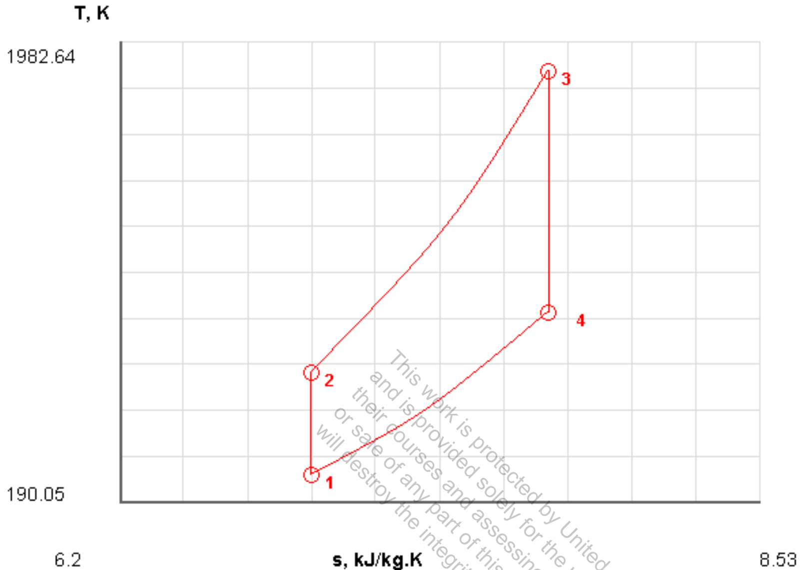
7-3-1 [OIJ] An ideal Otto cycle has a compression ratio of 9. At the beginning of compression, air is at 14.4 psia and 80°F. During constant-volume heat addition 450 Btu/lbm of heat is transferred. Calculate (a) the maximum temperature, (b) efficiency and (c) the net work output. Use the IG model. (d) What-if Scenario: What would the efficiency be if the air were at 100°F at the beginning of compression?

SOLUTION



State-1 (given p_1, T_1):

$$u_1 = 92.04 \ \frac{\text{Btu}}{\text{lbm}};$$

$$v_{r1} = 144.32;$$

State-2 (given $s_2 = s_1, r$):

$$v_{r2} = \frac{v_{r1}}{r} = \frac{144.32}{9} = 16.03;$$

$$u_2 = 221.33 \ \frac{\text{Btu}}{\text{lbm}};$$

$$T_2 = 1265.5°\text{R};$$

$$p_2 = p_1 \frac{T_2}{T_1}\frac{v_1}{v_2} = (14.4)\left(\frac{1265.5}{539.67}\right)(9) = 303.9 \text{ psia};$$

State-3 (given $v_3 = v_2, q_{\text{in}}$):

$$q_{in} = u_3 - u_2;$$

$$\Rightarrow u_3 = u_2 + q_{\text{in}} = 221.33 + 450 = 671.33 \ \frac{\text{Btu}}{\text{lbm}};$$

$$v_{r3} = 0.7954$$

$$p_3 = p_2 \frac{T_3}{T_2} = (303.9)\left(\frac{3381.27}{1265.5}\right) = 811.98 \text{ psia}$$

$$T_3 = 3381.27°R;$$

State-4 (given $s_4 = s_3, v_4 = v_1$):

$$v_{r4} = \frac{v_1}{v_2} v_{r3} = (9)(0.7954) = 7.16;$$

$$T_4 = 1678.57°\text{R};$$

$$u_4 = 301.76 \ \frac{\text{Btu}}{\text{lbm}};$$

(a) $T = 3381.27°\text{R}$

An energy analysis for the heat rejection processes yields:
Process 4-1:

$$q_{\text{out}} = -q_{41};$$

$$\Rightarrow q_{\text{out}} = u_4 - u_1;$$

$$\Rightarrow q_{\text{out}} = 301.76 - 92.04;$$

$$\Rightarrow q_{\text{out}} = 209.72 \ \frac{\text{Btu}}{\text{lbm}};$$

Therefore, the thermal efficiency and MEP are calculated as:

(b) $\eta_{\text{th}} = \dfrac{w_{\text{net}}}{q_{\text{in}}};$

$$\Rightarrow \eta_{\text{th}} = \frac{240.28}{450};$$

$$\Rightarrow \eta_{\text{th}} = 53.4\%$$

(c) $w_{\text{net}} = q_{\text{in}} - q_{\text{out}};$

$$\Rightarrow w_{\text{net}} = 450 - 209.72;$$

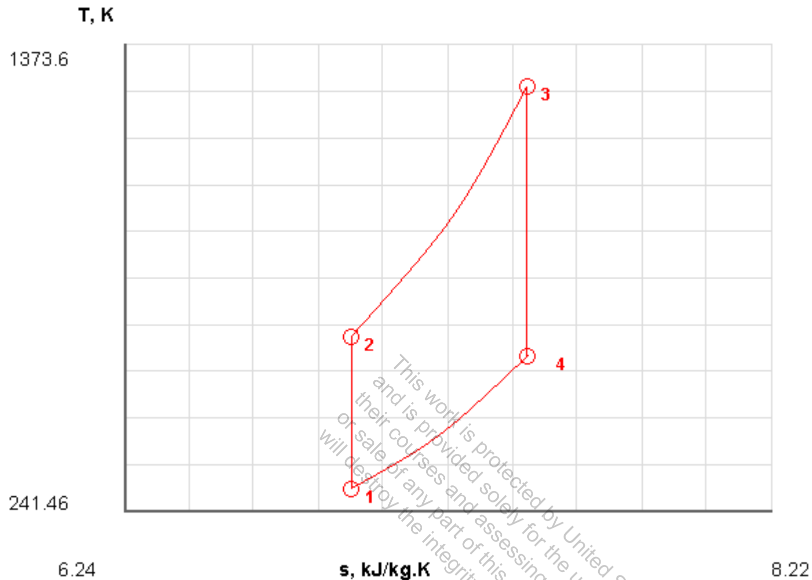
$$\Rightarrow w_{\text{net}} = 240.28 \ \frac{\text{Btu}}{\text{lbm}}$$

TEST Solution and What-if Scenario:

Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution and perform the what-if study. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-2 [OIW] An ideal Otto cycle with air as the working fluid has a compression ratio of 8. The minimum and maximum temperatures in the cycle are 25°C and 1000°C respectively. Using the IG model, determine (a) the amount of heat transferred per unit mass of air during the heat addition process, (b) the thermal efficiency and (c) the mean effective pressure.

SOLUTION



State-1 (given T_1):

$$v_{r1} = 631.9;$$

$$u_1 = 212.64\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given r):

$$v_{r2} = \frac{v_{r1}}{r} = \frac{631.9}{8} = 78.99;$$

$$T_2 = 670\ \text{K};$$

$$u_2 = 488.81\ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given T_3):

$$u_3 = 998.51\ \frac{\text{kJ}}{\text{kg}};$$

$$v_{r3} = 12.05;$$

State-4:

$$v_{r4} = \frac{v_4}{v_3} v_{r3} = r v_{r3} = (8)(12.05) = 96.4;$$

$$u_4 = 450.09 \ \frac{\text{kJ}}{\text{kg}};$$

An energy analysis for the heat addition and rejection processes yields:
Process 2-3:

(a) $q_{\text{in}} = u_3 - u_2;$

$$\Rightarrow q_{\text{in}} = 998.51 - 488.81;$$

$$\Rightarrow q_{\text{in}} = 509.7 \ \frac{\text{kJ}}{\text{kg}}$$

Process 4-1:

$$q_{\text{out}} = -q_{41};$$

$$\Rightarrow q_{\text{out}} = u_4 - u_1;$$

$$\Rightarrow q_{\text{out}} = 450.09 - 212.64;$$

$$\Rightarrow q_{\text{out}} = 237.45 \ \frac{\text{kJ}}{\text{kg}};$$

(b) Therefore, the thermal efficiency and MEP are calculated as:

$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}};$$

$$\Rightarrow \eta_{\text{th}} = 1 - \frac{124.68}{266.13};$$

$$\Rightarrow \eta_{\text{th}} = 53.4\%$$

(c) Assuming $v_1 = 101 \text{ kPa};$

$$\text{MEP} = \frac{w_{\text{net}}}{v_1 - v_2};$$

$$\Rightarrow \text{MEP} = \frac{q_{\text{in}} - q_{\text{out}}}{v_1\left(1 - \frac{1}{r}\right)} = \frac{q_{\text{in}} - q_{\text{out}}}{\left(\frac{RT_1}{p_1}\right)\left(1 - \frac{1}{r}\right)};$$

$$\Rightarrow \text{MEP} = \frac{509.70 - 237.45}{\frac{(0.287)(298)}{(101)}\left(1 - \frac{1}{8}\right)};$$

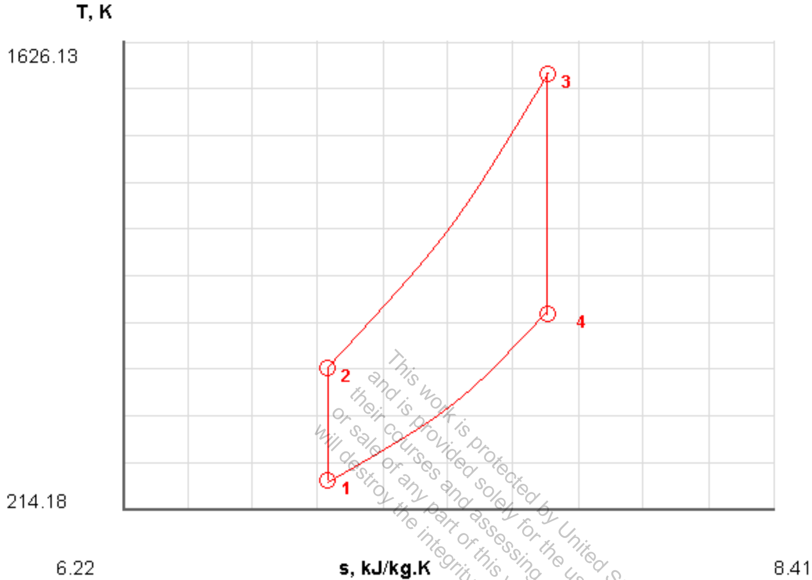
$$\Rightarrow \text{MEP} = 367.3 \text{ kPa}$$

TEST Solution:

Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-3 [OLR] An ideal Otto cycle has a compression ratio of 7. At the beginning of the compression process, air is at 98 kPa, 30°C and 766 kJ/kg of heat is transferred to air during the constant-volume heat addition process. Determine (a) the pressure (p) and temperature (T) at the end of the heat addition process, (b) the net work output, (c) the thermal efficiency and (d) the mean effective pressure for the cycle. Use the IG model.

SOLUTION



State-1 (given p_1, T_1):

$$u_1 = 216.23 \ \frac{\text{kJ}}{\text{kg}};$$

$$v_{r1} = 606.08;$$

$$v_1 = \frac{RT_1}{p_1} = \frac{(0.287)(303)}{98} = 0.887 \ \frac{\text{m}^3}{\text{kg}};$$

State-2 (given r):

$$v_{r2} = \frac{v_2}{v_1} v_{r1} = \frac{1}{r} v_{r1} = \frac{1}{7}(606.08) = 86.58;$$

$$T_2 = 646.6 \text{ K};$$

$$u_2 = 470.62 \ \frac{\text{kJ}}{\text{kg}};$$

$$\frac{p_2 v_2}{T_2} = \frac{p_1 v_1}{T_1};$$

$$\Rightarrow p_2 = p_1 \frac{T_2}{T_1}\frac{v_1}{v_2};$$

$$\Rightarrow p_2 = (98)\left(\frac{646.6}{303}\right)(7);$$

$$\Rightarrow p_2 = 1463.92 \text{ kPa};$$

State-3 (given $v_3 = v_3, q_{\text{in}}$):

$$q_{\text{in}} = u_3 - u_2;$$

$$\Rightarrow u_3 = u_2 + q_{\text{in}};$$

$$\Rightarrow u_3 = 460.62 + 766;$$

$$\Rightarrow u_3 = 1236.62 \ \frac{\text{kJ}}{\text{kg}};$$

(a) $T_3 = 1533.7 \text{ K}$

$$v_{r3} = 6.658;$$

$$\frac{p_3 v_3}{T_3} = \frac{p_2 v_2}{T_2};$$

$$\Rightarrow p_3 = p_2 \frac{T_3}{T_2};$$

$$\Rightarrow p_3 = (1463.92)\left(\frac{1533.7}{646.6}\right);$$

$$\Rightarrow p_3 = 3472.3 \text{ kPa}$$

State-4:

$$v_{r4} = \frac{v_1}{v_2} v_{r3} = (7)(6.658) = 46.6;$$

$$T_4 = 809.1 \text{ K};$$

$$u_4 = 599.74 \ \frac{\text{kJ}}{\text{kg}};$$

An energy analysis for the heat rejection processes yields:

$$q_{\text{out}} = -q_{41};$$

$$\Rightarrow q_{\text{out}} = u_4 - u_1;$$

$$\Rightarrow q_{\text{out}} = 599.74 - 216.23;$$

$$\Rightarrow q_{\text{out}} = 383.51 \ \frac{\text{kJ}}{\text{kg}};$$

Therefore, the net work, efficiency and MEP (on a per unit mass basis) are calculated as:

(b) $w_{\text{net}} = q_{\text{in}} - q_{\text{out}};$

$$\Rightarrow w_{\text{net}} = 766 - 383.48;$$

$$\Rightarrow w_{\text{net}} = 382.52 \ \frac{\text{kJ}}{\text{kg}}$$

(c) $\eta_{\text{th}} = \dfrac{w_{\text{net}}}{q_{\text{in}}};$

$$\Rightarrow \eta_{\text{th}} = \frac{382.52}{766};$$

$$\Rightarrow \eta_{\text{th}} = 49.9\%$$

(d) $\text{MEP} = \dfrac{w_{\text{net}}}{v_1 - v_2};$

$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}}{(v_1 - v_1 / r)};$$

$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}}{v_1(1 - 1/r)};$$

$$\Rightarrow \text{MEP} = \frac{382.53}{(0.877)(1 - 1/7)};$$

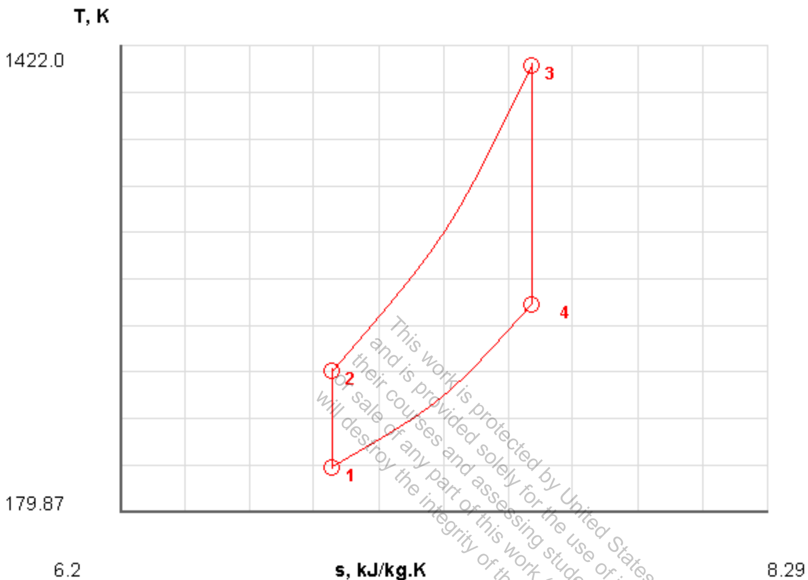
$$\Rightarrow \text{MEP} = 508.88 \text{ kPa}$$

TEST Solution:

Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-4 [OLO] An engine equipped with a single cylinder having a bore of 12 cm and a stroke of 50 cm operates on an Otto cycle. At the beginning of the compression stroke air is at 100 kPa, 25°C. The maximum temperature in the cycle is 1100°C. (a) If the clearance volume is 1500 cc, determine the air standard efficiency. (b) At 300 rpm, determine the engine output in kW. Use the PG model. (c) What-if Scenario: What would the efficiency and engine output be if the clearance volume were reduced to 1200 cc?

SOLUTION



Given:

$$c_v = 0.717 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$R = 0.287 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$k = 1.4;$$

State-1 (given p_1, T_1):

$$\cancel{V}_1 = \frac{\pi d^2}{4} L + \cancel{V}_2 = \frac{\pi (12)^2}{4}(50) + 1500 = 7154.8 \text{ cc};$$

$$m_1 = \frac{p_1 \cancel{V}_1}{T_1} = \frac{(100)(7154.8\times 10^{-6})}{(0.287)(298)} = 0.00837 \text{ kg};$$

State-2 (given $T_1, s_2 = s_1, \cancel{V}_2$):

$$T_2 = T_1 r^{k-1} = (298)\left(\frac{7154.8}{1500}\right)^{1.4-1} = 557 \text{ K};$$

State-3 (given T_3)

State-4 (given $s_4 = s_3$):

$$T_4 = \frac{T_3}{r^{k-1}} = \frac{1373}{(4.77)^{1.4-1}} = 734 \text{ K};$$

(a) The air standard efficiency is

$$\eta_{\text{th}} = \frac{W_{\text{net}}}{Q_{\text{in}}};$$

$$\Rightarrow \eta_{\text{th}} = 1 - \frac{Q_{\text{out}}}{Q_{\text{in}}};$$

$$\Rightarrow \eta_{\text{th}} = 1 - \frac{T_4 - T_1}{T_3 - T_2};$$

$$\Rightarrow \eta_{\text{th}} = 1 - \frac{734 - 298}{1373 - 557};$$

$$\Rightarrow \eta_{\text{th}} = 46.5\%$$

An energy analysis for the heat addition and rejection processes yields:
Process 2-3:

$$Q_{\text{in}} = Q_{23};$$

$$\Rightarrow Q_{\text{in}} = m(u_3 - u_2);$$

$$\Rightarrow Q_{\text{in}} = mc_v(T_3 - T_2);$$

$$\Rightarrow Q_{\text{in}} = (0.00837)(0.717)(1373 - 557);$$

$$\Rightarrow Q_{\text{in}} = 4.89 \text{ kJ};$$

Process 4-1:

$$Q_{\text{out}} = -Q_{41};$$

$$\Rightarrow Q_{\text{out}} = m(u_4 - u_1);$$

$$\Rightarrow Q_{\text{out}} = mc_v(T_4 - T_1);$$

$$\Rightarrow Q_{\text{out}} = (0.00837)(0.717)(734 - 298);$$

$$\Rightarrow Q_{\text{out}} = 2.62 \text{ kJ};$$

Therefore, the net work and engine output are calculated as:

$$W_{\text{net}} = Q_{\text{in}} - Q_{\text{out}};$$

$$\Rightarrow W_{\text{net}} = 4.89 - 2.62;$$

$$\Rightarrow W_{\text{net}} = 2.27 \text{ kJ};$$

(b) The engine output in kW is

$$N = 300 \text{ rpm} = 5 \ \frac{\text{rev}}{\text{s}};$$

$$\dot{W}_{\text{net}} = W_{\text{net}} N;$$

$$\Rightarrow \dot{W}_{\text{net}} = (2.27)(5);$$

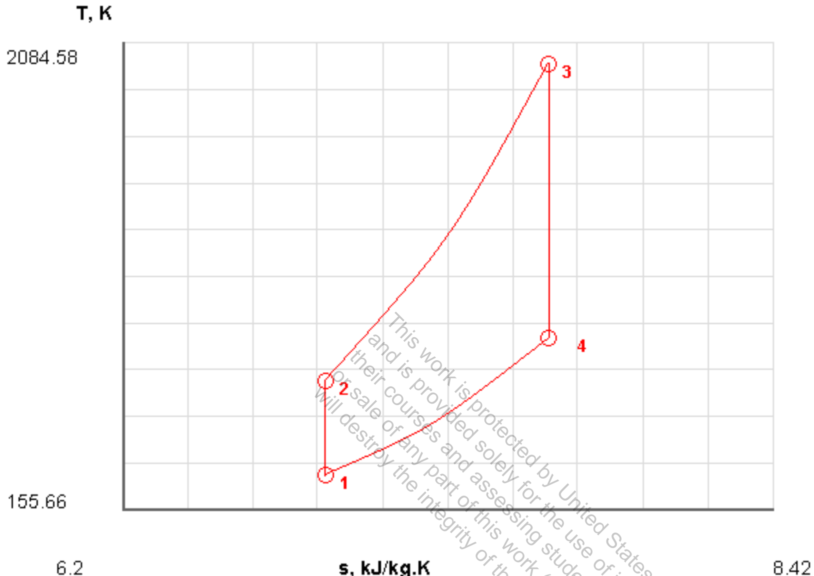
$$\Rightarrow \dot{W}_{\text{net}} = 11.35 \text{ kW}$$

TEST Solution and What-if Scenario:

Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution and perform the what-if study. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-5 [OLB] The temperature at the beginning of the compression process of an air standard Otto cycle with a compression ratio of 8 is 27°C, the pressure is 101 kPa, and the cylinder volume is 566 cm^3. The maximum temperature during the cycle is 1726°C. Determine (a) the thermal efficiency and (b) the mean effective pressure. Use the PG model for air. (c) What-if Scenario: What would the thermal efficiency be if the IG model were used?

SOLUTION



Given:

$$c_v = 0.717 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$R = 0.287 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$k = 1.4;$$

State-1 (given $p_1, T_1, \cancel{V}_1$):

$$m_1 = \frac{p_1 \cancel{V}_1}{RT_1} = \frac{(101)(5.66\times10^{-4})}{(0.287)(300)} = 6.65\times10^{-4} \text{ kg};$$

State-2 (given $s_2 = s_1, r$):

$$T_2 = T_1 r^{k-1} = (300)(8)^{1.4-1} = 689.22 \text{ K};$$

State-3 (given T_3)

State-4 (given $s_4 = s_3$):

$$T_4 = \frac{T_3}{r^{k-1}} = \frac{1999}{(8)^{1.4-1}} = 870.12\ \text{K};$$

An energy analysis for the heat addition and rejection processes yields:
Process 2-3:

$$Q_{\text{in}} = Q_{23};$$

$$\Rightarrow Q_{\text{in}} = m(u_3 - u_2);$$

$$\Rightarrow Q_{\text{in}} = mc_v(T_3 - T_2);$$

$$\Rightarrow Q_{\text{in}} = (6.65\times10^{-4})(0.717)(1999 - 689.22);$$

$$\Rightarrow Q_{\text{in}} = 0.625\ \text{kJ};$$

Process 4-1:

$$Q_{\text{out}} = -Q_{41};$$

$$\Rightarrow Q_{\text{out}} = m(u_4 - u_1);$$

$$\Rightarrow Q_{\text{out}} = mc_v(T_4 - T_1);$$

$$\Rightarrow Q_{\text{out}} = (6.65\times10^{-4})(0.717)(870.12 - 300);$$

$$\Rightarrow Q_{\text{out}} = 0.272\ \text{kJ};$$

Therefore, the net work, efficiency and MEP are calculated as:

$$W_{\text{net}} = Q_{\text{in}} - Q_{\text{out}};$$

$$\Rightarrow W_{\text{net}} = 0.625 - 0.272;$$

$$\Rightarrow W_{\text{net}} = 0.353\ \text{kJ};$$

(a) $\eta_{\text{th}} = \dfrac{W_{\text{net}}}{Q_H};$

$$\Rightarrow \eta_{\text{th}} = \frac{0.353}{0.625};$$

$$\Rightarrow \eta_{\text{th}} = 56.5\%$$

(b) $\text{MEP} = \dfrac{W_{\text{net}}}{V_d};$

$$\Rightarrow \text{MEP} = \frac{W_{\text{net}}}{V_1\left(1 - \frac{1}{r}\right)};$$

$$\Rightarrow \text{MEP} = \frac{0.353}{(5.66\times10^{-4})\left(1 - \frac{1}{8}\right)};$$

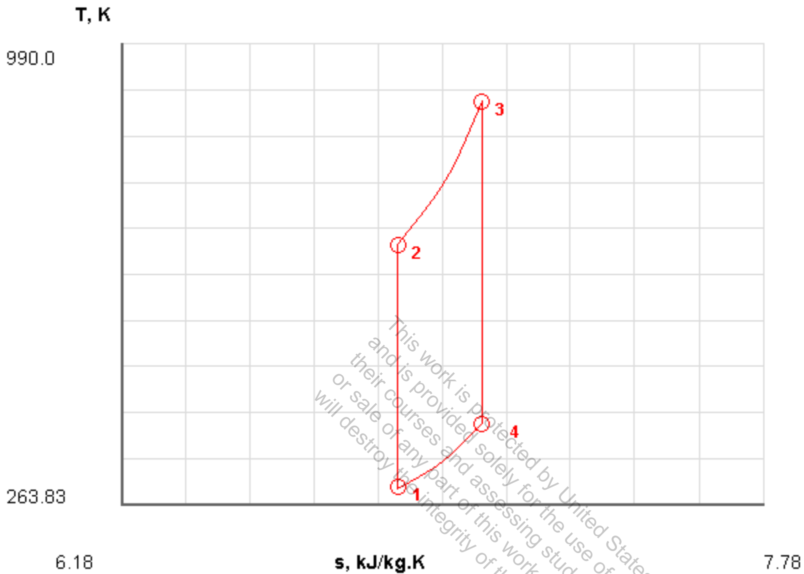
$$\Rightarrow \text{MEP} = 712.7\ \text{kPa}$$

TEST Solution and What-if Scenario:

Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution and perform the what-if study. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-6 [OLS] The compression ratio of an air standard Otto cycle is 8. Prior to isentropic compression, the air is at 100 kPa, 20°C and 500 cm^3. The temperature at the end of combustion process is 900 K. Determine (a) the highest pressure in the cycle, (b) the amount of heat input in kJ, (c) thermal efficiency and (d) MEP. Use the PG model. (e) What-if Scenario: What would the efficiency be if the compression ratio were increased to 10? Explain the change with the help of a *T*-*s* diagram.

SOLUTION



Given:

$$c_v = 0.717 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$R = 0.287 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$k = 1.4;$$

State-1 (given $p_1, T_1, \cancel{V}_1$):

$$m_1 = \frac{p_1 \cancel{V}_1}{RT_1} = \frac{(100)\left(5\times10^{-4}\right)}{(0.287)(293)} = 5.95\times10^{-4} \text{ kg};$$

State-2 (given $s_2 = s_1, r$):

$$T_2 = T_1 r^{k-1} = (293)(8)^{1.4-1} = 673 \text{ K};$$

$$\cancel{V}_2 = \frac{\cancel{V}_1}{8} = 6.25\text{x}10^{-5} \text{ m}^3;$$

$$p_2 = p_1\left(\frac{\cancel{V}_1}{\cancel{V}_2}\right)\left(\frac{T_2}{T_1}\right) = (100)(8)\left(\frac{673}{293}\right) = 1837.5 \text{ kPa};$$

State-3 (given T_3):

(a) $p_3 = p_2 \dfrac{T_3}{T_2} = (1837.5)\left(\dfrac{900}{673}\right) = 2457.3 \text{ kPa}$

State-4 (given $s_4 = s_3$):

$$T_4 = \frac{T_3}{r^{k-1}} = \frac{900}{(8)^{1.4-1}} = 391.7 \text{ K};$$

An energy analysis for the heat addition and rejection processes yields:

(b) Process 2-3:

$$Q_{\text{in}} = Q_{23};$$
$$\Rightarrow Q_{\text{in}} = m(u_3 - u_2);$$
$$\Rightarrow Q_{\text{in}} = mc_v(T_3 - T_2);$$
$$\Rightarrow Q_{\text{in}} = (5.95\times10^{-4})(0.717)(900-673);$$
$$\Rightarrow Q_{\text{in}} = 0.0968 \text{ kJ}$$

Process 4-1:

$$Q_{\text{out}} = -Q_{41};$$
$$\Rightarrow Q_{\text{out}} = m(u_4 - u_1);$$
$$\Rightarrow Q_{\text{out}} = mc_v(T_4 - T_1);$$
$$\Rightarrow Q_{\text{out}} = (5.95\times10^{-4})(0.717)(391.7-293);$$
$$\Rightarrow Q_{\text{out}} = 0.042 \text{ kJ};$$

$$W_{\text{net}} = Q_{\text{in}} - Q_{\text{out}};$$
$$\Rightarrow W_{\text{net}} = 0.096 - 0.042;$$
$$\Rightarrow W_{\text{net}} = 0.054 \text{ kJ};$$

(c) $\eta_{\text{th}} = \dfrac{W_{\text{net}}}{Q_{\text{in}}};$

$$\Rightarrow \eta_{\text{th}} = \frac{0.054}{0.096};$$
$$\Rightarrow \eta_{\text{th}} = 56.3\%$$

(d) $\text{MEP} = \dfrac{W_{\text{net}}}{V_d};$

$$\Rightarrow \text{MEP} = \frac{W_{\text{net}}}{\cancel{V}_1\left(1-\frac{1}{r}\right)};$$

$$\Rightarrow \text{MEP} = \frac{0.054}{\left(5\times10^{-4}\right)\left(1-\frac{1}{8}\right)};$$

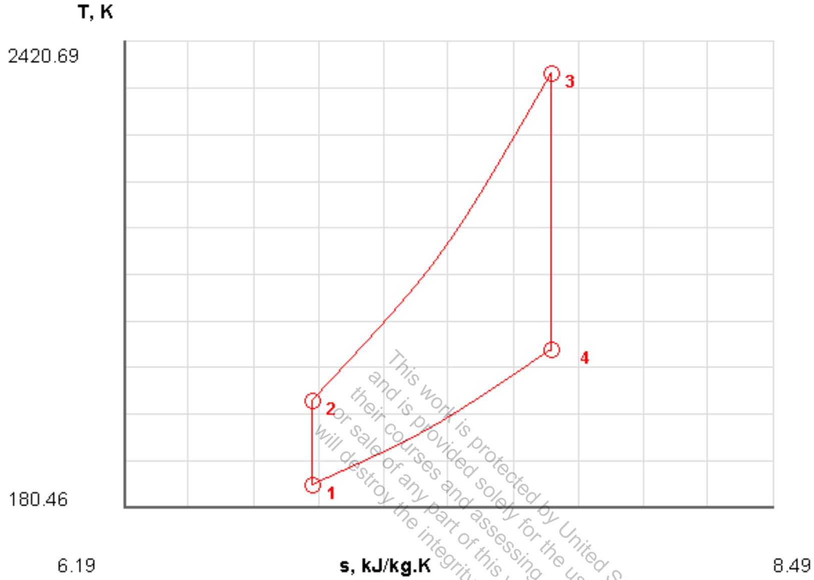
$$\Rightarrow \text{MEP} = 123.4\ \text{kPa}$$

TEST Solution and What-if Scenario:

Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution and perform the what-if study. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-7 [OLA] At the beginning of the compression process of an air standard Otto cycle, pressure is 100 kPa, temperature is 16°C, and volume is 300 cm^3. The maximum temperature in the cycle is 2000°C and the compression ratio is 9. Determine (a) the heat addition in kJ, (b) the net work (W_{net}) in kJ, (c) thermal efficiency and (d) MEP. Use the PG model.

SOLUTION



Given:

$$c_v = 0.717 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$R = 0.287 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$k = 1.4;$$

State-1 (given $p_1, T_1, \mathcal{V}_1$):

$$m_1 = \frac{p_1 \mathcal{V}_1}{RT_1} = \frac{(100)(0.3\times10^{-3})}{(0.287)(289)} = 3.62\times10^{-4} \text{ kg};$$

State-2 (given $s_2 = s_1, r$):

$$T_2 = (289)(9)^{1.4-1} = 695.98 \text{ K};$$

State-3 (given T_3)

State-4 (given $s_4 = s_3$):

$$T_4 = \frac{T_3}{r^{k-1}} = \frac{2273}{(9)^{1.4-1}} = 943.8 \text{ K};$$

An energy analysis for the heat addition and rejection processes yields:

(a) Process 2-3:

$$Q_{\text{in}} = Q_{23};$$
$$\Rightarrow Q_{\text{in}} = m(u_3 - u_2);$$
$$\Rightarrow Q_{\text{in}} = mc_v(T_3 - T_2);$$
$$\Rightarrow Q_{\text{in}} = (3.62 \times 10^{-4})(0.717)(2273 - 695.98);$$
$$\Rightarrow Q_{\text{in}} = 0.409 \text{ kJ}$$

Process 4-1:

$$Q_{\text{out}} = -Q_{41};$$
$$\Rightarrow Q_{\text{out}} = m(u_4 - u_1);$$
$$\Rightarrow Q_{\text{out}} = mc_v(T_4 - T_1);$$
$$\Rightarrow Q_{\text{out}} = (3.62 \times 10^{-4})(0.717)(943.8 - 289);$$
$$\Rightarrow Q_{\text{out}} = 0.170 \text{ kJ};$$

(b) $W_{\text{net}} = Q_{\text{in}} - Q_{\text{out}};$

$$\Rightarrow W_{\text{net}} = 0.409 - 0.17;$$
$$\Rightarrow W_{\text{net}} = 0.239 \text{ kJ}$$

(c) $\eta_{\text{th}} = \dfrac{W_{\text{net}}}{Q_{\text{in}}};$

$$\Rightarrow \eta_{\text{th}} = \frac{0.239}{0.409};$$
$$\Rightarrow \eta_{\text{th}} = 58.4\%$$

(d) $\text{MEP} = \dfrac{W_{\text{net}}}{\cancel{V}_d};$

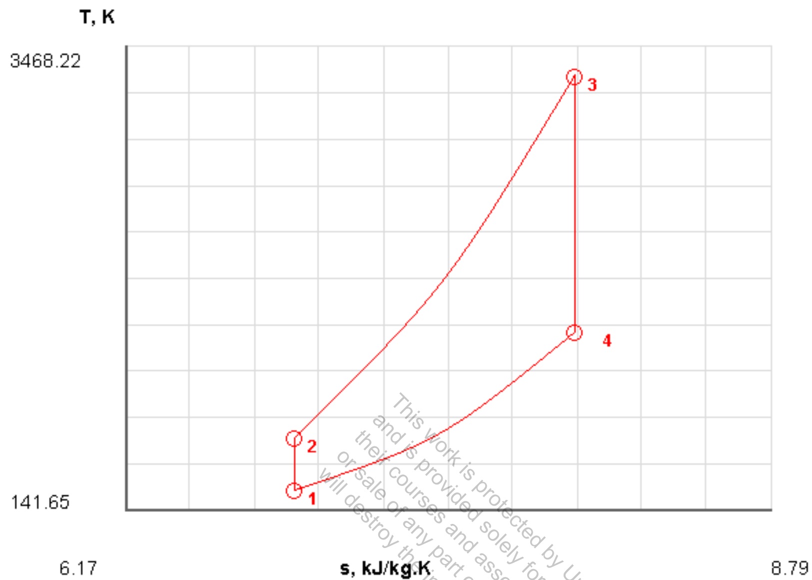
$$\Rightarrow \text{MEP} = \frac{W_{\text{net}}}{\cancel{V}_1\left(1 - \frac{1}{r}\right)};$$
$$\Rightarrow \text{MEP} = \frac{0.239}{(0.0003)\left(1 - \frac{1}{9}\right)};$$
$$\Rightarrow \text{MEP} = 896.25 \text{ kPa}$$

TEST Solution:

Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-8 [OLE] The compression ratio in an air standard Otto cycle is 8. At the beginning of the compression stroke, the pressure is 101 kPa and the temperature is 289 K. The heat transfer to the air per cycle is 1860 kJ/kg. Determine (a) the thermal efficiency and (b) the mean effective pressure. Use the PG model.

SOLUTION



Given:

$c_v = 0.717 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$

$R = 0.287 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$

$k = 1.4;$

State-1 (given p_1, T_1):

$$v_1 = \frac{RT_1}{p_1} = \frac{(0.287)(289)}{(101)} = 0.821 \ \frac{\text{m}^3}{\text{kg}};$$

State-2 (given $s_2 = s_1, r$):

$$T_2 = T_1 r^{k-1} = (289)(8)^{0.4} = 664 \text{ K};$$

$$p_2 = p_1 r^k = (101)(8)^{1.4} = 1856 \text{ kPa};$$

$$v_2 = \frac{v_1}{r} = \frac{0.821}{8} = 0.1027 \ \frac{\text{m}^3}{\text{kg}};$$

State-3 (given q_{in}):

$$q_{\text{in}} = c_v \left(T_3 - T_2\right);$$

$$\Rightarrow T_3 = \frac{q_{\text{in}}}{c_v} + T_2;$$

$$\Rightarrow T_3 = \frac{1860}{0.717} + 664;$$

$$\Rightarrow T_3 = 3258 \text{ K};$$

State-4 (given $s_4 = s_3$):

$$T_4 = \frac{T_3}{r^{k-1}} = \frac{3258}{(8)^{1.4-1}} = 1418 \text{ K};$$

An energy analysis for the heat rejection process yields:
Process 4-1:

$$q_{\text{out}} = -q_{41};$$

$$\Rightarrow q_{\text{out}} = c_v\left(T_4 - T_1\right);$$

$$\Rightarrow q_{\text{out}} = (0.717)(1418 - 289);$$

$$\Rightarrow q_{\text{out}} = 809\ \frac{\text{kJ}}{\text{kg}};$$

Now we can calculate the efficiency and MEP as:

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}};$$

$$\Rightarrow w_{\text{net}} = 1860 - 810;$$

$$\Rightarrow w_{\text{net}} = 1050\ \frac{\text{kJ}}{\text{kg}};$$

(a) $\eta_{\text{th}} = \dfrac{w_{\text{net}}}{q_{\text{in}}};$

$$\Rightarrow \eta_{\text{th}} = \frac{1050}{1860};$$

$$\Rightarrow \eta_{\text{th}} = 56.5\%$$

(b) $\text{MEP} = \dfrac{w_{\text{net}}}{v_1 - v_2};$

$$\Rightarrow \text{MEP} = \frac{1050}{(0.821) - (0.1027)};$$

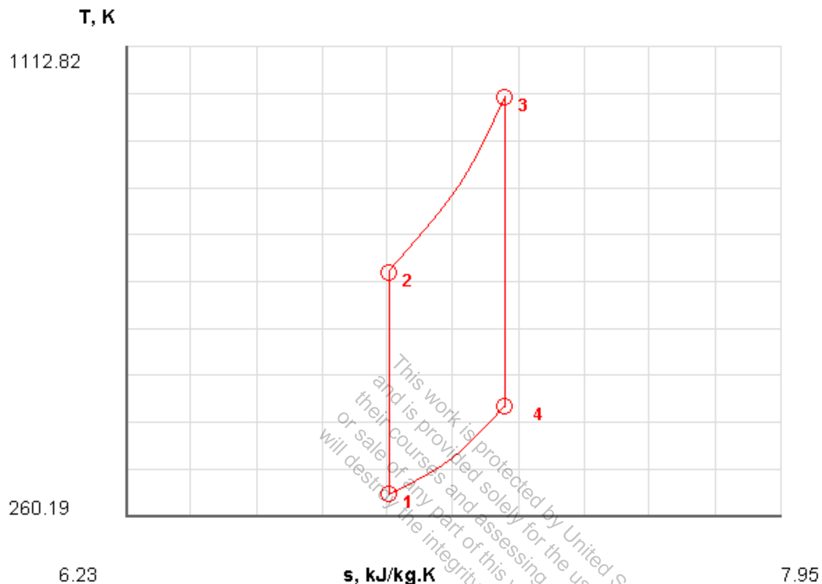
$$\Rightarrow \text{MEP} = 1463 \text{ kPa}$$

TEST Solution:

Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-9 [OLH] An air standard Otto cycle has a compression ratio of 9. At the beginning of the compression, pressure is 95 kPa and temperature is 30°C. Heat addition to the air is 1 kJ, and the maximum temperature in the cycle is 750°C. Using the IG model for air, determine (a) the net work (W_{net}) in kJ, (b) thermal efficiency and (c) MEP. Assume mass of air as 0.005 kg.

SOLUTION



State-1 (given p_1, T_1, m_1):

$$v_1 = 0.916\ \frac{\text{m}^3}{\text{kg}};$$

$$u_1 = -81.96\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $s_2 = s_1,\ r$):

$$v_2 = \frac{v_1}{r} = \frac{0.916}{9} = 0.1017\ \frac{\text{m}^3}{\text{kg}};$$

$$u_2 = 220.37\ \frac{\text{kJ}}{\text{kg}};$$

$$p_2 = \frac{RT_2}{v_2} = 1990.3\ \text{kPa};$$

State-3 (given $T_3, v_3 = v_2$):

$$p_3 = \frac{RT_3}{v_3} = 2886.9 \text{ kPa};$$

$$u_3 = 481.64 \ \frac{\text{kJ}}{\text{kg}};$$

State-4 (given $s_4 = s_3,\ v_4 = v_1$):

$$u_4 = 33.02 \ \frac{\text{kJ}}{\text{kg}};$$

An energy analysis for the heat rejection process yields:
Process 4-1:

$$Q_{\text{out}} = -Q_{41};$$

$$\Rightarrow Q_{\text{out}} = m\left(u_4 - u_1\right);$$

$$\Rightarrow Q_{\text{out}} = (0.005)(33.02 + 81.96);$$

$$\Rightarrow Q_{\text{out}} = 0.575 \text{ kJ};$$

Therefore, the net work, efficiency and MEP are calculated as:

(a) $W_{\text{net}} = Q_{\text{in}} - Q_{\text{out}};$

$$\Rightarrow W_{\text{net}} = 1 - 0.575;$$

$$\Rightarrow W_{\text{net}} = 0.425 \text{ kJ}$$

(b) $\eta_{\text{th}} = \dfrac{W_{\text{net}}}{Q_H};$

$$\Rightarrow \eta_{\text{th}} = \frac{0.425}{1};$$

$$\Rightarrow \eta_{\text{th}} = 42.5\%$$

(c) $\text{MEP} = \dfrac{W_{\text{net}}}{\cancel{V}_d};$

$$\Rightarrow \text{MEP} = \frac{W_{\text{net}}}{\cancel{V}_1\left(1 - \frac{1}{r}\right)};$$

$$\Rightarrow \text{MEP} = \frac{0.425}{(0.00458)\left(1 - \frac{1}{9}\right)};$$

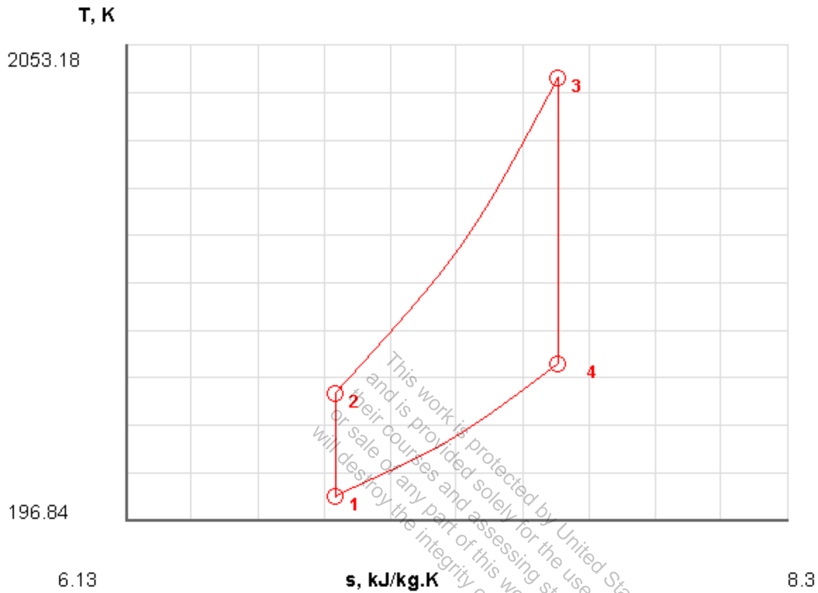
$$\Rightarrow \text{MEP} = 104.3 \text{ kPa}$$

TEST Solution:

Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-10 [OLN] The compression ratio of an air standard Otto cycle is 8.7. Prior to the isentropic compression process, air is at 120 kPa, 19^{o}C, and 660 cm^3. The temperature at the end of the isentropic expansion process is 810 K. Using the PG model, determine (a) the highest temperature and pressure in the cycle, (b) the amount of heat transfer in kJ, (c) the thermal efficiency and (d) MEP.

SOLUTION



Given:

$$c_v = 0.717 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$R = 0.287 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$k = 1.4;$$

State-1 (given $p_1, T_1, \cancel{V}_1$):

$$m_1 = \frac{p_1 \cancel{V}_1}{RT_1} = \frac{(120)(6.6 \times 10^{-4})}{(0.287)(292)} = 9.5 \times 10^{-4} \ \text{kg};$$

State-2 (given $s_2 = s_1, r$):

$$T_2 = T_1 r^{k-1} = (292)(8.7)^{1.4-1} = 693.7 \ \text{K};$$

$$p_2 = p_1 r^k = (120)(8.7)^{1.4} = 2480.2 \ \text{kPa};$$

State-3 (given $s_3 = s_4$):

$$T_3 = T_4 r^{k-1} = (810)(8.7)^{1.4-1} = 1924.4\text{ K};$$

$$p_3 = p_2 \frac{T_3}{T_2} = (2480.2)\left(\frac{1924.4}{693.7}\right) = 6880.3\text{ kPa};$$

State-4 (given T_4):

(a) $T = 1924.4\text{ K}$
$p = 6880.3\text{ kPa}$

An energy analysis for the heat addition and rejection processes yields:
(b) Process 2-3:

$$Q_{\text{in}} = Q_{23};$$
$$\Rightarrow Q_{\text{in}} = m(u_3 - u_2);$$
$$\Rightarrow Q_{\text{in}} = mc_v(T_3 - T_2);$$
$$\Rightarrow Q_{\text{in}} = (9.5\times10^{-4})(0.717)(1924.4 - 693.7);$$
$$\Rightarrow Q_{\text{in}} = 0.838\text{ kJ}$$

Process 4-1:

$$Q_{\text{out}} = -Q_{41};$$
$$\Rightarrow Q_{\text{out}} = m(u_4 - u_1);$$
$$\Rightarrow Q_{\text{out}} = mc_v(T_4 - T_1);$$
$$\Rightarrow Q_{\text{out}} = (9.5\times10^{-4})(0.717)(810 - 292);$$
$$\Rightarrow Q_{\text{out}} = 0.353\text{ kJ};$$

Therefore, the net work, efficiency and MEP are calculated as:

$$W_{\text{net}} = Q_{\text{in}} - Q_{\text{out}};$$
$$\Rightarrow W_{\text{net}} = 0.838 - 0.353;$$
$$\Rightarrow W_{\text{net}} = 0.485\text{ kJ};$$

(c) $\eta_{\text{th}} = \dfrac{W_{\text{net}}}{Q_H};$

$$\Rightarrow \eta_{\text{th}} = \frac{0.485}{0.838};$$
$$\Rightarrow \eta_{\text{th}} = 57.9\%$$

(d) $\text{MEP} = \dfrac{W_{\text{net}}}{\cancel{V}_d};$

$$\Rightarrow \text{MEP} = \frac{W_{\text{net}}}{\cancel{V}_1\left(1-\dfrac{1}{r}\right)};$$

$$\Rightarrow \text{MEP} = \frac{0.485}{\left(6.6\times10^{-4}\right)\left(1-\dfrac{1}{8.7}\right)};$$

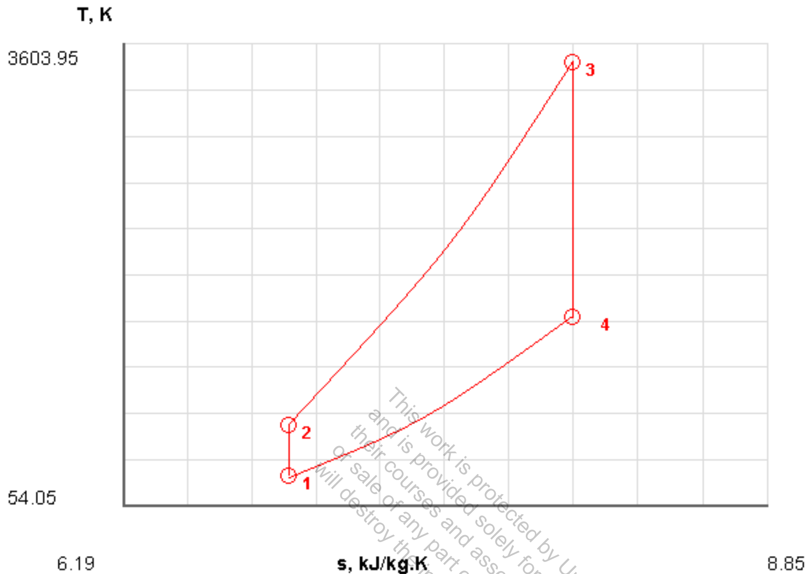
$$\Rightarrow \text{MEP} = 830.3\ \text{kPa}$$

TEST Solution:

Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-11 [OLG] The compression ratio in an air standard Otto cycle is 8. At the beginning of the compression stroke the pressure is 0.1 MPa and the temperature is 21^{o}C. The heat transfer to the air per cycle is 2000 kJ/kg. Determine (a) the thermal efficiency and (b) the mean effective pressure. Use the PG model for air.

SOLUTION



State-1 (given p_1, T_1):

$$v_1 = \frac{RT_1}{p_1} = 0.844 \ \frac{\text{m}^3}{\text{kg}};$$

State-2 (given $s_2 = s_1, r$):

$$v_2 = \frac{v_1}{r} = \frac{0.844}{8} = 0.1055 \ \frac{\text{m}^3}{\text{kg}};$$

$$T_2 = T_1 r^{k-1} = (294)(8)^{1.4-1} = 675 \text{ K};$$

State-3 (given q_{in}):

$$q_{\text{in}} = c_v (T_3 - T_2);$$

$$\Rightarrow T_3 = \frac{q_{\text{in}}}{c_v} + T_2;$$

$$\Rightarrow T_3 = \frac{2000}{0.717} + 675;$$

$$\Rightarrow T_3 = 3464 \text{ K};$$

State-4 (given $s_4 = s_3$):

$$T_4 = \frac{T_3}{r^{k-1}} = \frac{3464}{(8)^{1.4-1}} = 1508 \text{ K};$$

An energy analysis for the heat rejection process yields:
Process 4-1:

$$q_{\text{out}} = -q_{41};$$

$$\Rightarrow q_{\text{out}} = u_4 - u_1;$$

$$\Rightarrow q_{\text{out}} = c_v (T_4 - T_1);$$

$$\Rightarrow q_{\text{out}} = (0.717)(1508 - 294);$$

$$\Rightarrow q_{\text{out}} = 870 \ \frac{\text{kJ}}{\text{kg}};$$

Therefore, the net work, efficiency and MEP are calculated as:

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}};$$

$$\Rightarrow w_{\text{net}} = 2000 - 870;$$

$$\Rightarrow w_{\text{net}} = 1130 \ \frac{\text{kJ}}{\text{kg}};$$

(a) $\eta_{\text{th}} = \dfrac{w_{\text{net}}}{q_{in}};$

$$\Rightarrow \eta_{\text{th}} = \frac{1130}{2000};$$

$$\Rightarrow \eta_{\text{th}} = 56.5\%$$

(b) $\text{MEP} = \dfrac{w_{\text{net}}}{v_d};$

$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}}{v_1 - v_2};$$

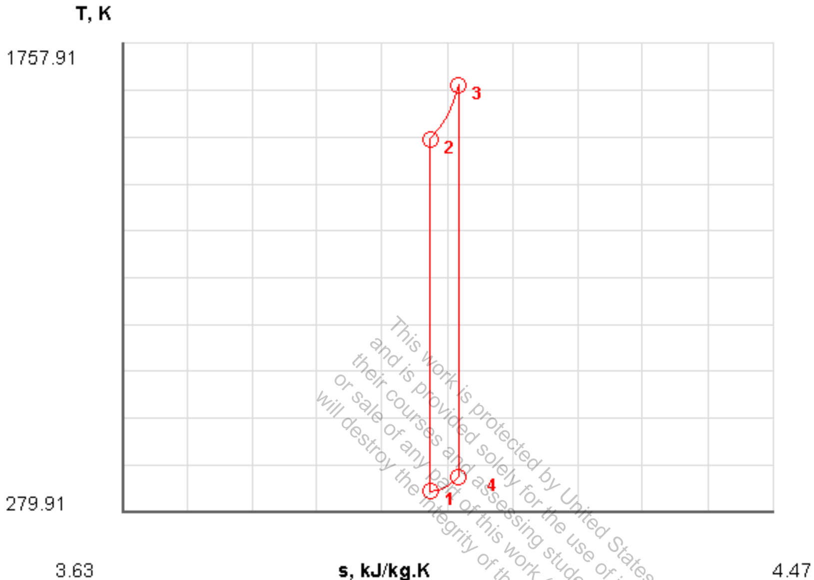
$$\Rightarrow \text{MEP} = \frac{1130}{0.844 - 0.1055};$$

$$\Rightarrow \text{MEP} = 1530 \text{ kPa}$$

TEST Solution:
Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-12 [OLI] An ideal Otto cycle with argon as the working fluid has a compression ratio of 8.5. The minimum and maximum temperatures in the cycle are 350 K and 1630 K. Accounting for variation of specific heats with temperature (that is, using the IG model for air), determine (a) the amount of heat transferred to the air during the heat addition process, (b) the thermal efficiency and (c) the thermal efficiency of a Carnot cycle operating between the same temperature limits.

SOLUTION



Assuming an initial volume of $1\,\text{m}^3$ and mass of 1 kg.

Given:

$$R = 0.208\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-1 (given $T_1, \cancel{V_1}, m_1$):

$$p_1 = \frac{RT_1}{v_1} = \frac{(0.208)(350)}{1} = 72.8\ \text{kPa};$$

$$u_1 = -45.86\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $s_2 = s_1, r$):

$$v_2 = \frac{v_1}{r} = \frac{1}{8.5} = 0.1176\ \frac{\text{m}^3}{\text{kg}};$$

$$u_2 = 299.9\ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $T_3,\ v_3 = v_2$):

$$p_3 = \frac{RT_3}{v_3} = \frac{(0.208)(1630)}{0.1176} = 2883\ \text{kPa};$$

$$u_3 = 353.74\ \frac{\text{kJ}}{\text{kg}};$$

State-4 (given $s_4 = s_3,\ v_4 = v_1$):

$$u_4 = -32.93\ \frac{\text{kJ}}{\text{kg}};$$

An energy analysis for the heat addition and rejection processes yields:
Process 2-3:

(a) $Q_{\text{in}} = Q_{23};$

$$\Rightarrow Q_{\text{in}} = m(u_3 - u_2);$$

$$\Rightarrow Q_{\text{in}} = (1)(353.74 - 299.9);$$

$$\Rightarrow Q_{\text{in}} = 53.84\ \text{kJ}$$

Process 4-1:

$$Q_{\text{out}} = -Q_{41};$$

$$\Rightarrow Q_{\text{out}} = m(u_4 - u_1);$$

$$\Rightarrow Q_{\text{out}} = (1)(-32.93 + 45.86);$$

$$\Rightarrow Q_{\text{out}} = 12.93\ \text{kJ};$$

Therefore, the net work, efficiency and MEP are calculated as:

$$W_{\text{net}} = Q_{\text{in}} - Q_{\text{out}};$$

$$\Rightarrow W_{\text{net}} = 53.84 - 12.93;$$

$$\Rightarrow W_{\text{net}} = 40.9\ \text{kJ};$$

(b) $\eta_{\text{th}} = \dfrac{W_{\text{net}}}{Q_{\text{in}}};$

$$\Rightarrow \eta_{\text{th}} = \frac{40.9}{53.84};$$

$$\Rightarrow \eta_{\text{th}} = 75.9\%$$

(c) $\eta_{\text{th},C} = 1 - \dfrac{T_C}{T_H};$

$$\Rightarrow \eta_{\text{th},C} = 1 - \frac{350}{1630};$$

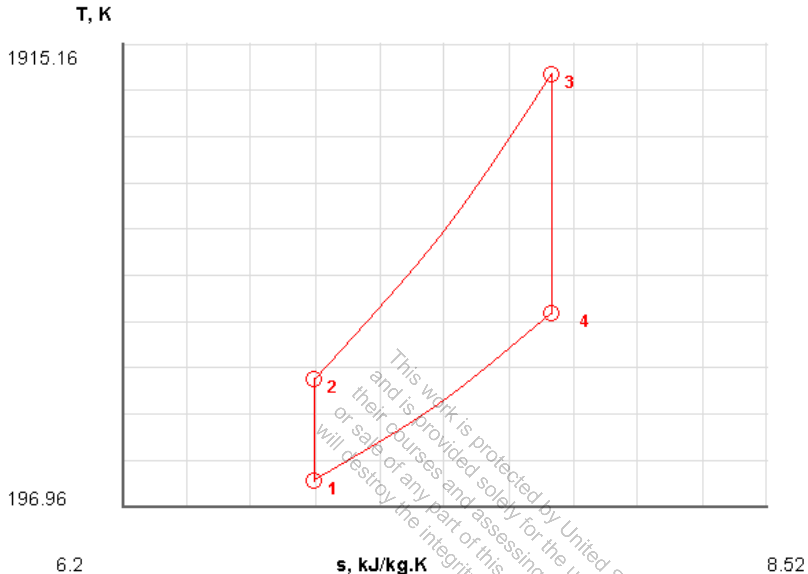
$$\Rightarrow \eta_{\text{th},C} = 78.5\%$$

TEST Solution:

Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-13 [OLL] An ideal Otto cycle has a compression ratio of 8.3. At the beginning of the compression process, air is at 100 kPa and 25°C, and 1000 kJ/kg of heat is transferred to air during the constant volume heat addition process. Using the IG model for air, determine (a) the maximum temperature and pressure that occur during the cycle, (b) the thermal efficiency and (c) the mean effective pressure for the cycle.

SOLUTION



State-1 (given p_1, T_1, r):

$$v_1 = \frac{RT_1}{p_1} = \frac{(0.287)(298)}{100} = 0.855 \ \frac{\text{m}^3}{\text{kg}};$$

$$v_{r1} = 631.9;$$

$$u_1 = 212.64 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given v_{r2}):

$$v_{r2} = \frac{v_2}{v_1} v_{r1} = \frac{1}{r} v_{r1} = \left(\frac{1}{8.3}\right)(631.9) = 76.13;$$

$$T_2 = 678.07 \text{ K};$$

$$u_2 = 495.11 \ \frac{\text{kJ}}{\text{kg}};$$

$$p_2 = p_1 \frac{T_2}{T_1} \frac{v_1}{v_2} = (100)\left(\frac{678.07}{298}\right)(8.3) = 1888.58 \text{ kPa};$$

State-3 (given $v_3 = v_2, q_{\text{in}}$):

$$q_{in} = u_3 - u_2;$$

$$\Rightarrow u_3 = u_2 + q_{in};$$
$$\Rightarrow u_3 = 495.11 + 1000;$$
$$\Rightarrow u_3 = 1495.11\ \frac{\text{kJ}}{\text{kg}};$$

$v_{r3} = 3.929;$

$T_3 = 1808.29\text{ K} = 1535.29°\text{C};$

$p_3 = p_2 \dfrac{T_3}{T_2} = (1888.58)\left(\dfrac{1808.29}{678.07}\right) = 5.03\text{ MPa};$

State-4 (given $v_4 = v_1$):

$v_{r4} = \dfrac{v_4}{v_3} v_{r3} = (8.3)(3.929) = 32.61;$

$T_4 = 915.9\text{ K};$

$u_4 = 687.9\ \dfrac{\text{kJ}}{\text{kg}};$

(a) $T_3 = 1535.29^{\text{o}}\text{C}$

$p_3 = 5.03\text{ MPa}$

An energy analysis for the heat rejection processes yields:
Process 4-1:

$q_{\text{out}} = -q_{41};$

$$\Rightarrow q_{\text{out}} = u_4 - u_1;$$
$$\Rightarrow q_{\text{out}} = 687.9 - 212.64;$$
$$\Rightarrow q_{\text{out}} = 475.26\ \frac{\text{kJ}}{\text{kg}};$$

Therefore, the thermal efficiency and MEP are calculated as:

$w_{\text{net}} = q_{\text{in}} - q_{\text{out}};$

$$\Rightarrow w_{\text{net}} = 1000 - 475.26;$$
$$\Rightarrow w_{\text{net}} = 524.74\ \frac{\text{kJ}}{\text{kg}};$$

(b) $\eta_{\text{th}} = \dfrac{w_{\text{net}}}{q_{\text{in}}};$

$$\Rightarrow \eta_{\text{th}} = \frac{524.74}{1000};$$

$$\Rightarrow \eta_{\text{th}} = 52.47\%$$

(c) $$\text{MEP} = \frac{w_{\text{net}}}{v_1 - v_2};$$

$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}}{v_1\left(1 - \frac{1}{r}\right)};$$

$$\Rightarrow \text{MEP} = \frac{524.74}{(0.855)\left(1 - \frac{1}{8.3}\right)};$$

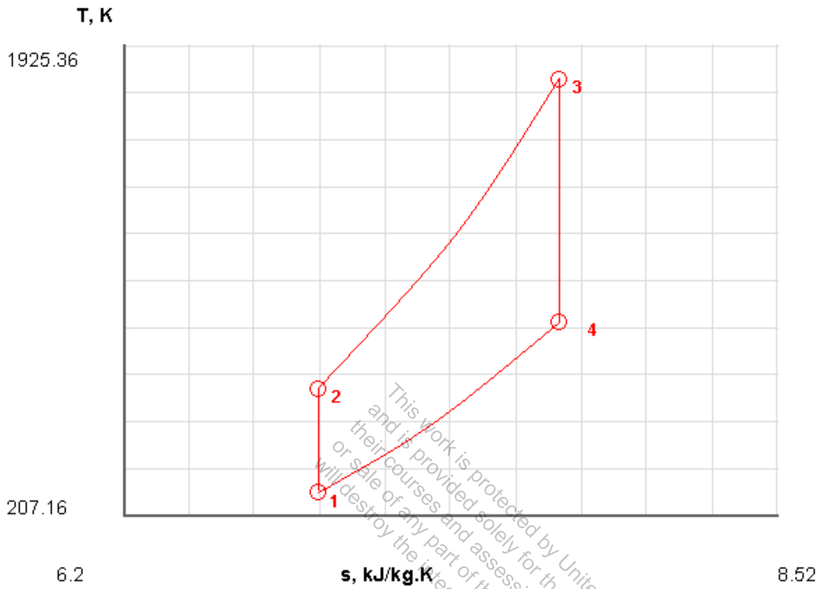
$$\Rightarrow \text{MEP} = 697.8 \text{ kPa}$$

TEST Solution:

Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-14 [OLZ] In problem 7-3-13 [OLL], assume the heat addition can be modeled as heat transfer from a source at 1700°C. Determine (a) the exergy transferred from the reservoir and (b) the exergy rejected to the atmosphere from the engine per unit mass of the gas. Assume the atmospheric conditions to be 100 kPa and 25°C.

SOLUTION



(a) Exergy transferred from the reservoir is:

$$q_k\left[1-\frac{T_0}{T_k}\right]=(1000)\left[1-\frac{298}{1973}\right]=849\ \frac{\text{kJ}}{\text{kg}}$$

(b) Exergy rejected to the atmosphere is the exergy stored at State-4, which i:

$$\phi_4=(u_4-u_0)-T_0(s_4-s_0)+p_0(v_4-v_0)+\cancel{ke_4}^{\,0}+\cancel{pe_4}^{\,0};$$

$$\Rightarrow\phi_4=(393.0-0)-(298)(7.743-6.887);$$

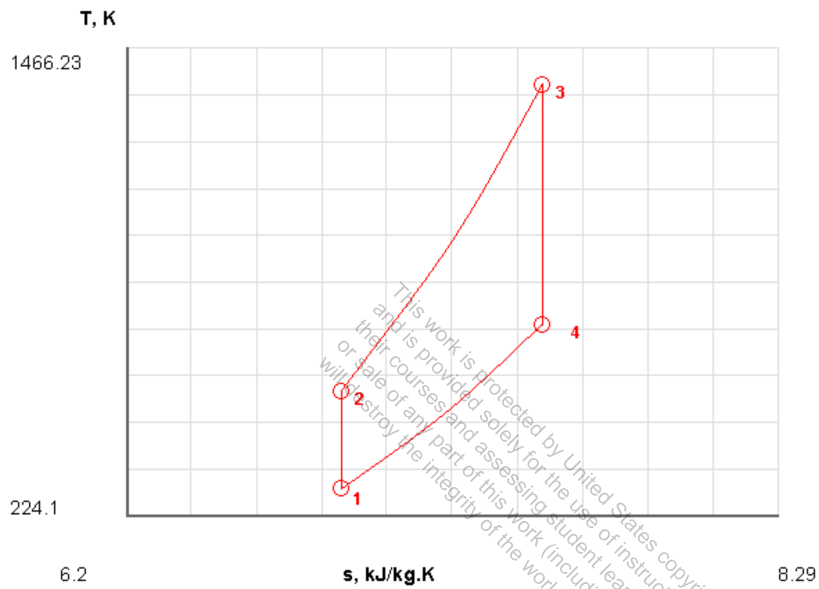
$$\Rightarrow\phi_4=223.3\ \frac{\text{kJ}}{\text{kg}}$$

TEST Solution:

Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

7-3-15 [OLK] An engine equipped with a single cylinder having a bore of 12 cm and a stroke of 50 cm operates on an Otto cycle. At the beginning of the compression stroke air is at the atmospheric conditions of 100 kPa, 25°C. The maximum temperature in the cycle is 1100°C and the heat addition can be assumed to take place from a reservoir at 1500°C. If the clearance volume is 1500 cm^3 and the engine runs at 300 rpm, determine (a) the engine output in kW, (b) the exergy destruction (*I*) over an entire cycle and (c) the rate of exergy destruction in kW. Use the PG model.

SOLUTION



Given:

$c_v = 0.717 \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}};$

$R = 0.287 \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}};$

$k = 1.4;$

State-1 (given p_1, T_1):

$$\cancel{V}_1 = \frac{\pi d^2}{4} L + \cancel{V}_c = \frac{\pi (12)^2}{4}(50) + 1500 = 7155 \text{ cm}^3;$$

$$m_1 = \frac{p_1 \cancel{V}_1}{RT_1} = \frac{(100)(7.155\times10^{-3})}{(0.287)(298)} = 0.008366 \text{ kg};$$

State-2 (given $s_2 = s_1, r$):

$r = \frac{\cancel{V}_1}{\cancel{V}_2} = \frac{7155}{1500} = 4.77;$

$T_2 = T_1 r^{k-1} = (298)(8)^{1.4-1} = 557 \text{ K};$

State-3 (given T_3)

State-4 (given $s_4 = s_3,\ v_4 = v_1$):

$T_4 = \frac{T_3}{r^{k-1}} = \frac{1373}{(4.77)^{1.4-1}} = 735 \text{ K};$

An energy analysis for the heat rejection and heat addition processes yield
Process 2-3:

$Q_{\text{in}} = Q_{23};$

$\Rightarrow Q_{\text{in}} = m(u_3 - u_2);$

$\Rightarrow Q_{\text{in}} = mc_v(T_3 - T_2);$

$\Rightarrow Q_{\text{in}} = (0.008366)(0.717)(1373 - 557);$

$\Rightarrow Q_{\text{in}} = 4.902 \text{ kJ};$

Process 4-1:

$Q_{\text{out}} = -Q_{41};$

$\Rightarrow Q_{\text{out}} = m(u_4 - u_1);$

$\Rightarrow Q_{\text{out}} = mc_v(T_4 - T_1);$

$\Rightarrow Q_{\text{out}} = (0.008366)(0.717)(735 - 298);$

$\Rightarrow Q_{\text{out}} = 2.625 \text{ kJ};$

Therefore, the engine output can be calculated as:

$W_{\text{net}} = Q_{\text{in}} - Q_{\text{out}};$

$\Rightarrow W_{\text{net}} = 4.902 - 2.625;$

$\Rightarrow W_{\text{net}} = 2.277 \text{ kJ};$

(a) $\dot{W}_{\text{net}} = n_C \frac{N}{2} W_{\text{net}};$

$\Rightarrow \dot{W}_{\text{net}} = (1)\frac{(300)}{(2)(60)}(2.277);$

$\Rightarrow \dot{W}_{\text{net}} = 5.7 \text{ kW}$

Exergy transferred from the reservoir during a single cycle:

$$Q_k\left[1-\frac{T_0}{T_k}\right]=(4.902)\left[1-\frac{298}{1773}\right]=4.08\text{ kJ};$$

Exergy rejected to the atmosphere is completely destroyed.

The exergy delivered in a single cycle is:
$W_u = W_{\text{net}} = 2.277\text{ kJ};$

(b) The exergy equation for the cyclic closed process simplifies as:

$$\cancel{\Delta\Phi}^0 = Q_k\left(1-\frac{T_0}{T_k}\right)-W_u-I;$$
$$\Rightarrow I = 4.08-2.277;$$
$$\Rightarrow I = 1.803\text{ kJ}$$

(c) The rate of exergy destruction is:

$$\cancel{\Delta\Phi}^0 = Q_k\left(1-\frac{T_0}{T_k}\right)-W_u-I=\sum_k \cancel{Q_k}^0\left(1-\frac{T_0}{T_k}\right)-W_{\text{rev}};$$
$$\Rightarrow \dot{I} = I\frac{N}{2};$$
$$\Rightarrow \dot{I} = (1.803)\frac{300}{60};$$
$$\Rightarrow \dot{I} = 9.015\text{ kW}$$

TEST Solution:
Use the PG (or IG based on problem statement) reciprocating closed-cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.