Sub: Heat Transfer (15ME63)

Model Question paper

Max Marks: 100

Instructions: Use of heat transfer data hand book is permitted.

PART - A

Q.1 a) Explain briefly: i) Thermal resistance concept.
ii) Convective heat transfer co-efficient.
iii) Boundary condition of 3rd kind. — 06 Marks

b) Heat is generated at a constant rate g_0 W/m³ in a copper rod of radius r=a by the passage of electric current. The heat is dissipated by convection from the boundary surface at r=a into the ambient air at temperature T_∞ with a heat transfer co-efficient h. Write mathematical formulation of this heat conduction problem for the determination of one dimensional steady state temperature distribution T(r) within the rod. — 04 Marks

c) A furnace wall is made of composite wall of total thickness 55cm. The inside layer is made of refractory material of K = 2.3 W/mK and outside layer is made of an insulating matrial of K=0.2 W/mK. The mean temperature of the gas inside furnace is 900°C and interface temperature is 520°C. The heat transfer co-efficient between gas and inner surface can be taken as 230 W/m²K and between outer surface and atmosphere as 46 W/m²K. Assuming temperature of surrounding air as 30°C,

Calculate i) required thickness of each layer.
ii) rate of heat loss per unit area and
iii) the temperature of surface exposed to gas and of the surface exposed to atmosphere
— 10 marks.

Q. 2 a) Show that for a sphere critical radius of insulation is given by, $r_c = \frac{2K_{ins}}{h}$ — 06 marks.

b) 'Adition of fins may not necessarily increase the heat transfer from a surface; it may even decrease the heat transfer' Comment on this statement. — 04 marks

c) Aluminium square fins (0.5mm x 0.5mm) of 10mm length are provided on the surface of an electronic device to carry 1W of energy generated by the device. The temperature at the surface of the device should not exceed 80°C, while temperature of surrounding medium is 40°C. Assume K for aluminium 190 W/mK, h = 120 W/m²K. Find the number of fins required, neglecting heat loss from the end of the fin. — 10 marks

Q 3 a) What is lumped system analysis? What is the crit[ical] to apply lumped system analysis? — 08 marks.

b) An orange of diameter 10 cm is initially at a uniform temperature of 30°C. It is placed in a refrigerator in which air temperature is 2°C. If heat transfer co-efficient between air and orange is 50 W/m²K, determine the time required for centre of the Orange to reach 10°C, assume the thermal properties of the Orange are the same as that of water at the same temperature. Also calculate the temperature at 3 cm from the surface of Orange at that time. — 12 Marks.

Q.4 a) The exact expression for the local drag co-efficient C_x for laminar flow over a flat plate is given by

$$C_x = \frac{0.664}{\sqrt{Re_x}}$$

Air at atmospheric pressure and at $T_\infty = 300K$ flows with a velocity of $u_\infty = 1.5\ m/s$ along the plate. Determine the distance from the leading edge of the plate, where transition begins from laminar to turbulent flow. Calculate the drag force acting per 1m width of the plate over the distance from $x = 0$ to where the transition starts. — 10 marks

b) A horizontal steam pipe of 10cm OD runs through a room where the ambient air is at 20°C. If the outside surface of the pipe is at 180°C and the emissivity of the surface is 0.9, find out the total heat loss per metre length of pipe. — 10 marks.

PART-B

Q.5 a) Water flows in a tube of ID 1.5cm at the rate of $0.05\ m^3/hr$. It receives a uniform wall heat flux $1000\ W/m^2$. Calculate

i) the value of local heat transfer co-efficient.

ii) the wall temperature at a section where both the velocity and temperature profiles are fully developed and the local bulk mean temperature is 40°C.

— 10 marks

b) A refrigerated truck is moving at a speed of 85 Km/hr where ambient temperature is 50°C. The body of truck is of rectangular shape of size 10m(L) x 4m(W) x 3m(H). Assume the boundary layer is turbulent and the wall surface temperature is at 10°C. Neglect the heat transfer from vertical front and back side of truck and flow of air is parallel to 10m long side. Calculate heat loss from the four surfaces.

— 10 marks.

Q. 6a) Draw temperature v/s length of heat exchanger profiles for i) Condenser ii) Evaporator iii) Counter flow heat exchanger with $C_h = C_c$

— 06 Marks

b) Water enters a counter flow double pipe heat exchanger at 15°C flowing at a rate of 1300 kg/hr. It is heated by oil (C_p = 2000 J/kg K) flowing at the rate of 550 kg/hr from an inlet temperature of 94°C for an area 1m² and overall heat transfer co-efficient of 1075 W/m²K. Determine the total heat transfer and outlet temperature of water and oil

— 14 Marks.

Q.7 a) State the Fick's law of diffusion and explain its analogy with Fourier's law of heat conduction.
— 06 marks

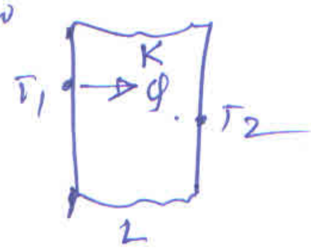
b) Dry saturated steam at a pressure of 2.45 bar condenses on the surface of a vertical tube of height 1m. The tube surface temperature is kept at 117°C. Estimate the thickness of condensate film and local heat transfer co-eff. at a distance of 0.2m from the upper end of the tube.
— 14 marks.

Q.8 a) Explain the following
i) emissivity ii) Black body iii) Grey body
— 06 marks.

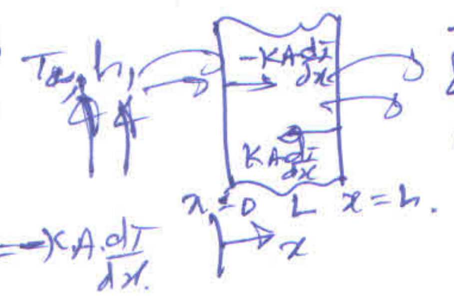
b) A cubical room 4m × 4m × 4m is heated through the ceiling by maintaining it at uniform temperature by 350 K while walls and the floor are at 300K. Assuming that all surfaces have an emissivity of 0.8 determine the rate of heat loss from ceiling by radiation.
— 14 marks

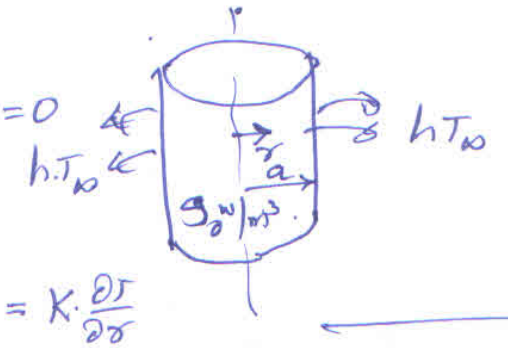
Department of Mechanical Engineering

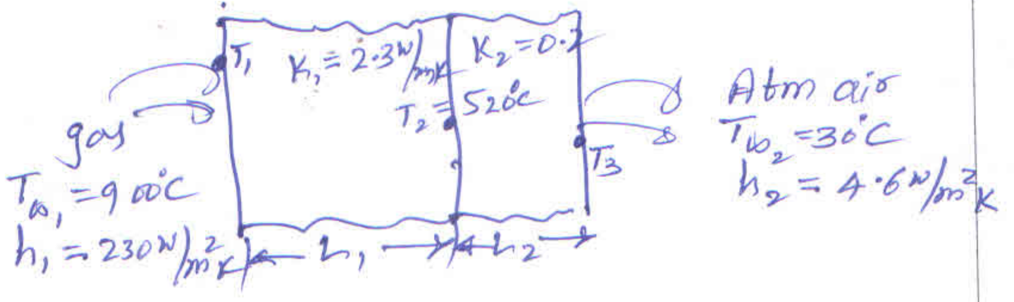
Subject with code: Heat Transfer (15ME63)

Q.No.	Solution and Scheme	Marks
1	a) i) Thermal resistance concept. The phenomenon of heat conduction and electric current flow have analogy because mechanism of heat conduction and current flow are same. Therefore laws applicable for current flow can be applied for heat conduction. As per Fourier law of heat conduction  $Q = -KA \cdot \frac{dT}{dx}$ $Q = -KA \frac{(T_2 - T_1)}{L}$  $R_{th} = \frac{L}{KA}$. $Q = \frac{T_1 - T_2}{L/KA} = \frac{T_1 - T_2}{R_{th}}$ ——— 2 marks ii) Convective heat transfer co-efficient (h) may be define as the convective heat transfer per unit surface area and unit temp difference between hot and cold region. $h = \frac{Q}{A \cdot dT} = W/m^2 {}^\circ C$ ——— 2 marks	

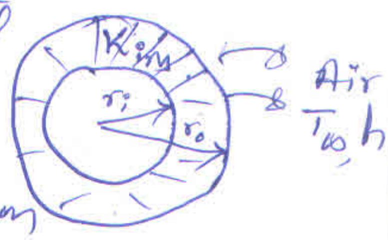
Q.No.	Solution and Scheme	Marks
1 a)	iii) B.C of 3rd kind (Convective boundary Condition)	
	If boundary surface of body is subjected to convection then the boundary is said to be Convective B.C.	
	Consider a slab of thickness L,	
	at $x = 0$	
	$h_1 A (T_{\infty 1} - T_{x=0}) = -KA \frac{dT}{dx}$	
	at $x = L$,	
	$h_2 A (T_{\infty 2} - T_{x=L}) = +K \cdot A \frac{dT}{dx}$	2 marks
b)	$\frac{1}{r} \cdot \frac{\partial}{\partial r}\left(r \cdot \frac{\partial T(r)}{\partial r}\right) + \frac{g_o}{K} = 0$	
	$r = 0, \frac{\partial T}{\partial r} = 0$	
	$r = a, h (T_\infty - T_{r=a}) = K \cdot \frac{\partial T}{\partial r}$	4 Marks
c)		







Q.No.	Solution and Scheme	Marks
1 c)	$q = \frac{T_{\infty 1} - T_2}{\frac{1}{h_1} + \frac{L_1}{K_1}} = \frac{900 - 520}{\frac{1}{230} + \frac{L_1}{2.3}}$ $\quad L_1 = \frac{874}{q} - 0.009982$	—— 3 marks
	iii) $q = \frac{T_2 - T_{\infty 2}}{\frac{L_2}{K_2} + \frac{1}{h_2}} = \frac{520 - 30}{\frac{L_2}{0.2} + \frac{1}{4.6}}$ $\quad L_2 = \frac{98}{q} - 0.004349$	
	But $L_1 + L_2 = 0.55\,m$	
	$q = 1722.39\ W/m^2$	—— 3 marks
	$q = \frac{T_{\infty 1} - T_1}{1/h_1}$, $\quad T_1 = 892.51\,^\circ C$	—— 1 mark
	$q = \frac{T_3 - T_{\infty 2}}{1/h_2}$, $\quad T_3 = 67.44\,^\circ C$	—— 1 mark
	$q = \frac{T_1 - T_2}{L_1/K_1}$, $\quad L_1 = 0.4974\,m$	—— 1 mark
	$q = \frac{T_2 - T_3}{L_2/K_2}$, $\quad L_2 = 0.05255\,m$	—— 1 mark
Q.2 a)	Consider a sphere of radius r_i, let it is insulated with material having thermal conductivity K_{ins} having outer radius r_o. The outer surface of insulation is exposed to ambient air at temp T_∞ having convective heat transfer co-eff h.	



Q.No.	Solution and Scheme	Marks
2 a)	$\phi = \dfrac{T_i - T_\infty}{\dfrac{r_o - r_i}{4\pi K_{ins} r_i r_o} + \dfrac{1}{4\pi r_o^2 \cdot h_o}}$	
	$\phi = \dfrac{4\pi (T_i - T_\infty)}{\dfrac{r_o - r_i}{K_{ins} \cdot r_i r_o} + \dfrac{1}{h_o r_o^2}}$	
	For maximum heat transfer, differentiating above equation w.r.t r_o and equating it to zero.	
	$\dfrac{d\phi}{dr_o} = \dfrac{d}{dr_o}\left[\dfrac{1}{\dfrac{r_o - r_i}{K_{ins} \cdot r_i r_o} + \dfrac{1}{h_o r_o^2}}\right] = 0$	
	$\dfrac{d\phi}{dr_o} = \dfrac{d}{dr_o}\left[\dfrac{r_o - r_i}{K_{ins} r_i r_o} + \dfrac{1}{h_o r_o^2}\right] = 0$	
	$\dfrac{d\phi}{dr_o} = \dfrac{d}{dr_o}\left[\dfrac{1}{K_{ins} r_i} - \dfrac{1}{K_{ins} r_o} + \dfrac{1}{h_o r_o^2}\right]$	
	$\dfrac{d\phi}{dr_o} = 0 + \dfrac{1}{K_{ins} r_o^2} - \dfrac{2}{h_o r_o^3} = 0$	
	$r_o = \dfrac{2K_{ins}}{h}$	
	since $\phi \rightarrow \phi_{max}$ $r_o \rightarrow r_c$	
	$\therefore r_c = \dfrac{2K_{ins}}{h}$	6 Marks

Q.No.	Solution and Scheme	Marks
2 b)	Adition of fins may not necessarily increase the rate of heat transfer from the surface, if its effectiveness is less than 1 We know that $\varepsilon = \frac{Q_{fin}}{Q_{without\ fin}} = \frac{\sqrt{hPKA_c}\cdot(T_0 - T_\infty)}{h.A_c(T_0 - T_\infty)}$ $\varepsilon = \sqrt{\frac{KP}{hA_c}}$ $\varepsilon < 1$ if thermal conductivity of fin material is less, less perimeter of fin and higher c/s area of fin. if $\varepsilon < 1$, the rate of heat transfer decreases from the surface even after adition of fin.	4 Marks
c)	Aluminium square fins of 0.5mm × 0.5mm $Q = 1\ W$, perimeter of fin $P = 4 \times 0.5 \times 10^{-3}\ m$. c/s " $A_c = 0.5 \times 0.5 \times 10^{-6}\ m^2$ $m = \sqrt{\frac{hP}{KA_c}} = 71.08\ m^{-1}$	4 Marks
	Heat transfer per fin $= \sqrt{hPKA_c} \times \theta_0 \times \tanh(mL)$ $= \sqrt{120 \times 4 \times 0.5 \times 10^{-3} \times 190 \times 0.5 \times 0.5 \times 10^{-6}} \times (80-40) \times \tanh(71.08 \times 10 \times 10^{-3})$ $= 0.0825\ W/fin.$	4 Marks

Q.No.	Solution and Scheme	Marks

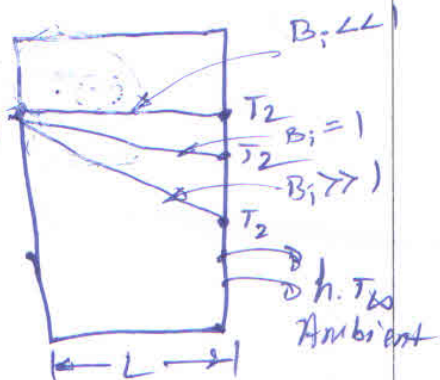
2 c) No. of fins required $= \dfrac{Q}{Q_{each\ fin}}$

$$= \frac{1}{0.0825} = 12.12 \simeq \underline{13 \text{ fins}}$$

— 2 marks

3 a) If temperature distribution within the solid is uniform with respect to position and is function of only time (τ), then the analysis is called lumped system.

Consider a slab of thickness L as shown. For temp. distribution to be uniform with resp. to position $T_1 \simeq T_2$.



$$\frac{KA}{L}(T_1 - T_2) = hA(T_2 - T_\infty)$$

$$B_i = \frac{T_1 - T_2}{T_2 - T_\infty} = \frac{L/KA}{1/hA} = \frac{\text{conductive resistance in slab}}{\text{convective resistance at surface of solid.}}$$

$$B_i = \frac{hL}{K}$$

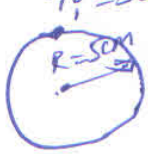
Criterian for application of lumped system

$B_i \le 0.1$

— 8 marks

b) $\tau = ?$ if $T_0 = 10°C$

$T(r) = ?$ at $r = 5 - 3 = 2\,cm$



$T_\infty = 2°C$

$h = 50\ W/m^2K$

Q.No.	Solution and Scheme	Marks
3 b)	Taking properties of orange as properties of water at avg. temp $= \frac{30+2}{2} = 16^\circ C$	
	from table, $\alpha = 1.4\times10^{-7}\ m^2/s$, $K = 0.59\ W/mK$	
	$B_i = \frac{hR_0}{K} = \frac{50\times5\times10^{-2}}{0.59} = 4.23 > 0.1$	4 Marks
	hence lumped system is not applicable	
	From transient temp charts, for sphere	
	centre temp $\frac{T_0 - T_\infty}{T_i - T_\infty} = 0.2857$	
	Fourier No. $= \frac{\alpha\tau}{R_0^2} = 5.6\times10^{-5}\tau$	
	From chart, $\frac{\alpha\tau}{R_0^2} = 0.31$	
	$\therefore 5.6\times10^{-5}\tau = 0.31$. $\therefore \tau = 5535$ sec $= 92$ mins.	4 Marks
	Temp. at 3cm from surface, $r = 5-3 = 2$ cm,	
	$\therefore$ Dimensionless position $= \frac{r}{R_0} = 0.4$	
	From chart, $\frac{T_r - T_\infty}{T_0 - T_\infty} = 0.86$.	4 Marks
	$\therefore T_r = 8.8^\circ C$	
4 a)	Physical properties of Atm. air at 300K are $\rho = 1.177\ Kg/m^3$, $\nu = 0.168\times10^{-4}\ m^2/s$	
	the transition occurs at dist $x = L$, where $Re_L = 5\times10^5$	

Q.No.	Solution and Scheme	Marks
	$\therefore Re_L = \frac{u_\infty L}{\nu} = \frac{1.5\,L}{0.168\times10^{-4}} = 5\times10^5$	
	$L = 5.6\,m.$	5 Marks
	The avg. drag co-efficient $C_m = \frac{1}{L}\int_0^L C_x\,dx$	
	$C_m = \frac{0.664}{L(u_\infty/\nu)^{1/2}}\int_0^L x^{-1/2}\,dx$	
	$C_m = 2\times\frac{0.664}{(Re_L)^{1/2}} = 2(C_x)_{x=L}$	
	$\therefore C_m = 2\times\frac{0.664}{5\times10^5} = 1.88\times10^{-3}$	
	$\therefore$ Drag force, $F = WL\,C_m\cdot\frac{\rho u_\infty^2}{2} = 2.09\times10^{-2}\,N.$	5 Marks
4 b)	$D = 0.1m$, $L = 1m$, $T_w = 180^\circ C$, $T_\infty = 20^\circ C$	
	$\varepsilon = 0.9$	
	$\therefore T_f = \frac{T_w + T_\infty}{2} = \frac{180+20}{2} = 100^\circ C$	
	properties at $T_f = 100^\circ C$	
	$\rho = 0.946\,m^3/kg$, $\nu = 23.02\times10^{-6}\,m^2/s$	
	$K = 0.03127\,W/mK.$, $C_p = 1011.3\,J/kg\,K$	
	$Pr = 0.704$	
	$\beta = \frac{1}{100+278} = 2.68\times10^{-3}\,\frac{1}{K}$	
	$Gr = \frac{g\beta(T_w - T_\infty)D^3}{\nu^2} = 7.94\times10^6$	3 marks
	$R_a = Gr\,Pr = 0.704\times7.94\times10^6 = 5.59\times10^6$	
	For horizontal cylinder $Nu = C\cdot(Gr.Pr)^n$	

Q.No.	Solution and Scheme	Marks
4 b)	From data handbook for $R_a = 5.59 \times 10^6$	
	$C = 0.48, \quad m = 0.25$	
	$Nu = 0.49\,(5.59 \times 10^6)^{0.25} = 23.34$	5 marks
	$\therefore h = \frac{Nu \cdot K}{D} = \frac{23.34 \times 0.03127}{0.1} = 7.298\ W/m^2K$	
	$q_{conv} = h(\pi D L)(T_w - T_\infty)$	
	$= 7.298(\pi \times 0.1 \times 5.6)(180 - 20)$	
	$= 366.85\ W/m$	
	$q_{rad} = \varepsilon(\pi D L)\sigma\,[(T_w + 273)^4 - (T_\infty + 273)^4]$	
	$= 556.94\ W/m$	
	$q_{total} = q_{conv} + q_{rad}$	
	$= 366.85 + 556.94$	
	$= 923.80\ W/m$	2 marks
	PART-B	
Q.5a)	properties of water at 40°C, $K = 0.634\ W/mK$	
	$\nu = 0.659 \times 10^{-6}\ m^2/s$	
	$V = \frac{4Q}{\pi D^2} = \frac{4 \times 0.05}{3600 \times \pi \times 0.015^2} = 0.0786\ m/s$	3 marks
	$\therefore Re_D = \frac{VD}{\nu} = 1789 \quad \therefore$ Flow is laminar.	
	For fully developed, constant heat flux	
	$Nu = 4.36, \quad \frac{hD}{K} = 4.36 \quad \therefore h = 184.4\ W/m^2K$	5 marks
	$h = \frac{q_w}{T_w - T_M} \quad \therefore T_w - T_M = \frac{1000}{184.4} = 5.4°C$	

Q.No.	Solution and Scheme	Marks
5a)	$\therefore T_W = 40 + 5.4 = 45.4^\circ C$	2 marks
b)	$T_W = 10^\circ C$, $T_\infty = 50^\circ C$, $L = 10m$, $W = 4m$, $H = 3m$.	

$\therefore A = L(W+H)2 = 140 m^2$

$T_f = \frac{T_W + T_\infty}{2} = \frac{10+50}{2} = 30^\circ C = 303K.$

$u = \frac{8500}{3600} = 23.611\ m/s.$

properties at T_f, $\nu = 16 \times 10^{-6}\ m^2/s$,

$\rho = 1.165\ kg/m^3$

$C_p = 1005\ J/kg\,K$, $Pr = 0.701$, $K = 0.02672\ W/mK$

$Re_L = \frac{uL}{\nu} = 1.476 \times 10^7 > 5 \times 10^5$ —— 5 marks

$\therefore$ Flow is turbulent.

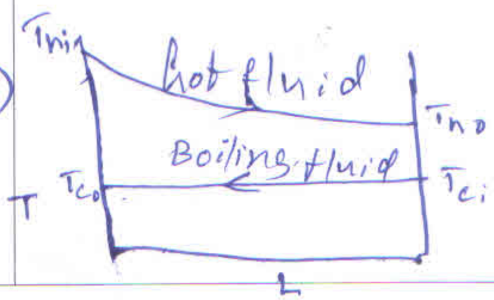
$\therefore Nu = 0.036\, Re_L^{0.8} \times Pr^{0.33}$

$Nu = 1.738 \times 10^4$

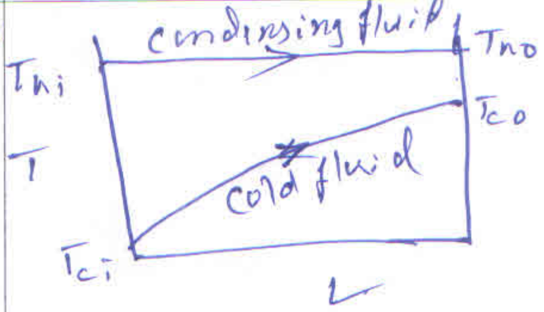
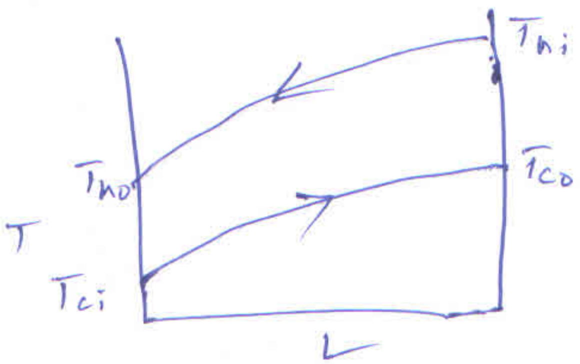
$h = \frac{K\,Nu}{L} = 46.448\ W/m^2K.$

$Q = hA(T_\infty - T_W) = 2.60 \times 10^5\ W$ —— 5 marks

6 a)



~~Boiler~~ Boiler —— 2 marks

Q.No.	Solution and Scheme	Marks
6a)	 condenser	2 marks
	 counter flow heat exchanger	2 marks
b)	$C_c = m_c c_{p_c} = \frac{1300}{3600} \times 4186 = 1511.6$ $C_h = m_h c_{p_h} = \frac{550}{3600} \times 2000 = 305.55$ $\therefore C_{max} = C_c = 1511.6 \quad C_{min} = C_h = 305.55$	4 Marks
	$C = \frac{C_{min}}{C_{max}} = \frac{305.55}{1511.6} = 0.202$ $\therefore NTU = \frac{UA}{C_{min}} = 3.518$	4 Marks
	$\varepsilon = \frac{1 - e^{-N(1-C)}}{1 - C \cdot e^{-N(1-C)}} = 0.95$ $\varepsilon = \frac{C_h (T_{hi} - T_{ho})}{C_{min}(T_{hi} - T_{ci})} \quad \therefore T_{ho} = 18.95^{\circ}C$	4 Marks

Q.No.	Solution and Scheme	Marks
6b)	$\text{lly}\quad \varepsilon = \dfrac{C_c(T_{co} - T_{ci})}{C_{min}(T_{hi} - T_{ci})} \quad \therefore T_{co} = 30.17^\circ C$	
	$Q = m_c C_{pc}(T_{co} - T_{ci}) = 22.93\ kW$ —	2 marks
Q.7a)	Fick's Law of Diffusion.	
	It states that the mass flux of constituent per unit area is proportional to the concentration gradient.	
	$\dfrac{\dot{m}_A}{A} = -D_{AB} \cdot \dfrac{d\rho_A}{dx}$ ————	4 Marks
	where $\dot{m}_A$ = mass flow rate of component A kg/s.	
	A = Area through which mass $\dot{m}_A$ flowing	
	$\dfrac{\dot{m}_A}{A}$ = mass flux of component A in kg/s.m²	
	ρ_A = mass concentration of component A. per unit vol. kg/m³	
	D_{AB} = constant of proportionality, called as diffusion co-eff. or mass diffusivity of comp. A in component B.	
	$\dfrac{d\rho_A}{dx}$ = concentration gradient of comp. A.	
	The negative sign indicates that mass	

Q.No.	Solution and Scheme	Marks
7a)	diffusion takes place in the direction of decreasing concentration. The Fick's Law of diffusion is analogous to Fourier law of heat conduction $\frac{Q}{A} = -K \cdot \frac{dT}{dx}$.	2 marks
b)	properties of steam at 2.45 bar $T_{sat} = 126.7^\circ C$, $h_{fg} = 2183.5 \times 10^3$ J/kg $T_f = \frac{T_{sat} + T_s}{2} = \frac{126.7 + 117}{2} = 121.85^\circ C$	4 marks
	from steam table $\rho = 943$ kg/m³, $\mu = 2.37 \times 10^{-6}$ kg/m.s $K = 0.686$ W/mK. thickness of condensate at $x = 0.2$ m $\delta_x = \left[\frac{4 \mu K x (T_{sat} - T_s)}{g \cdot h_{fg} \cdot \rho^2}\right]^{0.25}$ $\delta_x = \left[\frac{4 \times 2.37 \times 10^{-6} \times 0.686 \times 0.2 (126.7 - 117)}{9.81 \times 2183.5 \times 10^3 \times 943^2}\right]^{0.25}$ $\delta_x = 9.02 \times 10^{-5}$ m $= 0.09$ mm.	10 marks

Q.No.	Solution and Scheme	Marks
Q.8 A)	**Emissivity:** emissivity of a surface may be defined as ratio of radiation flux emitted by real body to the radiation flux emitted by black body at same temp. $\varepsilon = \frac{q_{real}}{q_{black}}$ ∴ for Black body $\varepsilon = 1$, for all other real body $\varepsilon < 1$	2 Marks
	Black body: Black body is one which absorbs all the thermal radiation falling on it ∴ $\alpha = 1$ for black body.	2 Marks
	Grey body: Grey body assumption is made to simplify the radiation problems. all radiation properties are assumed to be uniform over entire wavelength spectrum. Under this assumption, $\alpha = \varepsilon$ for grey body under thermal equilibrium condition	2 Marks
b)	$L = H = W = 4m$, $T_1 = 350K$, $T_2 = 300K$ $\varepsilon_1 = \varepsilon_2 = 0.8$	

Q.No.	Solution and Scheme	Marks
8b)	Considering floor as surface 1, ceiling as 2 and wall of room as surface 3.	
	$A_1 = 16 m^2$, $A_2 = 16 m^2$, $A_3 = 4 \times 16 = 64 m^2$	
	$R_2 = R_1 = \frac{1-\epsilon_1}{A_1 \epsilon_1} = 0.0156$	4 Marks
	since all energy leaving the floor will not reach ceiling and hence view factor F_{1-2} from chart $= 0.2$	
	since $F_{1-1} + F_{1-2} + F_{1-3} = 1$ and $F_{1-1} = 0$	
	$F_{1-3} = 1 - F_{1-2} = 1 - 0.2 = 0.8$	
	$R_{1-2} = \frac{1}{A_1 F_{1-2}} = \frac{1}{3.2}$, $R_{2-3} = R_{13} = \frac{1}{A_1 F_{1-3}} = \frac{1}{12.8}$	
	$\therefore \Sigma R_{total} = R_1 + \frac{1}{\frac{1}{R_{1-2}} + \frac{1}{R_{1-3}} + \frac{1}{R_{2-3}}} + R_2$	
	$\Sigma R_{total} = 0.1353$	6 marks
	$\therefore \phi = \frac{\sigma \cdot (T_1^4 - T_2^4)}{\Sigma R_{total}}$	
	$\phi = \frac{5.187 \times 10^{-8} \times (350^4 - 300^4)}{0.1353}$	
	$\phi = 2892.77 W$	4 Marks