Problem set 8

1) Refrigerant-134a enters the condenser of a steady flow Carnot refrigerator as a saturated vapor at 90 psia, and it leaves with a quality of 0.05. The heat absorption from the refrigerated space takes place at a pressure of 30 psia. Show the cycle on a T-s diagram relative to saturation lines, and determine
   a) The coefficient of performance
   b) The quality at the beginning of the heat-absorption process.
   c) The net work input.

2) A refrigerator uses refrigerant-134a as the working fluid and operates on an ideal vapor-compression refrigeration cycle between 0.12 and 0.7 MPa. The mass flow rate of the refrigerant is 0.05 kg/s. Show the cycle on a T-s diagram with respect to saturation lines. Determine
   a) The rate of heat removal from the refrigerated space.
   b) The power input to the compressor.
   c) The rate of heat rejection to the environment.
   d) The coefficient of performance.

3) Refrigerant-134a enters the compressor of a refrigerator at 140 kPa and -10°C at a rate of 0.3 m³/min and leaves at 1MPa. The isentropic efficiency of the compressor is 78%. The refrigerant enters the throttling valve at 0.95 MPa and 30°C and leaves the evaporator as saturated vapor at -18.5°C. Show the cycle on a T-s diagram with respect to saturation lines. Determine
   a) the power input to the compressor.
   b) the rate of heat removal from the refrigerated space.
   c) the pressure drop and rate of heat gain in the line between the evaporator and the compressor.
Problem Set 8

Given: R-134a, C4H10 refrigerant.

\[ P_3 = P_2 = 90 \text{ psia} \]
\[ X_3 = 0.05 \]
\[ P_4 = P_1 = 30 \text{ psia} \]

To Find:
- a) COP
- b) \( X_4 \)
- c) Work, in

Solution:

- COP: \( \text{COP}_{\text{rican't}} = \frac{T_c}{T_h - T_c} = \frac{T_{\text{sat}}(30 \text{ psia})}{T_{\text{sat}}(90 \text{ psia}) - T_{\text{sat}}(30 \text{ psia})} \)

\[ \text{COP}_{\text{rican't}} = \frac{(1538 + 460)R}{(72.83 - 15.38)R} = 8.27 \]

- \( X_4 \):

\[ S_2 = S_f + X_3 S_{fg} = 0.0729 + (0.05)(0.2172 - 0.0729) \]
\[ S_3 = 0.0801 \text{ Btu/lbm} \cdot \text{R} \]

\[ S_4 = S_3 \therefore X_4 = \frac{S_3 - S_f}{S_g - S_f} @ 30 \text{ psia} \]

\[ X_4 = \frac{0.0801 - 0.0364}{0.2209 - 0.0364} = 0.237 = X_4 \]
\[ \text{COP}_R = \frac{Q_c}{\text{Wet.in}} \Rightarrow \text{Wet} = \frac{Q_c}{\text{COP}_R} = \frac{h_1 - h_4}{\text{COP}_R} \]

\[ S_1 = S_2 = S_g (90 \text{ psi}) = 0.2172 \]

\[ \chi_1 = \frac{S_1 - S_f}{S_g - S_f} = \frac{0.2172 - 0.0364}{0.12209 - 0.0364} = 0.980 \]

\[ h_1 = h_f + \chi_1 h_{fg} \]

\[ h_1 = 16.31 + (0.980)(87.65) = 102.2 \]

\[ h_4 = 16.31 + (0.237)(87.65) = 37.1 \]

\[ \text{Wet} = \frac{102.2 - 37.1}{8.27} = 7.87 \]

\[ \text{Wet} = 7.87 \text{ lbm} \]
Given: Refrigeration system, R-134a

\[ P_h = 0.7 \text{ MPa} \quad m = 0.05 \text{ kg/s} \]
\[ L_P = 0.12 \text{ MPa} \]

To find:
1. \( \dot{Q}_L, \dot{W} \)
2. \( \dot{Q}_H \)
3. \( \text{COP}_R \)

\[ \dot{Q}_1 = h_g (0.12 \text{ MPa}) = 233.86 \frac{\text{kJ}}{\text{kg}} \]
\[ s_L = s_1 = s_g(\ ) = 0.9354 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \]
\[ h_L = h_g(0.7 \text{ MPa}, s_2) = 270.22 \frac{\text{kJ}}{\text{kg}} \]
\[ h_3 = h_f(0.7 \text{ MPa}) = 86.78 \frac{\text{kJ}}{\text{kg}} \]
\[ h_f = h_3 \]
\[ q_L = h_1 - h_f = 233.86 - 86.78 = 147.08 \frac{\text{kJ}}{\text{kg}} \]
\[ q_f = h_2 - h_3 = 270.22 - 86.78 = 183.44 \frac{\text{kJ}}{\text{kg}} \]
\[ \dot{Q}_L = m \dot{q}_L = (0.05) (147.08) = 7.35 \text{ kW} \]
\[ \dot{W}_L = m (q_f - q_L) = (0.05)(183.44 - 147.08) = 1.82 \text{ kW} \]
\[ \dot{Q}_H = m \dot{q}_H = (0.05)(183.44) = 9.17 \text{ kW} \]
\[ \text{COP}_R = \frac{\dot{Q}_L}{\dot{W}} = 4.04 \]
Given: Fig. 10-19, R-134a

\[ P_1 = 140 \text{ kPa}, \quad T_1 = -10^\circ \text{C} \]
\[ \dot{V}_1 = 0.3 \text{ m}^3/\text{min} \]
\[ P_2 = 1 \text{ MPa} \]
\[ \eta_{\text{comp}} = 0.78 \]
\[ P_3 = 0.95 \text{ MPa} \]
\[ T_3 = 30^\circ \text{C} \]
\[ T_5 = -18.5^\circ \text{C} \]

To find:

a) \( W_{\text{comp}} \)

b) \( Q_L = \)

c) \( \Delta P_{5-1} \)

\[ h_1 = h(p_1, T_1) = 243.40 \text{ kJ/kg} \]
\[ \bar{s}_1 = 0.9606 \text{ kJ/kg} \cdot \text{K} \]
\[ \bar{s}_{23} = \bar{s}_1 \Rightarrow h_{25} = h(P_2, s_1) = 286.04 + \bar{s}_{23} \text{ kJ/kg} \]
\[ W_{\text{mc}} = \left( \frac{w_2 - w_1}{\eta_{\text{comp}}} \right) \Rightarrow h_{24} = h_1 + \left( h_{25} - h_1 \right) \frac{\bar{s}_{23}}{\eta_{\text{comp}}} \]

\[ h_{26} = 243.40 + \frac{286.04 - 243.40}{0.78} = 298.07 \text{ kJ/kg} \]

\[ h_3 = h_p(T_3) = 91.49 \text{ kJ/kg} \]

\[ h_4 = h_3 \]

\[ h_5 = h_p(T_5) = 236.23 \text{ kJ/kg} \]

\[ P_5 = P_{\text{sat}}(T_5) = 0.1419 \text{ MPa} \]

\[ \bar{m} = \frac{\dot{V}_1}{A} = \frac{0.3 \text{ m}^3/\text{min}}{0.1455 \text{ m}^2/\text{min}} = 0.0344 \text{ kg/s} \]


\[ W_{\text{cmp}} = \dot{m} \left( h_2 - h_1 \right) = (298.07 - 243.4)(\dot{m} \times 0.0344) = 1.88 \text{ kJ} \]

\[ Q_L = \dot{m} \left( h_5 - h_4 \right) = (\dot{m} \times 0.0344)(236.23 - 91.49) = 4.98 \text{ kW} \]

\[ \Delta P_{S-1} = P_S - P_1 = 141.87 - 140 = 1.87 \text{ kPa} \]

\[ Q_{\text{gain}} = \dot{m} \left( h_1 - h_5 \right) = 0.0344 \times (243.4 - 236.23) = 0.247 \text{ kW} \]