**10-90** A combined gas-steam power plant is considered. The topping cycle is a gas-turbine cycle and the bottoming cycle is a nonideal reheat Rankine cycle. The moisture percentage at the exit of the low-pressure turbine, the steam temperature at the inlet of the high-pressure turbine, and the thermal efficiency of the combined cycle are to be determined.

***Assumptions*** **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible. **3** Air is an ideal gas with variable specific heats.

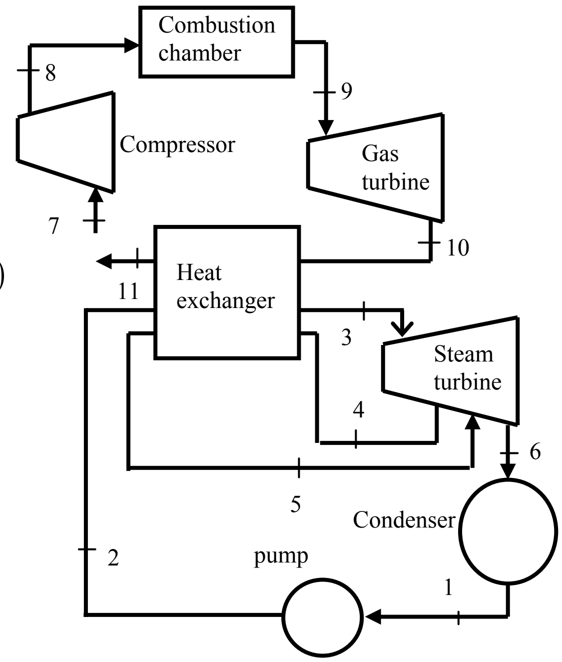
***Analysis*** (*a*) We obtain the air properties from EES. The analysis of gas cycle is as follows

$$T_7 = 15°\text{C} \longrightarrow h_7 = 288.50 \text{ kJ/kg}$$

$$\left.\begin{array}{l} T_7 = 15°\text{C} \\ P_7 = 100 \text{ kPa} \end{array}\right\} s_7 = 5.6648 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_8 = 700 \text{ kPa} \\ s_8 = s_7 \end{array}\right\} h_{8s} = 503.47 \text{ kJ/kg}$$

$$\eta_C = \frac{h_{8s} - h_7}{h_8 - h_7} \longrightarrow h_8 = h_7 + (h_{8s} - h_7)/\eta_C = 290.16 + (503.47 - 290.16)/(0.80) = 557.21 \text{ kJ/kg}$$



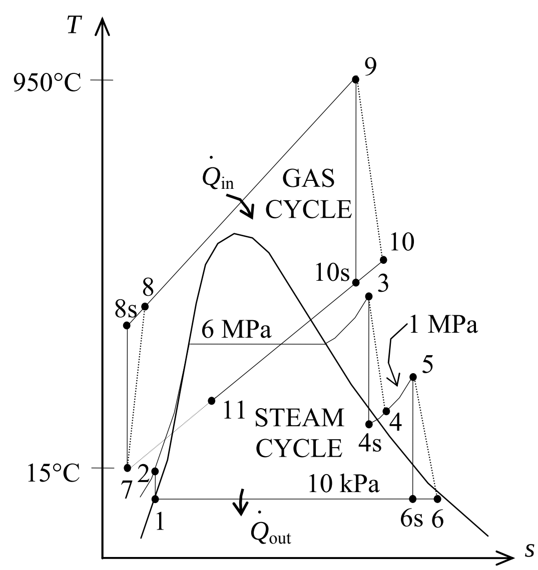

$$T_9 = 950°\text{C} \longrightarrow h_9 = 1304.8 \text{ kJ/kg}$$

$$\left.\begin{array}{l} T_9 = 950°\text{C} \\ P_9 = 700 \text{ kPa} \end{array}\right\} s_9 = 6.6456 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_{10} = 100 \text{ kPa} \\ s_{10} = s_9 \end{array}\right\} h_{10s} = 763.79 \text{ kJ/kg}$$

$$\eta_T = \frac{h_9 - h_{10}}{h_9 - h_{10s}} \longrightarrow h_{10} = h_9 - \eta_T (h_9 - h_{10s}) = 1304.8 - (0.80)(1304.8 - 763.79) = 871.98 \text{ kJ/kg}$$

$$T_{11} = 200°\text{C} \longrightarrow h_{11} = 475.62 \text{ kJ/kg}$$




From the steam tables (Tables A-4, A-5, and A-6 or from EES),

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

$$w_{\text{pI,in}} = \boldsymbol{v}_1 (P_2 - P_1)/\eta_p = (0.00101 \text{ m}^3\text{/kg})(6000 - 10 \text{ kPa})\left(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3}\right)/0.80 = 7.56 \text{ kJ/kg}$$

$$h_2 = h_1 + w_{\text{pI,in}} = 191.81 + 7.65 = 199.37 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_5 = 1 \text{ MPa} \\ T_5 = 400°\text{C} \end{array}\right\} \begin{array}{l} h_5 = 3264.5 \text{ kJ/kg} \\ s_5 = 7.4670 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_6 = 10 \text{ kPa} \\ s_{6s} = s_5 \end{array}\right\} \begin{array}{l} x_{6s} = \dfrac{s_{6s} - s_f}{s_{fg}} = \dfrac{7.4670 - 0.6492}{7.4996} = 0.9091 \\ h_{6s} = h_f + x_{6s} h_{fg} = 191.81 + (0.9091)(2392.1) = 2366.4 \text{ kJ/kg} \end{array}$$

$$\eta_T = \frac{h_5 - h_6}{h_5 - h_{6s}} \longrightarrow h_6 = h_5 - \eta_T(h_5 - h_{6s}) = 3264.5 - (0.80)(3264.5 - 2366.4) = 2546.0 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_6 = 10 \text{ kPa} \\ h_6 = 2546.5 \text{ kJ/kg} \end{array}\right\} x_6 = 0.9842$$

Moisture Percentage $= 1 - x_6 = 1 - 0.9842 = 0.0158 =$ **1.6%**

(*b*) Noting that $\dot{Q} \cong \dot{W} \cong \Delta\text{ke} \cong \Delta\text{pe} \cong 0$ for the heat exchanger, the steady-flow energy balance equation yields

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\sum \dot{m}_i h_i = \sum \dot{m}_e h_e$$

$$\dot{m}_s(h_3 - h_2) + \dot{m}_s(h_5 - h_4) = \dot{m}_{\text{air}}(h_{10} - h_{11})$$

$$(1.15)[(3346.5 - 199.37) + (3264.5 - h_4)] = (10)(871.98 - 475.62) \longrightarrow h_4 = 2965.0 \text{ kJ/kg}$$

Also,

$$\left.\begin{array}{l} P_3 = 6 \text{ MPa} \\ T_3 = ? \end{array}\right\} \begin{array}{l} h_3 = \\ s_3 = \end{array} \qquad \left.\begin{array}{l} P_4 = 1 \text{ MPa} \\ s_{4s} = s_3 \end{array}\right\} h_{4s} =$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} \longrightarrow h_4 = h_3 - \eta_T(h_3 - h_{4s})$$

The temperature at the inlet of the high-pressure turbine may be obtained by a trial-error approach or using EES from the above relations. The answer is $T_3$ = **468.0ºC**. Then, the enthalpy at state 3 becomes: $h_3$ = 3346.5 kJ/kg

(*c*) $\dot{W}_{\text{T,gas}} = \dot{m}_{\text{air}}(h_9 - h_{10}) = (10 \text{ kg/s})(1304.8 - 871.98) \text{ kJ/kg} = 4328 \text{ kW}$

$$\dot{W}_{\text{C,gas}} = \dot{m}_{\text{air}}(h_8 - h_7) = (10 \text{ kg/s})(557.21 - 288.50) \text{ kJ/kg} = 2687 \text{ kW}$$

$$\dot{W}_{\text{net,gas}} = \dot{W}_{\text{T,gas}} - \dot{W}_{\text{C,gas}} = 4328 - 2687 = 1641 \text{ kW}$$

$$\dot{W}_{\text{T,steam}} = \dot{m}_s(h_3 - h_4 + h_5 - h_6) = (1.15 \text{ kg/s})(3346.5 - 2965.0 + 3264.5 - 2546.0) \text{ kJ/kg} = 1265 \text{ kW}$$

$$\dot{W}_{\text{P,steam}} = \dot{m}_s w_{pump} = (1.15 \text{ kg/s})(7.564) \text{ kJ/kg} = 8.7 \text{ kW}$$

$$\dot{W}_{\text{net,steam}} = \dot{W}_{\text{T,steam}} - \dot{W}_{\text{P,steam}} = 1265 - 8.7 = 1256 \text{ kW}$$

$\dot{W}_{\text{net,plant}} = \dot{W}_{\text{net,gas}} + \dot{W}_{\text{net,steam}} = 1641 + 1256 =$ **2897 kW**

(*d*) $\dot{Q}_{\text{in}} = \dot{m}_{\text{air}}(h_9 - h_8) = (10 \text{ kg/s})(1304.8 - 557.21) \text{ kJ/kg} = 7476 \text{ kW}$

$\eta_{\text{th}} = \dfrac{\dot{W}_{\text{net,plant}}}{\dot{Q}_{\text{in}}} = \dfrac{2897 \text{ kW}}{7476 \text{ kW}} = 0.388 =$ **38.8%**