Thermodynamics and Heat Transfer LE6 Part 2
Nguyen Xuan Binh 887799

Problem 1: Find the heat transfer per unit area through the composite wall in Figure 1. Assume one dimensional heat flow (20 points).

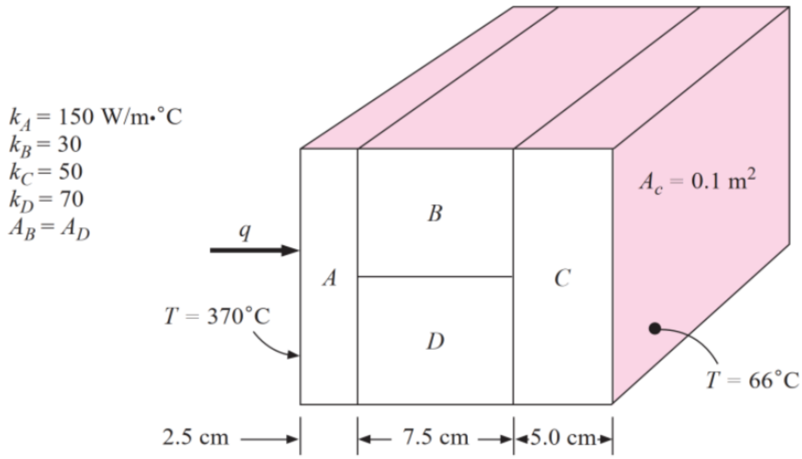

Figure 1

Problem 1:

Formula: $\dot{Q}_{cond,wall} = \dfrac{T_1 - T_2}{R_{wall}}$, $R_{wall} = \dfrac{L}{kA}$

- $R_{wall,A} = \dfrac{0.025\,m}{150\ W/m°C \times 0.1\,m^2} = 0.1667 \times 10^{-2}$ (C/W)
- $R_{wall,B} = \dfrac{0.075\,m}{30\ W/m°C \times \left(\frac{0.1}{2}\right) m^2} = 0.05$ C/W
- $R_{wall,C} = \dfrac{0.05\,m}{50\ W/m°C \times 0.1\,m^2} = 0.01$ C/W
- $R_{wall,D} = \dfrac{0.075\,m}{70\ W/m°C \times \left(\frac{0.1}{2}\right) m^2} = 0.02143$ C/W

$\Rightarrow \Sigma R_{wall} = R_A + \dfrac{R_B R_D}{R_B + R_D} + R_C = 0.02667$ C/W

The heat transfer per unit area through the composite wall would be:

$\dot{Q}_{wall} = \dfrac{T_1 - T_2}{\Sigma R_{wall}} = \dfrac{370°C - 66°C}{0.02667\ C/W} = 11398.57$ W (answer)

Problem 2: A steel tube having k = 46 W/m.◦C has an inside diameter of 3.0 cm and a tube wall thickness of 2 mm. A fluid flows on the inside of the tube producing a convection coefficient of 1500 W/m2.◦C on the inside surface, while a second fluid flows across the outside of the tube producing a convection coefficient of 197 W/m2.◦C on the outside tube surface. The inside fluid temperature is 223◦C while the outside fluid temperature is 57◦C. Calculate the heat lost by the tube per meter of length (15 points).

Problem 2:

$k = 46\ W/m°C$, $d_{in} = 3cm$, thickness $= 2mm \Rightarrow d_{out} = 3.4cm$

$h_{in} = 1500\ W/m^2°C$, $h_{out} = 197\ W/m^2°C$ $\Rightarrow r_{in} = 1.5cm$, $r_{out} = 1.7\ cm$

$T_{in} = 223°C$, $T_{out} = 57°C$ $\Rightarrow$ find heat loss / meter

We have: $R_{total} = R_{conv,1} + R_{cyl} + R_{conv,2}$

$$= \frac{1}{(2\pi r_{in} L) h_{in}} + \frac{\ln(r_{out}/r_{in})}{2\pi L k} + \frac{1}{(2\pi r_{out} L) h_{out}}$$

$$= \left[\frac{1}{0.03m \cdot \pi \cdot 1500} + \frac{\ln(0.017/0.015)}{2\pi \cdot 46} + \frac{1}{0.034m \cdot \pi \cdot 197}\right] \frac{1}{L}$$

$$= (0.0070735 + 0.000433 + 0.047523)\ 1/L$$

$$= 0.055029 \cdot 1/L$$

The heat loss by the tube per meter of length is

$$\frac{\dot{Q}}{L} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{total}\ L} = \frac{223 - 57}{0.055029\ L \cdot \frac{1}{L}} = 3016.59\ W/m \text{ (answer)}$$

Problem 3: A spherical tank, 1m in diameter, is maintained at a temperature of 120∘C and exposed to a convection environment. With h = 25 W/m2.∘C and T∞ = 15∘C, what thickness of urethane foam should be added to ensure that the outer temperature of the insulation does not exceed 40∘C? What percentage reduction in heat loss results from installing this insulation (15 points)?

Problem 3:

$T_{tank} = 120^\circ C$, $T_\infty = 15^\circ C$, $h = 25\ W/m^2\,^\circ C$, $k_{foam} = 0.02\ W/m\,^\circ C$

$\Delta x = ?$ so T_{out} not exceed $40^\circ C$. % reduction in $\dot{Q}$? $d = 1m$

- Heat convection

$$\dot{Q}_{conv} = hA(T_{tank} - T_\infty) = 25 \cdot \left(4\pi \left(\frac{1m}{2}\right)^2\right)(120^\circ C - 15^\circ C)$$
$$= 8246.68\ W$$

Without the insulation by urethane foam, the heat transfer rate is $\dot{Q} = 8246.68W$

- With insulation by the urethane foam

Heat conduction: $$\dot{Q}_{cond} = \frac{4\pi k\, r_{out}\, r_{in}\,(T_{tank} - T_{max})}{r_{out} - r_{in}}$$
$$= \frac{4\pi\, 0.02 \times r_{out} \times 0.5\,(120 - 40)}{r_{out} - 0.5} = \frac{10.053\, r_{out}}{r_{out} - 0.5}$$

Heat convection: $$\dot{Q}_{conv} = hA(T_{max} - T_\infty) = 4\pi r_{out}^2 \cdot h\,(T_{max} - T_\infty)$$
$$= 4\pi r_{out}^2\, 25\,(40^\circ C - 15^\circ C) = 7853.98\, r_{out}^2$$

The heat transfer of the convection enviroment is the same as the conduction of heat through the sphere $\Rightarrow \dfrac{10.053\, r_{out}}{r_{out} - 0.5} = 7853.98\, r_{out}^2$

$\Rightarrow r_{out} \approx 0.502\,m$

$\Rightarrow$ Thickness of urethane foam should be: $\Delta x = r_{out} - r_{in} = 0.502 - 0.5\ (m)$

$= 2\,mm$ (answer)

With the insulation by the foam, the heat transfer rate is

$$\dot{Q}_{conv} = 7853.98\, r_{out}^2 = 7853.98 \times (0.502)^2 = 1979.234\ W$$

Percentage reduction in heat loss from installing the insulation is

$$\%\dot{Q}_{reduce} = \frac{\dot{Q}_{before} - \dot{Q}_{after}}{\dot{Q}_{before}} \times 100\% = \frac{8246 - 1979.234}{8246} \times 100\%$$

$= 75.99\%$ (answer)