UNIT: IV RADIATION

1. State Planck's distribution law. (Nov/Dec 2013)

The relationship between the monochromatic emissive power of a black body and wave length of a radiation at a particular temperature is given by the following expression, by Planck.

$$E_{b\lambda} = \frac{C_1 \lambda^{-5}}{e^{\left(\frac{C_2}{\lambda T}\right)} - 1}$$

Where

$c_1 = 0.374 \times 10^{-15}$ W m^2

$c_2 = 14.4 \times 10^{-3}$ mK

2. State Wien's displacement law & Stefan – Boltzmann law. (Nov/Dec 2010)

The Wien's law gives the relationship between temperature and wave length corresponding to the maximum spectral emissive power of the black body at that temperature.

$$\lambda_{max} T = 2.9 \times 10^{-3} mK$$

The emissive power of a black body is proportional to the fourth power of absolute temperature.

$E_b = \sigma T^4$

Where σ = Stefan – Boltzmann constant

$= 5.67 \times 10^{-8}$ W/m^{2}K^4

$\Rightarrow E_b = (5.67 \times 10^{-8}) (2773)^4$

$E_b = 3.35 \times 10^6$ W/m^2

3. State Kirchoff's law of radiation. (April/May 2015)

This law states that the ratio of total emissive power to the absorptivity is constant for all surfaces which are in thermal equilibrium with the surroundings. This can be written as

$$\frac{E_1}{\alpha_1} = \frac{E_2}{\alpha_2} = \frac{E_3}{\alpha_3} \text{ ....}$$

It also states that the emissivity of the body is always equal to its absorptivity when the body remains in thermal equilibrium with its surroundings.

$\alpha_1 = E_1$; $\alpha_2 = E_2$ and soon.

4. What is the purpose of radiation shield? (Nov/Dec 2014)

Radiation shields constructed from low emissivity (high reflective) materials. It is used to reduce the net radiation transfer between two surfaces.

5. Define irradiation (G) and radiosity (J) (Nov/Dec 2015)

It is defined as the total radiation incident upon a surface per unit time per unit area. It is expressed in W/m2.

It is used to indicate the total radiation leaving a surface per unit time per unit area. It is expressed in W/m2.

6. What are the factors involved in radiation by a body. (Nov /Dec 2014)

- Wave length or frequency of radiation
- The temperature of surface
- The nature of the surface

7. What is meant by shape factor?

The shape factor is defined as the fraction of the radiative energy that is diffused from on surface element and strikes the other surface directly with no intervening reflections. It is represented by Fig. Other names for radiation shape factor are view factor, angle factor and configuration factor.

8. How radiation from gases differs from solids? (Nov/Dec 2013)

A participating medium emits and absorbs radiation throughout its entire volume thus gaseous radiation is a volumetric phenomenon, solid radiation is a surface phenomena Gases emit and absorb radiation at a number of narrow wavelength bands. This is in contrast to solids, which emit and absorb radiation over the entire spectrum.

9. What is black body and gray body?

Black body is an ideal surface having the following properties. A black body absorbs all incident radiation, regardless of wave length and direction. For a prescribed temperature and wave length, no surface can emit more energy than black body. If a body absorbs a definite percentage of incident radiation irrespective of their wave length, the body is known as gray body. The emissive power of a gray body is always less than that of the black body.

10. Define emissive power [E] and monochromatic emissive power. [$E_{b\lambda}$]

The emissive power is defined as the total amount of radiation emitted by a body per unit time and unit area. It is expressed in W/m^2.

The energy emitted by the surface at a given length per unit time per unit area in all directions is known as monochromatic emissive power.

11. Two parallel radiating Planes 10 x 50 cm are separated by a distance Of 50 cm .what is the radiation shape factor between the planes?(May/June 2012)

L=100 cm B= 50 cm D= 50 cm [From HMT data book ,Page no.92]

X=L/D=100/50=2 Y=B/D = 50/50=1

From table,for X=2 and Y=1

$F_{12}=F_{21}=0.28588$

12. What does the view factor represent? When is the view factor from a surface to itself not zero?

The view factor F_{i-j} represents the fraction of the radiation leaving surface i that strikes surface j directly. The view factor from a surface to itself is non-zero for concave surfaces.

13. State Lambert's cosine law.

It states that the total emissive power E_b from a radiating plane surface in any direction proportional to the cosine of the angle of emission

$E_b \propto \cos\theta$

14. Find the temperature of the sun assuming as a Block Body, if the intensity of radiation is maximum at the wavelength of 0.5μ

According to Wien's displacement law:

$\lambda_{max} T = 2.9\times 10^{-3}$ mK

0.5×10^{-6} T = 2.9×10^{-3}

T= 5800 K

15. What is a radiation shield? Why is it used?

Radiation heat transfer between two surfaces can be reduced greatly by inserting a thin, high reflectivity (low emissivity) sheet of material between the two surfaces. Such highly reflective thin plates or shells are known as radiation shields. Multilayer radiation shields constructed of about 20 shields per cm. thickness separated by evacuated space are commonly used in cryogenic and space applications to minimize heat transfer. Radiation shields are also used in temperature measurements of fluids to reduce the error caused by the radiation effect.

16. State Lamberts cosine law for radiation (April/May 2017)

It states that the total emissive power E_b from a radiating plane surface in any direction proportional to the cosine of the angle of emission. $E_b \propto \cos \theta$

17. Define monochromatic emissive power (Nov/Dec 2016)

The monochromatic emissive power Eλ, is defined as the rate, per unit area, at which the surface emits thermal radiation at a particular wavelength λ. Thus the total and monochromatic hemispherical emissive power are related by

$$E = \int_0^{\infty} E_\lambda d\lambda$$

18. What is meant by infrared and ultra violet radiation (Nov/Dec 2016)

Infrared radiation, or simply infrared or IR, is electromagnetic radiation (EMR) with longer wavelengths than those of visible light, and is therefore invisible Ultraviolet (UV) radiation is a type of radiation that is produced by the sun and some artificial sources, such as solariums

1. Calculate the following for an industrial furnace in the form of a black body and emitting radiation at 2500^{0}C

Monochromatic emissive power at 1.2 μm wave length.

i) **Wave length at which emission is maximum.**
ii) **Maximum emissive power.**
iii) **Total emissive power,**
iv) **The total emissive of the furnace if it is assumed as a real surface having emissivity equal to 0.9. (Nov / Dec 2014) (Nov / Dec 2015)**

Given: Surface temperature T = 2500^{0}C=2773K

Monochromatic emissive power $\lambda = 1.2 \times 10^{-6}$ m

Emissivity = 0.9

Solution:

Step 1. Monochromatic Emissive Power:

From Planck's distribution law, we know

$$E_{b\lambda} = \frac{C_1 \lambda^{-5}}{e^{\left(\frac{C_2}{\lambda T}\right)} - 1}$$ [From HMT data book, Page No.82]

Where

$c_1 = 0.374 \times 10^{-15}$ W m^2

$c_2 = 14.4 \times 10^{-3}$ mK

$\lambda = 1.2 \times 10^{-6}$ m [Given]

$E_{b\lambda}$=5.39x10^{12}

Step 2. Maximum wave length (λ_{max})

From Wien's law, we know

$\lambda_{max} T = 2.9 \times 10^{-3}\, mK$

$\lambda_{max} \times 2773 = 2.9 \times 10^{-3}\, mK$

λ_{max}=5.37× 10^{-16}

Step 3. Maximum emissive power ($E_{b\lambda}$) max:

Maximum emissive power

$(E_{b\lambda})_{max} = 1.307 \times 10^{-5} T^5$

$= 1.307 \times 10^{-5} \times (2773)^5$

$(E_{b\lambda})_{max} = 2.14 \times 10^{12}\ W/m^2$

Step 4. Total emissive power (E_b):

From Stefan – Boltzmann law, we know that

$E_b = \sigma T^4$ [From HMT data book Page No.72]

Where σ = Stefan – Boltzmann constant

$= 5.67 \times 10^{-8}\ W/m^2K^4$

$\Rightarrow E_b = (5.67 \times 10^{-8})\ (2773)^4$

$E_b = 3.35 \times 10^6\ W/m^2$

Step 5. Total emissive power of a real surface:

$(E_b)_{real} = \varepsilon\ \sigma\ T^4$

Where ε = Emissivity = 0.9

$(E_b)_{real} = 0.9x5.67x10^{-8}(2773)^4$

$(E_b)_{real} = 3.0110^6\ W/m^2$

2.Two parallel plates of size 1.0 m x 1.0 m spaced 0.5 m aprat are ;ocated in very large room , the walls are maintained at a temperature of 27⁰C .one plate is maintained at a temperature of 900⁰C and other at 400⁰C .their emissivities are 0.2 and 0.5 respectively .if the plate exchange heat themselves and surroundings , find the heat transfer to each plate and to them . consider only the plate surface facing each other.(May/June 2012&Nov/Dec 2014)

Given:

Size of the Plate = 1.0 m x 1.0 m

Distance between plates = 0.5 m

Room Temperature ,$T_3 = 27^0C + 273 = 300$ K

First plate temperature , $T_1 = 900^0C + 273 = 1173$ K

Second plate temperature , $T_2 = 400^0C + 273 = 673$ K

Emissivity of first plate, $\varepsilon_1 = 0.2$

Emissivity of second plate, $\varepsilon_2 = 0.5$

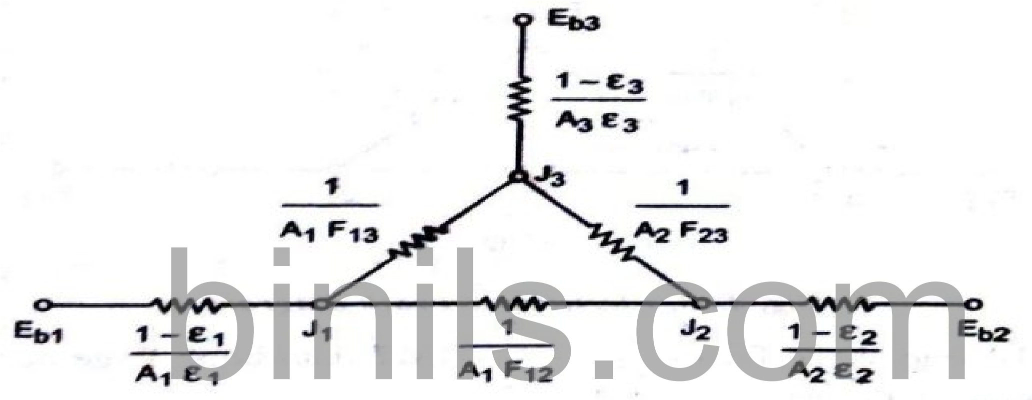
To Find:

1. **Net Heat Transfer to each**

2. **Net heat transfer to room**

Solution:

In this problem heat exchange take place between two plates and the room .so, this is three surface problem and the corresponding radiation network is given below.



Electrical network diagram

Area , $A_1 = 1 \times 1 = 1$ m^2

$A_1 = A_2 = 1$ m^2

Since the room is large , $A_3 = \infty$

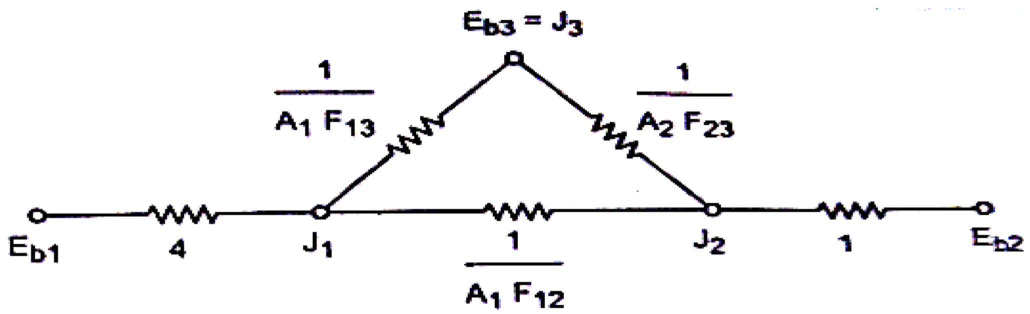
Step:1 From electrical network diagram,

$$\frac{1-\varepsilon_1}{A_1\varepsilon_1} = \frac{1-0.2}{1\times 0.2} = 4$$

$$\frac{1-\varepsilon_2}{A_2\varepsilon_2} = \frac{1-0.5}{1\times 0.5} = 1$$

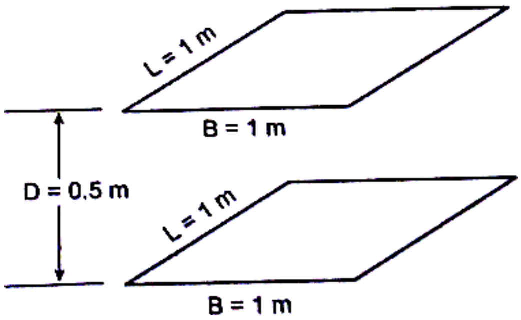
$$\frac{1-\varepsilon_3}{A_3\varepsilon_3} = 0 \qquad [A_3=\infty]$$

Apply $\frac{1-\varepsilon_1}{A_1\varepsilon_1} = 4, \frac{1-\varepsilon_2}{A_2\varepsilon_2} = 1, \frac{1-\varepsilon_3}{A_3\varepsilon_3} = 0$ values in electrical network diagram.



Electrical network diagram

Step:2 To find shape factor F_{12},refer HMT data book page no.92 and 93



$X = \frac{L}{D} = \frac{1}{0.5} = 2$

$Y = \frac{B}{D} = \frac{1}{0.5} = 2$

X value is 2,Y value is 2 .From that ,we can find corresponding shape factor value is 0.41525 [From the table]

i.e $F_{12} = 0.41525$

we know that ,

$F_{11} + F_{12} + F_{13} = 1$, we know that $F_{11} = 0$

$F_{13} = 1 - 0.41525$

$F_{13} = 0.5847$

Similarly, $F_{21} + F_{22} + F_{23} = 1$ We Know that, $F_{22} = 0$

$F_{23} = 1 - F_{21}$

$= 1 - F_{12} = 1 - 0.41525$

$= 0.5847$

From electrical network diagram,

$$\frac{1}{A_1 F_{13}} = \frac{1}{1 \times 0.5847} = 1.7102$$

$$\frac{1}{A_2F_{23}} = \frac{1}{1\times 0.5847} = 1.7102$$

$$\frac{1}{A_1F_{12}} = \frac{1}{1\times 0.41525} = 2.408$$

Step: 3 From stefan-Boltzmann Law,

$E_b = \varsigma T^4$

$E_{b1} = \varsigma T_1^4$

$= 5.67 \times 10^{-8}[1173]^4$

$E_{b1} = 107.34 \times 10^{3}\ W/m^2$

$E_{b2} = \varsigma T_2^4$

$= 5.67 \times 10^{-8}[673]^4$

$E_{b2} = 11.63 \times 10^{3}\ W/m^2$

$E_{b3} = \varsigma T_3^4$

$= 5.67 \times 10^{-8}[300]^4$

$E_{b3} = 459.27\ W/m^2$

From the electrical network diagram , we know that

$E_{b3} = J_3 = 459.27\ W/m^2$

Step: 4

The radiosities J_1 and J_2 can be calculated by using Krichoff's

The sum of current entering the node J_1 is zero.

At Node J_1:

$$\frac{E_{b1} - J_1}{4} + \frac{J_2 - J_1}{\frac{1}{A_1F_{12}}} + \frac{E_{b3} - J_1}{\frac{1}{A_1F_{13}}} = 0$$ [From electrical network diagram]

$$\frac{107.34\times 10^3 - J_1}{4} + \frac{J_2 - J_1}{2.408} + \frac{459.27 - J_1}{1.7102} = 0$$

$26835-0.25J_1 + 0.415J_2 - 0.415J_1 + 268.54 - 0.5847J_1 = 0$

$-1.2497\ J_1 + 0.415\ J_2 = -27.10 \times 10^3$ ------------------------------ (1)

At Node J_2:

$$\frac{J_1 - J_2}{\frac{1}{A_1F_{12}}} + \frac{E_{b3} - J_1}{\frac{1}{A_2F_{23}}} + \frac{E_{b2} - J_2}{1} = 0$$

$$\frac{J_2 - J_1}{2.408} + \frac{459.27 - J_1}{1.7102} + \frac{11.63 \times 10^3}{1} = 0$$

$0.415 J_1 -1.4997 J_2 = -11.898 \times 10^3$ ------------------------------(2)

Solving the equation (1) and (2)

$-1.2497 J_1 + 0.415 J_2 = -27.10 \times 10^3$

$-0.415 J_1 -1.4997 J_2 = -11.898 \times 10^3$

$J_1 = 26.780 \times 10^3 \ W/m^2$

$J_2 = 15.34 \times 10^3 \ W/m^2$

Step: 5

Heat lost by plate (1) $Q_1 = \dfrac{E_{b1} - J_1}{\dfrac{1-\varepsilon_1}{A_1 \varepsilon_1}}$ [From electrical network diagram]

$$= \frac{107.34 \times 10^3 - 26.780 \times 10^3}{\dfrac{1-0.2}{1 \times 0.2}}$$

$Q_1 = 20.140 \times 10^3 \ W$

Heat lost by plate (1) $Q_2 = \dfrac{J_2 - E_{b2}}{\dfrac{1-\varepsilon_2}{A_2 \varepsilon_2}}$

$$= \frac{15.34 \times 10^3 - 11.63 \times 10^3}{\dfrac{1-0.5}{1 \times 0.5}}$$

$Q_2 = 3710 \ W$

Total heat lost by the plates(1) and(2)

$Q = Q_1 + Q_2$

$Q = 20.140 \times 10^3 + 3710$

$Q = 23.850 \times 10^3 \ W$

Total heat received or absorbed by the room

$$Q = \frac{J_1 - J_3}{\dfrac{1}{A_1 F_{13}}} + \frac{J_2 - J_3}{\dfrac{1}{A_2 F_{23}}}$$

$$Q = \frac{26.780\times10^3 - 459.27}{1.7102} + \frac{11.06\times10^3 - 459.27}{1.7102}$$

$Q = 24.09 \times 10^3$ W

Result:

1.Net heat lost by each plates

$Q_1 = 20.140 \times 10^3$ W

$Q_2 = 3710$ W

2. Net heat transfer to the room

$Q = 24.09 \times 10^3$ W

3.Emissivities of two large parallel planes maintained at 800⁰C and 300⁰C are 0.3 and 0.5 repectively.Find the net radiant heat exchange per square meter of theplates. Find the percentage of reduction in heat transfer when a polished aluminium shield (ε = 0.05) is placed between them. Also find the temperature of the shield (April/May 2015)(Nov/Dec 2015).(NOV/DEC 2013)

Given:

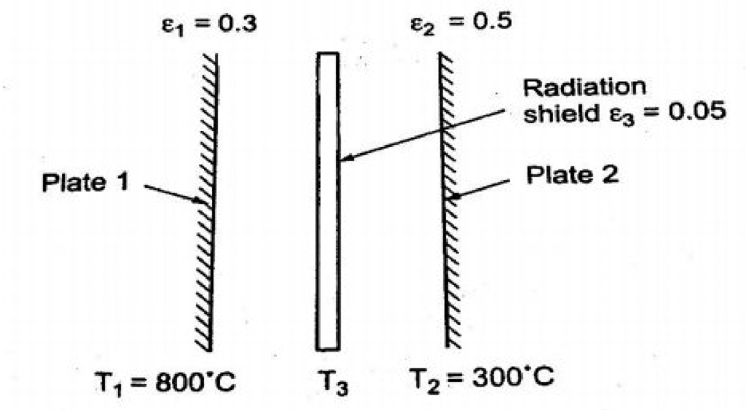
$T_1 = 800^{o}\,C + 273 = 1073$ K

$T_2 = 300^{o}\,C + 273 = 573$ K

$\varepsilon_1 = 0.3$

$\varepsilon_2 = 0.3$

Radiation shield emissivity $\varepsilon_3 = 0.05$



To find:

(i) Percentage of reduction in heat transfer due to radiation shield.

(ii) Temperature of the shield (T_3)

Solution:

Case: 1 Heat transfer without radiation shield:

Heat exchange between two large parallel plates without radiation shield is given by

Step: 1 $Q_{12} = \bar{\varepsilon}\sigma A[T_1^4 - T_2^4]$

Where $\bar{\varepsilon} = \dfrac{1}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1}$

$= \dfrac{1}{\dfrac{1}{0.3} + \dfrac{1}{0.5} - 1}$

$\bar{\varepsilon} = 0.2307$

$Q_{12} = 0.2307 \times 5.67 \times 10^{-8} \times A \times [(1073)^4 - (573)^4]$

Step: 2

$\dfrac{Q_{12}}{A} = 15.9 \times 10^3\ W/m^2$

Heat transfer without radiation shield $\dfrac{Q_{12}}{A}$ **= 15.9 x 10³ W/m² ------------------ (1)**

Case : 2 Heat transfer with radition shield:

Heat exchange between radiation plate 1 and radiation shield 3 is given

Step: 3

$Q_{13} = \bar{\varepsilon}\sigma A[T_1^4 - T_3^4]$

Where $\bar{\varepsilon} = \dfrac{1}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_3} - 1}$

$Q_{13} = \dfrac{\sigma A[T_1^4 - T_3^4]}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_3} - 1}$ **------------ (2)**

Heat exchange between radiation shield 3 and plate 2 is given

Step: 4

$Q_{32} = \bar{\varepsilon}\sigma A[T_3^4 - T_2^4]$

Where $\bar{\varepsilon} = \dfrac{1}{\dfrac{1}{\varepsilon_3} + \dfrac{1}{\varepsilon_2} - 1}$

$$Q_{32} = \frac{\sigma A[T_3^4 - T_2^4]}{\dfrac{1}{\varepsilon_3} + \dfrac{1}{\varepsilon_2} - 1} \quad \text{------------ (3)}$$

Step: 5

We know that,

$Q_{13} = Q_{32}$

$$\frac{\sigma A[T_1^4 - T_3^4]}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_3} - 1} = \frac{\sigma A[T_3^4 - T_2^4]}{\dfrac{1}{\varepsilon_3} + \dfrac{1}{\varepsilon_2} - 1}$$

$$\frac{\sigma A[1073^4 - T_3^4]}{\dfrac{1}{0.3} + \dfrac{1}{0.05} - 1} = \frac{\sigma A[T_3^4 - 573^4]}{\dfrac{1}{0.05} + \dfrac{1}{0.5} - 1}$$

$3.02 \times 10^{13} = 43.3\ T_3^4$

$T_3 = 913.8$ K

Temperature of the shield T_3 = 913.8 K

Substitute T_3 value in equation (2) or (3),

Heat transfer with radiation shield $Q_{13} = \dfrac{\sigma A[1073^4 - 913.8^4]}{\dfrac{1}{0.3} + \dfrac{1}{0.05} - 1}$

$$\frac{Q_{13}}{A} = 159.46 \text{ W/m}^2$$

Step: 6

Percentage of reduction in heat transfer due to radiation shield

$$= \frac{Q_{withoutshield} - Q_{withshield}}{Q_{withshield}}$$

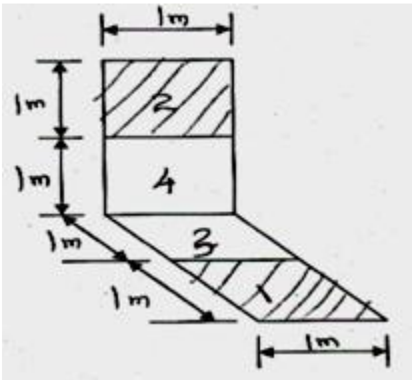
$$= \frac{Q_{12} - Q_{13}}{Q_{12}}$$

$$= \frac{15.8 \times 10^3 - 1594.6}{15.8 \times 10^3} \times 100$$

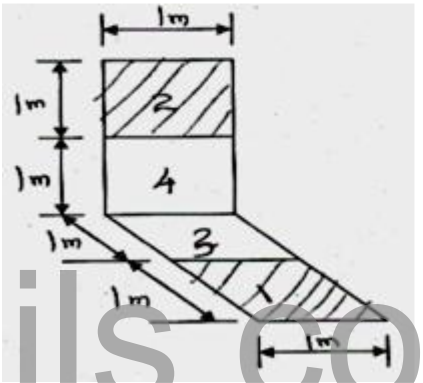
$= 0.899 \times 100\ \% = 89.9\%$

Percentage of reduction in heat transfer due to radiation shield= 89.9%

4. The area A_1 and A_2 are perpendicular but do not share the common edge .find the shape factor F_{1-2} for the arrangement. (Nov/Dec 2015).

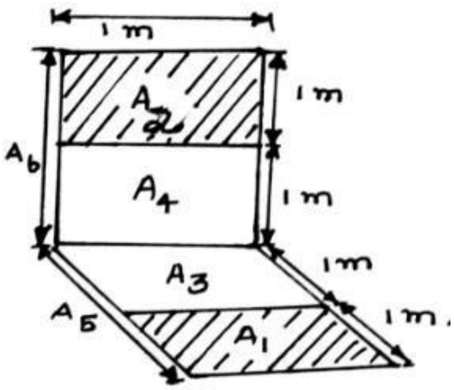


Given:



To find : Shape Factor of F_{1-2}

Solution:



From the figure we know that

Step: 1

$A_5 = A_1 + A_3$

$A_6 = A_2 + A_4$

Further **Step: 2**

$A_5 F_{5-6} = A_1 F_{1-6} + A_3 F_{3-6}$ $\qquad$ $[A_5 = A_1 + A_3,\ F_{5-6} = F_{1-6} + F_{3-6}]$

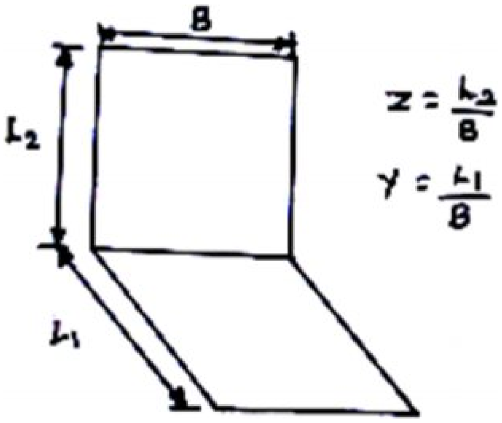
$= A_1 F_{1-2} + A_1 F_{1-4} + A_3 F_{3-6}$ $[F_{1-6} = F_{1-2} + F_{1-4}]$

$A_5 F_{5-6} = A_1 F_{1-2} + A_5 F_{5-4} - A_3 F_{3-4} + A_3 F_{3-6}$ $[A_1 = A_5 - A_3, F_{1-4} = F_{5-4} - F_{3-4}]$

$A_1 F_{1-2} = A_5 F_{5-6} - A_5 F_{5-4} + A_3 F_{3-4} - A_3 F_{3-6}$

$$F_{1-2} = \frac{A_5}{A_1}[F_{5-6} - F_{5-4}] + \frac{A_3}{A_1}[F_{3-4} - F_{3-6}] \text{------------------------------------} (1)$$

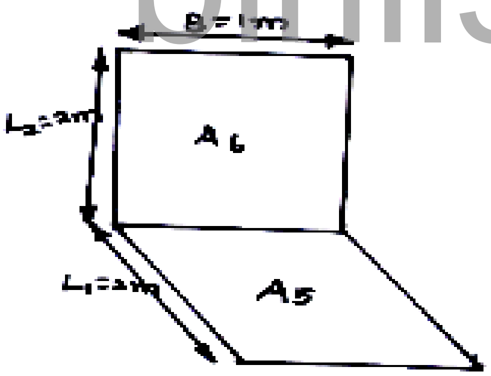
[Refer HMT data book, Page no.95]



$$Z = \frac{L_2}{B}, Y = \frac{L_1}{B}$$

Step: 3

Shape Factor for the area A_5 and A_6



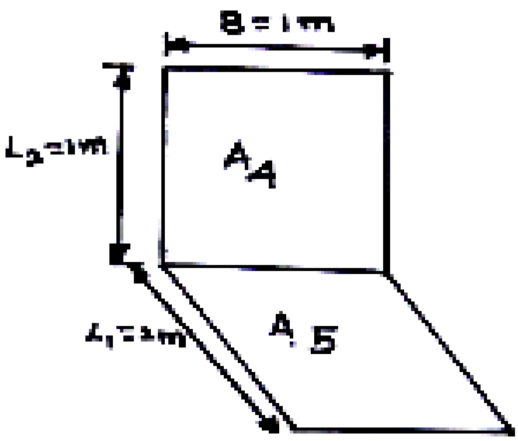
$$Z = \frac{L_2}{B} = \frac{2}{1} = 2$$

$$Y = \frac{L_1}{B} = \frac{2}{1} = 2$$

Z value is 2, Y value is 2 .From that, we can find Corresponding shape factor value is 0.14930

$$\mathbf{F_{5-6} = 0.14930}$$

Shape Factor for the area A_5 and A_4



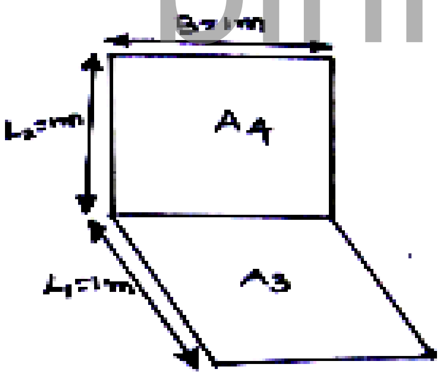
$$Z = \frac{L_2}{B} = \frac{1}{1} = 1$$

$$Y = \frac{L_1}{B} = \frac{2}{1} = 2$$

Z value is 1, Y value is 2 .From that, we can find Corresponding shape factor value is 0.11643

F_{5-4} = 0.11643

Shape Factor for the area A_3 and A_4



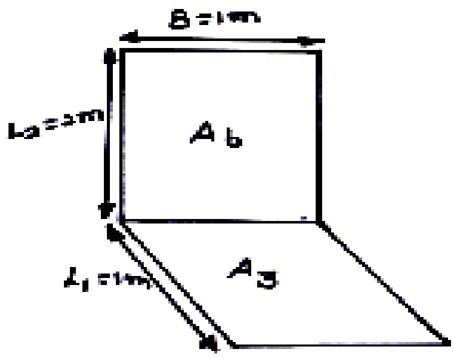
$$Z = \frac{L_2}{B} = \frac{1}{1} = 1$$

$$Y = \frac{L_1}{B} = \frac{1}{1} = 1$$

Z value is 1, Y value is 1 .From that, we can find Corresponding shape factor value is 0.2004

F_{3-4} = 0.2004

Shape Factor for the area A_3 and A_6:



$Z = \frac{L_2}{B} = \frac{2}{1} = 2$

$Y = \frac{L_1}{B} = \frac{1}{1} = 1$

Z value is 2, Y value is 1 .From that, we can find Corresponding shape factor value is 0.23285

$$F_{3\text{-}6} = 0.23285$$

Step: 4

Substitute $F_{3\text{-}6}$, $F_{3\text{-}4}$, $F_{5\text{-}4}$ and $F_{5\text{-}6}$ in equation (1)

$F_{1\text{-}2} = \frac{A_5}{A_1}[F_{5\text{-}6} - F_{5\text{-}4}] + \frac{A_3}{A_1}[F_{3\text{-}4} - F_{3\text{-}6}]$

$A_5 = 2$; $A_3 = A_1 = 1$

$F_{1\text{-}2} = \frac{2}{1}[0.14930-0.11643] + \frac{1}{1}[0.2004-0.23285]$

$$F_{1\text{-}2} = 0.03293$$

$$\boxed{F_{1\text{-}2} = 0.03293}$$

5. (a) State and Prove Kirchhoff's law of thermal radiation.

This law states that the ratio of total emissive power to the aborptivity is constant for all surfaces which are in thermal equilibrium with the surroundings.

$$\frac{E_1}{\alpha_1} = \frac{E_2}{\alpha_2} = \frac{E_3}{\alpha_3} ....$$

It also states that the emissivity of the body is always equal to its absorptivity hen the body remains in thermal equilibrium with its surroundings.

$$\alpha_1 = E_1;\ \alpha_2 = E_2 \text{ and soon.}$$

(b) What is a black body? A20 cm diameter spherical ball at 527^{0}c is suspended in the air. The ball closely approximates a black body. Determine the total black body emissive power, and spectral black body emissive power at a wavelength of 3 μm.

A black body absorbs all incident radiation, regardless of wave length and direction. For a prescribed temperature and wave length, no surface can emit more energy than black body.

Given:

In sphere, (Black body)

Diameter of sphere, d = 20 cm = 0.2 m

Temperature of spherical ball, T = 527^{0}C +273 = 800 K

To Find:

(i) Total black body emissive power, E_b

(ii) Spectral black body emissive power at wavelength of 3μm.

Solution:

(i) **Step:1** Total black body emissive power , E_b

$E_b = \varsigma A T^4 = 5.67 \times 10^{-8} \times \Pi \times (0.2)^2 \times (800)^4$

E_b = 2920 W

(ii) **Step:2** Spectral black body emissive power: at λ= 3μm

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

$$= \frac{0.374 \times 10^{-15}}{(3\times 10^{-}\ )\ [\exp(\frac{14.14 \times 10^{-13}}{3\times 10^{-6} \times 800}) - 1]}$$

$E_{b\lambda}$ = 3824.3 x 10^6 W/m^2

$E_{b\lambda}$ = 3824.3 x 10^6 W/m^2

6. Consider a cylinder furnace with outer radius = 1m and height=1 m. The top (surface 1) and the base (surface2) of the furnace have emissivities 0.8 and 0.4 and are maintained at uniform temperature of 700 K and 500 K

respectively. The side surface closely approximates a black body and is maintained at a temperature of 400 K. Find the net rate of radiation heat transfer at each surface during steady state operation. (May/June 2015)

Given:

Radius of the cylinder = 1m

Height of the cylinder = 1m

Top surface temperature T_1 = 700 K

Base surface temperature T_2 = 500 K

side surface temperature T_3 = 400 K

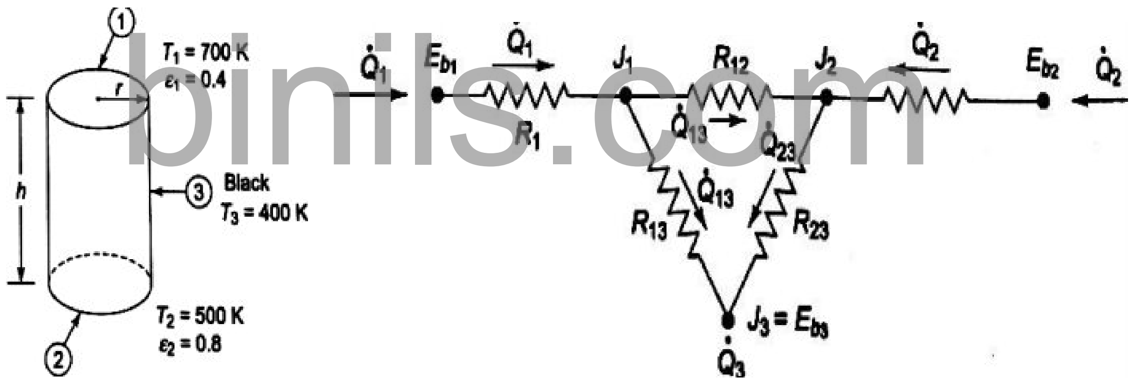
Top surface emissivities ε_1= 0.8

Base surface emissivities ε_2 = 0.4

To Find:

- Net rate of radiation heat transfer at each surface

Solution:



The furnace and the radiation network are shown in above figure .writing the energy balance for the node 1 and 2,

Step: 1

$$\frac{E_{b1}-J_1}{R_1} = \frac{J_1-J_2}{R_{12}} + \frac{J_1-J_3}{R_{13}} \quad \text{---------------------------- (1)}$$

$$\frac{E_{b2}-J_2}{R_2} = \frac{J_2-J_1}{R_{12}} + \frac{J_2-J_3}{R_{13}} \quad \text{-- (2)}$$

$E_{b1} = \varsigma\ T_1^4$ = 5.67 x 10^{-8} $(700)^4$ = 13614 W/m^2

$E_{b2} = \varsigma\ T_2^4$ = 5.67 x 10^{-8} $(500)^4$ = 3544 W/m^2

$E_{b3} = \varsigma\ T_3^4$ = 5.67 x 10^{-8} $(400)^4$ = 1452 W/m^2

$A_1 = A_2 = \Pi\ r^2 = \Pi(1)^2 = 3.14$m^2

Step: 2

From the HMT data Book [page no. 91]

The view factor from the base to top is found to be $F_{12} = 0.38$

Now , $F_{11} + F_{12} + F_{13} = 1$, we know that $F_{11} = 0$

$F_{13} = 1 - F_{12} = 1 - .062 = 0.38$

$R_1 = \frac{1-\varepsilon_1}{A_1\varepsilon_1} = \frac{1-0.8}{3.14\times0.8} = 0.0796 m^2$

$R_2 = \frac{1-\varepsilon_2}{A_2\varepsilon_2} = \frac{1-0.4}{3.14\times0.4} = 0.4777\ m^2$

$R_{12} = \frac{1}{A_1F_{12}} = \frac{1}{3.14\times0.38} = 0.8381\ m^2$

$R_{23} = \frac{1}{A_2F_{23}} = \frac{1}{3.14\times0.62} = 0.5137\ m^2 = R_{13}$

Step: 3

On substitution,of this value in above equation(1) and (2)

$$\frac{13614 - J_1}{0.0796} = \frac{J_1 - J_2}{0.8381} + \frac{J_1 - 1452}{0.5137}$$

$$\frac{3544 - J_2}{0.0777} = \frac{J_2 - J_1}{0.8381} + \frac{J_1 - 1452}{0.5137}$$

By solving the above equations,

$J_1 = 11418\ W/m^2$ and $J_2 = 4562\ W/m^2$

$Q_1 = \frac{E_{b1} - J_1}{R_1} = \frac{13614 - 11418}{0.0796} = 27,588W$

$Q_2 = \frac{E_{b2} - J_2}{R_2} = \frac{3544 - 4562}{0.4777} = 2132W$

$Q_3 + \frac{J_1 - J_3}{R_{13}} + \frac{J_2 - J_3}{R_{23}} = 0$

$Q_3 = \frac{1452 - 11418}{0.5137} + \frac{1452 - 4562}{0.5137} = 25455W$

Net rate of radiation heat transfer at each surface

Q_1 =27,588W **Q_2 =2132W** **Q_3=25455W**

7. The spectral emissivity function of an opaque surface at 1000 K is approximated as

$\varepsilon_{\lambda 1}$ = 0.4, 0 ≤ λ < 2μm;

$\varepsilon_{\lambda 2}$ = 0.7, 2 μm ≤ λ < 6 μm;

$\varepsilon_{\lambda 3}$ = 0.3, 6 μm ≤ λ < ∞

Determine the average emissivity of the surface and the rate of radiation emission from the surface, in W/m² (Nov / Dec 2015)

Given:

Surface temperature= 1000 K

$\varepsilon_{\lambda 1}$ = 0.4, 0 ≤ λ < 2μm;

$\varepsilon_{\lambda 2}$ = 0.7, 2 μm ≤ λ < 6 μm;

$\varepsilon_{\lambda 3}$ = 0.3, 6 μm ≤ λ < ∞

To Find: Rate of radiation emission from the surface, in W/m²

Solution:

The average emissivity can be determined by breaking the integral

Step:1

$$\varepsilon(T) = \frac{\varepsilon_1 \int_0^{\lambda_1} E_{b\lambda}(T)d\lambda}{\sigma T^4} + \frac{\varepsilon_2 \int_{\lambda_1}^{\lambda_2} E_{b\lambda}(T)d\lambda}{\sigma T^4} + \frac{\varepsilon_3 \int_{\lambda_2}^{\infty} E_{b\lambda}(T)d\lambda}{\sigma T^4}$$

$= \varepsilon_1 f_0 - \lambda_1(T) + \varepsilon_2 f_{\lambda 1} + \lambda_2(T) + \varepsilon_3 f_{\lambda 2} - \infty(T)$

$= \varepsilon_2 f_{\lambda 1} + \varepsilon_2(f_{\lambda 2} - f_{\lambda 1}) + \varepsilon_3(1 - f_{\lambda 2})$

Where $f_{\lambda 1}$ and $f_{\lambda 2}$ are black body radiation function corresponding to $\lambda_1 T$ to $\lambda_2 T$

Step:2

$\lambda_1 T = 2 \times 1000 = 2000$ μmK, $f_{\lambda 1} = 0.066728$

$\lambda_2 T = 6 \times 1000 = 6000$ μmK, $f_{\lambda 2} = 0.737818$ [From HMT data Book Page No: 83]

$\varepsilon = 0.4 \times 0.066728 + 0.7(0.737818 - 0.066728) + 0.3(1 - 0.737818)$

$\varepsilon = 0.5751$

Step:3

$E = \varepsilon \varsigma T^4 = 0.5715 \times 5.67 \times 10^{-8} \times (1000)^4$

E = 32608 W/m²

E = 32608 W/m²

8. The inner sphere of a liquid oxygen container is 400 mm dia., outer sphere is 500 mm dia., both have emissivity 0.05.Determine the rate of liquid oxygen evaporation at-183^{0}C, when the outer sphere temperature is 20^0 C. The latent heat of evaporation 210 KJ/kg .Neglect losses due to other modes of heat transfer. (May/ June 2016)

Given:

Inner wall temperature T_1 = -183^{0}C + 273 = 90K

Outer wall Temperature T_2 = 20^0 C + 273 =293 K

Inner diameter D_1= 400 mm= 0.4 m = r_1= 0.2 m

Outer diameter D_2 = 500 mm =0.5 m r_2 = 0.25 m

Emissivity ,$\varepsilon_1 = \varepsilon_2$ =0.05

Latent heat of evaporation = 210 KJ/kg = 210 x 10^3 J/kg

To Find:

Rate of liquid oxygen evaporation

Solution:

Heat transfer $Q_{12} = \bar{\varepsilon}\,\varsigma A_1[T_1^4 - T_2^4]$

$$\bar{\varepsilon} = \frac{1}{\frac{1}{\varepsilon_1} + \frac{A_1}{A_2}\left(\frac{1}{\varepsilon_2} - 1\right)}$$

$A_1 = 4x\Pi x r_1^2$ = 4x3.14x $(0.2)^2$ = 0.5026

$A_2 = 4x\Pi x r_2^2$ = 4x3.14x $(0.25)^2$ = 0.7853

$$= \frac{1}{\frac{1}{0.05} + \frac{0.5026}{0.7853}\left(\frac{1}{0.05} - 1\right)}$$

$\bar{\varepsilon}$ = 0.0310

$Q_{12} = \bar{\varepsilon}\,\varsigma A_1[T_1^4 - T_2^4]$

= 0.0310 x 5.67 x 10^{-8}x 0.5026[90^4-293^4]

Q = -6.4529 W

Rate of Evaporation = $\frac{heatTransfer}{LatentHeat}$

$$= \frac{6.4529}{210 \times 10^3}$$

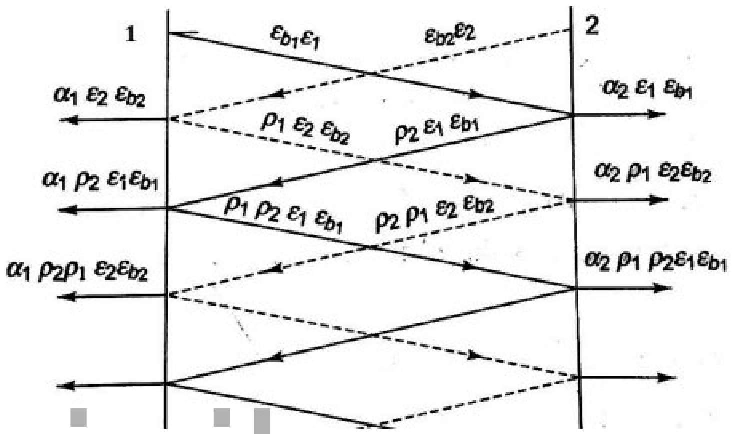
$= 3.07 \times 10^{-5}$

Rate of liquid oxygen evaporation = 3.07 x 10^{-5}

Rate of liquid oxygen evaporation = 3.07 x 10^{-5}

9. Derive relation for heat exchange between infinite parallel planes. (May/June 2014).

The radiant interchange between two infinite parallel gray planes involves no geometry factor, since $F_{12} = F_{21} = 1.0$.let us consider two gray planes,



For gray surface $\alpha=\varepsilon$ and $\rho=1-\varepsilon$. Surface 1 emits $\varepsilon_1 E_{b1}$ per unit time and area. surface 2 absorbs $\alpha_2 \varepsilon_2 E_{b2}$ or $\alpha_2 \varepsilon_1 E_{b1}$ and reflects $\rho_2 \varepsilon_1 E_{b1}$ or $(1-\varepsilon_2)\,\varepsilon_1 E_{b1}$ back towards A_1.the net heat transferred per unit of surface 1 to 2 is the emission $\varepsilon_1 E_{b1}$ minus the fraction of $\varepsilon_1 E_{b1}$ and $\varepsilon_2 E_{b2}$ which is ultimately absorbed by surface 1 after successive reflections. Therefore.

$$(Q_{1-2})_{net} = \{A_1 \varepsilon_1 E_{b1} [1-\varepsilon_1(1-\varepsilon_2) - \varepsilon_1 (1-\varepsilon_1)(1-\varepsilon_2)^2 - \varepsilon_1 (1-\varepsilon_1)^2 (1-\varepsilon_2)^3 \quad]\}-$$

$$\{A_2 \varepsilon_2 E_{b2} [\varepsilon_1 + \varepsilon_1 (1-\varepsilon_1)](1-\varepsilon_2) + \varepsilon_1 [(1-\varepsilon_1)^2 (1-\varepsilon_2)^2 + \ldots]]\}$$

$$A_1 \varepsilon_1 E_{b1}\left[1-\frac{\varepsilon_1(1-\varepsilon_2)}{1-(1-\varepsilon_1)(1-\varepsilon_2)}\right] - A_2 \varepsilon_2 E_{b2}\left[1-\frac{\varepsilon_1}{1-(1-\varepsilon_1)(1-\varepsilon_2)}\right]$$

$$= A \frac{\varepsilon_1 \varepsilon_2}{\varepsilon_1 + \varepsilon_2 - \varepsilon_1 \varepsilon_2} [E_{b1} - E_{b2}] \qquad \text{since}[A_1 = A_2 = A]$$

$$(Q_{1-2})_{net} = A\,\varsigma \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} (T_1^4 - T_2^4)$$

$$\mathbf{(Q_{1-2})_{net} = A\, \sigma\, F_{1-2} (T_1^4 - T_2^4)}$$

$$F_{1-2} = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

$$\boxed{(Q_{1-2})_{net} = A\,\sigma\,F_{1-2}(T_1^4 - T_2^4)}$$

10. A gas mixture contains 20% CO_2 and 10% H_2o by volume. The total pressure is 2 atm. The temperature of the gas is 927°C. The mean beam length is 0.3 m. Calculate the emissivity of the mixture.

Given : Partial pressure of CO_2, P_{CO_2} = 20% = 0.20 atm

Partial pressure of H_2o, P_{H_2O} = 10% = 0.10 atm.

Total pressure P = 2 atm

Temperature T = 927°C + 273

= 1200 K

Mean beam length L_m = 0.3 m

To find: Emissivity of mixture (ε_{mix}).

Solution: Step: 1

To find emissivity of CO_2

$$P_{CO_2} \times L_m = 0.2 \times 0.3$$

$$\boxed{P_{CO_2} \times L_m = 0.06 \text{ m - atm}}$$

From HMT data book, Page No.106, we can find emissivity of CO_2.

From graph, Emissivity of CO_2 = 0.09

$$\boxed{\varepsilon_{CO_2} = 0.09}$$

Step: 2

To find correction factor for CO_2

Total pressure, P = 2 atm

$$P_{CO_2}\, L_m = 0.06 \text{ m - atm.}$$

From HMT data book, Page No.107, we can find correction factor for CO_2

From graph, correction factor for CO_2 is 1.25

$$\boxed{C_{CO_2} = 1.25}$$

$\varepsilon_{CO_2} \times C_{CO_2} = 0.09 \times 1.25$

$$\boxed{\varepsilon_{CO_2} \times C_{CO_2} = 0.1125}$$

Step: 3

To find emissivity of H_2o :

$P_{H_2o} \times L_m = 0.1 \times 0.3$

$$\boxed{P_{H_2o} L_m = 0.03 \text{ m - atm}}$$

From HMT data book, Page No.108, we can find emissivity of H_2o.

From graph Emissivity of H_2o = 0.048

$$\boxed{\varepsilon_{H_2o} = 0.048}$$

Step: 4

To find correction factor for H_2o :

$$\frac{P_{H_2o} + P}{2} = \frac{0.1 + 2}{2} = 1.05$$

$$\frac{P_{H_2o} + P}{2} = 1.05,$$

$P_{H_2o} L_m = 0.03 \text{ m - atm}$

From HMT data book, Page No.108 we can find emission of H_20

1. **Two large parallel plates with ε = 0.5 each, are maintained at different temperatures and are exchanging heat only by radiation. Two equally large radiation shields with surface emissivity 0.05 are introduced in parallel to the plates.find the percentage of reduction in net radiative heat transfer.**

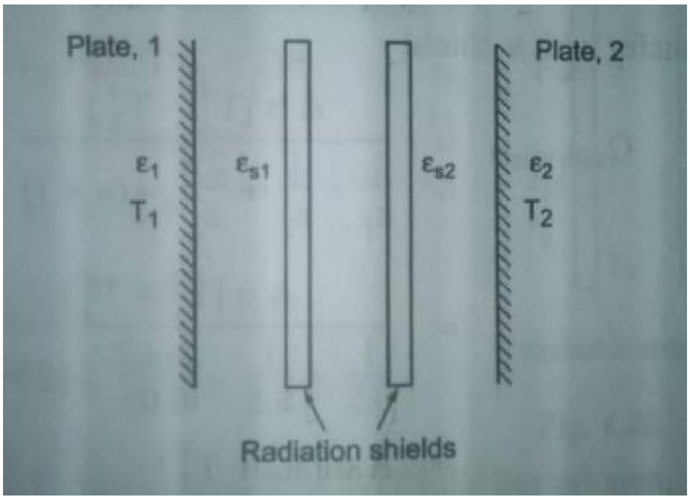
Given:

Emissivity of plate 1, $\varepsilon_1 = 0.5$

Emissivity of plate 2, $\varepsilon_2 = 0.5$

Emissivity of shield, $\varepsilon_s = \varepsilon_{s1} = \varepsilon_{s2} = 0.05$

Number of shields, n =2



To find:

Percentage of reduction in net radiative heat transfer

Solution:

Case 1:

Heat transfer without radiation shield

$Q12 = \varepsilon * \varsigma * A * [\, T_1^4 - T_2^4]$

$\varepsilon\ = 1 / (((1/ \varepsilon_1) + (1/ \varepsilon_2) - 1\ ))$

$\varepsilon\ = 1 / (((1/ 0.5) + (1/ 0.5) - 1\ ))$

$\varepsilon\ = 0.333.$

$Q12 = \varepsilon * \varsigma * A * [\, T14 - T24]$

$Q12 = 0.333 * \varsigma * A * [\, T14 - T24]$

CASE 2: Heat transfer with radiation shield

$Q_{\text{with shield}} = (\varsigma * A * [\, T14 - T24]) / \ ((1/ \varepsilon_1) + (1/ \varepsilon_2) + (2n / \varepsilon_s) - (n+1))$

$= (\varsigma * A * [\, T14 - T24]) / \ ((1/ 0.5) + (1/ 0.5) + ((2*2) / 0.05) - (2+1))$

$= (\varsigma * A * [\, T14 - T24]) / \ 81$

Qwith shield $= 0.0123 * (\varsigma * A * [\, T14 - T24])$

We know that

Radiation in heat transfer due to radiation shield

$= (Q_{\text{WITHOUT SHIELD}} - Q_{\text{WITH SHIELD}}) / \ Q_{\text{WITHOUT SHIELD}}$

$$= \frac{((0.333 * \varsigma * A * [\, T14 - T24]) - (0.0123 * (\varsigma * A * [\, T14 - T24])))}{(0.333 * \varsigma * A * [\, T14 - T24])}$$

$= 0.963$

= 96.3 %

Percentage of reduction in net radiative heat transfer = 96.3 .

2. A black body at 3000 K emits radiation Calculate the following

1. Monochromatic emissive power at 1 μm wave length

2. Wave length at which emission is maximum

3. Maximum emissive power

4. Total emissive power

5. Calculate the total emissive of the furnace if it is assumed as a real surface having emissivity equal to 0.85

Given

Surface temperature T = 3000K

To find

1. Monochromatic emissive power $E_{b\lambda}$ at λ=1 μ = 1 x 10^{-6}m
2. Maximum wave length, (λ_{max})
3. Maximum emissive power$(E_{b\lambda})_{max}$
4. Total emissive power, E_b
5. Emissive power of real surface at ε=0.85

Solution

1. Monochromatic emissive power

From Planck's distribution law, we know that

$$E_{b\lambda} = \frac{c_1 \lambda^{-5}}{e^{\frac{c_2}{\lambda T}} - 1}$$

C_1=0.374 x 10^{-15} Wm^2

C_2= 14.4 x 10^{-3} mK

λ =1 x 10^{-6} m

$$E_{b\lambda} = \frac{0374\ X10^{-15}\ [1\ X\ 10^{-6}]^{-5}}{e^{[\frac{14.4\ X\ 10^{-3}}{1\ X\ 10^{-6}\ X\ 3000}]} - 1}$$

$E_{b\lambda} = 3.10\ X\ 10^{12}\ W/m^2$

2. Mamimum wave length (λ_{max})

λ_{max} T = 2.9 X 10^{-3}mK

$\lambda_{max} = \frac{2.9 X 10^{-3}}{3000}$

$\lambda_{max} = 0.966 X 10^{-6}$ m

3. **Maximum emissive power** $(E_{b\lambda})_{max}$

$(E_{b\lambda})_{max} = 1.307 X 10^{-5} T^5$

$= 1.307 X 10^{-5} X (3000)^5$

$(E_{b\lambda})_{max} = 3.17 X 10^{12}$ W/m^2

4. Total emissive power E_b

$E_b = \sigma x T^4$ (From HMT data book P.No 8)

σ = Stefen Boltzman Constant

= 5.67 x 10^{-8} W/m^2 K^4

$E_b = (5.67 x 10^{-8}) x (3000)^4$

$E_b = 4.59 x 10^{-6}$ W/m^2

5. Total emissive power of real surface

$(Eb)_{real} = \varepsilon \sigma T^4$

ε - Emissivity = 0.85

$(Eb)_{real} = 0.85 x 5.67 x 10^{-8} x (3000)^4$

$(Eb)_{real} = 3.90 x 10^6$ W/m^2

Result

1. $E_{b\lambda} = 3.10 X 10^{12}$ W/m^2 **2.** $\lambda_{max} = 0.966 X 10^{-6}$ µm

3. $(E_{b\lambda})_{max} = 3.17 X 10^{12}$ W/m^2 4. $(Eb)_{real} = 3.90 x 10^6$ W/m^2