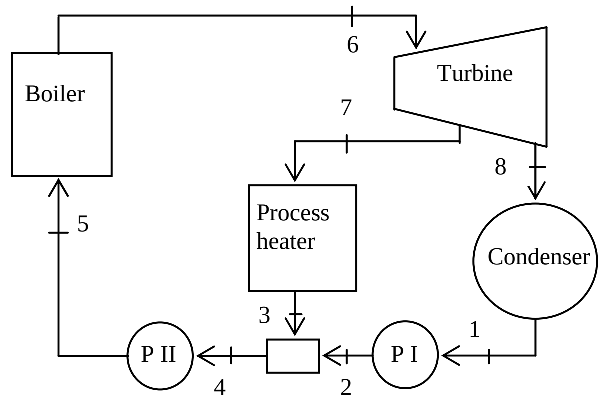
10-74 A cogeneration plant is to generate power and process heat. Part of the steam extracted from the turbine at a relatively high pressure is used for process heating. The net power produced and the utilization factor of the plant are to be determined.

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),

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



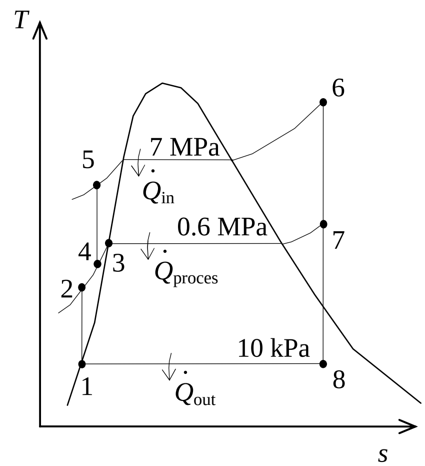
$$w_{\text{pI,in}} = \boldsymbol{v}_1(P_2 - P_1) = (0.00101\ \text{m}^3/\text{kg})(600 - 10\ \text{kPa})\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right) = 0.60\ \text{kJ/kg}$$
$$h_2 = h_1 + w_{\text{pI,in}} = 191.81 + 0.60 = 192.41\ \text{kJ/kg}$$

$$h_3 = h_{f\ @\ 0.6\ \text{MPa}} = 670.38\ \text{kJ/kg}$$

Mixing chamber:

$$\dot{E}_{\text{in}} - \dot{E}_{\text{out}} = \Delta\dot{E}_{\text{system}}^{\nearrow 0\ \text{(steady)}} = 0 \longrightarrow \dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$
$$\sum \dot{m}_i h_i = \sum \dot{m}_e h_e \longrightarrow \dot{m}_4 h_4 = \dot{m}_2 h_2 + \dot{m}_3 h_3$$

or, $$h_4 = \frac{\dot{m}_2 h_2 + \dot{m}_3 h_3}{\dot{m}_4} = \frac{(22.50)(192.41) + (7.50)(670.38)}{30} = 311.90\ \text{kJ/kg}$$
$$\boldsymbol{v}_4 \cong \boldsymbol{v}_{f\ @\ h_f = 311.90\ \text{kJ/kg}} = 0.001026\ \text{m}^3/\text{kg}$$



$$w_{p\text{II,in}} = \boldsymbol{v}_4(P_5 - P_4) = (0.001026\ \text{m}^3/\text{kg})(7000 - 600\ \text{kPa})\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right) = 6.57\ \text{kJ/kg}$$
$$h_5 = h_4 + w_{p\text{II,in}} = 311.90 + 6.57 = 318.47\ \text{kJ/kg}$$

$$\left.\begin{array}{l} P_6 = 7\ \text{MPa} \\ T_6 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_6 = 3411.4\ \text{kJ/kg} \\ s_6 = 6.8000\ \text{kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_7 = 0.6\ \text{MPa} \\ s_7 = s_6 \end{array}\right\} h_7 = 2774.6\ \text{kJ/kg}$$

$$\left.\begin{array}{l} P_8 = 10\ \text{kPa} \\ s_8 = s_6 \end{array}\right\} \begin{array}{l} x_8 = \dfrac{s_8 - s_f}{s_{fg}} = \dfrac{6.8000 - 0.6492}{7.4996} = 0.8201 \\ h_8 = h_f + x_8 h_{fg} = 191.81 + (0.8201)(2392.1) = 2153.6\ \text{kJ/kg} \end{array}$$

Then,

$$\dot{W}_{\text{T,out}} = \dot{m}_6(h_6 - h_7) + \dot{m}_8(h_7 - h_8) = (30\ \text{kg/s})(3411.4 - 2774.6)\text{kJ/kg} + (22.5\ \text{kg/s})(2774.6 - 2153.6)\text{kJ/kg} = 33{,}077\ \text{kW}$$
$$\dot{W}_{\text{p,in}} = \dot{m}_1 w_{\text{pI,in}} + \dot{m}_4 w_{\text{pII,in}} = (22.5\ \text{kg/s})(0.60\ \text{kJ/kg}) + (30\ \text{kg/s})(6.57\ \text{kJ/kg}) = 210.6\ \text{kW}$$
$$\dot{W}_{\text{net}} = \dot{W}_{\text{T,out}} - \dot{W}_{\text{p,in}} = 33{,}077 - 210.6 = \mathbf{32{,}866\ \ kW}$$

Also, $$\dot{Q}_{\text{process}} = \dot{m}_7(h_7 - h_3) = (7.5\ \text{kg/s})(2774.6 - 670.38)\ \text{kJ/kg} = 15{,}782\ \text{kW}$$

$$\dot{Q}_{\text{in}} = \dot{m}_5(h_6 - h_5) = (30\ \text{kg/s})(3411.4 - 318.47) = 92{,}788\ \text{kW}$$

and $$\varepsilon_u = \frac{\dot{W}_{\text{net}} + \dot{Q}_{\text{process}}}{\dot{Q}_{\text{in}}} = \frac{32{,}866 + 15{,}782}{92{,}788} = \mathbf{52.4\%}$$