7-88 A geothermal power plant uses geothermal liquid water at 160ºC at a specified rate as the heat source. The actual and maximum possible thermal efficiencies and the rate of heat rejected from this power plant are to be determined.

Assumptions **1** The power plant operates steadily. **2** The kinetic and potential energy changes are zero. **3** Steam properties are used for geothermal water.

Properties Using saturated liquid properties, the source and the sink state enthalpies of geothermal water are (Table A-4)

$$\left.\begin{array}{l} T_{\text{source}} = 160°\text{C} \\ x_{\text{source}} = 0 \end{array}\right\} h_{\text{source}} = 675.47 \text{ kJ/kg}$$

$$\left.\begin{array}{l} T_{\text{sink}} = 25°\text{C} \\ x_{\text{sink}} = 0 \end{array}\right\} h_{\text{sink}} = 104.83 \text{ kJ/kg}$$

Analysis (*a*) The rate of heat input to the plant may be taken as the enthalpy difference between the source and the sink for the power plant

$$\dot{Q}_{\text{in}} = \dot{m}_{\text{geo}}(h_{\text{source}} - h_{\text{sink}}) = (440 \text{ kg/s})(675.47 - 104.83) \text{ kJ/kg} = 251{,}083 \text{ kW}$$

The actual thermal efficiency is

$$\eta_{\text{th}} = \frac{\dot{W}_{\text{net,out}}}{\dot{Q}_{\text{in}}} = \frac{22 \text{ MW}}{251.083 \text{ MW}} = \mathbf{0.0876} = \mathbf{8.8\%}$$

(*b*) The maximum thermal efficiency is the thermal efficiency of a reversible heat engine operating between the source and sink temperatures

$$\eta_{\text{th,max}} = 1 - \frac{T_L}{T_H} = 1 - \frac{(25+273) \text{ K}}{(160+273) \text{ K}} = \mathbf{0.312} = \mathbf{31.2\%}$$

(*c*) Finally, the rate of heat rejection is

$$\dot{Q}_{\text{out}} = \dot{Q}_{\text{in}} - \dot{W}_{\text{net,out}} = 251.1 - 22 = \mathbf{229.1 \text{ MW}}$$

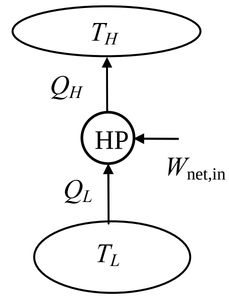
7-131 An expression for the COP of a completely reversible heat pump in terms of the thermal-energy reservoir temperatures, T_L and T_H is to be derived.

Assumptions The heat pump operates steadily.

Analysis Application of the first law to the completely reversible heat pump yields

$$W_{\text{net,in}} = Q_H - Q_L$$

This result may be used to reduce the coefficient of performance,



$$\text{COP}_{\text{HP,rev}} = \frac{Q_H}{W_{\text{net,in}}} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - Q_L / Q_H}$$

Since this heat pump is completely reversible, the thermodynamic definition of temperature tells us that,

$$\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$$

When this is substituted into the COP expression, the result is

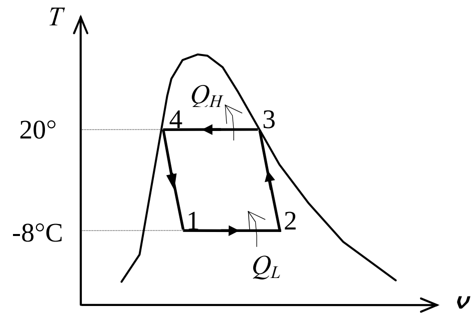
$$\text{COP}_{\text{HP,rev}} = \frac{1}{1 - T_L / T_H} = \frac{T_H}{T_H - T_L}$$

7-135 A Carnot refrigeration cycle is executed in a closed system with a fixed mass of R-134a. The net work input and the maximum and minimum temperatures are given. The mass fraction of the refrigerant that vaporizes during the heat addition process, and the pressure at the end of the heat rejection process are to be determined.

Properties The enthalpy of vaporization of R-134a at -8°C is h_{fg} = 204.52 kJ/kg (Table A-12).

Analysis The coefficient of performance of the cycle is

$$\text{COP}_\text{R} = \frac{1}{T_H / T_L - 1} = \frac{1}{293/265 - 1} = 9.464$$



and

$$Q_L = \text{COP}_\text{R} \times W_\text{in} = (9.464)(15\text{ kJ}) = 142\text{ kJ}$$

Then the amount of refrigerant that vaporizes during heat absorption is

$$Q_L = mh_{fg@T_L=-8^\circ\text{C}} \longrightarrow m = \frac{142\text{ kJ}}{204.52\text{ kJ/kg}} = 0.695\text{ kg}$$

since the enthalpy of vaporization h_{fg} at a given T or P represents the amount of heat transfer per unit mass as a substance is converted from saturated liquid to saturated vapor at that T or P. Therefore, the fraction of mass that vaporized during heat addition process is

$$\frac{0.695\text{ kg}}{0.8\text{ kg}} = 0.868 \text{ or } \mathbf{86.8\%}$$

The pressure at the end of the heat rejection process is

$$P_4 = P_{\text{sat@}20^\circ\text{C}} = \mathbf{572.1 kPa}$$