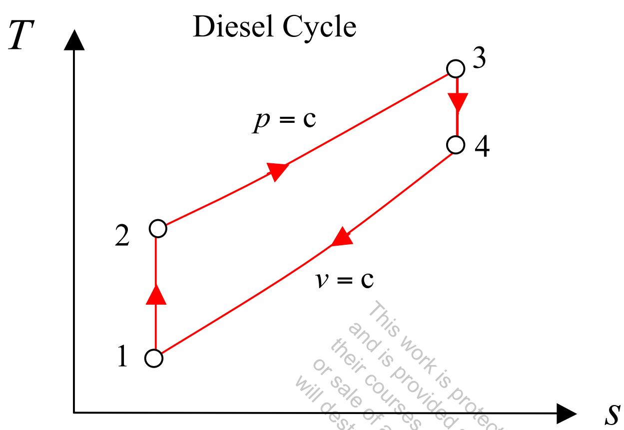
7-4-1 [OLP] An ideal cold air standard Diesel cycle has a compression ratio of 20. At the beginning of compression, air is at 95 kPa and 20°C. If the maximum temperature during the cycle is 2000°C, determine (a) the thermal efficiency and (b) the mean effective pressure. Use the PG model. (c) What-if Scenario: What would the MEP be if the compression ratio were reduced to 10? Explain the change with the help of a *T-s* diagram.

SOLUTION



Given:

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

$$c_p = 1.005 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

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

$$k = 1.4$$

State-1 (given p_1, T_1):

$$v_1 = \frac{RT_1}{p_1} = \frac{(0.287)(293)}{95} = 0.885 \frac{\text{m}^3}{\text{kg}}$$

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

$$T_2 = T_1 r^{k-1} = (293)(20)^{1.4-1} = 971 \text{ K}$$

$$p_2 = p_1 r^k = (95)(20)^{1.4} = 6297.5 \text{ kPa}$$

State-3 (given $p_3 = p_2$):

$$r_c = \frac{v_3}{v_2} = \frac{T_3}{T_2} = \frac{2273}{971} = 2.34$$

State-4 (given $s_4 = s_3$)

$$\frac{v_4}{v_3} = \frac{v_4}{v_2}\frac{v_2}{v_3} = \frac{r}{r_c} = \frac{20}{2.34} = 8.55$$

$$T_4 = \frac{T_3}{\left(\frac{v_4}{v_3}\right)^{k-1}} = \frac{2273}{(8.55)^{1.4-1}} = 963.4 \text{ K}$$

$$p_4 = \frac{p_3}{\left(\frac{v_4}{v_3}\right)^{k}} = \frac{6297.5}{8.55^{1.4}} = 312.2 \text{ kPa}$$

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

$$q_{\text{in}} = q_{23};$$
$$\Rightarrow q_{\text{in}} = u_3 - u_2;$$
$$\Rightarrow q_{\text{in}} = c_p\left(T_3 - T_2\right);$$
$$\Rightarrow q_{\text{in}} = (1.005)(2273 - 971);$$
$$\Rightarrow q_{\text{in}} = 1308.5\ \frac{\text{kJ}}{\text{kg}}$$

Process 4-1:

$$q_{\text{out}} = -q_{41};$$
$$\Rightarrow q_{\text{out}} = u_4 - u_1;$$
$$\Rightarrow q_{\text{out}} = c_v\left(T_4 - T_1\right);$$
$$\Rightarrow q_{\text{out}} = (0.717)(963.4 - 293);$$
$$\Rightarrow q_{\text{out}} = 480.7\,\frac{\text{kJ}}{\text{kg}}$$

Therefore, the net work, efficiency and MEP can be calculated as

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}};$$
$$\Rightarrow w_{\text{net}} = 1308.5 - 480.7;$$
$$\Rightarrow w_{\text{net}} = 827.8\,\frac{\text{kJ}}{\text{kg}}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}};$$
$$\Rightarrow \eta_{\text{th}} = \frac{827.8}{1308.5};$$
$$\Rightarrow \eta_{\text{th}} = 63.3\%$$

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

$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}}{v_2\left(r-1\right)};$$

$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}p_2}{\left(r-1\right)RT_2};$$

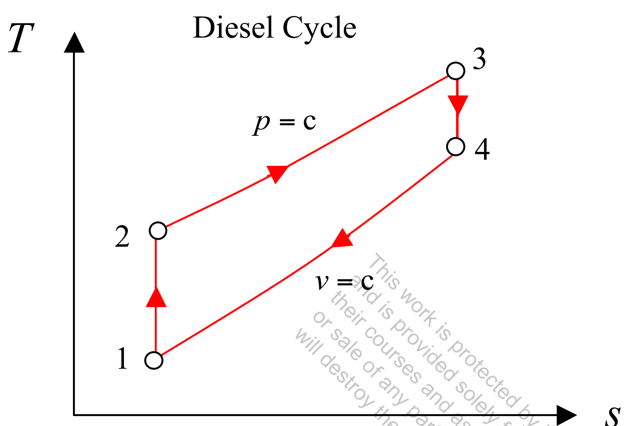
$$\Rightarrow \text{MEP} = \frac{\left(827.8\right)\left(6297.5\right)}{\left(19\right)\left(0.287\right)\left(971\right)};$$

$$\Rightarrow \text{MEP} = 984.6 \text{ kPa}$$

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.

7-4-2 [OLU] The displacement volume of an internal combustion engine is 3 L. The processes within each cylinder of the engine are modeled as an air standard Diesel cycle with a cut off ratio of 2. The state of air at the beginning of the compression is fixed by p_1 = 100 kPa, T_1= 25°C, and $\mathcal{V}_1$= 3.5 L. Determine (a) the net work (W_{net}) per cycle, (b) efficiency and (c) the power developed by the engine, if the cycle is executed 1500 times per min. (d) What-if Scenario: What would the efficiency and power developed be if the cut-off ratio were 2.5? Explain the changes with the help of a *T*-*s* diagram.

SOLUTION



Given:

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

$$c_p = 1.005 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

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

$$k = 1.4$$

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

$$m_1 = \frac{p_1 \mathcal{V}_1}{RT_1} = \frac{(100)(3.5\times10^{-3})}{(0.287)(298)} = 4.10\times10^{-3} \text{ kg}$$

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

$$\mathcal{V}_2 = \mathcal{V}_c = \mathcal{V}_1 - \mathcal{V}_d = 3.5 - 3 = 0.5L = 0.0005\,\text{m}^3$$

$$T_2 = T_1\left(\frac{\mathcal{V}_1}{\mathcal{V}_2}\right)^{k-1} = (298)\left(\frac{0.0035}{0.0005}\right)^{1.4-1} = 649 \text{ K}$$

$$p_2 = p_1\left(\frac{\mathcal{V}_1}{\mathcal{V}_2}\right)^{k} = (100)\left(\frac{0.0035}{0.0005}\right)^{1.4} = 1524.5 \text{ kPa}$$

State-3: (given $p_3 = p_2, r_c$):

$$\cancel{V}_3 = r_c \cancel{V}_2 = (2)(0.0005) = 0.001\ \text{m}^3$$

$$T_3 = T_2\left(\frac{\cancel{V}_3}{\cancel{V}_2}\right) = (649)\left(\frac{0.001}{0.0005}\right) = 1298\ \text{K}$$

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

$$T_4 = T_3\left(\frac{\cancel{V}_3}{\cancel{V}_4}\right)^{k-1} = (1298)\left(\frac{0.001}{0.0035}\right)^{1.4-1} = 786.4\ \text{K}$$

$$p_4 = p_3\left(\frac{\cancel{V}_3}{\cancel{V}_4}\right)^{k} = (1524.5)\left(\frac{0.001}{0.0035}\right)^{1.4} = 263.9\ \text{kPa}$$

Process 2-3:

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

$$\Rightarrow Q_{\text{in}} = mc_p\left(h_3 - h_2\right);$$

$$\Rightarrow Q_{\text{in}} = m\left(T_3 - T_2\right);$$

$$\Rightarrow Q_{\text{in}} = \left(4.1\times10^{-3}\right)(1.005)(1298-649);$$

$$\Rightarrow Q_{\text{in}} = 2.67\ \text{kJ}$$

Process 4-1:

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

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

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

$$\Rightarrow Q_{\text{out}} = \left(4.1\times10^{-3}\right)(0.717)(786.4-298);$$

$$\Rightarrow Q_{\text{out}} = 1.44\ \text{kJ}$$

Therefore, the net work, efficiency and power developed by engine are calculated as

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

$$\Rightarrow W_{\text{net}} = 2.67 - 1.44;$$

$$\Rightarrow W_{\text{net}} = 1.24\ \text{kJ}$$

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

$$\Rightarrow \eta_{\text{th}} = \frac{1.24}{2.67};$$

$$\Rightarrow \eta_{\text{th}} = 46.4\%$$

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

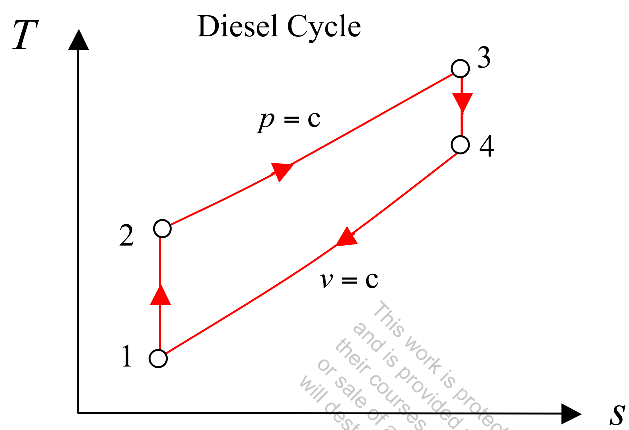
$$\Rightarrow \dot{W}_{\text{net}} = (1.24)\frac{(1500)}{(60)};$$

$$\Rightarrow \dot{W}_{\text{net}} = 31 \text{ kW}$$

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.

7-4-3 [OLV] An air standard Diesel cycle has a compression ratio of 15 and cutoff ratio of 3. At the beginning of the compression process, air is at 97 kPa and 30°C. Using the PG model for air, determine (a) the temperature (T_3) after the heat addition process, (b) the thermal efficiency and (c) the mean effective pressure. (d) What-if Scenario: What would the thermal efficiency be if the IG model were used?

SOLUTION



Given:

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

$$c_p = 1.005 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

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

$$k = 1.4$$

State-1 (given p_1, T_1):

$$v_1 = \frac{RT_1}{p_1} = \frac{(0.287)(303)}{97} = 0.897 \ \frac{\text{m}^3}{\text{kg}}$$

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

$$T_2 = T_1 r^{k-1} = (303)(15)^{1.4-1} = 895.1 \text{ K}$$

$$p_2 = p_1 r^k = (97)(15)^{1.4} = 4298.33 \text{ kPa}$$

State-3 (given $p_3 = p_2, r_c$):

$$T_3 = T_2 \frac{v_3}{v_2} = T_2 r_c = (895.1)(3) = 2685.3 \text{ K}$$

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

$$\frac{v_4}{v_3} = \frac{v_4}{v_2}\frac{v_2}{v_3} = \frac{r}{r_c} = \frac{15}{3} = 5$$

$$T_4 = \frac{T_3}{\left(\frac{v_4}{v_3}\right)^{k-1}} = \frac{2685.3}{(5)^{1.4-1}} = 1410.6\text{ K}$$

$$p_4 = \frac{p_3}{\left(\frac{v_4}{v_3}\right)^{k}} = \frac{4298.33}{(5)^{1.4}} = 451.6\text{ kPa}$$

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

$$q_{\text{in}} = q_{23};$$
$$\Rightarrow q_{\text{in}} = (u_3 - u_2);$$
$$\Rightarrow q_{\text{in}} = c_p(T_3 - T_2);$$
$$\Rightarrow q_{\text{in}} = (1.005)(2685.3 - 895.1);$$
$$\Rightarrow q_{\text{in}} = 1799.15\ \frac{\text{kJ}}{\text{kg}}$$

Process 4-1:

$$q_{\text{out}} = -q_{41};$$
$$\Rightarrow q_{\text{out}} = (u_4 - u_1);$$
$$\Rightarrow q_{\text{out}} = c_v(T_4 - T_1);$$
$$\Rightarrow q_{\text{out}} = (0.717)(1410.6 - 303);$$
$$\Rightarrow q_{\text{out}} = 794.15\ \frac{\text{kJ}}{\text{kg}}$$

Therefore, the net work, efficiency and MEP, on a per mass basis, can be calculated as

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}};$$
$$\Rightarrow w_{\text{net}} = 1799.15 - 794.15;$$
$$\Rightarrow w_{\text{net}} = 1005\ \frac{\text{kJ}}{\text{kg}}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}};$$

$$\Rightarrow \eta_{\text{th}} = \frac{1005}{1799.15};$$

$$\Rightarrow \eta_{\text{th}} = 55.8\%$$

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

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

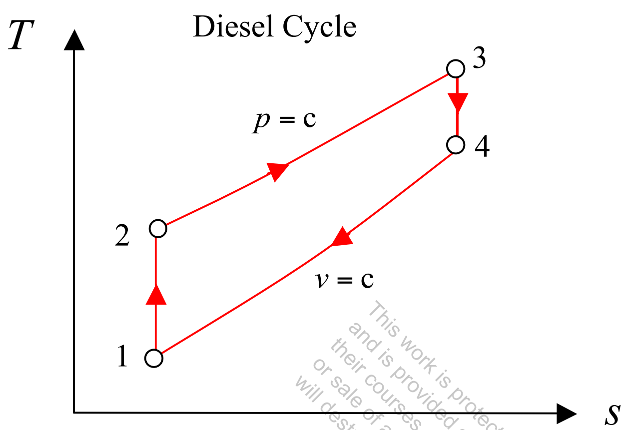
$$\Rightarrow \text{MEP} = \frac{1005}{(0.897)\left(1 - \frac{1}{15}\right)};$$

$$\Rightarrow \text{MEP} = 1200.4 \text{ kPa}$$

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.

7-4-4 [OLX] An air standard Diesel cycle has a compression ratio of 16 and cutoff ratio of 2. At the beginning of the compression process, air is at 100 kPa, 15°C and has a volume of 0.014 m^3. Determine (a) the temperature (T_3) after the heat addition process, (b) the thermal efficiency and (c) the mean effective pressure. Use the PG model. (d) What-if Scenario: What would the efficiency be if the IG model were used?

SOLUTION



Given:

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

$$c_p = 1.005 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

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

$$k = 1.4$$

State-1 (given $p_1, T_1, \forall_1$):

$$m = \frac{p_1 \forall_1}{RT_1} = \frac{(100)(0.014)}{(0.287)(288)} = 0.0169 \text{ kg}$$

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

$$T_2 = T_1 r^{k-1} = (288)(16)^{1.4-1} = 873 \text{ K}$$

$$p_2 = p_1 r^k = (100)(16)^{1.4} = 4850.3 \text{ kPa}$$

State-3 (given $p_3 = p_2, r_c$):

$$T_3 = T_2 r_c = (873)(2) = 1746 \text{ K}$$

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

$$\frac{v_4}{v_3} = \frac{v_4}{v_2}\frac{v_2}{v_3} = \frac{r}{r_c} = \frac{16}{2} = 8$$

$$T_4 = \frac{T_3}{\left(\frac{v_4}{v_3}\right)^{k-1}} = \frac{1746}{(8)^{1.4-1}} = 759.9 \text{ K}$$

$$p_4 = \frac{p_3}{\left(\frac{v_4}{v_3}\right)^{k}} = \frac{4850.3}{(8)^{1.4}} = 263.9 \text{ kPa}$$

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

$$Q_{\text{in}} = Q_{23};$$
$$\Rightarrow Q_{\text{in}} = m(u_3 - u_2);$$
$$\Rightarrow Q_{\text{in}} = mc_p(T_3 - T_2);$$
$$\Rightarrow Q_{\text{in}} = (0.0169)(1.005)(1746 - 873);$$
$$\Rightarrow Q_{\text{in}} = 14.8 \text{ kJ}$$

Process 4-1:

$$Q_{\text{out}} = -Q_{41};$$
$$\Rightarrow Q_{\text{out}} = m(u_4 - u_1);$$
$$\Rightarrow Q_{\text{out}} = mc_v(T_4 - T_1);$$
$$\Rightarrow Q_{\text{out}} = (0.0169)(0.718)(759.9 - 288);$$
$$\Rightarrow Q_{\text{out}} = 5.73 \text{ kJ}$$

Therefore, the net work, efficiency and MEP can be calculated as

$$W_{\text{net}} = Q_{\text{in}} - Q_{\text{out}};$$
$$\Rightarrow W_{\text{net}} = 14.8 - 5.73;$$
$$\Rightarrow W_{\text{net}} = 9.1 \text{ kJ}$$
$$\eta_{\text{th}} = \frac{W_{\text{net}}}{Q_{\text{in}}};$$
$$\Rightarrow \eta_{\text{th}} = \frac{9.1}{14.8};$$
$$\Rightarrow \eta_{\text{th}} = 61.5\%$$

$$\text{MEP} = \frac{W_{\text{net}}}{\cancel{V}_d};$$

$$\Rightarrow \text{MEP} = \frac{W_{\text{net}}}{m\left(v_1 - v_2\right)};$$

$$\Rightarrow \text{MEP} = \frac{W_{\text{net}}}{mv_2\left(r - 1\right)};$$

$$\Rightarrow \text{MEP} = \frac{W_{\text{net}}\,p_2}{m\left(r - 1\right)RT_2};$$

$$\Rightarrow \text{MEP} = \frac{(9.1)(4850.3)}{(0.0169)(15)(0.287)(873)};$$

$$\Rightarrow \text{MEP} = 695\ \text{kPa}$$

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.

7-4-5 [OLC] At the beginning of the compression process of an air standard Diesel cycle operating with a compression ratio of 10, the temperature is 25°C and the pressure is 100 kPa. The cutoff ratio of the cycle is 2. Determine (a) the thermal efficiency and (b) the mean effective pressure. Use the PG model. (c) What-if Scenario: What would the efficiency be if the compression ratio were increased to 15?

SOLUTION

Given:

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

$$c_p = 1.005 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

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

$$k = 1.4$$

State-1 (given p_1, T_1):

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

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

$$T_2 = T_1 r^{k-1} = (298)(10)^{1.4-1} = 748.5 \text{ K}$$

$$p_2 = p_1 r^k = (100)(10)^{1.4} = 2511.9 \text{ kPa}$$

State-3 (given $p_3 = p_2, r_c$):

$$T_3 = T_2 \frac{v_3}{v_2} = T_2 r_c = (748.5)(2) = 1497 \text{ K}$$

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

$$\frac{v_4}{v_3} = \frac{v_4}{v_2}\frac{v_2}{v_3} = \frac{r}{r_c} = \frac{10}{2} = 5$$

$$T_4 = \frac{T_3}{\left(\frac{v_4}{v_3}\right)^{k-1}} = \frac{1497}{(5)^{1.4-1}} = 786.4 \text{ K}$$

$$p_4 = \frac{p_3}{\left(\frac{v_4}{v_3}\right)^{k}} = \frac{2511.9}{(5)^{1.4}} = 263.9 \text{ kPa}$$

An energy analysis for the heat addition and rejection processes yields

Process 2-3:

$$q_{\text{in}} = q_{23};$$
$$\Rightarrow q_{\text{in}} = (u_3 - u_2);$$
$$\Rightarrow q_{\text{in}} = c_p (T_3 - T_2);$$
$$\Rightarrow q_{\text{in}} = (1.005)(1497 - 748.5);$$
$$\Rightarrow q_{\text{in}} = 752.24\ \frac{\text{kJ}}{\text{kg}}$$

Process 4-1:

$$q_{\text{out}} = -q_{41};$$
$$\Rightarrow q_{\text{out}} = (u_4 - u_1);$$
$$\Rightarrow q_{\text{out}} = c_v (T_4 - T_1);$$
$$\Rightarrow q_{\text{out}} = (0.717)(786.4 - 298);$$
$$\Rightarrow q_{\text{out}} = 350.18\ \frac{\text{kJ}}{\text{kg}}$$

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}};$$
$$\Rightarrow w_{\text{net}} = 752.24 - 350.18;$$
$$\Rightarrow w_{\text{net}} = 402.06\ \frac{\text{kJ}}{\text{kg}}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{in}};$$
$$\Rightarrow \eta_{\text{th}} = \frac{402.06}{752.24};$$
$$\Rightarrow \eta_{\text{th}} = 53.4\%$$

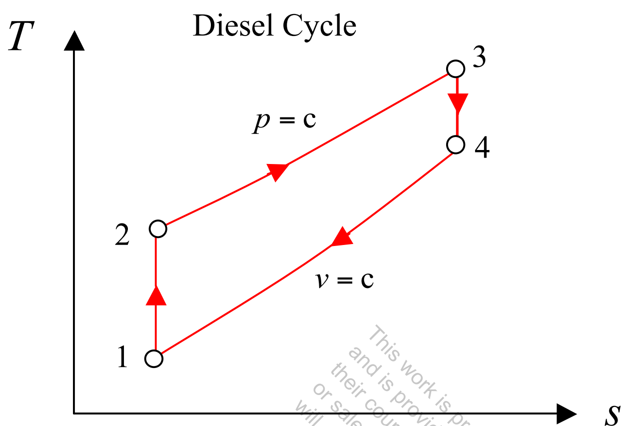
$$\text{MEP} = \frac{w_{\text{net}}}{v_1 - v_2};$$
$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}}{v_1\left(1 - \frac{1}{r}\right)};$$
$$\Rightarrow \text{MEP} = \frac{402.06}{(0.855)\left(1 - \frac{1}{10}\right)};$$
$$\Rightarrow \text{MEP} = 522.5\ \text{kPa}$$

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.

7-4-6 [OLQ] The conditions at the beginning of the compression process of an air standard Diesel cycle are 150 kPa and 100°C. The compression ratio is 15 and the heat addition per unit mass is 750 kJ/kg Determine (a) the maximum temperature, (b) the maximum pressure, (c) the cutoff ratio, (d) the net work (w_{net}) per unit mass of air and (e) the thermal efficiency.

SOLUTION



Given:

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

$$c_p = 1.005 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

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

$$k = 1.4$$

State-1 (given p_1, T_1)

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

$$T_2 = T_1 r^{k-1} = (373)(15)^{1.4-1} = 1101.91 \text{ K}$$

$$p_2 = p_1 r^k = (150)(15)^{1.4} = 6646.9 \text{ kPa} = 6.6 \text{ MPa}$$

State-3 (given $p_3 = p_2, q_{in}$):

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

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

$$\Rightarrow T_3 = 1101.91 + \frac{750}{1.005};$$

$$\Rightarrow T_3 = 1848.18\ \text{K}$$

$$r_c = \frac{v_3}{v_2} = \frac{T_3}{T_2} = \frac{1848.18}{1101.91} = 1.68$$

State-4 (given $s_4 = s_1$):

$$\frac{v_4}{v_3} = \frac{v_4}{v_2}\frac{v_2}{v_3} = \frac{r}{r_c} = \frac{15}{1.68} = 8.93$$

$$T_4 = \frac{T_3}{\left(\dfrac{v_4}{v_3}\right)^{k-1}} = \frac{1848.18}{\left(8.93\right)^{1.4-1}} = 769.85\ \text{K}$$

$$p_4 = \frac{p_3}{\left(\dfrac{v_4}{v_3}\right)^{k}} = \frac{6646.9}{\left(8.93\right)^{1.4}} = 310.04\ \text{kPa}$$

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

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

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

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

$$\Rightarrow q_{\text{out}} = \left(0.717\right)\left(769.85 - 373\right);$$

$$\Rightarrow q_{\text{out}} = 284.54\ \frac{\text{kJ}}{\text{kg}}$$

The net work and efficiency on a per mass basis

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

$$\Rightarrow w_{\text{net}} = 750 - 284.54;$$

$$\Rightarrow w_{\text{net}} = 465.5\ \frac{\text{kJ}}{\text{kg}}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}};$$

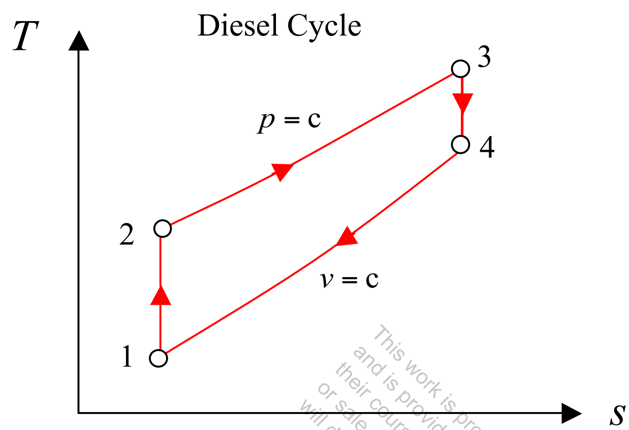
$$\Rightarrow \eta_{\text{th}} = \frac{465.5}{750};$$

$$\Rightarrow \eta_{\text{th}} = 62.1\%$$

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.

7-4-7 [OLT] An air standard Diesel cycle has a compression ratio of 20 and cutoff ratio of 3. At the beginning of the compression process, air is at 90 kPa and 20°C. Using the PG model for air, determine (a) the temperature (T_3) after the heat addition process, (b) the thermal efficiency and (c) the mean effective pressure. What-if Scenario: What would the answers be if the cutoff ratio were (d) 2 and (e) 4?

SOLUTION



Given:

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

$$c_p = 1.005 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

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

$$k = 1.4$$

State-1 (given p_1, T_1):

$$v_1 = \frac{RT_1}{p_1} = \frac{(0.287)(293)}{(90)} = 0.934 \ \frac{\text{m}^3}{\text{kg}}$$

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

$$T_2 = T_1 r^{k-1} = (293)(20)^{1.4-1} = 971.1 \text{ K}$$

$$p_2 = p_1 r^k = (90)(20)^{1.4} = 5966 \text{ kPa}$$

State-3 (given $p_3 = p_2, r_c$):

$$T_3 = T_2 \frac{v_3}{v_2} = T_2 r_c = (971.1)(3) = 2913.3 \text{ K}$$

State-4 (given $s_4 = s_1$):

$$\frac{v_4}{v_3} = \frac{v_4}{v_2}\frac{v_2}{v_3} = \frac{r}{r_c} = \frac{20}{3} = 6.67$$

$$T_4 = \frac{T_3}{\left(\frac{v_4}{v_3}\right)^{k-1}} = \frac{2913.3}{(6.67)^{1.4-1}} = 1363.8 \text{ K}$$

$$p_4 = \frac{p_3}{\left(\frac{v_4}{v_3}\right)^{k}} = \frac{5966}{(6.67)^{1.4}} = 418.7 \text{ kPa}$$

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

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

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

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

$$\Rightarrow q_{\text{in}} = (1.005)(2913.3 - 971.1);$$

$$\Rightarrow q_{\text{in}} = 1951.9 \ \frac{\text{kJ}}{\text{kg}}$$

Process 4-1:

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

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

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

$$\Rightarrow q_{\text{out}} = (0.717)(1363.8 - 293);$$

$$\Rightarrow q_{\text{out}} = 767.8 \ \frac{\text{kJ}}{\text{kg}}$$

The net work, efficiency, and MEP on a per mass basis

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

$$\Rightarrow w_{\text{net}} = 1951.9 - 767.8;$$

$$\Rightarrow w_{\text{net}} = 1184.1 \ \frac{\text{kJ}}{\text{kg}}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}};$$

$$\Rightarrow \eta_{\text{th}} = \frac{1184.1}{1951.9};$$

$$\Rightarrow \eta_{\text{th}} = 60.7\%$$

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

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

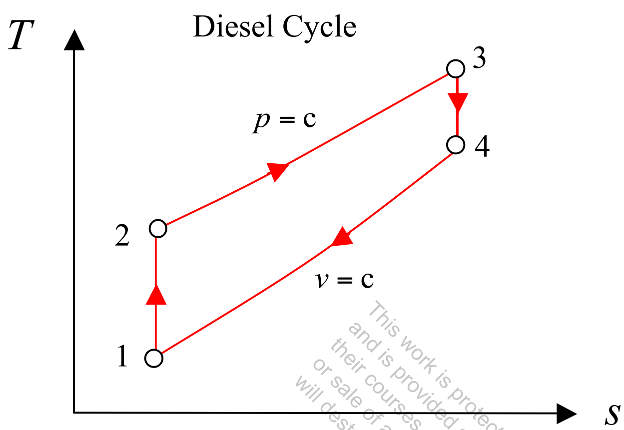
$$\Rightarrow \text{MEP} = \frac{1184.1}{(0.934)\left(1 - \frac{1}{20}\right)};$$

$$\Rightarrow \text{MEP} = 1334.5 \text{ kPa}$$

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.

7-4-8 [OLY] An air standard Diesel cycle has a compression ratio of 17.9. Air is at 85°F and 15.8 psia at the beginning of the compression process and at 3100°R at the end of the heat addition process. Accounting for the variation of specific heats with temperature, determine (a) the cutoff ratio, (b) the heat rejection per unit mass and (c) the thermal efficiency. Use the IG model for air.

SOLUTION



State-1 (given p_1, T_1):

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

$$v_{r1} = 141.8$$

$$v_{r2} = \frac{v_2}{v_1} v_{r1} = \frac{1}{r} v_{r1} = \left(\frac{1}{17.9}\right)(141.8) = 7.92$$

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

$$T_2 = 1625.9°\text{R}$$

$$u_2 = 289.74\ \frac{\text{Btu}}{\text{lbm}}$$

$$p_2 = p_1 \frac{T_2}{T_1}\frac{v_1}{v_2} = (15.8)\left(\frac{1625.9}{544.6}\right)(17.9) = 844.36 \text{ psia}$$

State-3 (given $p_3 = p_2, T_3$):

$$r_c = \frac{v_3}{v_2} = \frac{T_3}{T_2} = \frac{3100}{1625.9} = 1.91$$

$$u_3 = 607.53\ \frac{\text{Btu}}{\text{lbm}}$$

$$v_{r3} = 1.060$$

State-4 (given $s_4 = s_1$)

$$v_{r4} = \frac{v_4}{v_3} v_{r3} = \frac{r}{r_c} v_{r3} = \frac{17.9}{1.91} 1.060 = 9.93$$

$$u_4 = 266.05 \ \frac{\text{Btu}}{\text{lbm}}$$

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

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

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

$$\Rightarrow q_{\text{in}} = 607.53 - 289.74;$$

$$\Rightarrow q_{\text{in}} = 317.79 \ \frac{\text{Btu}}{\text{lbm}}$$

Process 4-1:

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

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

$$\Rightarrow q_{\text{out}} = 266.05 - 92.04;$$

$$\Rightarrow q_{\text{out}} = 174.01 \ \frac{\text{Btu}}{\text{lbm}}$$

Therefore, the thermal efficiency can be calculated as

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

$$\Rightarrow w_{\text{net}} = 317.79 - 174.01;$$

$$\Rightarrow w_{\text{net}} = 143.78 \ \frac{\text{Btu}}{\text{lbm}}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}};$$

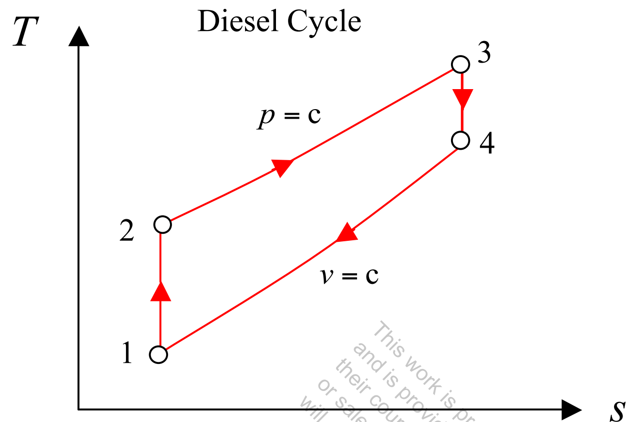
$$\Rightarrow \eta_{\text{th}} = \frac{143.78}{317.79};$$

$$\Rightarrow \eta_{\text{th}} = 45.24\%$$

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.

7-4-9 [OLF] An air standard Diesel cycle has a compression ratio of 18 and cutoff ratio of 3. At the beginning of the compression process, air is at 100 kPa and 20°C. Using the PG model for air, determine (a) the net work per unit mass (w_{net}) per cycle and (b) the thermal efficiency. (c) What-if Scenario: What would the answers be if the compression ratio were 21?

SOLUTION



Given:

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

$$c_p = 1.005 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

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

$$k = 1.4$$

State-1 (given p_1, T_1)

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

$$T_2 = T_1 r^{k-1} = (293)(18)^{1.4-1} = 931.1 \text{ K}$$

$$p_2 = p_1 r^k = (100)(18)^{1.4} = 5719.8 \text{ kPa}$$

State-3 (given $p_3 = p_2, r_c$):

$$T_3 = T_2 \frac{v_3}{v_2} = T_2 r_c = (931.1)(3) = 2793.3 \text{ K}$$

State-4 (given $s_4 = s_1$):

$$\frac{v_4}{v_3} = \frac{v_4}{v_2}\frac{v_2}{v_3} = \frac{r}{r_c} = \frac{18}{3} = 6$$

$$T_4 = \frac{T_3}{\left(\frac{v_4}{v_3}\right)^{k-1}} = \frac{2793.3}{(6)^{1.4-1}} = 1364.1 \text{ K}$$

$$p_4 = \frac{p_3}{\left(\frac{v_4}{v_3}\right)^{k}} = \frac{5719.8}{(6)^{1.4}} = 465.6 \text{ kPa}$$

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

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

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

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

$$\Rightarrow q_{\text{in}} = (1.005)(2793.3 - 931.1);$$

$$\Rightarrow q_{\text{in}} = 1871.5 \ \frac{\text{kJ}}{\text{kg}}$$

Process 4-1:

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

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

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

$$\Rightarrow q_{\text{out}} = (0.717)(1364.1 - 293);$$

$$\Rightarrow q_{\text{out}} = 768 \ \frac{\text{kJ}}{\text{kg}}$$

The net work, efficiency, and MEP on a per mass basis

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

$$\Rightarrow w_{\text{net}} = 1871.5 - 768;$$

$$\Rightarrow w_{\text{net}} = 1103.5 \ \frac{\text{kJ}}{\text{kg}}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}};$$

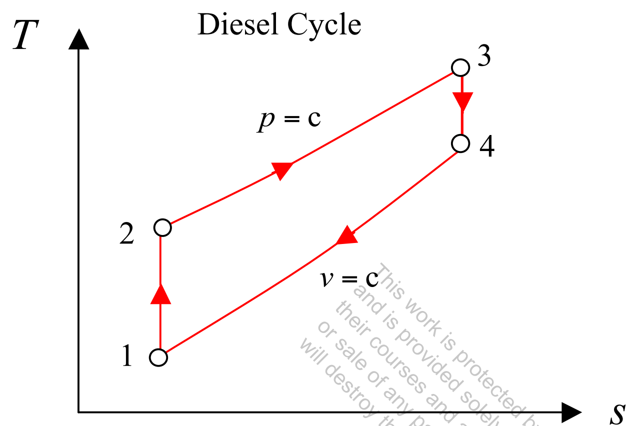
$$\Rightarrow \eta_{\text{th}} = \frac{1103.5}{1871.5};$$

$$\Rightarrow \eta_{\text{th}} = 59\%$$

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.

7-4-10 [OLJ] An ideal diesel engine has a compression ratio of 20 and uses nitrogen gas as working fluid. The state of nitrogen gas at the beginning of the compression process is 95 kPa and 20°C. If the maximum temperature in the cycle is not to exceed 2200 K, determine (a) the thermal efficiency and (b) the mean effective pressure. Use the PG model for nitrogen. (c) What-if Scenario: What would the efficiency and MEP be if carbon-dioxide were used as the working substance?

SOLUTION



Given:

$$c_v = 0.743 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

$$c_p = 1.039 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

$$R = 0.297 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

$$k = 1.404$$

State-1 (given p_1, T_1)

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

$$T_2 = T_1 r^{k-1} = (293)(20)^{1.404-1} = 982.8 \text{ K}$$

$$p_2 = p_1 r^k = (95)(20)^{1.404} = 6373.4 \text{ kPa}$$

State-3 (given $p_3 = p_2, T_3$):

$$r_c = \frac{v_3}{v_2} = \frac{T_3}{T_2} = \frac{2200}{982.8} = 2.23$$

State-4 (given $s_4 = s_1$):

$$\frac{v_4}{v_3} = \frac{v_4}{v_2}\frac{v_2}{v_3} = \frac{r}{r_c} = \frac{20}{2.23} = 8.97$$

$$T_4 = \frac{T_3}{\left(\dfrac{v_4}{v_3}\right)^{k-1}} = \frac{2200}{(8.97)^{1.404-1}} = 906.8\ \text{K}$$

$$p_4 = \frac{p_3}{\left(\dfrac{v_4}{v_3}\right)^{k}} = \frac{6373.4}{(8.97)^{1.404}} = 292.9\ \text{kPa}$$

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

Process 2-3:

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

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

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

$$\Rightarrow q_{\text{in}} = (1.039)(2200 - 982.8);$$

$$\Rightarrow q_{\text{in}} = 1264.7\ \frac{\text{kJ}}{\text{kg}}$$

Process 4-1:

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

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

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

$$\Rightarrow q_{\text{out}} = (0.743)(906.8 - 293);$$

$$\Rightarrow q_{\text{out}} = 456.1\ \frac{\text{kJ}}{\text{kg}}$$

Therefore, the net work, efficiency and MEP can be calculated as

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

$$\Rightarrow w_{\text{net}} = 1264.7 - 456.1;$$

$$\Rightarrow w_{\text{net}} = 808.6$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}};$$

$$\Rightarrow \eta_{\text{th}} = \frac{808.6}{1264.7};$$

$$\Rightarrow \eta_{\text{th}} = 64\%$$

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

$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}}{v_2\left(r-1\right)};$$

$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}\,p_2}{\left(r-1\right)RT_2};$$

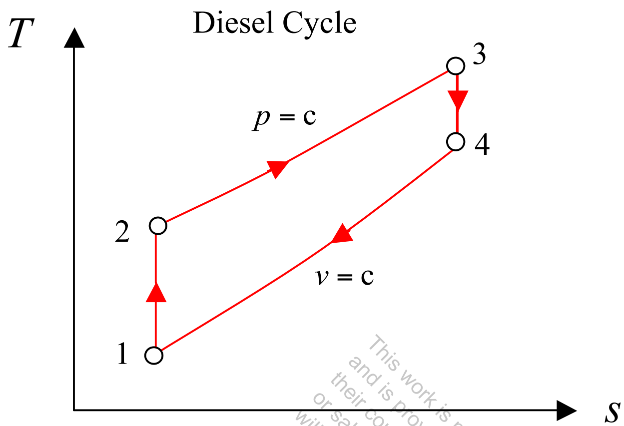
$$\Rightarrow \text{MEP} = \frac{\left(808.6\right)\left(6373.4\right)}{\left(19\right)\left(0.297\right)\left(982.8\right)};$$

$$\Rightarrow \text{MEP} = 929.2 \text{ kPa}$$

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.

7-4-11 [OLD] An ideal diesel engine has a compression ratio of 22 and uses air as working fluid. The state of air at the beginning of the compression process is 95 kPa and 22°C. If the maximum temperature in the cycle is not exceed 1900°C, determine (a) the thermal efficiency and (b) the mean effective pressure. Use the PG model.

SOLUTION



Given:

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

$$c_p = 1.005 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

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

$$k = 1.4$$

State-1 (given p_1, T_1)

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

$$T_2 = T_1 r^{k-1} = (295)(22)^{1.4-1} = 1015.7 \text{ K}$$

$$p_2 = p_1 r^k = (95)(22)^{1.4} = 7196.4 \text{ kPa}$$

State-3 (given $p_3 = p_2, T_3$):

$$r_c = \frac{v_3}{v_2} = \frac{T_3}{T_2} = \frac{2173}{1015.7} = 2.14$$

State-4 (given $s_4 = s_1$):

$$\frac{v_4}{v_3} = \frac{v_4}{v_2}\frac{v_2}{v_3} = \frac{r}{r_c} = \frac{22}{2.14} = 10.3$$

$$T_4 = \frac{T_3}{\left(\frac{v_4}{v_3}\right)^{k-1}} = \frac{2173}{(10.3)^{1.4-1}} = 854.9 \text{ K}$$

$$p_4 = \frac{p_3}{\left(\frac{v_4}{v_3}\right)^{k}} = \frac{7196.4}{(10.3)^{1.4}} = 274.9 \text{ kPa}$$

An energy analysis for the heat addition and rejection processes yields

Process 2-3:

$$q_{\text{in}} = q_{23};$$
$$\Rightarrow q_{\text{in}} = u_3 - u_2;$$
$$\Rightarrow q_{\text{in}} = c_p\left(T_3 - T_2\right);$$
$$\Rightarrow q_{\text{in}} = (1.005)(2173 - 1015.7);$$
$$\Rightarrow q_{\text{in}} = 1163.1 \ \frac{\text{kJ}}{\text{kg}}$$

Process 4-1:

$$q_{\text{out}} = -q_{41};$$
$$\Rightarrow q_{\text{out}} = u_4 - u_1;$$
$$\Rightarrow q_{\text{out}} = c_v\left(T_4 - T_1\right);$$
$$\Rightarrow q_{\text{out}} = (0.717)(854.9 - 295);$$
$$\Rightarrow q_{\text{out}} = 401.4 \ \frac{\text{kJ}}{\text{kg}}$$

Therefore, the net work, efficiency and MEP on a per mass basis can be calculated as

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}};$$
$$\Rightarrow w_{\text{net}} = 1163.1 - 401.4;$$
$$\Rightarrow w_{\text{net}} = 761.1 \ \frac{\text{kJ}}{\text{kg}}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}};$$
$$\Rightarrow \eta_{\text{th}} = \frac{761.1}{1163.1};$$
$$\Rightarrow \eta_{\text{th}} = 65.4\%$$

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

$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}}{v_2\left(r-1\right)};$$

$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}\,p_2}{\left(r-1\right)RT_2};$$

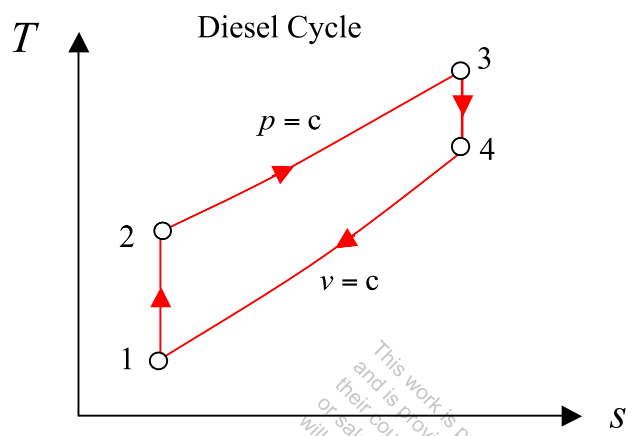
$$\Rightarrow \text{MEP} = \frac{\left(761.1\right)\left(7196.4\right)}{\left(21\right)\left(0.287\right)\left(1015.7\right)};$$

$$\Rightarrow \text{MEP} = 894.7 \text{ kPa}$$

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.

7-4-12 [OLM] At the beginning of the compression process of the standard Diesel cycle, air is at 100 kPa and 298 K. If the maximum pressure and temperature during the cycle are 7 MPa and 2100 K, determine (a) the compression ratio, (b) the cutoff ratio, (c) the thermal efficiency, and (d) the mean effective pressure.

SOLUTION



Given:

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

$$c_p = 1.005 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

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

$$k = 1.4$$

State-1 (given p_1, T_1)

State-2 (given $p_2 = p_3, s_2 = s_1$):

$$r = \left(\frac{p_2}{p_1}\right)^{\frac{1}{k}} = \left(\frac{7000}{100}\right)^{\frac{1}{1.4}} = 20.8$$

$$T_2 = T_1 r^{k-1} = (298)(20.8)^{1.4-1} = 1003.3 \text{ K}$$

State-3 (given p_3, T_3):

$$r_c = \frac{v_3}{v_2} = \frac{T_3}{T_2} = \frac{2100}{1003.3} = 2.09$$

State-4 (given $s_4 = s_1$):

$$\frac{v_4}{v_3} = \frac{v_4}{v_2}\frac{v_2}{v_3} = \frac{r}{r_c} = \frac{20.8}{2.09} = 9.95$$

$$T_4 = \frac{T_3}{\left(\frac{v_4}{v_3}\right)^{k-1}} = \frac{2100}{(9.95)^{1.4-1}} = 837.7 \text{ K}$$

$$p_4 = \frac{p_3}{\left(\frac{v_4}{v_3}\right)^{k}} = \frac{7000}{(9.95)^{1.4}} = 280.6 \text{ kPa}$$

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

$$q_{\text{in}} = q_{23};$$
$$\Rightarrow q_{\text{in}} = u_3 - u_2;$$
$$\Rightarrow q_{\text{in}} = c_p\left(T_3 - T_2\right);$$
$$\Rightarrow q_{\text{in}} = (1.005)(2100 - 1003.3);$$
$$\Rightarrow q_{\text{in}} = 1102.2\ \frac{\text{kJ}}{\text{kg}}$$

Process 4-1:

$$q_{\text{out}} = -q_{41};$$
$$\Rightarrow q_{\text{out}} = u_4 - u_1;$$
$$\Rightarrow q_{\text{out}} = c_v\left(T_4 - T_1\right);$$
$$\Rightarrow q_{\text{out}} = (0.717)(837.7 - 298);$$
$$\Rightarrow q_{\text{out}} = 386.9\ \frac{\text{kJ}}{\text{kg}}$$

Therefore, the net work, efficiency and MEP on a per mass basis can be calculated as

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}};$$
$$\Rightarrow w_{\text{net}} = 1102.2 - 386.9;$$
$$\Rightarrow w_{\text{net}} = 715.3\ \frac{\text{kJ}}{\text{kg}}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}};$$
$$\Rightarrow \eta_{\text{th}} = \frac{715.3}{1102.2};$$
$$\Rightarrow \eta_{\text{th}} = 64.9\%$$

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

$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}}{v_2\left(r-1\right)};$$

$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}\,p_2}{\left(r-1\right)RT_2};$$

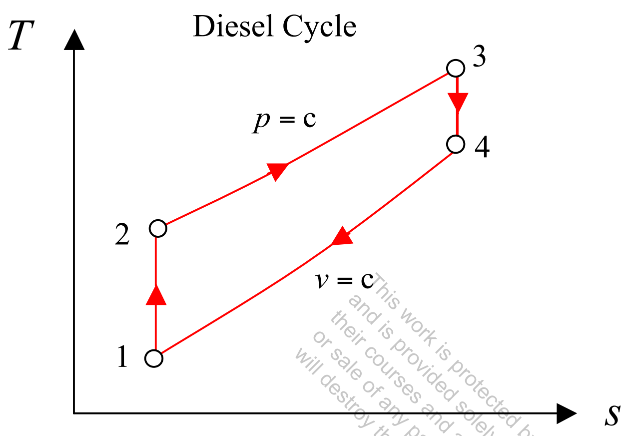
$$\Rightarrow \text{MEP} = \frac{\left(715.3\right)\left(7000\right)}{\left(19.8\right)\left(0.287\right)\left(1003.3\right)};$$

$$\Rightarrow \text{MEP} = 878.2 \text{ kPa}$$

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.

7-4-13 [OGO] A four cylinder 3-L (maximum volume per cylinder) diesel engine that operates on an ideal Diesel cycle has a compression ratio of 18 and a cutoff ratio of 3. Air is at 25°C and 95 kPa at the beginning of the compression process. Using the cold-air standard assumptions, determine (a) how much power the engine will deliver at 1700 rpm. (b) What-if Scenario: What would the power be if the engine speed decreased to 1500 rpm?

SOLUTION



Given:

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

$$c_p = 1.005 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

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

$$k = 1.4$$

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

$$m_1 = \frac{p_1 \cancel{V}_1}{RT_1} = \frac{(95)(3.0\times10^{-3})}{(0.287)(298)} = 3.33\times10^{-3} \text{ kg}$$

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

$$T_2 = T_1 r^{k-1} = (298)(18)^{1.4-1} = 946.95 \text{ K}$$

$$p_2 = p_1 r^k = (95)(18)^{1.4} = 5433.8 \text{ kPa}$$

State-3: (given $p_3 = p_2, r_c$):

$$T_3 = T_2 r_c = (946.95)(3) = 2840 \text{ K}$$

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

$$\frac{v_4}{v_3} = \frac{v_4}{v_2}\frac{v_2}{v_3} = \frac{r}{r_c} = \frac{18}{3} = 6$$

$$T_4 = \frac{T_3}{\left(\frac{v_4}{v_3}\right)^{k-1}} = \frac{2840}{(6)^{1.4-1}} = 1387 \text{ K}$$

$$p_4 = \frac{p_3}{\left(\frac{v_4}{v_3}\right)^{k}} = \frac{5433.8}{(6)^{1.4}} = 442.3 \text{ kPa}$$

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

$$Q_{\text{in}} = Q_{23};$$
$$\Rightarrow Q_{\text{in}} = m(u_3 - u_2);$$
$$\Rightarrow Q_{\text{in}} = mc_p(T_3 - T_2);$$
$$\Rightarrow Q_{\text{in}} = (3.33\times10^{-3})(1.005)(2840 - 946.95);$$
$$\Rightarrow Q_{\text{in}} = 6.33 \text{ kJ}$$

Process 4-1:

$$Q_{\text{out}} = -Q_{41};$$
$$\Rightarrow Q_{\text{out}} = m(u_4 - u_1);$$
$$\Rightarrow Q_{\text{out}} = mc_v(T_4 - T_1);$$
$$\Rightarrow Q_{\text{out}} = (3.33\times10^{-3})(0.717)(1386.9 - 298);$$
$$\Rightarrow Q_{\text{out}} = 2.60 \text{ kJ}$$

Therefore, the net work and power are calculated as

$$W_{\text{net}} = Q_{\text{in}} - Q_{\text{out}};$$
$$\Rightarrow W_{\text{net}} = 6.33 - 2.6;$$
$$\Rightarrow W_{\text{net}} = 3.73 \text{ kJ}$$

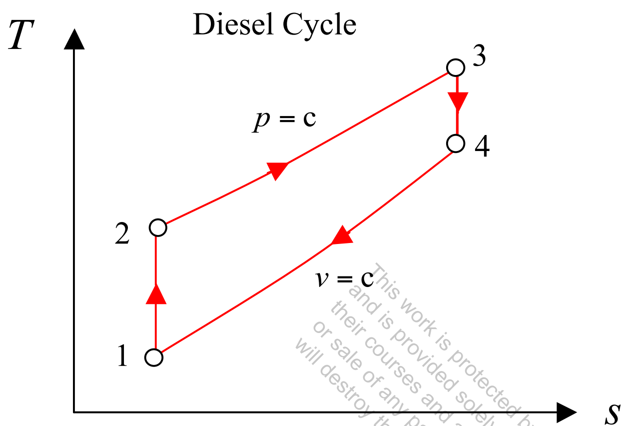
The engine power developed by the 4 cylinders is

$$\dot{W}_{\text{net,total}} = n_C \frac{N}{2} W_{\text{net}};$$
$$\Rightarrow \dot{W}_{\text{net,total}} = (4)\frac{(1700)}{(2)(60)}(3.73);$$
$$\Rightarrow \dot{W}_{\text{net,total}} = 211.4 \text{ kW}$$

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.

7-4-14 [OLW] A diesel engine operates at 3000 rpm on a standard Diesel cycle has a compression ratio of 14. The state of air at the beginning of the compression process is 98 kPa and 24°C. If the maximum temperature in the cycle is not exceed 1700°C, determine (a) the thermal efficiency and (b) the specific fuel consumption. Assume diesel fuel has a heating value of 45 MJ/kg. Use the PG model. (c) What-if Scenario: What would the answers be if the engine operates at 2500 rpm instead?

SOLUTION



Given:

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

$$c_p = 1.005 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

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

$$k = 1.4$$

State-1 (given p_1, T_1)

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

$$T_2 = T_1 r^{k-1} = (297)(14)^{1.4-1} = 853.5 \text{ K}$$

$$p_2 = p_1 r^k = (98)(14)^{1.4} = 3942.8 \text{ kPa}$$

State-3 (given $p_3 = p_2, T_3$):

$$r_c = \frac{v_3}{v_2} = \frac{T_3}{T_2} = \frac{1973}{853.5} = 2.31$$

State-4 (given $s_4 = s_1$):

$$\frac{v_4}{v_3} = \frac{v_4}{v_2}\frac{v_2}{v_3} = \frac{r}{r_c} = \frac{14}{2.31} = 6.06$$

$$T_4 = \frac{T_3}{\left(\frac{v_4}{v_3}\right)^{k-1}} = \frac{1973}{(6.06)^{1.4-1}} = 959.7\text{ K}$$

$$p_4 = \frac{p_3}{\left(\frac{v_4}{v_3}\right)^{k}} = \frac{3942.6}{(6.06)^{1.4}} = 316.5\text{ kPa}$$

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

$$q_{\text{in}} = q_{23};$$
$$\Rightarrow q_{\text{in}} = u_3 - u_2;$$
$$\Rightarrow q_{\text{in}} = c_p\left(T_3 - T_2\right);$$
$$\Rightarrow q_{\text{in}} = (1.005)(1973 - 853.5);$$
$$\Rightarrow q_{\text{in}} = 1125.1\ \frac{\text{kJ}}{\text{kg}}$$

Process 4-1:

$$q_{\text{out}} = -q_{41};$$
$$\Rightarrow q_{\text{out}} = u_4 - u_1;$$
$$\Rightarrow q_{\text{out}} = c_v\left(T_4 - T_1\right);$$
$$\Rightarrow q_{\text{out}} = (0.717)(959.7 - 297);$$
$$\Rightarrow q_{\text{out}} = 475.2\ \frac{\text{kJ}}{\text{kg}}$$

Therefore, the net work, efficiency and MEP on a per mass basis can be calculated as

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}};$$
$$\Rightarrow w_{\text{net}} = 1125.1 - 475.2 = 649.9\ \frac{\text{kJ}}{\text{kg}}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{649.9}{1125.1} = 57.8\%$$

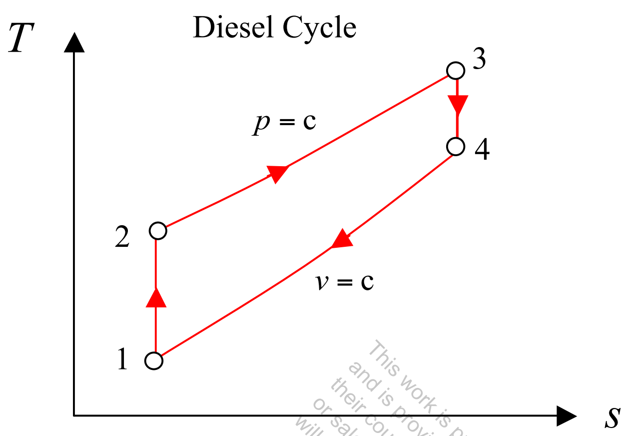
$$\text{sfc} = \frac{1}{\eta_{\text{th}} q_{\text{comb}}} = \frac{1}{(0.578)(45000)} = 38.44 \times 10^{-6}\ \frac{\text{kg}}{\text{kJ}}$$

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.

7-4-15 [OGR] An air standard Diesel cycle has a compression ratio of 19, and heat transfer to the working fluid per cycle is 2000 kJ/kg. At the beginning of the compression process the pressure is 105 kPa and the temperature is 20°C. Determine (a) the net work (w_{net}) per unit mass, (b) the thermal efficiency and (c) the mean effective pressure.

SOLUTION



Given:

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

$$c_p = 1.005 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

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

$$k = 1.4$$

State-1 (given p_1, T_1)

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

$$T_2 = T_1 r^{k-1} = (293)(19)^{1.4-1} = 951.4 \text{ K}$$

$$p_2 = p_1 r^k = (105)(19)^{1.4} = 6478 \text{ kPa}$$

State-3 (given $p_3 = p_2, q_{\text{in}}$):

$$T_3 = T_2 + \frac{q_{\text{in}}}{c_p} = 951.4 + \frac{2000}{1.005} = 2941.4 \text{ K}$$

$$r_c = \frac{v_3}{v_2} = \frac{T_3}{T_2} = \frac{2941.4}{951.4} = 3.09$$

State-4 (given $s_4 = s_1$):

$$\frac{v_4}{v_3} = \frac{v_4}{v_2}\frac{v_2}{v_3} = \frac{r}{r_c} = \frac{19}{3.09} = 6.1$$

$$T_4 = \frac{T_3}{\left(\frac{v_4}{v_3}\right)^{k-1}} = \frac{2941.4}{(6.1)^{1.4-1}} = 1427\ \text{K}$$

$$p_4 = \frac{p_3}{\left(\frac{v_4}{v_3}\right)^{k}} = \frac{6478}{(6.1)^{1.4}} = 515.2\ \text{kPa}$$

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

$$q_{\text{out}} = -q_{41};$$
$$\Rightarrow q_{\text{out}} = u_4 - u_1;$$
$$\Rightarrow q_{\text{out}} = c_v\left(T_4 - T_1\right);$$
$$\Rightarrow q_{\text{out}} = (0.717)(1427 - 293);$$
$$\Rightarrow q_{\text{out}} = 813\ \text{kJ}$$

Therefore, the net work, efficiency and MEP can be calculated as

$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}};$$
$$\Rightarrow w_{\text{net}} = 2000 - 813;$$
$$\Rightarrow w_{\text{net}} = 1187\ \frac{\text{kJ}}{\text{kg}}$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}};$$
$$\Rightarrow \eta_{\text{th}} = \frac{1187}{2000};$$
$$\Rightarrow \eta_{\text{th}} = 59.4\%$$

$$\text{MEP} = \frac{w_{\text{net}}}{v_1 - v_2};$$
$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}}{v_2(r-1)};$$
$$\Rightarrow \text{MEP} = \frac{w_{\text{net}}\,p_2}{(r-1)RT_2};$$
$$\Rightarrow \text{MEP} = \frac{(1187)(6478)}{(18)(0.287)(951.4)};$$
$$\Rightarrow \text{MEP} = 1564.5\ \text{kPa}$$

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.