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# ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

# Mechanical Engineering

## Test-3 : Fluid Mechanics + Fluid Machinery + Power Plant

Name : ..........................................................................

Roll No :

| Test Centres | | | Student's Signature |
|---|---|---|---|
| Delhi ☑ | Bhopal ☐ | Jaipur ☐ | |
| Pune ☐ | Kolkata ☐ | Hyderabad ☐ | |

**Instructions for Candidates**

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

**FOR OFFICE USE**

| Question No. | Marks Obtained |
|---|---|
| Section-A | |
| Q.1 | 41 |
| Q.2 | 01 |
| Q.3 | – |
| Q.4 | 19 |
| Section-B | |
| Q.5 | 20 |
| Q.6 | 40 |
| Q.7 | – |
| Q.8 | – |
| **Total Marks Obtained** | 121 |

Signature of Evaluator: Gaurav Sharma ..................

Cross Checked by ..........................

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## IMPORTANT INSTRUCTIONS

**CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.**

### DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

### DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

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**Section A : Fluid Mechanics + Fluid Machinery + Power Plant**

**Q.1 (a)** An impulse turbine has nozzle inclined to 25° to the plane of rotation. The inlet and exit angle of the moving blades are equal, the blade friction factor is 0.8 and the mean diameter of the blade is 0.6 m. The steam leaves the nozzle with a velocity of 780 m/s. Determine the optimum value of the blade angles, the steam flow rate required to produce 20 kW power and the blade efficiency.

**[12 marks]**

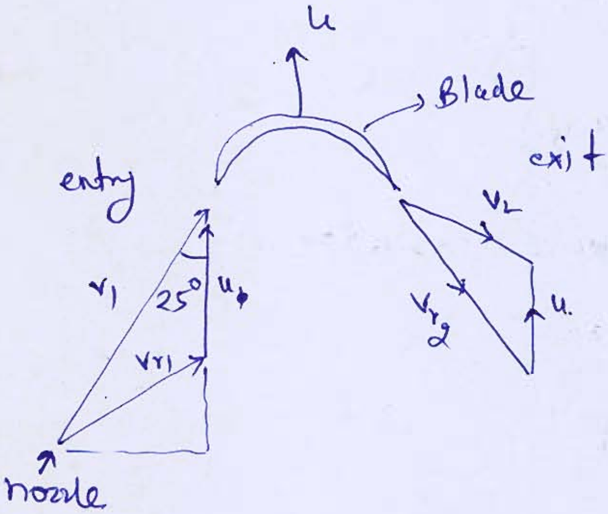
Ans

$U = 780$ m/sec

$k = 0.8$

$d = 0.6$ m

$V_1 = 780$ m/sec



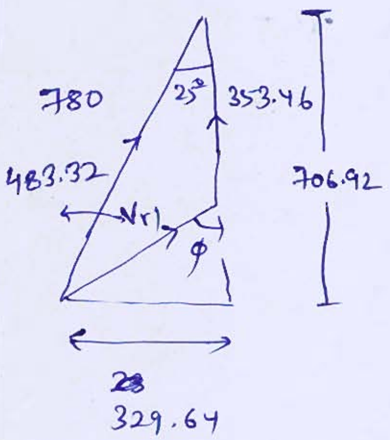

for impulse turbine

at maxi $\eta$

$$\frac{u}{V_1} = \frac{\cos\alpha}{2}$$

$$u = \frac{\cos 25^\circ}{2} \times V_1$$

$$= 353.46 \ \frac{m}{sec}$$




Blade Angle at entry

$$\tan\phi = \frac{329.64}{706.92 - 353.46}$$

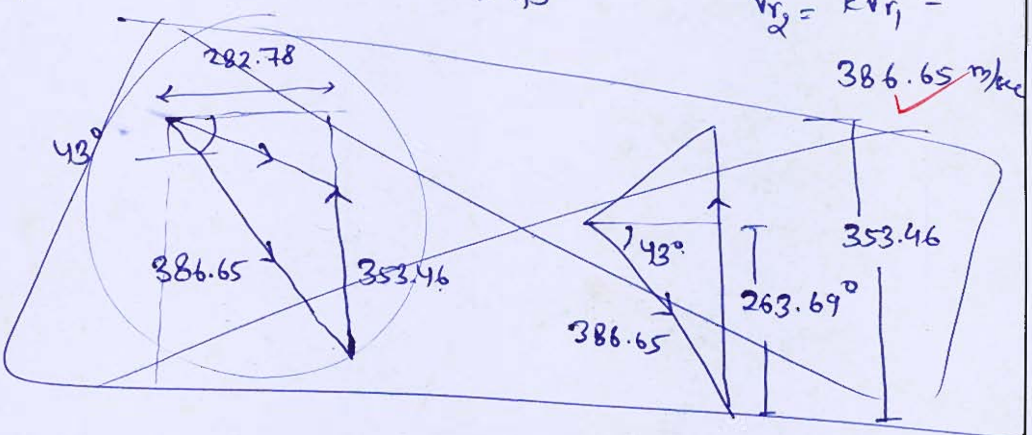
$$\boxed{\phi = 43^\circ}$$

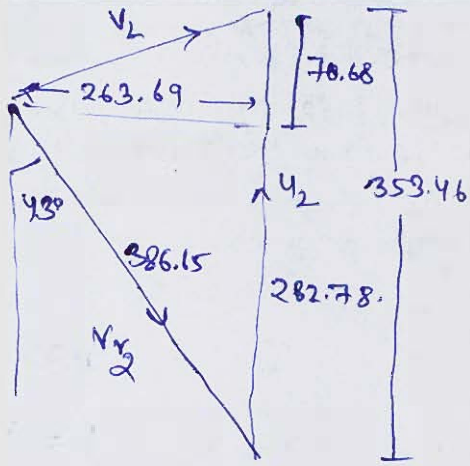
Blade Angle at exit

$= 43°$

$V_{r_2} = k V_{r_1} =$

$386.65$ m/sec






$V_{w_2} = 70.68$ m/sec

$$\text{power} = \dot{m}(u_1 V_{w_1} - u_2 V_{w_2})$$

$$20\times10^3 = \dot{m}(353.46\times706.92 - 353.46\times70.68)$$

$$\dot{m} = 0.08893 \text{ kg/sec}$$

$$\boxed{\dot{m} = 320.16 \text{ kg/hr}}$$

Blade

$$\eta = \frac{\text{power output}}{\frac{1}{2}\dot{m}V_1^2} = \frac{20\times10^3}{\frac{1}{2}\times0.08893\times780^2}\times100$$

$$\boxed{\eta = 73.93\ \%}$$

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Do not write in this margin

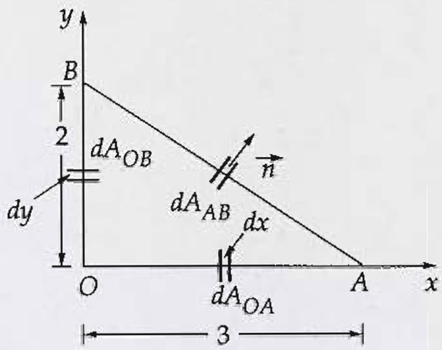
Q.1 (b) Explain the working principle of a Electrostatic Precipitator (ESP) with the help of a neat and schematic diagram. Describe the main components of an ESP and their functions. Also, discuss the various factors that influence the performance of an ESP, and highlight the key advantages and disadvantages of using ESP.

**[12 marks]**

Q.1 (c) A stream function is given by

$\psi = 3x^2y + 4(2+t)y^2$

Find the flow rates across the faces of the triangular prism *OAB* shown in the figure, having a thickness of 1 unit in the *z*-direction at time $t = 2$.




**[12 marks]**

Ans

thickness = 1 unit

flowrate $= \psi_1 - \psi_2$

at $t=2$

$\psi$ at $(0,0) = 3\times0 + 4\times2\times0 = 0$

$\psi$ at $(3,0) = 0$

$\psi$ at $(0,2) = 0 + 4(2+2)\times4$

$= 64$

flow rate through OB $= \psi(0,2) - \psi(0,0)$

$= 64 - 0$

$= 64$ unit/sec

flow rate through OA $= \psi(3,0) - \psi(0,0)$

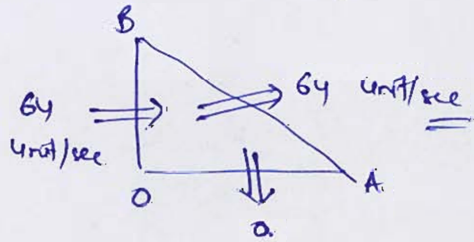
$= 0 - 0$

$= 0$ unit/sec

flow rate through AB $= \psi(0,2) - \psi(3,0)$

$= 64 - 0$

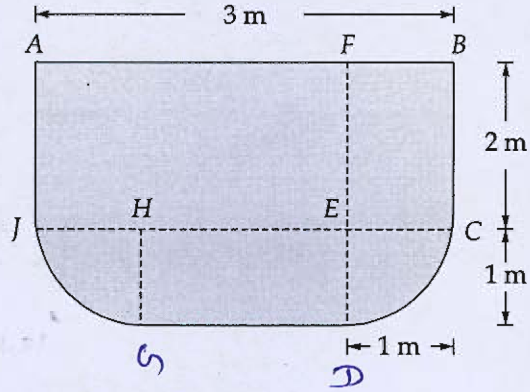
$= 64$ unit/sec




12

**Q.1 (d)** A container of geometry shown in figure contains a liquid of specific gravity 0.7 upto depth of 3 m. Determine the magnitude and direction of hydrostatic pressure force per unit length of container exerted on its vertical *BC*, curved corner *CD* and horizontal bottom *DG*.

**[12 marks]**



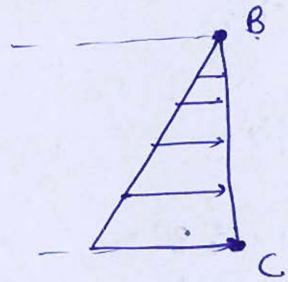

hydrostatic pressure force

width = 1 m

on BC = $\rho g \bar{h} \times$ Area

= 13734 N.

= 13.734 kN




direction → ⟶ horizontal.

$\rho g = 0.7 \times 1000 \times 9.81$
$= 6867 \ N/m^3$

$\bar{h} = 2/1 = 1 \ m$

Area = $2 \times 1$
$= 2 m$

force on CD

(1) horizontal force

$= \rho g \bar{h} \times$ Area ← projected Area = $r \times 1$ $= 1 \times 1 = 1 \ m^2$

$\bar{h} = 2 + \frac{1}{2} = 2.5 \ m$

$= 6867 \times 1 \times 2.5$

$= 17167.5$ N

$= 17.1675$ kN ⟶

(2) Verticle force

= (Volume of water above DC P) × $\rho g$

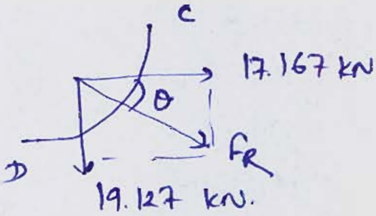
$= \left\{ \left( \frac{\pi r^2}{4} \right) \times 1 \right\} \times \rho g$
$+ 2 \times 1 \times 1$

$r = 1$ m

$= 2.7853 \times 6867$

$= 19127.33 \ N = 19.127 \ kN$ ↓

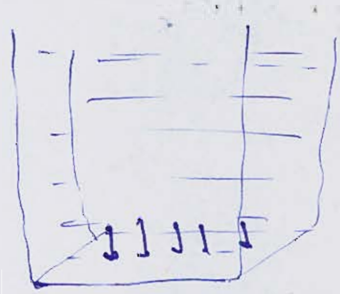
$\theta = \tan^{-1}\left(\frac{19.127}{17.167}\right)$




$= 48.07^{\circ}$ with Horizontal direction

force on DG

$= \rho g V$



volume $= 1 \times 1 \times 3$

$= 3\ m^3$

$F \Rightarrow 6867 \times 3 = 20601\ N = 20.601\ kN \downarrow$ (downward)

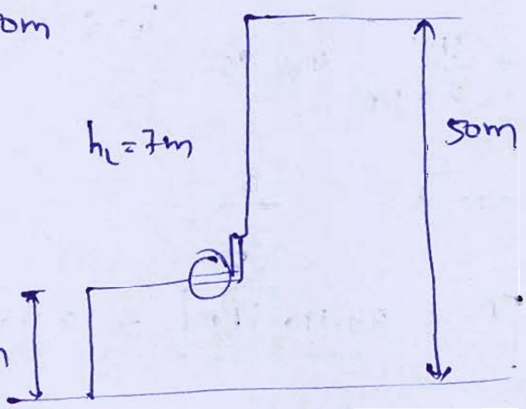
12

Q.1 (e) A centrifugal pump lifts water under a static head of 50 m of which 4 m is suction lift. The suction and delivery pipes are both of 37 cm diameter. The friction loss in suction pipe is 2.5 m and in delivery pipe it is 7 m. The impeller is 0.6 m in diameter and 3.3 cm wide at outlet and runs at a speed of 1250 rpm. The exit blade angle is 20°. If the manometric efficiency of the pump is 85%. Determine the pressures at the suction and delivery ends of the pump and the discharge (assume the flow to be radial at the inlet).

**[12 marks]**

Ans

$H_m = 50 m$

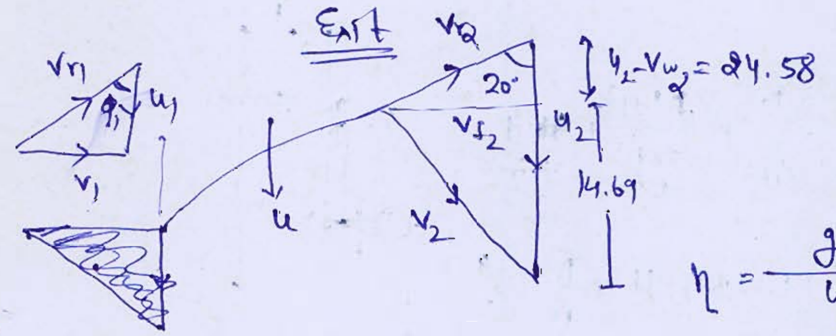



exit

$u_2 = \frac{\pi D N}{60}$

$= \frac{\pi \times 0.6 \times 1250}{60}$

$u_2 = 39.27$ m/sec




$\eta = \frac{g H_m}{u_2 V_{w_2}} = 0.85$

5

$\tan 20° = \frac{V_{f_2}}{u_2 - V_{w_2}} = \frac{V_{f_2}}{24.58}$

$\frac{9.81 \times 50}{0.85} = u_2 V_{w_2}$

$577.06 = u_2 V_{w_2}$

$V_{f_2} = 8.946$ m/sec

$V_{w_2} = 14.69$ m/sec

$Q = V_{f_2} \times (\pi D) \times t$

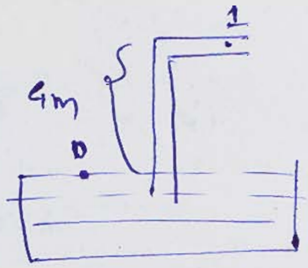
$= 8.946 \times \pi \times 0.6 \times 0.033$

$= 0.556$ m³/sec

$V_1 = \frac{Q}{A} = \frac{Q}{\left(\frac{\pi d^2}{4}\right)_{pipe}} = \frac{0.556}{\left(\frac{\pi \times 0.37^2}{4}\right)} = 5.171$ m/sec velocity in pipe = 5.171 m/sec

Applying Bernoulli equation

At suction




$$\frac{P_0}{\rho g} + 0 = \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 + h_L$$

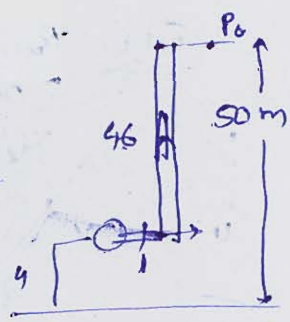
$h_L = 2.5m$

$$\frac{1.01325\times10^5}{1000\times9.81} = \frac{P_1}{\rho g} + \frac{5.171^2}{2\times9.8} + 4 + 2.5$$

$$10.3287 - 1.3628 - 4 - 2.5 = \frac{P_1}{\rho g}$$

absolute pressure $P_1 = 24.190$ kPa $= 2.4659$ m $\times \rho g$ ⇒ pressure head

at Exit




$$\frac{P_0}{\rho g} + 50 + 0 = \frac{P_1}{\rho g} + \frac{5.171^2}{2\times g} + 4 + 7$$

$$10.32 + 50 = 1.3628 + 11 + \frac{P_1}{\rho g}$$

$$P_1 = (47.957 \text{ m}) \times \rho g$$

$P_1 = 47.04$ kPa

Q.2 (a) In a reheat cy.cle, steam at 500°C expands in a H.P. turbine till it is saturated vapour. It is then reheated upto a temperature of 400°C and then expands in the L.P. turbine to 50°C. If the maximum moisture content of the turbine exhaust is limited to 18%. Determine

**(i)** the reheat pressure

**(ii)** the boiler pressure

**(iii)** the net specific work output

**(iv)** the cycle efficiency

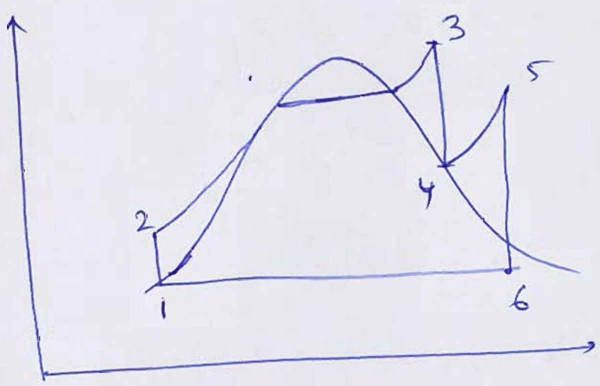
**(v)** the steam rate

Assume all process are ideal.

[Use Steam Tables attached at the end]

**[20 marks]**

Ans




1

$x_6 = 0.82$

**Q.2 (b)** A solid hemisphere of density ρ and radius $r$ floats with its plane base immersed in a liquid of density $\rho_l (\rho_l > \rho)$. Show that the equilibrium is stable and the metacentric height is

$$\frac{3}{8} r \left( \frac{\rho_l}{\rho} - 1 \right)$$

**[20 marks]**

**Q.2 (c)** A turbo-jet engine consumes air at the rate of 50 kg/s when flying at a speed of 1800 km/h. Calculate

**(i)** Exit velocity of the jet when the enthalpy change for the nozzle is 300 kJ/kg and velocity coefficient is 0.96.

**(ii)** Fuel flow rate is kg/s when air-fuel ratio is 70 : 1.

**(iii)** Thrust specific fuel consumption.

**(iv)** Thermal efficiency of the plant when the combustion efficiency is 95% and calorific value f fuel used is 42000 kJ/kg.

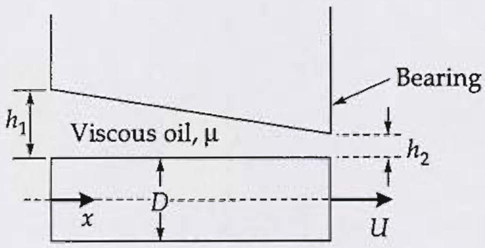
**(v)** Propulsive power

**(vi)** Propulsive efficiency

**(vii)** Overall efficiency

**[20 marks]**

Q.3 (a) (i) A shaft with diameter $D$ = 80 mm and a length 400 mm, as shown in figure is pulled with a constant velocity of U = 5 m/s through a bearing with variable diameter. The clearance between shaft and bearing, which varies from $h_1$ = 1.2 mm to $h_2$ = 0.4 mm, is filled with a Newtonian lubricant whose dynamic viscosity is 0.10 Pa.s. The shaft is rotating with a constant angular speed of $n$ = 1450 rpm in a bearing with variable diameter. The torque required to maintain the motion is




(ii) Define viscosity, state and explain Newton's law of viscosity. Derive the expression for shear stress in terms of velocity gradient. Support your explanation with a neat diagram.

**[10 + 10 marks]**

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**Q.3 (b)** **(i)** Explain radial flow reaction turbine. Describe its main components with the help of schematic diagram.

**(ii)** A Francis turbine with an overall efficiency of 75% is required to produce 150 kW power. It is working under a head (H) of 7.5 m. The peripheral velocity = $0.25\sqrt{2gH}$ and the radial velocity of flow at inlet is $0.95\sqrt{2gH}$. The wheel runs at 160 rpm and hydraulic losses in the turbine are 20% of the available energy. Assuming radial discharge, determine:

**(i)** The guide blade angle

**(ii)** The wheel angle at inlet

**(iii)** Diameter of wheel at inlet, and

**(iv)** Width of the wheel at inlet

**[10 + 10 marks]**

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**Q.3 (c)** The ultimate analysis of a coal used in steam generator is as follows carbon 63.0%, hydrogen 1.8%, sulphur 0.9%, nitrogen 1.7%, oxygen 1.4%, moisture 4.5% and ash 26.7% HHV of coal is 26 MJ/kg.

Analysis of flue gas reveals the following points.

$CO_2$ = 12.5%, CO = 1.7%, $O_2$ = 8%, $N_2$ = 77.8%

It is assumed that there is no unburnt carbon after combustion. Exhaust gas temperature is measured as 180°C, Unaccounted energy loss = 2.5% of HHV, Steam generation rate = 175 T/h, Steam condition at boiler outlet is equivalent to 120 bar and 500°C. Feed water inlet temperature is kept at 150°C. Heat of reaction for CO and $CO_2$ are 33 MJ/kg carbon and 9.5 MJ/kg carbon. Consider specific heat for dry flue gas as 1.05 kJ/kgK and ambient temperature as 35°C. Calculate

**(i)** The amount of dry flue gas produced per kg of fuel.

**(ii)** The dry exhaust loss and incomplete combustion loss per kg of fuel.

**(iii)** Efficiency of boiler

**(iv)** Burning rate of the fuel

**(v)** The percentage of excess air used

[Use Steam Table attached at the end]

**[20 marks]**

**Q.4 (a)** Air is flowing over a flate plate 500 mm long and 500 mm wide with a velocity of 5 m/s. The kinematic viscosity of air is given by $0.1 \times 10^{-4}$ m²/s. Find

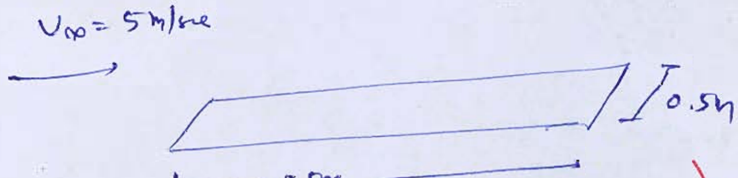
**(i)** the boundary layer thickness at the end of the plate.

**(ii)** shear stress at the end of the plate.

The velocity profile over the plate as $\frac{U}{U_\infty} = \sin\left(\frac{\pi}{2}\cdot\frac{y}{\delta}\right)$ and density of air 1.2 kg/m³

**[20 marks]**

Ans



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**Q.4 (b)** A 4800 kW gas turbine generating set operates with two compressor stages, the overall pressure ratio is 9 : 1. A high pressure turbine is used to drive the compressors, and a low pressure turbine drives the generator. The temperature of the gases at entry to the high pressure turbine is 650°C and the gases are reheated to 650° after expansion in the first turbine. The exhaust gases leaving the low pressure turbine are passed through a heat exchanger to heat air leaving the high pressure stage compressor. The compressors have equal pressure ratios and intercooling, is complete between the stages. The air inlet temperature to the unit is 25°C. The isentropic efficiency of each compressor stage is 0.82 and the isentropic efficiency of each turbine stage is 0.85, the heat exchanger thermal ratio is 0.8. A mechanical efficiency of 92% can be assumed for both the power shaft and compressor turbine shaft. Neglecting all pressure losses and changes in kinetic energy. Calculate

**(i)** The thermal efficiency.

**(ii)** Work ratio of the plant.

**(iii)** The mass flow in kg/s

Neglect the mass of the fuel and assume the following:

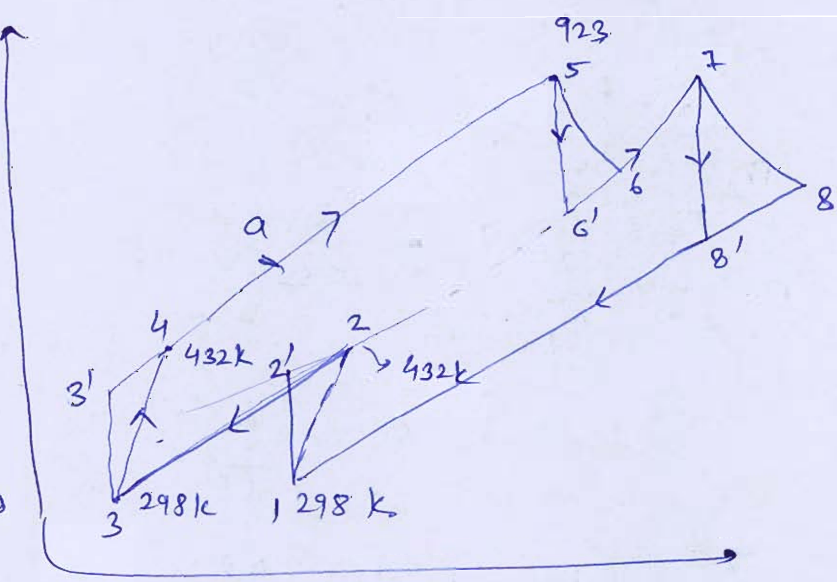
For air, $c_{pa}$ = 1.005 kJ/kgK and $\gamma$ = 1.4

For gases in the combustion chamber and in turbines and heat exchanger, $c_{pg}$ = 1.15 kJ/kgK and $\gamma$ = 1.333

**[20 marks]**

Ans

↑ T




s →

* Assuming air as Ideal gas

$Pv^{\gamma}$ = Const

Isentropic

$$\frac{T_2'}{T_1} = (P_r)^{\frac{\gamma-1}{\gamma}} = 3^{\frac{0.4}{1.4}} =$$

$$T_2' = 407.88 \text{ K}$$

$$\eta_{comp} = 0.82 = \frac{T_2' - T_1}{T_2 - T_1} \qquad T_2 = \text{~~430.92K~~} = 432 \text{ K}$$

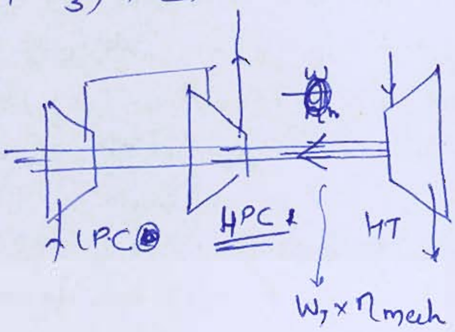
7

High P turbine is used to drive compressor.

So $\eta_{mech} \times C_{p_g}(T_5 - T_6) = C_{p_a}(T_4 - T_3) \times 2$

$0.92 \times 1.15 \times (923 - T_6)$

$= 1.005 \times (432 - 298) \times 2$




$T_6 = 658.92\ K$

$$\eta_T = \frac{T_5 - T_6}{T_5 - T_6'} = \frac{923 - 658.92}{923 - T_6'} = 0.85$$

$T_6' = 612.317\ K$

$$\frac{T_5}{T_6'} = (P_{r_1})^{\frac{0.323}{1.323}}$$

$P_{r_1} = 5.169$

$P_{r_1} \times P_{r_2} = 9$

$P_{r_2} = \frac{9}{5.169}$

$= 1.741$

$T_7 = 923$

$$\frac{T_7}{T_8'} = (P_{r_2})^{\frac{0.33}{1.33}}$$

$T_8' = 804.36$

$$\eta_T = \frac{T_7 - T_8}{T_7 - T_8'} = 0.85$$

$T_8 = 822.156\ K$

Heat exchanger thermal ratio = 0.8

$$\frac{C_{p_g}(T_8 - T_9)}{C_{p_g}(T_8 - T_4)} = 0.8$$

~~$T_9 = -0.8(822.156 - 432) + 822.156$~~

$T_9 =$ ~~849.386~~ ~~K~~ $510.032\ K$

(ii) power output = 4800 kW

$$\dot{m}_g \times c_{p_g} \times (T_8 - T_7) \times \eta_{turb\,mech} = 4800 \times$$

$$\boxed{\dot{m}_g = 44.9889 \text{ kg/sec}}$$

(i) thermal efficiency

$$q_{input} = \dot{m} \times c_{p_g}\left[(T_5 - T_4) + (T_7 - T_6)\right]$$

$$= \dot{m} \times 778.6 \text{ kW}$$

$$W_{output} = \dot{m} \times c_{p_g} (T_7 - T_8) \times \eta_{mech\,shaft}$$
(0.92)

$$= \dot{m} \times 106.69 \text{ kW}$$

$$\eta = \frac{106.69\,\dot{m}}{778.6\,\dot{m}} \times 100 = 13.7\,\%$$

(iii) Work ratio $= \frac{W_{out}}{W_{Total}}$

$$= \frac{\dot{m} \times 106.69}{\dot{m} \times 106.69 + \dot{m} \times c_{p_g}(T_5 - T_6)\,\eta}$$

$$= \frac{106.69}{106.69 + 279.39}$$

$$= 0.2763$$

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**Q.4 (c)** (i) A jet of water having a velocity of 30 m/s impinges on a series of vanes moving with a velocity of 14 m/s. The jet makes an angle of 25° to the direction of motion of vanes entering and leaves at an angle of 125°. Draw the velocity triangles at inlet and outlet and find

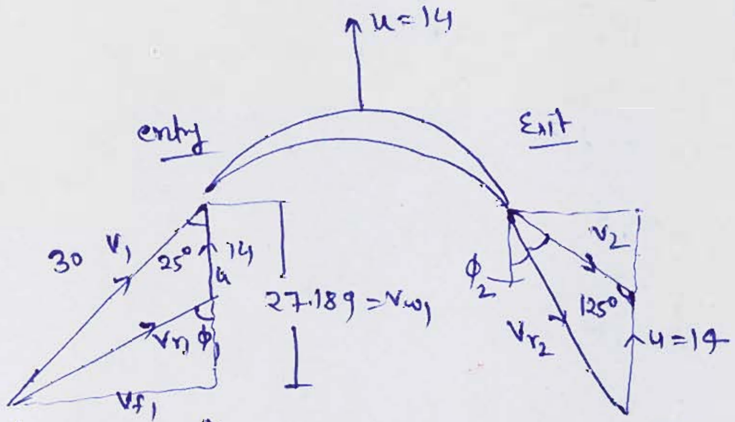
1. the angles of vanes tip so that water enters and leaves without shock.
2. the work done per unit weight of water entering and leaves without shock.
3. the efficiency

(ii) Derive the expression for the efficiency of a pelton turbine. Also determine the condition for maximum efficiency and obtain the expression for the maximum efficiency of turbine.

**[10 + 10 marks]**

Ans

(2)




$V_{r_1} = \sqrt{12.678^2 + (27.189-14)^2}$

$= 18.29$ m/sec

(i)

$\tan\phi_1 = \dfrac{12.678}{27.189-14}$

$\boxed{\phi_1 = 43.818^\circ}$

assuming no friction

$V_{r_2} = V_{r_1} = 18.29$ m/sec

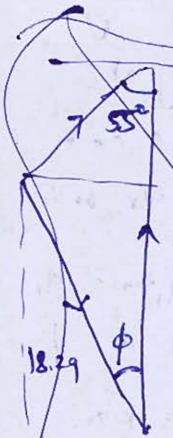
$\dfrac{\sin(90-\phi_2)}{14} = \dfrac{\sin 125^\circ}{18.29}$

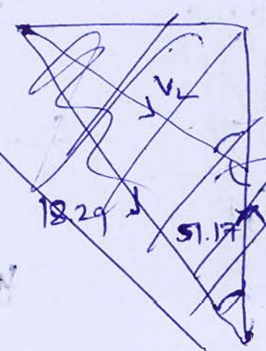
$\boxed{\phi_2 = 51.17^\circ}$

2 Workdone per unit wt

$= V_{w_1} * u_1 + V_{w_2} * u_2$

$= 27.189 \times 14 + V_{w_2} \times 14$




$\frac{V_2}{\sin 51.17} = \frac{18.29}{\sin 125}$

$V_2 = 17.393$ m/sec

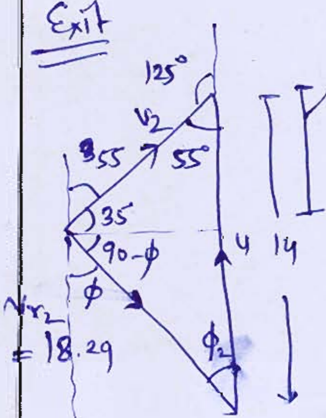
$V_{w_2} = V_2 \cos 55°$

$= 9.976$ m/sec

Work done $= 520.31$ w/kg

Efficiency $= \frac{\text{workdone}}{\frac{1}{2} V_1^2} = \frac{520.31}{\frac{1}{2} \times 30^2}$

Exit



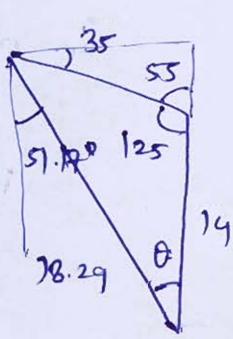

$\frac{18.29}{\sin 55°} = \frac{14}{\sin(90 - \phi + 35)}$ $\Rightarrow$ $\phi_2 = 86.17°$

(2) workdone $= u(V_{w_1} - V_{w_2})$

$= 14[27.189 - 12.778]$

$= 201.754$

(3) Blade $\eta = \frac{201.754}{0.5 \times 36^2} = 44.83\%$




$\eta = \frac{\text{work done}}{\text{K.E at Inlet}}$

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(ii) pelton turbine

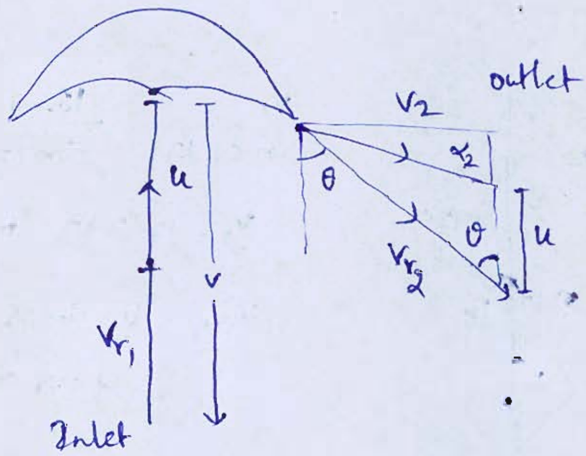
assume Nozzle velocity $= V$

Blade velocity $= u$

Relative velocity at entry and exit are $V_{r_1}$ & $V_{r_2}$

friction coefficient of Blade $= k$

$V_{r_2} = k V_{r_1}$




$$\text{workdone} = u\,(V_{w_1} + V_{w_2})$$

$$= u\left\{\left[V - u\right] + \left(V_{r_2}\cos\theta - u\right)\right\}$$

$$= u\left[(V - u) + k(V - u)\cos\theta - u\right]$$

$$= u\,[V - u]\,[1 + k\cos\theta]$$

efficiency

$$\eta = \frac{\text{Workdone}}{\frac{1}{2}V_1^2} = \frac{u(V-u)[1+k\cos\theta]}{\frac{1}{2}V^2}$$

$$\eta = 2\frac{u}{V}\left(1 - \frac{u}{V}\right)[1 + k\cos\theta]$$

assume $\frac{u}{V} = \rho$

$$\eta = 2\rho(1-\rho)\,[1 + k\cos\theta]$$

for maximisation $\frac{d\eta}{d\rho} = 0$ $\quad 1 - 2\rho = 0 \quad \rho = \frac{1}{2}$

$$\boxed{\frac{u}{V} = \frac{1}{2}}$$

$$\eta_{max} = 2 \times \frac{1}{2} \times \frac{1}{2} \times (1 + k\cos\theta)$$

$$\boxed{\eta_{max} = \frac{1 + k\cos\theta}{2}}$$

10

**Section B : Fluid Mechanics + Fluid Machinery + Power Plant**

**Q.5 (a)** **(i)** The tangential component of velocity of incompressible fluid in 2-D flow is

$$v_\theta = -\frac{c\sin\theta}{r^2}$$

where $c$ is a constant

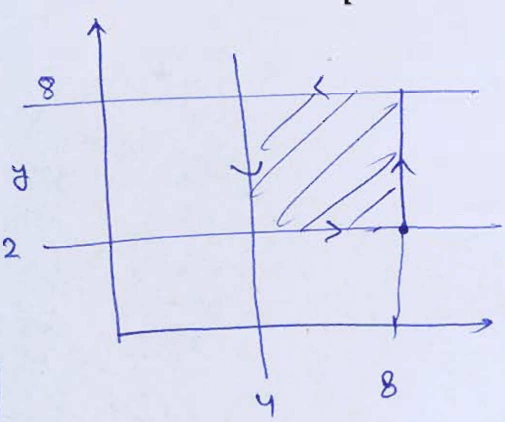
1. Using continuity equation, determine the expression for radial velocity $v_r$.
2. Find the magnitude and direction of resultant velocity

**(ii)** If the velocity field is given by $u = (16y - 8x)$, $v = (8y - 7x)$, find the circulation around the closed curve defined by $x = 4$, $y = 2$, $x = 8$, $y = 8$.

**[6 + 6 marks]**

Ans.

(ii) Circulation = $\oint u \cdot dr$




$$\oint u\cdot dr = \int \nabla \times u \cdot dA$$

$$\nabla \times u = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ 16y-8x & 8y-7x & 0 \end{vmatrix} = \hat{k}(16+7) = 23\hat{k}$$

6

$$\int \nabla \times u \cdot dA \Rightarrow 23 \times 4 \times 6 \Rightarrow 23 \times 24 = 552 \text{ unit}$$

(i) $$U_\theta = -\frac{c\sin\theta}{r^2}$$

$$\frac{\partial^2 u_r}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial \theta}\left(\frac{1}{r}\frac{\partial u_\theta}{\partial \theta}\right) = 0$$

2

$$\frac{\partial^2 u_r}{\partial r^2} + \frac{1}{r}\cdot\frac{\partial}{\partial \theta}\left(\frac{1}{r} \times -\frac{c\cos\theta}{r^2}\right] = 0$$

$$\frac{\partial^2 u_r}{\partial r^2} + \frac{c\sin\theta}{r^4} = 0$$

$$\frac{\partial u_r}{\partial r} = + \quad \frac{c\sin\theta}{3r^3} + C_1$$

~~$u_r = \frac{-20\, c \sin\theta}{r^6} + c_1 r + c_2$~~

$$u_r = -\frac{c \sin\theta}{6 r^2} + c_1 r + c_2$$

assuming $c_1$ & $c_2 = 0$

(1) $$u_r = -\frac{c \sin\theta}{6 r^2}$$

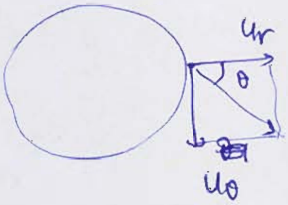
(2) Magnitute $= \sqrt{u_r^2 + u_\theta^2}$

$$= \frac{c \sin\theta}{r^2} \left( \sqrt{\frac{1}{36} + 1} \right.$$

$$= \frac{1.0138\, c \sin\theta}{r^2}$$

$$\tan\theta = \frac{u_\theta}{u_r}$$

$$= \frac{-1}{-1/6}$$




$$\theta = \tan^{-1}(6)$$

$$= 80.54^\circ$$

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**Q.5 (b)** An elbow type draft tube has a circular section of 1.8 $m^2$ at the top and a rectangular section of 13.5 $m^2$ at the exit section. The turbine is set at a height of 2 m above the tail race level. If the velocity at the inlet of the to the draft tube is 12.5 m/s. Determine

**(i)** Negative pressure head at the inlet to the draft tube.

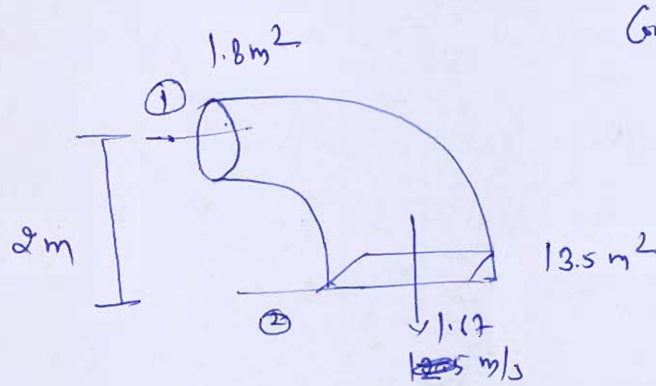
**(ii)** Power thrown away into the tail race and

**(iii)** Efficiency of the draft tube

Assume the frictional losses in the draft tube to be 10% of the inlet velocity head.

**[12 marks]**

Ans




Continuity

$A_1 V_1 = A_2 V_2$

$V_2 = 1.67 \frac{m}{sec}$

$H_L = \frac{V_1^2}{2g} \times 0.10$

$H_L = 0.796$ m

(i) Using Bernoulli equation at ① and ②

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + 2 = \frac{0}{\rho g} + \frac{V_2^2}{2g} + 0 + H_L$$

$$\frac{P_1}{\rho g} = \frac{1.67^2}{2g} + 0.796 - \frac{12.5^2}{2g} - 2$$

$$\frac{P_1}{\rho g} = -9.0256 \text{ m}$$

$P_1 = -88.541$ kPa

negative pressure ⇒ 88.541 kPa

(Vaccume pressure)

(ii) Power thrown away in the tail race

$\dot{m} = \rho A_1 V_1$

$= 22500 \frac{m^3}{sec}$

$= \frac{1}{2} \dot{m} V_2^2$

$= 31.375$ kW

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(3) Efficiency $\Rightarrow \dfrac{\left(\dfrac{V_1^2}{2g} - \dfrac{V_2^2}{2g}\right) - H_L}{\dfrac{V_1^2}{2g}}$

$$\Rightarrow \dfrac{\dfrac{12.5^2}{2g} - \dfrac{1.17^2}{2g} - 0.796}{\dfrac{12.5^2}{2g}} \times 100$$

$$= 88.21\ \%$$

12

Q.5 (c) Briefly explain the following:

1. Turbojet engine
2. Turbofan engine
3. Turboprop engine
4. Ramjet engine
5. Scramjet engine
6. Pulse jet engine

[12 marks]

A

~~Turbojet engine~~ ⇒

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**Q.5 (d)** With the help of a neat schematic explain the working of a circulating type fluidized bed boilers.

**[12 marks]**

**Q.5 (e)** A surface condenser deals with 14000 kg of steam per hour. The leakage air in the system amounts to 2 kg per 2800 kg of steam. The vacuum in the air pump suction is 710 mm of mercury (barometer reads 760 mm of Hg) and temperature is 35°C.

Determine the discharging capacity of the wet air pump which remove both air and condensate in $m^3$ per minute, taking the volumetric efficiency of the pump as 92%.

If the air pump is single acting and runs at 80 rpm and piston stroke is 1.25 times the diameter of the pump, find the dimensions of the wet air pump.

[Use Steam Table attached at the end]

**[12 marks]**

**Q.6 (a)** Following data relate to a performance test of a single acting 15 cm × 10 cm reciprocating compressor:

Suction pressure = 1 bar; Suction temperature = 25°C

Discharge pressure = 8 bar; Discharge temperature = 200°C

Speed of compressor = 1250 rpm; Shaft power = 8.25 kW

Mass of air delivered = 2 kg/min

Calculate the following:

**(i)** The actual volumetric efficiency.

**(ii)** The indicated power.

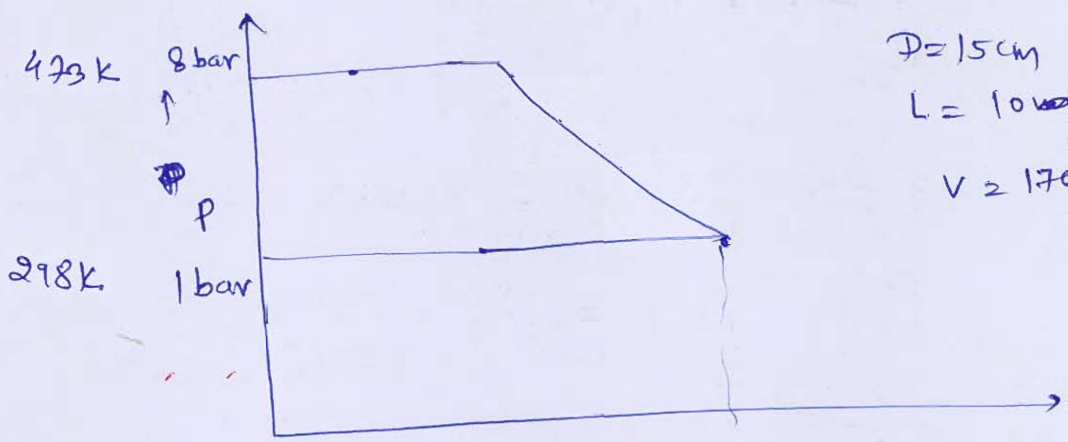
**(iii)** The isothermal efficiency.

**(iv)** The mechanical efficiency.

**(iii)** The overall isothermal efficiency

**[20 marks]**

Ans




$D = 15$ cm

$L = 10$ cm

$V = 1767.14$ cm³

$\dot{m} = 2$ kg/min

$\rho = \frac{P_1}{RT_1} = \frac{10^2}{0.287 \times 298}$

$\rho = 1.169$ kg/m³

$\dot{V}_{actual} = \frac{\dot{m}}{\rho}$

$= 1.7108$ m³/min

$\dot{V}_{Ideal} = N \times V = 1250 \times 1767.14 \times 10^{-6}$

$= 2.2089$ m³/min

(1)

$\eta = \frac{1.7108}{2.2089} = 0.7745$

$PV^n = C$

$\left(\frac{8}{1}\right)^{\frac{n-1}{n}} = \left(\frac{473}{298}\right)$

$n = 1.2856$

(ii) ~~work done per cycle~~ ~~Input~~

power input $\Rightarrow \frac{n}{n-1}(P_1V_1 - P_2V_2)$

$= \frac{1.2856}{0.2856} \times (\dot{m}RAT)$

Indicated Power $\Rightarrow 7.536$ kW

~~$IP = \frac{1.4}{0.4} \times \frac{2}{60} \times 0.287 \times 175 \Rightarrow 5.857$ kW~~

Shaft power $= 8.25$ kW

(iii) Isothermal ~~work done~~ power input $= \dot{m}RT\ln\left(\frac{P_2}{P_1}\right)$

$= \frac{2}{60} \times 0.287 \times 298 \times \ln(8)$

$= 5.9282$ kW

$\eta_{Isothermal} = \frac{5.9282}{7.536}$

$\eta_{Isotherm} = 78.66\ \%$

friction power $\Rightarrow 8.25 - 7.536$

shaft power $-$ IP $= 0.724$

(iv)

$\eta_{mech} = \frac{7.536}{8.25} = 91.34$

$\eta_{mech} = 91.34\ \%$

(v) overall isothermal $\eta = \frac{5.9282}{8.25} \times 100$

$\eta_o = 71.85\%$

(20)

Q.6 (b) The diameter of the runner of a vertical-shaft turbine is 450 mm at the inlet. The width of the runner at the inlet is 50 mm. The diameter and width at the outlet are 300 mm and 75 mm, respectively. The blades occupy 8% of the circumference. The guide vane angle is 24°, the inlet angle of the runner blade is 95° and the outlet angle is 30°. The fluid leaves the runner without any whirl. The pressure head at the inlet is 55 mm above that at the exit from the runner. The fluid friction losses account for 18% of the pressure head at inlet. Calculate the speed of the runner and the output power (use mechanical efficiency as 95%)

**[20 marks]**

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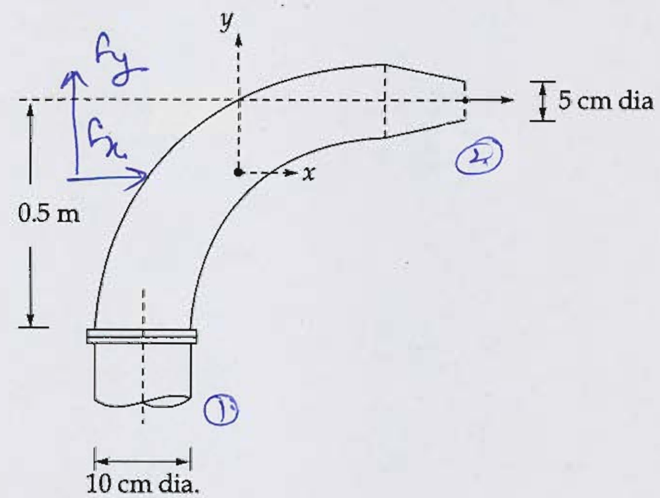
**Q.6 (c)** Water flows into atmosphere through a vertical bend nozzle assembly shown in figure below. The pipe diameter is 10 cm and the nozzle exit diameter is 5 cm. The rate of flow of water is 2400 litre per minute. The interior volume of the assembly is 18.2 litre. The head loss in the bend is $0.5\,v^2/2g$ and in the nozzle it is $v^2/g$, where $v$ is the velocity of water in the pipe. Determine the hydrodynamic force on the system and its direction.




**[20 marks]**

Ans

$V_1 = \frac{Q}{A_1} = \frac{2.4}{60 \times \frac{\pi \times 0.1^2}{4}} = 5.0929$ m/sec

$V_2 = \frac{Q}{A_2} = \frac{2.4}{60 \times \frac{\pi \times 0.05^2}{4}} = 20.3718$ m/sec

in Bend

$H_{L_B} = 0.5\frac{V^2}{2g} = 0.66$ m

in nozzle

$H_{L_N} = \frac{V^2}{g} = 2.64$ m

$P_2 = 1$ atm

$P_1 = ?$

Using Bernoulli eq.

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

$\frac{P_1}{\rho g} + 1.3219 + 0 = 10.33 + 21.152 + 0.66 + 2.64 + 0.5$

$\frac{P_1}{\rho g} = 33.46 + 0.5$

$P_1 = 328.243 \text{ kPa} + 4.905 = 333.148 \text{ kPa}$

$P_{gauge_1} = 226.9 \text{ kPa} + 4.905 = 231.85 \text{ kPa}$

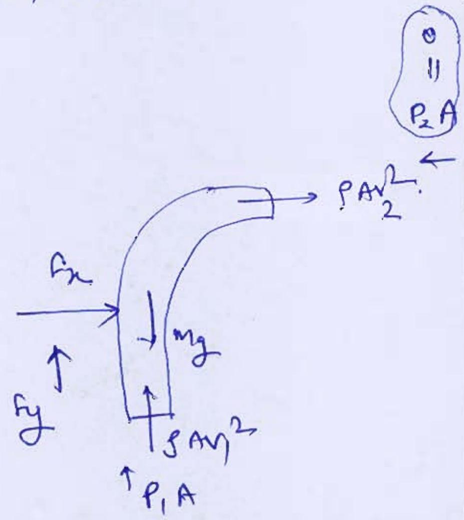
$P_{gauge_2} = 0$

By pipe on fluid

$F_x = \rho A V_2^2$

$= ~~101.856 \text{ N}~~$

$= 814.87 \text{ N}$




$F_y - mg + P_1 A = 0 - \rho A V_1^2$

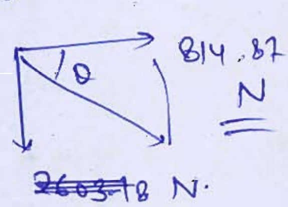
$mg = 18.2 \times 9.81 = 178.54 \text{ N}$

$F_y - 178.54 + 1820.94 ~~2578.01~~ = -203.71$

$F_y = -1846.11 ~~-2603.76~~ \text{ N}$

$F_y$ will be downward

By pipe on fluid




$\cos\theta$ ~~tanθ~~ $= \frac{814.87}{1846.11}$

$\theta = 66.183^\circ$

20

Q.7 (a) (i) A pipeline carrying water has surface protrusions of average height of 0.12 mm. If the shear stress developed is 8.6 Pa, determine whether the pipe surface acts as smooth, rough or in transition. For water take $\rho = 1000 \text{ kg/m}^3$ and kinematic viscosity $\nu = 0.0093$ stokes.

(ii) The velocity of flow in a badly corroded 8 cm pipe is found to increase 20 percent as a Pitot tube is moved from a point 1 cm from the wall to a point 2 cm from the wall. Estimate the height of roughness elements.

**[10 + 10 marks]**

Q.7 (b) (i) Explain the working principle of a wet type cooling tower. Also, classify and describe the various types of wet cooling towers with neat sketches.

(ii) Water at 35°C flows into a cooling tower at the rate of 1.2 kg per kg air. Air enters the tower at *dbt* of 25°C and relative humidity of 50% and leaves it at *dbt* of 30°C and 80% relative humidity. Makeup water is supplied at 25°C. Determine

(i) The temperature of water leaving the tower.

(ii) The fraction of water evaporated and

(iii) The approach and range of cooling tower

[Take atmospheric pressure, $P = 1$ bar & specific heat of water as 4.18 kJ/kgK]

[Use Steam Table and Psychrometric chart attached at the end]

**[10 + 10 marks]**

**Q.7 (c)** The following data relate to a Kaplan turbine:

Shaft power = 22500 kW; Head = 20 m; Speed = 148 rpm;

Hydraulic efficiency = 95%; Overall efficiency = 89%; Diameter of the runner = 4.5 m

Diameter of the hub = 2 m; Runner vane angle at outlet = 34°

Assuming that the velocity of flow is constant. Find:

(i) Guide vane angle at inlet;

(ii) Runner vane angle at inlet

**[20 marks]**

Ans

Extra

$H = 20m \qquad N = 148$

$u_1 = \frac{\pi D_1 N}{60} = 15.498 \text{ m/s}$

$u_2 = \frac{\pi D_2 N}{60} = 34.87 \text{ m/sec}$

$P_{turbine} \times \eta_o = 22500$

$(\rho g H_Q) \times \eta_o = 22500$

$Q = \frac{0.1146 \text{ m}^3/\text{sec}}{0.89} \times 10^3$

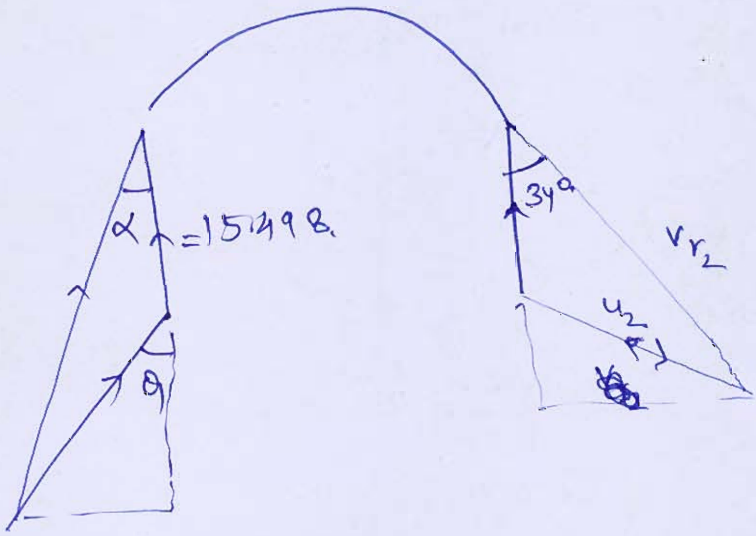
$Q = 0.1288 \times 10^3 \text{ m}^3/\text{sec}$

$\frac{V_f \times \pi (D_o^2 - D_i^2)}{4} = 0.1288 \times 10^3$

~~$V_f = 0.01 \text{ m/sec} \times 10^3$~~

$V_f = 10.09 \text{ m/sec}$

$\eta_H = 0.95$




$$\frac{u_1 V_{w_1} + u_2 V_w}{gH} = 0.95$$

$$u_1 V_{w_1} + u_2 V_{w_2} = 186.39$$

Q.8 (a) (i) A boiler uses 2100 kg/h of coal. The temperatures of air supplied is 290 K and the average temperature of the flue gas leaving the chimney is 620 K. The 35 m high chimney produces a drought of 22 mm of water column. Determine

1. Quantity of air supplied per kg of coal.
2. The draught in terms of column of hot gases, and
3. The base diameter of chimney.

Assume that 10% of the theoretical draught is used for creating the flow velocity of gases through the chimney.

(ii) The following readings were obtained during a boiler trial of 6 hours duration:

Mean steam pressure = 12 bar; Mass of steam generated = 45000 kg; Mean dryness fraction = 0.9; Mean feed water temperature = 30°C; Cool used 5000 kg; Calorific value of coal = 33500 kJ/kg.

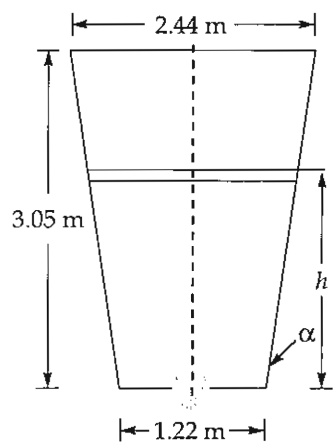
Calculate:

1. Factor of equivalent evaporation.
2. Equivalent evaporation from and at 100°C.
3. Efficiency of the boiler.

[Use Steam Table attached at the end]

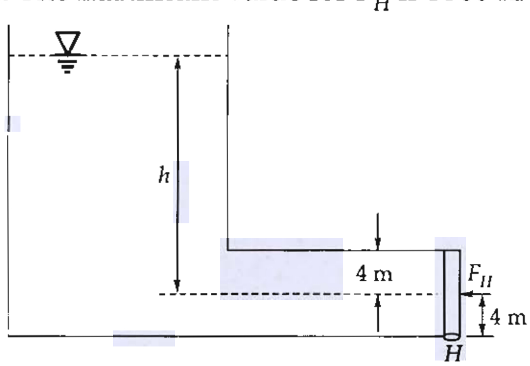
**[10 + 10 marks]**

.8 (b) (i) A tank has the form of a frustum of a cone, with a diameter of 2.44 m at the top and 1.22 m at the bottom is shown in figure. The bottom contains a circular orifice whose coefficient of discharge is 0.60. What diameter of the orifice will empty the tank in 6 minutes if the full depth is 3.05 m?




A tank in the form of a frustum of a cone

(ii) A 3 m wide, 8 m high rectangular gate is located at the end of a rectangular passage that is connected to a large open tank filled with water as shown in figure. The gate is hinged at its bottom and held closed by a horizontal force, $F_H$ located at the centre of the gate. The maximum value for $F_H$ is 3500 kN.




1. Determine the maximum water depth above the centre of the gate that can exist without the gate opening.
2. Will the answer be same, if the gate is hinged at the top? Explain your answer.

**[10 + 10 marks]**

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