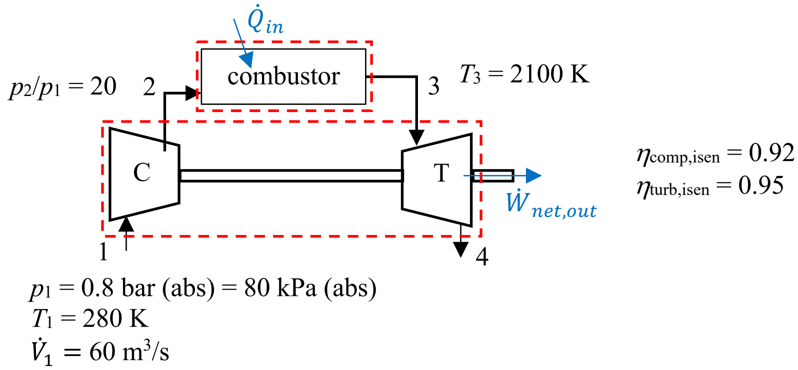
Air enters the compressor of an air-standard Brayton cycle with a volumetric flow rate of 60 $m^3/s$ at 0.8 bar (abs) and 280 K. The compressor pressure ratio is 20 and the maximum cycle temperature is 2100 K. The compressor and turbine isentropic efficiencies are 92% and 95%, respectively. Determine:

a. the net power developed from the cycle,
b. the rate of heat addition in the combustor, and
c. the thermal efficiency of the cycle.

SOLUTION:




Apply the 1st Law to a control volume surrounding the compressor and turbine,

$$0 = \dot{m}(h_1 - h_2 + h_3 - h_4) - \dot{W}_{out,net}, \tag{1}$$

(assuming steady state, negligible KE and PE, and adiabatic conditions)

$$\dot{W}_{out,net} = \dot{m}(h_1 - h_2 + h_3 - h_4). \tag{2}$$

The mass flow rate can be found from the conditions at State 1 and using the ideal gas law,

$$\dot{m} = \rho_1 \dot{V}_1 = \left(\frac{p_1}{RT_1}\right)\dot{V}_1, \tag{3}$$

⇨ $\dot{m} = 59.731$ kg/s

Now determine the specific enthalpies at each of the states.

State 1:

$T_1 = 280$ K => $h_1 = 280.1$ kJ/kg, $p_r(T_1) = 1.0889$ (from the Ideal Gas Table)

State 3:

$T_3 = 2100$ K => $h_3 = 2377$ kJ/kg, $p_r(T_3) = 2559$ (from the IGT)

State 2:

$$\eta_{comp,isen} = \frac{h_{2s} - h_1}{h_2 - h_1} \Rightarrow h_2 = h_1 + \frac{h_{2s} - h_1}{\eta_{comp,isen}}. \tag{4}$$

State 2*s*: $p_2/p_1 = p_{2s}/p_1 = 20$,

$$\frac{p_{2s}}{p_1} = \frac{p_r(T_{2s})}{p_r(T_1)} \Rightarrow p_r(T_{2s}) = p_r(T_1)\left(\frac{p_{2s}}{p_1}\right) \text{ (isentropic compression of an ideal gas),} \tag{5}$$

=> $p_r(T_{2s}) = 21.778$ => $T_{2s} = 649.33$ K, $h_{2s} = 659.29$ kJ/kg (from IGT)

Using Eq. (4) and the given and computed values,

$h_2 = 692.26$ kJ/kg.

State 4:

$$\eta_{turb,isen} = \frac{h_4 - h_3}{h_{4s} - h_3} \;=>\; h_4 = h_3 + \eta_{turb,isen}(h_{4s} - h_3). \qquad (6)$$

State 4*s*: $p_3/p_4 = p_3/p_{4s} = p_2/p_1 = 20$,

$$\frac{p_3}{p_{4s}} = \frac{p_r(T_3)}{p_r(T_{4s})} \;=>\; p_r(T_{4s}) = p_r(T_3)\left(\frac{p_{4s}}{p_3}\right) \quad \text{(isentropic expansion of an ideal gas),} \qquad (7)$$

=> $p_r(T_{4s}) = 127.95$ => $T_{4s} = 1029.19$ K, $h_{4s} = 1079.57$ kJ/kg (from IGT)

Using Eq. (6) and the given and computed values,

$h_4 = 1144.44$ kJ/kg.

Using the state data, mass flow rate, and Eq. (2),

$\boxed{\dot{W}_{out,net} = 49.0 \text{ MJ}}$.

The rate of heat addition into the combustor is found by applying the 1st Law to a control volume surrounding the combustor,

$$0 = \dot{m}(h_2 - h_3) + \dot{Q}_{in}, \qquad (8)$$

(assuming steady state, negligible KE and PE, and a passive device)

$$\dot{Q}_{in} = \dot{m}(h_3 - h_2). \qquad (9)$$

Using the previously calculated quantities,

$\boxed{\dot{Q}_{in} = 101 \text{ MW}}$.

The cycle's thermal efficiency is,

$$\eta = \frac{\dot{W}_{out,net}}{\dot{Q}_{in}},$$

=> $\boxed{\eta = 0.487 = 48.7\%}$.