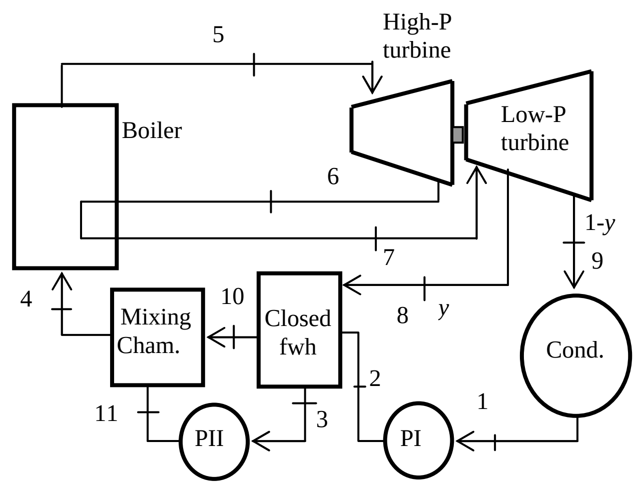
10-60 A steam power plant that operates on an ideal regenerative Rankine cycle with a closed feedwater heater is considered. The temperature of the steam at the inlet of the closed feedwater heater, the mass flow rate of the steam extracted from the turbine for the closed feedwater heater, the net power output, and the thermal efficiency are to be determined.

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),



$$h_1 = h_{f@\,20\text{ kPa}} = 251.42 \text{ kJ/kg}$$

$$\boldsymbol{v}_1 = \boldsymbol{v}_{f@\,20\text{ kPa}} = 0.001017 \text{ m}^3\text{/kg}$$

$$\begin{aligned} w_{pI,\text{in}} &= \boldsymbol{v}_1(P_2 - P_1)/\eta_p \\ &= (0.001017 \text{ m}^3\text{/kg})(8000 - 20 \text{ kPa})\frac{1}{0.88} \\ &= 9.22 \text{ kJ/kg} \end{aligned}$$

$$\begin{aligned} h_2 &= h_1 + w_{pI,\text{in}} \\ &= 251.42 + 9.223 \\ &= 260.65 \text{ kJ/kg} \end{aligned}$$

$$\left.\begin{array}{l} P_3 = 1 \text{ MPa} \\ \text{sat. liquid} \end{array}\right\} \begin{array}{l} h_3 = h_{f@\,1\text{ MPa}} = 762.51 \text{ kJ/kg} \\ \boldsymbol{v}_3 = \boldsymbol{v}_{f@\,1\text{ MPa}} = 0.001127 \text{ m}^3\text{/kg} \end{array}$$

$$\begin{aligned} w_{pII,\text{in}} &= \boldsymbol{v}_3(P_{11} - P_3)/\eta_p \\ &= (0.001127 \text{ m}^3\text{/kg})(8000 - 1000 \text{ kPa})/0.88 \\ &= 8.97 \text{ kJ/kg} \end{aligned}$$

$$h_{11} = h_3 + w_{pII,\text{in}} = 762.51 + 8.97 = 771.48 \text{ kJ/kg}$$

Also, $h_4 = h_{10} = h_{11} = 771.48$ kJ/kg since the two fluid streams which are being mixed have the same enthalpy.

$$\left.\begin{array}{l} P_5 = 8 \text{ MPa} \\ T_5 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_5 = 3399.5 \text{ kJ/kg} \\ s_5 = 6.7266 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_6 = 3 \text{ MPa} \\ s_6 = s_5 \end{array}\right\} h_{6s} = 3104.7 \text{ kJ/kg}$$

$$\eta_T = \frac{h_5 - h_6}{h_5 - h_{6s}} \longrightarrow h_6 = h_5 - \eta_T(h_5 - h_{6s})$$
$$= 3399.5 - (0.88)(3399.5 - 3104.7) = 3140.1 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_7 = 3 \text{ MPa} \\ T_7 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_7 = 3457.2 \text{ kJ/kg} \\ s_7 = 7.2359 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_8 = 1 \text{ MPa} \\ s_8 = s_7 \end{array}\right\} h_{8s} = 3117.1 \text{ kJ/kg}$$

$$\eta_T = \frac{h_7 - h_8}{h_7 - h_{8s}} \longrightarrow h_8 = h_7 - \eta_T(h_7 - h_{8s})$$
$$= 3457.2 - (0.88)(3457.2 - 3117.1) = 3157.9 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_8 = 1 \text{ MPa} \\ h_8 = 3157.9 \text{ kJ/kg} \end{array}\right\} T_8 = \mathbf{349.9°C}$$

$$\left.\begin{array}{l} P_9 = 20 \text{ kPa} \\ s_9 = s_7 \end{array}\right\} h_{9s} = 2385.2 \text{ kJ/kg}$$

$$\eta_T = \frac{h_7 - h_9}{h_7 - h_{9s}} \longrightarrow h_9 = h_7 - \eta_T\left(h_7 - h_{9s}\right)$$
$$= 3457.2 - (0.88)(3457.2 - 2385.2) = 2513.9 \text{ kJ/kg}$$

The fraction of steam extracted from the low pressure turbine for closed feedwater heater is determined from the steady-flow energy balance equation applied to the feedwater heater. Noting that $\dot{Q} \cong \dot{W} \cong \Delta ke \cong \Delta pe \cong 0$,

$$(1-y)(h_{10} - h_2) = y(h_8 - h_3)$$
$$(1-y)(771.48 - 260.65) = y(3157.9 - 762.51) \longrightarrow y = 0.1758$$

The corresponding mass flow rate is

$$\dot{m}_8 = y\dot{m}_5 = (0.1758)(15 \text{ kg/s}) = \mathbf{2.637 \text{ kg/s}}$$

(*c*) Then,

$$q_{\text{in}} = h_5 - h_4 + h_7 - h_6 = 3399.5 - 771.48 + 3457.2 - 3140.1 = 2945.2 \text{ kJ/kg}$$
$$q_{\text{out}} = (1-y)(h_9 - h_1) = (1 - 0.1758)(2513.9 - 251.42) = 1864.8 \text{ kJ/kg}$$

and

$$\dot{W}_{\text{net}} = \dot{m}(q_{\text{in}} - q_{\text{out}}) = (15 \text{ kg/s})(2945.8 - 1864.8)\text{kJ/kg} = \mathbf{16{,}206 \text{ kW}}$$

(*b*) The thermal efficiency is determined from

$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{1864.8 \text{ kJ/kg}}{2945.8 \text{ kJ/kg}} = 0.3668 = \mathbf{36.7\%}$$