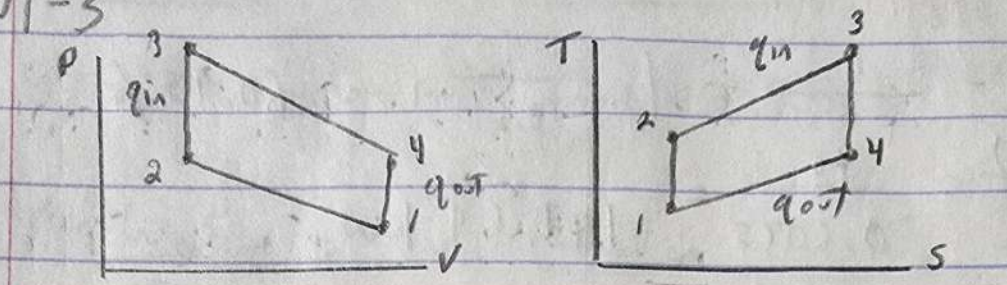
HW 1-3

9-33



(1) → (2) → (3) → (4)

P = 95 kPa P = 3818.03

T = 300 K T = 1538.696

$U_1 = 214.07$ kJ/kg $V_{r_1} = 621.2$

$\frac{V_1}{V_2} = \frac{V_{r_1}}{V_{r_2}}$ $\frac{1}{8} = \frac{621.2}{V_{r_2}}$ $V_{r_2} = \frac{621.2}{8} = 77.65$

$U_2 = 488.81 \text{ kJ/kg} + \frac{77.65 - 78.61}{75.50 - 78.61} \cdot (496.62 \frac{kJ}{kg} - 488.81 \frac{kJ}{kg})$

$U_2 = 491.22$ kJ/kg

$T_2 = 670K + \frac{77.65 - 78.61}{75.50 - 78.61} \cdot (680K - 670K) = 673.089K$

$q_{in} = U_3 - U_2 = 750 = U_3 - 491.22$ $U_3 = 1241.22$ kJ

$T_3 = 1520K + \frac{1241.22 - 1233.87 \text{ kJ/kg}}{1242.43 - 1223.87 \text{ kJ/kg}} \cdot (1540 - 1520K) =$

$T_3 = 1538.696K$

$V_{r_3} = 6.854 + \frac{1241.22 - 1223.87 \text{ kJ/kg}}{1242.43 - 1223.87 \text{ kJ/kg}} \cdot (6.569 - 6.854)$

$V_{r_3} = 6.588$

$V_{r_4} = 6.588 \cdot 8 = 52.704$

$U_4 = 560.61 + \frac{52.704 - 55.54}{51.69 - 55.54} \cdot (576.12 - 560.61 \text{ kJ/kg})$

$U_4 = 571.715$ kJ/kg

$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$ $P_2 = \frac{95 \cdot 673.089}{300} \cdot 8 = 1705.154$ kPa

a) $\frac{P_3}{T_3} = \frac{P_2}{T_2}$ $P_3 = \frac{1705.154 \cdot 1534.696\,K}{673.089} = 3898.03$ kPa

$T_3 = 1534.696$ K

$P_3 = 3898.03$ kPa

$q_{out} = u_4 - u_1 = 571.715 - 214.09 = 357.68$ kJ/kg

b) $w_{net} = q_{in} - q_{out} = 750 - 357.68 = 392.32$ kJ/kg

c) $\eta = \frac{w}{q_{in}} = \frac{392.32}{750} \cdot 100 = 52.31\%$

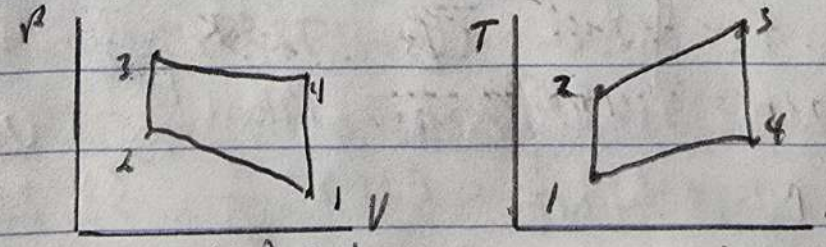
$P_1 V_1 = mRT_1$ $V_1 = \frac{0.287 \cdot 300}{95} = 0.906\ m^3/kg$

$V_2 = \frac{0.906}{8} = 0.11325\ m^3/kg$

d) MEP: $\frac{w}{V_1 - V_2} = \frac{392.32}{0.906 - 0.11325} = 494.815$ kPa

9-36 $c_p = 0.240$ BTU/lbm R $c_v = 0.171$ BTU/lbm R $T_1 = 565$ R

$T_3 = 2860$ R $k = 1.4$ $R = 0.06855$ BTU/lbm R



$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\frac{k-1}{k}} = 565\,k \cdot \frac{1}{0.098}^{\frac{(1.4-1)}{1.4}} = 1097.16\ R = T_2$

$\frac{T_3}{T_4} = \left(\frac{V_1}{V_2}\right)^{\frac{k-1}{k}}$ $T_4 = 2860K \cdot (0.098)^{\frac{1.4-1}{1.4}} = 1472.80K = t_4$

$q_{in} = c_v(T_3 - T_2)$ $0.171 \cdot (2860 - 1097.16) = 301.416$ BTU/lbm

$q_{out} = c_v(T_4 - T_1) = 0.171 \cdot (1472.80 - 565) = 155.234 \text{ BTU/lbm}$

$w_{net} = q_{in} - q_{out} = 301.446 - 155.234 = 146.212 \text{ BTU/lbm}$

$V_1 - V_2 = \frac{\pi}{4} D^2 L = V_1 - 0.098 = \frac{\pi}{4} \cdot (3.5\text{in})^2 \cdot 3.9\text{in}$

$V_1 = 41.6 \text{ in}^3$

$$m = \frac{P_1 V_1}{R T_1} = \frac{14 \cdot 41.6}{0.06855 \frac{\text{BTU}}{\text{lbm R}} \cdot \frac{778.169 \text{ lbf·ft}}{1 \text{ BTU}} \cdot \frac{12\text{in}}{1\text{ft}} \cdot 565 \text{ R}}$$

$m = 0.001603 \text{ lbm}$

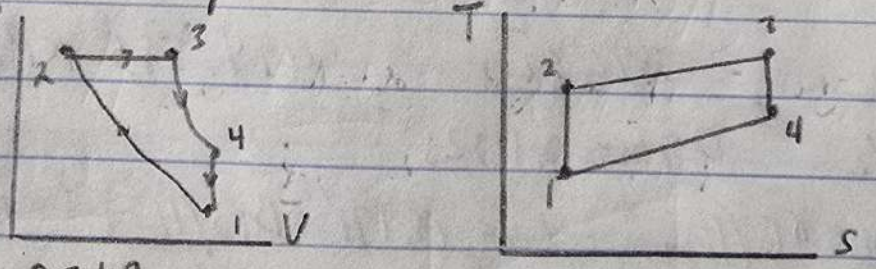
$W_{net} = m \cdot w_{net} = 0.001603 \text{ lbm} \cdot 146.212 \frac{\text{BTU}}{\text{lbm}}$

$W_{net} = 0.23545 \text{ BTU}$

$P = n W_{net} \frac{N}{2} = 6 \cdot 0.23545 \text{ BTU} \cdot \frac{1}{1} \cdot 2500 \text{ R/min} \cdot \frac{1 \text{ min}}{60 \text{ s}}$

$P = 41.624 \text{ hp}$

9-46



$P_1 = 95 \text{ kPa}$

$T_1 = 300\text{k}$ $T_2 = 862.4\text{k}$ $T_3 = 1725 \text{ K}$

$u_1 = 214.07 \text{ kJ/kg}$ $h_2 = 890.9 \text{ kJ/kg}$ $h_3 = 1910.6 \frac{\text{kJ}}{\text{kg}}$ $u_4 = 659.7 \frac{\text{kJ}}{\text{kg}}$

$V_{r1} = 621.2$ $V_{r2} = V_{r1} \cdot \frac{1}{r} = 621.2 \cdot \frac{1}{16} = 38.825$

a) $T_3 = r_c \cdot T_2 = 2 \cdot 862.4 = 1724.8 \text{ K}$

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

$V_{r4} = \frac{V_4}{V_3} \cdot V_{r3} = \frac{16}{2} \cdot 4.541 = 36.37$

$q_{out} = u_4 - u_1 = 659.7 - 214.7 = 445.7 \text{ kJ/kg}$

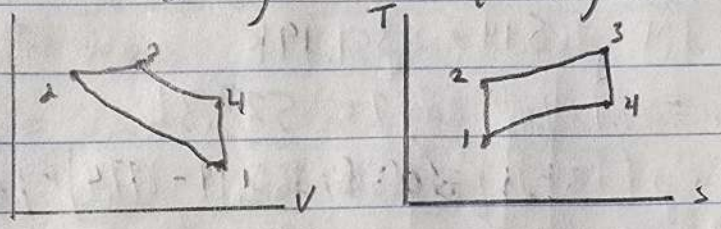
b) $\eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{445.63}{1019.7} = 0.563 = 56.3\%$

$w_{net} = q_{in} - q_{out} = 1019.7 - 445.63 = 574.07 \frac{kJ}{kg}$

$V_1 = \frac{RT_1}{P_1} = \frac{0.287 \cdot 300}{95} = 0.906 \ m^3/kg$

c) $MEP = \frac{w_{net}}{V_1 \cdot \left(1 - \frac{1}{r}\right)} = \frac{574.07}{0.906\left(1 - \frac{1}{16}\right)} = 675.9 \ kPa$

9-57



$r = 22 \quad T_1 = 343 \ K$

$r_c = 1.8 \quad P_1 = 97 \ kPa$

$k = 1.4$

$T_2 = T_1 \cdot r^{(k-1)} = 343 \cdot 22^{(1.4-1)} = 1176 \ K$

$T_3 = T_2 \cdot r_c = 1176 \cdot 1.8 = 2117 \ K$

$T_4 = T_3 \cdot \left(\frac{V_3}{V_4}\right)^{(k-1)} = 2117 \cdot \left(\frac{1.8}{22}\right)^{(1.4-1)} = 778 K$

$m = \frac{P_1 V_1}{RT_1} = \frac{97 \cdot 0.0006}{0.287 \cdot 343} = 0.000591 \ kg \text{ per cylinder}$

$m_{total} = 4 \cdot 0.000591 = 0.002364 \ kg \text{ per cycle}$

$Q_{in} = c_p (T_3 - T_2) = 1.005 (2117 - 1176) = 947.7 \ kJ/kg$

$Q_{out} = c_v (T_4 - T_1) = 0.718 (778 - 343) = 312.3 \ kJ/kg$

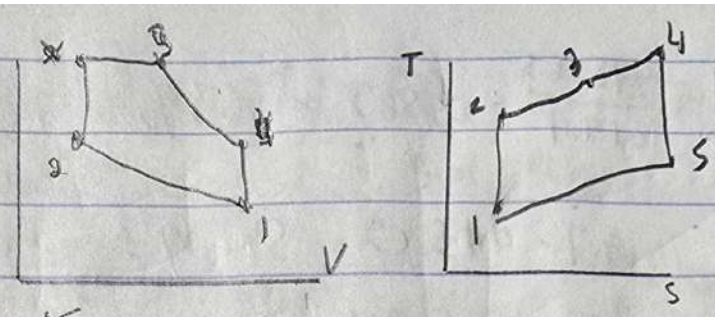
$w_{net} = Q_{in} - Q_{out} = 947.7 - 312.3 = 635$

$w_{cycle} = m_{total} \cdot w_{net} = 0.002364 \cdot 635.4 = 1.501 \ kJ \text{ per cycle}$

$\text{Cycle per sec} = \frac{3500}{60} = 58.333 \ Hz$

$P = 1.501 \cdot 58.333 = 87.6 \ kW$

9-59



$r = 15$

$r_c = 1.4$ $\quad T_2 = T_1 \cdot r^{(k-1)} = 297 \cdot 15^{1.4-1} = 877.4\,k$

$k = 1.4$ $\quad \alpha = \frac{P_x}{P_2} = 1.1 \quad T_x = \alpha \cdot T_2 = 1.1 \cdot 877.4 = 965.14k$

$T_3 = r_c \cdot T_2 = 1.4 \cdot 965.14 = 1351.19k$

$T_4 = \alpha \cdot r_c^{k} \cdot T_1 = 1.1 \cdot 1.4^{1.4} \cdot 297 = 523.3k$

$c_v (T_x - T_2) + c_p (T_3 - T_x) = 0.718(965.14 - 877.4) + 1.005(1351.19 - 965.14)$

Specific heat $= 450.97\ KJ/kg = 193.9\ BTU/lbm$

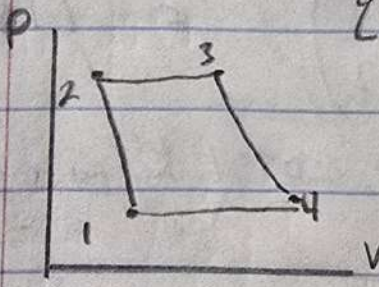
$W_{net} = 450.97 - c_v (T_4 - T_1)$

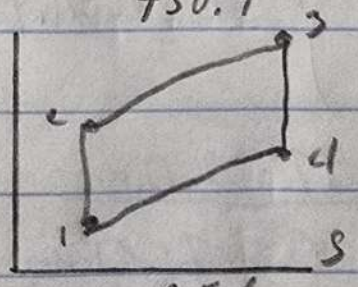
$450.97 - 0.718(523.4 - 297)$

$= 288.42\ KJ/KJ$ or $124\ Btu/lbm$

$\eta_{th} = \frac{W_{net}}{Q_{in}} = \frac{288.42}{450.9} = 0.639 \quad 64\%$

9-80





$T_1 = 520\,R$ $\quad h_1 = 124.27\ BTU/lbm$

$r_p = 10$ $\quad P_{r1} = 1.2147$

$P_{r2} = r_p \cdot P_{r1} = 10 \cdot 1.2147 = 12.147$

$\frac{12.147 - 11.93}{12.30 - 11.93} = \frac{T_2 - 980}{1000 - 980} = \frac{h_2 - 236.02}{240.98 - 236.02}$

$T_2 = 996.48\,R$

$h_2 = 240.100\ BTU/lbm$

$T_3 = 2000°R$ $h_3 = 504.71 \text{ BTU/lbm}$ $P_{r3} = 174$

$P_{r4} = \frac{P_{r3}}{r_p} = \frac{174}{10} = 17.4$

$\frac{17.40 - 16.28}{18.60 - 17.40} = \frac{h_4 - 260.97}{271.03 - 260.97} = \frac{T_4 - 1080}{1120 - 1080}$

$h_4 = 265.827 \text{ BTU/lbm}$ $T_4 = 1099.3 K$

b) $r_{bw} = \frac{W_{comp}}{W_{turb}} = \frac{h_2 - h_1}{h_3 - h_4} = \frac{240.108 - 124.27}{504.71 - 265.827} = 0.4847$ 48.47%

c) $\eta_{th} = \frac{W_{net}}{Q_{in}} = \frac{123.845}{264.602} = 0.465$ 46.5%