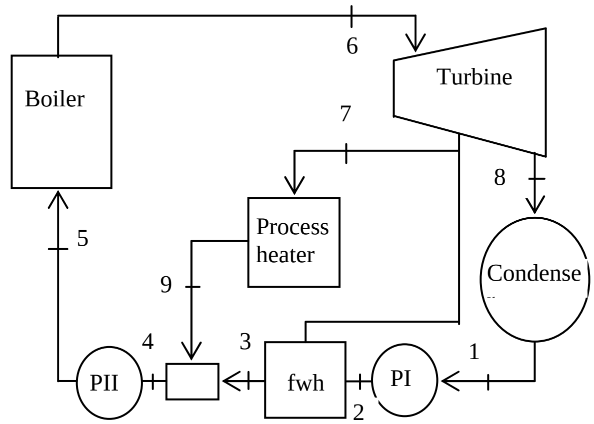
10-77 A cogeneration plant modified with regeneration is to generate power and process heat. The mass flow rate of steam through the boiler for a net power output of 25 MW is to be determined.

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

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



$$h_1 = h_{f\,@\,10\text{ kPa}} = 191.81\text{ kJ/kg}$$
$$\boldsymbol{v}_1 = \boldsymbol{v}_{f\,@\,10\text{ kPa}} = 0.00101\ \text{m}^3/\text{kg}$$

$$\begin{aligned} w_{\text{pI,in}} &= \boldsymbol{v}_1(P_2 - P_1) \\ &= \left(0.00101\ \text{m}^3/\text{kg}\right)\left(1600 - 10\text{ kPa}\right)\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right) \\ &= 1.61\text{ kJ/kg} \end{aligned}$$

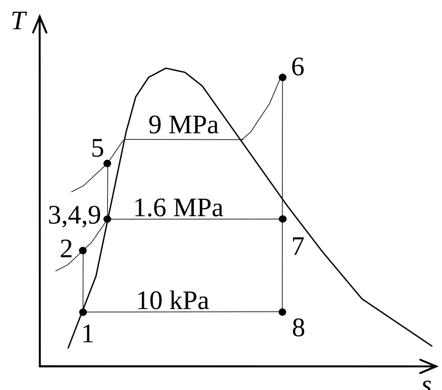
$$h_2 = h_1 + w_{\text{pI,in}} = 191.81 + 1.61 = 193.41\text{ kJ/kg}$$

$$h_3 = h_4 = h_9 = h_{f\,@\,1.6\text{ MPa}} = 858.44\text{ kJ/kg}$$

$$\boldsymbol{v}_4 = \boldsymbol{v}_{f\,@\,1.6\text{ MPa}} = 0.001159\text{ m}^3/\text{kg}$$

$$\begin{aligned} w_{\text{pII,in}} &= \boldsymbol{v}_4(P_5 - P_4) \\ &= \left(0.001159\ \text{m}^3/\text{kg}\right)\left(9000 - 400\text{ kPa}\right)\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right) \\ &= 8.57\text{ kJ/kg} \end{aligned}$$

$$h_5 = h_4 + w_{\text{pII,in}} = 858.44 + 8.57 = 867.02\text{ kJ/kg}$$



$$\left.\begin{aligned} P_6 &= 9\text{ MPa} \\ T_6 &= 400°\text{C} \end{aligned}\right\} \begin{aligned} h_6 &= 3118.8\text{ kJ/kg} \\ s_6 &= 6.2876\text{ kJ/kg}\cdot\text{K} \end{aligned}$$

$$\left.\begin{aligned} P_7 &= 1.6\text{ MPa} \\ s_7 &= s_6 \end{aligned}\right\} \begin{aligned} x_7 &= \frac{s_7 - s_f}{s_{fg}} = \frac{6.2876 - 2.3435}{4.0765} = 0.9675 \\ h_7 &= h_f + x_7 h_{fg} = 858.44 + (0.9675)(1934.4) = 2730.0\text{ kJ/kg} \end{aligned}$$

$$\left.\begin{aligned} P_8 &= 10\text{ kPa} \\ s_8 &= s_6 \end{aligned}\right\} \begin{aligned} x_8 &= \frac{s_8 - s_f}{s_{fg}} = \frac{6.2876 - 0.6492}{7.4996} = 0.7518 \\ h_8 &= h_f + x_8 h_{fg} = 191.81 + (0.7518)(2392.1) = 1990.2\text{ kJ/kg} \end{aligned}$$

Then, per kg of steam flowing through the boiler, we have

$$\begin{aligned} w_{\text{T,out}} &= (h_6 - h_7) + (1-y)(h_7 - h_8) \\ &= (3118.8 - 2730.0)\text{ kJ/kg} + (1 - 0.35)(2730.0 - 1990.2)\text{ kJ/kg} \\ &= 869.7\text{ kJ/kg} \end{aligned}$$

$$\begin{aligned} w_{\text{p,in}} &= (1-y)w_{\text{pI,in}} + w_{\text{pII,in}} \\ &= (1 - 0.35)(1.61\text{ kJ/kg}) + (8.57\text{ kJ/kg}) \\ &= 9.62\text{ kJ/kg} \end{aligned}$$

$$w_{\text{net}} = w_{\text{T,out}} - w_{\text{p,in}} = 869.7 - 9.62 = 860.1\text{ kJ/kg}$$

Thus,

$$\dot{m} = \frac{\dot{W}_{\text{net}}}{w_{\text{net}}} = \frac{25{,}000\text{ kJ/s}}{860.1\text{ kJ/kg}} = \mathbf{29.1\ kg/s}$$