10-69 A single-flash geothermal power plant uses hot geothermal water at 230ºC as the heat source. The power output from the turbine, the thermal efficiency of the plant, the exergy of the geothermal liquid at the exit of the flash chamber, and the exergy destructions and exergy efficiencies for the flash chamber, the turbine, and the entire plant are to be determined.

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

Analysis (*a*) We use properties of water for geothermal water (Tables A-4, A-5, and A-6)

$$\left.\begin{array}{l} T_1 = 230°\text{C} \\ x_1 = 0 \end{array}\right\} \begin{array}{l} h_1 = 990.14 \text{ kJ/kg} \\ s_1 = 2.6100 \text{ kJ/kg.K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 500 \text{ kPa} \\ h_2 = h_1 = 990.14 \text{ kJ/kg} \end{array}\right\} \begin{array}{l} x_2 = 0.1661 \\ s_2 = 2.6841 \text{ kJ/kg.K} \end{array}$$

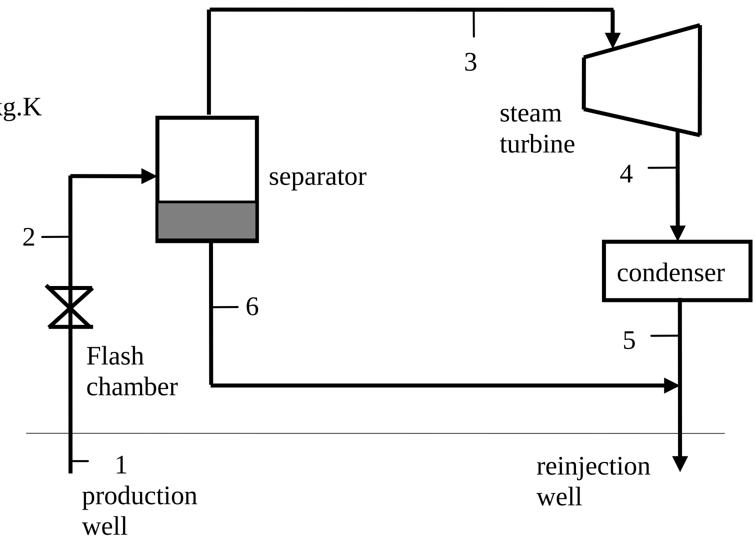
$$\dot{m}_3 = x_2 \dot{m}_1 = (0.1661)(230 \text{ kg/s}) = 38.19 \text{ kg/s}$$

$$\left.\begin{array}{l} P_3 = 500 \text{ kPa} \\ x_3 = 1 \end{array}\right\} \begin{array}{l} h_3 = 2748.1 \text{ kJ/kg} \\ s_3 = 6.8207 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\left.\begin{array}{l} P_4 = 10 \text{ kPa} \\ x_4 = 0.95 \end{array}\right\} \begin{array}{l} h_4 = 2464.3 \text{ kJ/kg} \\ s_4 = 7.7739 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\left.\begin{array}{l} P_6 = 500 \text{ kPa} \\ x_6 = 0 \end{array}\right\} \begin{array}{l} h_6 = 640.09 \text{ kJ/kg} \\ s_6 = 1.8604 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\dot{m}_6 = \dot{m}_1 - \dot{m}_3 = 230 - 38.19 = 191.81 \text{ kg/s}$$



The power output from the turbine is

$$\dot{W}_{\text{T}} = \dot{m}_3(h_3 - h_4) = (38.19 \text{ kJ/kg})(2748.1 - 2464.3)\text{kJ/kg} = \mathbf{10{,}842 \text{ kW}}$$

We use saturated liquid state at the standard temperature for dead state properties

$$\left.\begin{array}{l} T_0 = 25°\text{C} \\ x_0 = 0 \end{array}\right\} \begin{array}{l} h_0 = 104.83 \text{ kJ/kg} \\ s_0 = 0.3672 \text{ kJ/kg} \end{array}$$

$$\dot{E}_{\text{in}} = \dot{m}_1(h_1 - h_0) = (230 \text{ kJ/kg})(990.14 - 104.83)\text{kJ/kg} = 203{,}622 \text{ kW}$$

$$\eta_{\text{th}} = \frac{\dot{W}_{\text{T,out}}}{\dot{E}_{\text{in}}} = \frac{10{,}842}{203{,}622} = 0.0532 = \mathbf{5.3\%}$$

(*b*) The specific exergies at various states are

$$\psi_1 = h_1 - h_0 - T_0(s_1 - s_0) = (990.14 - 104.83)\text{kJ/kg} - (298 \text{ K})(2.6100 - 0.3672)\text{kJ/kg.K} = 216.53 \text{ kJ/kg}$$

$$\psi_2 = h_2 - h_0 - T_0(s_2 - s_0) = (990.14 - 104.83)\text{kJ/kg} - (298 \text{ K})(2.6841 - 0.3672)\text{kJ/kg.K} = 194.44 \text{ kJ/kg}$$

$$\psi_3 = h_3 - h_0 - T_0(s_3 - s_0) = (2748.1 - 104.83)\text{kJ/kg} - (298 \text{ K})(6.8207 - 0.3672)\text{kJ/kg.K} = 719.10 \text{ kJ/kg}$$

$$\psi_4 = h_4 - h_0 - T_0(s_4 - s_0) = (2464.3 - 104.83)\text{kJ/kg} - (298 \text{ K})(7.7739 - 0.3672)\text{kJ/kg.K} = 151.05 \text{ kJ/kg}$$

$$\psi_6 = h_6 - h_0 - T_0(s_6 - s_0) = (640.09 - 104.83)\text{kJ/kg} - (298 \text{ K})(1.8604 - 0.3672)\text{kJ/kg.K} = 89.97 \text{ kJ/kg}$$

The exergy of geothermal water at state 6 is

$$\dot{X}_6 = \dot{m}_6 \psi_6 = (191.81 \text{ kg/s})(89.97 \text{ kJ/kg}) = \mathbf{17{,}257 \text{ kW}}$$

(*c*) Flash chamber:

$$\dot{X}_{\text{dest, FC}} = \dot{m}_1(\psi_1 - \psi_2) = (230\ \text{kg/s})(216.53 - 194.44)\text{kJ/kg} = \mathbf{5080\ kW}$$

$$\eta_{\text{II,FC}} = \frac{\psi_2}{\psi_1} = \frac{194.44}{216.53} = 0.898 = \mathbf{89.8\%}$$

(*d*) Turbine:

$$\dot{X}_{\text{dest,T}} = \dot{m}_3(\psi_3 - \psi_4) - \dot{W}_{\text{T}} = (38.19\ \text{kg/s})(719.10 - 151.05)\text{kJ/kg} \text{ -}10{,}842\ \text{kW} = \mathbf{10{,}854\ kW}$$

$$\eta_{\text{II,T}} = \frac{\dot{W}_{\text{T}}}{\dot{m}_3(\psi_3 - \psi_4)} = \frac{10{,}842\ \text{kW}}{(38.19\ \text{kg/s})(719.10 - 151.05)\text{kJ/kg}} = 0.500 = \mathbf{50.0\%}$$

(*e*) Plant:

$$\dot{X}_{\text{in,Plant}} = \dot{m}_1\psi_1 = (230\ \text{kg/s})(216.53\ \text{kJ/kg}) = 49{,}802\ \text{kW}$$

$$\dot{X}_{\text{dest,Plant}} = \dot{X}_{\text{in,Plant}} - \dot{W}_{\text{T}} = 49{,}802 - 10{,}842 = \mathbf{38{,}960\ kW}$$

$$\eta_{\text{II,Plant}} = \frac{\dot{W}_{\text{T}}}{\dot{X}_{\text{in,Plant}}} = \frac{10{,}842\ \text{kW}}{49{,}802\ \text{kW}} = 0.2177 = \mathbf{21.8\%}$$