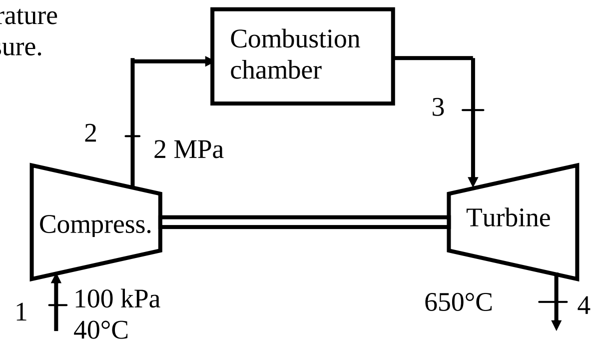
9-100 A gas-turbine plant operates on the simple Brayton cycle. The net power output, the back work ratio, and the thermal efficiency are to be determined.

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 (Table A-1).

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.



Process 1-2: Compression

$$T_1 = 40°\text{C} \longrightarrow h_1 = 313.6 \text{ kJ/kg}$$

$$\left.\begin{array}{l} T_1 = 40°\text{C} \\ P_1 = 100 \text{ kPa} \end{array}\right\} s_1 = 5.749 \text{ kJ/kg}\cdot\text{K}$$

$$\left.\begin{array}{l} P_2 = 2000 \text{ kPa} \\ s_2 = s_1 = 5.749 \text{ kJ/kg.K} \end{array}\right\} h_{2s} = 736.7 \text{ kJ/kg}$$

$$\eta_\text{C} = \frac{h_{2s} - h_1}{h_2 - h_1} \longrightarrow 0.85 = \frac{736.7 - 313.6}{h_2 - 313.6} \longrightarrow h_2 = 811.4 \text{ kJ/kg}$$

Process 3-4: Expansion

$$T_4 = 650°\text{C} \longrightarrow h_4 = 959.2 \text{ kJ/kg}$$

$$\eta_\text{T} = \frac{h_3 - h_4}{h_3 - h_{4s}} \longrightarrow 0.88 = \frac{h_3 - 959.2}{h_3 - h_{4s}}$$

We cannot find the enthalpy at state 3 directly. However, using the following lines in EES together with the isentropic efficiency relation, we find h_3 = 1873 kJ/kg, T_3 = 1421ºC, s_3 = 6.736 kJ/kg.K. The solution by hand would require a trial-error approach.

```
h_3=enthalpy(Air, T=T_3)
s_3=entropy(Air, T=T_3, P=P_2)
h_4s=enthalpy(Air, P=P_1, s=s_3)
```

The mass flow rate is determined from

$$\dot{m} = \frac{P_1 \dot{V}_1}{RT_1} = \frac{(100 \text{ kPa})(700/60 \text{ m}^3\text{/s})}{(0.287 \text{ kPa}\cdot\text{m}^3\text{/kg}\cdot\text{K})(40 + 273 \text{ K})} = 12.99 \text{ kg/s}$$

The net power output is

$$\dot{W}_\text{C,in} = \dot{m}(h_2 - h_1) = (12.99 \text{ kg/s})(811.4 - 313.6)\text{kJ/kg} = 6464 \text{ kW}$$

$$\dot{W}_\text{T,out} = \dot{m}(h_3 - h_4) = (12.99 \text{ kg/s})(1873 - 959.2)\text{kJ/kg} = 11{,}868 \text{ kW}$$

$$\dot{W}_\text{net} = \dot{W}_\text{T,out} - \dot{W}_\text{C,in} = 11{,}868 - 6464 = \mathbf{5404\ kW}$$

(*b*) The back work ratio is

$$r_\text{bw} = \frac{\dot{W}_\text{C,in}}{\dot{W}_\text{T,out}} = \frac{6464 \text{ kW}}{11{,}868 \text{ kW}} = \mathbf{0.545}$$

(*c*) The rate of heat input and the thermal efficiency are

$$\dot{Q}_\text{in} = \dot{m}(h_3 - h_2) = (12.99 \text{ kg/s})(1873 - 811.4)\text{kJ/kg} = 13{,}788 \text{ kW}$$

$$\eta_{th} = \frac{\dot{W}_\text{net}}{\dot{Q}_\text{in}} = \frac{5404 \text{ kW}}{13{,}788 \text{ kW}} = 0.392 = \mathbf{39.2\%}$$