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Homework 1.3

Problem 9-33

In ideal Otto cycle has a compression ratio of 8. At the beginning of the compression process, air is at 95 kPa and 27°C, and 750 kJ/kg of heat is transferred to air during the constant-volume heat-addition process. Taking into account the variation of specific heats with temperature, determine;

- (a) the pressure and temperature 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.

Given:

- Ratio = 8
- $P_1 = 95 \text{ kPa}$
- $T_1 = 27^\circ\text{C} = 300.15 \text{ K}$
- $Q_{in} = 750 \text{ kJ/kg}$
- Use Textbook Appendix to find specific volume and the internal energy at State 1:
 - $U_1 = 214.07 \text{ kJ/kg}$
 - $r_1 = 621.2$
 - $R = 0.287$
- Use Textbook Appendix and Linear Interpolation to find the Temperature and the internal energy at State 2:
 - $T_2 = 673 \text{ K}$
 - $U_2 = 491.2 \text{ kJ/kg}$
- Use Textbook Appendix and Linear Interpolation to find the Temperature and the specific volume at State 3:
 - $T_3 = 1539 \text{ K}$
 - $r_3 = 6.59$

To Find Specific Volume at State 2:

Use:

- $r_2 = r_1 / \text{Ratio}$
- $r_2 = 621.2 / 8$
- $r_2 = 77.65$

To Find the Pressure at State 2:

Use:

- $P_2 = P_1 * \text{Ratio} * (T_2 / T_1)$
- $P_2 = 95 * 8 * (673 / 300.15)$
- $P_2 = 1704.1 \text{ kPa}$

To Find the Internal Energy at State 3

Use:

- $U_3 = U_2 + Q_{\text{in}}$
- $U_3 = 491.2 + 750$
- $U_3 = 1241.2 \text{ kJ/kg}$

To Find the Pressure at State 3 (Part (a)):

Use:

- $P_3 = P_2 * (T_3 / T_2)$
- $P_3 = 1704.1 * (1539 / 673)$
- $P_3 = 3896.9 \text{ kPa}$

To Find the Specific Volume at State 4:

Use:

- $r_4 = \text{Ratio} * r_3$
- $r_4 = 8 * 6.59$
- $r_4 = 52.72$

To Find the Net Work Output between States 4 and State 1 (Part (b)):

Use:

- $W = Q_{\text{in}} - Q_{\text{out}}$

Or

- $W = Q_{in} - (U_4 - U_1)$
- $W = 750 - (571.74 - 214.07)$
- $W = 392.33 \text{ kJ/kg}$

To Find the Thermal Efficiency (Part (c)):

Use:

- $\eta = W / Q_{in}$
- $\eta = 392.33 / 750$
- $\eta = 0.52$

To Find the Mean Effective Pressure (MEP) (Part (d)):

Use:

- $MEP = W / (a_1 - a_2)$

Or

- $MEP = W / (a_1 * (1 - (1 / r)))$

Or

- $MEP = r * W * (P_1 / (R * T_1 * (r - 1)))$
- $MEP = 8 * 392.33 * (95 / (0.287 * 300.15 * (8-1)))$
- $MEP = 495 \text{ kPa}$

Problem 9-36

A six-cylinder, four-stroke, spark-ignition engine operating on the ideal Otto cycle takes in air at 14 psia and 105°F, and is limited to a maximum cycle temperature of 2400°F. Each cylinder has a bore of 3.5 in, and each piston has a stroke of 3.9 in. The minimum enclosed volume is 9.8 percent of the maximum enclosed volume. How much power will this engine produce when operated at 2500 rpm? Use constant specific heats at room temperature.

Given:

- #Cylinders = 4
- $P_1 = 14 \text{ psia}$
- $T_1 = 105^\circ\text{F} = 565 \text{ R}$
- $T_3 = 2400^\circ\text{F} = 2860 \text{ R}$
- $B = 3.5 \text{ in} = 0.291 \text{ ft}$

- $S = 3.9 \text{ in} = 0.325 \text{ ft}$
- $V_{\text{Min}} = 9.8\% = 0.098$
- $\text{RPM} = 2500$
- Use Textbook Appendix to find Air Properties at Room Temperature:
 - $R = 0.3704$
 - $r = 1.4$
 - $C_u = 0.171$

To Find Internal Energy between State 1 and 2

Use:

- $U_1 = (R * T_1) / P_1$
- $U_1 = (0.3704 * 565) / 14$
- $U_1 = 14.95 \text{ ft}^3 / \text{lbm}$

To Find Internal Energy between State 2 and 3

Use:

- $U_2 = V_{\text{Min}} * U_1$
- $U_2 = 0.098 * 14.95$
- $U_2 = 1.47 \text{ ft}^3 / \text{lbm}$

To Find Temperature at State 2:

Use:

- $T_2 = T_1 * (U_1 / U_2)^{(r-1)}$
- $T_2 = 565 * (14.95 / 1.47)^{(1.4 - 1)}$
- $T_2 = 1428.8 \text{ R}$

To Find the Pressure at State 2:

Use:

- $P_2 = (R * T_2) / U_2$
- $P_2 = (0.3704 * 1428.8) / 1.47$
- $P_2 = 360 \text{ psia}$

To Find the Work in State 1:

Use:

- $W_1 = C_u * (T_1 - T_2)$
- $W_1 = 0.171 * (565 - 1428.8)$
- $W_1 = -147.7 \text{ Btu} / \text{lbm}$

To Find Heat Transfer in State 1:

Use:

- $Q_1 = C_u * (T_3 - T_2)$
- $Q_1 = 0.171 * (2860 - 1428.8)$
- $Q_1 = 244.74 \text{ Btu / lbm}$

To Find the Pressure at State 3:

Use:

- $P_3 = (R * T_3) / U_2$
- $P_3 = (0.3704 * 2860) / 1.47$
- $P_3 = 720.64$

To Find the Temperature at State 4:

Use:

- $T_4 = T_3 * V_{\text{Min}}^{(r-1)}$
- $T_4 = 2860 * 0.098^{(1.4-1)}$
- $T_4 = 1129.42 \text{ R}$

To Find the Pressure at State 4:

Use:

- $P_4 = (R * T_4) / U_1$
- $P_4 = (0.3704 * 1129.42) / 14.95$
- $P_4 = 27.98 \text{ psia}$

To Find the Work at State 3:

Use:

- $W_3 = C_u * (T_3 - T_4)$
- $W_3 = 0.171 * (2860 - 1129.42)$
- $W_3 = 295.93 \text{ Btu / lbm}$

To Find the Net Work when the System Resets (State 4 - 1):

Use:

- $W_{\text{Net}} = W_1 + W_3$
- $W_{\text{Net}} = -147.7 + 295.93$
- $W_{\text{Net}} = 148.23 \text{ Btu / lbm}$

To Find the Mass Occupied by the Four Cylinders:

Use:

- $M = \text{Volume}_{\text{Displaced}} / (U_1 * \# \text{Cylinders})$
- $M = (6 * ((3.14) * B^2 * S)) / (U_1 * 4)$
- $M = (6 * (3.14) * 0.291^2 * 0.325)) / (14.95 * 4)$
- $M = 0.0087 \text{ lbm}$

To Find the Work per Cycle:

Use:

- $W_{\text{Cycle}} = W_{\text{Net}} * M$
- $W_{\text{Cycle}} = 148.23 * 0.0087$
- $W_{\text{Cycle}} = 1.29 \text{ Btu}$

To Find the Power Produced:

Use:

- $\text{Power} = (W_{\text{Cycle}} * \text{RPM}) / (2 * 60)$
- $\text{Power} = (1.29 * 2500) / (2 * 60)$
- **$\text{Power} = 26.88 \text{ HP}$**

Problem 9-46

An air-standard Diesel cycle has a compression ratio of 16 and a cutoff ratio of 2. At the beginning of the compression process, air is at 95 kPa and 27°C. Accounting for the variation of specific heats with temperature, determine

- (a) the temperature after the heat-addition process
- (b) the thermal efficiency, and
- (c) the mean effective pressure

Given:

- Ratio = 16
- Cut off Ratio (R_{Cut}) = 2
- $P_1 = 95 \text{ kPa}$
- $T_1 = 27^\circ\text{C} = 300.15 \text{ K}$
- Use Textbook Appendix to find Air Properties:
 - $U_1 = 214.07 \text{ kJ/kg}$
 - $V_{r1} = 621.2$
- Use Textbook Appendix to find Air Properties:
 - $T_2 = 862.4 \text{ K}$
 - $h_2 = 890.9 \text{ kJ/kg}$
- Use Textbook Appendix to find Air Properties:
 - $h_3 = 1910.6 \text{ kJ/kg}$
 - $V_{r3} = 4.55$
- Use Textbook Appendix to find Air Properties:
 - $U_4 = 659.7 \text{ kJ/kg}$
- Use Textbook Appendix to find Air Properties:
 - $R = 0.287 \text{ kJ/kg}\cdot\text{K}$

To Find V_{r2} :

Use:

- $V_{r2} = V_{r1} / \text{Ratio}$
- $V_{r2} = 621.2 / 16$
- $V_{r2} = 38.83$

To Find the Temperature at State 3 (Part (a)):

Use:

- $T_3 = R_{\text{Cut}} * T_2$
- $T_3 = 2 * 862.4$
- $T_3 = 1724.8 \text{ K}$

To Find V_{r4} :

Use:

- $V_{R4} = (\text{Ratio} / R_{\text{Cut}}) * V_{r3}$
- $V_{R4} = (16 / 2) * 4.55$
- $V_{R4} = 36.4$

To Find the Heat Added to the System:

Use:

- $Q_{in} = h_3 - h_2$
- $Q_{in} = 1910.6 - 890.9$
- $Q_{in} = 1019.7 \text{ kJ/kg}$

To Find the Heat Lost by the System:

Use:

- $Q_{Out} = U_4 - U_1$
- $Q_{Out} = 659.7 - 214.07$
- $Q_{Out} = 445.63 \text{ kJ/kg}$

To Find the Thermal Efficiency (Part (b)):

Use:

- $N = 1 - (Q_{Out} / Q_{in})$
- $N = 1 - (445.63 / 1019.7)$
- $N = 0.563 = 56.3\%$

To Find the Net Work:

Use:

- $W_{Net} = Q_{in} - Q_{Out}$
- $W_{Net} = 1019.7 - 445.63$
- $W_{Net} = 574.07$

To Find the Specific Volume at State 1:

Use:

- $V_1 = R * (T_1 / P_1)$
- $V_1 = 0.287 * (300.15 / 95)$
- $V_1 = 0.907 \text{ m}^3 / \text{kg}$

To Find the Mean Effective Pressure (MEP) (Part (c)):

Use:

- $MEP = W_{Net} / (V_1 * (1 - (1 / \text{Ratio})))$
- $MEP = 574.07 / (0.907 * (1 - (1/16)))$
- $MEP = 675.13 \text{ kPa}$

Problem 9-57

A four-cylinder two-stroke 2.4-L diesel engine that operates on an ideal Diesel cycle has a compression ratio of 22 and a cutoff ratio of 1.8. Air is at 70°C and 97 kPa at the beginning of the compression process. Using the cold-air- standard assumptions, determine how much power the engine will deliver at 3500 rpm

Given:

- $V = 2.4 \text{ L}$
- Ratio = 22
- Cutoff Ratio (R_{cut}) = 1.8
- $T_1 = 70^\circ\text{C} = 343.15 \text{ K}$
- $P_1 = 97 \text{ kPa}$
- Speed (S) = 3500 RPM
- Use Textbook Appendix to find Air Properties:
 - $R = 0.287 \text{ kJ/kg}\cdot\text{K}$
 - $C_v = 0.718$
 - $C_p = 1.005$
 - $k = 1.4$

To Find the Temperature at State 2:

Use:

- $T_2 = T_1 * r^{(k-1)}$
- $T_2 = 343.15 * 22^{(1.4 - 1)}$
- $T_2 = 1181.55 \text{ K}$

To Find the Temperature at State 3:

Use:

- $T_3 = T_2 * R_{\text{cut}}$
- $T_3 = 1181.55 * 1.8$
- $T_3 = 2126.79 \text{ K}$

To Find the Temperature at State 4:

Use:

- $T_4 = T_3 * (R_{\text{cut}} / R)^{(k-1)}$
- $T_4 = 2126.79 * (1.8 / 22)^{(1.4-1)}$
- $T_4 = 781.38 \text{ K}$

To Find the Heat Added to the System Between States 2 and 3:

Use:

- $Q_{in} = ((P_1 * V) / R) * C_p * \text{Ratio}^{(k-1)} * (R_{cut} - 1)$
- $Q_{in} = ((97 * 2.4) / 0.287) * 1.005 * 22^{(1.4-1)} * (1.8 - 1)$
- $Q_{in} = 2245.57 \text{ kJ/kg}$

To Find the Heat Lost by the System Between States 4 and 1:

Use:

- $Q_{Loss} = ((P_1 * V) / R) * C_v * R_{Cut}^{(k-1)}$
- $Q_{Loss} = ((97 * 2.4) / 0.287) * 0.718 * 1.8^{(1.4-1)}$
- $Q_{Loss} = 743.79 \text{ kJ/kg}$

To Find the Work of the Engine:

Use:

- $W = ((S * P_1 * V) / R) * (Q_{in} - Q_{Loss})$
- $W = ((3500 * 97 * 2.4) / 0.287) * (2245.57 - 743.79)$
- $W = 4.26 \text{ kW}$

Problem 9-59

An ideal dual cycle has a compression ratio of 15 and a cutoff ratio of 1.4. The pressure ratio during constant volume heat addition process is 1.1. The state of the air at the beginning of the compression is $P_1 = 14.2 \text{ psia}$ and $T_1 = 75^\circ\text{F}$. Calculate the cycle's net specific work, specific heat addition, and thermal efficiency. Use constant specific heats at room temperature

Given:

- Ratio = 15
- Cutoff Ratio (R_{Cut}) = 1.4
- Pressure Ratio ($R_{Pressure}$) = 1.1
- $P_1 = 14.2 \text{ psia}$
- $T_1 = 75^\circ\text{F} = 297 \text{ K}$
- Use Textbook Appendix to find Air Properties:
 - $C_v = 0.718$
 - $C_p = 1.005$

To Find the Temperature at State 2:

Use:

- $T_2 = (\text{Ratio}^{(R_{\text{Cut}} - 1 / R_{\text{Cut}})}) * T_1$
- $T_2 = (15^{(1.4 - 1 / 1.4)}) * 297$
- $T_2 = 643.85 \text{ K}$

To Find the Temperature at State 3:

Use:

- $T_3 = T_2 * R_{\text{Pressure}}$
- $T_3 = 643.85 * 1.1$
- $T_3 = 708.24 \text{ K}$

To Find the Temperature at State 4:

Use:

- $T_4 = T_3 * R_{\text{Cut}}$
- $T_4 = 708.24 * 1.4$
- $T_4 = 991.54 \text{ K}$

To Find the Pressure Ratio per Cycle (R_{cycle}):

Use:

- $R_{\text{cycle}} = \text{Ratio} / R_{\text{Cut}}$
- $R_{\text{cycle}} = 15 / 1.4$
- $R_{\text{cycle}} = 10.71$

To Find the Temperature at State 5:

Use:

- $T_5 = T_4 / (R_{\text{cycle}}^{(R_{\text{Cut}} - 1)})$
- $T_5 = 991.54 / (10.71^{(1.4 - 1)})$
- $T_5 = 384.1 \text{ K}$

To Find the Specific Volume Between States 2 and 3 (r_{2-3}):

Use:

- $r_{2-3} = C_v * (T_3 - T_2)$
- $r_{2-3} = 0.718 * (708.24 - 643.85)$
- $r_{2-3} = 46.23$

To Find the Specific Pressure Between States 3 and 4(p_{3-4}):

Use:

- $p_{3-4} = C_p * (T_4 - T_3)$
- $p_{3-4} = 1.005 * (991.54 - 708.24)$
- $p_{3-4} = 284.72$

To Find the Specific Volume Between States 5 and 1(r_{5-1}):

Use:

- $r_{5-1} = C_v * (T_5 - T_1)$
- $r_{5-1} = 0.718 * (384.1 - 297)$
- $r_{5-1} = 62.54$

To Find the Net Specific Work (Part (a))

Use:

- $W_{Net} = r_{2-3} + p_{2-3} - r_{5-1}$
- $W_{Net} = 46.23 + 284.72 - 62.54$
- $W_{Net} = 268.41 \text{ kJ / kg}$

To Find the Specific Heat Added to the System (r_{Heat}):

Use:

- $r_{Heat} = r_{2-3} + p_{2-3}$
- $r_{Heat} = 46.23 + 284.72$
- $r_{Heat} = 330.95 \text{ kJ/kg}$

To Find the Thermal Efficiency (Part (c)):

Use:

- $N = 1 - (1 / \text{Ratio})^{(R_{Cut} - 1)} * ((R_{Pressure} * R_{cut}^{R_{cut}} - 1) / ((R_{Pressure} - 1) + R_{Pressure} * R_{cut} * (R_{cut} - 1)))$
- $N = 1 - (1/15)^{(1.4-1)} * ((1.1 * 1.4^{1.4} - 1) / ((1.1 - 1) + 1.1 * 1.4 * (1.4 - 1)))$
- $N = 0.64 = 64\%$

Problem 9-80

A simple ideal Brayton cycle with air as the working fluid has a pressure ratio of 10. The air enters the compressor at 520 R and the turbine at 2000 R. Accounting for the variation of specific heats with temperature, determine:

- (a) the air temperature at the compressor exit
- (b) the back work ratio
- (c) the thermal efficiency

Given

- Ratio = 10
- T_1 (Compressor Entrance) = 520 R
- T_3 (Turbine Entrance) = 2000 R
- Use Textbook Appendix to find Air Properties:
 - $h_1 = 124.27$
 - $P_{r1} = 1.215$
- Use Textbook Appendix to find Air Properties:
 - $h_2 = 240.11$
- Use Textbook Appendix to find Air Properties:
 - $h_3 = 504.71$
 - $P_{r3} = 174.0$
- Use Textbook Appendix to find Air Properties:
 - $h_4 = 264.82$

To Find the Pressure from States 1 to 2:

Use:

- $P_{1-2} = \text{Ratio} * P_{r1}$
- $P_{1-2} = 10 * 1.215$
- $P_{1-2} = 12.15 \text{ Btu / lmb}$

To Find the Temperature at State 2 (Part (a)):

Use Textbook Appendix to find corresponding Air Properties:

- $h_2 = 240.1$
- $T_2 = 996.5 \text{ R}$

To Find the Pressure from States 3 to 4 (Turbine Exit):

Use:

- $P_{3-4} = P_{r3} / \text{Ratio}$
- $P_{3-4} = 174.0 / 10$
- $P_{3-4} = 17.4 \text{ Btu / lmb}$

To Find the Specific Work at the Compressor:

Use:

- $W_{\text{Compressor}} = h_2 - h_1$
- $W_{\text{Compressor}} = 240.11 - 124.17$
- $W_{\text{Compressor}} = 115.94$

To Find the Specific Work at the Turbine:

Use:

- $W_{\text{Turbine}} = h_3 - h_4$
- $W_{\text{Turbine}} = 504.71 - 264.82$
- $W_{\text{Turbine}} = 239.89$

To Find the Back Work Ratio (Part (b)):

Use:

- $BWR = W_{\text{Compressor}} / W_{\text{Turbine}}$
- $BWR = 115.94 / 239.89$
- $BWR = 0.483$

To Find the Thermal Efficiency (Part (c)):

Use:

- $N = (W_{\text{Turbine}} - W_{\text{Compressor}}) / (h_3 - h_2)$
- $N = (239.89 - 115.94) / (504.71 - 240.11)$
- $N = 0.468 = 46.8\%$