NAME -

ROLL NO :-

TEST NO: 14

total marks 263

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Q - 1'a'

$V_a = 300\,m/s$, (air speed)

(Ambient temp) $T_a = -10 + 273 = 263\,K$

h_a = Ambient air enthalpy $= 265\ kJ/kg$

∴ Stagnation Enthalpy at inlet

$$h_i = h_a + \frac{V_a^2}{2}$$

$$\Rightarrow \boxed{h_i = 265 + \frac{300^2}{2\times1000} = 310\ kJ/kg}$$

Let $\dot m_a$ = Mass flow of air

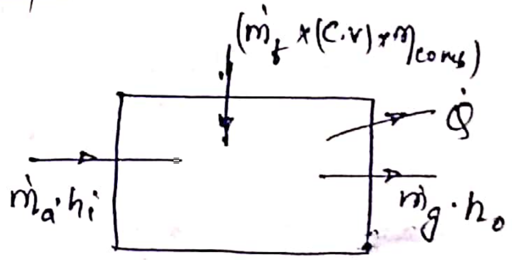
$\dot m_f$ = Mass rate of fuel

∴ $\dot m_g$ = Mass of gas at nozzle $= (\dot m_a + \dot m_f)$

and Given

$$\boxed{\frac{\dot m_a}{\dot m_f} = \frac{1}{0.022}}$$

h_o = Stagnation enthalpy at nozzle outlet



$$\therefore\ \dot m_a h_i + \dot m_f \times (C.V.) \times \eta_{comb} = (\dot m_a + \dot m_f) \times h_o + \dot Q$$

$$\Rightarrow \left(\frac{\dot m_a}{\dot m_f}\right) h_i + (C.V) \times \eta_{comb} = \left(\frac{\dot m_a}{\dot m_f} + 1\right) \times h_o + \left(\frac{\dot m_a}{\dot m_f} \times 30\right)$$

$$\Rightarrow \left(\frac{1}{0.022} \times 310\right) + 44.5 \times 1000 \times 0.95 = \left(\frac{1}{0.022} + 1\right) \times h_o + \frac{1}{0.022} \times 30$$

$$\Rightarrow \boxed{h_o = \frac{55002.273}{\left(1 + \frac{1}{0.022}\right)} = 1184\ kJ/kg}$$

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But h_o = Enthalpy at exit + $\frac{V_o^2}{2}$

$$\Rightarrow \boxed{V_o = \sqrt{(1184 - 965) \times 1000 \times 2} = 661.82\ m/s}$$

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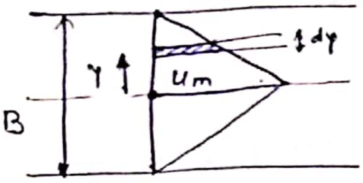
Q - 1'b'

Consider a strip at a distance 'y' from centre of duct and of thickness 'dy'



dA = Area of strip $= (dy \times 1)$

u = velocity profile at any position

$$\Rightarrow \boxed{u = \frac{u_m}{(B/2)} \times y = \frac{2u_m}{B} \times y}$$

Also Mass flow rate at Avg velocity = Mass flow rate at Actual velocity

$$\Rightarrow \rho \cdot (B \times 1) \times u_{avg} = \int_{-B/2}^{B/2} \rho \cdot (dy \times 1) \cdot u$$

$$\Rightarrow u_{avg} = \frac{1}{B} \times 2 \int_0^{B/2} \frac{2u_m}{B} y \, dy$$

$$\Rightarrow \boxed{u_{avg} = \frac{4u_m}{B^2}\left[\frac{y^2}{2}\right]_0^{B/2} = \frac{2u_m}{B^2}\left(\frac{B^2}{4}\right) = \frac{2u_m}{4} = \frac{u_m}{2}}$$

$\therefore$ β = (Momentum Correction factor) $= \dfrac{(\text{Momentum/sec}) \text{ at actual velocity}}{(\text{Momentum/sec}) \text{ at Avg velocity}}$

$$\Rightarrow \beta = \frac{1}{A \times u_{avg}^2} \int_{-B/2}^{B/2} u^2 \, dA = \frac{1}{(B \times 1) \times \left(\frac{u_m}{2}\right)^2} \cdot \int_{-B/2}^{B/2} \left(\frac{2u_m}{B} y\right)^2 dy$$

$$\Rightarrow \beta = \frac{4}{u_m^2 \times B} \times 2 \times \left(\frac{2u_m}{B}\right)^2 \times \int_0^{B/2} y^2 \, dy = \frac{16 \times 2}{B^3}\left[\frac{y^3}{3}\right]_0^{B/2}$$

$$\Rightarrow \boxed{\beta = \frac{16 \times 2}{3} \times \frac{1}{B^3}\left(\frac{B}{2}\right)^3 = \frac{16 \times 2}{3B^3} \times \frac{B^3}{8} = \frac{4}{3} = 1.333}$$

1

energy correction factor is missing

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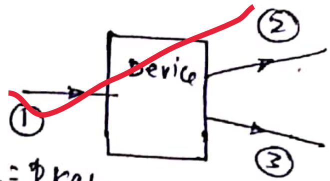
04

$\boxed{Q-1'c'}$

$\boxed{m_1 = m_2 + m_3}$ $\Rightarrow$ Mass Conservation

$P_2 = 1\ bar$
$T_2 = 330K$
$\dot m_2 = 1\ kg/s$



$\dot m_1 = 2 kg/s$
$P_1 = 4\ bar$
$T_1 = 300K$

$\dot m_3 = 1 kg/s$
$P_3 = 1\ bar$
$T_3 = 270K$

For ambient

$T_a = 300K$ & $P_a = 1\ bar$

Now

~~Available Energy~~

Availability at inlet stream ①

$$\phi_1 = \dot m_1 [(h_1 - h_a) - T_a(s_1 - s_a)]$$

$$\Rightarrow \phi_1 = 2\times\left[c_p\cdot(T_1 - T_a) - T_a\left\{c_p \ln\left(\frac{T_1}{T_a}\right) - R\ln\left(\frac{P_1}{P_a}\right)\right\}\right]$$

$$\Rightarrow \phi_1 = 2\times\left[1.005\times(300-300) - 300\left\{1.005\times\ln\left(\frac{300}{300}\right) - 0.287\times\ln\left(\frac{4}{1}\right)\right\}\right]$$

$$\Rightarrow \boxed{\phi_1 = 238.72\ kW}$$

* Availability at stream ②

$$\phi_2 = \dot m_2 [(h_2 - h_a) - T_a(s_2 - s_a)]$$

$$\Rightarrow \phi_2 = 1\times\left[1.005\times(330-300) - 300\cdot\left\{1.005\times\ln\left(\frac{330}{300}\right) - 0.287\ln\left(\frac{1}{1}\right)\right\}\right]$$

$$\Rightarrow \boxed{\phi_2 = 1.414\ kW}$$

* Availability at stream ③

$$\phi_3 = \dot m_3[(h_3 - h_a) - T_a(s_3 - s_a)]$$

$$\Rightarrow \phi_3 = 1\times\left[1.005\times(270-300) - 300\times\left\{1.005\times\ln\frac{270}{300}\right\}\right]$$

$$\Rightarrow \boxed{\phi_3 = 1.616\ kW}$$

η_{isen} 0.89 $= 573.521K$

04

please comment about device possibility

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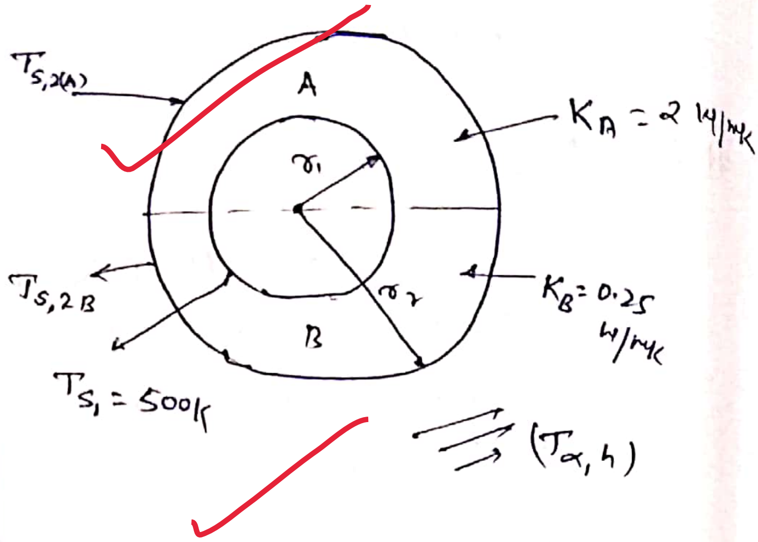
Q- 1'd'

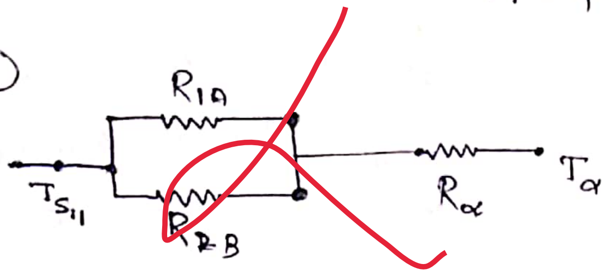
$r_1 = 50\,mm$

$r_2 = 100\,mm$

$T_\alpha = 300K$, $h = 25\, W/m^2K$



(i)



$$\cancel{R_{1A} = \frac{\ln(r_2/r_1)}{(2\pi K_A L)/2}}$$

$$\boxed{R_{1A} = \frac{\ln(r_2/r_1)}{4\pi K_A L}}, \quad \boxed{R_{2B} = \frac{\ln(r_2/r_1)}{4\pi K_B L}}$$

and $\boxed{R_\alpha = \frac{1}{h A_{outer}}}$

(ii)

~~Total Loss, $Q = Q_A + Q_1$~~

$$\text{Total loss, } Q = \frac{(T_{s_1} - T_\alpha)}{\left(\frac{R_{1A} * R_{2B}}{R_{1A} + R_{2B}}\right) + R_\alpha}$$

$$R_{1A} = \frac{\ln(r_2/r_1)}{4\pi K_A L} = \frac{\ln\left(\frac{0.1}{0.05}\right)}{4\pi \times 2 \times 1}$$ (assume unit length)

$$\Rightarrow \boxed{R_{1A} = 0.02758\ \frac{K}{W}}$$

$$\boxed{R_{2B} = \frac{\ln(r_2/r_1)}{4\pi K_B L} = \frac{\ln\left(\frac{0.1}{0.05}\right)}{4\pi \times 0.25 \times 1} = 0.2206\ \frac{K}{W}}$$

Conv

$$R_\alpha = \frac{1}{h A_{outer}} = \frac{1}{25 \times 2\pi r_2 \times 1} = \frac{1}{50\pi \times 0.1}$$

$$\boxed{R_\alpha = 0.06366\ K/W}$$

$$\therefore\ Q = \frac{(500 - 300)}{\left(\frac{0.02758 \times 0.2206}{0.02758 + 0.2206}\right) + 0.06366} =$$

$$\Rightarrow \boxed{Q = \cancel{2268.215\ W}}$$

$q \Rightarrow$ Heat Loss per unit length

Also

$$Q_A = \frac{(T_{s,2A} - T_\alpha)}{\frac{1}{h \times 2\pi \times \frac{r_2}{2} \times 1}} = \frac{(T_{s_1} - T_{s,2A})}{\frac{\ln(r_2/r_1)}{4\pi K_A \times 1}}$$

$$\Rightarrow (T_{s,2A} - 300) \times \pi \times 0.1 \times 25 = \frac{(500 - T_{s,2A}) \times 4\pi \times 2}{\ln\left(\frac{0.1}{0.05}\right)}$$

$$\Rightarrow 0.2166 \times (T_{s,2A}) - 0.2166 \times 300 = 500 - T_{s,2A}$$

$$\Rightarrow \boxed{(T_{s,2A}) = \cancel{464.39\ K}}$$

Similarly

$$(T_{s,2B} - T_\alpha) \times h\pi \times r_2 = \frac{4\pi K_B \times (T_{s_1} - T_{s,2B})}{\ln(r_2/r_1)}$$

$$\Rightarrow (T_{s,2B} - 300) \times \frac{25 \times \pi \times 0.1 \times \ln\left(\frac{0.1}{0.05}\right)}{4\pi \times 0.25} = (500 - T_{s,2B})$$

$$\Rightarrow 1.733 \times T_{s,2B} - 1.733 \times 300 = 500 - T_{s_2,B}$$

$$\Rightarrow \boxed{T_{s,2B} = \cancel{373.18\ K}}$$

refer solution

02

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Q - 1'e'

No. of cylinder, $K = 4$

4 - stroke

Diameter of orifice, $d = 8\,cm$

$C_d = 0.65$

Given, D = Bore dia = 10 cm

L = Stroke = 15 cm, $N = 2500$ rpm

$\therefore \dot{V}_s$ = swept vol. = $\frac{\pi}{4} \times D^2 \times L \times K \times \frac{N}{60 \times 2}$

$\Rightarrow \dot{V}_s = \frac{\pi}{4} \times (0.1)^2 \times 0.15 \times 4 \times \frac{2500}{120}$

$\Rightarrow \boxed{\dot{V}_s = 9.817 \times 10^{-2}\ m^3/sec}$

$\dot{m}_f$ = fuel consumption = 10 kg/hr = $\left(\frac{10}{3600}\right)$ kg/s

$(C.V)_{fuel} = 42000$ KJ/kg

$\therefore$ Heat Added, $\dot{Q} = \dot{m}_f \times (CV) = \frac{10}{3600} \times 42000$

$\Rightarrow \boxed{\dot{Q} = 116.67\ KW}$

Also (ρ_{air}) at free air condition

$\rho_{air} = \frac{P_1}{RT} = \frac{100}{0.287 \times 290} = 1.201\ kg/m^3$

$\therefore$ pressure drop across the orifice, ΔP = ~~$\rho_w g$~~ 4 cm of water

$\Rightarrow \Delta P = \rho_w g \times h = 1000 \times 9.81 \times \frac{4}{100} = 392.4\ Pa$

$\therefore$ Air column height, corresponding to this pressure drop

$\Rightarrow \boxed{h_{air} = \frac{\Delta P}{\rho_{air} \times g} = \frac{392.4}{9.81 \times 1.201} = \cancel{5.771}\ 33.306\ m}$

$\therefore$ Theoretical air velocity, $V_{air} = \sqrt{2 g h_{air}}$

$\Rightarrow \boxed{V_{air} = \sqrt{2 \times 9.81 \times \cancel{5.771}\ 33.306} = \cancel{10.64}\ 25.56\ m/s}$

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∴ Actual Mass flow Rate, $\dot{m}_{air} = C_d \cdot \rho_{air} A_0 V_{air}$

$\Rightarrow \dot{m}_{air} = 0.65 \times 1.201 \times \frac{\pi}{4} \times (0.08)^2 \times \cancel{10.64}\ 25.58$

$\Rightarrow \boxed{\dot{m}_{air} = \cancel{0.04175}\ 0.1003 \text{ Kg/s}}$

∴ Actual volume flow rate of air, $\dot{V}_a = \frac{\dot{m}_{air}}{\rho_{air}}$

$\Rightarrow \boxed{\dot{V}_a = \frac{\cancel{0.04175}\ 0.1003}{1.201} = \cancel{0.03476}\ 0.08351 \text{ m}^3/\text{sec}}$

(i) Brake thermal η

$\Rightarrow \eta_{th} = \frac{B.P.}{Q} \times 100 = \frac{36}{116.67} \times 100$

$\Rightarrow \boxed{\eta_{th} = 30.86\%}$

(ii) Brake mean effective pressure

$P_{bmep} = \frac{B.P.}{\dot{V}_s} = \frac{36}{9.817 \times 10^{-2}} = 366.71 \text{ kPa}$

$= 3.6671 \text{ bar}$

(iii) $\boxed{P_{bmep} = 3.6671 \text{ bar}}$

(iii) volumetric $\eta = \frac{\dot{V}_a}{\dot{V}_s} \times 100 = \frac{\cancel{0.03476}\ 0.08351}{9.817 \times 10^{-2}} \times 100$

$\Rightarrow \cancel{\boxed{\eta_{vol} = 35.408\%}}$

$\Rightarrow \boxed{\eta_{vol} = 85.067\%}$

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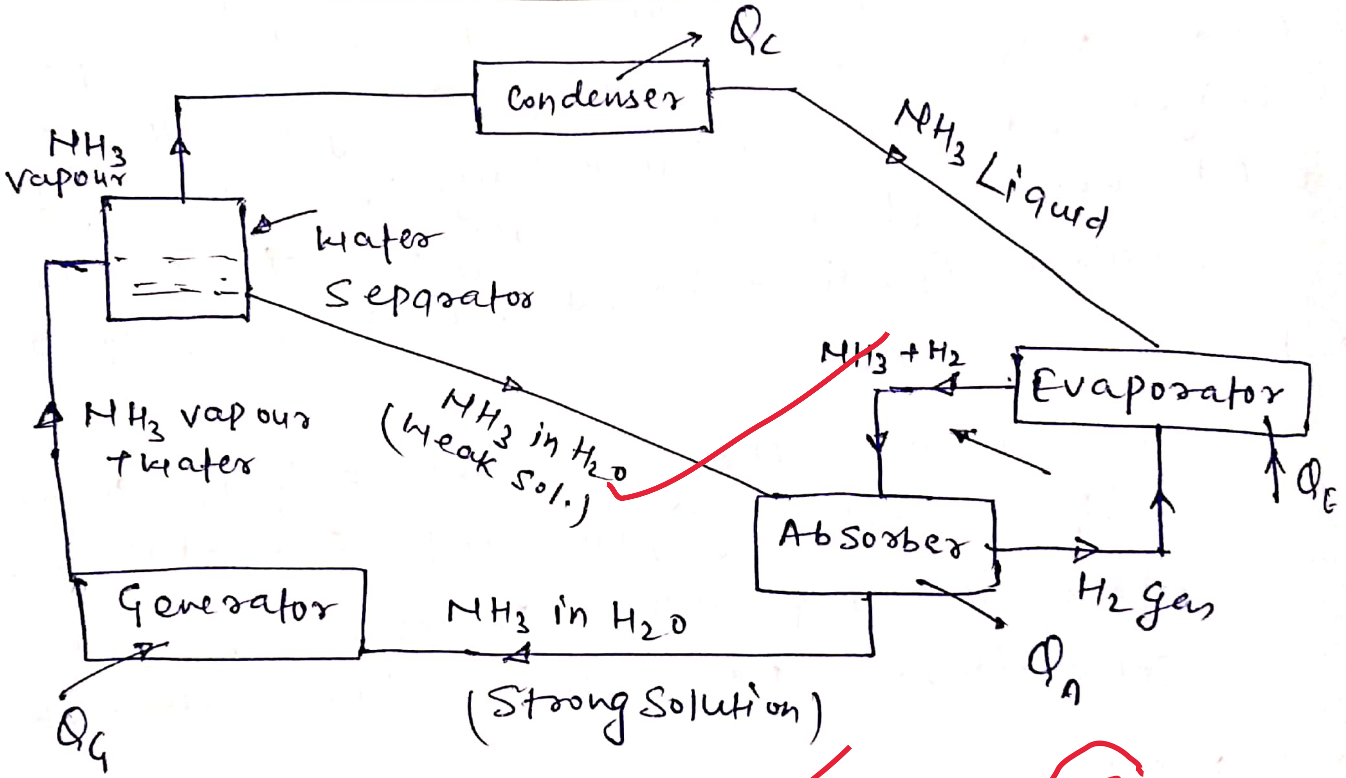
Q- 4'a, (1) Schematic diagram of Electrolux Refrigerator



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Electrolux Refrigerator

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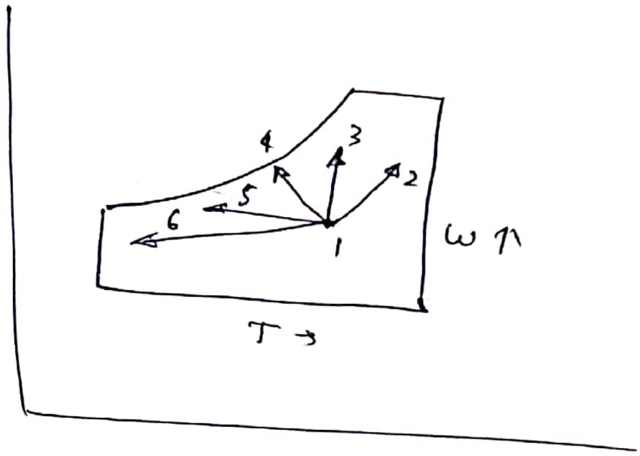
Q-4 'a' (ii)

* various processes, which can be done in air washer due to variation of mean surface temp. of water:

(i) process 1-2

↳ Heating and ~~dehum~~ humidification ($T_s > T_1$)

↳ Mean surface of temp of water is greater than dry-bulb temp of air. Heat is supplied to water externally



(ii) process 1-3 (humidification)

↳ If water from pan is heated to the dry-bulb temp of air and then sprayed, the air would only be humidified.

→ This is practically not possible

(iii) process 1-4

↳ The recirculated water reaches the equilibrium temp which is equal to the Thermodynamic wet-bulb temp.

(iv) process (1-5)

↳ Sensible Cooling

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→ If water is cooled up to the dew point temp of air, the process 1-5 would be sensible cooling process

(v) process (1-6) (→ Cooling & dehumidification)

↳ water is cooled to the temp below the dew Point of air

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Q-4b'

Given

Stroke vol. = 0.0015 m^3

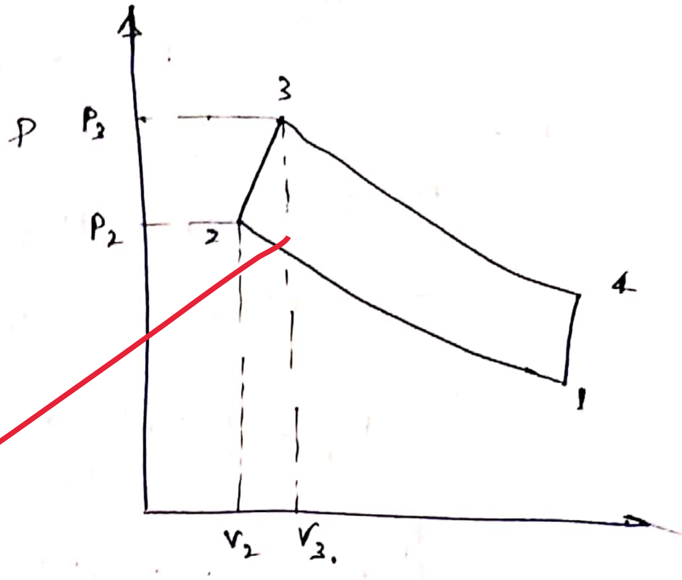
$\Rightarrow \boxed{(V_1 - V_2) = 0.0015 \ m^3}$

$r = 6 \Rightarrow$ Compression Ratio

$P_2 = 8$ bar, $T_2 = (350 + 273)K$

$\boxed{T_2 = 623 \ K}$

$P_3 = 25$ bar



and $(V_3 - V_2) = \frac{1}{30} \times (V_1 - V_2) = \frac{1}{30} \times 0.0015 = 5 \times 10^{-5} \ m^3$

$\therefore$ Work done during process 2-3

W_{2-3} = Area under 2-3

$= P_2 \times (V_3 - V_2) + \frac{1}{2} \times (P_3 - P_2) \times (V_3 - V_2)$

$\Rightarrow W_{2-3} = 800 \times (5 \times 10^{-5}) + \frac{1}{2} \times (25 - 8) \times 100 \times 5 \times 10^{-5}$

$\Rightarrow \boxed{W_{2-3} = 0.0825 \ KJ = 82.5 \ J}$

Also $(V_1 - V_2) = 0.0015$

$\Rightarrow \left(\frac{V_1}{V_2}\right) - \left(\frac{V_2}{V_2}\right) = \frac{0.0015}{V_2}$

$\Rightarrow r - 1 = \frac{0.0015}{V_2} \Rightarrow \boxed{V_2 = \left(\frac{0.0015}{6-1}\right) = 3 \times 10^{-4} \ m^3}$

and $\boxed{V_3 = 5 \times 10^{-5} + 3 \times 10^{-4} = 3.5 \times 10^{-4} \ m^3}$

also, $m_2 = \frac{P_2 V_2}{R T_2}$ (Assuming ideal Gas)

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$$\Rightarrow m_2 = \frac{800 \times 1000 \times 3 \times 10^{-4}}{287 \times 623} = 1.3423 \times 10^{-3}\ \text{Kg}$$

Also

$$m_2 = m_{mixt} = m_a + m_f$$

$$\Rightarrow (1.3423 \times 10^{-3}) = 16 \times m_f + m_f \quad \left[\text{Given } \frac{m_a}{m_f} = \frac{16}{1}\right]$$

$$\Rightarrow m_f = \left(\frac{1.3423 \times 10^{-3}}{17}\right) \text{Kg} \Rightarrow \text{Mass of Gasoline}$$

$$\Rightarrow \boxed{m_f = 7.896 \times 10^{-5}\ \text{Kg}}$$

Now

$$\boxed{T_3 = \frac{P_3 V_3}{mR} = \frac{25 \times 10^5 \times 3.5 \times 10^{-4}}{1.3423 \times 10^{-3} \times 287} = 2271.31\ K}$$

and (Change in internal Energy in process 2-3), $\Delta U = m_2 C_v (T_3 - T_2)$

$$\Rightarrow (\Delta U)_{2-3} = (1.3423 \times 10^{-3}) \times (C_p - R) \times (2271.31 - 623)$$

$$\Rightarrow (\Delta U)_{2-3} = 2.2125 \times (1000 - 287)$$

$$\Rightarrow \boxed{(\Delta U)_{2-3} = 1577.51\ J}$$

∴ Actual Heat transfer in 2-3

$$Q_{2-3} = (\Delta U)_{2-3} + W_{2-3} = 1577.51 + 82.5$$

$$\Rightarrow \boxed{Q_{2-3} = 1660.01\ J}$$

But Actual heat ~~en~~ Given by fuel

$$= m_f \times (C.V) = (7.896 \times 10^{-5}) \times (42000 \times 1000)\ J$$

$$= 3316.32\ J$$

$$\therefore \boxed{\left(\begin{array}{l}\text{Heat Lost}\\ \text{per Kg of charge}\end{array}\right) = \left(\frac{3316.32 - 1660.01}{1.3423 \times 10^{-3}}\right) \times 10^{-3} = 1233.93\ \text{KJ/kg}}$$

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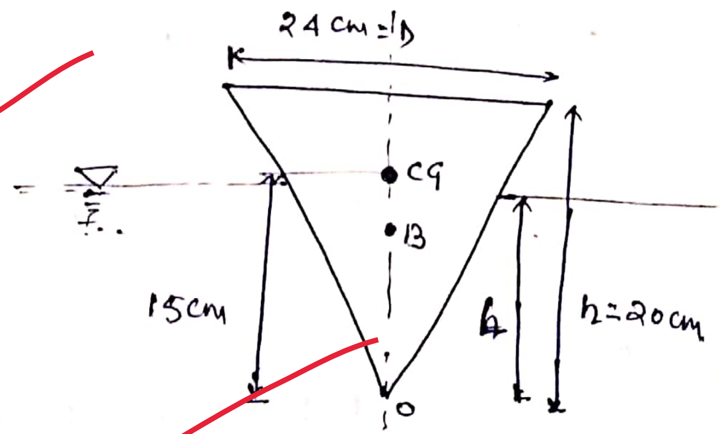
Q. 4 (c)

Given

a cone with

Dia, D = 24 cm

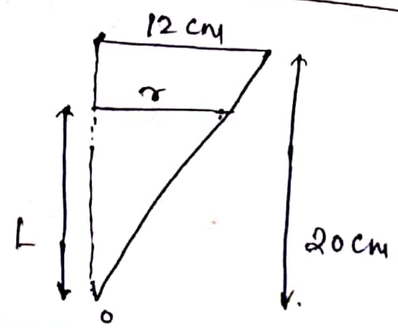
Height, h = 20 cm



Centre of Gravity of Inverted (CG) cone = $\left(\frac{3h}{4}\right)$ (from vertex)

$\Rightarrow (C.G) = \frac{3 \times 20}{4} = 15$ cm

* 'B' is the centre of buoyance and L = Length of cone submerged.



∴ Buoyance 'B' is at $\left(\frac{3L}{4}\right)$ dist. from vertex

∴ Distance between CG & B

$= BG = \left(15 - \frac{3L}{4}\right)$ —(1)

Now At free surface,

r = Radius of cone

∴ From similar triangle

$$\frac{12}{r} = \frac{20}{L}$$

$$\Rightarrow \boxed{r = \frac{12L}{20} = \frac{3L}{5} = 0.6L}$$

Now for stability

$$\boxed{\left(\frac{I_{min}}{V}\right) - BG \geq 0}$$, where I_{min} = Min Area I of the free surface

$= \frac{\pi}{64} \times (2r)^4$ — (i)

and V = Submerged volume of Cone.

$= \frac{1}{3} \times \pi r^2 L$ — (ii)

Now

By Theory of ~~floation~~ Floatation of body

(Weight of Cone) = Weight of the water Displaced by the submerged vol.

$\Rightarrow \rho_c \times g \times (\text{Vol.})_{cone} = \rho_w \times g \times (V)_{submerged}$

$\Rightarrow 800 \times \frac{1}{3} \times \pi \times \left(\frac{D}{2}\right)^2 \times h = 1000 \times \frac{1}{3} \pi \times (r)^2 \times L$

$\Rightarrow 800 \times \left(\frac{24}{2}\right)^2 \times 20 = 1000 \times (0.6L)^2 \times L$

$\Rightarrow 0.36 \times L^3 = 0.8 \times (12)^2 \times 20$

$\Rightarrow L = \left(\frac{0.8 \times (12)^2 \times 20}{0.36}\right)^{1/3} = 18.567 \text{ cm}$

$\therefore \boxed{BG = 15 - \frac{3 \times 18.567}{4} = 1.07475 \text{ cm}}$

and $\left(\frac{I_{min}}{V}\right) = \frac{\left(\frac{\pi}{64}\right) \times (2r)^4}{\frac{1}{3} \times \pi \times r^2 \times L} = \frac{16 \times (0.6 \times L)^4}{64 \times \frac{1}{3} \times (0.6 \times L)^2 \times L}$

$$\Rightarrow \boxed{\left(\frac{I_{min}}{V}\right) = \frac{16 \times (0.6)^4 \times (18.567)^4 \times 3}{64 \times 0.36 \times (18.567)^3} = 5.01309 \text{ cm}}$$

$$\therefore \boxed{\left(\frac{I_{min}}{V}\right) - BG = 5.01309 - 1.07475 = 3.93834 > 0}$$

So, Cone is in Stable equilibrium.

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Q- 5'a'

* Solar Still

* ~~Const~~

* Purpose

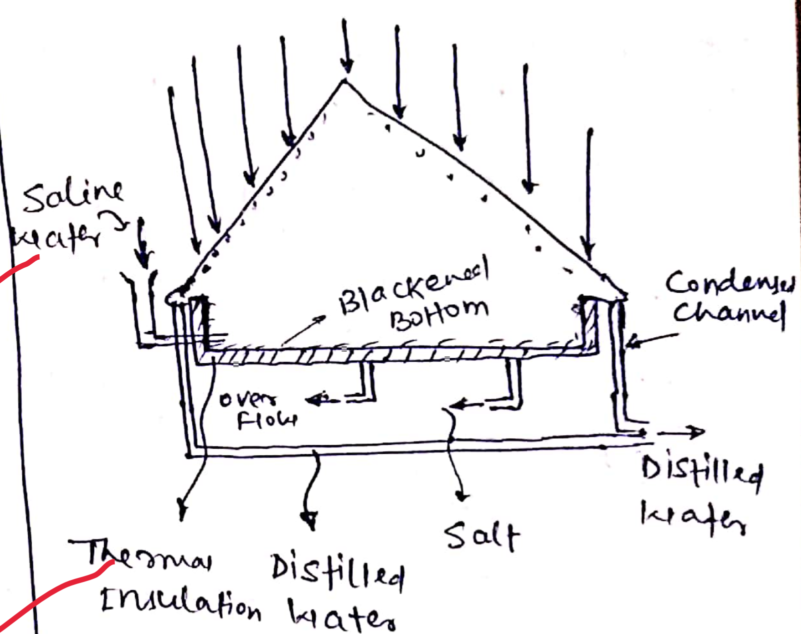
↳ Solar still is used to convert or obtained distilled water from saline water, for the various applications, like Agri-culture, Household use etc.

* Construction

↳ → It consist of a blackened bottom surface ~~in~~ on which saline water is heated

→ A roof-like transparent structure, to allow solar Radiation. It is slopy.

→ Condensed channels are present ~~to use~~ which flows the distilled water obtained to desired location



Simple Solar Still

* Working

↳ Solar radiation is passes through

the transparent roof and it is absorbed by the black bottom, which raises the saline water temp, and it evaporates.

→ Evaporated water is condensed on ~~roof~~ inside of roof surface which is ~~to~~ Less temp.

→ This condensed disstilled water is collected through Condensate channels.

→ In generally saline water level maintains at 5 to 10 cm.

10

Q-5 'b'

* Classification of Reaction turbine

~~The~~ (I) Francis turbine

(II) Kaplan turbine

(III) propeller turbine

(I) ~~Kaplan~~ francis turbine

→ ~~Kaplan~~ Francis turbine is a reaction turbine ie pressure change occurs in both ~~the~~ Stator & Rotor.

→ It may be Radially inward flow or Radially outward flow turbine

→ Generally, Radially inward flow is preferred in which Direction of motion of water is along radial, in which water is entered ~~radial~~ at outer radius and exit at inner radius.

→ part Load efficiency of ~~Kaplan~~ Francis turbine is poor

→ Its specific speed is in between 60 to 300

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→ Its size is Large for a given Load as compared to kaplan and No. of blades are also more in number.

(ii) Kaplan turbine

→ Kaplan turbine is an axial flow reaction turbine, In which direction of motion water is along the axis of rotation of blades i.e. axially.

→ Due to Axial motion, Losses are less in Kaplan turbine and hence its Efficiency is more

→ Part Load efficiency is good

→ Blades of kaplan turbine are adjustable, which can adjusted about its pivot to satisfy the required for flow and hence it can be adjusted for fluctuating Load, and hence Part Load efficiency is good

→ No. of Rotors are less as compared to Francis so, frictional losses are also less

→ Its specific speed is in between 600 to 1000

→ Size of the Kaplan turbine is less for the same power output as compared to Francis turbine

(iii) propeller turbine

→ propeller turbine is also an axial flow turbine, like Kaplan.

→ But it can not adjust its blades, so part Load efficiency is poor for this turbine

→ Specific speed is in between 300 to 600

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$\boxed{Q-5'C'}$

Given

$V_1 = 900\,m/s$ (velocity leaving Nozzle)

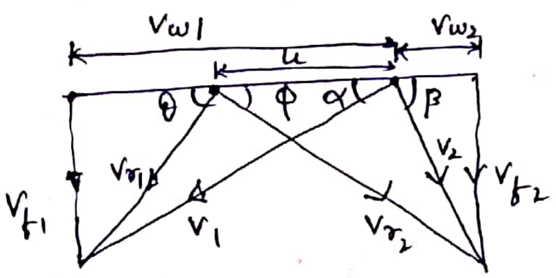
Nozzle angle, $\alpha = 20°$, u, blade velocity $= 300\,m/s$

$\boxed{K = \text{blade friction coefficient} = 0.7 = \frac{V_{r_2}}{V_{r_1}}}$

$\dot{m} = 1\,kg/s$

Given Symmetrical blading

i.e. $\boxed{\theta = \phi}$



Velocity triangle

$V_{w_1} = V_1 \cos\alpha = 900 \times \cos 20°$

$\Rightarrow \boxed{V_{w_1} = 845.72\,m/s}$

and $V_{f_1} = V_1 \sin\alpha = 900 \times \sin 20°$

$\Rightarrow \boxed{V_{f_1} = 307.82\,m/s}$

Also $V_{r_1}^2 = (V_{f_1})^2 + (V_{w_1} - u)^2$

$\Rightarrow V_{r_1} = \sqrt{(307.82)^2 + (845.72 - 300)^2}$

$\Rightarrow \boxed{V_{r_1} = 626.55\,m/s}$

and $\boxed{V_{r_2} = K V_{r_1} = 0.7 \times 626.55 = 438.585\,m/s}$

(1) Blade inlet angle (θ)

$\tan\theta = \left(\frac{V_{f_1}}{V_{w_1} - u}\right)$

$\Rightarrow \theta = \tan^{-1}\left(\frac{307.82}{845.72 - 300}\right)$

$\Rightarrow \boxed{\theta = 29.43°} = \phi$

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(2) Symmetrical blading

$\because \theta = \phi$

$\therefore \cos\phi = \frac{(u + V_{w_2})}{V_{r_2}}$

$\Rightarrow V_{w_2} = V_{r_2}\cos\phi - u = 438.585 \times \cos(29.43) - 300$

$\Rightarrow \boxed{V_{w_2} = 81.99 \text{ m/s}}$

$\therefore$ Driving force on wheel

$= \dot{m}(V_{w_1} + V_{w_2}) = 1 \times (845.72 + 81.99)$

$\Rightarrow \boxed{F_D = 927.71 \text{ N}}$

(3) Axial Thrust

$\tan\phi = \frac{V_{f_2}}{(u + V_{w_2})}$

$\Rightarrow V_{f_2} = (300 + 81.99) \times \tan(29.43)$

$\Rightarrow \boxed{V_{f_2} = 215.5 \text{ m/s}}$

$\therefore$ Axial thrust

$F_a = \dot{m}(V_{f_1} - V_{f_2}) = 1 \times (307.82 - 215.5)$

$\Rightarrow \boxed{F_a = 92.32 \text{ N}}$

(4) Diagram power

$P = F_D \times u = \frac{927.71 \times 300}{1000}$ kW

$\Rightarrow \boxed{P = 278.313 \text{ kW}}$

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⑤ Diagram efficiency

$$\eta = \frac{P_D}{\left(\frac{1}{2} \times \dot{m} \times V_1^2\right)} = \left\{\frac{278.313 \times 2 \times 1000}{1 \times (900)^2}\right\}$$

$$\Rightarrow \boxed{\eta = 0.6872 = 68.72\,\%}$$

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$\boxed{Q\text{-}5'd'}$

Mass flow rate, $\dot{m} = 4$ kg/s

$T_1 = 300K$

No. of stages, $N = 10$

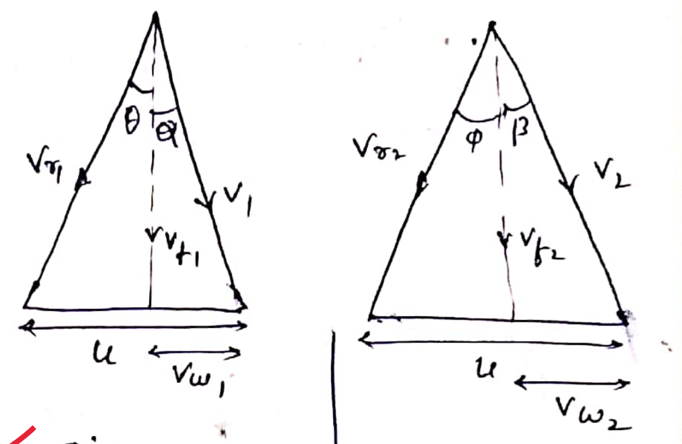
$\eta_{isen} = 0.89$

V_f = Axial Velocity $= 125$ m/s

$u = 200$ m/s

R : Degree of Reaction $= 50\%$.

i.e $\boxed{\theta = \beta}$ and $\boxed{\alpha = \phi}$



inlet velocity triangle

outlet velocity triangle

$R = 0.5$

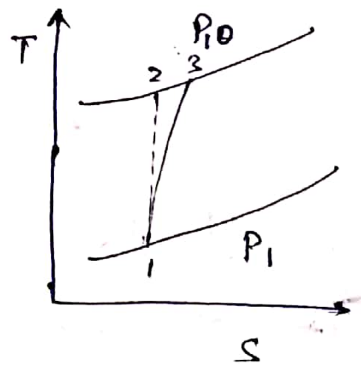
$\Rightarrow \dfrac{V_f}{2u}(\tan\theta + \tan\phi) = 0.5$

$\Rightarrow \tan\theta + \tan\phi = \dfrac{0.5 \times 2 \times 200}{125}$

$\Rightarrow \boxed{(\tan\theta + \tan\phi) = 1.6}$ — (1)

and ~~Also from velocity triangle~~

~~$u = V_f(\tan\theta + \tan\alpha)$~~



$\left(\dfrac{P_{10}}{P_1}\right) = (r_p) = 8$

$\Rightarrow \left(\dfrac{T_2}{T_1}\right) = (r_p)^{\frac{\gamma-1}{\gamma}}$

$\Rightarrow \boxed{T_2 = (8)^{0.4/1.4} \times 300 = 543.434\ K}$

$\therefore \boxed{T_3 = T_1 + \dfrac{T_2 - T_1}{\eta_{isen}} = 300 + \dfrac{543.434 - 300}{0.89} = 573.521\ K}$

$\therefore$ Assuming equal Temp change in each stage

$(\Delta T)_{stage} = \left(\dfrac{T_3 - T_1}{N}\right) = \dfrac{573.521 - 300}{10} = 27.352\ K$

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$$\boxed{(\Delta T)_{stage} = 27.352\ K}$$

Also

$$C_p (\Delta T)_{stage} = (V_{w_2} - V_{w_1}) \times u$$

$$\Rightarrow (V_{w_2} - V_{w_1}) = \frac{1.005 \times 27.352 \times 1000}{200}$$

$$\Rightarrow \boxed{(V_{w_2} - V_{w_1}) = 137.444\ m/s}$$

$$\Rightarrow (V_f \tan\beta - V_f \tan\alpha) = 137.444$$

$$\Rightarrow \boxed{(\tan\theta - \tan\phi) = \frac{137.444}{125} = 1.1} \quad \text{(ii)}$$

$$(\because \theta = \beta \ \& \ \phi = \alpha)$$

$\therefore$ from (i) & (ii)

$$2\tan\theta = 1.6 + 1.1 = 2.7$$

$$\Rightarrow \boxed{\theta = \tan^{-1}\left(\frac{2.7}{2}\right) = 53.47^\circ}$$

and $\tan\phi = \tan\theta - 1.1 = \tan(53.47) - 1.1$

$$\Rightarrow \phi = \tan^{-1}\left[\tan(53.47) - 1.1\right]$$

$$\Rightarrow \boxed{\phi = 14.03^\circ}$$

$$\therefore \boxed{\theta = \beta = 53.47^\circ} \quad \text{and} \quad \boxed{\alpha = \phi = 14.03^\circ}$$

and Power Given to air

$$P = \dot{m} C_p (\Delta T)_{total}$$

$$\Rightarrow P = 4 \times 1.005 \times (573.521 - 300)$$

$$\Rightarrow \boxed{P = 1099.55\ kW}$$

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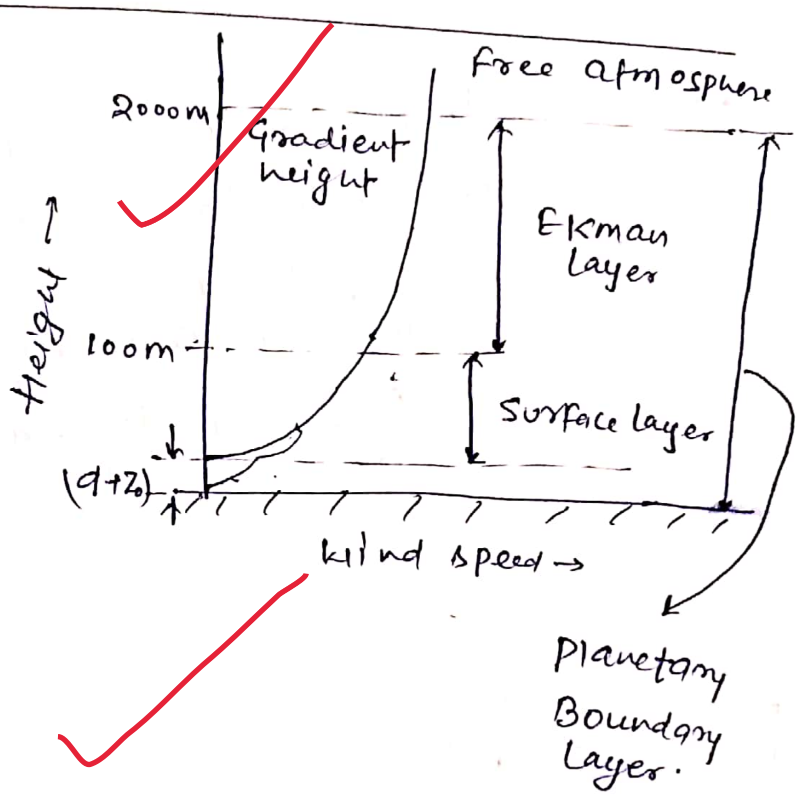
Q-5'e'

* Variation of wind speed with height:



→ At surface wind speed is zero and it increases with height

→ Wind shear

↳ The change of wind speed with height is called wind shear.

→ Gradient height

↳ Due to resistance between the layers of air motion, lower layer opposes the upper layer and mean air velocity changes with the height. At the sufficient height, when this shear effect is negligible, that height is called Gradient height. It is generally 2000 m.

→ Free atmosphere

↳ Above the Gradient height, shear effect are negligible and ~~air m~~ wind speed is not much affected by ground conditions. This is called free atmosphere.

→ Planetary boundary layer

↳ The layer of air from ground to the gradient height is called planetary boundary layer.

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→ Two parts of Planetary boundary layer

- (i) Surface layer → upto 100 m
- (ii) Ekman layer → from 100 m to gradient height

→ A simple empirical Power law model can be used to estimate wind speed, u_z at a height z relative to that available at standard ref. height H

$$\boxed{u_z = u_H \left(\frac{Z}{H}\right)^a}$$

, α → Depends on surface roughness

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Q-6 (a)

(i) Priming

→ Priming is the process in which the impeller of a centrifugal pump will get fully submerged in liquid without any air trap inside.

→ This is required before the start of pump

* Need of priming

→ Head developed by the pump is independent of Density,

→ So; if pump is run with air, head developed is same but it is the form of head ~~of~~ of air.

04

→ Since, air has low density, if we convert this developed head in terms of water head, it will be very small and chances are there, that water may not sucked.

So priming is necessary

(ii) * Methods of priming

→ (I) Manually
(II) With vacuum pump
(III) With Jet pump
(IV) With seperator

(I) In manually, water is poured in the pump through funnel. When priming is being done, an air escapes through air vent valve.

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(ii) With vacuum pump

2> In this Method, a small size reciprocating pump is used priming the main centrifugal pump.

→ The suction line of reciprocating pump is connected to the delivery line of main centrifugal pump.

(iii) With Jet Pump

2> In this Method, water available at high head is allowed to flow through a nozzle.

→ The nozzle is so designed that at the jet outside the nozzle the pressure is less than atm pressure so it is possible to suck water from the sump

(iv) With seperator

2> An air separator is provided on the delivery side of pump and bent suction pipe portion is provided at the inlet of pump

→ Bent suction pipe always contain some liquid.

→ The liquid heavier than air, so it falls back into seperator and air moves in upward dir.

→ Therefore the liquid & air are separated in separator

* Self priming

2> Self priming of centrifugal pump is necessary in that case when, pump

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Q.1 b'

has to be placed above the level of liquid, ex - when emptying an underground storage tank

→ A self-priming centrifugal pump has two phases of operation
  - (i) priming mode
  - (ii) pumping mode

→ In priming mode, the pump essentially acts as a liquid-ring pump. The rotating impeller generates a vacuum at the impeller's eye, which draws air into the pump from the suction line. At the same time, it also creates a cylindrical ring of liquid on the inside of the pump casing. This effectively forms a gas tight-seal, stopping air returning from the discharge line to the suction line. Air bubbles are trapped in the liquid within the impeller's vanes and transported to the discharge port.

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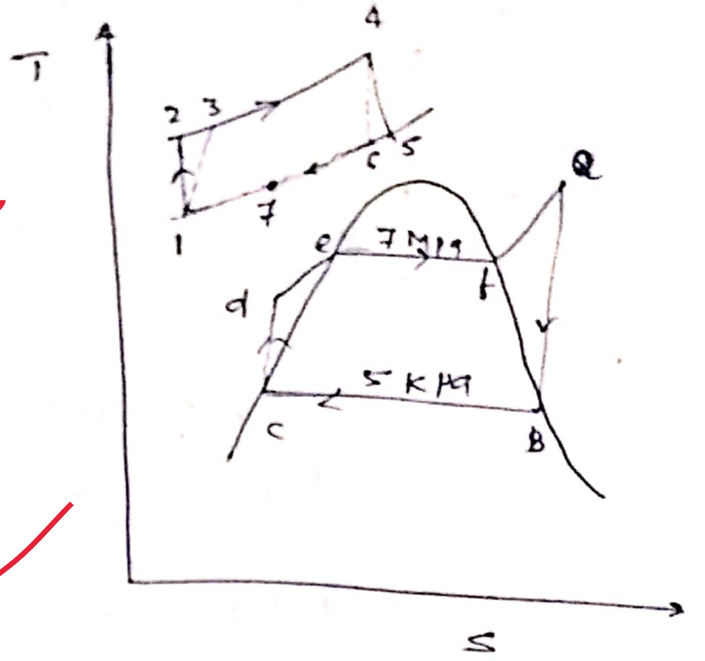
Q-6'b'



for Gas turbine

r_p = pr. Ratio = 9

$T_1 = 298K$

$T_4 = (1127°C + 273)\ K$

$\Rightarrow \boxed{T_4 = 1400K}$ $\boxed{T_7 = 450K}$

$\boxed{\eta_{comp} = \eta_{turb} = 0.88}$

$\therefore T_3 = T_1 + \dfrac{T_2 - T_1}{\eta_{comp}}$

$\Rightarrow \boxed{T_3 = 298 + \dfrac{T_2 - 298}{0.88}}$

& $T_2 = T_1 \times (r_p)^{\frac{\gamma-1}{\gamma}}$

$\Rightarrow T_2 = (298) \times (9)^{0.4/1.4}$

$\Rightarrow \boxed{T_2 = 558.286K}$

$\therefore T_3 = 298 + \dfrac{(558.286 - 298)}{0.88}$

$\Rightarrow \boxed{T_3 = 593.78K}$

Given

At 7 Mpa, $t_{sat} = 285.83°C = t_f = t_e$

and $t_a = 500°C$.

Now

$T_6 = \cancel{T_4 \times}\ T_4 \times \left(\dfrac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}} = 1400 \times \left(\dfrac{1}{9}\right)^{0.4/1.4}$

$\Rightarrow \boxed{T_6 = 747.29\ K}$

and

$T_5 = T_4 - (T_4 - T_6) \times \eta_{tur} = 1400 - 0.88 \times (1400 - 747.29)$

$\Rightarrow \boxed{T_5 = 825.615\ K}$

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$\therefore$ at, $P = 7\,MPa$ & $t = 500°C$

$$\boxed{h_a = \cancel{3074.3}\ 3410.6\ kJ/kg}$$

and

$$\boxed{h_{g@70bar} = \cancel{1267.5}\ 2773.4\ kJ/kg}$$

$\therefore$ (i) Let m_{com} = mass of Combustion gases

m_s = Mass of steam

$\therefore$ By Energy Conservation

$$\dot{m}_s \times (h_a - h_f) = \dot{m}_a \cdot (C_{pa}) \cdot (T_6 - T_7)$$

$$\Rightarrow \left(\frac{\dot{m}_s}{\dot{m}_{com}}\right) = \frac{1.005 \times (747.29 - 450)}{\cancel{1267.5}\ (\cancel{3074.3} - \cancel{1267.5})\ (3410.6 - 2773.4)}$$

$$\Rightarrow \boxed{\frac{\dot{m}_s}{\dot{m}_{com}} = \cancel{0.1654}\ 0.469}$$

(ii)

$$(W_{net})_{gas\,turbine} = (W_T) - (W_{comp})$$

$$\Rightarrow (W_{net})_{GT} = (C_{pa}) \cdot (T_4 - T_5) - (C_{pa}) \cdot (T_3 - T_1)$$

$$\Rightarrow (W_{net})_{GT} = 1.005 \times [1400 - 825.615 - 593.78 + 298]$$

$$\Rightarrow \boxed{(W_{net})_{GT} = 279.998\ kJ/kg \text{ of Comb. gas}}$$

Also

$$S_a = S_b = 6.8\ kJ/kgK \quad [\text{at } 7\,MPa, 500°C]$$

$$\Rightarrow \boxed{S_c + S_{fg@5kPa} \times x_b = 6.8}$$

$$S_c = (S_f)_{@5kPa} = 0.4762\ kJ/kgK$$

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and $s_{fg} = 7.9176 \text{ KJ/kg K}$

$$\therefore \boxed{x_b = \frac{6.8 - 0.4762}{7.9176} \simeq 0.8}$$

$\therefore h_b = h_c + x_b \times (h_{fg})_{@5\,kPa}$

$$\Rightarrow \boxed{h_b = 137.75 + 0.8 \times 2423 = 2076.15 \text{ KJ/Kg}}$$

$\therefore$ Also

$h_d = h_c + v\Delta P = 137.75 + 0.001005 \times (7000 - 5)$

$$\Rightarrow \boxed{h_d = 144.78 \text{ KJ/kg}}$$

$\therefore \eta_I$ = Efficiency of Gas turbine

$\Rightarrow$ ~~Wnet~~ $\eta_I = \dfrac{(W_{net})_{GT}}{\text{Heat Add.}} = \dfrac{279.998}{c_{pa} \times [T_4 - T_3]} \times 100$

$\Rightarrow \eta_I = \dfrac{279.998}{1.005 \times (1400 - 593.78)} \times 100$

$$\Rightarrow \boxed{\eta_I = 34.56\,\%}$$

and η_{II} = Efficiency of steam turbine.

$(W_{net})_{\substack{steam\\turb}} = (W_T) - (W_P) = (h_a - h_b) - (h_d - h_c)$

$\Rightarrow (W_{net})_{steam} = (\cancel{3074.3}^{\,3410.6} - \cancel{2076.15}^{\,2773.4}) - (144.78 - 137.75)$

$$\Rightarrow \boxed{(W_{net})_{steam} = \cancel{991.12}^{\,627.17} \text{ KJ/kg}}$$

$\therefore (\eta_{II}) = \dfrac{(W_{net})_{steam}}{Q_{boiler}} = \dfrac{\cancel{991.12}^{\,627.17}}{(h_f - h_d)} \times 100 = \dfrac{\cancel{991.12}^{\,627.17}}{(\cancel{2775}^{\,2773.4} - 144.78)} \times 100$

$= \cancel{88.278\%}$ $23.86\,\%$

$\therefore \boxed{\eta_o = \begin{pmatrix}\text{overall}\\ \eta\end{pmatrix}} = \eta_I + \eta_{II} - \eta_I \times \eta_{II} = 0.3456 + \cancel{0.88278}^{\,0.2386} - 0.3456 \times \cancel{0.88278}^{\,0.2386}$

$= 0.9233 = 92.33\,\%$

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Q-5'd'

η_{II} = efficiency of steam turbine

$(W_{net})_{steam} = (W_T) - (W_c) = (h_a - h_b) - (h_d - h_c)$

$\Rightarrow (W_{net})_{steam} = (3410.6 - \cancel{2773.4}\ 2076.15) - (144.78 - 137.75)$

$\Rightarrow \boxed{(W_{net})_{steam} = \cancel{627.17}\ 1327.42 \text{ KJ/Kg}}$

and $\boxed{Q_{boiler} = (h_f - h_d) = (2773.4 - 144.78) = 2628.62 \text{ KJ}}$

$\therefore \boxed{(\eta_{II}) = \frac{(W_{net})_{steam}}{Q_{boiler}} = \frac{1327.42}{2628.62} \times 100 = 50.5\%}$

$\therefore \eta_{overall} = (\eta_I) + (\eta_{II}) - \eta_{II} \times \eta_I$

$\Rightarrow \eta_o = \frac{34.56}{100} + \frac{50.5}{100} - \frac{34.56 \times 50.5}{10000}$

$\Rightarrow \boxed{\eta_o = 0.676 = 67.6\%}$

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Q-6'C'

Anode Reaction

$$CH_3OH + H_2O(l) \rightarrow CO_2 + 6H^+ + 6e^-$$

Cathode → $\frac{3}{2} O_2 + 6H^+ + 6e^- \rightarrow 3H_2O(l)$

Overall → $CH_3OH + \frac{3}{2} O_2 \rightarrow CO_2 + 2H_2O(l)$

∴ n = No. of electrons transferred = 6

ΔG ; Gibbs free energy change = -39.59 KCal/mol

$= -39.59 \times 4.186 \times 1000 \frac{KJ}{Kg\,mole}$

$$\Rightarrow \boxed{\Delta G = -165723.74 \frac{KJ}{kg\,mole}}$$

and

ΔH, Enthalpy change $= -56.8$ KCal/mol

$\Rightarrow \Delta H = -56.8 \times 1000 \times 4.18 \frac{KJ}{Kg\,mole}$

$$\Rightarrow \boxed{\Delta H = -237764.8 \frac{KJ}{Kg\,mole}}$$

(i) Fuel Voltage at no load

$$(V_{noLoad}) = \frac{-\Delta G}{n \cdot F}$$

F = Faraday's const = 96500 Coulomb/gram mole

$$\therefore \boxed{(V_{noLoad}) = \frac{-(-165723.74)}{6 \times 96500} = 0.286 \text{ volt}}$$

(ii) Max^m η

By First Law of Thermodynamics

$$\boxed{(\Delta Q - \Delta W) = \Delta H + \Delta KE + \Delta PE}$$

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* Assuming

$\Delta KE = 0$, $\Delta PE = 0$

$\therefore \boxed{\Delta Q - \Delta W = \Delta H}$ — (I)

Now for maxm W_{max}, process has to be Reversible

$\therefore \boxed{\Delta Q = T(\Delta S)}$ for Reversible process — (II)

$\therefore$ from (I) & (II)

$$(T\Delta S) - \Delta W_{max} = \Delta H$$

$$\Rightarrow \boxed{(\Delta W)_{max} = (T\Delta S - \Delta H)} \quad \text{— (III)}$$

Also Gibbs free energy

$$G = H - TS$$

$$\Rightarrow \Delta G = \Delta H - (T\Delta S + S\Delta T)$$

Assuming No temp change, i.e $\Delta T = 0$

$$\therefore \Delta G = \Delta H - T\Delta S$$

$$\Rightarrow \boxed{(-\Delta G) = (T\Delta S - \Delta H)} \quad \text{— (IV)}$$

From eq. (III) & (IV)

$$\boxed{\Delta W_{max} = -\Delta G}$$

$$\therefore \eta_{max} = \left(\frac{\Delta W_{max}}{-\Delta H}\right) = \frac{-\Delta G}{-(\Delta H)} = \left(\frac{\Delta G}{\Delta H}\right)$$

$$\Rightarrow \boxed{\eta_{max} = \frac{165723.71}{237764.8} \times 100 = 69.7\,\%}$$

(III) Now

$$W_{max} = -\Delta G = 39.59 \times 4.186 = 165.724 \text{ KJ/mole.}$$

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(i'e)

~~E~~ 165.724 kJ of electrical energy is produced by 1 mole of CH_3OH & $\frac{3}{2} = 1.5$ mole of O_2

ie

1 mole of $CH_3OH = (12+3\times1+16+1) = 32g$
1 mole of $O_2 = 32g$

i'e

32 g of $CH_3OH \longrightarrow 165.724$ kJ
and $1.5\times 32g = 48g$ of $O_2 \longrightarrow 165.724$ kJ

i'e for $165.724 \frac{kJ}{s}$ (kW) required $\longrightarrow$ 32 g/sec of CH_3OH

$\therefore$ 100 kW power required $\longrightarrow \left(\frac{32}{165.724}\times 100\right)\frac{g}{sec}$ of CH_3OH

$\therefore$ $\boxed{\text{Flow Rate of Methanol} = \left(\frac{32\times100}{165.724}\times\frac{3600}{1000}\right)\frac{kg}{hr} = 69.513\ \frac{kg}{hr}}$

and $\boxed{\text{Flow Rate of } O_2 = \left(\frac{48\times100}{165.724}\times\frac{3600}{1000}\right)\frac{kg}{hr} = 104.27\ \frac{kg}{hr}}$

(iv) ~~A~~ Now

Heat Removal

$\Delta Q = \Delta H + \Delta W = (\Delta H - \Delta G) = -56.8 + 39.59$

$\Rightarrow \boxed{\Delta Q = -17.21\ \cancel{kJ/m}\cdot kcal/mol = -72.041\ kJ/mol}$

-ve sign indicated heat Removal

For ~~100~~ 1 mole of $CH_3OH = 32g$.

ie 32 g/sec ie 1 mole of $CH_3OH \longrightarrow 72.041\ \frac{kJ}{sec}$

$\therefore \left(\frac{69.513\times1000}{3600}\right) g/s \longrightarrow \frac{72.041}{32}\times\left(\frac{69.513\times1000}{3600}\right)$

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$\therefore$ $\boxed{\text{Heat Removed} = 43.47\ kW}$

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Q - 8'a'

Given

Dark saturation current, $I_0 = 1.7 \times 10^{-8}\ A/m^2$

Short circuit current density, $I_{sc} = 250\ A/m^2$

Temp, $T = 27 + 273 = 300K$

$K = 1.381 \times 10^{-23}\ J/K$

$e = 1.602 \times 10^{-19}\ J/V$

(1) Open circuit voltage (V_{oc})

$$I = I_{sc} - I_j = I_{sc} - I_g = I_{sc} - I_0\left[\exp\left(\frac{eV}{KT}\right) - 1\right]$$

When, $V = V_{oc}$,

then $I = 0$

$$\therefore\ 0 = I_{sc} - I_0\left[\exp\left(\frac{eV_{oc}}{KT}\right) - 1\right]$$

$$\Rightarrow \exp\left(\frac{eV_{oc}}{KT}\right) - 1 = \frac{I_{sc}}{I_0}$$

$$\Rightarrow \left(\frac{eV_{oc}}{KT}\right) = \ln\left(1 + \frac{I_{sc}}{I_0}\right) = \ln\left(1 + \frac{250}{1.7 \times 10^{-8}}\right)$$

$$\Rightarrow V_{oc} = \left(\frac{KT}{e}\right) \times 23.411 = \frac{(1.381 \times 10^{-23}) \times 300 \times 23.411}{1.602 \times 10^{-19}}$$

$$\Rightarrow \boxed{V_{oc} = 0.605\ \text{volt}}$$

(2)

$$\text{power, } P = V \times I = V \times \left[I_{sc} - I_0\left\{\exp\left(\frac{eV}{KT}\right) - 1\right\}\right]$$

$$\Rightarrow \boxed{P = V I_{sc} - V I_0 \exp\left(\frac{eV}{KT}\right) + V I_0}$$

For maxm power

$$\frac{dp}{dV} = 0$$

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$$\Rightarrow \frac{d}{dV}\left[VI_{sc} - VI_0 \exp\left(\frac{eV}{KT}\right) + VI_0 \right] = 0$$

$$\Rightarrow I_{sc} + I_0 - I_0 \left\{ \cancel{V \times V \times \exp\, e} \; V \cdot \left(\frac{e}{KT}\right) \cdot \exp\left(\frac{eV}{KT}\right) + \exp\left(\frac{eV}{KT}\right) \cdot \right\} = 0$$

$$\Rightarrow I_{sc} + I_0 - I_0 \left[\exp\left(\frac{eV}{KT}\right) \left\{ 1 + \frac{eV}{KT} \right\} \right] = 0$$

$$\Rightarrow \left(1 + \frac{eV}{KT}\right) \exp\left(\frac{eV}{KT}\right) = \frac{I_{sc} + I_0}{I_0} = \left(1 + \frac{I_{sc}}{I_0}\right)$$

$$\Rightarrow \exp\left(\frac{eV_{max}}{KT}\right) = \frac{\left(1 + \frac{250}{1.7 \times 10^{-8}}\right)}{1 + \frac{1.602 \times 10^{-19} \times V_{max}}{1.381 \times 10^{-23} \times 300}}$$

$$\Rightarrow \exp\left(\frac{1.602 \times V_{max} \times 10^{-19}}{1.381 \times 10^{-23} \times 300}\right) = \left(\frac{1.4706 \times 10^{10}}{1 + 38.668 \times V_{max}}\right)$$

$$\Rightarrow (38.668) \times V_{max} = \ln(1.4706 \times 10^{10}) - \ln(1 + 38.668 \times V_{max})$$

$$\cancel{\Rightarrow V_{max} = \frac{23.4115}{38.668}}$$

$$\Rightarrow (38.668) \times V_{max} + \ln(1 + 38.668 \times V_{max}) - 23.4115 = 0$$

on solving

$$\boxed{V_{max} = 0.5264 \text{ volt}} \Rightarrow \text{voltage at max}^m \text{ power}$$

(iii) current density at max^m power, I_{max}

$$I_{max} = I_{sc} - I_0 \left[\exp\left(\frac{eV_{max}}{KT}\right) - 1 \right]$$

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$$\Rightarrow I_{max} = 250 - 1.7\times10^{-8}\left[\exp\left(\frac{1.602\times10^{-19}\times0.5264}{1.381\times10^{-23}\times300}\right)-1\right]$$

$$\Rightarrow \boxed{I_{max} = 238.24 \ A/m^2}$$

(IV) $\therefore P_{max} = V_{max} \times I_{max} = 0.5264 \times 238.24$

$$\Rightarrow \boxed{P_{max} = 125.409 \ W/m^2}$$

(V) $$\eta_{max} = \frac{P_{max}}{\text{Solar intensity}} \times 100 = \frac{125.409}{820} \times 100 = 15.294\%$$

$$\therefore \boxed{\eta_{max} = 15.294\%}$$

Also

output $= 20W$

$\therefore$ Min^m area Required, $A = \frac{20}{P_{max}} = \frac{20}{125.409} \ m^2$

$$\Rightarrow \boxed{A = 0.159 \ m^2}$$

$\rightarrow$ Fill factor $= \frac{V_m \times I_m}{V_{oc} \times I_{sc}} = \frac{125.409}{0.605 \times 750}$

$$\boxed{F.F = 0.276}$$

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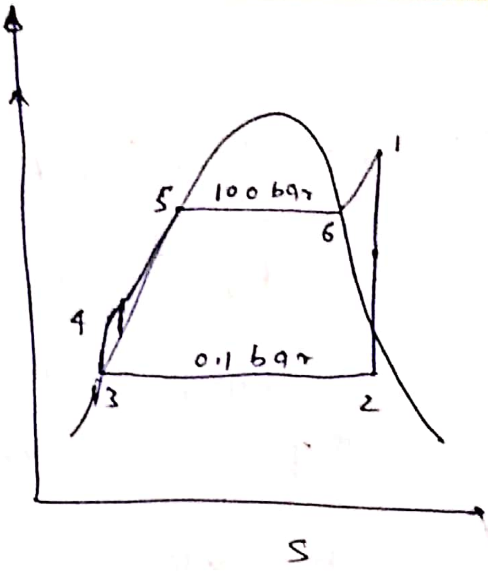
Q - 8'b'



Given,

Entry to turbine is at

1 (100 bar, 500°C)

$\therefore h_1 = \cancel{3342.4}\ 3375.1$ KJ/kg

$s_1 = 6.5995$ KJ/kgK $= s_2$

Also At 0.1 bar

$S_3 = S_{f @ 0.1 bar} = 0.6492$ KJ/kgK

$S_{fg @ 0.1 bar} = 7.4995$ KJ/kgK

$\therefore S_2 = S_3 + x_2 \cdot S_{fg}$

$$\Rightarrow \boxed{x_2 = \frac{6.5995 - 0.6492}{7.4995} = 0.793}$$

and $h_3 = h_{f @ 0.1 bar} = 191.81$ KJ/kg

$h_{fg @ 0.1 bar} = 2392.1$ KJ/kg

$\therefore h_2 = h_3 + x_2 \cdot h_{fg} = 191.81 + 0.793 \times 2392.1$

$$\Rightarrow \boxed{h_2 = 2088.7453 \text{ KJ/kg}}$$

(1)

Given $P = 120$ MW

$\Rightarrow \dot{m}_s [W_T - W_P] = 120 \times 1000$

Neglecting pump work.

$\dot{m}_s W_T = 120 \times 1000$

$$\Rightarrow \boxed{\dot{m}_s \text{ (Steam Rate)} = \frac{120 \times 1000}{(h_1 - h_2)} = \frac{120 \times 1000}{3375.1 - 2088.7453} = 93.29 \text{ kg/s}}$$

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(2) Fuel burning Rate

$$h_4 = 675.5 \text{ KJ/kg}$$

$$\eta_{boiler} = 0.9$$

$\dot{m}_f$ = fuel rate , $(C.V.)_{fuel} = 25.7$ MJ/kg

$\therefore$

$$(\dot{m}_f) \times (C.V)_{fuel} \times \eta_{boiler} = \dot{m}_s \times (h_1 - h_4)$$

$$\Rightarrow (\dot{m}_f) = \frac{(93.29) \times (3375.1 - 675.5)}{(25.7 \times 1000) \times 0.9}$$

$$\Rightarrow \boxed{\dot{m}_f = 10.89 \text{ kg/s}} = \boxed{39204 \frac{\text{kg}}{\text{hr}} = 39.204 \frac{\text{tonn}}{\text{hr}}}$$

~~(3) Evaporation factor~~

$$E.f. = \frac{(h_1 - h_5)}{(h_{fg})_{@100°c}} = \left(\frac{3375.1 - 1407.8}{2256.9}\right)$$

$$\Rightarrow \boxed{E.f. = 0.872}$$

(4) Pressure head available for natural circulation

$$\boxed{\Delta P = gH(\rho_f - \rho_m)}$$

H = Height of Furnace Wall = 40m

ρ_f = Density of Liquid $= \frac{1}{v_f}$

and ρ_m = Mean Density of Liquid vapour mixt in Riser

$$\boxed{\rho_m = \left(\frac{\rho_{top} + \rho_f}{2}\right)}$$

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Now At 100 bar

$v_f = 0.001452 \ m^3/kg$

and $\cancel{v_{fg}} = v_g = 0.018028 \ m^3/kg$

$\therefore \ v_{top} = v_f + x_{top} \cdot v_{fg} = 0.001452 + 0.08 \times (0.018028 - 0.001452)$

$\Rightarrow \boxed{v_{top} = \cancel{2.89424} \ 2.77808 \times 10^{-3} \ m^3/kg}$

$\therefore \ \boxed{\rho_f = \frac{1}{v_f} = \frac{1}{0.001452} = 688.705 \ kg/m^3}$

and $\boxed{\rho_{top} = \frac{1}{v_{top}} = \frac{1}{\cancel{2.89424} \ 2.77808 \times 10^{-3}} = \cancel{345.514} \ 359.96 \ kg/m^3}$

$\therefore \ \boxed{\rho_m = \left(\frac{\rho_{top} + \rho_f}{2}\right) = \left(\frac{\cancel{345.514} \ 359.96 + 688.705}{2}\right) = \cancel{517.11} \ 524.33 \ kg/m^3}$

$\therefore$ pressure head, $\Delta P = 9.81 \times 40 \times (688.705 - \cancel{517.11} \ 524.33)$

$\Rightarrow \boxed{\Delta P = \cancel{67333.88 \ Pa} = \cancel{67.334 \ kPa} \quad 64500.75 \ Pa = 64.5 \ kPa}$

(5) Circulation Ratio (CR)

$CR = \frac{1}{x_{top}} = \frac{1}{0.08} = 12.5$

$\boxed{CR = 12.5}$

(6)

Riser outer Diameter, $D_o = 60 \ mm$

Wall thickness, $t = 3 \ mm$

$\therefore$ Inner diameter, $D_i = D_o - 2t = 60 - 6$

$= 54 \ mm$

$\therefore \left(\text{Mass Flow of steam formation in Riser}\right) = \left(\frac{\pi}{4} D_i^2 \times \rho_{top} \times V_i \times x_{top}\right)$

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$\therefore$ Mass of steam in one Riser $= \frac{\pi}{4} \times \left(\frac{54}{1000}\right)^2 \times (\cancel{345.575}\ 359.96) \times (0.08) \times 2$

$\Rightarrow \boxed{\dot{m}_{one\ Riser} = \cancel{0.1266}\ 0.132 \text{ Kg/s}}$

$\therefore$ No. of Riser $= \frac{\dot{m}_s}{\dot{m}_{one\ Riser}} = \frac{93.29}{\cancel{0.1266}\ 0.132} = 706.74$

$\boxed{n = 707}$

(7) Heat Absorption Rate per unit projected area of Riser

Projected area, $A_p = D_o \times H = 0.06 \times 40$
$= 2.4\ m^2$

~~and~~

$\therefore$ Heat Absorption $= \frac{\dot{m}_{one\ Riser} \times (h_{fg})_{@100bar}}{A_p}$

$\Rightarrow$ (Heat absorption) $= \frac{0.132 \times (1319.7)}{2.4}$

$\Rightarrow \boxed{\text{Heat absorption} = 72.58\ kW/m^2}$

(8) Evaporation factor

$\boxed{E.F. = \frac{\dot{m}_s}{\dot{m}_f} = \frac{93.29}{10.89} = 8.57}$

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Q - 8'C'

Total isentropic enthalpy drop

$\Rightarrow \Delta h = 1467.4$ KJ/kg

$u =$ ~~500~~ 300 m/s

$\eta_{nozzle} = 0.95$ (except Curtis)

$\eta_{nozzle} = 0.9$ (Curtis)

$\alpha_i = 15°$ ⇒ Nozzle angle for impulse stages

$\alpha_r = 25°$ ⇒ Nozzle angle for reaction stages

(1) All simple impulse stages

For impulse stage, optimum speed Ratio

$$\rho = \frac{u}{V_1} = \frac{\cos \alpha_i}{2}$$

$$\Rightarrow \boxed{V_1 = \left(\frac{2u}{\cos\alpha_i}\right) = \frac{2 \times 300}{\cos 15} = 621.166 \text{ m/s}}$$

~~Let n =~~

For one stage

$$V_1^2 = 2(\Delta h)_{stage} \times \eta_{nozzle}$$

~~$\Rightarrow V_1 = 2 \times$~~

$$\Rightarrow (\Delta h)_{stage} = \frac{V_1^2}{2 \times \eta_{nozzle}} = \frac{(621.166)^2}{2 \times 0.95} \times 10^{-3}$$

$$\Rightarrow \boxed{(\Delta h)_{stage} = \cancel{203077.47}\ 203.077 \text{ KJ/kg}}$$

$$\therefore n = \text{No. of stage} = \frac{(\Delta h)_{total}}{(\Delta h)_{stage}} = \frac{1467.4}{203.077} = 7.23$$

$$\therefore \boxed{n = 8}$$

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② All 50% reaction stages

for 50% reaction stage,

optimum speed ration, $\rho = \frac{u}{V_1} = \cos\alpha_r$

$$\Rightarrow \boxed{V_1 = \frac{u}{\cos\alpha_r} = \frac{300}{\cos 25^\circ} = 331.013 \text{ m/s}}$$

$\because$ In 50% reaction stage, enthalpy drop of equal amount occurs in both stator and rotor.

$$\therefore V_1^2 = 2\left\{\frac{(\Delta h)_{stage}}{2}\right\} \cdot (\eta_{nozzle})$$

$$\Rightarrow (\Delta h)_{stage} = \left(\frac{V_1^2}{\eta_{nozzle}}\right) \times 10^{-3} \text{ KJ/kg}$$

$$\Rightarrow \boxed{(\Delta h)_{stage} = \left(\frac{331.013^2}{0.95}\right) \times 10^{-3} = 115.336 \text{ KJ/kg}}$$

$\therefore$ No. of stages, $n = \frac{(\Delta h)_{total}}{(\Delta h)_{stage}} = \frac{1467.4}{115.336} = 12.72$

$$\therefore \boxed{n = 13}$$

③ A - 2-row curtis stage followed by a simple impulse stage

for 2-row curtis stage, $\rho = \frac{u}{V_1} = \frac{\cos\alpha_i}{4}$

$$\Rightarrow \boxed{V_1 = \frac{4u}{\cos\alpha_i} = \frac{4 \times 300}{\cos 15^\circ} = 1242.33 \text{ m/s}}$$

$$\therefore V_1^2 = 2 \times (\Delta h)_{\substack{2\text{-row} \\ \text{curtis}}} \times \eta_{nozzle}$$

$$\Rightarrow (\Delta h)_{\substack{2\text{-row} \\ \text{curtis}}} = \frac{(1242.33)^2}{2 \times 0.9} \times 10^{-3} \text{ KJ/kg}$$

$$\Rightarrow \boxed{(\Delta h)_{\substack{2\text{-row} \\ \text{curtis}}} = 857.435 \text{ KJ/kg}}$$

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$\therefore \left(\begin{array}{l}\text{Enthalpy drop in} \\ \text{~~Remaining~~ following} \\ \text{simple impulse} \\ \text{stage}\end{array}\right) = \begin{array}{l}\text{Enthalpy drop} \\ \text{in simple impulse} \\ \text{stage, if all stages} \\ \text{are simple} \\ \text{stage}\end{array}$

$\therefore \left(\begin{array}{l}\text{Enthalpy drop} \\ \text{in following impulse} \\ \text{stage}\end{array}\right) = \underset{\text{OR total}}{(\Delta h)_{isent}} - (\Delta h)_{2\text{-row curtis}}$

$= 1467.4 - 857.435$

$\Rightarrow \boxed{(\Delta h)_{\text{impulse stage}} = 609.965 \text{ kJ/kg}}$

$\therefore \boxed{\text{No. of stages of impulse} = \left(\frac{609.965}{203.077}\right) = 3}$

ie Here, $\boxed{n = \underbrace{1}_{\text{2-row Curtis}} + \underbrace{3}_{\text{simple impulse stage}}}$

(4) A - 2 row curtis stage followed by 50% Reaction stage

$(\Delta h)_{\text{2-row curtis stage}} = 857.435 \text{ kJ/kg}$

$\therefore \left(\begin{array}{l}\text{Enthalpy drop in} \\ \text{~~Remaining~~ following} \\ \text{50\% Reaction stage}\end{array}\right) (\Delta h)_{50\%} = (\Delta h)_{isen} - (\Delta h)_{\text{2-row curtis}}$

$= 1467.4 - 857.435$

$= 609.965 \text{ kJ/kg}$

$\therefore$ No. of stages of 50% Reaction $= \frac{609.965}{115.336} = 5.29$

≈ 6

$\therefore \boxed{n = \underbrace{1}_{\text{2-row curtis}} + \underbrace{6}_{\text{50\% Reaction}}}$

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