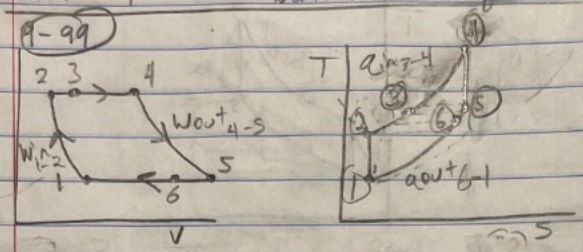
HW 1.4 Nathan Cherny's

9-99



constant cp/cv

$r_p = \frac{P_2}{P_1} = 10$

$T_3 = T_5 - 10°K$ → counter flow

① isent compression → ② P const → ③ P const → ④ isent expansion → ⑤ P const → ⑥ P const →

①	②	③	④	⑤	⑥
$100kpa = P_1$	$P_2 = r_p \cdot P_1 = 1000kpa$	$T_3 = 545.757$	$P_4 = P_3 = 1000kpa$	$T_5 = 555.757°K$	$P_6 = P_1 = 100kpa$
$303°K = T_1$	$T_2 = 585°K$	$P_3 = P_2 = 1000kpa$	$T_4 = 1073°K$	$P_5 = P_6 = 100kpa$	$T_6 = 595°K$

isentropic + const cp/cv

$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}} \Rightarrow T_2 = (10)^{0.2857} \cdot 303°K = 595°K$

$T_2 = 595°K$

4-5

$W_{net} = [W_{out_{4-5}} - W_{in_{1-2}}]$ → isentropic → open system → $\frac{K \cdot R(T_4 - T_5)}{K-1}$

$W_{out} = \frac{1.4 \frac{KJ}{Kg \cdot K} \cdot 0.287 \frac{KJ}{Kg \cdot K} (1073 - 555.757)}{0.4}$

$W_{out_{4-5}} = 519.57 \frac{KJ}{Kg}$

1-2 → isentropic → open system

$W_{in_{1-2}} = \frac{K \cdot R \cdot (T_2 - T_1)}{K-1}$

$= \frac{1.4 \frac{KJ}{Kg \cdot K} \cdot .287 \frac{KJ}{Kg \cdot K} (585°K - 303°K)}{0.4}$

$= 283.269 \frac{KJ}{Kg}$

$W_{net} = 519.57 \frac{KJ}{Kg} - 283.269$

$W_{net} = 236.301 \frac{KJ}{Kg}$

given: 115 KW = $\dot{W}_{net}$ $\quad \dot{m} = \frac{\dot{W}_{net}}{W_{net}} = \frac{115 \frac{KJ}{S}}{236.301 \frac{KJ}{Kg}} = 0.4867 \frac{Kg}{S}$

6-1

$q_{out_{6-1}}$

$cp = 1.005 \frac{KJ}{Kg \cdot K}$

1st law

$q/n^0 - q_{out} + W/n^0 - W/o^0 = \Delta h \rightarrow \Delta h = cp(T_6 - T_1)$

$-q_{out} = 1.005 \cdot (595°K - 303°K)$

$-q_{out} = 293.46 \frac{KJ}{Kg}$

$293.46 \frac{KJ}{Kg} \cdot 0.4867 \frac{Kg}{S} = \boxed{142.817 \frac{KJ}{S}}$

$T_5 = \left(\frac{P_5}{P_4}\right)^{\frac{K-1}{K}} \cdot T_4$

$T_5 = \left(\frac{100}{1000}\right)^{\frac{.4}{1.4}} \cdot 1073°K$

$T_5 = 555.757°K$

$T_3 = 555.757°K - 10°K$

$T_3 = 545.757°K$

$q_{in_{2-3}} = q_{out_{5-6}}$

1st law

$q_{in} - q_{out} + W_{in} - W_{out} = \Delta h$

constant cp/cv → $\Delta h = cp(\Delta T)$

$q_{in_{2-3}} = cp(T_3 - T_2)$

$q_{out_{5-6}} = cp(T_5 - T_6)$

$cp(T_3 - T_2) = cp(T_5 - T_6)$

$545.757°K - 585 = 555.757 - T_6$

$-595. = -T_6$

3-4

1st law

$q_{in_{3-4}} = h_4 - h_3 \rightarrow cp(T_4 - T_3)$

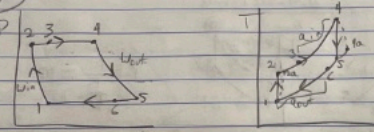
$1.005(1073°K - 545.757°K)$

$= 529.878 \frac{KJ}{Kg}$

$q_{in_{3-4}} \cdot \dot{m} = \dot{Q}_{in_{3-4}}$

$529.878 \frac{KJ}{Kg} \cdot 0.4867 \frac{Kg}{S} = \boxed{257.87 \frac{KJ}{S}}$

9-107



$r_p = 7$

$\epsilon = 0.65$

Assume Variable $c_p(T)$

① isentropic compression → ② const P → ③ const v → ④ isentropic expansion → ⑤ const P → ⑥ const v

$0.75 = \eta_c$

$T_1 = 310K$ $\quad T_2 = 537.016°K$ $\quad T_3 = 715.288K$ $\quad T_4 = 1130°K$ $\quad T_5 = 783.389°K$

$h_1 = 310.24 \frac{kJ}{kg}$ $\quad h_{2s} = 541.256 \frac{kJ}{kg}$ $\quad h_3 = 730.388 \frac{kJ}{kg}$ $\quad (h_4 = 1219.245 \frac{kJ}{kg})$ $\quad h_{5s} = 711.72 \frac{kJ}{kg}$

isentropic $\rightarrow \frac{P_2}{P_1} = \frac{P_{r2}}{P_{r1}}$ $\quad P_{r1}@310K = 1.5546$ $\quad 0 = s_4 - s_5 + R \cdot \ln\left(\frac{P_5}{P_4}\right)$

$7 \cdot 1.5546 = 10.8822 = P_{r2}@T_2$ $\quad s_5 = s_4 + R \cdot \ln\left(\frac{1}{r_p}\right) = 3.1241 + 0.287 \cdot \ln\left(\frac{1}{7}\right)$

ideal ↑

interpolate $\quad s_5 = 2.5705 \frac{kJ}{kg°K}$ interpolate h_{5s}

$T_2 = 537.016°K$

$\eta_c = \frac{h_{2s} - h_1}{h_2 - h_1} = \frac{541.256 - 310.24}{h_2 - 310.24} = 0.75$

$\eta_T = 0.82 = \frac{h_4 - h_5}{h_4 - h_{5s}}$

$= 0.75h_2 - 232.68 = 231.016$

$0.82(1219.245) = 711.72 = (1219.245 - h_{5s})$

$h_2 = 618.264 \frac{kJ}{kg}$

$416.1705 = 1219.245$

-1219.245

$+803.075 = h_{5s}$

interpolate → $T_5 = 783.389°K$

$\epsilon = 0.65 = \frac{h_3 - h_2}{h_{3s} - h_2}$

regenerator

$0.65(803.075 - 618.264) = h_3 - 618.264$

$120.182 + 618.264 = h_3$

$h_3 = 730.388 \frac{kJ}{kg}$

interpolate $T_3 = 715.288°K$

1st law $q_{in} - q_{out} + w_{in} - w_{out} = \Delta h$

9-5

$-w_{out\,4-5} = h_{5s} - h_4 = 803.075 \frac{kJ}{kg} - 1219.245 \frac{kJ}{kg}$

$+w_{out\,4-5} = 416 \frac{kJ}{kg}$

1-2

$w_{in\,1-2} = h_{2s} - h_1$

$= 618.264 \frac{kJ}{kg} - 310.24 \frac{kJ}{kg} = 308.021 \frac{kJ}{kg}$

$w_{net} = w_{out} - w_{in} \rightarrow 416 \frac{kJ}{kg} - 308.021 \frac{kJ}{kg} = 107.9 \frac{kJ}{kg} = w_{net}$

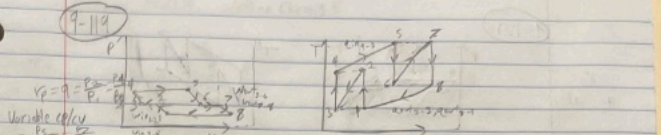
3-4

1st law $q_{in} - q_{out} + w_{in} - w_{out} = \Delta h$

$q_{in} = h_4 - h_3 = 1219.245 - 730.388 \frac{kJ}{kg} = 488.857 \frac{kJ}{kg}$

$\frac{w_{net}}{q_{in}} = \eta_{th} = \frac{107.9 \frac{kJ}{kg}}{488.857 \frac{kJ}{kg}} = 0.2207 = \eta_{th}$

9-119



$r_p = 9 = \frac{P_{max}}{P_{min}} = \frac{P_4}{P_1} = \frac{P_5}{P_8}$

Variable c_p/c_v

$\gamma_4 = \frac{c_p}{c_v}$

① isentropic compression → ② exhaust P const → ③ isentropic compression → ④ combustion P const

$T_1 = 300K$ $\quad T_2 = 410.135°K$ $\quad T_3 = 300°K$ $\quad T_4 = 410.135°K$

$h_1 = 300.19 \frac{kJ}{kg}$ $\quad h_2 = 411.257 \frac{kJ}{kg}$ $\quad h_3 = 300.19$ $\quad h_4 = 411.257 \frac{kJ}{kg}$

⑤ isentropic expansion → ⑥ combustion P const → ⑦ isentropic expansion → ⑧ exhaust P const

$T_5 = 1200°K$ $\quad T_6 = 911.96°K$ $\quad T_7 = \text{next}$ $\quad T_8 = 911.96°K$

$h_5 = 1277.79$ $\quad h_6 = 946.359 \frac{kJ}{kg}$ $\quad h_7 = 1277.79$ $\quad h_8 = 946.359 \frac{kJ}{kg}$

Variable calculations:

isentropic → h_s Spreadsheets	isent. V. Spreadsheets	isent. V. Spreadsheets
$\frac{P_2}{P_1} = \frac{P_{r2}}{P_{r1}}$	$\frac{P_4}{P_3} \cdot P_{r3} = P_{r4}$	$\frac{P_5}{P_6} = \frac{P_{r5}}{P_{r6}}$ $\quad P_{r5}@T_{max} = 23.8$ $\quad T_6 = T_8$
$3 \cdot 1.386 = P_{r2}$		
$P_{r2} = 4.158$;	$P_{r3} = 1.386@300°K$	$\frac{P_5}{P_6} = \frac{1}{3} \cdot 23.8 = P_{r6} = 79.33$
interpolate → $T_2 = 410.135°K$	$T_4 = 410.135°K$	$T_6 = 911.96°K$

$r_p = 9$ overall

$3 \times 3 = 9$

perfect gas

$r_p = 3$

$w_{in} = (h_2 - h_1) + (h_4 - h_3)$

$= (411.257 \frac{kJ}{kg} - 300.19 \frac{kJ}{kg}) \cdot 2$

$w_{in} = 222.134 \frac{kJ}{kg}$

$-w_{out} = (h_5 - h_6) + (h_8 - h_7)$

$= (946.358 \frac{kJ}{kg} - 1277.79 \frac{kJ}{kg}) \cdot 2$

$+w_{out} = +662.864$

$w_{net} = w_{out} - w_{in} = 662.864 - 222.134 = 440.73 \frac{kJ}{kg}$

$\dot{m} = \frac{W_{net}}{w_{net}} = \frac{110 \frac{kJ}{s}}{440.73 \frac{kJ}{kg}}$

$= 249.5859 \rightarrow 250 \frac{kg}{s} = \dot{m}$

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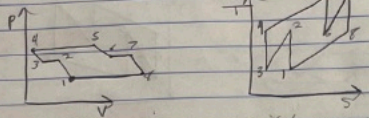
$r_p = 3$

v. cpk v



① isent. compression → ② P const → ③ heat expansion → ④ combustion process

$T_1 = 300°K$ $T_2 = 410.135°K$ $T_3 = 300°K$ $T_4 = T_2$

$h_1 = 300.19 \frac{kJ}{kg}$ $h_2 = 411.257 \frac{kJ}{kg}$ $h_3 = 300.19 \frac{kJ}{kg}$ $h_4 = 411.25 \frac{kJ}{kg}$

combustion ⑤ isent. expansion → ⑥ P const → ⑦ isent. expansion → ⑧ other process

$T_5 = 1200°K$ $T_6 = 911.969°K$ $T_7 = 1200°K$ $T_8 = T_6$

$h_5 = 1277.79 \frac{kJ}{kg}$ $h_6 = 946.358 \frac{kJ}{kg}$ $h_7 = 1277.79 \frac{kJ}{kg}$ $h_8 = 946.358 \frac{kJ}{kg}$

isentropic → variable c/v

$\frac{P_2}{P_1} = r_p = \frac{P_4}{P_3} = \frac{P_5}{P_6} = \frac{P_7}{P_8}$

$\frac{P_2}{P_1} = \frac{Pr_2}{Pr_1} \rightarrow r_p \cdot Pr_1 = Pr_2 = 1.158$ → interpolate $T_2 = 410.135°K$

$3 \cdot 1.386 =$

$\frac{P_5}{P_6} = \frac{Pr_5}{Pr_6} \rightarrow \frac{Pr_5}{r_p} = \frac{238}{3} = 79.33$ → interpolate $T_6 = 946.358°K$

(1) (1-2) (3-4)

1st Law: $q_{in} - q_{out} + w_{in} - w_{out} = \Delta h$

variable cp/cv

$w_{in\,1-2/3-4} = 2 \cdot (h_2 - h_1) = 2 \cdot (411.257 \frac{kJ}{kg} - 300.19 \frac{kJ}{kg}) = 222.134 \frac{kJ}{kg}$

$q_{in} - q_{out} + w_{in} - w_{out} = 2(h_5 - h_6) = 2(946.358 \frac{kJ}{kg} - 1277.79 \frac{kJ}{kg}) = 662.864 \frac{kJ}{kg}$ (5-6) (7-8)

Back Work ratio $= \frac{w_{in\,cp}}{w_{out\,tur}} = \frac{222.134 \frac{kJ}{kg}}{662.864 \frac{kJ}{kg}} = 0.335 = r_{BW}$

$q_{in} - q_{out} + w_{in} - w_{out} = q_{in} = (h_5 - h_4) + (h_7 - h_6)$ (4-5) (6-7)

$= (1277.79 \frac{kJ}{kg} - 411.257 \frac{kJ}{kg}) + (1277.79 \frac{kJ}{kg} - 946.358 \frac{kJ}{kg})$

$q_{in} = 1197.965 \frac{kJ}{kg}$ $w_{net} = 662.864 \frac{kJ}{kg} - 222.134 \frac{kJ}{kg} = 440.73 \frac{kJ}{kg}$

$\eta_{th} = \frac{w_{net}}{q_{in}} \rightarrow \frac{440.73 \frac{kJ}{kg}}{1197.965 \frac{kJ}{kg}} = 0.368 = \eta_{th}$

(b)

$r_{BW} = 0.335$ → same like normal

regen effectiveness $= 0.75$

$w_{regen} = \epsilon(h_7 - h_4) = (946.358 \frac{kJ}{kg} - 411.257) \cdot 0.75 = 401.325 \frac{kJ}{kg}$

$q_{in} = q_{in\,a} - q_{regen} = 1197.965 \frac{kJ}{kg} - 401.325 \frac{kJ}{kg} = 796.64 \frac{kJ}{kg}$

$\eta_{th} = \frac{w_{net}}{q_{in}} \rightarrow \frac{440.73 \frac{kJ}{kg}}{796.64 \frac{kJ}{kg}} = 0.553 = \eta_{th}$

9-88

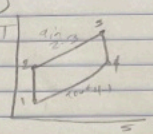
constant cp/cv

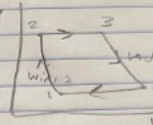
$r_p = 10 = \frac{P_2}{P_1} = \frac{P_3}{P_4}$

$Q_{in} = 500 kW$

$\dot{m} = 1 \frac{kg}{s}$

$cp = 1.005 \frac{kJ}{kg \cdot K}$





① isent. compression → ② P const → ③ isent. expansion → ④ P const

$P_1 = 70 kPa$ $T_2 = 527.08$ $P_3 = 700 kPa$ $P_4 = P_4 = 70 kPa$

$T_1 = 277.8°K$ $P_2 = 10 \cdot P_1 = 700 kPa$ $T_3 = 1024.59°K$ $T_4 = 530.6837°K$

isent. constant cp/cv → $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = (10)^{\frac{0.4}{1.4}} \cdot 277.8K$

$T_2 = 527.08°K$

1st Law (2-3): $Q_{in} - \dot{W}_{out} + \dot{m}h_{in} - \dot{m}h_{out} = \Delta h$

$Q_{in} = \dot{m} \cdot cp(T_3 - T_2)$

$\frac{500 kW}{1 \cdot 1.005 \frac{kJ}{kg \cdot K}} = T_3 - 527.08K$

$T_3 = 1024.59°K$

$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{k-1}{k}} = \left(\frac{1}{r_p}\right)^{\frac{k-1}{k}} \cdot T_3 = T_4 = (0.1)^{\frac{0.4}{1.4}} \cdot 1024.59°K = 530.6837°K$

$w_{net} = w_{out} - w_{in}$

(3-4) $w_{out\,3-4} = \dot{m} \cdot cp \cdot (T_3 - T_4) = 1 \frac{kg}{s} \cdot 1.005 \frac{kJ}{kg \cdot K} (1024.59K - 530.6837°K)$

$= 496.376 \frac{kJ}{kg}$

$w_{in\,1-2} = \dot{m} \cdot cp \cdot (T_2 - T_1) = 1 \frac{kg}{s} \cdot 1.005 \frac{kJ}{kg \cdot K} (527.08K - 273°K)$

$= 255.194 \frac{kJ}{kg}$

$w_{net} = 496.376 \frac{kJ}{kg} - 255.194 \frac{kJ}{kg} = 241.176 \frac{kJ}{kg}$

$\eta_{th} = \frac{w_{net}}{Q_{in}} = \frac{241.176 kW}{500 kW} = 0.482 = \eta_{th}$