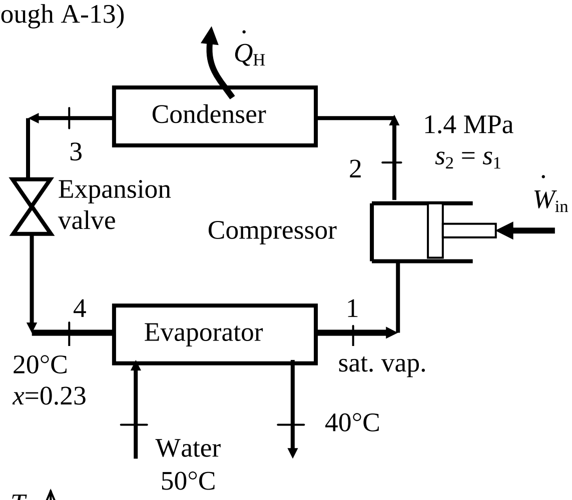
11-49 A geothermal heat pump is considered. The degrees of subcooling done on the refrigerant in the condenser, the mass flow rate of the refrigerant, the heating load, the COP of the heat pump, the minimum power input are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

Analysis (*a*) From the refrigerant-134a tables (Tables A-11 through A-13)



$$\left.\begin{array}{l}T_4 = 20°\text{C}\\ x_4 = 0.23\end{array}\right\} \begin{array}{l}P_4 = 572.1\,\text{kPa}\\ h_4 = 121.24\,\text{kJ/kg}\end{array}$$

$$h_3 = h_4$$

$$\left.\begin{array}{l}P_1 = 572.1\,\text{kPa}\\ x_1 = 1\,(\text{sat. vap.})\end{array}\right\} \begin{array}{l}h_1 = 261.59\,\text{kJ/kg}\\ s_1 = 0.9223\,\text{kJ/kg}\end{array}$$

$$\left.\begin{array}{l}P_2 = 1400\,\text{kPa}\\ s_2 = s_1\end{array}\right\} h_2 = 280.00\,\text{kJ/kg}$$

From the steam tables (Table A-4)

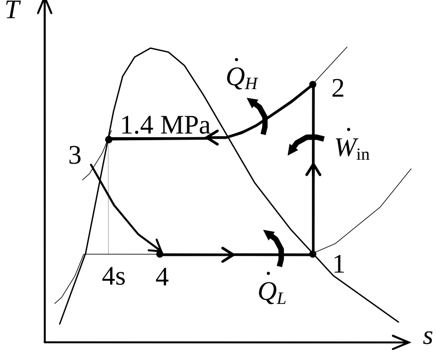
$$h_{w1} = h_{f\,@\,50°\text{C}} = 209.34\,\text{kJ/kg}$$

$$h_{w2} = h_{f\,@\,40°\text{C}} = 167.53\,\text{kJ/kg}$$

The saturation temperature at the condenser pressure of 1400 kPa and the actual temperature at the condenser outlet are

$$T_{\text{sat}\,@\,1400\,\text{kPa}} = 52.40°\text{C}$$

$$\left.\begin{array}{l}P_3 = 1400\,\text{kPa}\\ h_3 = 121.24\,\text{kJ/kg}\end{array}\right\} T_3 = 48.59°\text{C}\ \ (\text{from EES})$$



Then, the degrees of subcooling is

$$\Delta T_{\text{subcool}} = T_{\text{sat}} - T_3 = 52.40 - 48.59 = \mathbf{3.81°C}$$

(*b*) The rate of heat absorbed from the geothermal water in the evaporator is

$$\dot{Q}_L = \dot{m}_w(h_{w1} - h_{w2}) = (0.065\,\text{kg/s})(209.34 - 167.53)\text{kJ/kg} = 2.718\,\text{kW}$$

This heat is absorbed by the refrigerant in the evaporator

$$\dot{m}_R = \frac{\dot{Q}_L}{h_1 - h_4} = \frac{2.718\,\text{kW}}{(261.59 - 121.24)\text{kJ/kg}} = \mathbf{0.01936\ kg/s}$$

(*c*) The power input to the compressor, the heating load and the COP are

$$\dot{W}_{\text{in}} = \dot{m}_R(h_2 - h_1) + \dot{Q}_{\text{out}} = (0.01936\,\text{kg/s})(280.00 - 261.59)\text{kJ/kg} = 0.6564\,\text{kW}$$

$$\dot{Q}_H = \dot{m}_R(h_2 - h_3) = (0.01936\,\text{kg/s})(280.00 - 121.24)\text{kJ/kg} = \mathbf{3.074\ kW}$$

$$\text{COP} = \frac{\dot{Q}_H}{\dot{W}_{in}} = \frac{3.074\,\text{kW}}{0.6564\,\text{kW}} = \mathbf{4.68}$$

(*d*) The reversible COP of the cycle is

$$\text{COP}_{\text{rev}} = \frac{1}{1 - T_L/T_H} = \frac{1}{1 - (25 + 273)/(50 + 273)} = 12.92$$

The corresponding minimum power input is

$$\dot{W}_{\text{in,min}} = \frac{\dot{Q}_H}{\text{COP}_{\text{rev}}} = \frac{3.074\,\text{kW}}{12.92} = \mathbf{0.238\ kW}$$