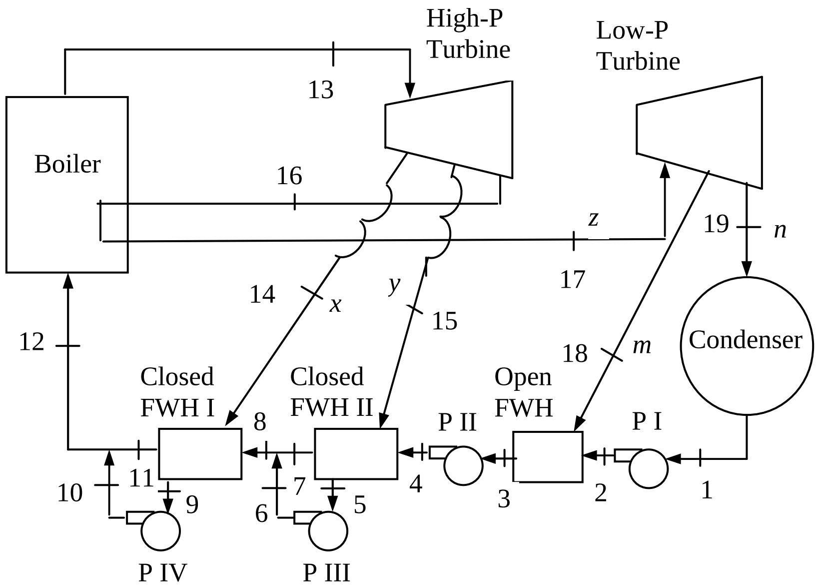
10-104 A steam power plant operating on the ideal reheat-regenerative Rankine cycle with three feedwater heaters is considered. Various items for this system per unit of mass flow rate through the boiler are to be determined.

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



Analysis The compression processes in the pumps and the expansion processes in the turbines are isentropic. Also, the state of water at the inlet of pumps is saturated liquid. Then, from the steam tables (Tables A-4, A-5, and A-6),

$$h_1 = 168.75 \text{ kJ/kg} \qquad h_{13} = 3423.1 \text{ kJ/kg}$$
$$h_2 = 168.84 \text{ kJ/kg} \qquad h_{14} = 3204.5 \text{ kJ/kg}$$
$$h_3 = 417.51 \text{ kJ/kg} \qquad h_{15} = 3063.6 \text{ kJ/kg}$$
$$h_4 = 419.28 \text{ kJ/kg} \qquad h_{16} = 2871.0 \text{ kJ/kg}$$
$$h_5 = 884.46 \text{ kJ/kg} \qquad h_{17} = 3481.3 \text{ kJ/kg}$$
$$h_6 = 885.86 \text{ kJ/kg} \qquad h_{18} = 2891.5 \text{ kJ/kg}$$
$$h_9 = 1008.3 \text{ kJ/kg} \qquad h_{19} = 2454.7 \text{ kJ/kg}$$
$$h_{10} = 1011.8 \text{ kJ/kg}$$

For an ideal closed feedwater heater, the feedwater is heated to the exit temperature of the extracted steam, which ideally leaves the heater as a saturated liquid at the extraction pressure. Then,

$$\left.\begin{array}{l} P_7 = 1800 \text{ kPa} \\ T_7 = T_5 = 207.1°\text{C} \end{array}\right\} h_7 = 884.91 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_{11} = 3000 \text{ kPa} \\ T_{11} = T_9 = 233.9°\text{C} \end{array}\right\} h_{11} = 1008.8 \text{ kJ/kg}$$

Enthalpies at other states and the fractions of steam extracted from the turbines can be determined from mass and energy balances on cycle components as follows:

Mass Balances:

$$x + y + z = 1$$
$$m + n = z$$

Open feedwater heater:

$$mh_{18} + nh_2 = zh_3$$

Closed feedwater heater-II:

$$zh_4 + yh_{15} = zh_7 + yh_5$$

Closed feedwater heater-I:

$$(y+z)h_8 + xh_{14} = (y+z)h_{11} + xh_9$$

Mixing chamber after closed feedwater heater II:

$$zh_7 + yh_6 = (y+z)h_8$$

Mixing chamber after closed feedwater heater I:

$$xh_{10} + (y+z)h_{11} = 1h_{12}$$

Substituting the values and solving the above equations simultaneously using EES, we obtain

$$h_8 = 885.08 \text{ kJ/kg}$$
$$h_{12} = 1009.0 \text{ kJ/kg}$$
$$x = \mathbf{0.05334}$$
$$y = \mathbf{0.1667}$$
$$z = 0.78000$$
$$m = \mathbf{0.07124}$$
$$n = \mathbf{0.70882}$$

Note that these values may also be obtained by a hand solution by using the equations above with some rearrangements and substitutions. Other results of the cycle are

$$w_{\text{T,out,HP}} = x(h_{13} - h_{14}) + y(h_{13} - h_{15}) + z(h_{13} - h_{16}) = \mathbf{502.3 \text{ kJ/kg}}$$
$$w_{\text{T,out,LP}} = m(h_{17} - h_{18}) + n(h_{17} - h_{19}) = \mathbf{769.6 \text{ kJ/kg}}$$
$$q_{\text{in}} = h_{13} - h_{12} + z(h_{17} - h_{16}) = \mathbf{2890 \text{ kJ/kg}}$$
$$q_{\text{out}} = n(h_{19} - h_1) = \mathbf{1620 \text{ kJ/kg}}$$
$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{1620}{2890} = 0.4394 = \mathbf{43.9\%}$$