5.104

Oxygen at 300 kPa, 100°C is in a piston/cylinder arrangement with a volume of 0.1 m^3. It is now compressed in a polytropic process with exponent, *n* = 1.2, to a final temperature of 200°C. Calculate the heat transfer for the process.

Solution:

Continuty: $m_2 = m_1$

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

State 1: T_1 , P_1 & ideal gas, small change in T, so use Table A.5

$$\Rightarrow m = \frac{P_1V_1}{RT_1} = \frac{300 \times 0.1 \text{ m}^3}{0.25983 \times 373.15} = 0.309 \text{ kg}$$

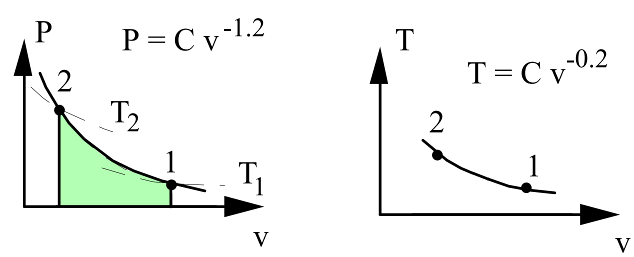
Process: PV^n = constant

$${}_1W_2 = \frac{1}{1\text{-n}}(P_2V_2 - P_1V_1) = \frac{mR}{1\text{-n}}(T_2 - T_1) = \frac{0.309 \times 0.25983}{1 - 1.2}(200 - 100)$$

$$= -40.2 \text{ kJ}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 \cong mC_v(T_2 - T_1) + {}_1W_2$$

$$= 0.3094 \times 0.662\ (200 - 100) - 40.2 = \mathbf{-19.7\ kJ}$$

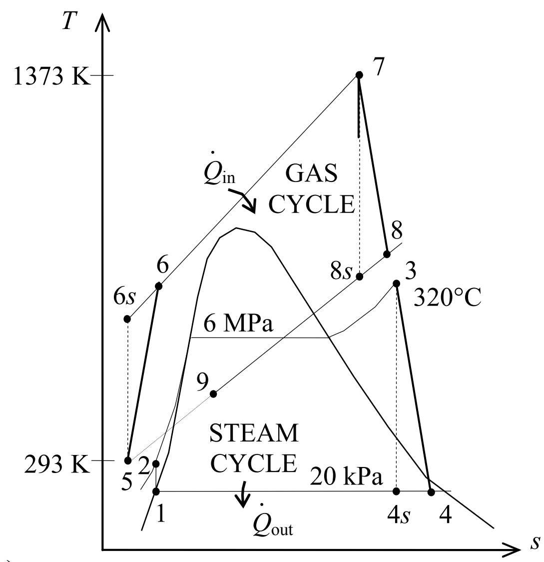


10-85 A combined gas-steam power cycle uses a simple gas turbine for the topping cycle and simple Rankine cycle for the bottoming cycle. The mass flow rate of air for a specified power output is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The air-standard assumptions are applicable fo Brayton cycle. **3** Kinetic and potential energy changes are negligible. **4** 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-2a).

Analysis Working around the topping cycle gives the following results:



$$T_{6s} = T_5\left(\frac{P_6}{P_5}\right)^{(k-1)/k} = (293\text{ K})(8)^{0.4/1.4} = 530.8\text{ K}$$

$$\eta_C = \frac{h_{6s} - h_5}{h_6 - h_5} = \frac{c_p(T_{6s} - T_5)}{c_p(T_6 - T_5)}$$

$$\longrightarrow T_6 = T_5 + \frac{T_{6s} - T_5}{\eta_C}$$
$$= 293 + \frac{530.8 - 293}{0.85} = 572.8\text{ K}$$

$$T_{8s} = T_7\left(\frac{P_8}{P_7}\right)^{(k-1)/k} = (1373\text{ K})\left(\frac{1}{8}\right)^{0.4/1.4} = 758.0\text{ K}$$

$$\eta_T = \frac{h_7 - h_8}{h_7 - h_{8s}} = \frac{c_p(T_7 - T_8)}{c_p(T_7 - T_{8s})} \longrightarrow T_8 = T_7 - \eta_T(T_7 - T_{8s})$$
$$= 1373 - (0.90)(1373 - 758.0)$$
$$= 819.5\text{ K}$$

$$T_9 = T_{\text{sat @ 6000 kPa}} = 275.6°\text{C} = 548.6\text{ K}$$

Fixing the states around the bottom steam cycle yields (Tables A-4, A-5, A-6):

$$h_1 = h_{f @ 20\text{ kPa}} = 251.42\text{ kJ/kg}$$
$$v_1 = v_{f @ 20\text{ kPa}} = 0.001017\text{ m}^3\text{/kg}$$

$$w_{\text{p,in}} = v_1(P_2 - P_1)$$
$$= (0.001017\text{ m}^3\text{/kg})(6000 - 20)\text{kPa}\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right)$$
$$= 6.08\text{ kJ/kg}$$
$$h_2 = h_1 + w_{\text{p,in}} = 251.42 + 6.08 = 257.5\text{ kJ/kg}$$

$$\left.\begin{array}{l} P_3 = 6000\text{ kPa} \\ T_3 = 320°\text{C} \end{array}\right\} \begin{array}{l} h_3 = 2953.6\text{ kJ/kg} \\ s_3 = 6.1871\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_4 = 20\text{ kPa} \\ s_4 = s_3 \end{array}\right\} h_{4s} = 2035.8\text{ kJ/kg}$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} \longrightarrow h_4 = h_3 - \eta_T(h_3 - h_{4s})$$
$$= 2953.6 - (0.90)(2953.6 - 2035.8)$$
$$= 2127.6\text{ kJ/kg}$$

The net work outputs from each cycle are

$$\begin{aligned} w_{\text{net, gas cycle}} &= w_{\text{T,out}} - w_{\text{C,in}} \\ &= c_p(T_7 - T_8) - c_p(T_6 - T_5) \\ &= (1.005\ \text{kJ/kg}\cdot\text{K})(1373 - 819.5 - 572.7 + 293)\text{K} \\ &= 275.2\ \text{kJ/kg} \end{aligned}$$

$$\begin{aligned} w_{\text{net, steam cycle}} &= w_{\text{T,out}} - w_{\text{P,in}} \\ &= (h_3 - h_4) - w_{\text{P,in}} \\ &= (2953.6 - 2127.6) - 6.08 \\ &= 819.9\ \text{kJ/kg} \end{aligned}$$

An energy balance on the heat exchanger gives

$$\dot{m}_a c_p (T_8 - T_9) = \dot{m}_w (h_3\text{-}h_2) \longrightarrow \dot{m}_w = \frac{c_p(T_8 - T_9)}{h_3\text{-}h_2}\dot{m}_a = \frac{(1.005)(819.5 - 548.6)}{2953.6 - 257.5} = 0.1010\dot{m}_a$$

That is, 1 kg of exhaust gases can heat only 0.1010 kg of water. Then, the mass flow rate of air is

$$\dot{m}_a = \frac{\dot{W}_{\text{net}}}{w_{\text{net}}} = \frac{100{,}000\ \text{kJ/s}}{(1\times 275.2 + 0.1010\times 819.9)\ \text{kJ/kg air}} = \mathbf{279.3\ kg/s}$$