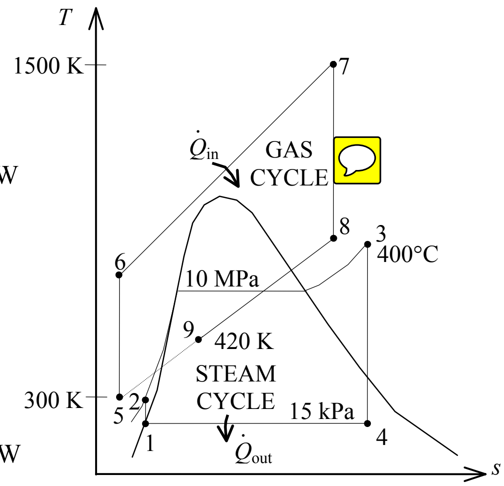
10-76 A combined gas-steam power cycle is considered. The topping cycle is a gas-turbine cycle and the bottoming cycle is a simple ideal Rankine cycle. The mass flow rate of the steam, the net power output, and the thermal efficiency of the combined cycle are to be determined.

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

Properties The properties of air at room temperature are c_p = 1.005 kJ/kg·K and k = 1.4 (Table A-2).

Analysis (*a*) The analysis of gas cycle yields



$$T_6 = T_5\left(\frac{P_6}{P_5}\right)^{(k-1)/k} = (300\text{ K})(16)^{0.4/1.4} = 662.5\text{ K}$$

$$\begin{aligned}\dot{Q}_{in} &= \dot{m}_{air}(h_7 - h_6) = \dot{m}_{air}c_p(T_7 - T_6)\\ &= (14\text{ kg/s})(1.005\text{ kJ/kg}\cdot\text{K})(1500 - 662.5)\text{ K} = 11{,}784\text{ kW}\end{aligned}$$

$$\begin{aligned}\dot{W}_{C,gas} &= \dot{m}_{air}(h_6 - h_5) = \dot{m}_{air}c_p(T_6 - T_5)\\ &= (14\text{ kg/s})(1.005\text{ kJ/kg}\cdot\text{K})(662.5 - 300)\text{ K} = 5100\text{ kW}\end{aligned}$$

$$T_8 = T_7\left(\frac{P_8}{P_7}\right)^{(k-1)/k} = (1500\text{K})\left(\frac{1}{16}\right)^{0.4/1.4} = 679.3\text{ K}$$

$$\begin{aligned}\dot{W}_{T,gas} &= \dot{m}_{air}(h_7 - h_8) = \dot{m}_{air}c_p(T_7 - T_8)\\ &= (14\text{ kg/s})(1.005\text{ kJ/kg}\cdot\text{K})(1500 - 679.3)\text{ K} = 11{,}547\text{ kW}\end{aligned}$$

$$\dot{W}_{net,gas} = \dot{W}_{T,gas} - \dot{W}_{C,gas} = 11{,}547 - 5{,}100 = 6447\text{ kW}$$

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

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

$$w_{pI,in} = \boldsymbol{v}_1(P_2 - P_1) = (0.001014\ \text{ m}^3\text{/kg})(10{,}000 - 15\text{ kPa})\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right) = 10.12\text{ kJ/kg}$$

$$h_2 = h_1 + w_{pI,in} = 225.94 + 10.13 = 236.06\text{ kJ/kg}$$

$$\left.\begin{aligned}P_3 &= 10\text{ MPa}\\ T_3 &= 400°\text{C}\end{aligned}\right\}\begin{aligned}h_3 &= 3097.0\text{ kJ/kg}\\ s_3 &= 6.2141\text{ kJ/kg}\cdot\text{K}\end{aligned}$$

$$\left.\begin{aligned}P_4 &= 15\text{ kPa}\\ s_4 &= s_3\end{aligned}\right\}\begin{aligned}x_4 &= \frac{s_4 - s_f}{s_{fg}} = \frac{6.2141 - 0.7549}{7.2522} = 0.7528\\ h_4 &= h_f + x_4h_{fg} = 225.94 + (0.7528)(2372.3) = 2011.8\text{ kJ/kg}\end{aligned}$$

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

$$\dot{E}_{in} - \dot{E}_{out} = \Delta\dot{E}_{system}^{\nearrow 0\text{ (steady)}} = 0 \longrightarrow \dot{E}_{in} = \dot{E}_{out}$$

$$\sum \dot{m}_i h_i = \sum \dot{m}_e h_e \longrightarrow \dot{m}_s(h_3 - h_2) = \dot{m}_{air}(h_8 - h_9)$$

$$\dot{m}_s = \frac{h_8 - h_9}{h_3 - h_2}\dot{m}_{air} = \frac{c_p(T_8 - T_9)}{h_3 - h_2}\dot{m}_{air} = \frac{(1.005\text{ kJ/kg}\cdot\text{K})(679.3 - 420)\text{ K}}{(3097.0 - 236.06)\text{ kJ/kg}}(14\text{ kg/s}) = \mathbf{1.275\ \ kg/s}$$

(*b*)
$$\dot{W}_{T,steam} = \dot{m}_s(h_3 - h_4) = (1.275\text{ kg/s})(3097.0 - 2011.5)\text{ kJ/kg} = 1384\text{ kW}$$

$$\dot{W}_{p,steam} = \dot{m}_s w_p = (1.275\text{ kg/s})(10.12\text{ kJ/kg}) = 12.9\text{ kW}$$

$$\dot{W}_{net,steam} = \dot{W}_{T,steam} - \dot{W}_{p,steam} = 1384 - 12.9 = 1371\text{ kW}$$

and
$$\dot{W}_{net} = \dot{W}_{net,steam} + \dot{W}_{net,gas} = 1371 + 6448 = \mathbf{7819\ kW}$$

(*c*)
$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{7819\text{ kW}}{11{,}784\text{ kW}} = \mathbf{66.4\%}$$