total marks= 263

NAME :

BATCH : MAINS A

ROLL :

Q 1) (a) isothermal compressibility, $\alpha = \frac{1}{\rho}\left(\frac{\partial \rho}{\partial P}\right)_T$

Coefficient of volume expansion, $\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_P$

$\rho = f(T, P)$

$d\rho = \left(\frac{\partial \rho}{\partial T}\right)_P dT + \left(\frac{\partial \rho}{\partial P}\right)_T dP$

$$\boxed{d\rho = -\beta \rho \, dT + \alpha \rho \, dP}$$

Then the fractional change in density is approximately.

$\Delta \rho = \alpha \rho \Delta P - \beta \rho \Delta T$

$\Delta \rho = (\alpha \Delta P - \beta \Delta T)\rho$

It is given that $\Rightarrow$ $\alpha = 4.8 \times 10^{-5} \, atm^{-1}$

$\beta = 0.337 \times 10^{-3} \, K^{-1}$

$\Delta P = 90 \, bar = 88.82 \, atm$

$\Delta T = T_2 - T_1 = 20^\circ C - 50^\circ C = -30^\circ C = -30 \, K$

$\rho = 990 \, Kg/m^3$

$\Rightarrow \Delta \rho = (4.26 \times 10^{-3} + 10.1 \times 10^{-3}) \, 990$

$\Rightarrow \Delta \rho = 14.226 \, Kg/m^3$

$\therefore$ the final density is :-

$\rho_2 = \rho_1 + \Delta \rho = 990 + 14.226$ ~~= 1000~~

$$\boxed{\rho_2 = 1004.23 \, Kg/m^3}$$

$\therefore$ the final density of water is $1004.23 \, Kg/m^3$

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Q1(b) $Q_1 = 20\ m^3/s$ $P_1 = 1 bar = 100 kPa$ $T_1 = 288K$

$PV^{1.4} = C$ (isentropic) $\frac{P_2}{P_1} = 1.5$

Assuming air to be ideal gas

$V_{f_1} = V_{f_2} = 100\ m/s$

$D_1 = 0.6m$ $D_2 = 1.2m$

$N = 5000$ rpm

$\Rightarrow \omega = 523.6$ rad/s

$\Rightarrow u_1 = 157.08\ m/s$ $u_2 = 314.16\ m/s$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{0.4}{1.4}}$$

$\Rightarrow T_2 = 323.37K$

for centrifugal compressure assuming radial entry.

$\Rightarrow \alpha = 90° \Rightarrow V_1 = V_{f_1}$

$$\Rightarrow \tan\theta = \frac{V_{f_1}}{u_1}$$

$\Rightarrow \boxed{\theta = 32.48°}$ (inlet blade angle)

Power, $P = \dot{m} C_p (T_2 - T_1) = \dot{m} V_{w_2} u_2$

$\Rightarrow V_{w_2} = 113.19\ m/s$

$V_{w_2} < u_2$ $(\phi < 90°)$ backward curved blade

$$\therefore \tan\phi = \frac{V_{f_2}}{u_2 - V_{w_2}}$$

$\boxed{\phi = 26.4°}$ (outlet blade angle)

$\tan\beta = \dfrac{V_{f_2}}{V_{w_2}}$

$\Rightarrow \boxed{\beta = 41.47^\circ}$ (diffuser inlet angle)

very good

$\rho_1 = \dfrac{P_1}{RT_1} = 1.2098\ kg/m^3$

$\rho_2 = \dfrac{P_2}{RT_2} = 1.616\ kg/m^3$

$P_1 Q_1 = \dot{m} R T_1$

$\Rightarrow \dot{m} = 24.196\ kg/s$

$\Rightarrow \dot{m} = \rho_1 A_1 V_f = \rho_1 \pi D_1 B_1 V_f$

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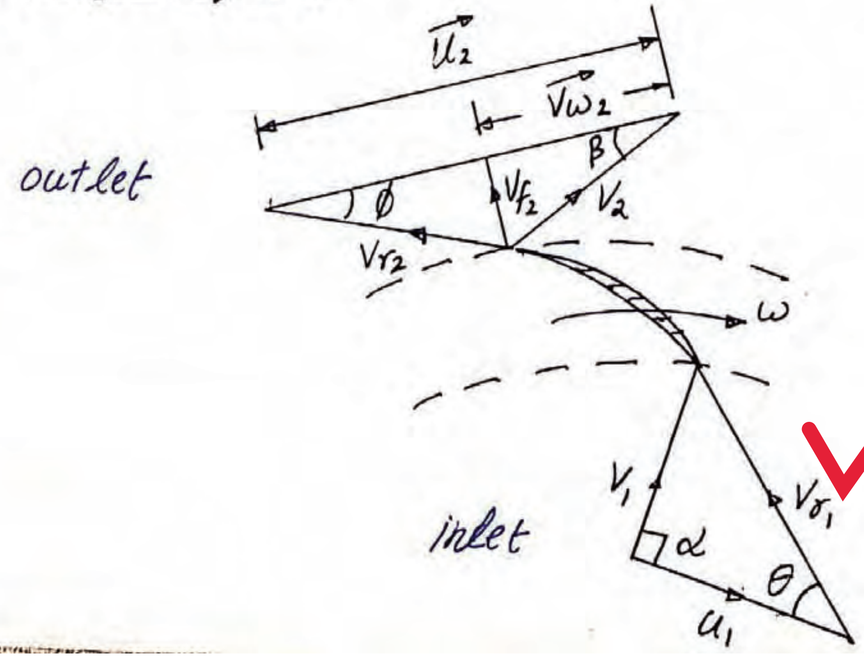
$\Rightarrow B_1 = 0.1061\ m$

$\Rightarrow \boxed{B_1 = 10.6\ cm}$

$\Rightarrow \dot{m} = \rho_2 A_2 V_f = \rho_2 \pi D_2 B_2 V_f$

$\Rightarrow \boxed{B_2 = 0.0397\ m = 3.97\ cm}$

velocity triangles:-




$\alpha = 90^\circ$

$\theta = 32.48^\circ$

$\beta = 41.47^\circ$

$\phi = 26.9^\circ$

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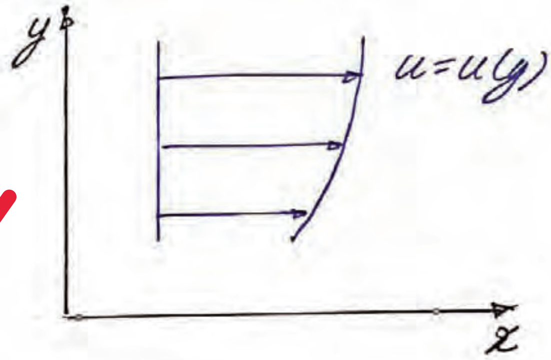
Q.1) c) Viscosity is the ~~q~~ quantitative measure of a fluid's resistance to flow. It determines the fluid strain rate that is generated by a given applied shear stress. It is a fluid property which comes into picture when fluid is in motion. In a fluid flow when fluid elements move with different velocities, each element will feel some resistance due to fluid friction within the elements.

Therefore, ~~shere~~ shear stresses are developed between the fluid elements having different velocities.

For a newtonian fluid :-




$$\tau = \mu \frac{du}{dy}$$

where $\tau$ = shear stress

$\mu$ = dynamic viscosity

$\frac{du}{dy}$ = velocity gradient

* Causes of viscosity in a fluid are attributed to two factors:-

(i) Intermolecular force of cohesion

(ii) molecular momentum exchange

Intermolecular cohesion is predominant in liquids.

molecular momentum exchange is dominant in gases.

As the temperature increases the cohesion forces decrease there for the viscosity of liquids decreases with increase in temperature.

As the temperature increases the molecular momentum exchange in gas molecules increases and hence the viscosity of gases increase with increase in temp.

Gases : $\mu = \dfrac{a\sqrt{T}}{1+b/T}$ a & b are constants

liquids : $\mu = a\,10^{(b/(T-c))}$ a, b, c are constants

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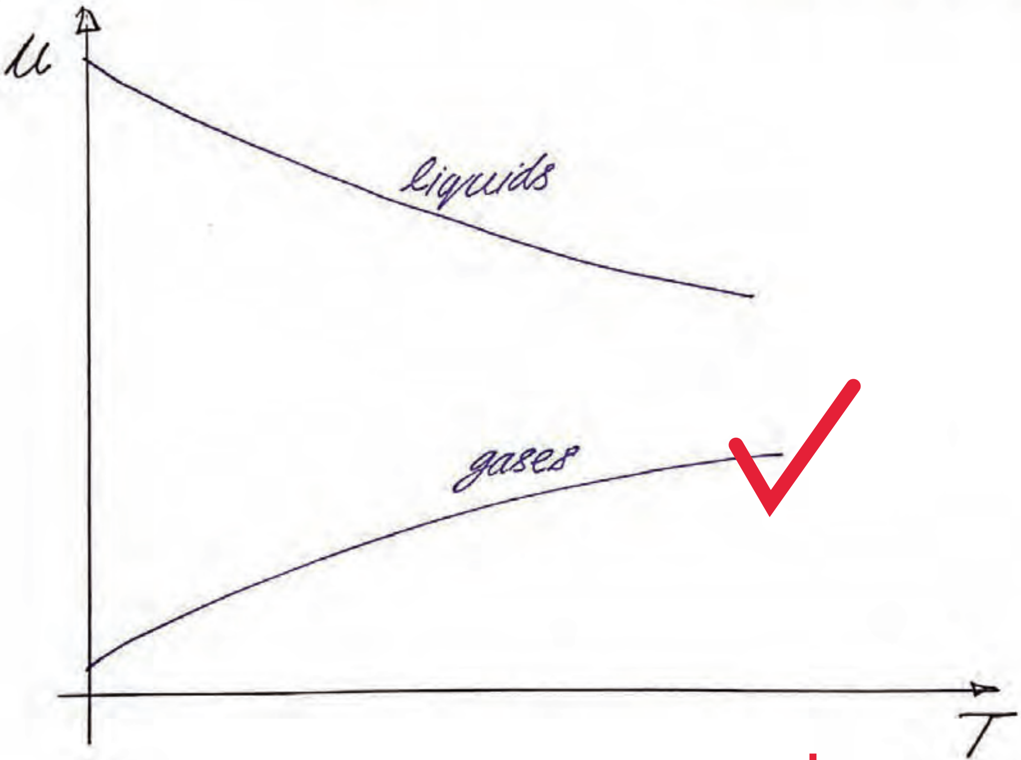


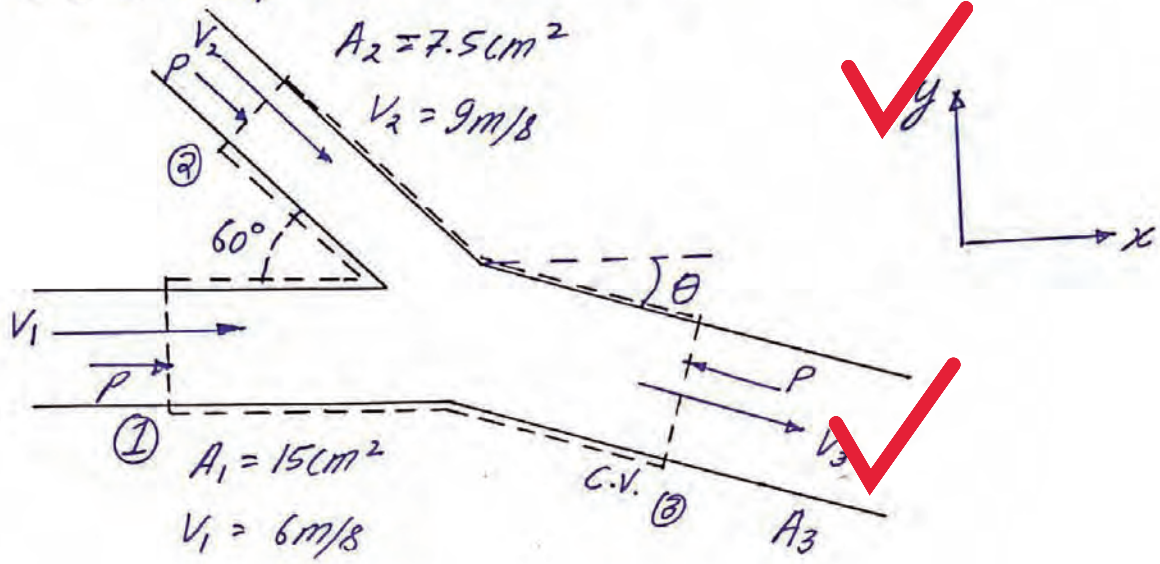

good

Q1).(d) Assumption:- (i) Pressure is atmospheric everywhere

(ii) assuming $P_a = 1\,bar = 100\,kPa$

(iii) steady state

(iv) Incompressible fluid ($\rho$ = const)




Conservation of mass :-

$$\Sigma \dot{m}_{in} = \Sigma \dot{m}_{out} \quad \text{(steady state)}$$

$$\rho A_1 V_1 + \rho A_2 V_2 = \rho A_3 V_3$$

$$\Rightarrow \quad A_3 V_3 = 15.75 \times 10^{-3} \quad \text{—(I)}$$

Conservation of linear momentum (x-direction)

$$\Sigma F_x = PA_1 + PA_2 \cos 60° - PA_3 \cos\theta$$

$$= \rho A_3 V_3^{\,3} \cos\theta - (\rho A_1 V_1^2 + \rho A_2 V_2^2 \cos 60°)$$

$$\Rightarrow \quad 271.875 = \left(\frac{0.248}{A_3} + 100000 A_3\right) \cos\theta \quad \text{(II)}$$

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Conservation of linear momentum (Y direction)

$$\Sigma F_y = P A_3 \sin\theta - P A_2 \sin 60^\circ = -\rho A_3 V_3^2 \sin\theta - (-\rho A_2 V_2^2 \sin 60^\circ)$$

$$\Rightarrow \quad 117.56 = \left(\frac{0.298}{A_3} + 100000 A_3\right) \sin\theta \quad \text{(ii)}$$

$$\text{(ii)}/\text{(i)} \Rightarrow \quad \tan\theta = \frac{117.56}{271.875}$$

$$\Rightarrow \boxed{\theta = 23.38^\circ \text{ (C.W. from +ve x axis)}}$$

from eq. (i)

$$271.875 = \frac{0.228}{A_3} + 91789.32 A_3$$

$$\Rightarrow \quad 91789.32 A_3^2 - 271.875 A_3 + 0.228 = 0$$

$$A_3 = 1.481 \times 10^{-3} \ m^2$$

$$\boxed{A_3 = 14.81 \ cm^2}$$

$\therefore$ from eq. (i), $\boxed{V_3 = 10.63 \ m/s}$

Assuming that the temp. of water remains constant

$\therefore$ internal energy change $= 0$

Assuming point 1, 2, 3 lie very close to mixing region and are on the datum

$$\therefore \text{loss of energy rate} = \left(\frac{P}{\rho} + \frac{1}{2}V^2 + gZ\right)_{out} \dot{m}_{out} - \left(\frac{P}{\rho} + \frac{V^2}{2} + gZ\right)_{in} \dot{m}_{in}$$

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$$\dot{E}_{loss} = \left(\frac{P}{\rho} + \frac{V^2}{2}\right)_3 \dot{m}_3 - \left(\frac{P}{\rho} + \frac{V^2}{2}\right)_1 \dot{m}_1 - \left(\frac{P}{\rho} + \frac{V^2}{2}\right)_2 \dot{m}_2$$

$\cancel{\dot{E}_{loss} =}$ $\dot{m}_3 = 15.74\ kg/s$

4 $\dot{m}_1 = 9\ kg/s$

$\dot{m}_2 = 6.74\ kg/s$

$$\Rightarrow \dot{E}_{loss} = (156.5)(15.74) - (118)(9) - (140.5)(6.75)$$

$$\Rightarrow \boxed{\dot{E}_{loss} = 452.935\ W}$$

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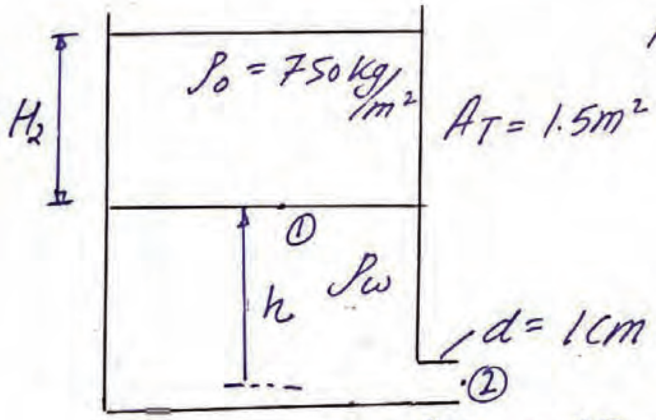
Q1 (e) part 1 :- Water is flowing out




$A_T = 1.5m^2$

$Cd = 0.85$

$H = H_1 + H_2 = 4m$

$\because$ Volume of oil = Vol. of water

$H_1 = H_2 = 2m$

$\rho_w = 1000\ kg/m^3$

Conservation of mass : $\Rightarrow$ $\rho_w A_T V_1 = \rho_w A_o V_2$

$$V_1 = \frac{A_o}{A_T} V_2 \quad -(1)$$

Applying Bernoulli eq. b/w point ① & ②

$$\frac{P_1}{\rho_w} + \frac{1}{2} V_1^2 + g Z_1 = \frac{P_2}{\rho_w} + \frac{1}{2} V_2^2 + g Z_2$$

$$\Rightarrow \frac{\rho_o g H_2}{\rho_w} + \frac{1}{2}\left(\frac{A_o}{A_T}\right)^2 V_2^2 + gh = V_2^2$$

$$\Rightarrow V_2 = \sqrt{\frac{2\left(\frac{\rho_o}{\rho_w}+1\right)gh}{1-\left(\frac{A_o}{A_T}\right)^2}}$$

$$A_o <<< A_T$$

$$\Rightarrow \boxed{V_2 = \sqrt{2\left(\frac{\rho_o}{\rho_w}+1\right)gh}}$$

$$V = C_d\sqrt{2\left(\frac{\rho_o}{\rho_w}+1\right)gh}$$

Assuming steady state

$$\dot{m}_{out} = -\dot{m}_{store}$$

$$C_d A_o\sqrt{2\left(\frac{\rho_o}{\rho_w}+1\right)gh} = -\frac{A_T\,dh}{dt}$$

$$\Rightarrow \int_0^{t_w} dt = \frac{-A_T}{C_d A_o\sqrt{2\left(\frac{\rho_o}{\rho_w}+1\right)g}}\int_{H_1}^{0}\frac{dh}{\sqrt{h}}$$

$$\Rightarrow t_w = \frac{2A_T\sqrt{H_1}}{C_d A_o\sqrt{2\left(\frac{\rho_o}{\rho_w}+1\right)g}}$$

calculation mistake

$$\Rightarrow \boxed{t_w = 10845.7 \text{ seconds}}$$

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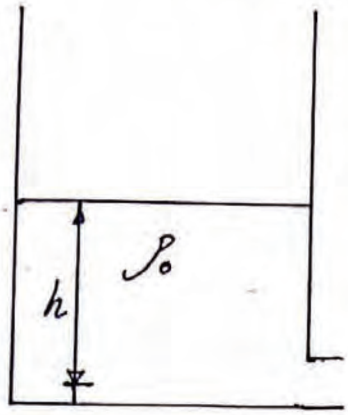
## Part 2:- Oil is flowing out




$V = C_d\sqrt{2gh}$

$$\dot{m}_{out} = -\dot{m}_{store}$$

$$C_d A_o \sqrt{2gh} = -\left(\frac{A_T\,dh}{dt}\right)$$

$$\int_0^{t_0} dt = \frac{-A_T}{C_d A_o \sqrt{2g}} \int_{H_2}^{0} \frac{dh}{\sqrt{h}}$$

$$\Rightarrow \boxed{t_0 = \frac{2A_T\sqrt{H_2}}{C_d A_o \sqrt{2g}}}$$

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$\Rightarrow t_0 = 14347.5$ seconds

total time, $t_{total} = 25193.25$ second $\simeq$ 7 hours

$\therefore$ the tank will be empty in 7 hours.

read question properly

Q.2(a) The given velocity field is

$$\vec{V} = 4x\hat{i} + (5y+3)\hat{j} + (3t^2)\hat{k}$$

It is given that the location of particle

at $t = 1 \Rightarrow (x, y, z) = (1m, 2m, 4m)$

$$u = \frac{dx}{dt} = 4x$$

$$\Rightarrow \frac{dx}{x} = 4\,dt$$

$$\Rightarrow \ln x = 4t + C_1$$

at $t = 1$, $x = 1$

$$\Rightarrow C_1 = -4$$

$$\Rightarrow \ln x = 4t - 4 \quad \text{--- (I)}$$

$$v = \frac{dy}{dt} = 5y + 3$$

$$\Rightarrow \frac{dy}{(5y+3)} = dt$$

$$\Rightarrow \frac{\ln(5y+3)}{5} = t + C_2$$

at $t = 1$ $y = 2$

$$\Rightarrow C_2 = -0.487$$

$$\Rightarrow \ln(5y+3) = 5t - 2.435 \quad \text{--- (II)}$$

$$w = \frac{dz}{dt} = 3t^2$$

$$\Rightarrow dz = 3t^2\,dt$$

$\Rightarrow z = t^3 + C_3$

$z = 4$ at $t = 1$

$\Rightarrow C_3 = 3$

$\Rightarrow z = t^3 + 3$ —(iii)

Adding (i) & (ii)

$\ln x + \ln(5y+3) = 9t - 6.435$

$\Rightarrow \ln x + \ln(5y+3) + 6.435 = 9t$

cubing both sides :-

$\Rightarrow [\ln x + \ln(5y+3) + 6.435]^3 = 729 t^3$

$\Rightarrow t^3 = \frac{1}{729}[\ln x + \ln(5y+3) + 6.435]^3$

using the value of $t^3$ in eq. (iii)

$$\boxed{z = f(x,y) = \frac{1}{729}[\ln x + \ln(5y+3) + 6.435]^3 + 3}$$

The above eq$^n$. is the desired path line for the given fluid particle.

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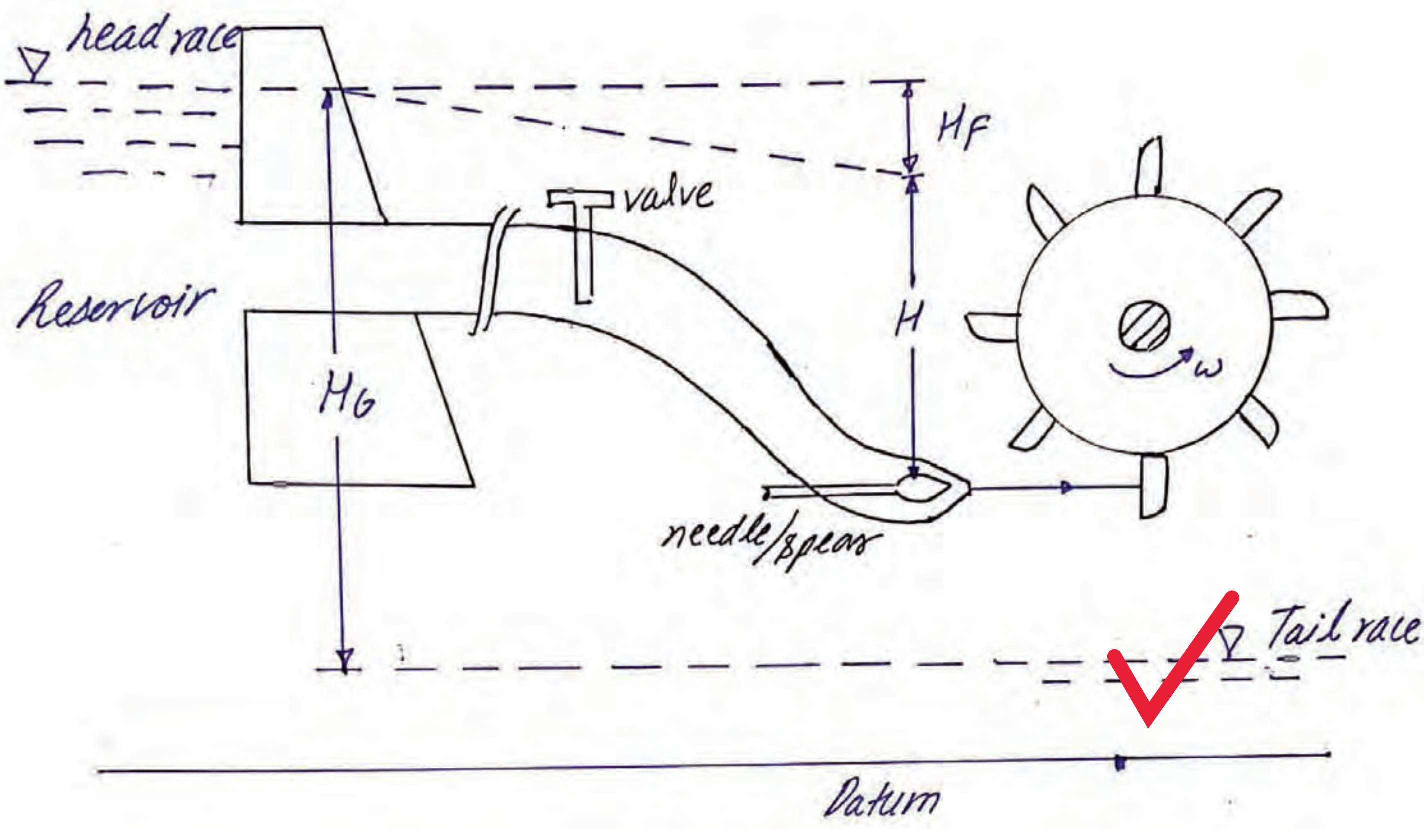
Q2 (b)




It is given that shaft power, S.P. = 750KW

diameter of nozzle, d = 10 cm

frictional losses in penstock = $90Q^2 = H_F$

gross head, $H_G$ = Constant = 200 m

Net heat, $H = H_G - H_F$

$C_v$ for nozzle = 0.98

$V_1$ = jet velocity = $C_v\sqrt{2gH}$ —(1)

$H = 200 - 90Q^2$

$Q = V_1 a$ $\quad$ a = area of nozzle

$\Rightarrow H = 200 - 90(V_1 a)^2$

$\Rightarrow H = 200 - 5.55\times10^{-3}\, V_1^2$ —(II) using eq. (ii) in eq. (i)

$$\left(\frac{V_1}{C_v}\right)^2 = 2g\left(200 - 5.55\times10^{-3} V_1^2\right)$$

$$\Rightarrow 1.041 V_1^2 = 3924 - 0.109 V_1^2$$

$$\Rightarrow V_1^2 = 3412.49$$

$$\Rightarrow V_1 = 58.42 \text{ m/s}$$

$$\Rightarrow Q = \frac{\pi}{4} d^2 V_1$$

$$\Rightarrow \boxed{Q = 0.459 \text{ m}^3/\text{s}}$$

$\therefore H = 181.06$ m

water power, $W.P. = \frac{\rho g Q H}{1000} = 815.27$ KW

overall efficiency $\eta_o = \frac{S.P.}{W.P.} = \frac{750}{815.27}$

$$\boxed{\eta_o = 92\%}$$

(1) $\because$ S.P. is reduced to 650 KW

and $\eta_o$ remains constant

$$W.P. = \frac{\rho g Q H}{1000} = \frac{S.P.}{\eta_o} = \frac{650}{0.92} = 706.52 \text{ KW}$$

If discharge is changed by operating the needle in nozzle the value of discharge in penstock will be same as old discharge so in this case the net head remains unchanged.

$H = 181.06$ m in this case

$$\frac{\rho g Q H}{1000} = 706.52\,kW$$

$$\Rightarrow \boxed{Q = 0.3977\ m^3/s}$$ If needle is operated.

(3) If the valve is operated the value of net head will change since the discharge inside penstock will be different in this case

$$\frac{\rho g Q H}{1000} = 706.52$$

$$\Rightarrow QH = 72.02$$

$$\Rightarrow Q(200 - 90Q^2) = 72.02 \quad (\because H_G = \text{const.})$$

$$\Rightarrow 200Q - 90Q^2 = 72.02$$

$$\Rightarrow 90Q^3 - 200Q + 72.02 = 0$$

$Q_1 = 1.259\ m^3/s$ (not possible $\because$ valve has been closed Q must decrease)

$Q_2 = -1.64\ m^3/s$ (not possible $\because$ Q can't be −ve)

$Q_3 = 0.3859\ m^3/s$ (possible)

$$\therefore \boxed{Q = 0.3859\ m^3/s}$$ If valve in the mains is operated

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read from solution

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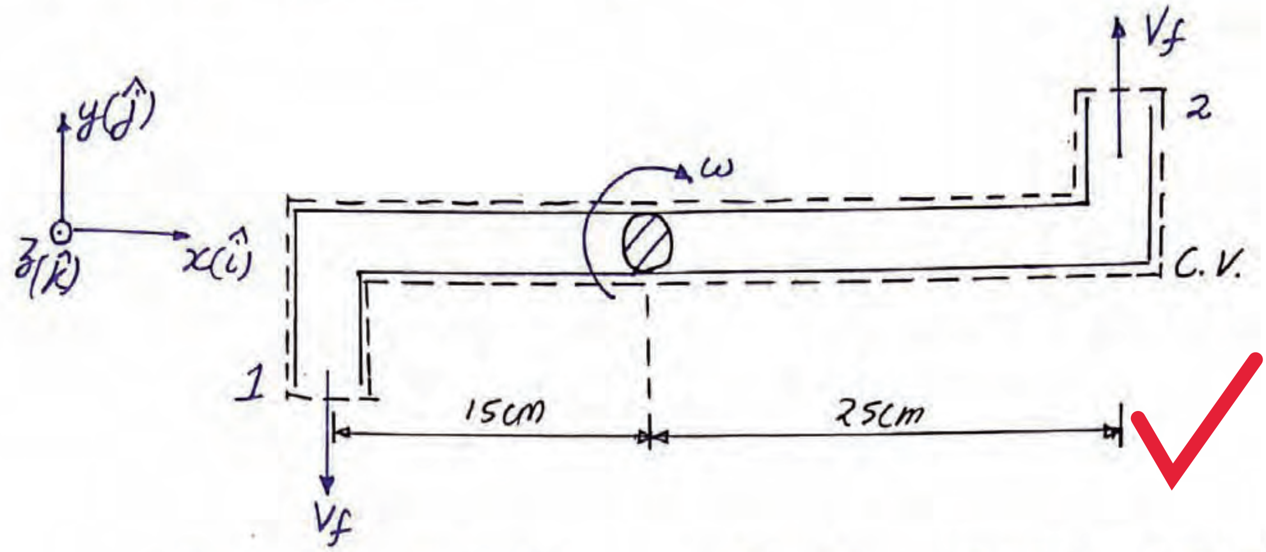
Q.2(c) Assumption:- steady state




$Q_{total} = 2.8$ litre/s $\qquad Q_1 = Q_2 = \frac{Q_{total}}{2} = 1.4\,l/s$

$\dot{m}_{out}/\text{nozzle} = 1.4\ kg/s/\text{nozzle}$

$V_f = V_{f_1} = V_{f_2} = \frac{Q_1}{A} = 11.41\ m/s$

$V_1 = -V_f\hat{j} + R_1\omega\hat{j} = (R_1\omega - V_f)\hat{j}$

$V_2 = V_f\hat{j} - R_2\omega\hat{j} = (V_f - R_2\omega)\hat{j}$

~~$\Sigma M_o =$~~

(i) zero resisting torque $T_R = 0$

$\Sigma M_o = 0\hat{k} = \dot{L}_{out} - \cancel{\dot{L}_{in}}^{\,0}$ (conservation of angular momentum)

$\Rightarrow 0\hat{k} = (r_1 \times V_1)\dot{m}_{out} + (r_2 \times V_2)\dot{m}_{out}$

$r_1 = -R_1\hat{i} \qquad r_2 = +R_2\hat{i}$

$(r_1 \times V_1) = -R_1\hat{i} \times (R_1\omega - V_f)\hat{j} = (R_1V_f - R_1^2\omega)\hat{k}$

$(r_2 \times V_2) = R_2\hat{i} \times (V_f - R_2\omega)\hat{j} = (R_2V_f - R_2^2\omega)\hat{k}$

$$\Rightarrow 0\hat{k} = \dot{m}_{out}(R_1 V_f - R_1^2\omega)\hat{k} + \dot{m}_{out}(R_2 V_f - R_2^2\omega)\hat{k}$$

$$\Rightarrow R_1^2\omega + R_2^2\omega = R_1 V_f + R_2 V_f$$

$$\Rightarrow \omega = \left(\frac{R_1 + R_2}{R_1^2 + R_2^2}\right) V_f$$

$$\Rightarrow \boxed{\omega = 53.685 \text{ rad/s } (C.W.)}$$

$\therefore$ the speed of the sprinkler with zero resisting torque will be 512.65 rpm

(ii) Resisting torque, $T_R = 6$ N-m

$\because$ $\omega$ in clock wise direction frictional torque willbe in counter clockwise direction, $T_R\hat{k}$

$$\Rightarrow \Sigma M_o = T_R\hat{k} = (r_1 \times V_1)\dot{m}_{out} + (r_2 \times V_2)\dot{m}_{out}$$

$$\Rightarrow T_R\hat{k} = \dot{m}_{out}(R_1 V_f - R_1^2\omega)\hat{k} + \dot{m}_{out}(R_2 V_f - R_2^2\omega)\hat{k}$$

$$\Rightarrow T_R = \dot{m}_{out}(R_1 + R_2)V_f - \dot{m}_{out}(R_1^2 + R_2^2)\omega$$

$$\Rightarrow \omega = \frac{\dot{m}_{out}(R_1 + R_2)V_f - T_R}{\dot{m}_{out}(R_1^2 + R_2^2)}$$

$$\Rightarrow \boxed{\omega = 3.27 \text{ rad/s}} \ (C.W.)$$

$\therefore$ the speed of sprinkler with 6 N-m frictional torque will be 31.25 rpm

(iii) To hold the sprinkler completely $\omega = 0$

$$\Rightarrow \quad \frac{\dot{m}_{out}(R_1+R_2)V_f - T_R}{\dot{m}_{out}(R_1^2+R_2^2)} = 0$$

$$\Rightarrow \quad T_R = \dot{m}_{out}(R_1+R_2)V_f$$

$$\Rightarrow \quad T_R = \cancel{2.8}\ 1.4(0.4)\ 11.41$$

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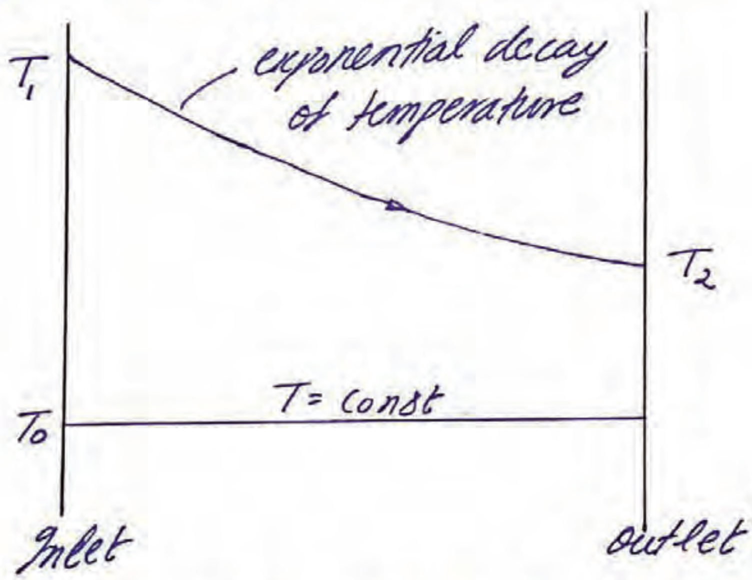
$$\Rightarrow \quad \boxed{T_R = 6.389 \text{ N-m (C.C.W)}}$$

$\therefore$ the resisting torque required to hold the sprinkler completely is 6.389 N-m in counter clockwise direction.

Q5(a) The surface temperature of a tube will remain constant if a fluid is undergoing phase change outside the tube. Now if another fluid flows inside this tube having constant surface temperature then the temperature of the fluid inside the tube will vary logrithmically w.r.t. the length of tube. Therefore, the temperature difference b/w the fluid and the tube surface will vary logarithmically along the tube length. This logathitmic variation is represented by logarithmic mean temperature difference (LMTD).




$i \rightarrow$ inlet

$e \rightarrow$ outlet

$\theta = \Delta T$

$$LMTD = \frac{\theta_i - \theta_e}{\ln\left(\frac{\theta_i}{\theta_e}\right)}$$

exponential decrease ....

LMTD refects the true exponential decrease in local temp. of the fluid.

If this decrease in temperature difference is linear, we can use arithmetic mean temperature, $\Delta T_{am} = \frac{\theta_i + \theta_e}{2}$.

It is possible only in balanced counter flow heat exchanger in which $LMTD = \Delta T_{am}$

$$LMTD = \frac{\theta_i - \theta_e}{\ln(\theta_i/\theta_e)} = \frac{\theta_i - \theta_e}{\ln\left(\frac{1 + (\theta_i - \theta_e)/(\theta_i + \theta_e)}{1 - (\theta_i - \theta_e)/(\theta_i + \theta_e)}\right)}$$

Let $\dfrac{\theta_i - \theta_e}{\theta_i + \theta_e} = x$, then $x < 1$

$$\Rightarrow \ln\left(\frac{1+x}{1-x}\right) = \ln(1+x) - \ln(1-x)$$

$$= \left(x + \frac{x^3}{3} + \frac{x^5}{5} + \dots\right) - \left(-x - \frac{x^3}{3} - \frac{x^5}{5} - \dots\right)$$

$$= 2\left(x + \frac{x^3}{3} + \frac{x^5}{5} + \dots\right)$$

$$\Rightarrow LMTD = \frac{\theta_i - \theta_e}{2\left[\frac{\theta_i - \theta_e}{\theta_i + \theta_e} + \frac{1}{3}\left(\frac{\theta_i - \theta_e}{\theta_i + \theta_e}\right)^3 + \frac{1}{5}\left(\frac{\theta_i - \theta_e}{\theta_i + \theta_e}\right)^5 + \dots\right]}$$

$$\Rightarrow LMTD = \frac{\theta_i - \theta_e}{2\left(\frac{\theta_i - \theta_e}{\theta_i + \theta_e}\right)\left[1 + \frac{1}{3}\left(\frac{\theta_i - \theta_e}{\theta_i + \theta_e}\right)^2 + \dots\right]}$$

$$\Rightarrow LMTD = \frac{\Delta T_{am}}{1 + \frac{1}{3}\left(\frac{\cancel{\Delta T}\,\theta_i - \theta_e}{\theta_i + \theta_e}\right)^2 + \dots}$$

$\therefore$ for any values of $\theta_i$ & $\theta_e$ $\Rightarrow$ $\boxed{LMTD \leq \Delta T_{am}}$

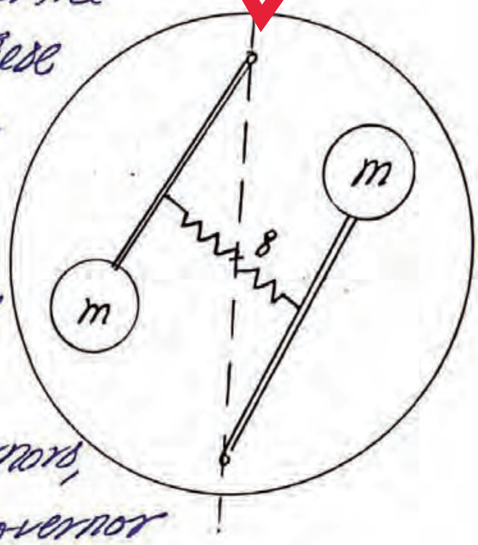
$\Rightarrow$ Therefore it is always safer for designer to use LMTD so as to provide larger heating surface for a certain amount of heat transfer.

11 $LMTD = \Delta T_{am}$ only if $\theta_i = \theta_e$ (Balanced counter flow)

## Q.5 (b) Inertia Governor

It is works on the principle of inertia of matter and is operated by acceleration or deacceleration of the rotating masses in addition to centrifugal forces.

**Construction:-** The two balls of the inertia governor are kept on a disc. These balls are connected to each other by an arm. This arm connecting the two balls is pivoted & operates the throttle valve. Similar to spring loaded centrifugal governors, a spring is available on this governor to control movement of the balls.




**Working:-** When the disc rotates and it is accelerated the balls move in opposite direction to the rotation of disc. This movement of ball is controlled by the spring. When the balls move in opposite direction, the arm also moves and it controls the throttle valve. When movement of balls increases in opposite direction, the throttle valve closes and fuel supply is reduced. When disc retards, ball moves back to initial position, arm opens the throttle valve to increase fuel supply.

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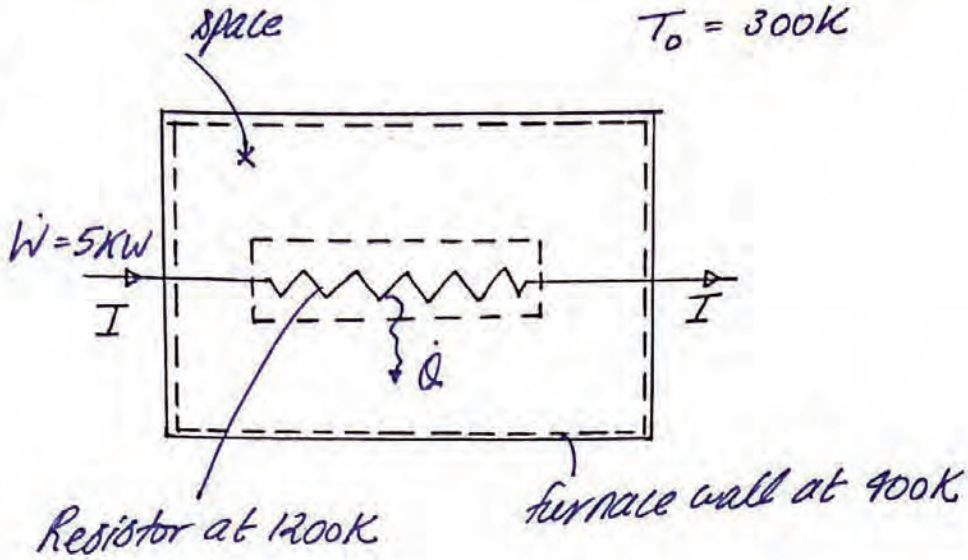
**Limitation:-** Difficult to balance completely.

* When ~~a~~ acceleration or deacceleration is very small, the inertia force becomes zero and Inertia governor behaves as centrifugal governor.

~~Q.5(b)~~
Q.5(c)

$T_0 = 300K$




<ins>for resistor</ins> as the system :-
Assuming steady state

$$\dot{Q} = \Delta\dot{U} + \dot{W} = \dot{W} = -5\,kW \quad (1^{st}\text{ Law of thermo.})$$

A → Availability

$$\Rightarrow \frac{dA}{dt} = \left(1 - \frac{T_0}{T_R}\right)\dot{Q} + \left(\dot{W} - P_0 \cancelto{0}{\frac{dV}{dt}}\right) - \dot{I}_R = 0$$

⇒ Rate of irreversibility in Resistor $\dot{I}_R = \left(1 - \frac{T_0}{T}\right)\dot{Q} + \dot{W}$

$$\dot{I}_R = \left(1 - \frac{300}{1200}\right)(-5) + 5 = \underline{\underline{1.25\,kW}}$$

for the space between resistor and furnace wall as the system:-
Assuming steady state

$$\frac{dA}{dt} = \left(1 - \frac{T_0}{T_R}\right)\dot{Q} - \left(1 - \frac{T_0}{T_w}\right)\dot{Q} - \cancelto{0}{\dot{W}} - \dot{I}_S = 0$$

⇒ Rate of irreversibility in space $= \dot{I}_S$

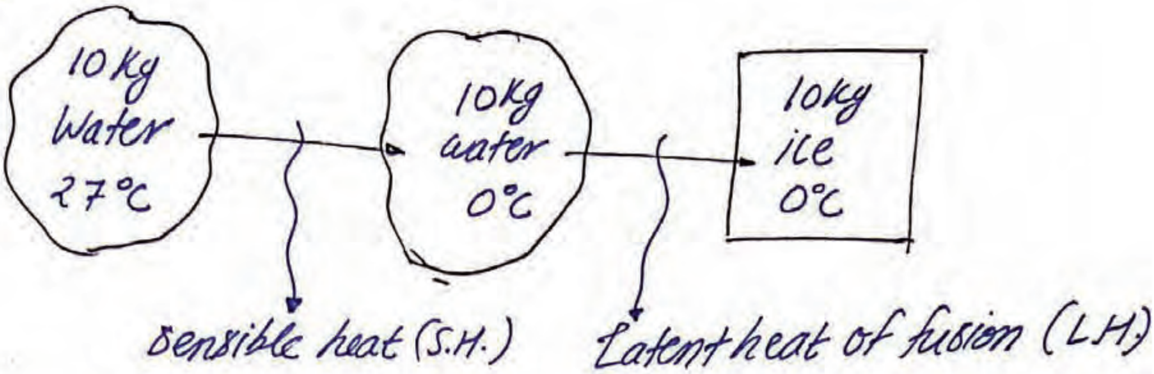
$$\Rightarrow \dot{I}_S = \left(1 - \frac{300}{1200}\right)5 - \left(1 - \frac{300}{400}\right)5 = 3.75 - 1.25$$

12 $\Rightarrow \boxed{\dot{I}_S = 2.5\,kW}$

good

⇒ The rate of irreveorsibility between resistor and furnace walls is $\underline{\underline{2.5\,kW}}$

Q.5(d)




time take $= t = 1\,\text{day} = (24 \times 3600)$ seconds

Refrigeration effect (R.E.) $=$ S.H. $+$ L.H.

Refrigeration capacity (R.C.) $= \dfrac{S.H. + L.H.}{t}$

$$\Rightarrow R.C. = \frac{10\left(4.18(27) + 333.33\right)}{24 \times 3600} \cancel{= 0.0516\,kW = 51.6}$$

$$\Rightarrow R.C. = 0.0516\ kW = \underline{\underline{51.6\ W}}$$

Power, $P = \dfrac{V^2}{R} = \dfrac{(12)^2}{36} = 4\,W$

$\therefore$ the COP of inventors thermoelectric device :-

$$COP_{actual} = \frac{R.C.}{P} = \frac{51.6}{4} = \underline{\underline{12.91}}$$

$$\text{Carnot COP} = \frac{T_L}{T_H - T_L} = \frac{268}{40} \qquad \left\{ \begin{matrix} T_L = -5°C \\ T_H = 35°C \end{matrix} \right\} \text{given}$$

$$\text{Carnot COP} = \underline{\underline{6.7}}$$

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~~$\therefore$ COPactual > (Carnot COP)~~

$\therefore$ $COP_{actual} >$ (Carnot COP)

which is not possible. Therefore the claims of the Inventor are false.

Q.5)(e) The convection heat transfer rate b/w a surface ($T_w$) and a fluid ($T_\infty$) is given by :-

$$Q = hA(T_w - T_\infty)$$

for heat transfer from hot gas to a liquid through a wall, $h_{gas} \ll h_{liquid}$. To compensate for low heat transfer coefficient, surface ~~area~~ area A on the gas side may be increased. This is done by extended surface called fin.

from the above equation if $T_w$ is fixed, heat transfer can be increased in 3 ways:-

(i) increase h, has limitation as costs of ~~bet~~ blower, pump will increase.

(ii) ~~Change~~ Reduce $T_\infty$, which is impractical.

(iii) Increase surface area, which can be easily achieved through fins.

Effectiveness of fin

$$\epsilon_f = \frac{\text{heat transfer rate with fin}}{\text{heat transfer rate without fin}}$$

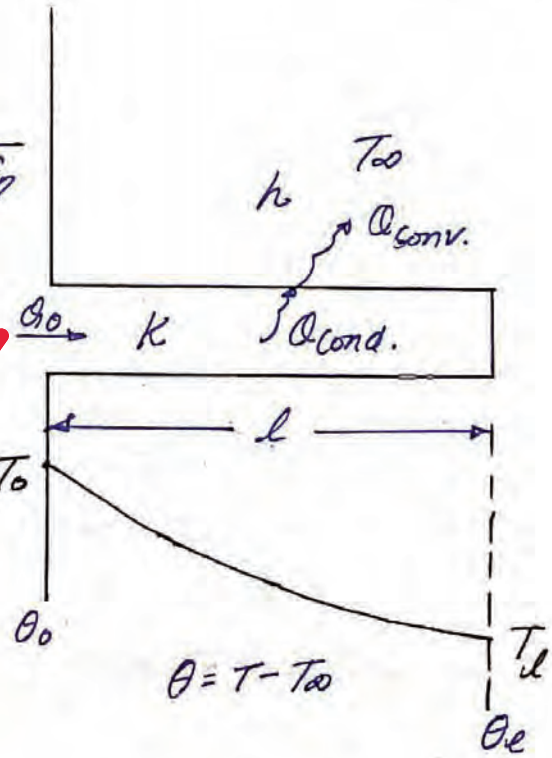
$$\epsilon_f = \frac{Q_0}{hA\theta_0}$$

A = base area

$$\text{efficiency, } \eta_f = \frac{Q_0}{Q_{max}} = \frac{Q_0}{hA_f\theta_0}$$

$A_f$ = area of fin = $Pl$

P = perimeter



It is not necessary that the heat transfer rate will increase by adding fin.

for example for long fins $Q_0 = \sqrt{hPKA}\,\theta_0 = KAm\theta_0$

where $m = \sqrt{\frac{hP}{KA}}$

If $h/mK = 1 \Rightarrow Q_0 = hA\theta_0$

In this case $\epsilon = 1$ ∴ no increase in heat transfer rate will occur.

If $h/mK > 1 \Rightarrow Q < hA\theta_0$, therefore the added surface will ~~as~~ act like insulation.

effectiveness of a single fin, $\epsilon_f = \frac{\text{heat transfer rate from fin}}{\text{heat transfer rate without fin}}$

$$\boxed{\epsilon_f = \frac{Q_0}{hA\theta_0}}$$ $A \rightarrow$ base area of fin

overall effectiveness takes into consideration the total heat transfer from finned as well as unfinned surface

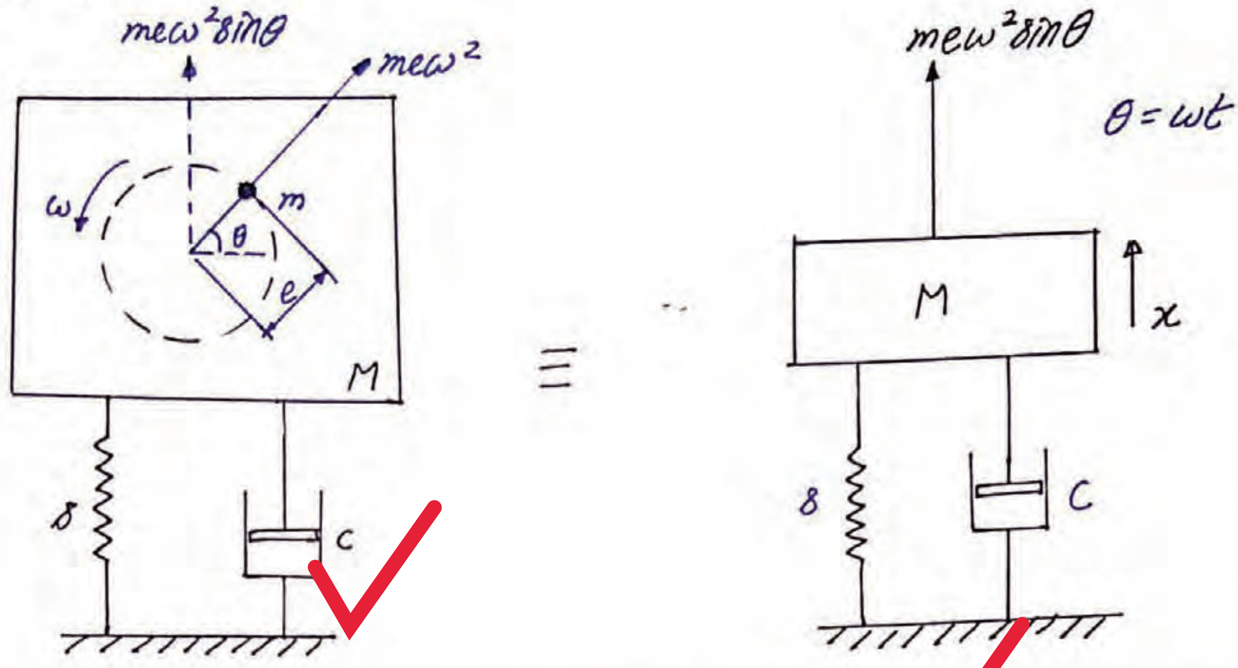
$$Q_{total} = Q_{fin} + Q_{unfinned}$$
$$= \eta_f A_f h\theta_0 + (A_t - A_f)h\theta_0$$
$$Q_{total} = h\theta_0(A_t - (1-\eta_f)A_f)$$

$A_t \rightarrow$ base area of all fins plus unfinned area

$$\boxed{\epsilon_{overall} = \frac{h\theta_0(A_t - (1-\eta_f)A_f)}{hA_t\theta_0}}$$

12

Q. 6.(a)(i)




The unbalance force in direction of $x$, $F_{un} = mew^2 \sin\theta$

∴ from the equivalent system diagram, the equation of motion is :-

In $x$ direction ⇒ $M\ddot{x} + c\dot{x} + 8x = mew^2 \sin\omega t$

dividing the eqn by $M$:-

$$\Rightarrow \quad \ddot{x} + \frac{c}{M}\dot{x} + \frac{8}{M}x = \left(\frac{me}{M}\right)\omega^2 \sin\omega t$$

$$\frac{c}{M} = 2\xi\omega_n \qquad \frac{8}{M} = (\omega_n)^2$$

where, $\xi$ = Damping factor

$\omega_n$ = natural frequency of the system.

∴ the equation of motion is :-

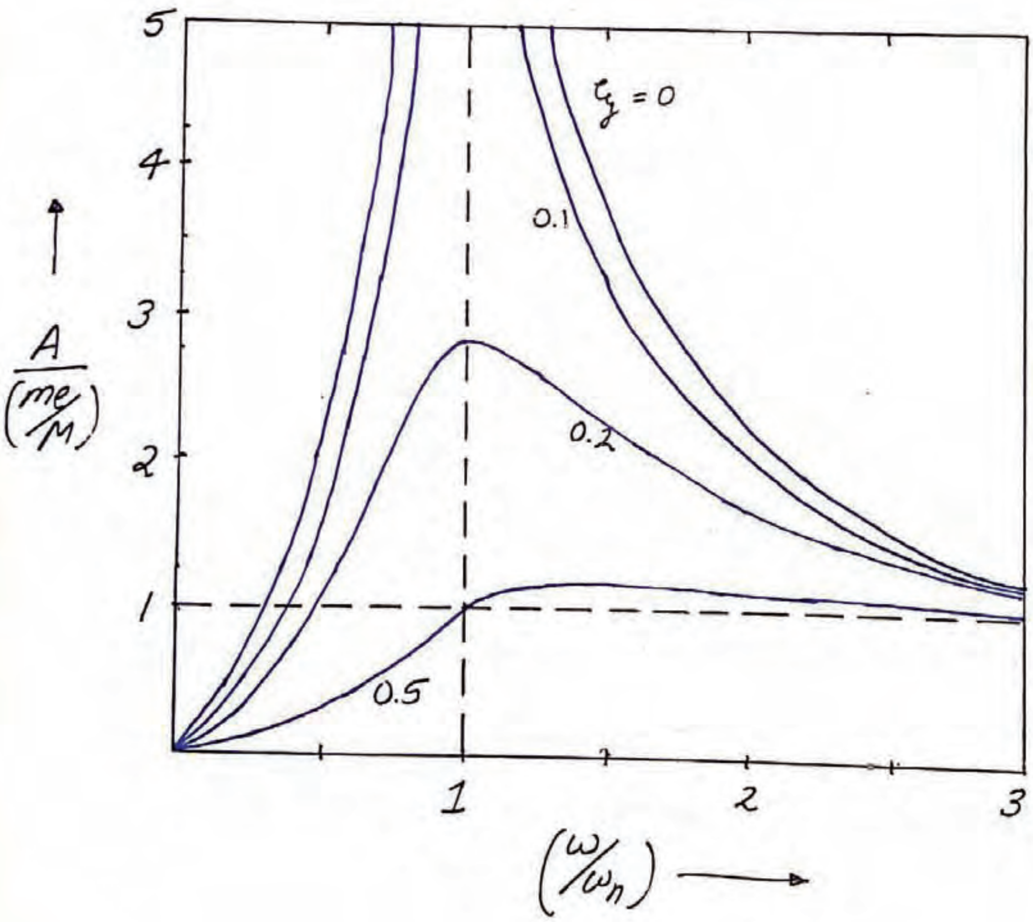
$$\boxed{\ddot{x} + (2\xi\omega_n)\dot{x} + (\omega_n)^2 x = \left(\frac{me}{M}\right)\omega^2 \sin\omega t}$$

The steady state amplitude will be :-

$$\boxed{A = \frac{me\omega^2/\delta}{\sqrt{\left(1-\left(\frac{\omega}{\omega_n}\right)^2\right)^2 + \left(2\xi\frac{\omega}{\omega_n}\right)^2}}}$$

$$\frac{me\omega^2}{\delta} = me\frac{\omega^2/M}{\delta/M} = \frac{me}{M}\left(\frac{\omega}{\omega_n}\right)^2$$

$$\Rightarrow \quad \frac{A}{me/M} = \frac{(\omega/\omega_n)^2}{\sqrt{\left(1-(\omega/\omega_n)^2\right)^2 + \left(2\xi\frac{\omega}{\omega_n}\right)^2}}$$




very good writing and presentation

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Q 6).(a) (ii)

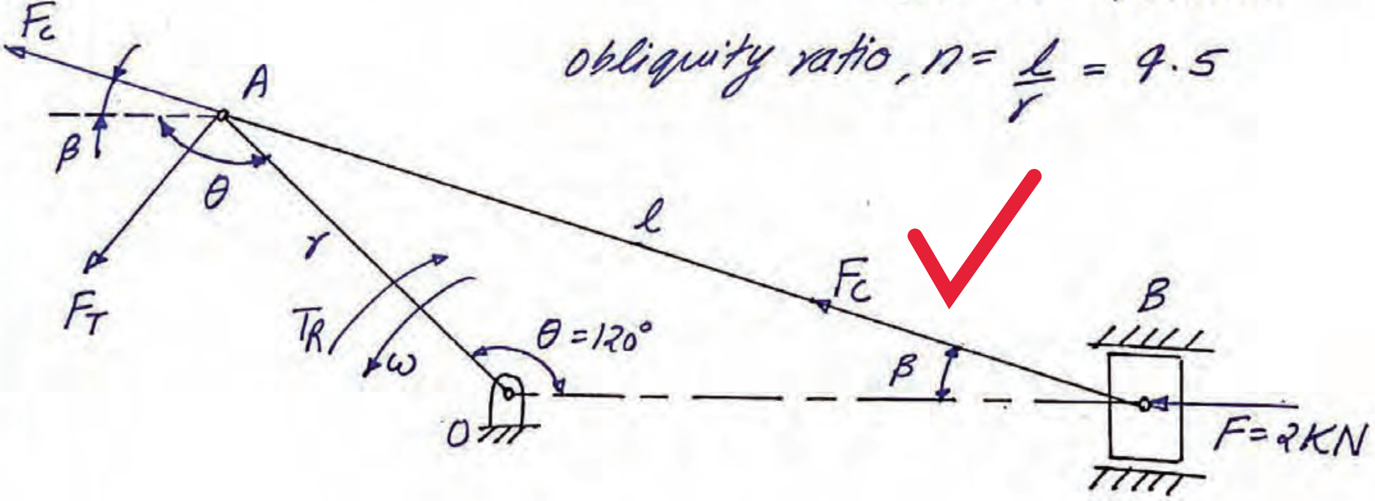
## Inversions of Slider Crank Mechanism

| I. Single Slider crank Mechanism | |
|---|---|
| Inversion | Application |
| 1st Inversion cylinder fixed | Reciprocating Engine, Reciprocating compressor |
| 2nd Inversion Crank fixed | whitworth quick return motion, Rotary IC Engine (GENOME) |
| 3rd Inversion Connecting Rod fixed | Crank & Slotted lever QRMM, oscillating cylinder Engine |
| 4th Inversion Slider fixed | Handpump |
| II. Double slider crank mechanism | |
| Inversion 1 Slotted plate fixed | Elliptical trammel |
| 2nd Inversion one slider fixed | Scotch Yoke mechanism |
| 3rd Inversion Connecting link fixed | Old ham's coupling. |

It is given that, $OA = r = 100\,mm$

$AB = l = 450\,mm$

obliquity ratio, $n = \frac{l}{r} = 4.5$

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In $\Delta OAB$, by sine rule $\Rightarrow \sin\beta = \frac{\sin\theta}{n}$

$\Rightarrow \beta = 11.09°$

force transmitted to connecting rod, $F_c = \frac{F}{\cos\beta}$

$\Rightarrow F_c = 2.038\,KN$

from the diagram, crank effort, $F_T = F_c \sin(\theta+\beta)$

$\Rightarrow F_T = 1.536\,KN$

$\therefore$ The resisting torque on crank $T_R = r F_T$

$\Rightarrow \boxed{T_R = 153.6\,N\text{-}m\ (CW)}$

$\therefore$ The resisting torque required at the crank in order to keep the mechanism in static equilibrium is 153.6 N-m in clockwise direction.

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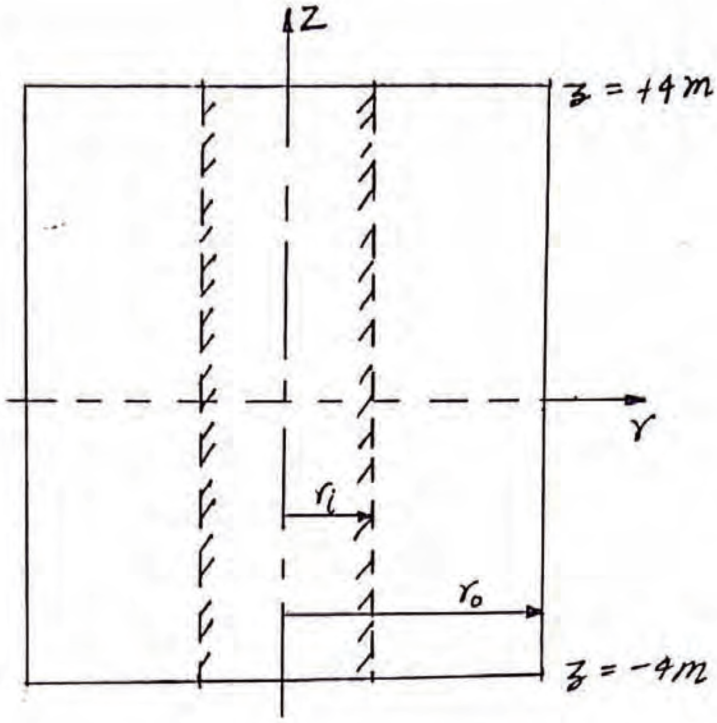
Q.6 (b)




Assumptions :- (i) Steady - state conditions
(ii) Two dimensional conduction with constant properties and volumetric heat generation.

Given ⇒ $K = 22\ W/mK$ $\quad r_o = 1.5m$ $\quad a = -20°C$ $\quad b = 150°C/m^2$

$T(r,z) = a + br^2 + c\ln r + dz^2$ $\quad c = -12°C$ $\quad d = -300°C/m^2$

(i) since inner surface, $r = r_i$, is insulated

$\therefore q_r''(r_i, z) = 0$

∴ the temp. gradient at $r = r_i$ in r-direction must be zero.

$$\left(\frac{\partial T}{\partial r}\right)_{r=r_i} = 0 + 2br_i + \frac{c}{r_i} + 0 = 0$$

$$\Rightarrow r_i = \left(-\frac{c}{2b}\right)^{1/2} = \left(-\frac{(-12)}{2\times 150}\right)^{1/2} = \underline{\underline{0.2m}}$$

$$\therefore \boxed{r_i = 0.2m}$$

(ii) The generalized heat conduction equation in cylindrical coordinates :-

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2} + \frac{\dot{q}_g}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

$$\frac{\partial^2 T}{\partial \theta^2} = 0 \qquad \frac{\partial T}{\partial t} = 0 \qquad (\because T = f(r,z) \text{ only})$$

$$\Rightarrow \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{\partial^2 T}{\partial z^2} + \frac{\dot{q}_g}{k} = 0$$

$$\Rightarrow \frac{1}{r}\frac{\partial}{\partial r}\left[r\left(2br + c/r\right)\right] + \frac{\partial}{\partial z}(2dz) + \frac{\dot{q}_g}{k} = 0$$

$$\Rightarrow \frac{1}{r}(4br) + 2d + \frac{\dot{q}_g}{k} = 0$$

$$\Rightarrow \dot{q}_g = -k(4b + 2d) = -22(4\times150 + 2\times(-300))$$

$$\Rightarrow \boxed{\dot{q}_g = 0 \ W/m^3}$$

(iii) $$q_r''(r_0, z) = -k\left(\frac{\partial T}{\partial r}\right)_{r=r_0} = -k\left(2br_0 + c/r_0\right)$$

$$\Rightarrow q_r''(r_0, z) = -22\left(2(150)(1.5) + \frac{(-12)}{1.5}\right)$$

20

$$\Rightarrow \boxed{q_r''(r_0, z) = -9724 \ W/m^2}$$

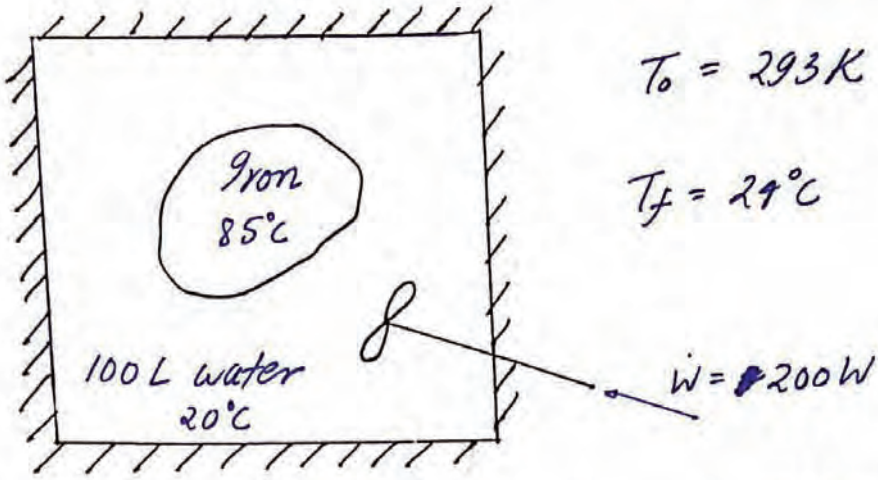
$$Q_r(r_0) = A_0\, q_r''(r_0, z) \qquad A_0 = 2\pi r_0 (2z_0)$$

$$Q_r(r_0) = -4\pi(1.5)\cancel{(8)}(4)(9724)$$

$$\boxed{Q_r(r_0) = -733.17 \ kW}$$

$\because$ the sign is −ve, heat flows in +ve r direction

Q6(c)




Assumptions:- (i) water & Iron are incompressible
(ii) Constant specific heats.
(iii) $\Delta KE = 0$ ; $\Delta PE = 0$
(iv) The tank is insulated, $Q = 0$

water $\Rightarrow$ $\rho = 997\ kg/m^3$ $\quad C_{pw} = 4.18\ KJ/kgK$

Iron $\Rightarrow$ $C_{p_i} = 0.45\ KJ/kgK$

(i) from 1st law of thermodynamics:-

$$\cancel{Q}^{0} = \Delta U + W$$

$$\Delta U = -W = \Delta U_{iron} + \Delta U_{water} \quad (1)$$

$$W = \dot{W}\,\Delta t = 0.2 \times 20 \times 60 = \underline{\underline{240\ KJ}}$$

$$m_{water} = \rho V = 997 \times 0.1 = 99.7\ kg$$

from eq. (1):-

$$-(-240) = m_{iron}\left(0.45(24-85)\right) + 99.7(4.18)(24-20)$$

$$\Rightarrow \boxed{m_{iron} = 51.98\ Kg \simeq 52\ Kg}$$

$\therefore$ the mass of iron block is $\underline{\underline{52\ Kg}}$.

(ii) $(\Delta S)_{system} = \cancel{\frac{\partial Q}{T}}^{0} + S_{gen}$

here the system is Iron & water.

$\Rightarrow \Delta S_{iron} + \Delta S_{water} = S_{gen}.$

$\Delta S_{iron} = m_i C_{p_i} \ln\left(\frac{T_2}{T_1}\right) = 52 \times 0.45 \ln\left(\frac{297}{358}\right) = -4.371 \, KJ/K$

$\Delta S_{water} = m_w C_{pw} \ln\left(\frac{T_2}{T_1}\right) = 99.7 \times 4.18 \ln\left(\frac{297}{293}\right) = +5.651 \, KJ/K$

Exergy destoyed $= X_{des} = T_0 S_{gen} = T_0 (\Delta S_{iron} + \Delta S_{water})$

$\Rightarrow X_{des} = 293(-4.371 + 5.651)$

$\Rightarrow \boxed{X_{des} = 375.04 \, KJ}$

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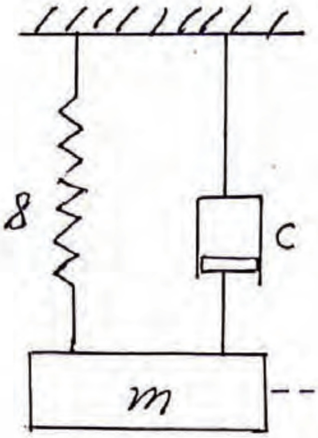
exergy of system is asked

Q.7 (a)




---- $x=0$ (static equilibrium)

Initial conditions

at $t=0$ $\frac{dx}{dt} = 2\omega_n$

at $t=0$ $x=0$

The equation of motion for spring mass dashpot system:-

$$m\ddot{x} + c\dot{x} + 8x = 0$$

$$\Rightarrow \ddot{x} + \frac{c}{m} + \dot{x} + \frac{8}{m}x = 0$$

It is a second order differential equation

The solution will be:-

$$x = Ae^{\alpha_1 t} + Be^{\alpha_2 t} \qquad A, B = \text{const}$$

$\alpha_1$ & $\alpha_2$ are roots of auxiliary equation:-

$$\alpha^2 + \frac{c}{m}\alpha + \frac{8}{m} = 0$$

$$\alpha_{1,2} = -\frac{c}{2m} \pm \sqrt{\left(\frac{c}{2m}\right)^2 - \frac{8}{m}}$$

damping factor $\xi = \frac{c}{2\sqrt{8m}}$ $\qquad \frac{8}{m} = \omega_n^2$

$$\Rightarrow \alpha_{1,2} = -\xi \pm \sqrt{\xi^2 - 1}\,\omega_n \quad (1)$$

(i) $\xi = 2.0$ ($\xi > 1$, overdamped system)

the solution is, $x = Ae^{\alpha_1 t} + Be^{\alpha_2 t}$

from eq. (1) $\alpha_1 = (-2+\sqrt{3})\omega_n$ $\qquad \alpha_2 = -(2+\sqrt{3})\omega_n$

$$\frac{dx}{dt} = \alpha_1 Ae^{\alpha_1 t} + \alpha_2 Be^{\alpha_2 t}$$

at $t=0$ $\frac{dx}{dt} = Z\omega_n$

$\Rightarrow Z\omega_n = \alpha_1 A + \alpha_2 B$

$\Rightarrow Z\cancel{\omega_n} = (-2+\sqrt{3})\cancel{\omega_n} A - (2+\sqrt{3})\cancel{\omega_n} B$

$\Rightarrow Z = (-2+\sqrt{3})A - (2+\sqrt{3})B$ (II)

at $t=0$, $x=0$

$\Rightarrow 0 = A + B$ (III)

multiply $(-2+\sqrt{3})$ in eq. (III) & subtract it from eq. (II)

we get, $B = \frac{-Z}{2\sqrt{3}}$

$\therefore$ from eq. (III) $\Rightarrow A = \frac{Z}{2\sqrt{3}}$

$\therefore$ the solution for the given initial conditions and $\zeta = 2.0$

$$\Rightarrow \boxed{x = \frac{Z}{2\sqrt{3}}\left[e^{(-2+\sqrt{3})\omega_n t} - e^{-(2+\sqrt{3})\omega_n t}\right]}$$

(ii) $\zeta = 1$ (critically damped system)

for this case $\alpha_1 = \alpha_2$

the solution becomes

$$x = (A+Bt)e^{-\omega_n t}$$

$$\frac{dx}{dt} = Be^{-\omega_n t} + (A+Bt)(-\omega_n)e^{-\omega_n t}$$

at $t=0$ $\frac{dx}{dt} = Z\omega_n \Rightarrow Z\omega_n = B - \omega_n A$ (IV)

~~at x=0~~ at $t=0$ $x=0$

$\Rightarrow$ $A=0$

$\therefore$ from eq$^n$ (IV) $B = Z\omega_n$

$\therefore$ the solution for given initial conditions & $\xi = 1$ is:-

$$\boxed{x = Z\omega_n t e^{-\omega_n t}}$$

(ii) $\xi = 0.2$ (Under damped system)

here $\alpha_{1,2}$ are imaginery.

$\therefore$ the solution becomes :-

$$x = X e^{-\xi\omega_n t} \sin(\omega_d t + \phi)$$

where $X$ & $\phi$ are constants

$$\omega_d = \sqrt{1-\xi^2}\,\omega_n \cancel{= 1.02\omega_n}$$

$$\Rightarrow \omega_d = 0.98\,\omega_n$$

$$\frac{dx}{dt} = (-\xi\omega_n)(X)e^{-\xi\omega_n t}\sin(\omega_d t + \phi)$$
$$+ X e^{-\xi\omega_n t}(\omega_d)\cos(\omega_d t + \phi)$$

at $t=0$ $\frac{dx}{dt} = Z\omega_n$

$\Rightarrow$ $Z\omega_n = -\xi\omega_n X\sin\phi + \omega_d X\cos\phi$ (V)

at $t=0$ $x=0$

$\Rightarrow$ $X\sin\phi = 0$

$\Rightarrow$ $\sin\phi = 0$ $\Rightarrow$ $\phi = \pi n$ ; $n \in I$

using the value of $\phi$ in eq. (v), we get

$$Z\omega_n = 0 + \omega_d X \cos(\pi n)$$

$$\cos(\pi n) = \pm 1$$

20 $\Rightarrow X = \pm \frac{Z\omega_n}{\omega_d} = \pm 1.02 Z$

$\therefore$ the solution for given initial conditions and $\xi = 0.2$ is

$$\boxed{x = \pm 1.02 Z e^{-0.2\omega_n t} \sin(0.98\omega_n t + \pi n)}$$

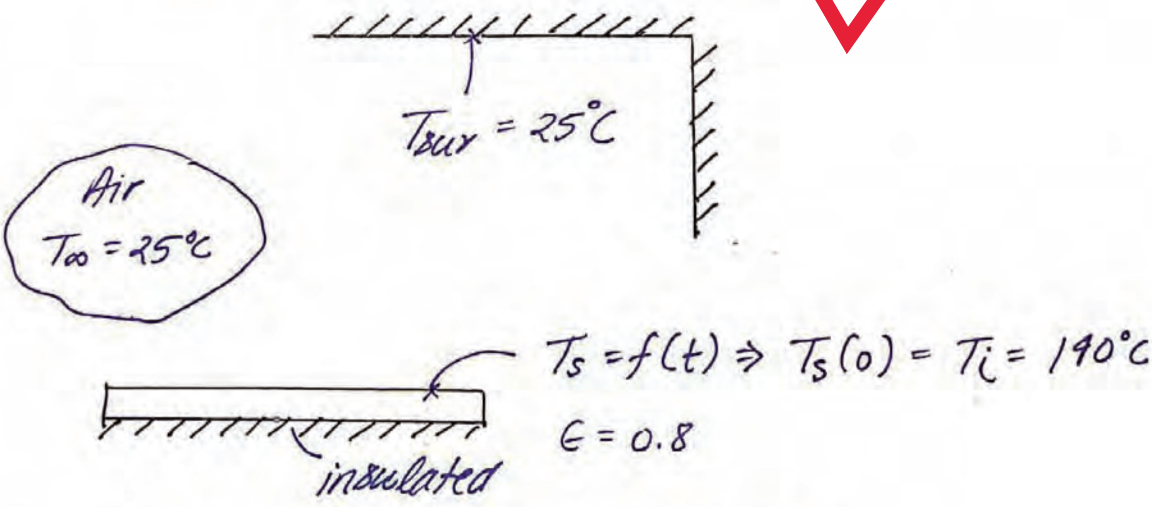
$n \in I$

---

<u>Q.7 (b)</u> <u>Assumptions</u>:- (i) for the tile $T_s \neq f(\text{space})$

(i) bottom of tile is perfectly insulated

~~(iii) Forced~~ (iii) surrounding is large compared to tile




Pyrex $\Rightarrow$ $\rho = 2225\ kg/m^3$, $C_p = 835\ J/kgK$

$k = 1.4\ W/mK$ $\quad \epsilon = 0.80$

Air $\Rightarrow$ $\alpha = 27.01 \times 10^{-6}\ m^2/s$ $\quad \nu = 18.96 \times 10^{-6}\ m^2/s$

$k = 0.0286\ W/mK$ $\quad Pr = 0.7027$

$$(T_{avg})_{air} = \frac{\bar{T}_s + T_\infty}{2} = \cancel{57.5^\circ C}\ 57.5^\circ C = 330.5K$$

$$\bar{T}_s = \left(\frac{140+90}{2}\right) = 90^\circ C = 363K$$

side of the ~~d~~ tile, $L = 200\,mm$

depth of tile, $d = 10\,mm$

surface area, $A_s = L^2$ Volume $= L^2 d = V$

Perimeter $= P = 4L$

Let $\bar{h}$ = heat transfer coefficient for combined convection and ~~radi~~ radiation heat transfer processes

$$\bar{h} = \bar{h}_{conv.} + \bar{h}_{rad} \quad (1)$$

$$\bar{h}_{rad} = \epsilon\sigma(\bar{T}_s + T_{sur})(\bar{T}_s^2 + T_{sur}^2)$$

$$\bar{h}_{rad} = 0.8 \times 5.67 \times 10^{-8}(363+298)(363^2+298^2)$$

$$\Rightarrow \boxed{\bar{h}_{rad} = 6.61\ W/m^2K}$$

$$Ra_L = \frac{g\beta\Delta T L^3}{\nu\alpha}$$

$$L = A_s/P = L^2/4L = 0.25L$$

$$\Rightarrow Ra_L = \frac{9.81\,(1/330)(363-298)(0.25\times 0.2)^3}{(18.96\times 10^{-6})(27.01\times 10^{-6})}$$

$$\Rightarrow Ra_L = 4.712\times 10^5$$

$$\because\ 10^4 < Ra_L < 10^7 \Rightarrow \bar{Nu}_L = 0.54(Ra_L)^{1/4}$$

$$\Rightarrow \overline{Nu}_L = 0.54\,(4.712\times10^5)^{1/4} = 14.18$$

$$\Rightarrow \bar{h}_{conv} = \frac{\overline{Nu}_L\,K}{L} = \frac{14.18\times0.0286}{0.25\times0.2} = \underline{\underline{8.09}}\ W/m^2K$$

$$\Rightarrow \boxed{\bar{h}_{conv} = 8.09\ W/m^2K}$$

from eq. (9) $\bar{h} = 6.61 + 8.09 = 14.7\ W/m^2K$

$$\Rightarrow \boxed{\bar{h} = 14.7\ W/m^2K}$$

for lumped capacitance system $\Rightarrow$

$$\frac{T_s - T_\infty}{T_i - T_\infty} = e^{\left(-\frac{\bar{h}A_s}{\rho V c}t\right)} \qquad \frac{A_s}{V} = d$$

$$\Rightarrow \frac{40-25}{140-25} = \exp\left[\frac{-14.7\,t_f}{2225\times0.01\times835}\right]$$

$$\Rightarrow \boxed{t_f = 25748 = 42.9\,min}$$

$\therefore$ It will take 42.9 min for the tile to cool from 140°C to 40°C in the given conditions.

20

Q.7 (c) Assumptions:- (i) $C_2H_6$ & $CH_4$ are ideal gases

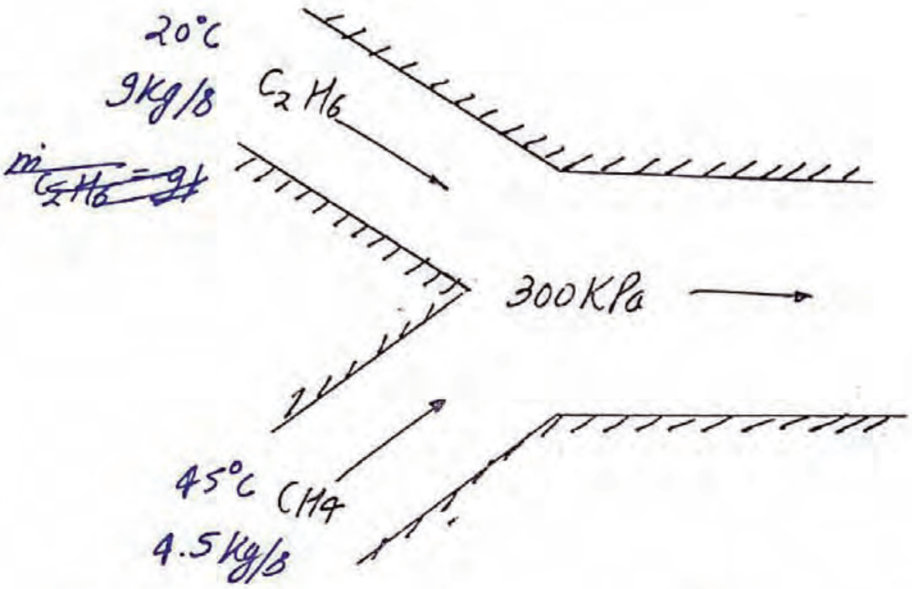
(ii) The mixture is ideal gas mixture

(iii) mixing chamber is insulated

(iv) $W = 0$

(v) steady flow process

(vi) $\Delta KE = 0$, $\Delta PE = 0$




$(c_p)_{C_2H_6} = 1.7662 \text{ KJ/kg K}$ $\quad (c_p)_{CH_4} = 2.2537 \text{ KJ/kg K}$

$\dot{W} = \dot{Q} = 0$

$\dot{E}_{in} = \dot{E}_{out}$ (steady state)

$\Sigma \dot{m}_i h_i = \Sigma \dot{m}_e h_e$

$\Rightarrow \dot{m}_{C_2H_6}(h_e - h_i)_{C_2H_6} + \dot{m}_{CH_4}(h_e - h_i)_{CH_4} = 0$

$\Rightarrow [\dot{m} c_p (T_e - T_i)]_{C_2H_6} + [\dot{m} c_p (T_e - T_i)]_{CH_4} = 0$

$\Rightarrow 9(1.7662)(T_f - 20) + 4.5(2.2537)(T_f - 45) = 0$

$\Rightarrow \boxed{T_f = 29.7°C = 302.7 K}$

Entropy balance:- $\dot{S}_{gen} = \dot{S}_{out} - \dot{S}_{in}$ (steady state)

$$\Rightarrow \dot{S}_{gen} = [\dot{m}(s_2 - s_1)]_{C_2H_6} + [\dot{m}(s_2 - s_1)]_{CH_4} \quad -(1)$$

$$\dot{n}_{C_2H_6} = \left(\frac{\dot{m}}{M}\right)_{C_2H_6} = \frac{9}{30} = 0.3 \text{ kmol/s}$$

$$\dot{n}_{CH_4} = \left(\frac{\dot{m}}{M}\right)_{CH_4} = \frac{4.5}{16} = 0.2813 \text{ kmol/s}$$

$y$ — mole fraction

$$y_{C_2H_6} = \frac{0.3}{0.3 + 0.2813} = 0.516$$

$$y_{CH_4} = \frac{0.2813}{0.3 + 0.2813} = 0.484$$

$$(s_2 - s_1)_{C_2H_6} = \left[c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{yP_2}{P_1}\right)\right]_{C_2H_6} \quad [P_2 = P_1]$$

$$\Rightarrow (s_1 - s_2)_{C_2H_6} = 0.24 \text{ KJ/kgK}$$

$$(s_2 - s_1)_{C_2H_4} = \left[c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln(y)\right]_{CH_4}$$

$$\Rightarrow (s_2 - s_1)_{CH_4} = 0.265 \text{ KJ/kgK}$$

$\therefore$ from eq. (1)

$$\dot{S}_{gen} = 9(0.24) + 4.5(0.265)$$

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$$\boxed{\dot{S}_{gen} = 3.353 \text{ KW/K}}$$

good in concept and presentation