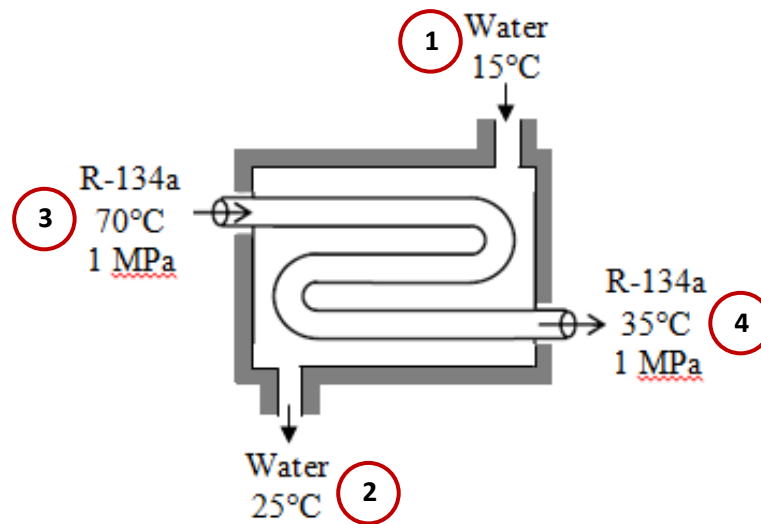


Thermodynamics Question Solution



Mass balance:

$$\dot{m}_{in} = \dot{m}_{out}$$

for each fluid stream since there is no mixing. Thus,

$$\dot{m}_1 = \dot{m}_2 = \dot{m}_W$$

and,

$$\dot{m}_3 = \dot{m}_4 = \dot{m}_R = 6 \text{ kg/min} = 0.1 \text{ kg/s}$$

5 marks

Energy balance for entire heat exchanger:

$$\dot{Q} - \dot{W} = \sum_{out} \dot{m} \cdot \left(h + \frac{1}{2} \cdot c^2 + g \cdot z \right) - \sum_{in} \dot{m} \cdot \left(h + \frac{1}{2} \cdot c^2 + g \cdot z \right)$$

$$\therefore \quad \dot{Q} = \sum_{out} \dot{m} \cdot (h) - \sum_{in} \dot{m} \cdot (h) \quad (\text{since } \dot{W} \cong ke \cong pe \cong 0)$$

$$\therefore \quad \dot{Q} = (\dot{m}_2 h_2 + \dot{m}_4 h_4) - (\dot{m}_1 h_1 + \dot{m}_3 h_3)$$

Combining the mass and energy balances and rearranging give

$$\dot{Q} = (\dot{m}_W h_2 + \dot{m}_R h_4) - (\dot{m}_W h_1 + \dot{m}_R h_3)$$

$$\therefore \quad \dot{Q} = \dot{m}_W (h_2 - h_1) + \dot{m}_R (h_4 - h_3)$$

5 marks

Now we need to determine the enthalpies at all four states. Water exists as a compressed liquid at both the inlet and the exit since the temperature at both locations are below the saturation temperature of water at 300 kPa (133.52°C). Approximating the compressed liquid as a saturated liquid at the given temperatures, we have:

$$\begin{aligned} h_1 &\cong h_{f@15^\circ\text{C}} = 62.982 \text{ kJ/kg} \\ h_2 &\cong h_{f@25^\circ\text{C}} = 104.83 \text{ kJ/kg} \end{aligned} \quad (\text{Table A-4})$$

2 marks

The refrigerant enters the condenser as a superheated vapour and leaves as a compressed liquid at 35°C. From refrigerant-134a tables,

$$\left. \begin{array}{l} P_3 = 1 \text{ MPa} \\ T_3 = 70^\circ\text{C} \end{array} \right\} h_3 = 303.85 \text{ kJ/kg} \quad (\text{Table A-13})$$

$$\left. \begin{array}{l} P_4 = 1 \text{ MPa} \\ T_4 = 35^\circ\text{C} \end{array} \right\} h_4 \cong h_{f@35^\circ\text{C}} = \frac{102.33 + 99.4}{2} = 100.865 \text{ kJ/kg} \quad (\text{Table A-11})$$

3 marks

Substituting, we find:

$$Q = \dot{m}_W(h_2 - h_1) + \dot{m}_R(h_4 - h_3)$$

$$\therefore Q = \dot{m}_W(104.83 - 62.982) + 0.1 \times (100.87 - 303.85)$$

$$\therefore Q = \dot{m}_W(41.848) + 0.1 \times (-202.98)$$

$$\therefore Q = 41.848 \dot{m}_W - 20.298$$

To determine the heat transfer from the refrigerant to the water, we have to choose a control volume whose boundary lies on the path of heat transfer. We can choose the volume occupied by either fluid as our control volume. We choose the volume occupied by the refrigerant. The energy balance for this refrigerant system reduces to:

$$\dot{Q}_r = \dot{m}_R h_4 - \dot{m}_R h_3$$

$$\therefore \dot{Q}_r = \dot{m}_R(h_4 - h_3)$$

$$\therefore \dot{Q}_r = 0.1 \times (100.87 - 303.85)$$

$$\therefore \dot{Q}_r = -20.2985 \text{ kJ/s} = -1217.91 \text{ kJ/min}$$

5 marks

Therefore, knowing that $Q = 10\% \dot{Q}_r$

$$Q = 41.848 \dot{m}_W - 20.298$$

$$\therefore 0.1 \times \dot{Q}_r = 41.848 \dot{m}_W - 20.298$$

$$\therefore \dot{m}_W = \frac{0.1 \times \dot{Q}_r + 20.298}{41.848}$$

$$\therefore \dot{m}_W = \frac{0.1 \times (-20.298) + 20.298}{41.848} = \frac{18.2682}{41.848}$$

$$\therefore \dot{m}_W = 0.4365 \text{ kg/s} = 26.192 \text{ kg/min}$$

5 marks