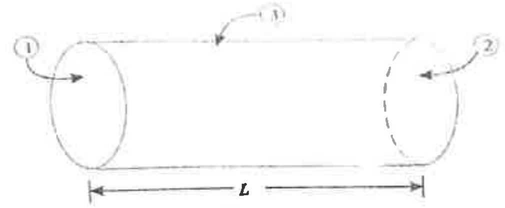
QP code: 27944

1(e)

Q1 e) *The radiation* **shape** *factor of the circular surface* **of** *a thin hollow cylinder of 10 cm diameter and 10 cm length* **is** *0.1716. What is the shape factor* **of** *the curved surface of the cylinder with respect to itself ?*



Solution. *Given:* $r_1 = r_2 = \frac{10}{2} = 5$ cm; $L = 10$ cm; $F_{1-2} = 0.1716$

$F_{1-2} = F_{2-1} = 0.1716$ as $A_1 = A_2$

The shape factor releation among three surfaces is given by

$$F_{1-1} + F_{1-2} + F_{1-3} = 1 \quad ...(i)$$

$$F_{3-3} + F_{3-2} + F_{3-1} = 1 \quad ...(ii)$$

But $F_{3-1} = F_{3-2}$ ...(iii)

Also $F_{1-1} = F_{2-2} = 0$

Substituting (*iii*) in (*ii*), we get

$$F_{3-3} + F_{3-1} + F_{3-1} = 1$$

$\therefore$ $F_{3-3} = (1 - 2F_{3-1})$ ...(iv)

Also $A_1 F_{1-3} = A_3 F_{3-1}$

$\therefore$ $$F_{3-1} = F_{1-3} \times \frac{A_1}{A_3} = F_{1-3} \times \frac{\pi r^2}{2\pi r L} = F_{1-3} \times \frac{r}{2L} \quad ...(v)$$

From eqn. (*i*), we have $F_{1-3} = 1 - F_{1-2}$ as $F_{1-1} = 0$

$= 1 - 0.1716 = 0.8284$ ...(vi)

Now substituting from (*vi*) in (*v*), we get

$$F_{3-1} = 0.8284 \times \frac{5}{2 \times 10} = 0.2071 \quad ...(vi)$$

Now substituting from (*vii*) in (*iv*), we obtain

$$F_{3-3} = 1 - 2 \times 0.2071 = \mathbf{0.5858}$$

2(a)

Q2 a) . *A wall of a furnace is made up of inside layer of silica brick 120 mm thick covered with a layer of magnesite brick 240 mm thick. The temperatures at the inside surface of silica brick wall and outside surface of magnesite brick wall are 725°C and 110°C respectively. The contact thermal resistance between the two walls at the interface is 0.0035°C/W per unit wall area. If thermal conductivities of silica and magnesite bricks are 1.7 W/m°C and 5.8 W/m°C, calculate.*

(*i*) *The rate of heat loss per unit area of walls, and*

(*ii*) *The temperature drop at the interface.*

Solution.

Given : $L_A = 120$ mm $= 0.12$ m;

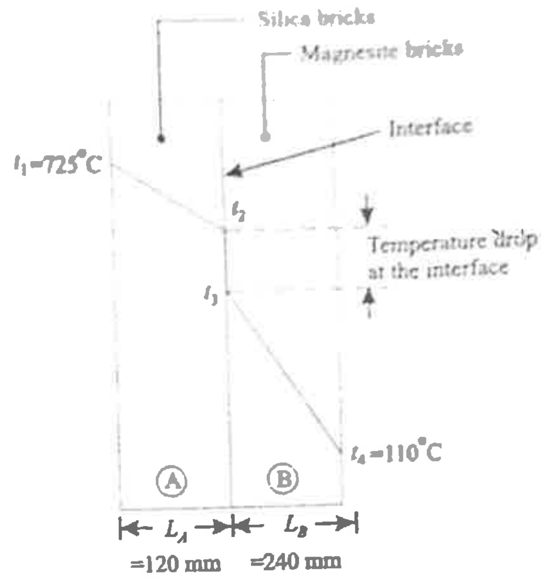
$L_B = 240$ mm $= 0.24$ m;

$k_A = 1.7$ W/m°C; $k_B = 5.8$ W/m°C

The contact thermal resistance $(R_{th})_{cont}$ $= 0.0035$°C/W

The temperature at the inside surface of silica brick wall, $t_1 = 725$°C

The temperature at the outside surface of the magnesite brick wall, $t_4 = 110$°C



(*i*) **The rate of heat loss per unit area of wall, q :**

$$q = \frac{\Delta t}{\Sigma R_{th}} = \frac{\Delta t}{R_{th-A} + (R_{th})_{cont.} + R_{th-B}}$$

$$= \frac{(t_1 - t_4)}{L_A / k_A + 0.0035 + L_B / k_B}$$

$$= \frac{(725 - 110)}{0.12/1.7 + 0.0035 + 0.24/5.8}$$

$$= \frac{615}{0.0706 + 0.0035 + 0.0414}$$

$$= 5324.67 \text{ W/m}^2$$

$\therefore$ **The rate of heat loss per unit area of wall, $q = 5324.67$ W/m²** **(Ans.)**

(*ii*) The temperature drop at the interface, $(t_2 - t_3)$:

As the same heat flows through each layer of composite wall, therefore,

$$q = \frac{t_1 - t_2}{L_A / k_A} = \frac{t_3 - t_4}{L_B / k_B}$$

or, $$5324.67 = \frac{(725 - t_2)}{0.12/1.7}$$

or, $$t_2 = 725 - 5324.67 \times \frac{0.12}{1.7} = 349.14°\text{C}$$

Similarly, $$5324.67 = \frac{(t_3 - 110)}{0.24/5.8}$$

or, $$t_3 = 110 + 5324.67 \times \frac{0.24}{5.8} = 330.33°\text{C}$$

Hence, the temperature drop at the interface $= t_2 - t_3$

$$= 349.14 - 330.33 = \boxed{18.81°\text{C}}$$ **(Ans.)**

4 (b)

~~Q3 a)~~ *Air at 20°C is flowing over a flat plate which is 200 mm wide and 500 mm long. The plate is maintained at 100°C. Find the heat loss per hour from the plate if the air is flowing parallel to 500 mm side with 2m/s velocity. What will be the effect on heat transfer if the flow is parallel to 200 mm side.*

The properties of air at (100 + 20)/2 = 60°C are $\nu = 18.97 \times 10^{-6}\ m^2/s$, $k = 0.025\ W/m°C$ *and* $Pr = 0.7$.

Solution. *Given:* $U = 2$ m/s, $\nu = 18.97 \times 10^{-6}$ m²/s, $k = 0.025$ W/m°C and $Pr = 0.7$.

Heat loss per hour from the plate, Q :

Case I. *When the flow is parallel to 500 mm side :*

$$\overline{Nu} = \frac{\bar{h} L}{k} = 0.664\,(Re_L)^{1/2}\,(Pr)^{1/3}$$

where,
$$Re_L = \frac{UL}{\nu} = \frac{2 \times 0.5}{18.19 \times 10^{-6}} = 5.27 \times 10^4$$

$$\therefore \quad \bar{h} = \frac{k}{L} \times 0.664\,(Re_L)^{1/2}\,(Pr)^{1/3}$$

$$= \frac{0.025}{0.5} \times 0.664\,(5.27 \times 10^4)^{1/2}\,(0.7)^{1/3} = 6.767\ \text{W/m}^2\text{°C}$$

$$\therefore \quad Q = \bar{h} A_s (t_s - t_\infty) = 6.767 \times (0.5 \times 0.2)\,(100 - 20) = \mathbf{54.14\ W} \quad \textbf{(Ans.)}$$

Case II. *When the flow is parallel to 200 mm side :*

$$Re_L = \frac{2 \times 0.2}{18.97 \times 10^{-6}} = 2.11 \times 10^4$$

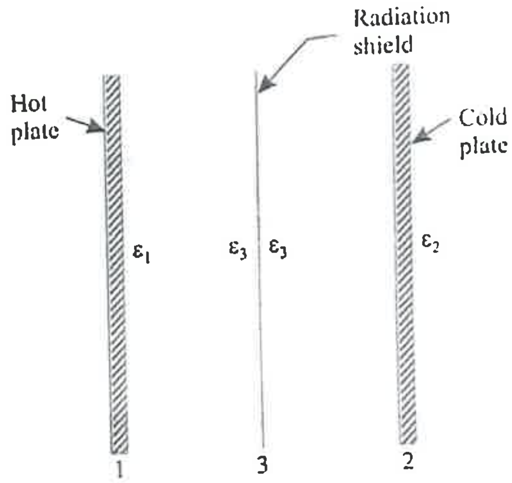
$$\therefore \quad \bar{h} = \frac{0.025}{0.2} \times 0.664 \times (2.11 \times 10^4)^{1/2}\,(0.7)^{1/3} = \mathbf{10.7\ W/m^2\,°C} \quad \textbf{(Ans.)}$$

$$\therefore \quad Q = \bar{h} \times A_s (t_s - t_\infty) = 10.7 \times (0.2 \times 0.5) \times (100 - 20) = \mathbf{85.6\ W} \quad \textbf{(Ans.)}$$

5(b) *Calculate the net radiant heat exchange per m^2 area for two large parallel plates at temperatures of 427° C and 27° C respectively. ε (hot plate) = 0.9 and ε (cold plate) = 0.6.*

If a polished aluminium shield is placed between them, find the percentage reduction in the heat transfer; ε (shield) = 0.4.

Solution. *Given :* $T_1 = 427 + 273 = 700$ K; $T_2 = 27 + 273 = 300$ K; ε_1 (hot plate) = 0.9, ε_2 (cold plate) = 0.6, ε_3 (shield) = 0.4.



Net radiant heat exchange per m² area:

In the absence of radiation shield the heat flow between plates 1 and 2 is given by

$$(Q_{12})_{net} = \frac{\sigma (T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1}$$

$$= \frac{5.67\left[\left(\dfrac{700}{100}\right)^4 - \left(\dfrac{300}{100}\right)^4\right]}{\dfrac{1}{0.9} + \dfrac{1}{0.6} - 1}$$

$$= \frac{13154.4}{1.777} = \mathbf{7402.6\ W.\ (Ans.)}$$

Percentage reduction in the heat transfer flow:

When a shield is placed between the plates 1 and 2, then

$$(Q_{13})_{net} = (Q_{32})_{net}$$

$$\therefore \quad \frac{A\,\sigma\,(T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_3} - 1} = \frac{A\,\sigma\,(T_3^4 - T_2^4)}{\frac{1}{\varepsilon_3} + \frac{1}{\varepsilon_2} - 1}$$

or,
$$\frac{\left(\frac{700}{100}\right)^4 - \left(\frac{T_3}{100}\right)^4}{\frac{1}{0.9} + \frac{1}{0.4} - 1} = \frac{\left(\frac{T_3}{100}\right)^4 - \left(\frac{300}{100}\right)^4}{\frac{1}{0.4} + \frac{1}{0.6} - 1}$$

or,
$$\frac{2401 - x^4}{1.11 + 25 - 1} = \frac{x^4 - 81}{25 + 1.67 - 1} \qquad \left[\text{where } x = \frac{T_3}{100}\right.$$

or,
$$2401 - x^4 = \frac{25.11}{25.67}(x^4 - 81) = 0.9782 = (x^4 - 81)$$

or,
$$1.9782\,x^4 = 2480.2 \qquad \therefore x^4 = 1253.8$$

or,
$$x = \frac{T_3}{100} = (1253.8)^{1/4} = 5.95 \text{ or } T_3 = 595\text{ K}$$

$$\therefore \quad (Q_{13})_{net} = \frac{\sigma\,(T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_3} - 1} = \frac{5.67\left[\left(\frac{700}{100}\right)^4 - \left(\frac{595}{100}\right)^4\right]}{\frac{1}{0.9} + \frac{1}{0.4} - 1}$$

$$= \frac{6507.2}{25.11} = 259.1\text{ W}$$

$\therefore$ Reduction in heat flow due to shield

$$= (Q_{12})_{net} - (Q_{13})_{net} = 7402.6 - 259.1 = 7143.5\text{ W}$$

or, Percentage reduction $= \frac{7143.5}{7402.6} \times 100$ = **96.5% (Ans.)**

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3(b)

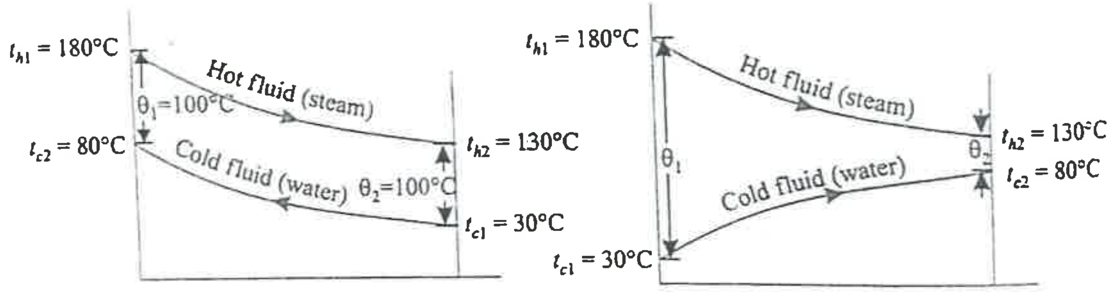
~~Q5(b)~~ A counter-flow double pipe heat exchanger using superheated steam is used to heat water at the rate of 10500 kg/h. The steam enters the heat exchanger at 180°C and leaves at 130°C. The inlet and exit temperatures of water are 30°C and 80°C respectively. If overall heat transfer coefficient from steam to water is 814 W/m²°C, calculate the heat transfer area. What would be the increase in area if the fluid flows were parallel?

Solution. *Given* : $\dot{m}_w\ (= \dot{m}_c) = \dfrac{10500}{3600} = 2.917$ kg/s; $t_{h1} = 180°C$; $t_{h2} = 130°C$; $t_{c1} = 30°C$; $t_{c2} = 80°C$; $U = 814\ W/m^2°C$.

(*i*) *When the flow is counter* :

$$\theta_m = \frac{\theta_1 - \theta_2}{ln\ (\theta_1/\theta_2)}$$

In this $\theta_m = \theta_1 = \theta_2 = 100°C$



(*a*) Counter-flow (*b*) Parallel flow

The heat transfer rate is given by $Q = UA\theta_m$

or. $$m_c \times c_{pc} \times (t_{c2} - t_{c1}) = UA\theta_m$$

or. $$2.917 \times 4.187 \times 10^3 \times (80 - 30) = 814 \times A \times 100$$

or. $$A = \frac{2.917 \times 4.187 \times 10^3\ (80 - 30)}{814 \times 100} = \mathbf{7.5\ m^2} \quad \textbf{(Ans.)}$$

(*ii*) *When the flow is parallel* :

$$\theta_m = \frac{\theta_1 - \theta_2}{\ln\ (\theta_1/\theta_2)} = \frac{(t_{h1} - t_{c1}) - (t_{h2} - t_{c2})}{\ln\ [(t_{h1} - t_{c1})/(t_{h2} - t_{c2})]}$$

$$= \frac{(180 - 30) - (130 - 80)}{\ln\ [(180 - 30)/(130 - 80)]} = \frac{150 - 50}{\ln\ (150/50)} = 91°C$$

Again. $$Q = UA\theta_m$$

or. $$2.917 \times (4.187 \times 10^3) \times (80 - 30) = 814 \times A \times 91$$

$$A = \frac{2.917 \times (4.187 \times 10^3) \times (80 - 30)}{814 \times 91} = 8.24\ m^2$$

$$= \frac{8.24 - 7.5}{7.5} = 0.098\ or\ 9.87\%$$

6b)

~~Q6c)~~ *An egg with mean diameter of 40 mm and initially at 20°C is placed in a boiling water pan for 4 minutes and found to be boiled to the consumer's taste. For how long should a similar egg for same consumer be boiled when taken from a refrigerator at 5°C. Take the following properties for egg:*

$k = 10$ W/m°C, $\rho = 1200$ kg/m³, $c = 2$ kJ/kg°C and h (heat transfer coefficient) = 100 W/m²°C

Use lump theory.

Solution. *Given :* $R = \frac{40}{2} = 20$ mm = 0.02 m; $t_i = 20°C$; $\tau = 4 \times 60 = 240$ s; $k = 10$ W/m°C

$\rho = 1200$ kg/m³; $c = 2$ kJ/kg°C; $h = 100$ W/m²°C.

For using the lump theory, the required condition is $B_i < 0.1$

$$B_i = \frac{h L_c}{k} \text{ where } L_c \text{ is the characteristic length which is given by,}$$

$$L_c = \frac{V \text{ (volume)}}{A_s \text{ (surface area)}} = \frac{\frac{4}{3}\pi R^3}{4\pi R^2} = \frac{R}{3}$$

$$\therefore \quad B_i = \frac{h}{k} \times \frac{R}{3} = \frac{100 \times 0.02}{10 \times 3} = 0.067$$

As $B_i < 0.1$, we can use lump theory.

The temperature variation with time is given by :

$$\frac{t - t_a}{t_i - t_a} = \exp\left[-\frac{hA_s}{\rho Vc}\tau\right]$$

$$\frac{hA_s}{\rho Vc} = \left(\frac{h}{\rho c}\right)\left(\frac{A_s}{V}\right) = \left(\frac{100}{1200 \times 2000}\right)\left(\frac{3}{R}\right)$$

$$= \left(\frac{100}{1200 \times 2000}\right)\left(\frac{3}{0.02}\right) = 0.00625$$

Substituting the values in eqn. (1), we get

$$\frac{t - 100}{20 - 100} = e^{-0.00625 \times 240} = e^{-1.50} = \frac{1}{e^{1.50}} = \frac{1}{4.4817} = 0.223$$

or, $\quad t = 100 + (20 - 100) \times 0.223 = 82.16°C$ say 82°C

Now let us find 'τ' when the given data is : $t_i = 5°C$, $t_a = 100°C$ and $t = 82°C$

Again using eqn. (1), we get

$$\frac{82 - 100}{5 - 100} = e^{-0.00625\,\tau} = \frac{1}{e^{0.00625\,\tau}}$$

or, $\quad 0.1895 = \frac{1}{e^{0.00625\,\tau}} \quad$ or $\quad e^{0.00625\tau} = 5.277$

$$0.00625\tau = 1.6633 \text{ or } \tau = \frac{1.6633}{0.00625} = 266.13s = 4.435 \text{ min}$$