9-179 A gas-turbine plant operates on the regenerative Brayton cycle with reheating and intercooling. The back work ratio, the net work output, the thermal efficiency, the second-law efficiency, and the exergies at the exits of the combustion chamber and the regenerator are to be determined.

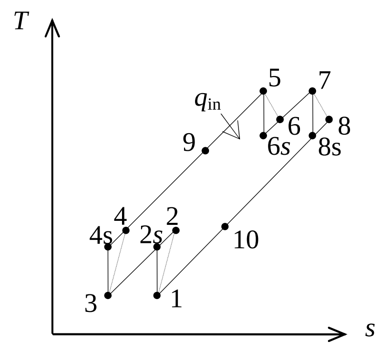
Assumptions **1** The air-standard assumptions are applicable. **2** Kinetic and potential energy changes are negligible. **3** Air is an ideal gas with variable specific heats.

Properties The gas constant of air is R = 0.287 kJ/kg·K.

Analysis (a) For this problem, we use the properties from EES software. Remember that for an ideal gas, enthalpy is a function of temperature only whereas entropy is functions of both temperature and pressure.

Optimum intercooling and reheating pressure is

$$P_2 = \sqrt{P_1 P_4} = \sqrt{(100)(1200)} = 346.4\text{ kPa}$$



Process 1-2, 3-4: Compression

$$T_1 = 300\text{ K} \longrightarrow h_1 = 300.43\text{ kJ/kg}$$

$$\left.\begin{array}{l} T_1 = 300\text{ K} \\ P_1 = 100\text{ kPa} \end{array}\right\} s_1 = 5.7054\text{ kJ/kg}\cdot\text{K}$$

$$\left.\begin{array}{l} P_2 = 346.4\text{ kPa} \\ s_2 = s_1 = 5.7054\text{ kJ/kg.K} \end{array}\right\} h_{2s} = 428.79\text{ kJ/kg}$$

$$\eta_C = \frac{h_{2s} - h_1}{h_2 - h_1} \longrightarrow 0.80 = \frac{428.79 - 300.43}{h_2 - 300.43} \longrightarrow h_2 = 460.88\text{ kJ/kg}$$

$$T_3 = 350\text{ K} \longrightarrow h_3 = 350.78\text{ kJ/kg}$$

$$\left.\begin{array}{l} T_3 = 350\text{ K} \\ P_3 = 346.4\text{ kPa} \end{array}\right\} s_3 = 5.5040\text{ kJ/kg}\cdot\text{K}$$

$$\left.\begin{array}{l} P_4 = 1200\text{ kPa} \\ s_4 = s_3 = 5.5040\text{ kJ/kg.K} \end{array}\right\} h_{4s} = 500.42\text{ kJ/kg}$$

$$\eta_C = \frac{h_{4s} - h_3}{h_4 - h_3} \longrightarrow 0.80 = \frac{500.42 - 350.78}{h_4 - 350.78} \longrightarrow h_4 = 537.83\text{ kJ/kg}$$

Process 6-7, 8-9: Expansion

$$T_6 = 1400\text{ K} \longrightarrow h_6 = 1514.9\text{ kJ/kg}$$

$$\left.\begin{array}{l} T_6 = 1400\text{ K} \\ P_6 = 1200\text{ kPa} \end{array}\right\} s_6 = 6.6514\text{ kJ/kg}\cdot\text{K}$$

$$\left.\begin{array}{l} P_7 = 346.4\text{ kPa} \\ s_7 = s_6 = 6.6514\text{ kJ/kg.K} \end{array}\right\} h_{7s} = 1083.9\text{ kJ/kg}$$

$$\eta_T = \frac{h_6 - h_7}{h_6 - h_{7s}} \longrightarrow 0.80 = \frac{1514.9 - h_7}{1514.9 - 1083.9} \longrightarrow h_7 = 1170.1\text{ kJ/kg}$$

$$T_8 = 1300\text{ K} \longrightarrow h_8 = 1395.6\text{ kJ/kg}$$

$$\left.\begin{array}{l} T_8 = 1300\text{ K} \\ P_8 = 346.4\text{ kPa} \end{array}\right\} s_8 = 6.9196\text{ kJ/kg}\cdot\text{K}$$

$$\left.\begin{array}{l} P_9 = 100\text{ kPa} \\ s_9 = s_8 = 6.9196\text{ kJ/kg.K} \end{array}\right\} h_{9s} = 996.00\text{ kJ/kg}$$

$$\eta_T = \frac{h_8 - h_9}{h_8 - h_{9s}} \longrightarrow 0.80 = \frac{1395.6 - h_9}{1395.6 - 996.00} \longrightarrow h_9 = 1075.9 \text{ kJ/kg}$$

Cycle analysis:

$$w_{\text{C,in}} = h_2 - h_1 + h_4 - h_3 = 460.88 - 300.43 + 537.83 - 350.78 = 347.50 \text{ kJ/kg}$$

$$w_{\text{T,out}} = h_6 - h_7 + h_8 - h_9 = 1514.9 - 1170.1 + 1395.6 - 1075.9 = 664.50 \text{ kJ/kg}$$

$$r_{\text{bw}} = \frac{w_{\text{C,in}}}{w_{\text{T,out}}} = \frac{347.50}{664.50} = \mathbf{0.523}$$

$$w_{\text{net}} = w_{\text{T,out}} - w_{\text{C,in}} = 664.50 - 347.50 = \mathbf{317.0\ kJ/kg}$$

Regenerator analysis:

$$\varepsilon_{\text{regen}} = \frac{h_9 - h_{10}}{h_9 - h_4} \longrightarrow 0.75 = \frac{1075.9 - h_{10}}{1075.9 - 537.83} \longrightarrow h_{10} = 672.36 \text{ kJ/kg}$$

$$\left.\begin{array}{l} h_{10} = 672.36 \text{ K} \\ P_{10} = 100 \text{ kPa} \end{array}\right\} s_{10} = 6.5157 \text{ kJ/kg} \cdot \text{K}$$

$$q_{\text{regen}} = h_9 - h_{10} = h_5 - h_4 \longrightarrow 1075.9 - 672.36 = h_5 - 537.83 \longrightarrow h_5 = 941.40 \text{ kJ/kg}$$

(*b*) $$q_{\text{in}} = h_6 - h_5 = 1514.9 - 941.40 = 573.54 \text{ kJ/kg}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{317.0}{573.54} = \mathbf{0.553}$$

(*c*) The second-law efficieny of the cycle is defined as the ratio of actual thermal efficiency to the maximum possible thermal efficiency (Carnot efficiency). The maximum temperature for the cycle can be taken to be the turbine inlet temperature. That is,

$$\eta_{\max} = 1 - \frac{T_1}{T_6} = 1 - \frac{300 \text{ K}}{1400 \text{ K}} = 0.786$$

and

$$\eta_{II} = \frac{\eta_{th}}{\eta_{\max}} = \frac{0.553}{0.786} = \mathbf{0.704}$$

(*d*) The exergies at the combustion chamber exit and the regenerator exit are

$$\begin{aligned} x_6 &= h_6 - h_0 - T_0(s_6 - s_0) \\ &= (1514.9 - 300.43)\text{kJ/kg} - (300 \text{ K})(6.6514 - 5.7054)\text{kJ/kg.K} \\ &= \mathbf{930.7\ kJ/kg} \end{aligned}$$

$$\begin{aligned} x_{10} &= h_{10} - h_0 - T_0(s_{10} - s_0) \\ &= (672.36 - 300.43)\text{kJ/kg} - (300 \text{ K})(6.5157 - 5.7054)\text{kJ/kg.K} \\ &= \mathbf{128.8\ kJ/kg} \end{aligned}$$