leaves the runner with a whirl component **Draft tube with circular inlet and rectangular outlet:** Theses draft tube change from circular section in the vertical leg to the rectangular section in the horizontal leg takes place in the bend. The draft tube efficiency is about 85%			
IX.a	Total head (h_s+h_d)= H = 50m Flow rate Q = 60 lps = 0.060 m^3/s Overall efficiency, η_o = 70% = 0.7 Overall efficiency, $\eta_o = \frac{\rho g Q H}{P}$ Power required, $P = \frac{\rho g Q H}{\eta_o}$ $P = \frac{1000 \times 9.81 \times 0.06 \times 50}{0.7}$ Power required to drive the pump, P = 42042.8 W P = 42.042kW	5 3	8	
IX.b	 *Air lift pump.* **Air lift pump** The air lift pump is a device which is used for lifting water from a well or sump by using compressed air. The compressed air is made to mix with water. The density of mixture of air and water is reduced. The density of this mixture is much less than that of pure water. Hence a very small column of pure water can balance a very long column of air water mixture. This is the principle on which air lift pump works. Figure shows the air lift pump. The compressed air is introduced through one or more nozzles at the foot of the delivery pipe, which is fixed in the well from which water	Fig. 4 3	7	

	is to be lifted. In the delivery pipe a mixture of air and water is formed. The density of this air water mixture becomes very less as compared to the density of pure water. Hence a small column of pure water will balance a very long column of air water mixture. This air water mixture will be discharged out of the delivery pipe. The flow will continue as long as there is supply of compressed air.			
X.a	Stroke, $L = 400mm = 0.4\ m$ Diameter, $D = 200mm = 0.2m$ Total head $(h_s+h_d) = H = 50m$ Speed $N = 150\ rpm$ Overall efficiency, $\eta_o = 85\% = 0.85$ Theoretical discharge $Q_a = \frac{2LAN}{60}$ $= \frac{2 \times 0.4 \times \frac{\pi}{4} \times 0.2^2 \times 150}{60}$ $= 0.06283\ m^3/s$ Overall efficiency, $\eta_o = \frac{\rho g Q H}{P}$ Power required, $P = \frac{\rho g Q H}{\eta_o}$ $P = \frac{1000 \times 9.81 \times 0.06283 \times 50}{0.85}$ Power required to drive the pump, $P = 36257.67\ W$ $P = 36.257kW$	3 2 3	8	
X.b	**Multistage Centrifugal pumps** If a centrifugal pump consists of two or more impellers, the pump is called a multistage centrifugal pump. The impellers may be mount on the same shaft or on different shafts. A multistage pump is having the following two important functions: 1. To produce high head 2. To discharge a large quantity of liquid If a high head is to be developed, the impellers are connected in series (or on the same shaft) while for discharging large quantity of liquid, the impellers are connected in parallel. For developing a high head, a number of impellers are mounted in series or on the same shaft.	Fig. 4		



Two-stage pumps with impellers in series.

7

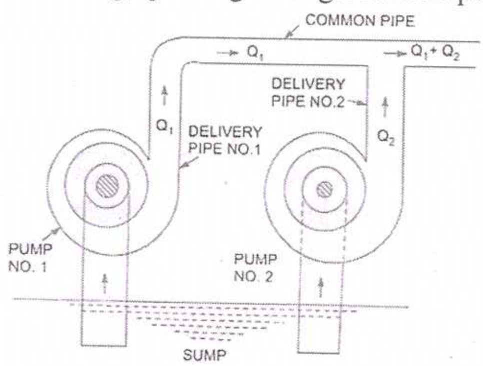
The water from the suction pipe enters first impeller at inlet and is discharged at outlet with increased pressure. The water with increased pressure from the outlet of the first impeller is taken to the inlet of the second impeller with the help of a connecting pipe. At the outlet of the second impeller, the pressure of water will be more than the pressure of water at the outlet of the first impeller. Thus if more impellers are mounted on the same shaft, the pressure at the outlet will be increased further. 3

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



Pumps in parallel.

For obtaining high discharge, the pumps should be connected in parallel. Each of the pumps lifts water from a common sump and discharges 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 = $n \times Q$