Modified

CBCS SCHEME

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BME601

Sixth Semester B.E./B.Tech. Degree Examination, June/July 2025
Heat Transfer

Time: 3 hrs. Max. Marks: 100

Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. M: Marks, L: Bloom's level, C: Course outcomes.
3. Use of Heat Transfer data Hand Book is permitted

			M	L	C
		Module – 1			
Q.1	a.	Derive on expression for temperature distribution and heat transfer in 1-D conduction heat transfer through SLAB.	10	L3	CO1
	b.	An exterior wall of a house may be approximated by a 10 cms layer of common brick (K=0.7w/m°c) followed by 4cms layer of gypsum plaster (K = 0.48w/m°c) Find thickness of loosely packed rock wool insulation (K =0.065 w/m°c) that should be added to reduce the heat loss (or gain) through the wall by 80%.	10	L3	CO1
		OR			
Q.2	a.	Explain basic laws of heat transfer.	6	L2	CO1
	b.	Discuss the expression for temperature distribution and the rate of heat transfer for an one dimensional hollow sphere.	4	L2	CO1
	c.	A 600 mm outer diameter sphere storing a liquid is provided with two insulating layers, a high temperature insulation of conductivity 0.35 w/m°c and a low temperature insulation of thermal conductivity 0.07w/m°c. The thickness of the former is 100mm. The temperature drop across high temperature insulation is required to be 2 ½ times that across the low temperature insulation, calculate the thickness of the latter.	10	L3	CO1
		Module – 2			
Q.3	a.	Derive the 1 D fin equation for a fin of uniform cross section. By integrating the fin equation, obtain the expression for the temperature variation in a long fin.	10	L3	CO2
	b.	A 1m long, 5cm diameter cylinder placed in an atmosphere of 40°c is provided with 12 longitudinal straight fins (K = 75W/mk) 0.75mm thick. The fin protrudes 2.5cm from the cylinder surface. The heat transfer coefficient is 23.3 W/m² K. Calculate the rate of heat transfer if the surface temperature of the cylinder is 150°c.	10	L3	CO2
		OR			
Q.4	a.	Obtain an expression for temperature distribution and total heat transfer for lumped heat analysis treatment of transient heat conduction.	10	L3	CO2
	b.	A 10cm diameter apple, approximately spherical in shape, is taken from a 20°c environment and placed in a refrigerator whose temperature is 5°c and average convective heat transfer coefficient over the surface of apple is 6w/m² °c. Calculate the temperature at the center of the apple after a period of 1 hour. Thermo physical properties of apple are ρ =998 kg/m³, C = 4180J/Kg K, K = 0.6W/m-K.	10	L3	CO2

		Module – 3			
Q.5	a.	Explain explicit scheme of solution to the one dimensional transient heat conduction problem without heat generation.	10	L2	CO3
	b.	Derive the relation between radiation intensity and emissive power.	10	L3	CO3
		OR			
Q.6	a.	Explain (i) Stefan Boltzmann law (ii) Kirchhoff's law (iii) Plancks law (iv) Wien's displacement law (v) Block body.	10	L2	CO3
	b.	Thin polished copper plate with an emissivity of 0.04 is inserted as radiation shield between two dull steel plates with emissivity of 0.8. Determine the percentage decrease in radiant energy transfer due to the presence of shield. Find percentage reduction if the copper plate gets oxidised with an emissivity of 0.6.	10	L3	CO3
		Module – 4			
Q.7	a.	With reference to fluid flow over a flat plate, discuss the concept of velocity boundary layer and thermal boundary layer.	10	L2	CO4
	b.	Air at 0°c and 20m/s flows over a flat plate of length 1.5m that is maintained at 50°c. Calculate the average heat transfer coefficient over the region where flow is laminar. Find the overage heat transfer coefficient and the heat loss for the entire plates per unit width.	10	L3	CO4
		OR			
Q.8	a.	Explain the significance of the following i. Grashof Number ii. Nusselt Number iii. Stanton Number iv. Prandtt Number v. Reynolds Number	10	L2	CO4
	b.	The water is heated in a tank by dipping vertically a plate (30cm × 30cm) size. The temperature of plate surface is maintained at 140°c. Assuming the temperature of surrounding water at 20°c. Find out the heat lost from the plate per hour.	10	L3	CO4
		Module – 5			
Q.9	a.	Explain in detail the regimes of pool boiling.	10	L2	CO5
	b.	One hundred tubes of 12mm in diameter are arranged in a square array and are exposed to steam at atmospheric pressure. Calculate the mass of steam condensed per unit length of the tube if the tube wall temperature is maintained at 98°c. The properties of water at mean temperature density = 960 Kg/m^3. Absolute viscosity = 282×10^{-6} Kg/m-s. Thermal conductivity = 0.61W/m–Kg, h_{fg} = 2255 KJ/Kg.	10	L3	CO5
		OR			
Q.10	a.	Derive an expression for LMTD for a counter flow heat exchanger.	10	L3	CO5
	b.	Water (C_p=4200 J/Kg °c) enters a counter flow double pipe heat exchanger at 38°C flowing at 0.076 kg/S. It is heated by oil (C_p=1880 J/Kg°C) flowing at the rate of 0.152 Kg/S from an inlet temperature of 116°C. For an area of $1m^2$ and U = 340 W/m^2 °C, determine the total heat transfer rate.	10	L3	CO5

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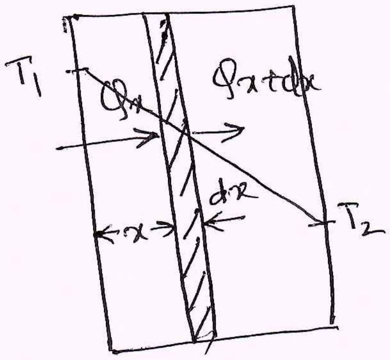
Solution of Question Paper

BME601 Heat Transfer June/July 2025

1 (a)



Applying Energy balance for the element shown in the fig

$$q_x - q_{x+dx} = 0 \quad \text{--- (1)}$$

$$q_x = -KA\frac{dT}{dx}$$

$$q_{x+dx} = q_x - KA\frac{d^2T}{dx^2}dx$$

$$\therefore \quad q_x - q_x + KA\frac{d^2T}{dx^2}dx = 0$$

$$\boxed{\frac{d^2T}{dx^2} = 0} \quad \text{--- (2)}$$

Integrate Eq. (2) twice

$$\frac{dT}{dx} = C_1 \quad \text{--- (3)}$$

$$T = C_1 x + C_2 \quad \text{--- (4)}$$

Applying Boundary conditions to Eq (4)

BC1: At $x=0$, $T=T_1$, $\boxed{C_2 = T_1}$

BC2: At $x=L$, $T=T_2$,

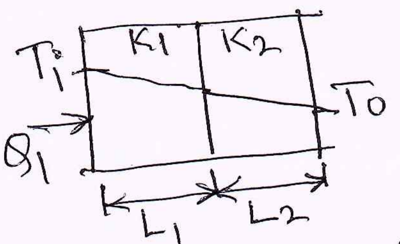
$$T_2 = C_1 L + T_1$$

$$\boxed{C_1 = \frac{T_2 - T_1}{L}}$$

$$\boxed{T = \frac{T_2 - T_1}{L}x + T_1} \quad \text{--- (5) Temp. Distr. Eq}$$

Heat Transfer $q = -KA\frac{dT}{dx} = -KA\frac{T_2 - T_1}{L} = \frac{KA(T_1 - T_2)}{L}$ --- (6)

1(b) case 1: Q_1 without Rockwool insulation

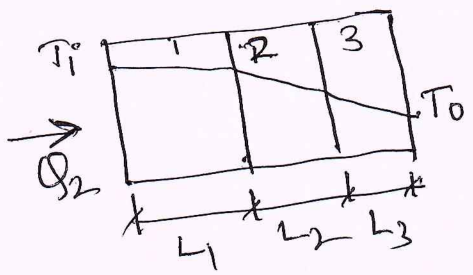


$$R_1 = \frac{L_1}{K_1} = \frac{0.1}{0.7}$$

$$R_2 = \frac{L_2}{K_2} = \frac{0.04}{0.48}$$

$$Q_1 = \frac{T_i - T_o}{R_1 + R_2} = 4.4248\,\Delta T$$

case 2: Q_2 with Rockwool insulation.



$$R_3 = \frac{L_3}{K_3} = \frac{L_3}{0.065}$$

$$Q_2 = \frac{T_i - T_o}{R_1 + R_2 + R_3}$$

$$Q_2 = 0.2\,Q_1 = 0.2 \times 4.4248 = \frac{\Delta T}{0.226 + R_3}$$

$$R_3 = 0.904 \text{ K/W}$$

$$L_3 = 5.876 \text{ cm} \quad \text{or} \quad 0.05876 \text{ m}$$

2(a) (i) Fourier's law of heat conduction

$$Q = -KA\frac{dT}{dx}$$

(ii) Newton's law of cooling

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

(iii) Stefan-Boltzman law of Radiation

$$Q = \sigma \cdot A \cdot T^4$$

2(b) Temperature distribution equation for hallow sphere which gives temp. value at any radius

$T = f(r)$

$$\frac{T - T_i}{T_i - T_o} = \frac{\left(\frac{1}{r_i} - \frac{1}{r}\right)}{\left(\frac{1}{r_o} - \frac{1}{r_i}\right)} \quad \text{—(1)}$$

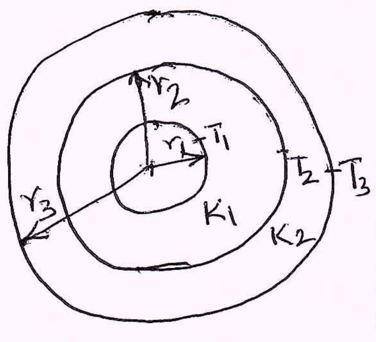
$$\text{Heat flow equation} = \frac{T_i - T_o}{\left(\frac{r_o - r_i}{4\pi K r_i r_o}\right)} \quad \text{—(2)}$$

which give heat transfer rate in W (J/s)

2 (c) $r_1 = 300mm = 0.3m$

$K_1 = 0.35\, W/m^\circ C,\ K_2 = 0.07\, W/m^\circ C$

$r_2 - r_1 = 100mm = 0.1m,\ r_2 = \cancel{0} 0.4m.$



$$Q = \frac{4\pi K_1 r_1 r_2 (T_1 - T_2)}{(r_2 - r_1)} = \frac{4\pi K_2 r_2 r_3 (T_2 - T_3)}{(r_3 - r_2)}$$

$$(T_1 - T_2) = 2.5(T_2 - T_3)$$

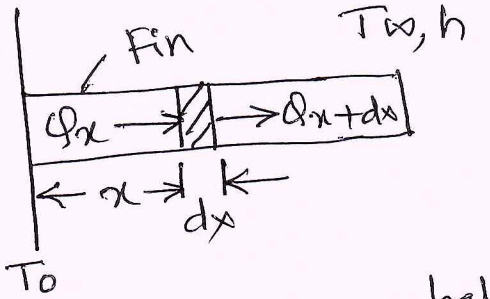
$$\frac{K_1 r_1 r_2 (\cancel{T_2 - T_3}) 2.5}{0.1} = \frac{K_2 0.4\, r_3 (\cancel{T_2 - T_3})}{(r_3 - 0.4)}$$

$$\underline{r_3 = 0.411\, m}$$

∴ Thickness of insulation

$$= \underline{(r_3 - r_2) = 0.411 - 0.4 = 0.011m \text{ or } 11mm}$$

3(a)



Applying energy balance for the element of fin.

Heat conducted into the element = Heat conducted out of the element + Heat convected out of the element

$$Q_x = Q_{x+dx} + Q_{conv.}$$

$$\frac{d^2T}{dx^2} - \frac{hP}{KA}(T_0 - T_\infty) = 0$$

Let $\theta = (T_0 - T_\infty)$, $\frac{d\theta}{dx} = \frac{dT}{dx}$, $\frac{d^2\theta}{dx^2} = \frac{d^2T}{dx^2}$, $m = \sqrt{\frac{hP}{KA}}$

$$\frac{d^2\theta}{dx^2} - m^2\theta = 0$$

$$\theta = C_1 e^{mx} + C_2 e^{-mx}$$

At $x=0$, $\theta = \theta_0$, $\theta_0 = C_1 + C_2$, At $x = \infty$, $\theta = 0$, $C_2 = \theta_0$

$$\frac{\theta}{\theta_0} = \frac{T - T_\infty}{T_0 - T_\infty} = e^{-mx}.$$

3(b) $A = \frac{\pi}{4} d^2 = 0.1571 m^2$

$A_{fin} = t \times L = 0.00075, \quad P = 2L = 2m.$

$L_c = h + \frac{t}{2} = 0.025375 m$

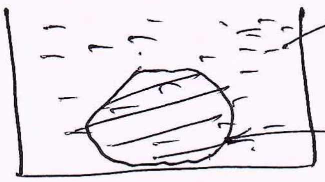
$m = \sqrt{\frac{hP}{KA}} = 28.78$

$\eta_{fin} = \frac{\tan(mL_c)}{m} = 0.8524 = 85.24\%$

$Q = \sqrt{hPKA}\,(T_0 - T_\infty) = -248.16$

$Q_{total} = -12 \times 248.16 = -2977.92\ W$

4(a)



Fluid at 'h', Ta

To = Temp. of body at time t=0.

Body of mass 'm', area 'A', density 'ρ'

Heat lost by the body by convection
= Rate of change of internal energy of the body

$$Q = -hA(T - T_a) = \rho v c \frac{dT}{dt}$$

$$hA(T - T_a) = -\rho c v \frac{dT}{dt}$$

$$\int_{T_0}^{T} \frac{dT}{(T - T_a)} = \int_{t=0}^{t} -\frac{hA}{\rho c v}\, dt$$

$$\ln \frac{T - T_a}{T_0 - T_a} = -\frac{hA}{\rho c v} t$$

$$\frac{T - T_a}{T_0 - T_a} = \frac{\theta}{\theta_0} = e^{-\frac{hA}{\rho c v} t} = e^{-B_i F_o}$$

$$Q = \rho c v \frac{dT}{dt} = -\int_0^t hA\, e^{\frac{-hA}{\rho c v} t} (T_0 - T_a)\, dt \quad \left\{ Q_T = \int Q\, dt \right\}$$

$$Q = \rho c v (T_0 - T_a) \left[e^{\frac{-hA}{\rho c v} \cdot t} - 1 \right]$$

$$= \rho c v\, \theta_0 \left[e^{B_i \cdot F_o} - 1 \right]$$

4(b) $r = 5\,cm = 0.05\,m$, $T_i = 20^\circ C$, $T_a = 5^\circ C$

$h = 6\,W/m^2\,{}^\circ C$.

$t = 1\,hr = 3600\,sec$

$\rho = 998\,kg/m^3$, $C = 4180\,J/kg\,K$, $K = 0.6\,W/m\text{-}K$

$$L_c = \frac{V}{A} = \frac{\cancel{4}/3\,\cancel{\pi}\,r^3}{\cancel{4}\,\cancel{\pi}\,r^2} = \frac{r}{3} = \frac{0.05}{3} = 1.67\times10^{-2}\,m$$

$$Bi = \frac{hL_c}{K} = \frac{6\times1.67\times10^{-3}}{0.6} = 0.167.$$

$0.1 > Bi < 100$ Hence Heisler charts are used

$$Fo = \frac{\alpha\cdot t}{r^2} = \left(\frac{K}{\rho C}\right)\cdot\frac{t}{r^2} = \left(\frac{0.6}{998\times4180}\right)\times\frac{3600}{0.05^2}$$

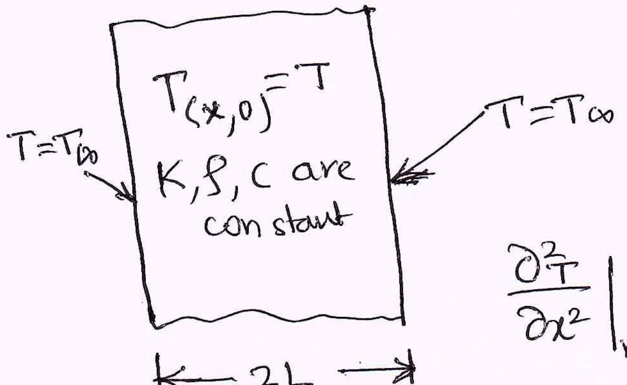
$Fo = 0.207$

$\frac{r}{r_0} = 0$ [Mid plane] from data handbook

$$\frac{T_0 - T_a}{T_i - T_a} = 0.85 \Rightarrow \underline{(20-5)\times0.85 = T_0 - 5}$$

$\therefore \boxed{T_0 = 17.75^\circ C}$

5(a) $0 < x < L$



$$\frac{\partial T(x,t)}{\partial t} = \alpha\cdot\frac{\partial^2 T}{\partial x^2}$$

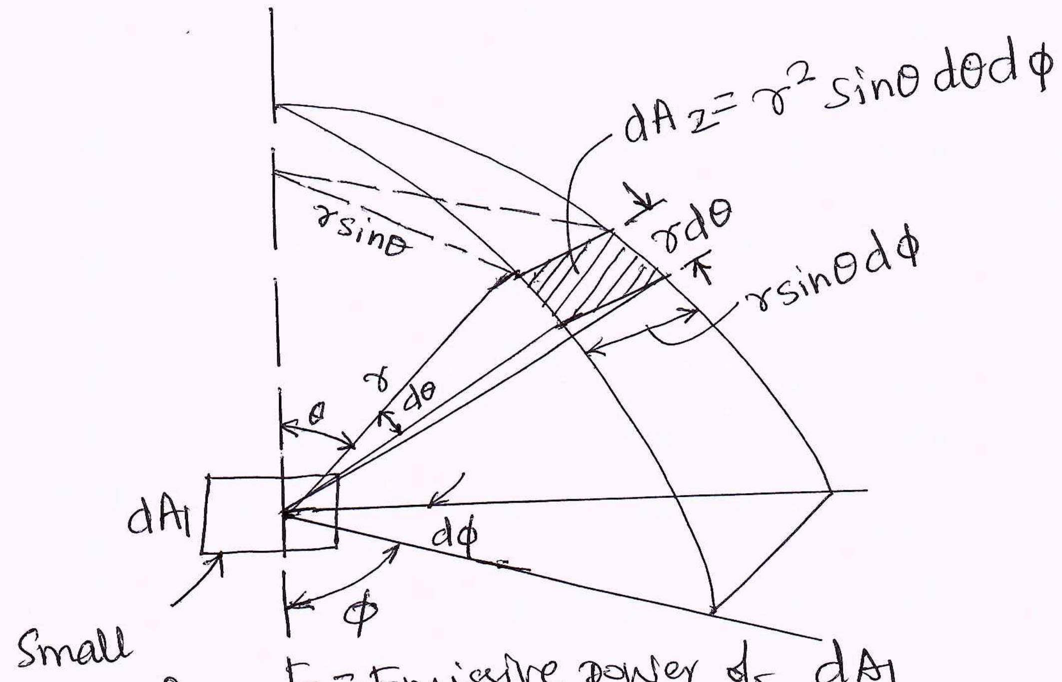
$$\left.\frac{\partial^2 T}{\partial x^2}\right|_{m,i} \simeq \frac{T^i_{(m-1)} + T^i_{(m+1)} - 2T^i_m}{\Delta x^2}$$

$$\left.\frac{\partial T}{\partial t}\right|_{m,i} = \frac{T_m^{i+1} - T_m^i}{\Delta t}$$

$$\frac{T_m^{i+1} - T_m^i}{\Delta t} = \alpha\,\frac{T^i_{m-1} + T^i - 2T^i_m}{\Delta x^2}$$

$$T_m^{i+1} = r\,(T^i_{m-1} + T^i_{m+1}) + (1-2r)T^i_m$$

5(b) I = Intensity of Radiation of area dA_1.



E = Emissive power of dA_1

Consider the radiation emitted by small black surface of area dA_1 reaches the area dA_2 at a distance 'r' from the area dA_1.

The projected area of dA_1 on line joining dA_1 and dA_2 on plane perpendicular to 'r' $= dA_1 \cos\theta$

Solid angle subtended by dA_2 at dA_1

$$d\omega = \frac{dA_2}{r^2} = \frac{r^2 \sin\theta \, d\theta \, d\phi}{r^2}$$

$dQ_{1\to2}$ = Rate of radiation heat transfer from dA_1 to dA_2

$$dQ_{1\to2} = I \, (dA_1 \cos\theta) \sin\theta \, \cancel{\cos\theta} \, d\theta \, d\phi$$

$$dQ_{1-2} = I \, dA_1 \sin\theta \cos\theta \, d\theta \, d\phi$$

Total radiation intercepted by the hemisphere is

$$Q = I \, dA_1 \int_{\theta=0}^{\theta=\pi/2} \int_{\phi=0}^{\phi=2\pi} \sin\theta \cos\theta \, d\theta \, d\phi$$

$$Q = 2\pi I \, dA_1 \int_{\theta=0}^{\theta=\pi/2} \sin\theta \cos\theta \, d\theta$$

$$Q = \pi I \, dA_1 \int_0^{\pi/2} \sin 2\theta \, d\theta = \pi I \, dA_1$$

$$Q = E \, \cancel{dA_1} = \pi I \, \cancel{dA_1} \quad \therefore \boxed{E = \pi I}$$

6(a) (i) Stefan Boltzman law:

It states that the radiant energy emitted by a black surface is directly proportional to the fourth power of its absolute temperature.

$$Q \propto T^4 \qquad Q = \text{Heat flux } (W/m^2)$$

$$Q = \sigma T^4$$

where σ = Stefan Boltzman constant
$= 5.67 \times 10^{-8}\ W/m^2K^4$.

(iii) Planck's distribution law: It gives the relation between monochromatic emissive power of black body and corresponding wavelength and temperature. It is given by

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

where C_1 & C_2 are constants.

(iv) Weins Displacement law: It states that the product of the value of the wavelength at which the emissive power is maximum and its corresponding temperature remains constant, It is given by

$$\lambda_{max} T = 2898\ \mu mK.$$

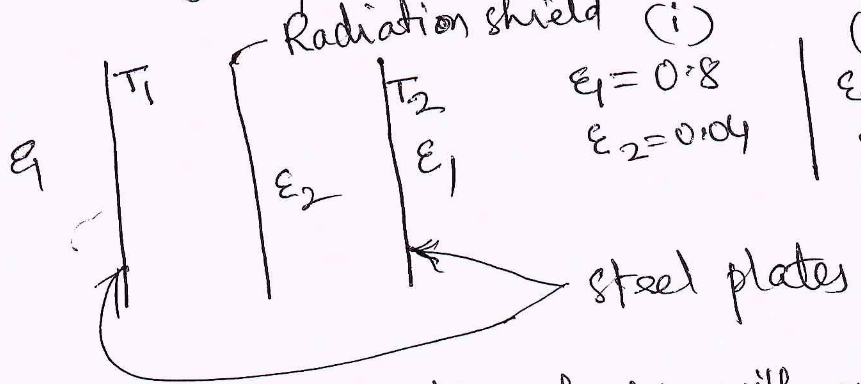
(ii) Kirchoff's law: It states that the emissivity of the body is equal to its absorbtivity when it is in thermal equillibrium with the surroundings.

$$\varepsilon = \alpha$$

(vi) Black Body: It is defined as the body which absorbs all the radiation falling on it and also emits maximum radiation.

The emissivity of a black surface/body is always equal to one.

6(b)



(i) $\varepsilon_1 = 0.8$, $\varepsilon_2 = 0.04$ | (ii) $\varepsilon_1 = 0.8$, $\varepsilon_2 = 0.6$

(i) when a radiation shield with emissivity 0.04 is inserted

$$\frac{Q_{12}}{A} = \frac{\sigma(T_1^4 - T_2^4)}{\left(\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1\right)+\left(\frac{1}{\varepsilon_2}+\frac{1}{\varepsilon_1}-1\right)}$$

$$\frac{Q_{12}}{A} = \frac{\sigma(T_1^4 - T_2^4)}{\left(\frac{1}{0.8}+\frac{1}{0.04}-1\right)+\left(\frac{1}{0.04}+\frac{1}{0.8}-1\right)}$$

$$\frac{Q_{12}}{A} = 0.0198\,\sigma(T_1^4 - T_2^4)$$

Heat transfer without radiation shield

$$\frac{Q_{12}}{A} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_1}-1} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{0.8}+\frac{1}{0.8}-1}$$

$$\frac{Q_{12}}{A} = 0.6666\,\sigma(T_1^4 - T_2^4)$$

% Reduction in heat transfer

$$= \frac{0.6666 - 0.0198}{0.6666} \times 100 = 97\%$$

(ii) When Radiation shield with emissivity 0·6 is inserted.

$$\frac{Q_{12}}{A} = \frac{\sigma(T_1^4 - T_2^4)}{\left(\frac{1}{0.8} + \frac{1}{0.6} - 1\right) + \left(\frac{1}{0.6} + \frac{1}{0.8} - 1\right)}$$

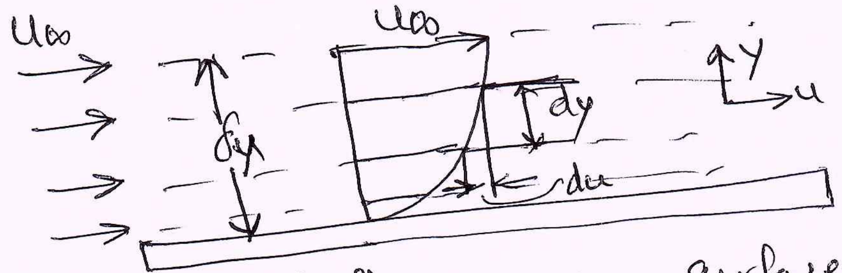
$$\frac{Q_{12}}{A} = 0.2608\sigma(T_1^4 - T_2^4)$$

% Reduction in heat transfer is

$$= \frac{0.6666 - 0.2608}{0.6666} \times 100 = 60.8\%.$$

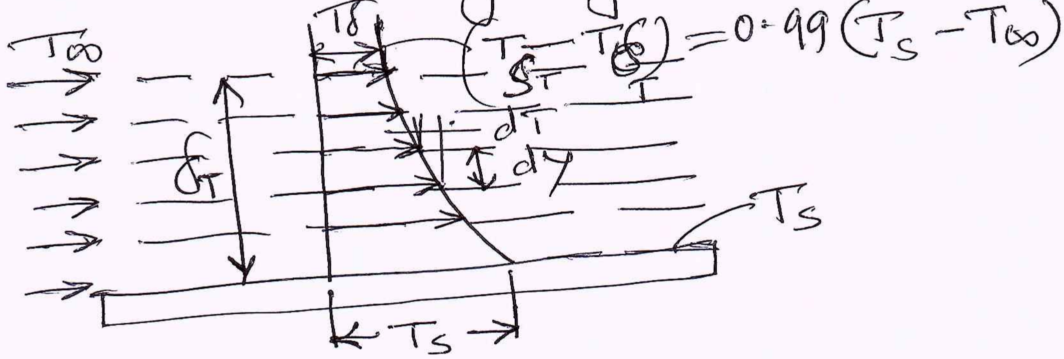
% Reduction in loss of heat transfer due to oxidised shield is $= 97 - 60.8 = 36.2\%$

7(a) Velocity boundary layer.



When fluid flows over a surface there is a velocity gradient $\left(\frac{du}{dy}\right)$ due to viscosity and frictional resistance offered by the surface. The velocity of the fluid is zero at the surface and increases parabolically in Y-direction reaching maximum value at the free surface. The region in fluid flow where the velocity gradient is observed is called as velocity boundary layer.

Thermal boundary layer



δ_T is boundary layer thickness (thermal) at which $\left(T_s - T_{\delta_T}\right) = 0.99(T_s - T_\infty)$

The region of flow in which temperature gradient $\left(\frac{dT}{dy}\right)$ is present is called as thermal boundary layer. The temperature of fluid varies parabolically in y-direction as shown in the above figure.

7(b) $T_a = 0°c$, $u = 20\ m/s$, $L = 1.5m$, $T_s = 50°C$

$\bar{h}$ for laminar flow = ?

$\bar{h}$ & Q = ? for entire plate

Mean film Temp, $T_f = \frac{T_a + T_s}{2} = 25°C$

From HMT handbook, properties of air at 25°C

$\rho = 1.85\ kg/m^3$, $\mu = 18.30 \times 10^{-6}\ Ns/m^2$, $Pr = 0.704$.

$K = 0.02580\ W/mK$.

For laminar flow $Re = 5\times10^5$

Laminar flow length of plate (L_x)

$$\frac{\rho u L_x}{\mu} = 5\times10^5$$

$$\frac{1.85 \times 20 \times L_x}{18.3\times10^{-6}} = 5\times10^5, \quad L_x = 0.3875m$$

$$Nu = \frac{\bar{h}_x L_x}{K} = 0.332\, Re^{0.5} Pr^{0.333} \text{ (From Data Book)}$$

$$Nu = 0.332 (5\times10^5)^{0.5} (0.704)^{0.333} = 417.33$$

$$\frac{\bar{h}_x \times 0.3875}{0.02580} = 417.33$$

$$\bar{h}_x = 28 \text{ W/m}^2\text{K}.$$

$$Q = \bar{h}_x L_x (T_s - T_a) = 28\times 0.3875 (50-0)$$

$$\underline{Q = 543 \text{ W/m}}$$

For entire plate

$$Re = \frac{\rho U L}{\mu} = \frac{1.85\times 20\times 1.5}{18.3\times10^{-6}} = 19.35\times10^5$$

$$Nu = 0.332 (19.35\times10^5)^{0.5} (0.704)^{0.333} = 2745$$

$$\frac{\bar{h}_L L}{K} = 2745$$

$$\bar{h}_L = \frac{2745\times 0.02580}{1.5} = 38 \text{ W/m}^2\text{K}$$

$$Q = \bar{h}_L L (T_s - T_a)$$

$$\underline{Q = 38\times 1.5 (50-0) = 2835 \text{ W/m}}$$

8(a) (i) Grashoff Number:

$$Gr = \frac{g\beta \Delta T L^3}{\nu^2} = \left(\frac{\text{Buoyant Force}}{\text{Viscous Force}}\right)\times\left(\frac{\text{Inertia force}}{\text{viscous force}}\right)$$

It indicates strength of free convection. Higher the value of 'Gr' indicates stronger natural convection currents.

(ii) Nusselt Number,

$$Nu = \frac{hL}{K} = \frac{hA\Delta T}{KA\Delta T/L} = \frac{\text{Convection HT}}{\text{Conduction HT}}$$

Higher the value of 'Nu' indicates better heat transfe by convection. It is used to calculate heat transfer coefficient.

(iii) Stanton Number:

$$St = \frac{Nu}{Re\,Pr} = \frac{\text{Wall heat transfer rate}}{\text{Heat transfer by convection}}$$

It represents heat transfer performance in flowing fluids.

(iv) Prandtl Number:

$$Pr = \frac{\mu C_p}{K} = \frac{\text{Momentum diffusivity}}{\text{Thermal diffusivity}}$$

It indicates relative thickness of velocity boundary layer and thermal boundary layer.

For $Pr < 1$, $\delta_T > \delta_u$

$Pr > 1$, $\delta_u > \delta_T$

(v) Reynolds Number:

$$Re = \frac{\rho u L}{\mu} \text{ or } \frac{\rho u D}{\mu} = \frac{\text{Inertia force}}{\text{Viscous force}}$$

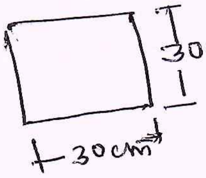
It indicates the nature of the flow, whether Laminar or turbulent.

Low 'Re' indicates Laminar flow.

High 'Re' indicates turbulent.

8(b) $A = 30\,cm \times 30\,cm = 900\,cm^2 =$

$T_s = 140°C, \quad T_w = 20°C$



$$T_f = \frac{T_s + T_w}{2} = \frac{140 + 20}{2} = 80°C$$

Thermophysical properties of water at T_f! from HMT data book

$\rho = 971.8\,kg/m^3$, $C = 4197\,J/kg.K$, $\mu = 0.355 \times 10^{-3}\,Ns/m^2$

$K = 0.668\,W/mK$.

$$Gr = \frac{g \beta \Delta T L_c^3 \rho^2}{\mu^2}$$

$$= \frac{9.81 \times \left(\frac{1}{80+273}\right) \times (140-20) \times 0.3^3 \times 971.8^2}{(0.355 \times 10^{-3})^2}$$

$$= 1.5353 \times 10^{11}$$

$$Pr = \frac{\mu C_p}{K} = \frac{0.355 \times 10^{-3} \times 4197}{0.668} = 2.23$$

$(Gr \cdot Pr) > 10^9$, Hence flow is turbulent flow.

$$Nu = 0.10\,(Gr \cdot Pr)^{0.333} = \frac{h\,(0.3)}{0.668}$$

$$h = 154\,W/m^2K$$

Heat lost from the plate

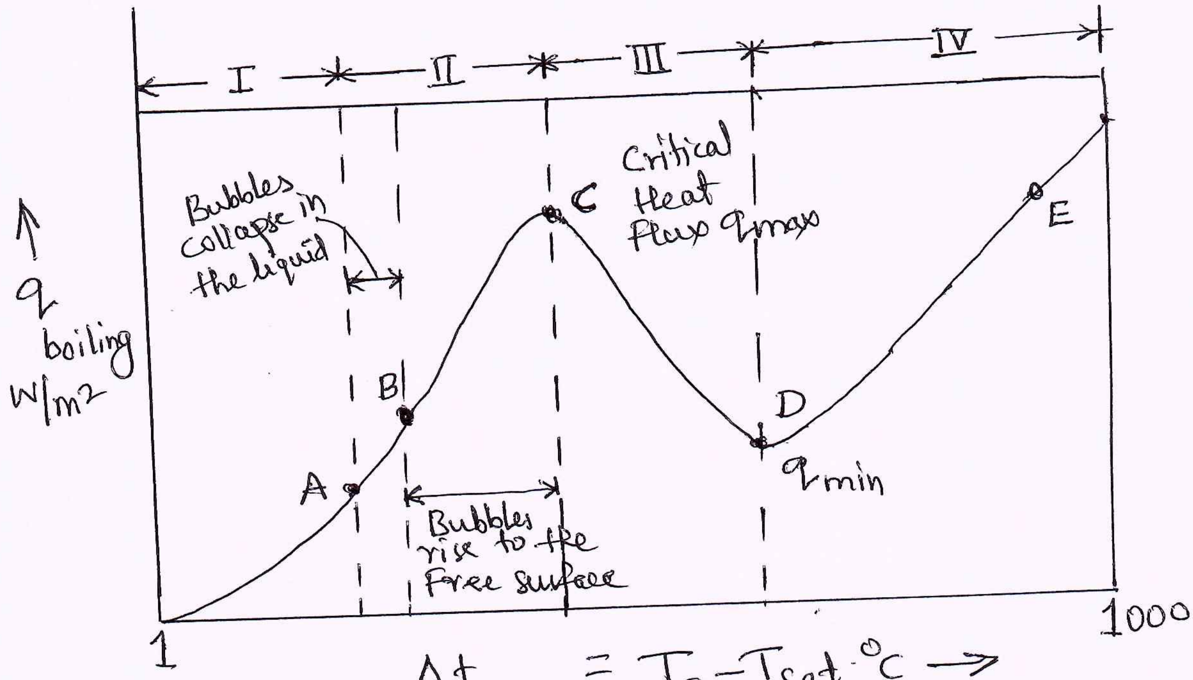
$Q = 2Ah(T_s - T_w)$

$= 2 \times 0.3 \times 0.3 \times 154(140 - 20)$

$= 33335.28\,J/s$

$\underline{Q = 120006.7\,KJ/hr.}$

9 (a)



Four different boiling regimes as shown in boiling curve in above fig. are:

I. Natural convection boiling: Boiling starts as soon as the saturation Temperature (T_{sat}) is reached, but bubbles are not formed until the liquid is heated few degrees above Tsat. So the bubbles are evaporated as it rised to the free surface, the fluid motion and the heat transfer is due to only natural convection currents.

II. Nucleate boiling: In this, bubbles starts forming at increased rate. This regime can be divided into two, between A–B isolated bubbles are formed and dissipated into the liquid after they seperate from the surface. As the heating is further increased, in B-C, bubbles forms at a greater rate such that it forms a continuous colums of vapour in the liquid. It continues till the critical heat flux 'C' is reached.

III. Transition Boiling: Once the temperature is increased past the point 'C', the heat flux decreases because large portion of the surface is convered by the vapour film, which acts as an insulation due to the low thermal conductivity of water vapour relative to the water.

iv. Film boiling: In this region the heater surface is completely covered by the continuous stable vapour film, point 'D' where the heat flux reaches a minimum. The heat transfer Increases with increasing temperature due to radiation heat transfer between the vapour film and the liquid.

9(b) $D = 0.012\,m$, No. of horizontal tubes in vertical colum $N = \sqrt{100} = 10$

At Patm, $T_{sat} = 100°C$

$T_W = 98°C$, $\Delta T = 100 - 98 = 2K$

Fluid properties: $\rho = 960\,kg/m^3$,

$\mu = 282 \times 10^{-6}\,kg/m\text{-}s$, $K = 0.61\,W/mK$.

$h_{fg} = 2255 \times 10^3\,J/kg$

$$h_{single} = 0.725\left[\frac{\rho^2 g h_{fg} K^3}{\mu D \Delta T}\right]$$

$$= 0.725\left[\frac{960^2 \times 9.81 \times 2255 \times 10^3 \times 0.61^3}{282 \times 10^{-6} \times 0.012 \times 2}\right]$$

$\therefore h_{single} = 20848\,W/m^2K$.

For a bank of N_r tubes in a vertical column,

$h_{avg} = h_{single} \times N_r^{-1/4} = 20848 \times 10^{-1/4} = 11724\,W/m^2K$

Total heat transfer rate per unit length

$$\frac{Q}{L} = h_{avg} \times (N\pi D) \times \Delta T$$

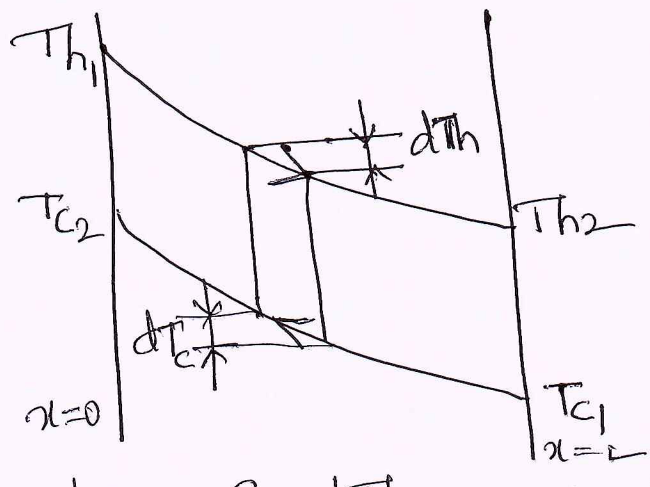
$$\frac{Q}{L} = 11724 \times (100 \times \pi \times 0.012) \times 2 = 88394 \text{ W/m}$$

Mass of steam condensed per unit length ($\dot{m}$)

$$\frac{\dot{m}}{L} = \frac{Q/L}{h_{fg}} = \frac{88394}{2255000} = 0.0392 \text{ kg/s·m}$$

$$\frac{\dot{m}}{L} = 0.392 \text{ kg/s·m or } 141.12 \text{ kg/hr·m}$$

10(a) LMTD - Counter flow heat exchanger



$C_h = m_h C_{ph}$

$C_c = m_c C_{pc}$

$$dQ = -C_h\, dT_h = -C_c\, dT_c$$

$$dQ = U\,dA\,(T_h - T_c)$$

$$Q = C_h(T_{h_1} - T_{h_2}) = C_c(T_{c_2} - T_{c_1})$$

$$dT_h - dT_c = -\frac{dQ}{C_h} + \frac{dQ}{C_c}$$

$$d(T_h - T_c) = \frac{U\,dA\,(T_h - T_c)}{Q}\left[-(T_{h_1} - T_{h_2}) + (T_{c_2} - T_{c_1})\right]$$

$$\int_{x=0}^{x=L} \frac{d(T_h - T_c)}{T_h - T_c} = \int_{0}^{A} \frac{U\,dA}{Q}\left[(T_{h_2} - T_{c_1}) - (T_{h_1} - T_{c_2})\right]$$

$$\ln\left[\frac{T_{h2}-T_{c1}}{T_{h1}-T_{c2}}\right] = \frac{UA}{Q}\left[(T_{h2}-T_{c1})-(T_{h1}-T_{c2})\right]$$

$$Q = UA\,\frac{(T_{h2}-T_{c1})-(T_{h1}-T_{c2})}{\ln\left[\frac{(T_{h2}-T_{c1})}{T_{h1}-T_{c2}}\right]}$$

$$Q = UA\ LMTD$$

$$LMTD = \frac{(T_{h2}-T_{c1})-(T_{h1}-T_{c2})}{\ln\left[\frac{T_{h2}-T_{c1}}{T_{h1}-T_{c2}}\right]}$$

(Dr. S.V. Channapattana)

10 (b) $C_c = 0.076 \times 4200 = 319.2\ W/°C$

$C_h = 0.152 \times 1880 = 285.7\ W/°C$

$\therefore C_{min} = C_h = 285.7$

$Q_{max} = C_{min}(T_{h1}-T_{c1})$

$= 285.7(116-38)$

$= 223\ W$

$C = \frac{C_{min}}{C_{max}} = 0.895$

$NTU = \frac{UA}{C_{min}} = \frac{340 \times 1}{285.76} = 1.19$

$$\varepsilon = \frac{1-\exp[-NTU(1-C)]}{1-C\exp[-NTU(1-C)]}$$

$$\varepsilon = \frac{1-e^{-1.19(1-0.895)}}{1-0.895\,e^{-1.19(1-0.895)}} = 0.54$$

$Q_{actual} = \varepsilon \cdot Q_{max} = 0.54 \times 22300 = \underline{12042\ W}$

$T_{h2} = 75°C,\ T_{c2} = 75°C,\ LMTD = 39°C$

$Q_{actual} = UA\,LMTD = \underline{13.26\ kW}$