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 properties of air are given in Table A-17.

**Analysis**

(a) Process 1-2: isentropic compression.

\[ T_1 = 300 \text{ K} \quad \Rightarrow \quad u_1 = 214.07 \text{ kJ/kg} \]
\[ v_{r_1} = 621.2 \]

\[ v_{r_2} = \frac{v_2}{v_1} = \frac{1}{r} v_{r_1} = \frac{1}{8} (621.2) = 77.65 \]
\[ T_2 = 673.1K \]
\[ u_2 = 491.2 \text{ kJ/kg} \]

\[ \frac{P_2 v_2}{T_2} = \frac{P_1 v_1}{T_1} \quad \Rightarrow \quad P_2 = \frac{v_1}{v_2} \frac{T_2}{T_1} P_1 = \left( \frac{673.1K}{300K} \right) (95kPa) = 1705kPa \]

Process 2-3: \( v = \text{constant heat addition} \).

\[ q_{23,in} = u_3 - u_2 \quad \Rightarrow \quad u_3 = u_2 + q_{23,in} = 491.2 + 750 = 1241.2 \text{ kJ/kg} \]
\[ \frac{T_3}{v_{r_3}} = 6.588 \quad \Rightarrow \quad T_3 = 1539 \text{ K} \]

\[ \frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \quad \Rightarrow \quad P_3 = \frac{T_3}{T_2} P_2 = \left( \frac{1539K}{673.1K} \right) (1705kPa) = 3898kPa \]

(b) Process 3-4: isentropic expansion.

\[ v_{r_4} = \frac{v_1}{v_2} v_{r_3} = (8)(6.588) = 52.70 \quad \Rightarrow \quad T_4 = 774.5K \]
\[ u_4 = 571.69 \text{ kJ/kg} \]

Process 4-1: \( v = \text{constant heat rejection} \).

\[ q_{out} = u_4 - u_1 = 571.69 - 214.07 = 357.62 \text{ kJ/kg} \]
\[ w_{net,out} = q_{in} - q_{out} = 750 - 357.62 = 392.38 \text{ kJ/kg} \]

(c) \[ \eta_{th} = \frac{w_{net,out}}{q_{in}} = \frac{392.38kJ/kg}{750kJ/kg} = 52.3\% \]

(d) \[ v_1 = \frac{RT_1}{P_1} = \frac{(0.287kPa \cdot m^3/kg \cdot K)(300K)}{95kPa} = 0.906m^3/kg = v_{\text{max}} \]
\[ v_{\text{min}} = v_2 = \frac{v_{\text{max}}}{r} \]

\[ MEP = \frac{w_{net,out}}{v_1 - v_2} = \frac{w_{net,out}}{(1 - 1/r)} = \frac{392.38kJ/kg}{(0.906m^3/kg)(1 - 1/8)} \left( \frac{kPa \cdot m^3}{kJ} \right) = 495.0kPa \]

EES solution of this (and other comprehensive problems designated with the computer icon) is available to instructors at the Instructor Manual section of the Online Learning Center (OLC) at www.mhhe.com/cengel-boles. See the Preface for access information.
A steam power plant that operates on a simple ideal Rankine cycle is considered. The quality of the steam at the turbine exit, the thermal efficiency of the cycle, and the mass flow rate of the steam are to be determined.

**Assumptions**

1. Steady operating conditions exist.
2. Kinetic and potential energy changes are negligible.

**Analysis**

(a) From the steam tables (Tables A-4, A-5, and A-6),

\[
h_1 = h_f @ 10 \text{ kPa} = 191.83 \text{ kJ/kg} \\
v_1 = v_f @ 10 \text{ kPa} = 0.00101 \text{ m}^3/\text{kg} \\
w_{p,\text{in}} = v_1(P_2 - P_1) \\
= (0.00101 \text{ m}^3/\text{kg})(10,000 - 10 \text{ kPa}) \left( \frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3} \right) \\
= 10.09 \text{ kJ/kg} \\
h_2 = h_1 + w_{p,\text{in}} = 191.83 + 10.09 = 201.92 \text{ kJ/kg}
\]

\[P_3 = 10 \text{ MPa} \quad h_3 = 3373.7 \text{ kJ/kg} \\
T_3 = 500 ^\circ \text{C} \quad s_3 = 6.5966 \text{ kJ/kg} \cdot \text{K}
\]

\[P_4 = 10 \text{ kPa} \quad s_4 = s_3 \quad x_4 = \frac{s_4 - s_f}{s_{fs}} = \frac{6.5966 - 0.6493}{7.5009} = 0.793
\]

\[h_4 = h_f + x_4 h_{fs} = 191.83 + (0.793)(2392.8) = 2089.3 \text{ kJ/kg}
\]

(b) \[q_{\text{in}} = h_3 - h_2 = 3373.7 - 201.92 = 3171.78 \text{ kJ/kg}
\]

\[q_{\text{out}} = h_4 - h_1 = 2089.3 - 191.83 = 1897.47 \text{ kJ/kg}
\]

\[w_{\text{net}} = q_{\text{in}} - q_{\text{out}} = 3171.78 - 1897.47 = 1274.31 \text{ kJ/kg}
\]

and

\[\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{1274.31 \text{ kJ/kg}}{3171.78 \text{ kJ/kg}} = 0.402 \%
\]

(c) \[\dot{m} = \frac{W_{\text{net}}}{w_{\text{net}}} = \frac{210,000 \text{kJ/s}}{1274.31 \text{ kJ/kg}} = 165 \text{ kg/s}
\]
A steam power plant that operates on a simple nonideal Rankine cycle is considered. The quality of the steam at the turbine exit, the thermal efficiency of the cycle, and the mass flow rate of the steam are to be determined.

**Assumptions**

1. Steady operating conditions exist.
2. Kinetic and potential energy changes are negligible.

**Analysis**

(a) From the steam tables (Tables A-4, A-5, and A-6),

\[
\begin{align*}
h_1 &= h_f @ 10 \text{kPa} = 191.83 \text{ kJ/kg} \\
v_1 &= v_f @ 10 \text{kPa} = 0.00101 \text{ m}^3/\text{kg} \\
w_{p,\text{in}} &= v_1 \left( P_2 - P_1 \right)/\eta_p \\
&= \left( 0.00101 \text{ m}^3/\text{kg} \right) \left( 10,000 - 10 \text{kPa} \right) \left( \frac{1 \text{ kJ}}{1 \text{kPa} \cdot \text{m}^3} \right) \left( 0.85 \right) \\
&= 11.87 \text{ kJ/kg} \\
h_2 &= h_1 + w_{p,\text{in}} = 191.83 + 11.87 = 203.70 \text{ kJ/kg} \\
P_3 &= 10 \text{ MPa} \quad \text{h}_3 = 3373.7 \text{ kJ/kg} \\
T_3 &= 500 \degree \text{C} \quad s_3 = 6.5966 \text{ kJ/kg} \cdot \text{K} \\
P_{4s} &= 10 \text{ kPa} \quad x_{4s} = \frac{s_{4s} - s_f}{s_{fg}} = \frac{6.5966 - 0.6493}{7.509} = 0.793 \\
s_{4s} &= s_3 \\
h_{4s} &= h_f + x_{4s} h_{fg} = 191.83 + (0.793)(2392.8) = 2089.3 \text{ kJ/kg} \\
\eta_T &= \frac{h_3 - h_4}{h_3 - h_{4s}} = h_4 = h_3 - \eta_T \left( h_3 - h_{4s} \right) \\
&= 3373.7 - \left( 0.85 \right) \left( 3373.7 - 2089.3 \right) = 2281.96 \text{ kJ/kg} \\
P_4 &= 10 \text{ kPa} \\
h_4 &= 2281.96 \text{ kJ/kg} \\
\left( b \right) \quad q_{\text{in}} &= h_3 - h_2 = 3373.7 - 203.70 = 3170.0 \text{ kJ/kg} \\
q_{\text{out}} &= h_4 - h_1 = 2281.96 - 191.83 = 2090.13 \text{ kJ/kg} \\
w_{\text{net}} &= q_{\text{in}} - q_{\text{out}} = 3170.0 - 2090.13 = 1079.87 \text{ kJ/kg} \\
\text{and}
\eta_{\text{th}} &= \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{1079.87 \text{ kJ/kg}}{3170.0 \text{ kJ/kg}} = 34.1\% \\
\left( c \right) \quad \dot{m} &= \frac{\dot{W}_{\text{net}}}{w_{\text{net}}} = \frac{210,000 \text{ kJ/s}}{1079.87 \text{ kJ/kg}} = 194.5 \text{ kg/s}
\end{align*}
\]
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 constant specific heats.

**Properties** The properties of air at room temperature are $C_p = 1.005 \text{ kJ/kg} \cdot \text{K}$, $C_v = 0.718 \text{ kJ/kg} \cdot \text{K}$, and $k = 1.4$ (Table A-2).

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

$$T_2 = T_1 \left( \frac{v_1}{v_2} \right)^{\frac{1}{k-1}} = (300 \text{K}) (8)^{0.4} = 689 \text{K}$$

$$\frac{P_2 v_2}{T_2} = \frac{P_1 v_1}{T_1} \quad \Rightarrow \quad P_2 = \frac{v_1}{v_2} \frac{T_2}{T_1} P_1 = (8) \left( \frac{689 \text{K}}{300 \text{K}} \right) (95 \text{kPa}) = 1745 \text{kPa}$$

Process 2-3: $v = \text{constant heat addition}$.

$$q_{23, \text{in}} = u_3 - u_2 = C_v(T_3 - T_2)$$

$$750 \text{kJ/kg} = (0.718 \text{kJ/kg} \cdot \text{K})(T_3 - 689) \text{K}$$

$$T_3 = 1734 \text{K}$$

$$\frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \quad \Rightarrow \quad P_3 = \frac{T_3}{T_2} P_2 = \left( \frac{1734 \text{K}}{689 \text{K}} \right) (1745 \text{kPa}) = 4392 \text{kPa}$$

(b) Process 3-4: isentropic expansion.

$$T_4 = T_3 \left( \frac{v_3}{v_4} \right)^{\frac{1}{k-1}} = (1734 \text{K}) \left( \frac{1}{8} \right)^{0.4} = 755 \text{K}$$

Process 4-1: $v = \text{constant heat rejection}$.

$$q_{\text{out}} = u_4 - u_1 = C_v(T_4 - T_1) = (0.718 \text{kJ/kg} \cdot \text{K})(755 - 300) \text{K} = 327 \text{kJ/kg}$$

$$w_{\text{net,out}} = q_{\text{in}} - q_{\text{out}} = 750 - 327 = 423 \text{kJ/kg}$$

$$\frac{\eta_{\text{th}}}{\text{net,out}} = \frac{w_{\text{net,out}}}{q_{\text{in}}} = \frac{423 \text{kJ/kg}}{750 \text{kJ/kg}} = 56.4\%$$

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

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

$$MEP = \frac{w_{\text{net,out}}}{v_1 - v_2} = \frac{423 \text{kJ/kg}}{v_1 (1 - 1/r)} = \frac{423 \text{kJ/kg}}{0.906 \text{m}^3/\text{kg} (1 - 1/8)} \left( \frac{\text{kPa} \cdot \text{m}^3}{\text{kJ}} \right) = 534 \text{kPa}$$
An ideal Otto cycle with air as the working fluid has a compression ratio of 8. The amount of heat transferred to the air during the heat addition process, the thermal efficiency, and the thermal efficiency of a Carnot cycle operating between the same temperature limits 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**
(a) Process 1-2: isentropic compression.

\[ T_1 = 300 \text{ K} \quad \rightarrow \quad u_1 = 214.07 \text{ kJ/kg} \]

\[ v_{r_2} = \frac{v_2}{v_1} \quad v_{r_2} = \frac{1}{r} v_{r_2} = \frac{1}{8} (621.2) = 77.65 \quad \rightarrow \quad u_2 = 491.44 \text{ kJ/kg} \]

Process 2-3: \( v \) = constant heat addition.

\[ T_3 = 1340 \text{ K} \quad \rightarrow \quad u_3 = 10.58.94 \text{ kJ/kg} \]

\[ q_{in} = u_3 - u_2 = (1058.94 - 491.44) \text{ kJ/kg} = 567.5 \text{ kJ/kg} \]

(b) Process 3-4: isentropic expansion.

\[ v_{r_4} = \frac{v_4}{v_3} v_{r_4} = r v_{r_3} = (8)(10.247) = 81.98 \quad \rightarrow \quad u_4 = 480.82 \text{ kJ/kg} \]

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

\[ q_{out} = u_4 - u_1 = 480.82 - 214.07 = 266.75 \text{ kJ/kg} \]

\[ \eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{266.75 \text{ kJ/kg}}{567.5 \text{ kJ/kg}} = 53\% \]

(c) \[ \eta_{th,C} = 1 - \frac{T_H}{T_L} = 1 - \frac{300 \text{ K}}{1340 \text{ K}} = 77.6\% \]
A simple ideal Brayton cycle with air as the working fluid has a pressure ratio of 10. The air temperature at the compressor exit, the back work ratio, 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 1-2 is isentropic,
\[ T_1 = 290 \text{ K} \quad \rightarrow \quad h_1 = 290.16 \text{ kJ/kg} \]
\[ P_{r_1} = 1.2311 \]
\[ P_{r_2} = \frac{P_2}{P_1} \cdot P_{r_1} = 10(1.2311) = 12.311 \quad \rightarrow \quad T_2 = 555.6 \text{ K} \]
\[ h_2 = 561.06 \text{ kJ/kg} \]

(b) Process 3-4 is isentropic, and thus
\[ T_3 = 1120 \text{ K} \quad \rightarrow \quad h_3 = 1184.28 \text{ kJ/kg} \]
\[ P_{r_3} = P_3 \quad \rightarrow \quad P_{r_4} = 179.7 \]
\[ P_{r_4} = \frac{P_4}{P_3} = \left( \frac{1}{10} \right) (179.7) = 17.97 \quad \rightarrow \quad h_4 = 624.19 \text{ kJ/kg} \]
\[ w_{C,in} = h_2 - h_1 = 561.06 - 290.16 = 270.9 \text{ kJ/kg} \]
\[ w_{T,out} = h_3 - h_4 = 1184.28 - 624.19 = 560.09 \text{ kJ/kg} \]

Then the back-work ratio becomes
\[ r_{bw} = \frac{w_{C,in}}{w_{T,out}} = \frac{270.9}{560.09} = 48.4\% \]

(c) \[ q_{in} = h_3 - h_2 = 1184.28 - 561.06 = 623.22 \text{ kJ/kg} \]
\[ w_{net,out} = w_{T,out} - w_{C,in} = 560.09 - 270.9 = 289.19 \text{ kJ/kg} \]
\[ \eta_{th} = \frac{w_{net,out}}{q_{in}} = \frac{289.19}{623.22} = 46.4\% \]
8-70 [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,

\[ T_1 = 310 \text{ K} \quad \rightarrow \quad h_1 = 310.24 \text{ kJ/kg} \]

\[ P_{r_1} = 1.5546 \]

\[ P_{r_1} = \frac{P_2}{P_1} P_{r_1} = (8)(1.5546) = 12.44 \quad \rightarrow \quad h_{2s} = 562.58 \text{ kJ/kg and } T_{2s} = 557.25 \text{ K} \]

\[ \eta_C = \frac{h_{2s} - h_1}{h_2 - h_1} \quad \rightarrow \quad h_2 = h_1 + \frac{h_{2s} - h_1}{\eta_C} \]

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

\[ T_3 = 1160 \text{ K} \quad \rightarrow \quad h_3 = 1230.92 \text{ kJ/kg} \]

\[ P_{r_3} = 207.2 \]

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

\[ \eta_T = \frac{h_4 - h_3}{h_4 - h_{4s}} \quad \rightarrow \quad h_4 = h_3 - \eta_T (h_3 - h_{4s}) \]

\[ = 1230.92 - (0.82)(1230.92 - 692.19) \]

\[ = 789.16 \text{ kJ/kg} \]

Thus, \( T_4 = 770.1 \text{ K} \)

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

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

\( W_{net,out} = W_{in} - W_{out} = 584.2 - 478.92 = 105.3 \text{ kJ/kg} \)

(c) \( \eta_{th} = \frac{W_{net,out}}{q_{in}} = \frac{105.3}{584.2} = 18.0\% \)

8-71 EES solution of this (and other comprehensive problems designated with the computer icon) is available to instructors at the Instructor Manual section of the Online Learning Center (OLC) at www.mhhe.com/cengel-boles. See the Preface for access information.
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 \( C_p = 1.005 \text{ kJ/kg·K} \) and \( k = 1.4 \) (Table A-2).

**Analysis**

(a) Using the isentropic relations,

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

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

\[
w_{s,C,in} = h_{2s} - h_1 = C_p (T_{2s} - T_1) = (1.005 \text{ kJ/kg·K})(610.2 - 300) \text{ K} = 311.75 \text{ kJ/kg}
\]

\[
w_{s,T,out} = h_3 - h_{4s} = C_p (T_3 - T_{4s}) = (1.005 \text{ kJ/kg·K})(1000 - 491.7) \text{ K} = 510.84 \text{ kJ/kg}
\]

\[
w_{s,net,out} = w_{s,T,out} - w_{s,C,in} = 510.84 - 311.75 = 199.09 \text{ kJ/kg}
\]

\[
\dot{m}_s = \frac{\dot{W}_{net,out}}{w_{s,net,out}} = \frac{90,000 \text{ kJ/s}}{199.09 \text{ kJ/kg}} = 452.1 \text{ kg/s}
\]

(b) The net work output is determined to be

\[
w_{a,net,out} = w_{a,T,out} - w_{a,C,in} = \eta \frac{w_{s,T,out} - w_{s,C,in}}{\eta_C}
\]

\[
= (0.80)(510.84 - 311.75)/0.80 = 18.98k\text{kJ/kg}
\]

\[
\dot{m}_a = \frac{\dot{W}_{net,out}}{w_{a,net,out}} = \frac{90,000 \text{ kJ/s}}{18.98 \text{ kJ/kg}} = 4742 \text{ kg/s}
\]
8-74 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,

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

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

\[
\eta_{in} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{C_p(T_4 - T_1)}{C_p(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{607.2 - 290}{1100 - 525.3} = 0.448
\]

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

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

\[
T_1 = 290\text{ K} \rightarrow h_1 = 290.16\text{ kJ/kg}
\]

\[
P_{r_2} = \frac{P_3}{P_1} = (8)(1.2311) = 9.8488 \rightarrow h_2 = 526.12\text{ kJ/kg}
\]

\[
T_3 = 1100\text{ K} \rightarrow h_3 = 1161.07\text{ kJ/kg}
\]

\[
P_{r_4} = \frac{P_4}{P_3} = \left( \frac{1}{8} \right)(167.1) = 20.89 \rightarrow h_4 = 651.37\text{ kJ/kg}
\]

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

\[
\dot{W}_{net, out} = \eta_{in} \dot{Q}_{in} = (0.431)(35,000\text{ kW}) = 15,085\text{ kW}
\]
8-75 An actual gas-turbine power plant operates at specified conditions. The fraction of the turbine work output used to drive the compressor 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) Using the isentropic relations,

\[ T_1 = 300 \text{ K} \quad \rightarrow \quad h_1 = 300.19 \text{ kJ/kg} \]
\[ T_2 = 580 \text{ K} \quad \rightarrow \quad h_2 = 586.04 \text{ kJ/kg} \]

\[ r_p = \frac{P_2}{P_1} = \frac{700}{100} = 7 \]

\[ q_{in} = h_3 - h_2 \quad \rightarrow \quad h_3 = 950 + 586.04 = 1536.04 \text{ kJ/kg} \]

\[ \rightarrow P_{t_3} = 474.11 \]

\[ P_{t_4} = \frac{P_4}{P_3} P_{t_3} = \left(\frac{1}{7}\right) (474.11) = 67.73 \quad \rightarrow \quad h_{t_4} = 905.83 \text{ kJ/kg} \]

\[ w_{C,in} = h_2 - h_1 = 586.04 - 300.19 = 285.85 \text{ kJ/kg} \]

\[ w_{T,out} = \eta_T (h_3 - h_{t_4}) = (0.86) (1536.04 - 905.83) = 542.0 \text{ kJ/kg} \]

Thus,

\[ \eta = \frac{w_{C,in}}{w_{T,out}} = \frac{285.85}{542.0} = 52.7\% \]

(b) \[ w_{net,out} = w_{T,out} - w_{C,in} = 542.0 - 285.85 = 256.15 \text{ kJ/kg} \]

\[ \eta_{th} = \frac{w_{net,out}}{q_{in}} = \frac{256.15}{950} = 27.0\% \]
9-15 A steam power plant operates on a simple ideal Rankine cycle between the specified pressure limits. The thermal efficiency of the cycle and the net power output of the plant are to be determined.

**Assumptions** 1 Steady operating conditions exist. 2 Kinetic and potential energy changes are negligible.

**Analysis** (a) From the steam tables (Tables A-4, A-5, and A-6),

\[
h_1 = h_f @ 50 \text{ kPa} = 340.49 \text{ kJ/kg}
\]

\[
v_1 = v_f @ 50 \text{ kPa} = 0.001030 \text{ m}^3/\text{kg}
\]

\[
w_{p,in} = v_1(P_2 - P_1) = (0.001030 \text{ m}^3/\text{kg})(3000 - 50) \text{kPa}\left(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3}\right) = 3.04 \text{ kJ/kg}
\]

\[
h_2 = h_1 + w_{p,in} = 340.49 + 3.04 = 343.53 \text{ kJ/kg}
\]

\[
P_3 = 3 \text{ MPa} \quad h_3 = 3230.9 \text{ kJ/kg}
\]

\[
T_3 = 400 \degree \text{C} \quad s_3 = 6.9212 \text{ kJ/kg} \cdot \text{K}
\]

\[
P_4 = 50 \text{ kPa} \quad s_4 = s_3
\]

\[
x_4 = \frac{s_4 - s_f}{s_{fg}} = \frac{6.9212 - 1.0910}{6.5029} = 0.8966
\]

\[
h_4 = h_f + x_4 h_{fg} = 340.49 + (0.8966)(2305.4) = 2407.5 \text{ kJ/kg}
\]

Thus,

\[
q_{in} = h_3 - h_2 = 3230.9 - 343.53 = 2887.37 \text{ kJ/kg}
\]

\[
q_{out} = h_4 - h_1 = 2407.5 - 340.49 = 2067.01 \text{ kJ/kg}
\]

\[
w_{net} = q_{in} - q_{out} = 2887.37 - 2067.01 = 820.36 \text{ kJ/kg}
\]

and

\[
\eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{2067.01}{2887.73} = 28.4\%
\]

(b) \[\dot{W}_{net} = \dot{m}w_{net} = (60 \text{ kg/s})(820.36 \text{ kJ/kg}) = 49.2 \text{ MW}\]