10-29 A combined flash-binary geothermal power plant uses hot geothermal water at 230ºC as the heat source. The mass flow rate of isobutane in the binary cycle, the net power outputs from the steam turbine and the binary cycle, and the thermal efficiencies for the binary cycle and the combined 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 through A-6)

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

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

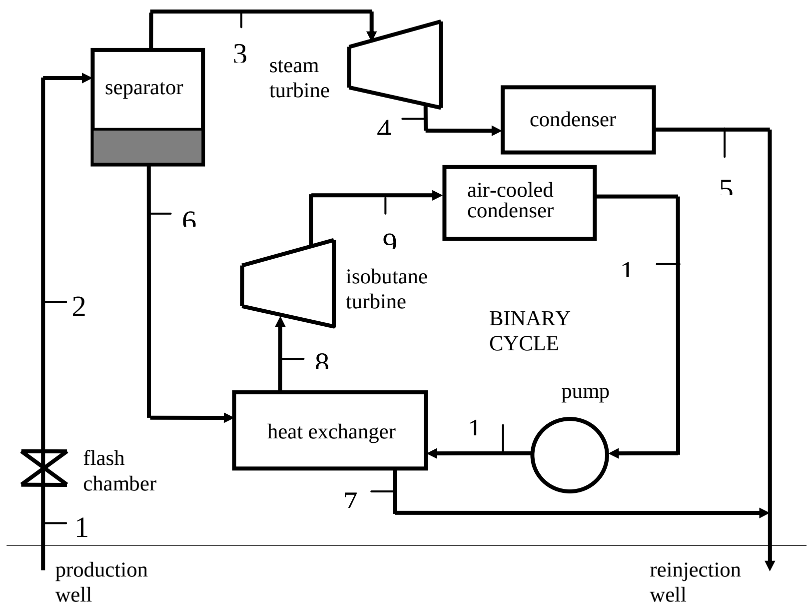
$$\dot{m}_3 = x_2\dot{m}_1 = (0.1661)(230 \text{ kg/s}) = 38.20 \text{ kg/s}$$
$$\dot{m}_6 = \dot{m}_1 - \dot{m}_3 = 230 - 38.20 = 191.80 \text{ kg/s}$$

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

$$\left.\begin{array}{l} P_4 = 10 \text{ kPa} \\ x_4 = 0.90 \end{array}\right\} h_4 = 2344.7 \text{ kJ/kg}$$

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

$$\left.\begin{array}{l} T_7 = 90°\text{C} \\ x_7 = 0 \end{array}\right\} h_7 = 377.04 \text{ kJ/kg}$$



The isobutane properties are obtained from EES:

$$\left.\begin{array}{l} P_8 = 3250 \text{ kPa} \\ T_8 = 145°\text{C} \end{array}\right\} h_8 = 755.05 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_9 = 400 \text{ kPa} \\ T_9 = 80°\text{C} \end{array}\right\} h_9 = 691.01 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_{10} = 400 \text{ kPa} \\ x_{10} = 0 \end{array}\right\} \begin{array}{l} h_{10} = 270.83 \text{ kJ/kg} \\ \boldsymbol{\upsilon}_{10} = 0.001839 \text{ m}^3\text{/kg} \end{array}$$

$$\begin{aligned} w_{p,\text{in}} &= \boldsymbol{\upsilon}_{10}(P_{11} - P_{10})/\eta_p \\ &= (0.001819 \text{ m}^3\text{/kg})(3250 - 400)\text{kPa}\left(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3}\right)/0.90 \\ &= 5.82 \text{ kJ/kg.} \end{aligned}$$

$$h_{11} = h_{10} + w_{p,\text{in}} = 270.83 + 5.82 = 276.65 \text{ kJ/kg}$$

An energy balance on the heat exchanger gives

$$\dot{m}_6(h_6 - h_7) = \dot{m}_{\text{iso}}(h_8 - h_{11})$$

$$(191.81 \text{ kg/s})(640.09 - 377.04)\text{kJ/kg} = \dot{m}_{\text{iso}}(755.05 - 276.65)\text{kJ/kg} \longrightarrow \dot{m}_{\text{iso}} = \mathbf{105.46 \text{ kg/s}}$$

(*b*) The power outputs from the steam turbine and the binary cycle are

$$\dot{W}_{\text{T,steam}} = \dot{m}_3(h_3 - h_4) = (38.19 \text{ kJ/kg})(2748.1 - 2344.7)\text{kJ/kg} = \mathbf{15{,}410 \text{ kW}}$$

$$\dot{W}_{\text{T,iso}} = \dot{m}_{iso}(h_8 - h_9) = (105.46 \text{ kJ/kg})(755.05 - 691.01)\text{kJ/kg} = 6753 \text{ kW}$$

$$\dot{W}_{\text{net,binary}} = \dot{W}_{\text{T,iso}} - \dot{m}_{\text{iso}} w_{p,in} = 6753 - (105.46 \text{ kg/s})(5.82 \text{ kJ/kg}) = \mathbf{6139 \text{ kW}}$$

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(*c*) The thermal efficiencies of the binary cycle and the combined plant are

$$\dot{Q}_{\text{in,binary}} = \dot{m}_{\text{iso}}(h_8 - h_{11}) = (105.46\text{ kJ/kg})(755.05 - 276.65)\text{kJ/kg} = 50{,}454\text{ kW}$$

$$\eta_{\text{th,binary}} = \frac{\dot{W}_{\text{net,binary}}}{\dot{Q}_{\text{in,binary}}} = \frac{6139}{50{,}454} = 0.122 = \mathbf{12.2\%}$$

$$\left.\begin{aligned} T_0 &= 25°\text{C} \\ x_0 &= 0 \end{aligned}\right\} h_0 = 104.83\text{ kJ/kg}$$

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

$$\eta_{\text{th,plant}} = \frac{\dot{W}_{\text{T,steam}} + \dot{W}_{\text{net,binary}}}{\dot{E}_{\text{in}}} = \frac{15{,}410 + 6139}{203{,}622} = 0.106 = \mathbf{10.6\%}$$

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