USN											CMRIT

Internal Assessment Test III – May 2019

Sub:	Heat Transfer	Sub Code:	15ME63	Branch:	ME
Date:	14/05/19	Duration: 90 min	Max Marks: 50	Sem/Sec:	6^{th}/A & B

- **Attempt any 5 questions**
- Use of Heat Transfer Data Hand Book is permitted

		MARKS	CO	RBT
1	Define: (i)Total emissive power (ii)Spectral emissive power (iii)Black Body (iv)White Body(v)Transparent Body (vi)Emissivity (vii)Stefan Boltzman's Law (viii)Wien's Law (ix)Lambert's Law (x)View Factor	[10]	CO3	L1
2	Derive an expression for rate of heat transfer between two infinite gray plates at temperatures T1 & T2 and emissivities ϵ1 & ϵ2 respectively..	[10]	CO3	L3
3 a	Derive a relation between emissive power and normal intensity of radiation for a black body in hemispherical enclosure.	[06]	CO3	L3
b	The temperature of black surface of $0.2 m^2$ area is 540^oC. Calculate (i) the total rate of energy emission (ii) The intensity of normal radiation (iii) the wavelength of maximum monochromatic emissive power.	[04]	CO3	L3
4	Calculate the net radiant heat exchange per m^2 area for two large parallel plates at temperatures of 427°C and 27°C respectively. Take emissivity of the hot plate and cold plates are 0.9 and 0.16 respectively. If a polished aluminium shield is placed between them, find the percentage reduction in the heat transfer. Take emissivity of shield as 0.4.	[10]	CO3	L3
5	Two circular disks of 1 m diameter are placed coaxially, parallel and symmetrically at a distance of 1 m. The disks have an emissivity of 0.6 and are at 1000 K and 500 K. Determine the reduction in radiant heat flow due to the introduction of a shield of equal diameter midway between the two. The shield has an emissivity of 0.1 on both sides. (neglect interactions to the outside space).	[10]	CO3	L3
6	A long cylindrical bar (k=17.4 W/mK, α=0.019 m^2/h) of radius 80 mm comes out of oven at 830^oC throughout and is cooled by quenching it in a large bath of 40^oC coolant with h=180 W/m^2K. Determine: i. The time taken by centre of the shaft to reach 120oC. ii. The surface temperature of the shaft when its centre temperature is 120oC. iii. Temperature gradient at outside surface at the same time.	[10]	CO2	L3
7	A thick concrete wall fairly large in size initially at 30°C suddenly has its surface temperature increased to 600°C by an intense fire which lasted for 25 minutes. The material will disintegrate up to a depth where the temperature reaches 400°C. Determine the thickness which may disintegrate. The thermal diffusivity is $4.92 \times 10^{-7} m^2/s$; k = 1.28 W/mK. Also determine the total heat flow/m^2 during the time	[10]	CO2	L3

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Internal Assessment TEST - III

Solutions.

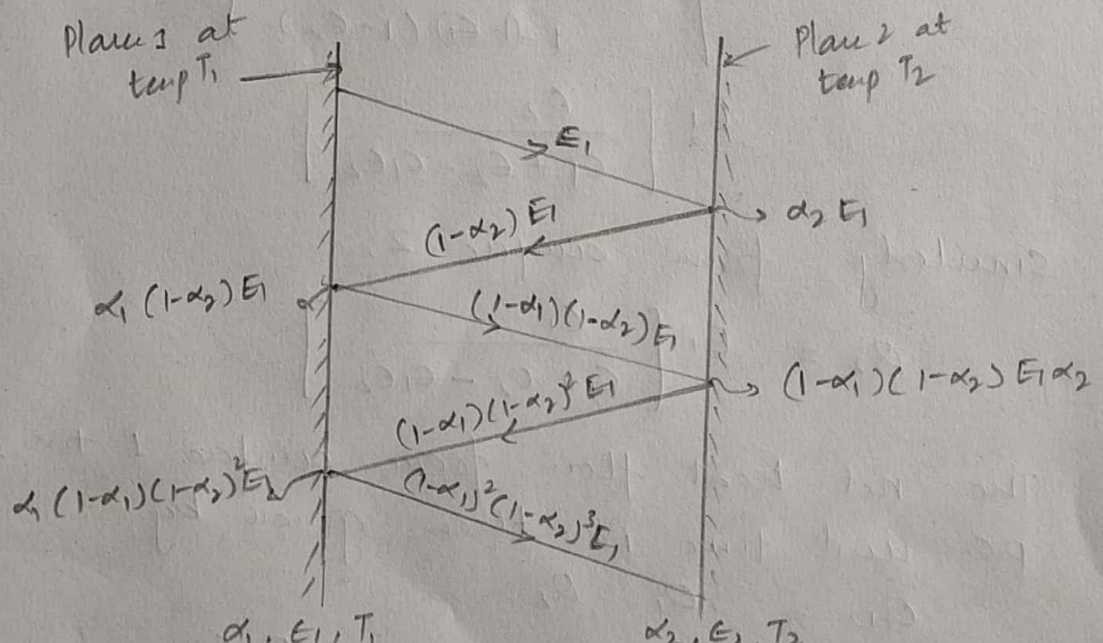
Q2) Derive an expression for rate of heat transfer between two infinite gray plates at temp. T_1 & T_2 and emissivities ϵ_1 & ϵ_2 resp.

Ans Assumptions :-

(i) The surfaces are arranged at small distance from each other and are of equal area.

(ii) The surfaces are diffuse and uniform in temp., and that reflective and emissive properties are constant over all the surfaces

(iii) The surface are separated by a non-absorbing medium such as air.



The surface 1 emits radiant energy E_1 which strikes the surface 2. From it a part $\alpha_2 E_1$ is absorbed by the surface 2 and the remainder $(1-\alpha_2) E_1$ is reflected back to surface 1. On reaching surface 1, a part $\alpha_1 (1-\alpha_2) E_1$ is absorbed and remainder

$(1-\alpha_1)(1-\alpha_2)E_1$ is reflected and so on.

$\therefore$ The amount of radiant energy which left surface 1 per unit time is :

$$Q_1 = E_1 - \left[\alpha_1(1-\alpha_2)E_1 + \alpha_1(1-\alpha_1)(1-\alpha_2)^2 E_1 + \cdots \right]$$

$$= E_1 - \alpha_1(1-\alpha_2)E_1 \left[1 + (1-\alpha_1)(1-\alpha_2) + (1-\alpha_1)^2(1-\alpha_2)^2 + \cdots \right]$$

$$= E_1 - \alpha_1(1-\alpha_2)E_1 \left[1 + P + P^2 + \cdots \right].$$

where $P = (1-\alpha_1)(1-\alpha_2)$

Since P is less than unity, the series $1 + P + P^2 \cdots$, when extended to infinity gives $\frac{1}{(1-P)}$

$$\therefore \quad Q_1 = E_1 - \frac{\alpha_1(1-\alpha_2)E_1}{(1-P)} = E_1 \left[1 - \frac{\alpha_1(1-\alpha_2)}{1-(1-\alpha_1)(1-\alpha_2)} \right]$$

from Kirchoff's law, $\alpha_1 = \epsilon_1$

$$\therefore \quad Q_1 = E_1 \left[1 - \frac{\epsilon_1(1-\epsilon_2)}{1-(1-\epsilon_1)(1-\epsilon_2)} \right]$$

$$= E_1 \left[\frac{\epsilon_2}{\epsilon_1 + \epsilon_2 - \epsilon_1\epsilon_2} \right]$$

Similarly from surface 2,

$$Q_2 = E_2 \left[\frac{\epsilon_1}{\epsilon_1 + \epsilon_2 - \epsilon_1\epsilon_2} \right]$$

$\therefore$ The net heat flow from surface 1 to 2 per unit time is then given by.

$$Q_{12} = Q_1 - Q_2$$

$$= \frac{E_1\epsilon_2}{\epsilon_1 + \epsilon_2 - \epsilon_1\epsilon_2} - \frac{E_2\epsilon_1}{\epsilon_1 + \epsilon_2 - \epsilon_1\epsilon_2}$$

$$= \frac{E_1\epsilon_2 - E_2\epsilon_1}{\epsilon_1 + \epsilon_2 - \epsilon_1\epsilon_2}$$

from Stefan - Blotzman law for non-black surface.

$$E_1 = \epsilon_1 \sigma_b T^4 \quad + \quad E_2 = \epsilon_2 \sigma_b T_2^4$$

$$\therefore \quad Q_{12} = \frac{\epsilon_1 \sigma_b T_1^4 \epsilon_2 - \epsilon_2 \sigma_b T^4 \epsilon_1}{\epsilon_1 + \epsilon_2 - \epsilon_1 \epsilon_2}$$

$$= \frac{\epsilon_1 \epsilon_2}{\epsilon_1 + \epsilon_2 - \epsilon_1 \epsilon_2} \sigma_b (T_1^4 - T_2^4)$$

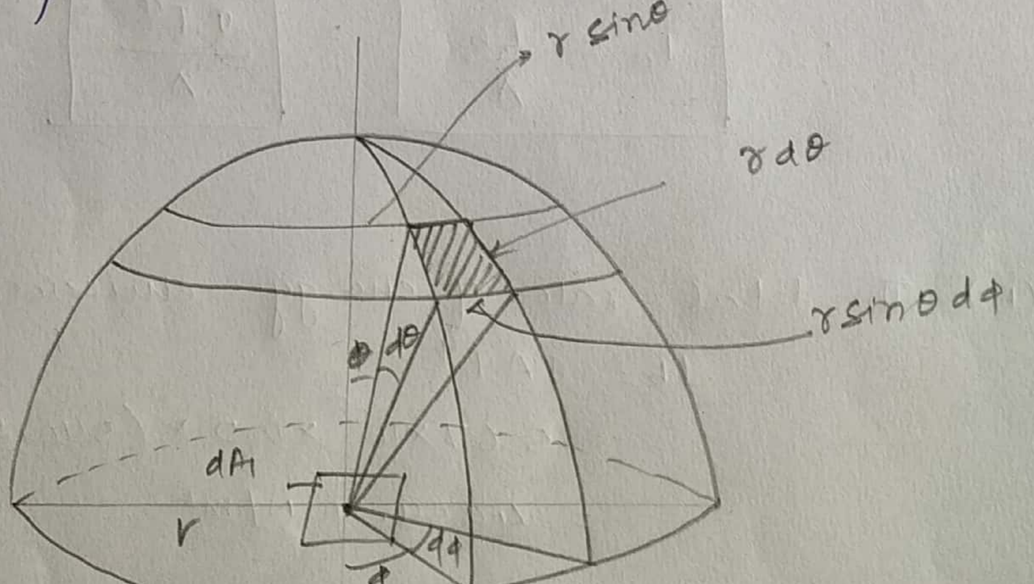
$$= f_{12} \sigma_b (T_1^4 - T_2^4)$$

where,

$$f_{12} = \frac{\epsilon_1 \epsilon_2}{\epsilon_1 + \epsilon_2 - \epsilon_1 \epsilon_2} = \frac{1}{1/\epsilon_1 + 1/\epsilon_2 - 1} \quad //$$

Q3» a)» Derive a relation between emissive power and normal intensity of radiation for a black body in hemispherical enclosure.

Ans



consider radiation emitted from an elemental black surface from area 'dA_1' & temp 'T_1'. Energy will emitted in all the directions in the entire hemisphere.

$$\text{solid angle}, \quad d\omega = \frac{dA}{r^2} = \frac{r^2 \sin\theta\, d\phi\, d\theta}{r^2} = \sin\theta\, d\theta\, d\phi$$

$$dA = r^2 \sin\theta\, d\theta\, d\phi$$

$r^2 d\omega = dA$.

$E_b = I\, d\omega \qquad \because I = I_0 \cos\theta$

putting the value of $d\omega$ & I for E_b equation.

$dE_b = I_0 \cos\theta \cdot \sin\theta\, d\theta\, d\phi$

Integrating $\theta = 0$ to $\theta = \pi/2$
$\phi = 0$ to $\phi = 2\pi$ for above equation

$$E_b = I_0 \int_0^{\pi/2} \sin\theta \cdot \cos\theta\, d\theta \int_0^{2\pi} d\phi$$

$$= I_0 \times \frac{1}{2} \times 2\pi$$

$$E_b = I_0 \pi$$

$$\therefore \boxed{I_0 = \frac{E_b}{\pi}} = \boxed{\frac{\sigma T^4}{\pi}}$$

Q 3)
b)) (i) The total rate of energy emission

$\therefore I_b = \sigma A T^4$

$= 5.67 \times 10^{-8} \times 0.2 \times (540+273)^4$

$= 4954.21\ N/m^2$

(ii) $\lambda_{max} T = 2898 \times 10^{-6}$

$\therefore \lambda_{max} = \frac{2898 \times 10^{-6}}{813} = 3.564 \times 10^{-6}\ m$,

(iii) $I_n = \frac{E_b}{\pi} = \frac{\sigma T^4}{\pi} = \frac{5.67 \times 10^{-8} \times (813)^4}{\pi}$

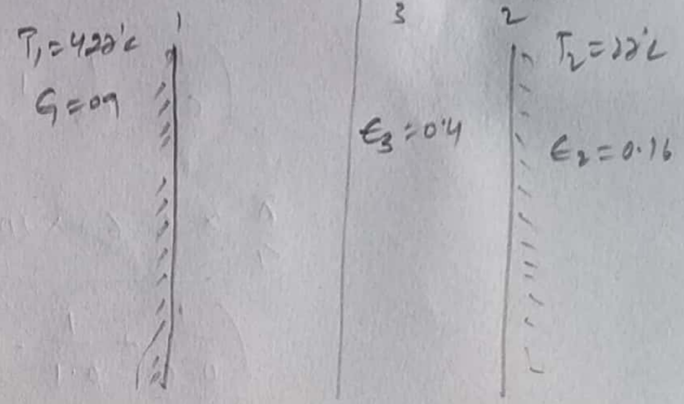
$= 7884.88$.

Q4))

As

$T_1 = 427 + 273 = 700\ k$

$T_2 = 27 + 273 = 300\ K$



From the figure

$$Q_{without\ shield} = \frac{A\sigma_b (T_1^4 - T_2^4)}{1/\epsilon_1 + 1/\epsilon_2 - 1}$$

$$= \frac{5.67\times10^{-8}(700^4 - 300^4)}{1/0.9 + 1/0.16 - 1}$$

$$= 2067.94\ \text{Watt}/m^2$$

$$Q_{with\ shield} = \frac{A\sigma_b (T_1^4 - T_2^4)}{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_3} - 1\right) + \left(\frac{1}{\epsilon_3} + \frac{1}{\epsilon_2} - 1\right)}$$

$$= \frac{5.67\times10^{-8}(700^4 - 300^4)}{\left(\frac{1}{0.9} + \frac{1}{0.4} - 1\right) + \left(\frac{1}{0.4} + \frac{1}{0.16} - 1\right)}$$

$$= 1269.59\ \text{watt}/m^2$$

$\therefore$ % Reduction in heat trasfer $= \frac{Q_{without} - Q_{with}}{Q_{without}} \times 100$

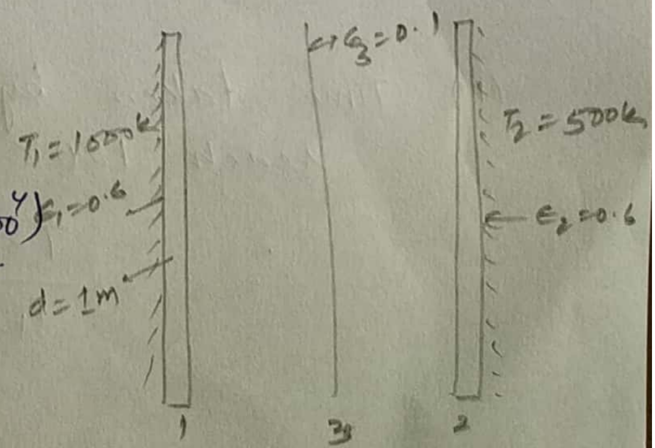
$= 38.6\ \%$

Q5))

$$Q_{without\ shield} = \frac{A\sigma_b (T_1^4 - T_2^4)}{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

$$= \frac{\frac{\pi}{4}\times1^2\times5.67\times10^{-8}(1000^4 - 500^4)}{\left(\frac{1}{0.6} + \frac{1}{0.6} - 1\right)}$$

$= 17892.35$ watts.



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Q with shield = $\dfrac{A\sigma_b(T_1^4 - T_2^4)}{\left(\frac{1}{\epsilon_1}+\frac{1}{\epsilon_3}-1\right)+\left(\frac{1}{\epsilon_3}+\frac{1}{\epsilon_2}-1\right)}$

$$= \frac{\frac{\pi}{4}\times 5.67\times10^{-8}(1000^4 - 500^4)}{\left(\frac{1}{0.6}+\frac{1}{0.1}-1\right)+\left(\frac{1}{0.6}+\frac{1}{0.1}-1\right)}$$

$= 1956.97$ watts.

$\therefore$ Reduction in radiant heat flow $= \dfrac{17892.35 - 1956.97}{17892.35}\times100$

$= 89.06\,\%$

Q6» Given :- Long cylinder

$k = 17.4$ W/mK

$\alpha = 0.019\ m^2/h = 5.27\times10^{-6}\ m^2/sec$

$r = 80$ mm

$T_i = 830^\circ C$

$T_\infty = 40^\circ C$

$h = 180\ W/m^2K$

$$Bi = \frac{hR}{k} = \frac{180\times0.08}{17.4} = 0.82$$

(i) Time taken by center of the shaft to reach $120^\circ C = T$

$$\therefore \frac{T - T_\infty}{T_i - T_\infty} = \frac{120-40}{830-40} = 0.101$$

$Bi = 0.82 \quad , \quad \frac{T - T_\infty}{T_i - T_\infty} = 0.101$

$\therefore \quad Fo = 1.9$

$\therefore \quad Fo = \frac{\alpha t}{R^2} \Rightarrow \frac{5.27 \times 10^{-6} \times t}{(0.08)^2} = 1.9$

$$\boxed{t = 2307.40 \text{ sec}}$$

(ii) The surface temp. at the shaft when its center temp. is 120°C.

$\frac{r}{R} = \frac{R}{R} = 1 \quad , \quad Bi = 0.82$

$\frac{T_{r/R} - T_\infty}{T_i - T_\infty} = 0.41$

$\therefore \quad \frac{T_{r/R} - 40}{120 - 40} = 0.41$

$$\boxed{T_{r/R} = 72.8\,°C}$$

(iii) Temperature gradient at outside surface at the same time.

$\Rightarrow \quad k\,(2\pi RL)\frac{dT}{dr} = h\,(2\pi RL)(T_{r/R} - T_\infty)$

$\frac{dT}{dr} = \frac{h}{k}(T_{r/R} - T_\infty)$

$\Rightarrow \quad \frac{dT}{dr} = \frac{180}{17.4}(72.8 - 40)$

$$\boxed{\frac{dT}{dr} = 339.31\ °C/m}$$

Q7) Given:-

$T_i = 30°C$

$T_\infty = 600°C$

$t = 25 \text{ min} = 1500 \text{ sec}$

$T_o = 400°C$

$\alpha = 4.92 \times 10^{-7} \, m^2/s$

$k = 1.28 \, W/mK$.

$\therefore$ from the Data hand book.

$$\frac{T_o - T_\infty}{T_i - T_\infty} = \text{erf}\left(\frac{x}{2\sqrt{\alpha t}}\right)$$

$$\Rightarrow \frac{400-600}{30-600} = 0.3508$$

z	erf(z)
0.32	0.34913
?	0.3508
0.33	0.35928

$z = 0.321$

$$\therefore \quad 0.321 = \frac{x}{2 \times \sqrt{4.92 \times 10^{-7} \times 1500}}$$

$$\boxed{x = 0.0174 \, m}$$

$\therefore$ Total heat flow/m^2 during the time.

$$q_x = \frac{k(T_o - T_i)}{\sqrt{\pi \alpha t}} \exp\left(-\frac{x^2}{4\alpha t}\right)$$

$$q_x = \frac{1.28(400-30)}{\sqrt{\pi \times 4.92 \times 10^{-7} \times 1500}} \exp\left(-\frac{0.0174^2}{4 \times 4.92 \times 10^{-7} \times 1500}\right)$$

$$\boxed{q_x = 8877.01 \text{ watt}/m^2}$$