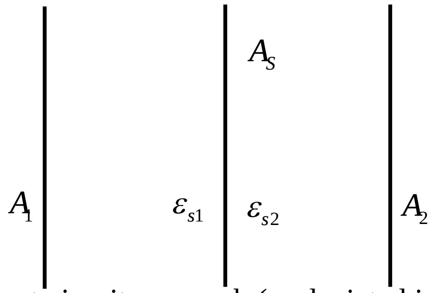
Model solution for Hear Transfer Class Test - II

1. (a)



Considering unit area and equivalent circuit approach (as depicted in the above scematic), we car write the heat transfer rate

$$Q = \frac{E_{b1} - E_{b2}}{\frac{1-\varepsilon_1}{A_1\varepsilon_1} + \frac{1}{A_1F_{1-s}} + \frac{1-\varepsilon_{s1}}{A_s\varepsilon_{s1}} + \frac{1-\varepsilon_{s2}}{A_s\varepsilon_{s2}} + \frac{1}{A_1F_{s-2}} + \frac{1-\varepsilon_2}{A_2\varepsilon_2}}$$

Substituting different terms, we can obtain

$$Q = \frac{5.67\left(10^4 - 4^4\right)}{\frac{1-0.8}{0.8} + 1 + \frac{1-0.05}{0.05} + \frac{1-0.6}{0.6} + 1 + \frac{1-0.8}{0.8}} = 2492.41W$$

Shield temperature can be determined as :

$$2492.41 = \frac{E_{b1} - E_{bs}}{\frac{1-\varepsilon_1}{\varepsilon_1} + \frac{1}{F_{1-2}} + \frac{1-\varepsilon_s}{\varepsilon_s}}, \text{ where } \varepsilon_s = 0.05$$

Thus, $2492.41 = \dfrac{5.67\left[10^4 - \left(\dfrac{T_s}{100}\right)^4\right]}{\dfrac{1-0.8}{0.8} + 1 + \dfrac{1-0.05}{0.05}} \Rightarrow T_s = 575.7\,\text{K}$

If the installation is wrong, the total resistance for radiation heat transfer is the same. Temperature of the shield can be obtained as:

$$2492.41 = \frac{5.67\left[10^4 - \left(\frac{T_s}{100}\right)^4\right]}{\frac{1-0.8}{0.8} + 1 + \frac{1-0.6}{0.6}} \Rightarrow T_s = 978.2\,\text{K}$$

(b) The resistance (radiation between two concentric cylinders) depends on the diameters . So the radius of the intermediate cylinder (Radiation Shield) will affect the rate of heat transfer. The heat transfer between two concentric cylinder is given by:

$$q_{12} = \frac{\sigma_{A1}\left(T_1^4 - T_2^4\right)}{\frac{1}{\varepsilon_1} + \frac{1-\varepsilon_2}{\varepsilon_2}\left(\frac{r_1}{r_2}\right)}$$

which clearly shows the dependence on radius.

2. (a) Considering viscosity $\mu = 0.04$ Pa s, the Reynolds number of the flow can be obtained as

$$Re = \frac{\rho VD}{\mu} = \frac{865 \times 3 \times \frac{1}{100}}{0.04} = 649$$

Thus, the flow is laminar, fully developed. Tube surface is maintained at $40\,^{o}C$. For this condition the average Nusselt number is $\overline{Nu}_D = 3.66$. Using this we can obtain the average heat transfer coefficient as

$$\frac{\overline{h}D}{k} = 3.66$$

$$\Rightarrow \overline{h} = \frac{3.66 \times k}{D} = \frac{3.66 \times 0.14}{\frac{1}{100}} = 3.66 \times 0.14 \times 100 \ \text{W/m}^2\text{-K}$$

$$\Rightarrow \overline{h} = 51.24\ \text{W/m}^2\text{-K}$$

Mass flow rate can be obtained as

$$\dot{m} = 865 \times \left\{\frac{\pi}{4} \times \left(\frac{1}{100}\right)^2\right\} \times 3 \ \text{kg/s} = 0.204\ \text{kg/s}.$$

Now, tube length can be obtained from the following equation

$$\ln\left(\frac{T_s - T_e}{T_s - T_i}\right) = -\frac{\bar{h}A}{\dot{m}c_p}$$

$$\Rightarrow \ln\left(\frac{40-45}{40-60}\right) = -\frac{51.24 \times \pi \times \frac{1}{100} \times L}{0.204 \times 1.78 \times 1000}$$

$$\Rightarrow L = 312.7 \text{ m.}$$

(b) For the case of forced convection the local Nusselt number is $Nu_x = \frac{h_x x}{k} = 0.332\, Re_x^{1/2}\, \mathrm{Pr}^{1/3}$, and average Nusselt number is $\overline{Nu}_H = \frac{\bar{h}_H H}{k} = 0.664\, Re_L^{1/2}\, \mathrm{Pr}^{1/3}$. Using these one can obtain $\frac{Nu_H}{\overline{Nu}_H} = \frac{1}{2}$, which means $\frac{h_H}{\bar{h}_H} = \frac{1}{2}$. Similarly, for the case of natural convection over vertical flat plate, $\frac{Nu_H}{\overline{Nu}_H} = \frac{3}{4}$, which means $\frac{h_H}{\bar{h}_H} = \frac{3}{4}$. The variation of $\frac{h_x}{\bar{h}_H}$ will be some nonlinear function (e.g. for the case of forced convection it can be obtained as $\frac{h_x}{\bar{h}_H} = \frac{1}{2}\sqrt{\frac{H}{x}}$). The variation of $\frac{h_x}{\bar{h}_H}$ along the plate height can be shown in the following way: