Problems related to Forced Convection - Internal flow

1) When 0.6 kg of water per minute is passed through a tube of 2 cm diameter, it is found to be heated from 20°c to 60°c. The heating is achieved by condensing Steam on the Surface of the tube and Subsequently the Surface temperature of the tube is maintained at 90°c. Determine the length of the tube required for fully developed flow.

Given data:

$$\dot{m} = 0.6\ kg/min$$
$$= 0.6/60$$
$$= 0.01\ kg/s.$$

$$D = 2\ cm = 0.02\ m$$

$$T_{mi} = 20°C$$

$$T_{mo} = 60°C$$

$$T_w = 90°C$$

To find:

(i) L

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Solution:

$$T_m = \frac{T_{m_i} + T_{m_o}}{2}$$

[From HMT Databook Pgno: 124]

$$= \frac{20+60}{2}$$

$$\boxed{T_m = 40°C}$$

Properties of water at 40°C is

$\rho = 995\ kg/m^3$

$\nu = 0.657 \times 10^{-6}\ m^2/s$

$Pr = 4.34.$

$K = 0.6280\ W/mK.$

$C_p = 4178\ J/kgK.$

We know mass flow rate

$$\dot{m} = \rho A U$$

$$0.01 = 995 \times \frac{\pi}{4} \times d^2 \times U$$

$$0.01 = 995 \times \frac{\pi}{4} \times 0.02^2 \times U$$

$$\boxed{U = 0.032\ m/s}$$

$$Re = \frac{UD}{\nu} = \frac{0.032 \times 0.02}{0.657 \times 10^{-6}}$$

$$\boxed{Re = 973.6}$$

So, $Re < 2300$

Hence the flow is Laminar.

So, the Nusselt Number

$$\boxed{Nu = 3.66}$$

Hence const well temperature is maintained

$$Nu = \frac{hD}{K}$$

$$3.66 = \frac{h \times 0.02}{0.628}$$

$$\boxed{h = 114.9 \ W/m^2K}$$

Heat transfer $Q = mc_p(T_{m_o} - T_{m_i})$

$$= 0.01 \times 4178 \times (60 - 20)$$

$$\boxed{Q = 1671.2 \ W}$$

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$$Q = hA(T_w - T_m)$$

$$1671.2 = 114.9 \times (\pi \times D \times L)(90-40)$$

$$1671.2 = 114.9 \times \pi \times 0.02 \times L \times 50$$

$$\boxed{L = 4.63\,m}$$

Result:

$L = 4.63\,m$

2) Water flows through 0.8 cm diameter, 3m long tube at an average temperature of 40°C. The flow of velocity is 0.65 m/s. and tube wall temperature is 140°C. Calculate the average heat transfer coefficient.

Given data:

$D = 0.8\,cm$

$= 0.008\,m$

$L = 3\,m$

$T_m = 40°C$

$U = 0.65\,m/s.$

$T_w = 140°C.$

To find:

h

Solution:

From the given data, $T_m = 40°C$

So, properties of water at $40°C$ is

$\rho = 995\ kg/m^3$

$\nu = 0.657 \times 10^{-6}\ m^2/s$

$Pr = 4.34$

$K = 0.628\ W/mK$

$$Re = \frac{UD}{\nu} = \frac{0.65 \times 0.008}{0.657 \times 10^{-6}}$$

$$\boxed{Re = 7914.76}$$

So, $Re > 2300$

So, the flow is turbulent

$$\frac{L}{D} = \frac{3}{0.008} = 375$$

So, $\frac{L}{D} < 400$

Hence,

$$Nu = 0.036\,(Re)^{0.8}\,(Pr)^{0.33} \times (D/L)^{0.055}$$

$$= 0.036 \times (7914.76)^{0.8} \times (4.34)^{0.33} \times (0.008/3)^{0.055}$$

$$\boxed{Nu = 55.44}$$

$$Nu = \frac{hD}{k}$$

$$55.44 = \frac{h \times 0.008}{0.628}$$

$$\boxed{h = 4352.04\ W/m^2K}$$

Result:

$h = 4352.04\ W/m^2K$.

Problems related to free convection.

Flow over Vertical Plate

1) A vertical plate of 0.75m height is at 170°c and is exposed to air at a temperature of 105°c and one atmosphere. Calculate mean heat transfer coefficient and rate of heat transfer per unit width of the plate.

Given data:

$L = 0.75 m$

$T_w = 170°c$

$T_\infty = 105°c$

$W = 1 m$

To find:

(i) h

(ii) Q.

Solution:

$$T_f = \frac{T_w + T_\infty}{2} = \frac{170 + 105}{2}$$

$$\boxed{T_f = 137.5°c}$$

Since the Temperature value is $T_f = 137.5^\circ C$

But the HMT Data Table does not have direct Value

So, we can use Interpolation method.

$A = 140$ $\quad a = 0.854$

$B = 137.5$ $\quad b = ?$

$c = 120$ $\quad c = 0.898$

$$\frac{A-C}{B-C} = \frac{a-c}{b-c} \Rightarrow \frac{140-120}{137.5-120} = \frac{0.854-0.898}{b-0.898}$$

$$1.143 = \frac{-0.044}{b-0.898}$$

$$b - 0.898 = \frac{-0.044}{1.143}$$

$$b - 0.898 = \cancel{0.314} -0.0385$$

$$\boxed{b = 0.85595}$$

Simultaneously for other Values also do this

For Temperature $T_f = 137.5^\circ C$

$\rho = 0.8595 \ kg/m^3$

$\nu = 27.506 \times 10^{-6} \ m^2/s$.

$Pr = 0.6843$

$K = 0.0347 \ W/mK$.

We know that $\beta = \frac{1}{T_f}$

[T_f must be converted to Kelvin]

$$\beta = \frac{1}{410.5}$$

$T_f = 137.5 + 273$

$\boxed{T_f = 410.5}$

$$\boxed{\beta = 2.4361 \times 10^{-3}\ K^{-1}}$$

$$Gr = \frac{g \times \beta \times L^3 \times \Delta T}{\nu^2}$$

$$Gr = \frac{9.81 \times 2.4361 \times 10^{-3} \times 0.75^3 \times (170 - 105)}{(27.506 \times 10^{-6})^2}$$

$$\boxed{Gr = 8.66 \times 10^8}$$

$$Gr \cdot Pr = 8.66 \times 10^8 \times 0.6843$$

$$\boxed{Gr \cdot Pr = 5.93 \times 10^8}$$

Since, $Gr \cdot Pr < 10^9$

So, the flow is laminar

$$Nu = 0.59\,(Gr \cdot Pr)^{0.25}$$

$$= 0.59\,(5.93 \times 10^8)^{0.25}$$

$$\boxed{Nu = 92.06}$$

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

$$92.06 = \frac{h \times 0.75}{0.0347}$$

$$\boxed{h = 4.23 \ W/m^2K}$$

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

$$= 4.23 \times (0.75 \times 1) \times (170 - 105)$$

$$\boxed{Q = 207.64 \ W}$$

Result:

$Q = 207.64$ W

$h = 4.23$ W/m^{2}K.

2. A vertical plate of 0.7m wide and 1.2m height maintained at a temperature of 90°c in a room at 30°c. Calculate the convective heat loss.

Given data:

$W = 0.7m$

$L = 1.2m$

$T_w = 90°C$

$T_\infty = 30°C$

To find:

Q.

Solution

$$T_f = \frac{T_w + T_\infty}{2}$$

$$= \frac{90 + 30}{2}$$

$$\boxed{T_f = 60^\circ C}$$

Properties of air at $60^\circ C$. [From HMT Data book Pg no: 34]

$\rho = 1.06\ kg/m^3$

$\nu = 18.97 \times 10^{-6}\ m^2/s$

$Pr = 0.696$

$K = 0.02896\ W/mK$.

$$\beta = \frac{1}{T_f} = \frac{1}{60+273}$$

$$\boxed{\beta = 3.003 \times 10^{-3}\ K^{-1}}$$

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$$Gr = \frac{g \times \beta \times L^3 \times \Delta T}{\nu^2}$$

$$= \frac{9.81 \times 3.003 \times 10^{-3} \times 1.2^3 \times (90-30)}{(18.97 \times 10^{-6})^2}$$

$$\boxed{Gr = 8.49 \times 10^9}$$

$Gr \times Pr = 8.49 \times 10^9 \times 0.696$

$$\boxed{Gr\,Pr = 5.91 \times 10^9}$$

$Gr \cdot Pr > 10^9$

So, the flow is turbulent

$$Nu = 0.10\,(Gr\,Pr)^{0.333}$$

$$= 0.10 \times (5.91 \times 10^9)^{0.333}$$

$$\boxed{Nu = 179.42}$$

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

$$179.42 = \frac{h \times 1.2}{0.02896}$$

$$\boxed{h = 4.33\ W/m^2K}$$

$Q = hA\Delta T$

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

$= 4.33 \times (1.2 \times 0.7) \times (90 - 30)$

$\boxed{Q = 218.23 \text{ W}}$

Result:

$Q = 218.23 \text{ W}$

Example 13.12: *A furnace of 2 m × 1.5 m × 1.5 m size contains gases at 1500 K while the walls are at 500 K. The gas contains 18% of CO_2 and 12% of water vapour by volume. Determine the heat exchange from the gases to the walls. The total pressure is 2 atm. Assume black surface.*

Solution: The characteristic length = 3.6 volume/surface area

$$= (3.6 \times 1.5 \times 1.5 \times 2)/(2(1.5 \times 1.5 + 2 \times 1.5 \times 2)) = 0.982 \text{ m}$$

The partial pressures are

$$C_{CO_2} = 0.18 \times 2 = 0.36, \qquad \therefore \quad Pl_{CO_2} = 0.354$$

$$P_{H_2O} = 0.12 \times 2 = 0.24 \qquad \therefore \quad Pl_{H_2O} = 0.236$$

The values of emissivities as read from chart for values of 1500 K and Pl

$$\varepsilon_{CO_2} = 0.145, \ \varepsilon_{H_2O} = \mathbf{0.155}$$

The correction factors for pressure, as the total pressure is 2 atm are

$$C_{CO_2} = 1.1 \text{ (at 2 and 0.354)}$$

$$C_{H_2O} = 1.42 \text{ (at 1.12 and 0.236)}$$

Correction for the simultaneous presence of the two gases:

$$P_{H_2O}/(P_{CO_2} + P_{H_2O}) = 0.24/(0.36 + 0.24) = 0.4$$

$$Pl_{CO_2} + Pl_{H_2O} = 0.354 + 0.236 = 0.590$$

$$\Delta\varepsilon = 0.047$$

$$\therefore \quad \varepsilon_g = 1.1 \times 0.145 + 1.42 \times 0.155 - 0.047 = \mathbf{0.3326}$$

To determine the absorptivity, the temperature of the wall has to be used. Reading corresponding to 500 K and $P1 = pl \times (T_s/T_g)$ *i.e.*, for $Pl_{CO_2} = 0.118$ and $Pl_{H_2O} = 0.079$

$$\varepsilon_{CO_2} = 0.105, \ \varepsilon_{H_2O} = \mathbf{0.17}$$

The correction factor are:

$$C_{CO_2} = 1.3 \text{ (at 2 atm and 0.118)}$$

$$C_{H_2O} = 1.58 \text{ (at 1.12 atm and 0.079)}$$

The subtractive correction factor is read at

0.4 and $(0.118 + 0.079 = 0.197)$, $\Delta\varepsilon = 0.026$

$$\therefore \quad \alpha_g = 1.3 \times 0.105 \times \left(\frac{1500}{500}\right)^{0.65} + 1.58 \times 0.17 \times \left(\frac{1500}{500}\right)^{0.45} - 0.026$$

$$= 0.2788 + 0.4404 - 0.026 = \mathbf{0.6932}$$

Heat exchange $= \sigma A_s \left[\varepsilon_g T_g^4 - \alpha_g T_s^4\right]$

$$= 5.67 \times 16.5 \left[0.3326 \times \left(\frac{1500}{100}\right)^4 - 0.6932\left(\frac{500}{100}\right)^4\right]$$

$$= \mathbf{1.5379 \times 10^6 \ W.}$$

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Example 13.13: *Determine the shape factor from the floor of a furnace of 1 m × 2 m size to the side surfaces and to the roof.*

Solution: The shape factors (**Also charts and Tables from Data Book are use problems).**

F_{1-2}, F_{1-3} and F_{1-4} are to be determined. Refer Fig. Ex. 13.13.

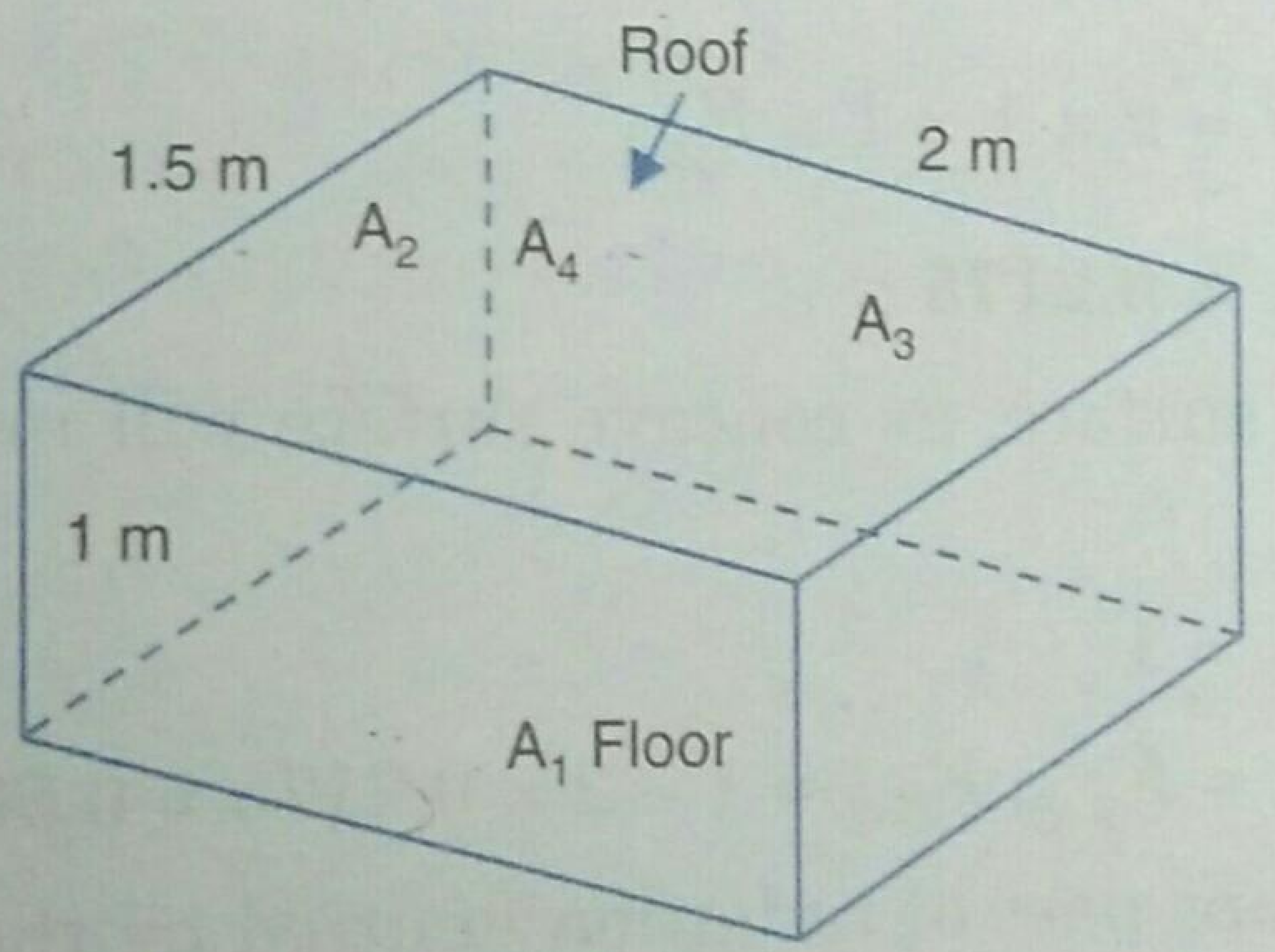

Fig. Ex. 13.13

The parameters for perpendicular surfaces are (**for floor to end wall**)

Z = height of the vertical surface/width = 1/1.5 = 0.67

Y = length of the horizontal surface/width = 2/1.5 = 1.33

As read from the chart the corresponding value of $\mathbf{F_{1-2}}$ = **0.140**

For F_{1-3} (**Floor to side wall**)

Z = 1/2.0 = 0.5

Y = 1.5/2.0 = 0.75

The value of F_{1-3} read from chart = **0.180**

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For parallel rectangles (**floor to ceiling,** F_{1-4}) the parameters

X = longer side/distance between planes = 2/1 = 2.0

Y = shorter side/distance between planes = 1.5/1 = 1.5

The corresponding value F_{1-4} = **0.36** (from chart)

Check: The sum of all shape factors should be equal to one $(2 \times 0.14 + 2 \times 0.18 + 0.36) = 1$

Summation rule and symmetry rules are applied in this case.

Heat exchange between surfaces can be determined if temperatures are specified, provided the surfaces are black (by equations discussed so far).

Example 13.14: *Determine the shape factor from the base of a cylinder to the curved surface. Also find the shape factor from curved surface to base and the curved surface to itself.*

Solution: The diameter is 1 m and height is also 1 m. The base (1) is enclosed by the top (3) and curved surface (2) (Fig. Ex. 13.14)

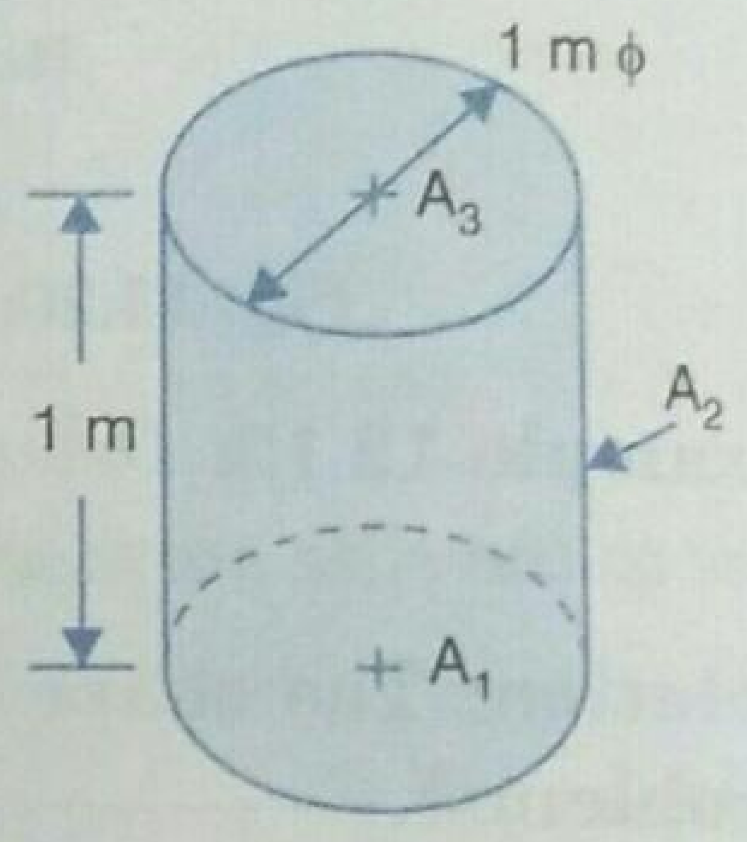

Fig. Ex. 13.14

$$\therefore \qquad F_{1-2} + F_{1-3} = 1$$

F_{1-3} can be determined by using the chart for parallel disks. The ratio, diameter/distance between planes = 1.

The corresponding value of shape factor **is 0.17.** Base to curved surface is

$$\therefore \qquad \mathbf{F_{1-2} = 1.0 - 0.17 = 0.83}$$

Using reciprocity theorem

$$A_1F_{1-2} = A_2F_{2-1}$$

$$\frac{\pi \times 1 \times 1}{4} \times 0.87 = \pi \times 1 \times 1 \times F_{2-1}$$

$$\therefore \qquad \mathbf{F_{2-1} = 0.2175}$$

Considering the curved surface, as concave surface will intercept some radiation from the surface itself.

$$F_{2-1} + F_{2-3} + F_{2-2} = 1$$

As $\qquad \mathbf{F_{2-1}} = F_{2-3}, F_{2-2} = 1 - 2 \times 0.2175 = \mathbf{0.565}$

Concave surfaces intercept part of radiation emitted by themselves. Here it intercepts more than half of the radiation.

Example 13.15: *Determine the shape factor from the surface 1 to surface 3 shown in Fig. Ex. 13.15 (vertical plane and non touching horizontal surface).*

Solution: Denoting surface in between as 2 and using equation (13.27)

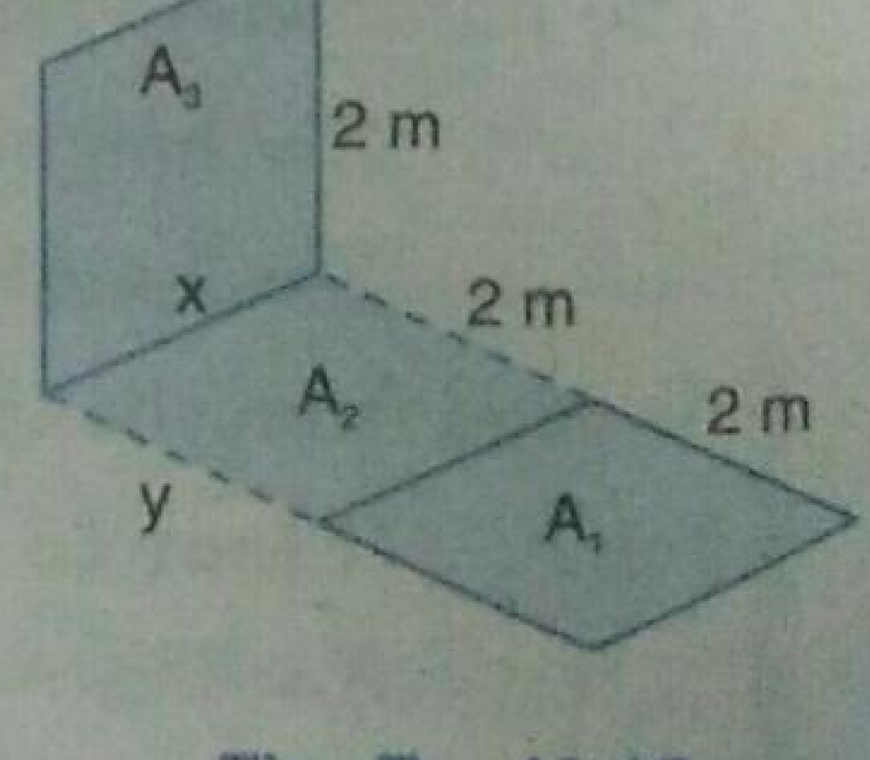

Fig. Ex. 13.15

$$(A_1 + A_2)\, F_{1,2-3} = A_1\, F_{1-3} + A_2\, F_{2-3}$$

F_{12-3} and F_{2-3} can be determined

Using the chart Fig. 13.17

For $\qquad F_{1,\,2-3},\ Y = y/x = 4/2 = 2$

$$Z = z/x = 2/2 = 1$$

$\therefore$ $\mathbf{F}_{1,\,2\text{-}3} = \mathbf{0.11643}$

For $F_{2\text{-}3}$, $Y = 2/2 = 1$, $Z = 2/2 = 1$

$\mathbf{F}_{2\text{-}3} = \mathbf{0.20004}$

Substituting

$$(2 \times 2 + 2 \times 2)\ 0.11643 = 2 \times 2F_{1\text{-}3} + 2 \times 2 \times 0.20004$$

$\therefore$ $\mathbf{F}_{1\text{-}3} = \mathbf{0.03282}$

To find $F_{3\text{-}1}$, $A_1 F_{1\text{-}3} = A_3 F_{3\text{-}1}$. In this case, the areas are equal and so $\mathbf{F}_{3\text{-}1} = \mathbf{0.03282}$.

Example 13.16: *Determine the shape factor between the floor and the 45° roof over a long corridor. The width is 2 m and the height on the lower sides is 2 m. (Fig. Ex. 13.16)*

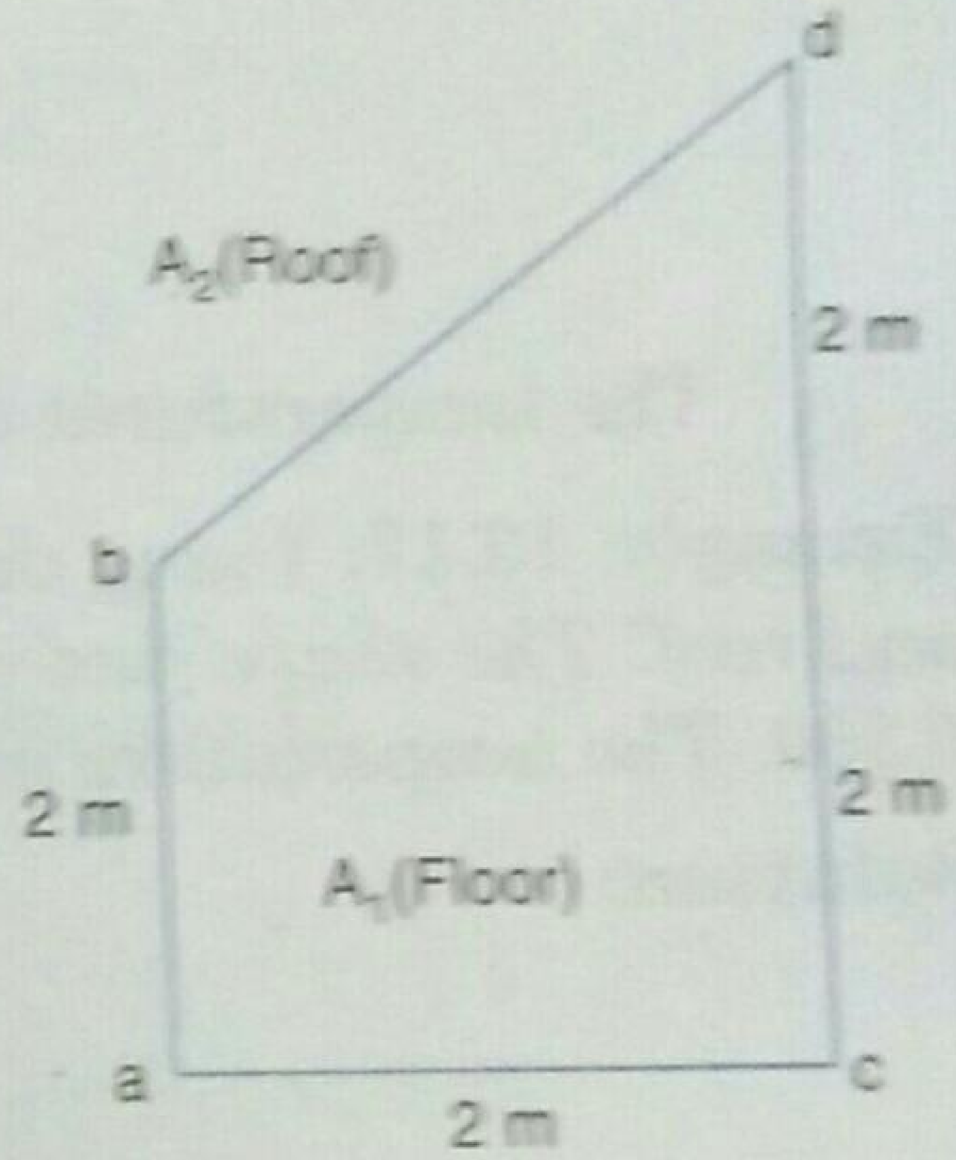

Fig. Ex. 13.16

Solution: In this case the crossed string method is to be used. (Approximate)

$$F_{1\text{-}2} = [(ad + bc) - (ab + cd)]/2L$$

$$ad = \sqrt{(2^2 + 4^2)} = 4.472$$

$$bc = \sqrt{(2^2 + 2^2)} = 2.828$$

$$\mathbf{F}_{1\text{-}.2} = [4.472 + 2.828 - (2 + 4)]/2 \times 2 = \mathbf{0.325.}$$

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... and Q goes to heating of the reradiating surfaces.

Example 13.19: *A furnace is in the shape of a cylinder of 1 m dia and 1 m height. The base is at 1000 K while the top is at 600 K. The curved surface is well insulated so that it can be taken as non absorbing reradiating surface (see example 13.14 for shape factors and example 13.18 for emissive power values). Determine the heat exchange between the base and the top with and without the reradiating surface.*

Solution: From example 13.14 the shape factor from base to top is found as 0.17. The shape factor form base or top to the curved surface is 0.83. The equivalent circuit is shown in Fig. Ex. 13.19.

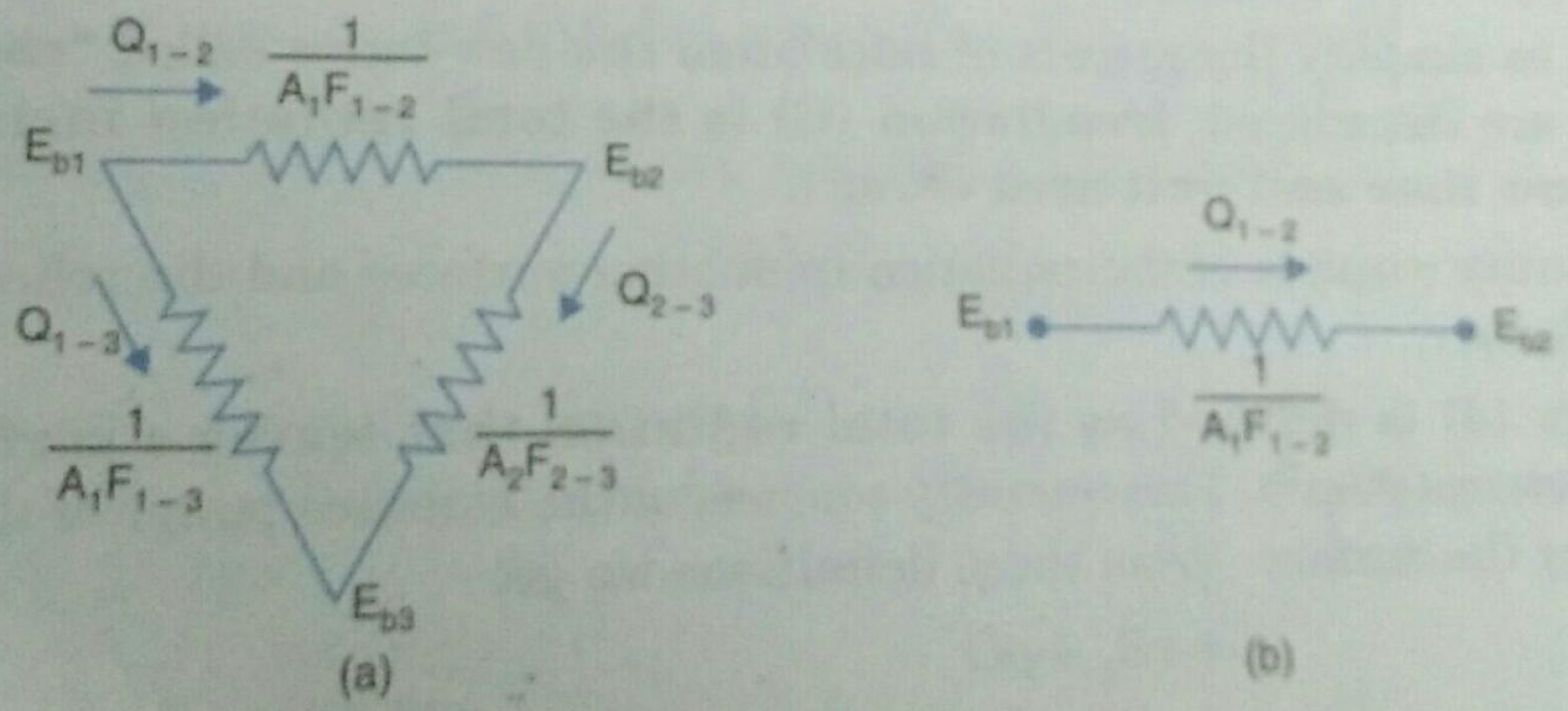

Fig. Ex. 13.19 (a) Circuit with reradiation (b) Circuit without reradiation

$$E_{b1} = 56700 \text{ W/m}^2$$
$$E_{b2} = 7348.32 \text{ W/m}^2$$

$$\frac{1}{A_1F_{1-2}} = \frac{1}{\frac{\pi \times 1^2}{4} \times 0.17} = 7.49$$

$$\frac{1}{A_2F_{2-3}} = \frac{1}{A_1F_{1-3}} = \frac{1}{\frac{\pi \times 1^2}{4} \times 0.83} = 1.534$$

With reradiation:

The equivalent resistance

$$R = \frac{1}{\frac{1}{7.49} + \frac{1}{2 \times 1.534}} = 2.1765$$

$$\therefore \qquad \mathbf{Q} = \frac{56700 - 7348.32}{2.1765} = \mathbf{22675\ W}$$

Without reradiation:

$$\mathbf{Q} = \frac{56700 - 7348.32}{7.49} = \mathbf{6589\ W}$$

This is about 30% of the heat flow with reradiation.

The **apparent shape factor** from base to top surface is

$$\mathbf{F_{1\text{-}2}} = \frac{22675}{56700} \times \frac{4}{\pi \times 1 \times 1} = \mathbf{0.5092}. \text{ (Compared to 0.17)}$$

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So the values ...

Example 13.22: *Consider the cylindrical furnace of example 13.19. If emissivities of the base and top surfaces are 0.8 and 0.5, determine the heat exchange.*

Solution: As determined in the example shape factor from the base to the top is 0.17.

$$\therefore \quad Q = \frac{56700 - 7348.32}{\dfrac{(1-0.8)4}{(\pi \times 1 \times 1) \times 0.8} + \dfrac{1 \times 4}{\pi \times 1 \times 1 \times 0.17} + \dfrac{(1-0.5)4}{\pi \times 1 \times 1 \times 0.5}} = 5434.5 \text{ W}$$

Compared to 6589 for black surface.

Example 13.23: *Two large parallel planes are at 1000 K and 600 K. Determine the heat exchange per unit area. (i) if surfaces are black (ii) if the hot one has an emissivity of 0.8 and the cooler one 0.5 (iii) if a large plate is inserted between these two, the plate having an emissivity of 0.2.*

Solution: Case (*i*): The equivalent circuit is shown in Fig. Ex. 13.23(*a*)

$$Q = \sigma A\, F_{1-2}\,(T_1^4 - T_2^4). \text{ As } F_{1-2} = 1$$

for large parallel surfaces, considering unit area.

$$\frac{Q}{A} = 5.67 \times 1 \left[\left(\frac{1000}{100}\right)^4 - \left(\frac{600}{100}\right)^4\right] = 49352 \text{ W/m}^2$$

Case (*ii*): The equivalent circuit is shown in Fig. Ex. 13.23(*b*)

$$\frac{Q}{A} = \frac{(E_{b1} - E_{b2})}{\dfrac{1-\varepsilon_1}{A_1\varepsilon_1} + \dfrac{1}{A_1F_{1-2}} + \dfrac{1-\varepsilon_2}{A_2\varepsilon_2}} = \frac{56700 - 7348.32}{\dfrac{0.2}{1 \times 0.8} + 1 + \dfrac{0.5}{0.5}} = 21934 \text{ W/m}^2$$

Case (*iii*): The equivalent circuit is shown in Fig. 13.23(*c*)

$$\frac{Q}{A} = \frac{56700 - 7348.32}{\dfrac{1-0.8}{0.8} + 1 + \dfrac{1-0.2}{0.2} + \dfrac{1-0.2}{0.2} + 1 + \dfrac{1-0.5}{0.5}} = 4387 \text{ W/m}^2$$

Problems Related to Forced Convection - External flow

Flow over plate

1) Air at 25°C flow over a flat plate at a speed of 5 m/s and heated at 135°C. The plate is 3m long and 1.5 m wide. Calculate the local heat transfer coefficient at x = 0.5 m and the heat transferred from the first 0.5 m of the plate.

Given data:

$T_\infty = 25°C$

$T_w = 135°C$

$U = 5\ m/s$

$L = 3m \Rightarrow L = 0.5m$

$W = 1.5m$

To find:

* Local heat transfer coefficient
* Heat transfer (Q at 0.5m)

Solution:

$$T_f = \frac{T_w + T_\infty}{2} = \frac{135+25}{2}$$

$$\boxed{T_f = 80°C}$$

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From HMT Databook, [Pg no: 34]

For the properties of air at 80°C

$\rho = 1 \, kg/m^3$

$\nu = 21.09 \times 10^{-6} \, m^2/s$

$Pr = 0.692$

$K = 0.03047 \, W/mK$

$$Re = \frac{UL}{\nu} = \frac{5 \times 0.5}{21.09 \times 10^{-6}}$$

$$Re = 1.186 \times 10^5$$

Since, Re is $< 5 \times 10^5$,

So the flow is Laminar flow

Local Nusselt Number [from HMT Databook Pg no: 113]

$$Nu_x = 0.332 \, (Re)^{0.5} \, (Pr)^{0.333}$$

$$= 0.332 \times (1.186 \times 10^5)^{0.5} \, (0.692)^{0.333}$$

$$\boxed{Nu_x = 101.3}$$

$$Nu_x = \frac{h_x \times L}{k}$$

$$101.3 = \frac{h_x \times 0.5}{0.03047}$$

$$\boxed{h_x = 6.17\ W/m^2K}$$

Average heat transfer coefficient

$$h = 2 \times h_x$$

$$= 2 \times 6.17$$

$$\boxed{h = 12.34\ W/m^2K}$$

Heat transfer $Q = hA(T_w - T_\infty)$

$$= 12.34 \times (1.5 \times 0.5) \times (135 - 25)$$

$$\boxed{Q = 1018.16\ W}$$

Result:

(i) $h_x = 6.17\ W/m^2K.$

$h = 12.34\ W/m^2K.$

(ii) $Q = 1018.16\ W$

2. Air at 20°c and one atmosphere flows over a flat plate at 35 m/s. The plate is 75 cm long and is maintained at 60°c. Calculate the heat transfer per unit width of the plate. Also calculate the boundary layer thickness at the end of the plate assuming it to develop from the leading edge of the plate.

Given data:

$$T_\infty = 20^\circ C$$

$$U = 35\ m/s$$

$$L = 75\ cm = 0.75\ m$$

$$T_w = 60^\circ C$$

$$W = 1m$$

To find:

(i) Q

(ii) δ_x

Solution:

$$T_f = \frac{T_w + T_\infty}{2} = \frac{60+20}{2}$$

$$\boxed{T_f = 40^\circ C}$$

From HMT Databook,

from HMT data book
Pg no : 34.

The properties of air at 40°C

$\rho = 1.128\ kg/m^3$

$\nu = 16.96 \times 10^{-6}\ m^2/s$.

$P_r = 0.699$

$k = 0.02756\ W/mK$.

$$Re = \frac{UL}{\nu} = \frac{35 \times 0.75}{16.96 \times 10^{-6}}$$

$$Re = 15.73 \times 10^5$$

Since $Re > 5 \times 10^5$

So, the flow is turbulent

From HMT Databook Pgno : 114,

$$Nu_x = 0.0296 \times Re^{0.8} \times P_r^{0.33}$$

$$= 0.0296 \times (15.73 \times 10^5)^{0.8} \times (0.699)^{0.33}$$

$$\boxed{Nu_x = 2384}$$

$$Nu_x = \frac{h_x \times L}{k}$$

$$2384 = \frac{h_x \times 0.75}{0.02756}$$

$$\boxed{h_x = 87.6 \ W/m^2K}$$

Average heat transfer coefficient

$$h = 1.25 \ h_x$$

$$= 1.25 \times 87.6$$

$$\boxed{h = 109.5 \ W/m^2K}$$

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

$$= 109.5 \times (0.75 \times 1)(60-20)$$

$$\boxed{Q = 3285.16 \ W}$$

Boundary Layer Thickness

$$\delta = 0.381 \times x \times (Re)^{-0.2}$$

$$\boxed{x = L}$$

$$= 0.381 \times 0.75 \times (15.73 \times 10^5)^{-0.2}$$

$$\boxed{\delta = 0.0165 \ m}$$

Result:

(i) $Q = 3285.16 \ W$

(ii) $\delta = 0.0165 \ m$