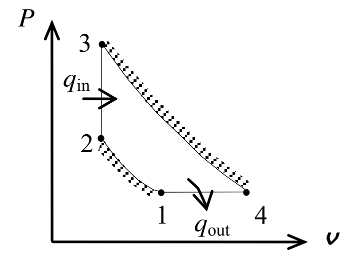
9-13 The four processes of an air-standard cycle are described. The cycle is to be shown on P-v and T-s diagrams, and the net work output and the thermal efficiency are to be determined.

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 properties of air are given in Table A-17.

Analysis (b) The properties of air at various states are



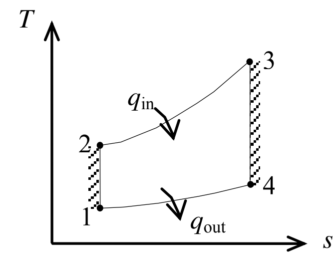
$$T_1 = 295\text{ K} \longrightarrow \begin{matrix} h_1 = 295.17\text{ kJ/kg} \\ P_{r_1} = 1.3068 \end{matrix}$$

$$P_{r_2} = \frac{P_2}{P_1} P_{r_1} = \frac{600\text{ kPa}}{100\text{ kPa}}(1.3068) = 7.841 \longrightarrow \begin{matrix} u_2 = 352.29\text{ kJ/kg} \\ T_2 = 490.3\text{ K} \end{matrix}$$

$$T_3 = 1500\text{ K} \longrightarrow \begin{matrix} u_3 = 1205.41\text{ kJ/kg} \\ P_{r_3} = 601.9 \end{matrix}$$

$$\frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \longrightarrow P_3 = \frac{T_3}{T_2} P_2 = \frac{1500\text{ K}}{490.3\text{ K}}(600\text{ kPa}) = 1835.6\text{ kPa}$$

$$P_{r_4} = \frac{P_4}{P_3} P_{r_3} = \frac{100\text{ kPa}}{1835.6\text{ kPa}}(601.9) = 32.79 \longrightarrow h_4 = 739.71\text{ kJ/kg}$$



From energy balances,

$$q_{in} = u_3 - u_2 = 1205.41 - 352.29 = 853.1\text{ kJ/kg}$$

$$q_{out} = h_4 - h_1 = 739.71 - 295.17 = 444.5\text{ kJ/kg}$$

$$w_{net,out} = q_{in} - q_{out} = 853.1 - 444.5 = \mathbf{408.6 kJ/kg}$$

(c) Then the thermal efficiency becomes

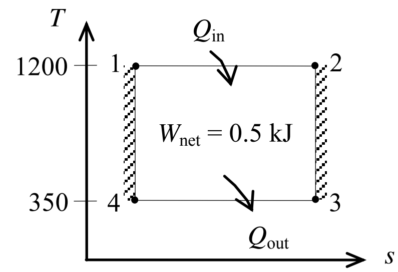
$$\eta_{th} = \frac{w_{net,out}}{q_{in}} = \frac{408.6\text{ kJ/kg}}{853.1\text{ kJ/kg}} = 0.479 = \mathbf{47.9\%}$$

9-18 A Carnot cycle with specified temperature limits is considered. The maximum pressure in the cycle, the heat transfer to the working fluid, and the mass of the working fluid are to be determined.

Assumptions Air is an ideal gas with variable specific heats.

Analysis (*a*) In a Carnot cycle, the maximum pressure occurs at the beginning of the expansion process, which is state 1.

$$T_1 = 1200\text{ K} \longrightarrow P_{r_1} = 238$$
$$T_4 = 350\text{ K} \longrightarrow P_{r_4} = 2.379 \qquad \text{(Table A-17)}$$



$$P_1 = \frac{P_{r_1}}{P_{r_4}} P_4 = \frac{238}{2.379}(300\text{ kPa}) = 30{,}013\text{ kPa} \cong \mathbf{30.0\ MPa} = P_{\max}$$

(*b*) The heat input is determined from

$$\eta_{\text{th}} = 1 - \frac{T_L}{T_H} = 1 - \frac{350\text{ K}}{1200\text{ K}} = 70.83\%$$

$$Q_{\text{in}} = W_{\text{net,out}} / \eta_{\text{th}} = (0.5\text{ kJ})/(0.7083) = \mathbf{0.706\ kJ}$$

(*c*) The mass of air is

$$s_4 - s_3 = \left(s_4^\circ - s_3^\circ\right)^{\nearrow 0} - R\ln\frac{P_4}{P_3} = -(0.287\text{ kJ/kg}\cdot\text{K})\ln\frac{300\text{ kPa}}{150\text{ kPa}}$$
$$= -0.199\text{ kJ/kg}\cdot\text{K} = s_1 - s_2$$

$$w_{\text{net,out}} = (s_2 - s_1)(T_H - T_L) = (0.199\text{kJ/kg}\cdot\text{K})(1200 - 350)\text{K} = 169.15\text{kJ/kg}$$

$$m = \frac{W_{\text{net,out}}}{w_{\text{net,out}}} = \frac{0.5\text{ kJ}}{169.15\text{ kJ/kg}} = \mathbf{0.00296\ kg}$$

9-22 An air-standard cycle executed in a piston-cylinder system is composed of three specified processes. The cycle is to be sketcehed on the *P*-$\boldsymbol{v}$ and *T*-*s* diagrams; the heat and work interactions and the thermal efficiency of the cycle are to be determined; and an expression for thermal efficiency as functions of compression ratio and specific heat ratio is to be obtained.

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

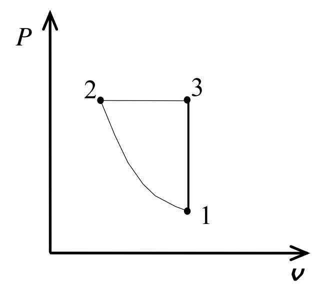
Properties The properties of air are given as R = 0.3 kJ/kg·K and c_v = 0.3 kJ/kg·K.

Analysis (a) The *P*-$\boldsymbol{v}$ and *T*-*s* diagrams of the cycle are shown in the figures.

(b) Noting that

$$c_p = c_v + R = 0.7 + 0.3 = 1.0\ \text{kJ/kg}\cdot\text{K}$$

$$k = \frac{c_p}{c_v} = \frac{1.0}{0.7} = 1.429$$

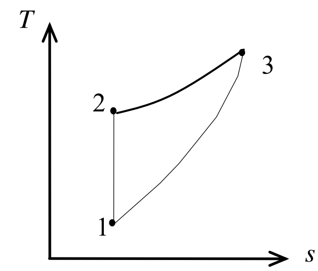


Process 1-2: Isentropic compression

$$T_2 = T_1\left(\frac{v_1}{v_2}\right)^{k-1} = T_1 r^{k-1} = (293\ \text{K})(5)^{0.429} = 584.4\ \text{K}$$

$$w_{1-2,\text{in}} = c_v(T_2 - T_1) = (0.7\ \text{kJ/kg}\cdot\text{K})(584.4 - 293)\ \text{K} = \mathbf{204.0 kJ/kg}$$

$$q_{1-2} = \mathbf{0}$$



From ideal gas relation,

$$\frac{T_3}{T_2} = \frac{v_3}{v_2} = \frac{v_1}{v_2} = r \longrightarrow T_3 = (584.4)(5) = 2922$$

Process 2-3: Constant pressure heat addition

$$w_{2-3,\text{out}} = \int_2^3 P\,dv = P_2(v_3 - v_2) = R(T_3 - T_2)$$
$$= (0.3\ \text{kJ/kg}\cdot\text{K})(2922 - 584.4)\ \text{K} = \mathbf{701.3 kJ/kg}$$

$$q_{2-3,\text{in}} = w_{2-3,out} + \Delta u_{2-3} = \Delta h_{2-3}$$
$$= c_p(T_3 - T_2) = (1\ \text{kJ/kg}\cdot\text{K})(2922 - 584.4)\ \text{K} = \mathbf{2338 kJ/kg}$$

Process 3-1: Constant volume heat rejection

$$q_{3-1,\text{out}} = \Delta u_{1-3} = c_v(T_3 - T_1) = (0.7\ \text{kJ/kg}\cdot\text{K})(2922 - 293)\ \text{K} = \mathbf{1840.3 kJ/kg}$$

$$w_{3-1} = \mathbf{0}$$

(c) Net work is

$$w_{\text{net}} = w_{2-3,\text{out}} - w_{1-2,\text{in}} = 701.3 - 204.0 = 497.3\ \text{kJ/kg}\cdot\text{K}$$

The thermal efficiency is then

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{497.3\ \text{kJ}}{2338\ \text{kJ}} = 0.213 = \mathbf{21.3\%}$$

(d) The expression for the cycle thermal efficiency is obtained as follows:

$$
\begin{aligned}
\eta_{\text{th}} &= \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{w_{2-3,\text{out}} - w_{1-2,\text{in}}}{q_{\text{in}}} \\
&= \frac{R(T_3 - T_2) - c_v(T_2 - T_1)}{c_p(T_3 - T_2)} \\
&= \frac{R}{c_p} - \frac{c_v(T_1 r^{k-1} - T_1)}{c_p(rT_1 r^{k-1} - T_1 r^{k-1})} \\
&= \frac{R}{c_p} - \frac{c_v T_1 r^{k-1}\left(1 - \dfrac{T_1}{T_1 r^{k-1}}\right)}{c_p T_1 r^{k-1}(r-1)} \\
&= \frac{R}{c_p} - \frac{1}{k(r-1)}\left(1 - \frac{T_1}{T_1 r^{k-1}}\right) \\
&= \frac{R}{c_p} - \frac{1}{k(r-1)}\left(1 - \frac{1}{r^{k-1}}\right) \\
&= \left(1 - \frac{1}{k}\right) - \frac{1}{k(r-1)}\left(1 - \frac{1}{r^{k-1}}\right)
\end{aligned}
$$

since

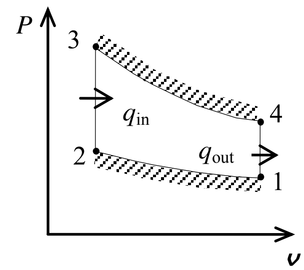
$$
\frac{R}{c_p} = \frac{c_p - c_v}{c_p} = 1 - \frac{c_v}{c_p} = 1 - \frac{1}{k}
$$

9-31 An ideal Otto cycle is considered. The thermal efficiency and the rate of heat input 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 constant specific heats.

Properties The properties of air at room temperature are c_p = 1.005 kJ/kg.K, c_v = 0.718 kJ/kg·K, and k = 1.4 (Table A-2a).

Analysis The definition of cycle thermal efficiency reduces to



$$\eta_{th} = 1 - \frac{1}{r^{k-1}} = 1 - \frac{1}{10.5^{1.4-1}} = 0.6096 = \mathbf{61.0\%}$$

The rate of heat addition is then

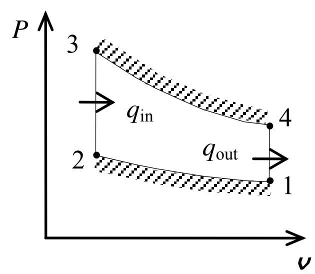
$$\dot{Q}_{in} = \frac{\dot{W}_{net}}{\eta_{th}} = \frac{90\text{ kW}}{0.6096} = \mathbf{148\ kW}$$

9-32 An ideal Otto cycle is considered. The thermal efficiency and the rate of heat input 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 constant specific heats.

Properties The properties of air at room temperature are c_p = 1.005 kJ/kg.K, c_v = 0.718 kJ/kg·K, and k = 1.4 (Table A-2a).

Analysis The definition of cycle thermal efficiency reduces to



$$\eta_{th} = 1 - \frac{1}{r^{k-1}} = 1 - \frac{1}{8.5^{1.4-1}} = 0.5752 = \mathbf{57.5\%}$$

The rate of heat addition is then

$$\dot{Q}_{in} = \frac{\dot{W}_{net}}{\eta_{th}} = \frac{90\text{ kW}}{0.5752} = \mathbf{157\ kW}$$