

Problem #3

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

Analysis (a) From the steam tables (Tables A-4, A-5, and A-6),

$$h_1 = h_{f@25 \text{ kPa}} = 271.96 \text{ kJ/kg}$$

$$v_1 = v_{f@25 \text{ kPa}} = 0.001020 \text{ m}^3/\text{kg}$$

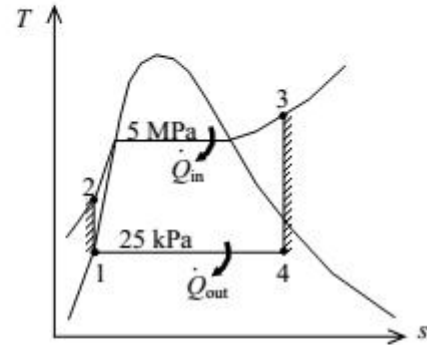
$$\begin{aligned} w_{p,\text{in}} &= v_1(P_2 - P_1) \\ &= (0.00102 \text{ m}^3/\text{kg})(5000 - 25 \text{ kPa}) \left(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3} \right) \\ &= 5.07 \text{ kJ/kg} \end{aligned}$$

$$h_2 = h_1 + w_{p,\text{in}} = 271.96 + 5.07 = 277.03 \text{ kJ/kg}$$

$$\left. \begin{aligned} P_3 &= 5 \text{ MPa} \\ T_3 &= 450^\circ\text{C} \end{aligned} \right\} \begin{aligned} h_3 &= 3317.2 \text{ kJ/kg} \\ s_3 &= 6.8210 \text{ kJ/kg} \cdot \text{K} \end{aligned}$$

$$\left. \begin{aligned} P_4 &= 25 \text{ kPa} \\ s_4 &= s_3 \end{aligned} \right\} x_4 = \frac{s_4 - s_f}{s_{fg}} = \frac{6.8210 - 0.8932}{6.9370} = 0.8545$$

$$h_4 = h_f + x_4 h_{fg} = 271.96 + (0.8545)(2345.5) = 2276.2 \text{ kJ/kg}$$



The thermal efficiency is determined from

$$q_{\text{in}} = h_3 - h_2 = 3317.2 - 277.03 = 3040.2 \text{ kJ/kg}$$

$$q_{\text{out}} = h_4 - h_1 = 2276.2 - 271.96 = 2004.2 \text{ kJ/kg}$$

and

$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{2004.2}{3040.2} = 0.3407$$

Thus,

$$\eta_{\text{overall}} = \eta_{\text{th}} \times \eta_{\text{comb}} \times \eta_{\text{gen}} = (0.3407)(0.75)(0.96) = \mathbf{24.5\%}$$

(b) Then the required rate of coal supply becomes

$$\dot{Q}_{\text{in}} = \frac{\dot{W}_{\text{net}}}{\eta_{\text{overall}}} = \frac{300,000 \text{ kJ/s}}{0.2453} = 1,222,992 \text{ kJ/s}$$

and

$$\dot{m}_{\text{coal}} = \frac{\dot{Q}_{\text{in}}}{C_{\text{coal}}} = \frac{1,222,992 \text{ kJ/s}}{29,300 \text{ kJ/kg}} \left(\frac{1 \text{ ton}}{1000 \text{ kg}} \right) = 0.04174 \text{ tons/s} = \mathbf{150.3 \text{ tons/h}}$$

Problem #4

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

Analysis (a) From the steam tables (Tables A-4, A-5, and A-6),

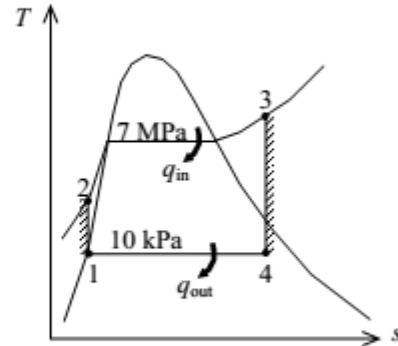
$$\begin{aligned}
 h_1 &= h_{f@10 \text{ kPa}} = 191.81 \text{ kJ/kg} \\
 v_1 &= v_{f@10 \text{ kPa}} = 0.00101 \text{ m}^3/\text{kg} \\
 w_{p,\text{in}} &= v_1(P_2 - P_1) \\
 &= (0.00101 \text{ m}^3/\text{kg})(7,000 - 10 \text{ kPa}) \left(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3} \right) \\
 &= 7.06 \text{ kJ/kg}
 \end{aligned}$$

$$h_2 = h_1 + w_{p,\text{in}} = 191.81 + 7.06 = 198.87 \text{ kJ/kg}$$

$$\begin{aligned}
 P_3 &= 7 \text{ MPa} \left. \begin{array}{l} h_3 = 3411.4 \text{ kJ/kg} \\ T_3 = 500^\circ\text{C} \end{array} \right\} s_3 = 6.8000 \text{ kJ/kg} \cdot \text{K}
 \end{aligned}$$

$$\begin{aligned}
 P_4 &= 10 \text{ kPa} \\
 s_4 &= s_3 \left. \begin{array}{l} \\ \end{array} \right\} x_4 = \frac{s_4 - s_f}{s_{fg}} = \frac{6.8000 - 0.6492}{7.4996} = 0.8201
 \end{aligned}$$

$$h_4 = h_f + x_4 h_{fg} = 191.81 + (0.8201)(2392.1) = 2153.6 \text{ kJ/kg}$$



Thus,

$$q_{\text{in}} = h_3 - h_2 = 3411.4 - 198.87 = 3212.5 \text{ kJ/kg}$$

$$q_{\text{out}} = h_4 - h_1 = 2153.6 - 191.81 = 1961.8 \text{ kJ/kg}$$

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}} = 3212.5 - 1961.8 = 1250.7 \text{ kJ/kg}$$

and

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{1250.7 \text{ kJ/kg}}{3212.5 \text{ kJ/kg}} = \mathbf{38.9\%}$$

$$(b) \quad \dot{m} = \frac{\dot{W}_{\text{net}}}{w_{\text{net}}} = \frac{45,000 \text{ kJ/s}}{1250.7 \text{ kJ/kg}} = \mathbf{36.0 \text{ kg/s}}$$

(c) The rate of heat rejection to the cooling water and its temperature rise are

$$\dot{Q}_{\text{out}} = \dot{m} q_{\text{out}} = (36.0 \text{ kg/s})(1961.8 \text{ kJ/kg}) = 70,586 \text{ kJ/s}$$

$$\Delta T_{\text{cooling water}} = \frac{\dot{Q}_{\text{out}}}{(\dot{m}c)_{\text{cooling water}}} = \frac{70,586 \text{ kJ/s}}{(2000 \text{ kg/s})(4.18 \text{ kJ/kg} \cdot ^\circ\text{C})} = \mathbf{8.4^\circ\text{C}}$$

Problem #5

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

Analysis (a) From the steam tables (Tables A-4, A-5, and A-6),

$$h_1 = h_{f@10 \text{ kPa}} = 191.81 \text{ kJ/kg}$$

$$v_1 = v_{f@10 \text{ kPa}} = 0.00101 \text{ m}^3/\text{kg}$$

$$\begin{aligned} w_{p,\text{in}} &= v_1(P_2 - P_1)/\eta_p \\ &= (0.00101 \text{ m}^3/\text{kg})(7,000 - 10 \text{ kPa}) \left(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3} \right) / (0.87) \\ &= 8.11 \text{ kJ/kg} \end{aligned}$$

$$h_2 = h_1 + w_{p,\text{in}} = 191.81 + 8.11 = 199.92 \text{ kJ/kg}$$

$$\left. \begin{aligned} P_3 &= 7 \text{ MPa} \\ T_3 &= 500^\circ\text{C} \end{aligned} \right\} \begin{aligned} h_3 &= 3411.4 \text{ kJ/kg} \\ s_3 &= 6.8000 \text{ kJ/kg} \cdot \text{K} \end{aligned}$$

$$\left. \begin{aligned} P_4 &= 10 \text{ kPa} \\ s_4 &= s_3 \end{aligned} \right\} x_4 = \frac{s_4 - s_f}{s_{fg}} = \frac{6.8000 - 0.6492}{7.4996} = 0.8201$$

$$h_{4s} = h_f + x_4 h_{fg} = 191.81 + (0.8201)(2392.1) = 2153.6 \text{ kJ/kg}$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} \longrightarrow h_4 = h_3 - \eta_T(h_3 - h_{4s}) = 3411.4 - (0.87)(3411.4 - 2153.6) = 2317.1 \text{ kJ/kg}$$

Thus,

$$q_{\text{in}} = h_3 - h_2 = 3411.4 - 199.92 = 3211.5 \text{ kJ/kg}$$

$$q_{\text{out}} = h_4 - h_1 = 2317.1 - 191.81 = 2125.3 \text{ kJ/kg}$$

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}} = 3211.5 - 2125.3 = 1086.2 \text{ kJ/kg}$$

and

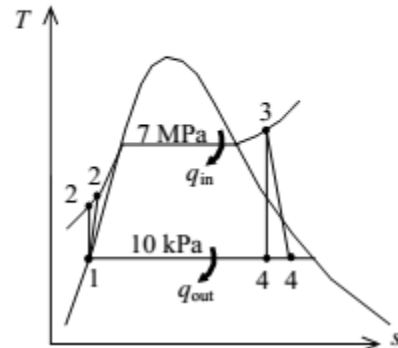
$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{1086.2 \text{ kJ/kg}}{3211.5 \text{ kJ/kg}} = \mathbf{33.8\%}$$

$$(b) \quad \dot{m} = \frac{\dot{W}_{\text{net}}}{w_{\text{net}}} = \frac{45,000 \text{ kJ/s}}{1086.2 \text{ kJ/kg}} = \mathbf{41.43 \text{ kg/s}}$$

(c) The rate of heat rejection to the cooling water and its temperature rise are

$$\dot{Q}_{\text{out}} = \dot{m} q_{\text{out}} = (41.43 \text{ kg/s})(2125.3 \text{ kJ/kg}) = 88,051 \text{ kJ/s}$$

$$\Delta T_{\text{cooling water}} = \frac{\dot{Q}_{\text{out}}}{(\dot{m}c)_{\text{cooling water}}} = \frac{88,051 \text{ kJ/s}}{(2000 \text{ kg/s})(4.18 \text{ kJ/kg} \cdot ^\circ\text{C})} = \mathbf{10.5^\circ\text{C}}$$



Problem #6

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)

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

$$\left. \begin{array}{l} P_2 = 500 \text{ kPa} \\ h_2 = h_1 = 990.14 \text{ kJ/kg} \end{array} \right\} x_2 = \frac{h_2 - h_f}{h_{fg}}$$

$$= \frac{990.14 - 640.09}{2108} = 0.1661$$

The mass flow rate of steam through the turbine is

$$\begin{aligned} \dot{m}_3 &= x_2 \dot{m}_1 \\ &= (0.1661)(230 \text{ kg/s}) \\ &= \mathbf{38.20 \text{ kg/s}} \end{aligned}$$

(b) Turbine:

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

$$\left. \begin{array}{l} P_4 = 10 \text{ kPa} \\ s_4 = s_3 \end{array} \right\} h_{4s} = 2160.3 \text{ kJ/kg}$$

$$\left. \begin{array}{l} P_4 = 10 \text{ kPa} \\ x_4 = 0.90 \end{array} \right\} h_4 = h_f + x_4 h_{fg} = 191.81 + (0.90)(2392.1) = 2344.7 \text{ kJ/kg}$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} = \frac{2748.1 - 2344.7}{2748.1 - 2160.3} = \mathbf{0.686}$$

(c) The power output from the turbine is

$$\dot{W}_{T,\text{out}} = \dot{m}_3 (h_3 - h_4) = (38.20 \text{ kJ/kg})(2748.1 - 2344.7) \text{ kJ/kg} = \mathbf{15,410 \text{ kW}}$$

