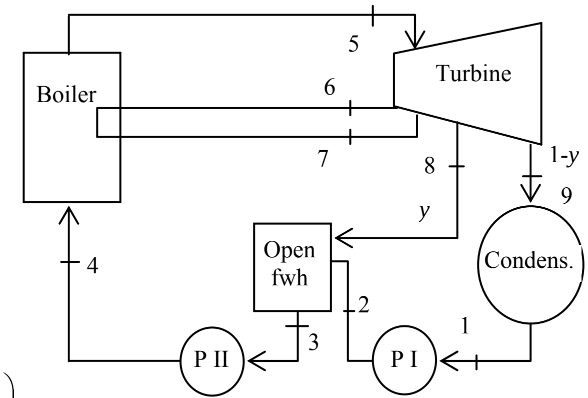
10-102 An ideal reheat-regenerative Rankine cycle with one open feedwater heater is considered. The fraction of steam extracted for regeneration and the thermal efficiency of the cycle are to be determined.

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),

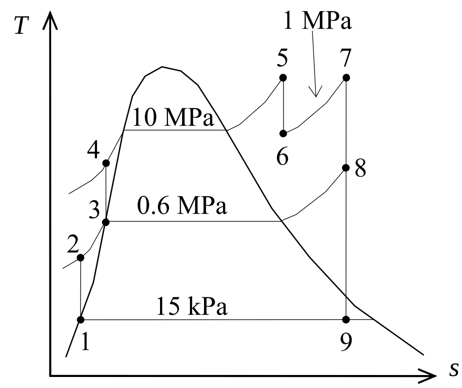
$$h_1 = h_{f\,@\,15\text{ kPa}} = 225.94\text{ kJ/kg}$$
$$\boldsymbol{v}_1 = \boldsymbol{v}_{f\,@\,15\text{ kPa}} = 0.001014\ \text{m}^3\text{/kg}$$

$$\begin{aligned} w_{\text{pI,in}} &= \boldsymbol{v}_1(P_2 - P_1) \\ &= (0.001014\ \text{m}^3\text{/kg})(600 - 15\text{ kPa})\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right) \\ &= 0.59\text{ kJ/kg} \end{aligned}$$
$$h_2 = h_1 + w_{\text{pI,in}} = 225.94 + 0.59 = 226.53\text{ kJ/kg}$$



$$\left.\begin{array}{l} P_3 = 0.6\text{ MPa} \\ \text{sat. liquid} \end{array}\right\} \begin{array}{l} h_3 = h_{f\,@\,0.6\text{ MPa}} = 670.38\text{ kJ/kg} \\ \boldsymbol{v}_3 = \boldsymbol{v}_{f\,@\,0.6\text{ MPa}} = 0.001101\ \text{m}^3\text{/kg} \end{array}$$

$$\begin{aligned} w_{\text{pII,in}} &= \boldsymbol{v}_3(P_4 - P_3) \\ &= (0.001101\ \text{m}^3\text{/kg})(10{,}000 - 600\text{ kPa})\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right) \\ &= 10.35\text{ kJ/kg} \end{aligned}$$
$$h_4 = h_3 + w_{\text{pII,in}} = 670.38 + 10.35 = 680.73\text{ kJ/kg}$$



$$\left.\begin{array}{l} P_5 = 10\text{ MPa} \\ T_5 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_5 = 3375.1\text{ kJ/kg} \\ s_5 = 6.5995\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_6 = 1.0\text{ MPa} \\ s_6 = s_5 \end{array}\right\} h_6 = 2783.8\text{ kJ/kg}$$

$$\left.\begin{array}{l} P_7 = 1.0\text{ MPa} \\ T_7 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_7 = 3479.1\text{ kJ/kg} \\ s_7 = 7.7642\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_8 = 0.6\text{ MPa} \\ s_8 = s_7 \end{array}\right\} h_8 = 3310.2\text{ kJ/kg}$$

$$\left.\begin{array}{l} P_9 = 15\text{ kPa} \\ s_9 = s_7 \end{array}\right\} \begin{array}{l} x_9 = \dfrac{s_9 - s_f}{s_{fg}} = \dfrac{7.7642 - 0.7549}{7.2522} = 0.9665 \\ h_9 = h_f + x_9 h_{fg} = 225.94 + (0.9665)(2372.3) = 2518.8\text{ kJ/kg} \end{array}$$

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

$$\dot{E}_{\text{in}} - \dot{E}_{\text{out}} = \Delta\dot{E}_{\text{system}}^{\nearrow 0\text{ (steady)}} = 0 \rightarrow \dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$
$$\sum \dot{m}_i h_i = \sum \dot{m}_e h_e \longrightarrow \dot{m}_8 h_8 + \dot{m}_2 h_2 = \dot{m}_3 h_3 \longrightarrow y h_8 + (1 - y)h_2 = 1(h_3)$$

where y is the fraction of steam extracted from the turbine ($= \dot{m}_8 / \dot{m}_3$). Solving for y,

$$y = \frac{h_3 - h_2}{h_8 - h_2} = \frac{670.38 - 226.53}{3310.2 - 226.53} = \mathbf{0.144}$$

(*b*) The thermal efficiency is determined from

$$q_{\text{in}} = (h_5 - h_4) + (h_7 - h_6) = (3375.1 - 680.73) + (3479.1 - 2783.8) = 3389.7\text{ kJ/kg}$$
$$q_{\text{out}} = (1 - y)(h_9 - h_1) = (1 - 0.1440)(2518.8 - 225.94) = 1962.7\text{ kJ/kg}$$

and $$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{1962.7\text{ kJ/kg}}{3389.7\text{ kJ/kg}} = \mathbf{42.1\%}$$