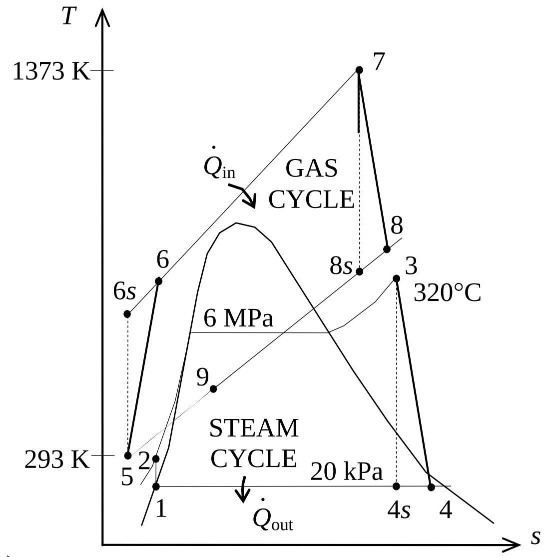
10-85 A combined gas-steam power cycle uses a simple gas turbine for the topping cycle and simple Rankine cycle for the bottoming cycle. The mass flow rate of air for a specified power output is to be determined.

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):

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

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

$$h_2 = h_1 + w_{p,in} = 251.42 + 6.08 = 257.5\,\text{kJ/kg}$$

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

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

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

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

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