

46.34 A 50 ft length of hot water piping with 1 in O.D. runs uninsulated through an open basement. The ambient temperature and average temperature of the walls and other surfaces is 60°F. The convective heat transfer coefficient is $6 \frac{Btu}{hr \cdot ft^2 \cdot ^\circ F}$. The average surface temperature of the pipe is 120°F. The emissivity for the pipe is 0.9. What is the total heat loss?

- A. $800 \frac{Btu}{hr}$
- B. $4680 \frac{Btu}{hr}$
- C. $5520 \frac{Btu}{hr}$
- D. $9640 \frac{Btu}{hr}$

Heat is lost from the pipe through both **Convection** and **Radiation**. For combined heat transfer, add the convection and radiation equations together.

$$\dot{Q}_{conv} = hA\Delta T$$

$$\dot{Q}_{rad} = \sigma \varepsilon A (T_s^4 - T_\infty^4)$$

$$\dot{Q}_t = \dot{Q}_{conv} + \dot{Q}_{rad} = hA\Delta T + \sigma \varepsilon A (T_s^4 - T_\infty^4)$$

Area is common to both equations and may be factored out of the combined equation.

$$\dot{Q}_t = A (h\Delta T + \sigma \varepsilon (T_s^4 - T_\infty^4))$$

Calculate the external surface area of the pipe.

$$A_s = \pi DL = \pi \left(\frac{1 \text{ in}}{12 \frac{\text{in}}{\text{ft}}} \right) (50 \text{ ft}) = 13.1 \text{ ft}^2$$

Substitute the convection coefficient, surface temperature, and surrounding air temperature into the convection portion of the equation. Substitute the **Stefan-Boltzmann Constant**, emissivity, pipe surface temperature, and the temperature of the surrounding surfaces in the radiation portion of the equation. Be sure to use absolute temperatures ie. Rankine for radiation. Determine the total heat loss.

$$\dot{Q}_t = (13.1 \text{ ft}^2) \times$$

$$\left[\left(6 \frac{Btu}{hr \cdot ft^2 \cdot ^\circ F} \right) (120^\circ F - 60^\circ F) + \left(0.1713 \times 10^{-8} \frac{Btu}{hr \cdot ft^2 \cdot ^\circ R^4} \right) (0.9) \left((580^\circ R)^4 - (520^\circ R)^4 \right) \right]$$

$$\dot{Q}_t = 5525 \frac{Btu}{hr}$$

Answer C

46.35 A variable frequency drive producing 100W of waste heat during continuous operation is housed in an insulated sheet metal enclosure mounted in a machine room. The insulation is $\frac{1}{8}$ in thick with a thermal conductivity of $0.2 \frac{Btu}{hr \cdot ft \cdot ^\circ F}$. The thermal resistance of the sheet metal is negligible. The surface area of the enclosure is $8 ft^2$. The machine room is maintained at $76^\circ F$. The film coefficients both inside and outside the enclosure are $4 \frac{Btu}{hr \cdot ft^2 \cdot ^\circ F}$. What is the steady state temperature inside the enclosure?

- A. $52^\circ F$
- B. $88^\circ F$
- C. $100^\circ F$
- D. $112^\circ F$

Model the enclosure as a **Composite Wall** with 3 layers: 2 films and the insulation. Negligible thermal resistance is provided by the sheet metal. The total heat transfer through the composite wall may be described by the equation $\dot{Q} = UA\Delta T$, where the overall coefficient of heat transfer, $U = \frac{1}{R_T}$, and where R_T is the total thermal resistance. Determine the total thermal resistance by adding the individual thermal resistances in series.

$$R_T = \frac{1}{h_i} + \frac{L_{ins}}{k_{ins}} + \frac{1}{h_o}$$

$$R_T = \frac{1}{\left(4 \frac{Btu}{hr \cdot ft^2 \cdot ^\circ F}\right)} + \frac{\left(\frac{1}{8} in\right) \left(\frac{1 ft}{12 in}\right)}{0.2 \frac{Btu}{hr \cdot ft \cdot ^\circ F}} + \frac{1}{\left(4 \frac{Btu}{hr \cdot ft^2 \cdot ^\circ F}\right)} = 0.55 \frac{hr \cdot ft^2 \cdot ^\circ F}{Btu}$$

Calculate the overall heat transfer coefficient from the total thermal resistance.

$$U = \frac{1}{R_T} = \frac{1}{0.55 \frac{hr \cdot ft^2 \cdot ^\circ F}{Btu}} = 1.8 \frac{Btu}{hr \cdot ft^2 \cdot ^\circ F}$$

Calculate the temperature differential using the total heat transfer, the overall heat transfer coefficient, and the surface area.

$$\Delta T = \frac{\dot{Q}}{UA} = \frac{(100W) \left(3.412 \frac{Btu}{hr \cdot W}\right)}{\left(1.8 \frac{Btu}{hr \cdot ft^2 \cdot ^\circ F}\right) (8 ft^2)} = 23.7^\circ F$$

Use the temperature differential to calculate the temperature inside the enclosure based on the room temperature.

$$\Delta T = T_{enclosure} - T_{room}$$

$$T_{enclosure} = \Delta T + T_{room} = 23.7^\circ F + 76^\circ F = 99.7^\circ F$$

Answer C