Hall Ticket Number:

III/IV B.Tech (Regular) DEGREE EXAMINATION

July/August, 2023 **Mechanical Engineering**

Sixth Semester **Heat Transfer**

Time: Three Hours **Maximum:** 70 Marks

Answer question 1 compulsory. **(14X1 = 14Marks)**

Answer one question from each unit. **(4X14=56 Marks)**

Note: Heat and mass transfer data book is allowed.

			CO	BL	M
1	a)	Why is the negative sign used in Fourier's law of heat conduction?	CO1	L2	1
	b)	Differentiate between conductivity and conductance.	CO1	L2	1
	c)	Define fin efficiency.	CO1	L1	1
	d)	What is lumped system?	CO2	L2	1
	e)	State the application of dimensional analysis in heat transfer processes.	CO2	L1	1
	f)	Mention some of the areas where free and forced convection mechanisms are predominant.	CO2	L1	1
	g)	What is the significance of Biot number?	CO2	L1	1
	h)	What is the physical significance of Grash of number with reference to heat transfer by natural convection?	CO3	L2	1
	i)	Differentiate between dropwise and filmwise condensation.	CO3	L2	1
	j)	Distinguish between the pool boiling and flow boiling.	CO3	L2	1
	k)	In a gas -to-liquid heat exchanger, why fins provided on the gas side?	CO3	L2	1
	l)	Define emissivity.	CO4	L1	1
	m)	What do you understand by monochromatic emissive power?	CO4	L2	1
	n)	Give examples of some surfaces which do not appear black, but have high values of absorptivity	CO4	L1	1
		Unit-I			
2	a)	Write down the expressions for the physical laws that govern each mode of heat transfer, and identify the variables involved in each relation.	CO1	L2	7M
	b)	A concrete wall 130 mm thick generates heat at the rate of 4000 w/m^3 due to chemical reaction. Its surfaces are exposed to ambient air at a temperature of 20 ^{0}C. Calculate the surface temperature of wall and maximum temperature inside the wall. Tae thermal conductivity is 0.6 w/m K convection heat transfer co-efficient is 50 w/m^2 K.	CO1	L3	7M
		(OR)			
3	a)	Derive the general heat conduction equation in Cartesian coordinate system.	CO1	L3	7M
	b)	A composite wall is made up of two layer of 0.3m and 0.15m thickness respectively with outer surfaces of the composite wall held at 600^{0}C and 20^{0}C respectively. If conductivities are 20 and 50 W/mK, determine the heat conducted. In order to restrict the heat loss to 5 kW/m^2 another layer of 0.15m thickness is proposed. Determine the thermal conductivity of material required.	CO1	L3	7M
		Unit-II			
4	a)	A slab of aluminum 10cm thick is originally at a temperature of 500^{o}C. It is suddenly immersed in a liquid at 100^{0}C resulting a heat transfer coefficient of 1200 W/m^{2}K. Determine the temperature at the centerline and the surface 1 minute after the immersion. Also calculate the total thermal energy removed per unit area of the slab during this period. The properties of aluminum for the given conditions are α = 8.4X10^{-5} m^2/s, K = 215 W/mK , ρ = 2700 kg/ m^3, C = 0.9 kJ/kg-K.	CO2	L3	7M
	b)	Air at 30^{o}C flows with a velocity of 10 m/s over a flat plate of length 1m and width 0.5 m whose surface is kept at a uniform temperature of 120^{o}C. Determine the average heat transfer coefficient and the rate of heat transfer.	CO2	L3	7M

P.T.O

(OR)

5	a)	A 12cm diameter long bar initially at a uniform temperature of 40°C is placed in a medium at 650°C with a convective coefficient of 22W/m^2 K. Calculate the time required for the bar to reach 255°C. Take k = 20W/m-K, ρ = 580kg/m^3 and C = 1050J/kg-K.	CO2	L3	7M
	b)	Engine oil at 25°C is forced over a 30cm X 20cm plate at a velocity of 1.5m/s. The flow is parallel to the 30cm side of the plate, which is heated to a uniform temperature of 55°C. Calculate the rate of heat transfer from the plate to the oil. Properties of engine oil at 40°C are ρ = 876kg/m^3,υ= 24*10^{-5}m^2/s, k = 0.144W/mK and Pr = 2870.	CO2	L3	7M

Unit-III

6	a)	Sketch temperature and velocity profiles in free convection on a vertical wall.	CO3	L2	7M
	b)	Derive an expression for LMTD in a parallel flow heat exchanger.	CO3	L3	7M

(OR)

7	a)	Draw the boiling curve for pool boiling of water and explain flow regime	CO3	L2	7M
	b)	In a lubricating oil cooler hot oil flowing at the rate of 2000kg/hr is cooled from 100°C to 60°C using cold water at 10°C flowing at the rate of 1500kg/hr. The specific heat of the oil is 2.6 KJ/kg-K and water is 4.2KJ/kg-K. Determine the rate of heat transfer and outlet temperature of the cold fluid.	CO3	L3	7M

Unit-IV

8	a)	State Wien's displacement law and explain its significance	CO4	L2	7M
	b)	A black body is kept at a temperature of 1000K. Determine the emissive power of the body.	CO4	L3	7M

(OR)

9	a)	State and prove Kirchoff's law of radition.	CO4	L2	7M
	b)	Emissivity of two large parallel plates maintained at 800 °C and 300 °C are 0.5 and 0.6 respectively. Find the percentage reduction in heat transfer when a polished aluminium radiation shield of emissivity 0.05 is placed between them.	CO4	L3	7M

1a) $Q = -KA\left(\frac{dT}{dx}\right)$

As $\left(\frac{dT}{dx}\right)$ is negative, to give a +ve value for Q., negative sign is used.

b) $K \rightarrow$ Thermal Conductivity

$Q = \frac{\Delta T}{R} = K \cdot \Delta T \rightarrow K \rightarrow$ Thermal Conductance

Thermal Conductivity:- Ability to conduct heat

Thermal Conductance:- Defined as the ratio of HT rate to the temp. difference across the body.

$\rightarrow$ Reciprocal of thermal resistance.

c) <u>fin efficiency</u>:- $\frac{Q_{fin}}{Q_{fin,max}}$ = $\frac{\text{Actual HT from fin}}{\text{Ideal or max. HT from the fin if the entire fin is at the base temp.}}$

d) <u>Lumped system</u>:- At a given instant, the entire body is at the same temp. $\Rightarrow$ There is no temp. gradient inside the body.

e) <u>Dimensional analysis</u>:- Convection HT.

Combining the variables into dimensionless groups, thereby analysis will be simplified.

f) <u>Free Convection</u>:: HT from I.C. Engines, motors etc.

<u>Forced Convection</u>:- Cooling of electric components by fans

<u>Cooling of oils and coolants in vehicles using forced air.</u>

g) Biot no: $= \frac{hL_c}{k} = \frac{\text{Convection HT}}{\text{Conduction HT}}$.

$Bi < 0.1$, Represents lumped system.

h) Grashof no: Criteria to predict laminar or turbulent flow.

$Nu = f(Gr, Pr)$.

i) <u>Dropwise Condensation</u>:- Droplets form on surface and move downwards.

<u>Filmwise Condensation</u>:- A film forms on the surface.

Pool boiling: In this the vapour produced near the heating surface form bubbles which grow and detach themselves from the surface and raises to the free surface due to buoyancy effect.

Flow boiling: In this case the boiling surface may itself be a portion of the flow passage. Generally associated with two phase flow confined through a passage.

Fins are provided on the gas side to minimise resistance.

Emissivity: - Ratio of emissive power of surface to emissive power of black body, at the same temp.

If is the emissive power at a given wavelength. (E_λ)

Snow, Ice etc.

UNIT-I

$Q = -KA\frac{dT}{dx}$ — Fourier's law — Conduction → 1M

$Q = h \cdot A \cdot \Delta T$ — Newton's law of cooling - Convection → 1M

$E_b = \sigma T^4$ — Stefan-Boltzmann's law - Radiation, → 1M

Q = Rate of HT
K = thermal conductivity
A = Area normal to surface
$\frac{dT}{dx}$ = Temp. gradient
} Conduction. → 1M

Q = Rate of HT.
h = Convection HT coefficient
A = Contact area or heat transfer area
ΔT = Temp. difference
} Convection. → 1M

E_b = Emissive power of a black body.
σ = Stefan Boltzmann's Const.
T = Surface temp. in K
} Radiation → 1M

Overall — 1M.

2b) $T_\infty = 20^\circ C$, $L = 130\,mm = 0.13\,m$. $\dot{q} = 4000\,W/m^3$

$K_{wall} = 0.6\,W/mK$; $h = 50\,W/m^2K$. → 1M

$$T_w = T_\infty + \frac{\dot{q}L}{2h} = 20 + \frac{4000 \times 0.13}{2 \times 50} = \underline{25.2^\circ C} \rightarrow 3M$$

$$T_{max} = T_w + \frac{\dot{q}L^2}{8K} = 25.2 + \frac{4000 \times (0.13)^2}{8 \times 0.6} = \underline{\underline{39.28^\circ C}} \rightarrow 3M$$

3a) <u>General HC equation.</u>

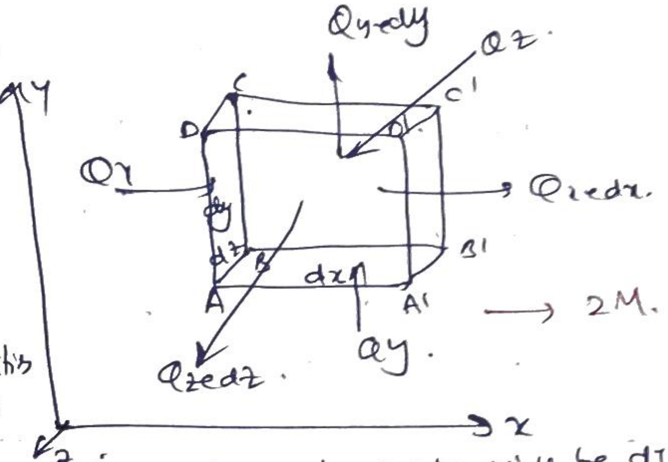
Consider a small volume element having sides dx, dy, dz.

$V = dx \cdot dy \cdot dz$.

ρ → density of the solid.

C_p → Sp. heat of solid.

K_x, K_y, K_z → Thermal conductivities of the solid along x, y & z directions



→ 2M.

In a small interval of time $\underline{dt}$ the temp. change of the body will be $\underline{dT}$

Energy balance of the solid element from 1st law of T.D.

$$\begin{bmatrix}\text{Net heat conducted} \\ \text{into the element} \\ \text{per unit time}\end{bmatrix} + \begin{bmatrix}\text{Internal heat} \\ \text{generation per} \\ \text{unit time}\end{bmatrix} = \begin{bmatrix}\text{Change or increase} \\ \text{in internal energy} \\ \text{per unit time}\end{bmatrix} + \begin{bmatrix}\text{Flow work done} \\ \text{by the element} \\ \text{per unit time}\end{bmatrix}$$

① ② ③ ④ → 2M

<u>Term IV</u>: Negligible [Flow work done by solids due to temp change is zero]

<u>Term III</u>: Change in internal energy during dt time $\Big\} =$ mass × Sp. heat × Change in temp.

$= (\rho \cdot dx dy dz)(C_p)(dT)$

$= \rho \cdot C_p \cdot dT \cdot (dx dy dz)$

∴ Change in internal energy / time $= \rho \cdot C_p \cdot \frac{\partial T}{\partial t} \cdot (dx\,dy\,dz)$ → 1M

<u>Term II</u>: $= \dot{q}(dx dy dz)$ where $\dot{q}$ = Internal HG per unit time per unit volume.

<u>Term I</u>: Heat will be conducted into and out of the element in each direction. We calculate net heat conducted for each direction and sum them to get the net heat conducted into the element per unit time.

<u>x-direction</u>: $Q_x = -K_x \frac{\partial T}{\partial x} \cdot dy\,dz$.

$$Q_{x+dx} = Q_x + \frac{\partial}{\partial x}(Q_x)dx =$$

∴ Net heat conducted $= Q_x - Q_{x+dx} = \frac{\partial}{\partial x}\left(K_x \frac{\partial T}{\partial x}\right)(dx\,dy\,dz)$ → 1M

<u>y-direction</u> → Net heat conducted $= \frac{\partial}{\partial y}\left(K_y \frac{\partial T}{\partial y}\right) dx\,dy\,dz$.

Z-direction → Net heat conducted $= \frac{\partial}{\partial z}\left(K_z \frac{\partial T}{\partial z}\right) \cdot dx\,dy\,dz$.

Substituting all terms and simplifying

$$\left(\frac{\partial}{\partial x}\left(K_x\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial T}{\partial z}\right)\right)dx\,dy\,dz+\dot{q}(dx\,dy\,dz)=\rho\cdot C_p\cdot\frac{\partial T}{\partial t}(dx\,dy\,dz)$$

$\div$ by $(dx\,dy\,dz)$ and assuming isotropic material $\Rightarrow K_x=K_y=K_z=K$.

$$\therefore \frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}+\frac{\dot{q}}{K}=\frac{\rho C_p}{K}\cdot\frac{\partial T}{\partial t}=\frac{1}{\alpha}\cdot\frac{\partial T}{\partial t} \rightarrow 1M$$

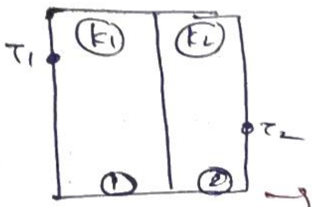
(or) $$\nabla^2 T+\frac{\dot{q}}{K}=\frac{1}{\alpha}\cdot\frac{\partial T}{\partial t}.$$

where α = Thermal diffusivity.

3b) $L_1 = 0.3\ m$, $L_2 = 0.15\ m$.

$T_1 = 600°C$ $T_2 = 20°C$.

$K_1 = 20\ W/mK$, $K_2 = 50\ W/mK$.



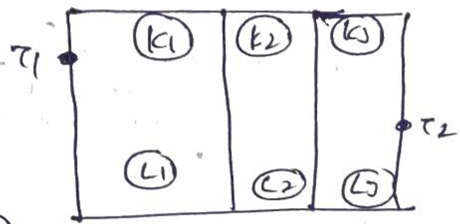
$\rightarrow 1M$

$$\frac{Q}{A}=\frac{T_1-T_2}{\frac{L_1}{K_1}+\frac{L_2}{K_2}}=\frac{600-20}{\frac{0.3}{20}+\frac{0.15}{50}}$$

$$=\frac{580}{0.015+0.003}=\frac{580}{0.018}=\underline{32222\ W/m^2} \rightarrow 3M.$$

$Q = 5000\ W/m^2$. $L_3 = 0.15\ m$ $K_3 = ?$.

$$\frac{Q}{A}=\frac{T_1-T_2}{\frac{L_1}{K_1}+\frac{L_2}{K_2}+\frac{L_3}{K_3}}=\frac{600-20}{\frac{0.3}{20}+\frac{0.15}{50}+\frac{0.15}{K_3}}$$



$\rightarrow 2M$

$$5000=\frac{580}{0.015+0.003+\left(\frac{0.15}{K_3}\right)}=\frac{580}{0.018+\left(\frac{0.15}{K_3}\right)}$$

$$\therefore 0.018+\left(\frac{0.15}{K_3}\right)=\frac{580}{5000}=0.116$$

$$\therefore \frac{0.15}{K_3}=0.116-0.018=0.098$$

$$\therefore K_3=\frac{0.15}{0.098}=1.53\ W/mK$$

$$\underline{K_3 = 1.53\ W/mK} \rightarrow 1M$$

4a) $L = 10cm = 0.1m$ $T_0 = 500°c$, $T_\alpha = 100°c$, $h = 1200\ W/m^2K$

$t = 60 sec$. $T = ?$.

$\alpha = 8.4 \times 10^{-5}\ m^2/s$ $k = 215\ W/mK$ $\rho = 2700\ kg/m^3$

$C_p = 900\ J/kgK$

$L_c = \frac{L}{2} = \frac{0.1}{2} = 0.05m \longrightarrow 2M$

$B_i = \frac{h L_c}{k} = \frac{1200 \times 0.05}{215} = 0.279 > 0.1 \longrightarrow 3M$

∴ Lumped system is not applicable $\longrightarrow 3M$.

4.b) $V = 10\ m/s = U_\alpha$ $L = 1m$, $W = 0.5m$ Flat plate. Air.

$T_s = 120°c$ $T_\alpha = 30°c$,

$T_f = \frac{120+30}{2} = 75°c$.

properties of air at $T_f = 75°c$ are

$\nu = 20.555 \times 10^{-6}\ m^2/s$; $Pr = 0.693$, $K = 0.030065 \longrightarrow 1M$

$Re_L = \frac{U_\alpha L}{\nu} = \frac{10 \times 1}{20.555 \times 10^{-6}} = 4.865 \times 10^5 < 5 \times 10^5 \longrightarrow 2M$.

∴ Laminar flow. Flat plate. Constant wall temp.

$\longrightarrow 1M$.

$\therefore \overline{Nu_L} = 0.664 \cdot Re_L^{0.5}\ Pr^{0.333}$

$= 0.664 \times (4.865 \times 10^5)^{0.5} (0.693)^{0.333}$

$= 0.664 \times 697.5 \times 0.885 = 409.88$

$\frac{hL}{K} = 409.88$

$\therefore h = 409.88 \times \frac{k}{L} = \frac{409.88 \times 0.030065}{1} = \underline{12.323\ W/m^2K} \longrightarrow 2M$

$Q = h \cdot A \cdot \Delta T = 12.323 \times (1 \times 0.5) \times (120-30)$

$= \underline{554.5\ W} \longrightarrow 1M$.

5 a) $T_0 = 40^\circ C$. $T_\infty = 650^\circ C$. $h = 22\ W/m^2K$; $T = 255^\circ C$. (6)

bar, $d = 12\ cm = 0.12\ m \Rightarrow R = 0.06\ m$.

$k = 20\ W/mK$; $\rho = 580\ kg/m^3$, $C_p = 1050\ J/kgK$.

$L_c = \frac{R}{2} = \frac{0.06}{2} = 0.03\ m$. $\longrightarrow$ 1M

$B_i = \frac{hL_c}{K} = \frac{22 \times 0.03}{20} = 0.033 < 0.1$. $\longrightarrow$ 2M.

$\therefore$ Lumped system is applicable.

$\therefore \frac{T - T_\infty}{T_0 - T_\infty} = \exp\left[-\frac{hA_s}{\rho c V} \cdot t\right] = \exp\left[-\frac{h}{\rho c L_c} \cdot t\right]$ $\longrightarrow$ 2M.

$\frac{255 - 650}{40 - 650} = \frac{395}{610} = 0.64754 = \exp\left[-\frac{h}{\rho c L_c} \cdot t\right]$.

Taking 'ln' on both sides.

$\therefore -\frac{h}{\rho c L_c} \cdot t = \ln(0.64754) = -0.43457$.

$\therefore \frac{h}{\rho c L_c} \cdot t = 0.43457$

$\therefore t = \frac{0.43457 \times \rho \cdot c \cdot L_c}{h} = \frac{0.43457 \times 580 \times 1050 \times 0.03}{22}$

$\therefore t = 361$ seconds $\longrightarrow$ 2M.

5 b) $U_\infty = 1.5\ m/s$; $T_\infty = 25^\circ C$. $T_s = 55^\circ C$. $L = 0.3\ m$, $W = 0.2\ m$.

Properties : at $T_f = 40^\circ C$. $\rho = 876\ kg/m^3$; $\nu = 24 \times 10^{-5}\ m^2/s$; $k = 0.144\ W/mK$; $Pr = 2870$. $\longrightarrow$ 1M

$Re_L = \frac{U_\infty \cdot L}{\nu} = \frac{1.5 \times 0.3}{24 \times 10^{-5}} = 0.01875 \times 10^5 < 5 \times 10^5$

$\therefore$ Laminar flow. flat plate. Constant wall temp. $\longrightarrow$ 2M.

$\therefore \overline{Nu} = 0.664 \cdot (Re_L)^{0.5} (Pr)^{0.333} = 0.664 \times (0.01875 \times 10^5)^{0.5} (2870)^{0.333}$ $\longrightarrow$ 1M

$\frac{hL}{k} = 0.664 \times 43.3 \times 14.1734 = 407.5$

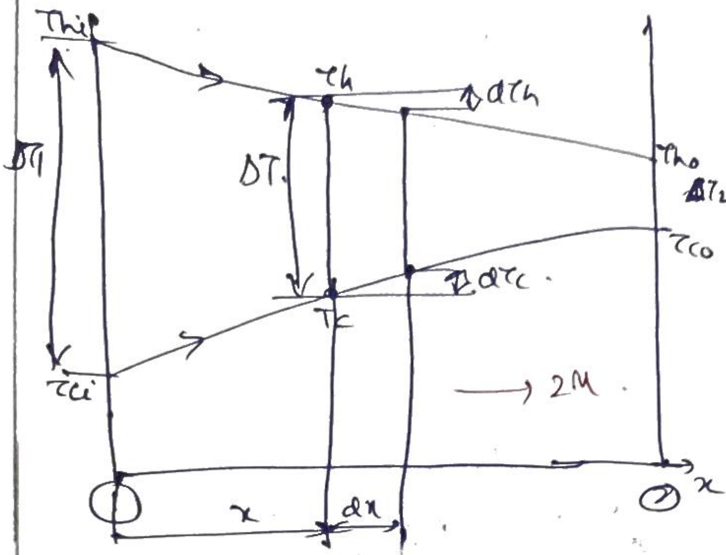
$\therefore h = \frac{407.5 \times k}{L} = \frac{407.5 \times 0.144}{0.3} = 195.6\ W/m^2K$

$\therefore h = 195.6\ W/m^2K$ $\longrightarrow$ 2M

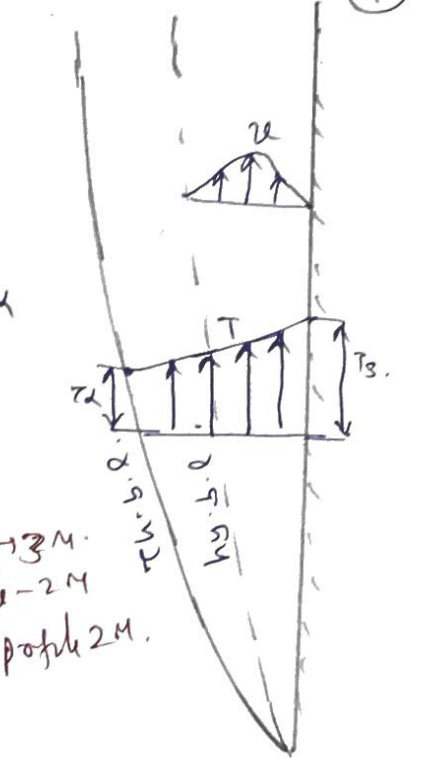
$\therefore Q = h \cdot A \cdot \Delta T = 195.6 \times (0.3 \times 0.2) \times (55 - 25)$

$Q = 352$ Watts $\longrightarrow$ 1M

6(b) LMTD for 11el flow HE



6(a)



BCs → 3M.
u profile - 2M
Temp. profile 2M.

Let us consider the HT between the hot and cold fluids for differential element of length 'dx'

$dQ = U \cdot dA \cdot \Delta T = U \cdot dA (T_h - T_c) \rightarrow (1)$. where dA = width × dx.

the energy balance for the hot and cold fluids is for the above differential element,

$$\left.\begin{aligned} dQ &= -\dot{m}_h \cdot C_h \, dT_h = -C_h \cdot dT_h \\ dQ &= \dot{m}_c \, c_c \cdot dT_c = C_c \cdot dT_c \end{aligned}\right\} (2)$$

where $C_h = \dot{m}_h C_h$ → 1M.
$C_c = \dot{m}_c c_c$.

We know that $\Delta T = T_h - T_c \Rightarrow d(\Delta T) = dT_h - dT_c$

Substituting the values of dT_h and dT_c from (2).

$$\therefore d(\Delta T) = \frac{-dQ}{C_h} - \frac{dQ}{C_c} = -dQ\left[\frac{1}{C_h} + \frac{1}{C_c}\right] \rightarrow 1M.$$

$$= -(U dA \cdot \Delta T) \cdot \left(\frac{1}{C_h} + \frac{1}{C_c}\right)$$

Integrating over the entire length of Heat exchanger,

$$\int_{\Delta T_1}^{\Delta T_2} \frac{d(\Delta T)}{\Delta T} = (-U)\left(\frac{1}{C_h} + \frac{1}{C_c}\right)\int_1^2 dA$$

$$\therefore \ln\left(\frac{\Delta T_2}{\Delta T_1}\right) = (-UA)\left(\frac{1}{C_h} + \frac{1}{C_c}\right)$$

$$= \frac{-UA}{Q}\left[(T_{hi} - T_{ho}) + (T_{co} - T_{ci})\right]$$

$$= \left(\frac{-UA}{Q}\right)\left[(T_{hi} - T_{ci}) - (T_{ho} - T_{co})\right]$$

$Q = \dot{m}_h C_h (T_{hi} - T_{ho})$
$= C_h (T_{hi} - T_{ho})$
$Q = \dot{m}_c c_c (T_{co} - T_{ci})$
$= C_c (T_{co} - T_{ci})$
→ 1M.

$$\ln\left(\frac{\Delta T_2}{\Delta T_1}\right) = \frac{-UA}{Q}(\Delta T_1 - \Delta T_2) = \left(\frac{UA}{Q}\right)(\Delta T_2 - \Delta T_1)$$

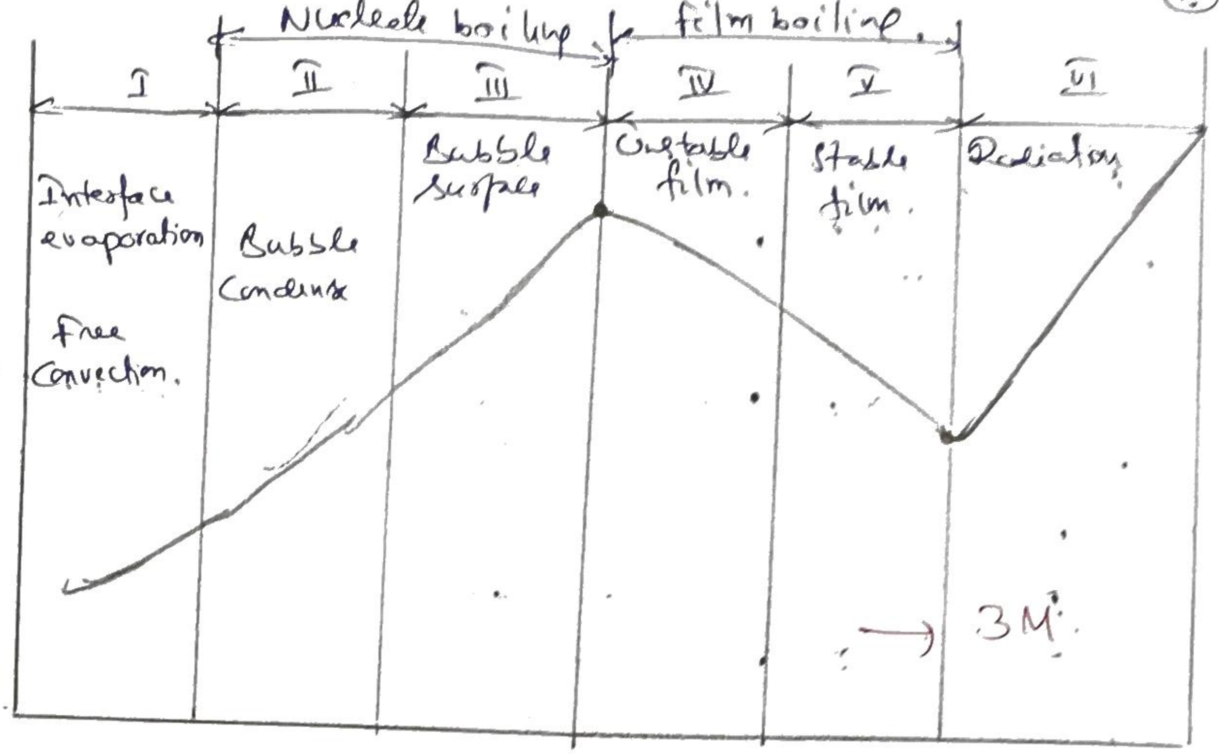
$$\therefore Q = UA \cdot \left[\frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2/\Delta T_1)}\right] = \cancel{Q \cdot A}$$

where $LMTD = \dfrac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2/\Delta T_1)}$

$$Q = UA \cdot (LMTD)$$

→ 2M.

7a)



I → Interface evaporation

II & III → Nucleate boiling

IV & V → film boiling.

Brief explanation required. → 4M.

7b)

Hot fluid → oil

$\dot{m}_h = 2000$ kg/hr.

$T_{hi} = 100°C$.

$T_{ho} = 60°C$

$C_h = 2600$ J/kgK

Cold fluid → water

$\dot{m}_c = 1500$ kg/hr.

$T_{ci} = 10°C$.

$c_c = 4200$ J/kgK.

Q = H.L. by hot fluid $= \dot{m}_h \cdot C_h \cdot (T_{hi} - T_{ho})$ → 1M

$= \frac{2000}{3600} \times 2600 \times (100-60) = \underline{57777.8}$ Watts.

$= \underline{\underline{57.777}}$ kW → 2M.

Q = H.G. by cold fluid → 2M

$= \dot{m}_c \; c_c \cdot (T_{co} - T_{ci})$

$\therefore (T_{co} - T_{ci}) = \frac{Q}{\dot{m}_c \cdot c_c} = \frac{57777.8}{\left(\frac{1500}{3600}\right) \times 4200} = 33°C$

$\therefore T_{co} = 33 + T_{ci} = 33 + 10 = 43°C$. → 2M

$\therefore$ outlet temp. of water $= \underline{\underline{43°C}}$.

8a) **Wien's displacement law**

$\lambda_{max} \cdot T = \text{Constant} \longrightarrow 3M$

It is the relationship between temp. of a black body and the wavelength at which the maximum monochromatic emissive power occurs. $\longrightarrow 3M$

$$E_{\lambda b} = \frac{C_1 \lambda^{-5}}{(\exp^{C_2/\lambda T} - 1)} \longrightarrow 1M.$$

$E_{\lambda b}$ becomes maximum if $\frac{d}{d\lambda}(E_{\lambda b}) = 0$.

↓ After differentiation and simplification.

$$\therefore \lambda_{max} \cdot T = \frac{C_2}{4.965} = \frac{1.4387 \times 10^{-2}}{4.965} \text{ mK}$$

$$\therefore \lambda_{max} \cdot T = 2898 \ \mu\text{m-K}$$

8b) Black body, $T = 1000K$.

$$E_b = \sigma T^4 = 5.67 \times 10^{-8} (1000^4)$$

$\longrightarrow 3M$ $= 5.67 (10^4)$

$= 5.67 \times 10^4 \ W/m^2$

$= 56700 \ W/m^2 \longrightarrow 4M.$

9a) **Kirchoff's law**

It states that at any temp. the ratio of the total emissive power to the absorptivity is a constant for all substances which are in thermal equilibrium (with their environment).

(a) At thermal equilibrium, the absorptivity and emissivity of a body are equal. $\longrightarrow 3M$.

Proof: Let three bodies are in thermal equilibrium with each other, then

$$\frac{E_1}{\alpha_1} = \frac{E_2}{\alpha_2} = \frac{E_3}{\alpha_3} = \text{Const.} \longrightarrow 2M$$

If the third body is a black body, then.

$$\frac{E_1}{\alpha_1} = \frac{E_2}{\alpha_2} = \frac{E_b}{\alpha_b = 1}.$$

$$\therefore \frac{E_1}{\alpha_1} = E_b \Rightarrow \frac{E_1}{E_b} = \alpha_1 \Rightarrow \epsilon_1 = \alpha_1$$

$$\text{III}^{ly} \ \frac{E_2}{\alpha_2} = E_b \Rightarrow \frac{E_2}{E_b} = \alpha_2 \Rightarrow \epsilon_2 = \alpha_2$$

$$\therefore \epsilon = \alpha. \longrightarrow 2M$$

9 b) Case 1.

$T_1 = 800+273 = 1073\,K$

$T_2 = 300+273 = 573\,K$.

$\epsilon_1 = 0.5,\ \epsilon_2 = 0.6.$

$$\therefore \left(\frac{Q_{12}}{A}\right) = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\epsilon_1}+\frac{1}{\epsilon_2}-1} \longrightarrow 2M$$

$$= \frac{5.67\times10^{-8}\left[1073^4 - 573^4\right]}{\left(\frac{1}{0.5}+\frac{1}{0.6}-1\right)}$$

$$= \frac{5.67\left(10.73^4 - 5.73^4\right)}{(2+1.667-1)} = \frac{5.67(13255.5 - 1078)}{2.667}$$

$$\left(\frac{Q_{12}}{A}\right) = \frac{69046.4}{2.667} = 25889\ W/m^2 \longrightarrow 2M.$$

Case 2. A shield is placed between the plates.

$\epsilon_s = 0.05$

$$\therefore \left(\frac{Q_{12}}{A}\right)_{\text{with shield}} = \frac{\sigma(T_1^4 - T_2^4)}{\left(\frac{1}{\epsilon_1}+\frac{1}{\epsilon_2}-1\right)+\left(\frac{2}{\epsilon_s}-1\right)} \longrightarrow 8$$

$$\left(\frac{2}{\epsilon_s}-1\right) = \frac{2}{0.05}-1 = 40-1 = 39$$

$$= \frac{69046.4}{2.667+39} = \frac{69046.4}{41.667}$$

$$= 1657\ W/m^2 \longrightarrow 2M$$

$$\%\ \text{Reduction in HT} = \left(\frac{25889 - 1657}{25889}\right)\times 100$$

$$= 93.6\,\% \longrightarrow 1M.$$