9.32

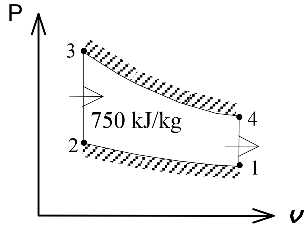
9-34 An ideal Otto cycle with air as the working fluid has a compression ratio of 8. The pressure and temperature at the end of the heat addition process, the net work output, the thermal efficiency, and the mean effective pressure for the cycle are to be determined.

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. The properties of air are given in Table A-17.

Analysis (*a*) Process 1-2: isentropic compression.

$$T_1 = 300\text{K} \longrightarrow \begin{array}{l} u_1 = 214.07\text{kJ/kg} \\ v_{r_1} = 621.2 \end{array}$$



$$v_{r_2} = \frac{v_2}{v_1} v_{r_1} = \frac{1}{r} v_{r_1} = \frac{1}{8}(621.2) = 77.65 \longrightarrow \begin{array}{l} T_2 = 673.1\text{K} \\ u_2 = 491.2 \text{ kJ/kg} \end{array}$$

$$\frac{P_2 v_2}{T_2} = \frac{P_1 v_1}{T_1} \longrightarrow P_2 = \frac{v_1}{v_2}\frac{T_2}{T_1} P_1 = (8)\left(\frac{673.1 \text{ K}}{300 \text{ K}}\right)(95 \text{ kPa}) = 1705 \text{ kPa}$$

Process 2-3: v = constant heat addition.

$$q_{23,\text{in}} = u_3 - u_2 \longrightarrow u_3 = u_2 + q_{23,\text{in}} = 491.2 + 750 = 1241.2 \text{ kJ/kg} \longrightarrow \begin{array}{l} T_3 = \mathbf{1539\ K} \\ v_{r_3} = 6.588 \end{array}$$

$$\frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \longrightarrow P_3 = \frac{T_3}{T_2} P_2 = \left(\frac{1539 \text{ K}}{673.1 \text{ K}}\right)(1705 \text{ kPa}) = \mathbf{3898\ kPa}$$

(*b*) Process 3-4: isentropic expansion.

$$v_{r_4} = \frac{v_1}{v_2} v_{r_3} = r v_{r_3} = (8)(6.588) = 52.70 \longrightarrow \begin{array}{l} T_4 = 774.5 \text{ K} \\ u_4 = 571.69 \text{ kJ/kg} \end{array}$$

Process 4-1: v = constant heat rejection.

$$q_{\text{out}} = u_4 - u_1 = 571.69 - 214.07 = 357.62 \text{ kJ/kg}$$

$$w_{\text{net,out}} = q_{\text{in}} - q_{\text{out}} = 750 - 357.62 = \mathbf{392.4\ kJ/kg}$$

(*c*) $$\eta_{\text{th}} = \frac{w_{\text{net,out}}}{q_{\text{in}}} = \frac{392.4 \text{ kJ/kg}}{750 \text{ kJ/kg}} = \mathbf{52.3\%}$$

(*d*) $$v_1 = \frac{RT_1}{P_1} = \frac{(0.287\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(300\text{K})}{95\text{kPa}} = 0.906\text{m}^3/\text{kg} = v_{\max}$$

$$v_{\min} = v_2 = \frac{v_{\max}}{r}$$

$$\text{MEP} = \frac{w_{\text{net,out}}}{v_1 - v_2} = \frac{w_{\text{net,out}}}{v_1(1-1/r)} = \frac{392.4 \text{ kJ/kg}}{(0.906 \text{ m}^3/\text{kg})(1-1/8)}\left(\frac{\text{kPa}\cdot\text{m}^3}{\text{kJ}}\right) = \mathbf{495.0\ kPa}$$

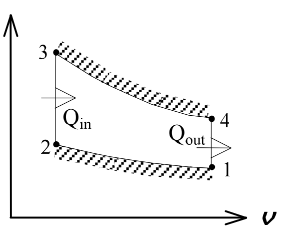
9.35

9-37 An ideal Otto cycle with air as the working fluid has a compression ratio of 9.5. The highest pressure and temperature in the cycle, the amount of heat transferred, the thermal efficiency, and the mean effective pressure 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, R = 0.287 kJ/kg·K, and k = 1.4 (Table A-2).

Analysis (*a*) Process 1-2: isentropic compression.



$$T_2 = T_1\left(\frac{v_1}{v_2}\right)^{k-1} = (308\text{ K})(9.5)^{0.4} = 757.9\text{ K}$$

$$\frac{P_2 v_2}{T_2} = \frac{P_1 v_1}{T_1} \longrightarrow P_2 = \frac{v_1}{v_2}\frac{T_2}{T_1}P_1 = (9.5)\left(\frac{757.9\text{ K}}{308\text{ K}}\right)(100\text{ kPa}) = 2338\text{ kPa}$$

Process 3-4: isentropic expansion.

$$T_3 = T_4\left(\frac{v_4}{v_3}\right)^{k-1} = (800\text{ K})(9.5)^{0.4} = \mathbf{1969\text{ K}}$$

Process 2-3: v = constant heat addition.

$$\frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \longrightarrow P_3 = \frac{T_3}{T_2}P_2 = \left(\frac{1969\text{ K}}{757.9\text{ K}}\right)(2338\text{ kPa}) = \mathbf{6072\text{ kPa}}$$

(*b*) $$m = \frac{P_1 V_1}{RT_1} = \frac{(100\text{ kPa})(0.0006\text{ m}^3)}{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(308\text{ K})} = 6.788\times10^{-4}\text{ kg}$$

$$Q_{in} = m(u_3 - u_2) = mc_v(T_3 - T_2) = (6.788\times10^{-4}\text{ kg})(0.718\text{ kJ/kg}\cdot\text{K})(1969 - 757.9)\text{K} = \mathbf{0.590\text{ kJ}}$$

(c) Process 4-1: v = constant heat rejection.

$$Q_{out} = m(u_4 - u_1) = mc_v(T_4 - T_1) = -(6.788\times10^{-4}\text{ kg})(0.718\text{ kJ/kg}\cdot\text{K})(800 - 308)\text{K} = \mathbf{0.240\text{ kJ}}$$

$$W_{net} = Q_{in} - Q_{out} = 0.590 - 0.240 = 0.350\text{ kJ}$$

$$\eta_{th} = \frac{W_{net,out}}{Q_{in}} = \frac{0.350\text{ kJ}}{0.590\text{ kJ}} = \mathbf{59.4\%}$$

(*d*) $$V_{min} = V_2 = \frac{V_{max}}{r}$$

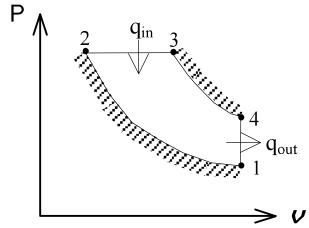
$$\text{MEP} = \frac{W_{net,out}}{V_1 - V_2} = \frac{W_{net,out}}{V_1(1-1/r)} = \frac{0.350\text{ kJ}}{(0.0006\text{ m}^3)(1-1/9.5)}\left(\frac{\text{kPa}\cdot\text{m}^3}{\text{kJ}}\right) = \mathbf{652\text{ kPa}}$$

9.45

9-47 An air-standard Diesel cycle with a compression ratio of 16 and a cutoff ratio of 2 is considered. The temperature after the heat addition process, the thermal efficiency, and the mean effective pressure 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. The properties of air are given in Table A-17.



Analysis (*a*) Process 1-2: isentropic compression.

$$T_1 = 300\text{K} \longrightarrow \begin{array}{l} u_1 = 214.07\text{kJ/kg} \\ v_{r_1} = 621.2 \end{array}$$

$$v_{r_2} = \frac{v_2}{v_1} v_{r_1} = \frac{1}{r} v_{r_1} = \frac{1}{16}(621.2) = 38.825 \longrightarrow \begin{array}{l} T_2 = 862.4\text{ K} \\ h_2 = 890.9\text{ kJ/kg} \end{array}$$

Process 2-3: P = constant heat addition.

$$\frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \longrightarrow T_3 = \frac{v_3}{v_2} T_2 = 2T_2 = (2)(862.4\text{ K}) = \mathbf{1724.8\text{ K}} \longrightarrow \begin{array}{l} h_3 = 1910.6\text{ kJ/kg} \\ v_{r_3} = 4.546 \end{array}$$

(*b*) $$q_{\text{in}} = h_3 - h_2 = 1910.6 - 890.9 = 1019.7\text{kJ/kg}$$

Process 3-4: isentropic expansion.

$$v_{r_4} = \frac{v_4}{v_3} v_{r_3} = \frac{v_4}{2v_2} v_{r_3} = \frac{r}{2} v_{r_3} = \frac{16}{2}(4.546) = 36.37 \longrightarrow u_4 = 659.7\text{kJ/kg}$$

Process 4-1: v = constant heat rejection.

$$q_{\text{out}} = u_4 - u_1 = 659.7 - 214.07 = 445.63\text{ kJ/kg}$$

$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{445.63\text{ kJ/kg}}{1019.7\text{ kJ/kg}} = \mathbf{56.3\%}$$

(*c*) $$w_{\text{net,out}} = q_{\text{in}} - q_{\text{out}} = 1019.7 - 445.63 = 574.07\text{ kJ/kg}$$

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(300\text{ K})}{95\text{ kPa}} = 0.906\text{ m}^3/\text{kg} = v_{\max}$$

$$v_{\min} = v_2 = \frac{v_{\max}}{r}$$

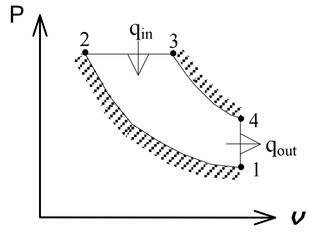
$$\text{MEP} = \frac{w_{\text{net,out}}}{v_1 - v_2} = \frac{w_{\text{net,out}}}{v_1(1 - 1/r)} = \frac{574.07\text{ kJ/kg}}{(0.906\text{ m}^3/\text{kg})(1 - 1/16)}\left(\frac{\text{kPa}\cdot\text{m}^3}{\text{kJ}}\right) = \mathbf{675.9\text{ kPa}}$$

9.46

9-48 An air-standard Diesel cycle with a compression ratio of 16 and a cutoff ratio of 2 is considered. The temperature after the heat addition process, the thermal efficiency, and the mean effective pressure 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, R = 0.287 kJ/kg·K, and k = 1.4 (Table A-2).



Analysis (*a*) Process 1-2: isentropic compression.

$$T_2 = T_1\left(\frac{v_1}{v_2}\right)^{k-1} = (300\text{K})(16)^{0.4} = 909.4\text{K}$$

Process 2-3: P = constant heat addition.

$$\frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \longrightarrow T_3 = \frac{v_3}{v_2}T_2 = 2T_2 = (2)(909.4\text{K}) = \mathbf{1818.8K}$$

(*b*) $$q_{\text{in}} = h_3 - h_2 = c_p(T_3 - T_2) = (1.005 \text{ kJ/kg}\cdot\text{K})(1818.8 - 909.4)\text{K} = 913.9 \text{ kJ/kg}$$

Process 3-4: isentropic expansion.

$$T_4 = T_3\left(\frac{v_3}{v_4}\right)^{k-1} = T_3\left(\frac{2v_2}{v_4}\right)^{k-1} = (1818.8\text{K})\left(\frac{2}{16}\right)^{0.4} = 791.7\text{K}$$

Process 4-1: v = constant heat rejection.

$$q_{\text{out}} = u_4 - u_1 = c_v(T_4 - T_1) = (0.718\text{kJ/kg}\cdot\text{K})(791.7 - 300)\text{K} = 353\text{kJ/kg}$$

$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{353 \text{ kJ/kg}}{913.9 \text{ kJ/kg}} = \mathbf{61.4\%}$$

(*c*) $$w_{\text{net.out}} = q_{\text{in}} - q_{\text{out}} = 913.9 - 353 = 560.9\text{kJ/kg}$$

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(300 \text{ K})}{95 \text{ kPa}} = 0.906 \text{ m}^3/\text{kg} = v_{\max}$$

$$v_{\min} = v_2 = \frac{v_{\max}}{r}$$

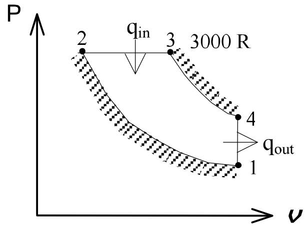
$$\text{MEP} = \frac{w_{\text{net,out}}}{v_1 - v_2} = \frac{w_{\text{net,out}}}{v_1(1 - 1/r)} = \frac{560.9 \text{ kJ/kg}}{(0.906 \text{ m}^3/\text{kg})(1 - 1/16)}\left(\frac{\text{kPa}\cdot\text{m}^3}{\text{kJ}}\right) = \mathbf{660.4\ kPa}$$

9.47 **9-49E** An air-standard Diesel cycle with a compression ratio of 18.2 is considered. The cutoff ratio, the heat rejection per unit mass, 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-17E.

Analysis (*a*) Process 1-2: isentropic compression.



$$T_1 = 540 \text{ R} \longrightarrow \begin{array}{l} u_1 = 92.04 \text{ Btu/lbm} \\ v_{r_1} = 144.32 \end{array}$$

$$v_{r_2} = \frac{v_2}{v_1} v_{r_1} = \frac{1}{r} v_{r_1} = \frac{1}{18.2}(144.32) = 7.93 \longrightarrow \begin{array}{l} T_2 = 1623.6 \text{ R} \\ h_2 = 402.05 \text{ Btu/lbm} \end{array}$$

Process 2-3: P = constant heat addition.

$$\frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \longrightarrow \frac{v_3}{v_2} = \frac{T_3}{T_2} = \frac{3000 \text{ R}}{1623.6 \text{ R}} = \mathbf{1.848}$$

(*b*) $$T_3 = 3000 \text{ R} \longrightarrow \begin{array}{l} h_3 = 790.68 \text{ Btu/lbm} \\ v_{r_3} = 1.180 \end{array}$$

$$q_{\text{in}} = h_3 - h_2 = 790.68 - 402.05 = 388.63 \text{ Btu/lbm}$$

Process 3-4: isentropic expansion.

$$v_{r_4} = \frac{v_4}{v_3} v_{r_3} = \frac{v_4}{1.848 v_2} v_{r_3} = \frac{r}{1.848} v_{r_3} = \frac{18.2}{1.848}(1.180) = 11.621 \longrightarrow u_4 = 250.91 \text{ Btu/lbm}$$

Process 4-1: v = constant heat rejection.

$$q_{\text{out}} = u_4 - u_1 = 250.91 - 92.04 = \mathbf{158.87 \text{ Btu/lbm}}$$

(*c*) $$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{158.87 \text{ Btu/lbm}}{388.63 \text{ Btu/lbm}} = \mathbf{59.1\%}$$

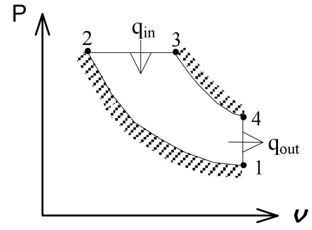
9.49

9-51 An ideal diesel engine with air as the working fluid has a compression ratio of 20. The thermal efficiency and the mean effective pressure 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, R = 0.287 kJ/kg·K, and k = 1.4 (Table A-2).

Analysis (*a*) Process 1-2: isentropic compression.



$$T_2 = T_1\left(\frac{v_1}{v_2}\right)^{k-1} = (293\text{ K})(20)^{0.4} = 971.1\text{ K}$$

Process 2-3: P = constant heat addition.

$$\frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \longrightarrow \frac{v_3}{v_2} = \frac{T_3}{T_2} = \frac{2200\text{K}}{971.1\text{K}} = 2.265$$

Process 3-4: isentropic expansion.

$$T_4 = T_3\left(\frac{v_3}{v_4}\right)^{k-1} = T_3\left(\frac{2.265 v_2}{v_4}\right)^{k-1} = T_3\left(\frac{2.265}{r}\right)^{k-1} = (2200\text{ K})\left(\frac{2.265}{20}\right)^{0.4} = 920.6\text{ K}$$

$$q_{in} = h_3 - h_2 = c_p(T_3 - T_2) = (1.005\text{ kJ/kg}\cdot\text{K})(2200 - 971.1)\text{K} = 1235\text{ kJ/kg}$$

$$q_{out} = u_4 - u_1 = c_v(T_4 - T_1) = (0.718\text{ kJ/kg}\cdot\text{K})(920.6 - 293)\text{K} = 450.6\text{ kJ/kg}$$

$$w_{net,out} = q_{in} - q_{out} = 1235 - 450.6 = 784.4\text{ kJ/kg}$$

$$\eta_{th} = \frac{w_{net,out}}{q_{in}} = \frac{784.4\text{ kJ/kg}}{1235\text{ kJ/kg}} = \mathbf{63.5\%}$$

(*b*)

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(293\text{ K})}{95\text{ kPa}} = 0.885\text{ m}^3/\text{kg} = v_{max}$$

$$v_{min} = v_2 = \frac{v_{max}}{r}$$

$$\text{MEP} = \frac{w_{net,out}}{v_1 - v_2} = \frac{w_{net,out}}{v_1(1 - 1/r)} = \frac{784.4\text{ kJ/kg}}{(0.885\text{ m}^3/\text{kg})(1 - 1/20)}\left(\frac{\text{kPa}\cdot\text{m}^3}{\text{kJ}}\right) = \mathbf{933\text{ kPa}}$$

9.63

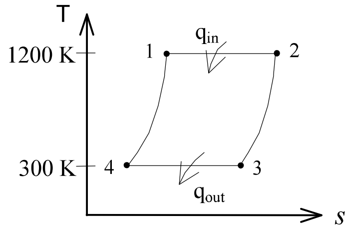
9-65 An ideal steady-flow Ericsson engine with air as the working fluid is considered. The maximum pressure in the cycle, the net work output, and the thermal efficiency of the cycle are to be determined.

Assumptions Air is an ideal gas.

Properties The gas constant of air is $R = 0.287$ kJ/kg.K (Table A-1).

Analysis (*a*) The entropy change during process 3-4 is

$$s_4 - s_3 = -\frac{q_{34,\text{out}}}{T_0} = -\frac{150 \text{ kJ/kg}}{300 \text{ K}} = -0.5 \text{ kJ/kg}\cdot\text{K}$$



and

$$s_4 - s_3 = c_p \ln\frac{T_4}{T_3}^{\nearrow 0} - R\ln\frac{P_4}{P_3}$$

$$= -(0.287 \text{ kJ/kg}\cdot\text{K})\ln\frac{P_4}{120 \text{ kPa}} = -0.5 \text{ kJ/kg}\cdot\text{K}$$

It yields $P_4 = \mathbf{685.2\ kPa}$

(*b*) For reversible cycles, $\frac{q_{\text{out}}}{q_{\text{in}}} = \frac{T_L}{T_H} \longrightarrow q_{\text{in}} = \frac{T_H}{T_L} q_{\text{out}} = \frac{1200 \text{ K}}{300 \text{ K}}(150 \text{ kJ/kg}) = 600 \text{ kJ/kg}$

Thus, $w_{\text{net,out}} = q_{\text{in}} - q_{\text{out}} = 600 - 150 = \mathbf{450\ \ kJ/kg}$

(*c*) The thermal efficiency of this totally reversible cycle is determined from

$$\eta_{\text{th}} = 1 - \frac{T_L}{T_H} = 1 - \frac{300\text{K}}{1200\text{K}} = \mathbf{75.0\%}$$

9.64

9-66 An ideal Stirling engine with helium as the working fluid operates between the specified temperature and pressure limits. The thermal efficiency of the cycle, the amount of heat transfer in the regenerator, and the work output per cycle are to be determined.

Assumptions Helium is an ideal gas with constant specific heats.

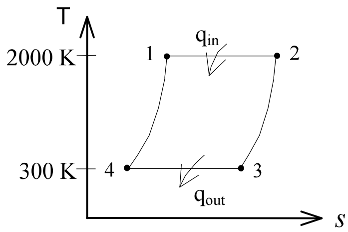
Properties The gas constant and the specific heat of helium at room temperature are $R = 2.0769$ kJ/kg.K, $c_v = 3.1156$ kJ/kg.K and $c_p = 5.1926$ kJ/kg.K (Table A-2).

Analysis (*a*) The thermal efficiency of this totally reversible cycle is determined from

$$\eta_{\text{th}} = 1 - \frac{T_L}{T_H} = 1 - \frac{300 \text{ K}}{2000 \text{ K}} = \mathbf{85.0\%}$$

(*b*) The amount of heat transferred in the regenerator is

$$Q_{\text{regen}} = Q_{41,\text{in}} = m(u_1 - u_4) = mc_v(T_1 - T_4)$$
$$= (0.12 \text{ kg})(3.1156 \text{ kJ/kg}\cdot\text{K})(2000 - 300)\text{K}$$
$$= \mathbf{635.6\ \ kJ}$$



(*c*) The net work output is determined from

$$\frac{P_3 v_3}{T_3} = \frac{P_1 v_1}{T_1} \longrightarrow \frac{v_3}{v_1} = \frac{T_3 P_1}{T_1 P_3} = \frac{(300 \text{ K})(3000 \text{ kPa})}{(2000 \text{ K})(150 \text{ kPa})} = 3 = \frac{v_2}{v_1}$$

$$s_2 - s_1 = c_v \ln\frac{T_2}{T_1}^{\nearrow 0} + R\ln\frac{v_2}{v_1} = (2.0769 \text{ kJ/kg}\cdot\text{K})\ln(3) = 2.282 \text{ kJ/kg}\cdot\text{K}$$

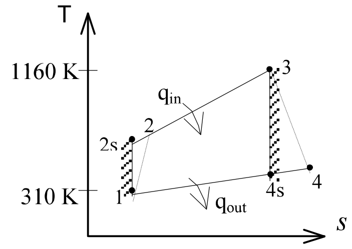
$$Q_{\text{in}} = mT_H(s_2 - s_1) = (0.12 \text{ kg})(2000 \text{ K})(2.282 \text{ kJ/kg}\cdot\text{K}) = 547.6 \text{ kJ}$$

$$W_{\text{net,out}} = \eta_{\text{th}} Q_{\text{in}} = (0.85)(547.6 \text{ kJ}) = \mathbf{465.5\ \ kJ}$$

9.71

9-73 [*Also solved by EES on enclosed CD*] A simple Brayton cycle with air as the working fluid has a pressure ratio of 8. The air temperature at the turbine exit, the net work output, and the thermal efficiency are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The air-standard assumptions are applicable. **3** Kinetic and potential energy changes are negligible. **4** Air is an ideal gas with variable specific heats.



Properties The properties of air are given in Table A-17.

Analysis (*a*) Noting that process 1-2s is isentropic,

$$T_1 = 310 \text{ K} \longrightarrow \begin{array}{l} h_1 = 310.24 \text{ kJ/kg} \\ P_{r_1} = 1.5546 \end{array}$$

$$P_{r_2} = \frac{P_2}{P_1} P_{r_1} = (8)(1.5546) = 12.44 \longrightarrow h_{2s} = 562.58 \text{ kJ/kg and } T_{2s} = 557.25 \text{ K}$$

$$\eta_C = \frac{h_{2s} - h_1}{h_2 - h_1} \longrightarrow h_2 = h_1 + \frac{h_{2s} - h_1}{\eta_C}$$

$$= 310.24 + \frac{562.58 - 310.24}{0.75} = 646.7 \text{ kJ/kg}$$

$$T_3 = 1160 \text{ K} \longrightarrow \begin{array}{l} h_3 = 1230.92 \text{ kJ/kg} \\ P_{r_3} = 207.2 \end{array}$$

$$P_{r_4} = \frac{P_4}{P_3} P_{r_3} = \left(\frac{1}{8}\right)(207.2) = 25.90 \longrightarrow h_{4s} = 692.19 \text{ kJ/kg and } T_{4s} = 680.3 \text{ K}$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} \longrightarrow h_4 = h_3 - \eta_T (h_3 - h_{4s})$$

$$= 1230.92 - (0.82)(1230.92 - 692.19)$$

$$= 789.16 \text{ kJ/kg}$$

Thus, T_4 = **770.1 K**

(*b*) $q_{\text{in}} = h_3 - h_2 = 1230.92 - 646.7 = 584.2 \text{ kJ/kg}$

$q_{\text{out}} = h_4 - h_1 = 789.16 - 310.24 = 478.92 \text{ kJ/kg}$

$w_{\text{net,out}} = q_{\text{in}} - q_{\text{out}} = 584.2 - 478.92 =$ **105.3 kJ/kg**

(*c*) $\eta_{\text{th}} = \frac{w_{\text{net,out}}}{q_{\text{in}}} = \frac{105.3 \text{ kJ/kg}}{584.2 \text{ kJ/kg}} =$ **18.0%**

9.73

9-75 A simple Brayton cycle with air as the working fluid has a pressure ratio of 8. The air temperature at the turbine exit, the net work output, and the thermal efficiency are to be determined.

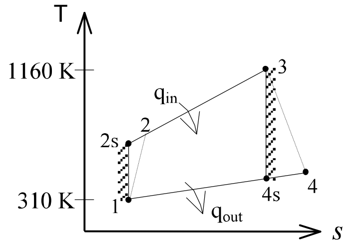
Assumptions **1** Steady operating conditions exist. **2** The air-standard assumptions are applicable. **3** Kinetic and potential energy changes are negligible. **4** Air is an ideal gas with constant specific heats.

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

Analysis (*a*) Using the compressor and turbine efficiency relations,

$$T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (310\text{ K})(8)^{0.4/1.4} = 561.5\text{ K}$$

$$T_{4s} = T_3\left(\frac{P_4}{P_3}\right)^{(k-1)/k} = (1160\text{ K})\left(\frac{1}{8}\right)^{0.4/1.4} = 640.4\text{ K}$$



$$\eta_C = \frac{h_{2s}-h_1}{h_2-h_1} = \frac{c_p(T_{2s}-T_1)}{c_p(T_2-T_1)} \longrightarrow T_2 = T_1 + \frac{T_{2s}-T_1}{\eta_C}$$
$$= 310 + \frac{561.5-310}{0.75} = 645.3\text{ K}$$

$$\eta_T = \frac{h_3-h_4}{h_3-h_{4s}} = \frac{c_p(T_3-T_4)}{c_p(T_3-T_{4s})} \longrightarrow T_4 = T_3 - \eta_T(T_3-T_{4s})$$
$$= 1160 - (0.82)(1160-640.4)$$
$$= \mathbf{733.9\text{ K}}$$

(*b*) $$q_{\text{in}} = h_3 - h_2 = c_p(T_3-T_2) = (1.005\text{ kJ/kg}\cdot\text{K})(1160-645.3)\text{K} = 517.3\text{ kJ/kg}$$

$$q_{\text{out}} = h_4 - h_1 = c_p(T_4-T_1) = (1.005\text{ kJ/kg}\cdot\text{K})(733.9-310)\text{K} = 426.0\text{ kJ/kg}$$

$$w_{\text{net,out}} = q_{\text{in}} - q_{\text{out}} = 517.3 - 426.0 = \mathbf{91.3\text{ kJ/kg}}$$

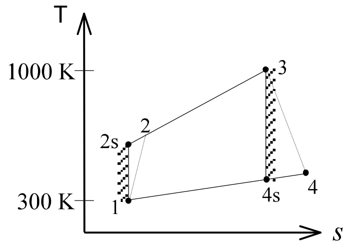
(*c*) $$\eta_{\text{th}} = \frac{w_{\text{net,out}}}{q_{\text{in}}} = \frac{91.3\text{ kJ/kg}}{517.3\text{ kJ/kg}} = \mathbf{17.6\%}$$

9.74

9-76 A gas turbine power plant that operates on the simple Brayton cycle with air as the working fluid has a specified pressure ratio. The required mass flow rate of air is to be determined for two cases.

Assumptions **1** Steady operating conditions exist. **2** The air-standard assumptions are applicable. **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-2).



Analysis (*a*) Using the isentropic relations,

$$T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (300\text{ K})(12)^{0.4/1.4} = 610.2\text{ K}$$

$$T_{4s} = T_3\left(\frac{P_4}{P_3}\right)^{(k-1)/k} = (1000\text{ K})\left(\frac{1}{12}\right)^{0.4/1.4} = 491.7\text{ K}$$

$$w_{\text{s,C,in}} = h_{2s} - h_1 = c_p(T_{2s} - T_1) = (1.005\text{ kJ/kg}\cdot\text{K})(610.2 - 300)\text{K} = 311.75\text{ kJ/kg}$$

$$w_{\text{s,T,out}} = h_3 - h_{4s} = c_p(T_3 - T_{4s}) = (1.005\text{ kJ/kg}\cdot\text{K})(1000 - 491.7)\text{K} = 510.84\text{ kJ/kg}$$

$$w_{\text{s,net,out}} = w_{\text{s,T,out}} - w_{\text{s,C,in}} = 510.84 - 311.75 = 199.1\text{ kJ/kg}$$

$$\dot{m}_s = \frac{\dot{W}_{\text{net,out}}}{w_{\text{s,net,out}}} = \frac{70{,}000\text{ kJ/s}}{199.1\text{ kJ/kg}} = \mathbf{352\ \ kg/s}$$

(*b*) The net work output is determined to be

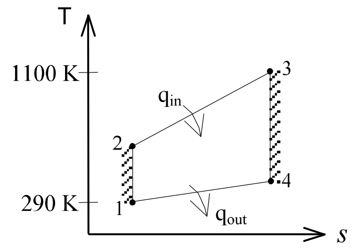
$$w_{\text{a,net,out}} = w_{\text{a,T,out}} - w_{\text{a,C,in}} = \eta_T w_{\text{s,T,out}} - w_{\text{s,C,in}}/\eta_C$$
$$= (0.85)(510.84) - 311.75/0.85 = 67.5\text{ kJ/kg}$$

$$\dot{m}_a = \frac{\dot{W}_{\text{net,out}}}{w_{\text{a,net,out}}} = \frac{70{,}000\text{ kJ/s}}{67.5\text{ kJ/kg}} = \mathbf{1037\ \ kg/s}$$

9.75

9-77 A stationary gas-turbine power plant operates on a simple ideal Brayton cycle with air as the working fluid. The power delivered by this plant is to be determined assuming constant and variable specific heats.

Assumptions **1** Steady operating conditions exist. **2** The air-standard assumptions are applicable. **3** Kinetic and potential energy changes are negligible. **4** Air is an ideal gas.



Analysis (*a*) Assuming constant specific heats,

$$T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (290\text{ K})(8)^{0.4/1.4} = 525.3\text{ K}$$

$$T_{4s} = T_3\left(\frac{P_4}{P_3}\right)^{(k-1)/k} = (1100\text{ K})\left(\frac{1}{8}\right)^{0.4/1.4} = 607.2\text{ K}$$

$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{c_p(T_4 - T_1)}{c_p(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{607.2 - 290}{1100 - 525.3} = 0.448$$

$$\dot{W}_{\text{net,out}} = \eta_{\text{th}}\dot{Q}_{\text{in}} = (0.448)(35{,}000\text{ kW}) = \mathbf{15{,}680\ kW}$$

(*b*) Assuming variable specific heats (Table A-17),

$$T_1 = 290\text{ K} \longrightarrow \begin{array}{l} h_1 = 290.16\text{ kJ/kg} \\ P_{r_1} = 1.2311 \end{array}$$

$$P_{r_2} = \frac{P_2}{P_1}P_{r_1} = (8)(1.2311) = 9.8488 \longrightarrow h_2 = 526.12\text{ kJ/kg}$$

$$T_3 = 1100\text{ K} \longrightarrow \begin{array}{l} h_3 = 1161.07\text{ kJ/kg} \\ P_{r_3} = 167.1 \end{array}$$

$$P_{r_4} = \frac{P_4}{P_3}P_{r_3} = \left(\frac{1}{8}\right)(167.1) = 20.89 \longrightarrow h_4 = 651.37\text{ kJ/kg}$$

$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} == 1 - \frac{h_4 - h_1}{h_3 - h_2} = 1 - \frac{651.37 - 290.16}{1161.07 - 526.11} = 0.431$$

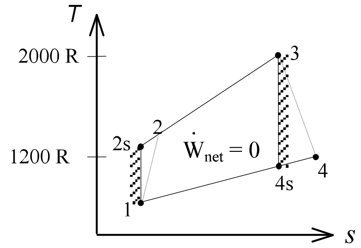
$$\dot{W}_{\text{net,out}} = \eta_T\dot{Q}_{\text{in}} = (0.431)(35{,}000\text{ kW}) = \mathbf{15{,}085\ kW}$$

9-81E A gas-turbine power plant operates on a simple Brayton cycle with air as the working fluid. The compressor efficiency for which the power plant produces zero net work is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The air-standard assumptions are applicable. **3** Kinetic and potential energy changes are negligible. **4** Air is an ideal gas with variable specific heats.

Properties The properties of air are given in Table A-17E.

Analysis Using variable specific heats,



$$T_3 = 2000 \text{ R} \longrightarrow h_3 = 504.71 \text{ Btu/lbm}$$

$$T_4 = 1200 \text{ R} \longrightarrow h_4 = 291.30 \text{ Btu/lbm}$$

$$r_p = \frac{P_2}{P_1} = \frac{120}{15} = 8$$

$$\dot{Q}_{out} = \dot{m}(h_4 - h_1) \longrightarrow h_1 = 291.30 - 6400/40 = 131.30 \text{ Btu/lbm} \longrightarrow P_{r_1} = 1.474$$

$$P_{r_2} = \frac{P_2}{P_1} P_{r_1} = (8)(1.474) = 11.79 \longrightarrow h_{2s} = 238.07 \text{ Btu/lbm}$$

Then, $\dot{W}_{C,in} = \dot{W}_{T,out} \longrightarrow \dot{m}(h_{2s} - h_1)/\eta_C = \dot{m}(h_3 - h_4)$

$$\eta_C = \frac{h_{2s} - h_1}{h_3 - h_4} = \frac{238.07 - 131.30}{504.71 - 291.30} = \mathbf{50.0\%}$$

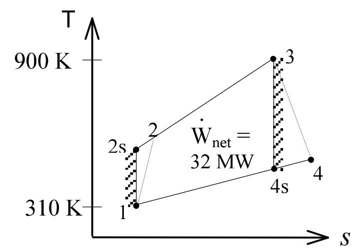
9.78

9-82 A 32-MW gas-turbine power plant operates on a simple Brayton cycle with air as the working fluid. The mass flow rate of air through the cycle is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The air-standard assumptions are applicable. **3** Kinetic and potential energy changes are negligible. **4** Air is an ideal gas with variable specific heats.

Properties The properties of air are given in Table A-17.

Analysis Using variable specific heats,



$$T_1 = 310 \text{ K} \longrightarrow \begin{array}{l} h_1 = 310.24 \text{ kJ/kg} \\ P_{r_1} = 1.5546 \end{array}$$

$$P_{r_2} = \frac{P_2}{P_1} P_{r_1} = (8)(1.5546) = 12.44 \longrightarrow h_{2s} = 562.26 \text{ kJ/kg}$$

$$T_3 = 900 \text{ K} \longrightarrow \begin{array}{l} h_3 = 932.93 \text{ kJ/kg} \\ P_{r_3} = 75.29 \end{array}$$

$$P_{r_4} = \frac{P_4}{P_3} P_{r_3} = \left(\frac{1}{8}\right)(75.29) = 9.411 \longrightarrow h_{4s} = 519.32 \text{ kJ/kg}$$

$$w_{net,out} = w_{T,out} - w_{C,in} = \eta_T (h_3 - h_{4s}) - (h_{2s} - h_1)/\eta_C$$
$$= (0.86)(932.93 - 519.32) - (562.26 - 310.24)/(0.80) = 40.68 \text{ kJ/kg}$$

and $\dot{m} = \frac{\dot{W}_{net,out}}{w_{net,out}} = \frac{32{,}000 \text{ kJ/s}}{40.68 \text{ kJ/kg}} = \mathbf{786.6 \text{ kg/s}}$

9.79

9-83 A 32-MW gas-turbine power plant operates on a simple Brayton cycle with air as the working fluid. The mass flow rate of air through the cycle is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The air-standard assumptions are applicable. **3** Kinetic and potential energy changes are negligible. **4** Air is an ideal gas with constant specific heats.

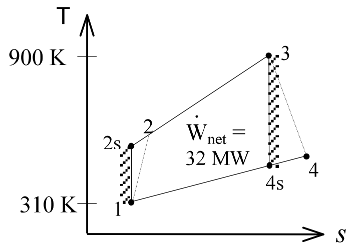
Properties The properties of air at room temperature are c_p = 1.005 kJ/kg·K and k = 1.4 (Table A-2).

Analysis Using constant specific heats,

$$T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (310\text{ K})(8)^{0.4/1.4} = 561.5\text{ K}$$

$$T_{4s} = T_3\left(\frac{P_4}{P_3}\right)^{(k-1)/k} = (900\text{ K})\left(\frac{1}{8}\right)^{0.4/1.4} = 496.8\text{ K}$$

$$\begin{aligned} w_{\text{net,out}} &= w_{\text{T,out}} - w_{\text{C,in}} = \eta_T c_p(T_3 - T_{4s}) - c_p(T_{2s} - T_1)/\eta_C \\ &= (1.005\text{ kJ/kg}\cdot\text{K})[(0.86)(900-496.8)-(561.5-310)/(0.80)]\text{K} \\ &= 32.5\text{ kJ/kg} \end{aligned}$$



and

$$\dot{m} = \frac{\dot{W}_{\text{net,out}}}{w_{\text{net,out}}} = \frac{32{,}000\text{ kJ/s}}{32.5\text{ kJ/kg}} = \mathbf{984.6\ kg/s}$$