MICHAEL DELACRUZ
MET 350
TEST 1

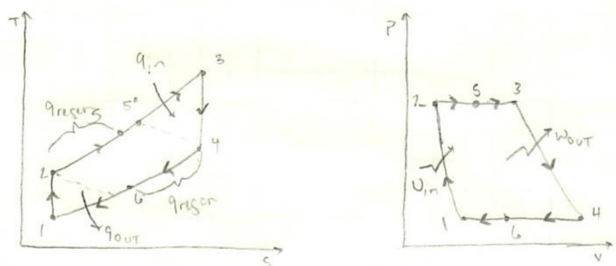
1)

PURPOSE: DETERMINE THE NETWORK, THE HEAT ADDITION & REJECTION, THE THERMAL EFFICIENCY & THE HEAT EXCHANGER EFFECTIVENESS OF:

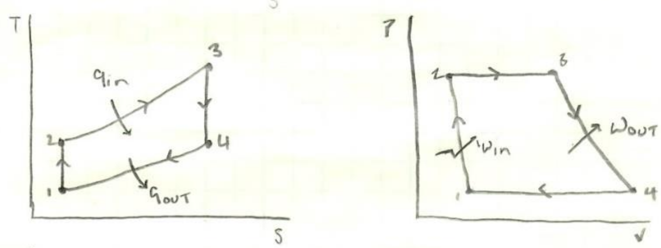
A) THE ORIGINAL DESIGN
B) THE ORIGINAL DESIGN W/O REGENERATION
C) THE ORIGINAL DESIGN W/ A PRESSURE RATIO OF 8.68 KEEPING SAME OTHER
D) THE ORIGINAL DESIGN W/ A MAXIMUM CYCLE TEMPERATURE OF 895.48°C KEEPING SAME OTHER VARIABLES
E) THE ORIGINAL DESIGN BUT REMOVING THE COMPRESSOR WITH A TWO STAGES COMPRESSOR WITH INTERCOOLING

SOURCES: CENGEL & BOLES. THERMODYNAMICS - AN ENGINEERING APPROACH 8TH EDITION MCGRAW HILL. 2015

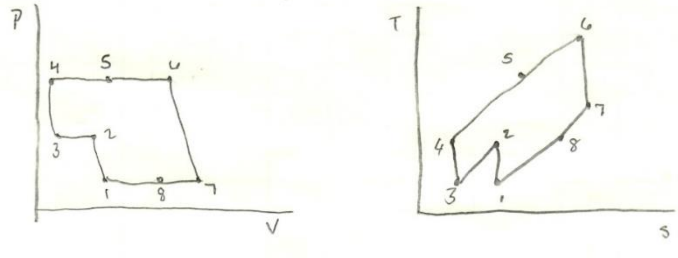
DIAGRAMS:



REGENERATOR



NO REGENERATOR



TWO STAGE W/ INTERCOOLING

DESIGN CONSIDERATION

1) AIR BEHAVES AS AN IDEAL GAS

2) CP + CV ARE CONSTANT

MATERIALS

AIR AS IDEAL GAS

DATA + VARIABLES

$T_1 = 30°C = 303.15\,K$

$P_1 = 100\,kPa$

$T_3 = 800°C$

$r_p = 10$

PROCEDURE

1) SOLVE FOR STATES PART A

2) SOLVE FOR STATES PART B W/O REGENERATOR

3) SOLVE FOR STATES PART C W/ $r_p = 8.58$

4) SOLVE FOR STATES PART D W/ MAX CYCLE TEMP 895.48°C

5) SOLVE FOR STATES PART E W/ TWO STAGE COMPRESSION

CALCULATION: $R = 0.287$

a)

① —ISENT→ ② —PCONST, REGEN→ ⑤ —PCONST→ ③ —ISENT→ ④ —PCONST, REGEN→ ⑥ —PCONST→

State 1: $T_1 = 30°C = 303.15K$, $P_1 = 100\ kPa$

State 2: $P_2 = (r_p)P_1 = (10)(100\ kPa) = 1000\ kPa$

State 5: $P_5 = P_2$, $P_5 = 1000\ kPa$

State 3: $T_3 = 800°C = 1073.15\ K$, $P_3 = P_5$, $P_3 = 1000\ kPa$

State 4: $P_4 = P_6$, $P_4 = 100\ kPa$

State 6: $P_6 = P_1$, $P_6 = 100\ kPa$

$$T_2 = T_1 (r_p)^{\frac{k-1}{k}} = 303.15 (10)^{\frac{1.4-1}{1.4}} = 585.29\ K$$

$$T_4 = T_3 \left(\frac{1}{10}\right)^{\frac{1.4-1}{1.4}} = 555.84\ K$$

$$T_5 = T_4 - 10 = 545.84K$$

1ST LAW

$$h_5 - h_2 = h_4 - h_6$$
$$c_p(T_5 - T_2) = c_p(T_4 - T_6)$$
$$T_5 - T_2 = T_4 - T_6$$
$$T_6 = T_4 - (T_5 - T_2) = 595.29K$$

NET WORK

$$W_{net} = W_{out} - W_{in} = c_p(T_3 - T_4) - c_p(T_2 - T_1)$$
$$= 1.005(1073.15K - 555.84K) - 1.005(585.29K - 303.15K)$$
$$= \boxed{236.34\ kJ/kg}$$

HEAT ADDITION + REJECTION

$$q_{in} = c_p(T_3 - T_5) = \boxed{529.94\ kJ/kg}$$

$$q_{out} = c_p(T_6 - T_1) = \boxed{293.60\ kJ/kg}$$

THERMAL EFFICIENCY

$$\eta_{TH} = \frac{W_{net}}{q_{in}} = \frac{236.34}{500.07} = 0.4459 = \boxed{44.59\%}$$

HEAT EXCHANGER EFFECTIVENESS

$$\epsilon = \frac{T_5 - T_2}{T_4 - T_2} = \frac{(545.84K - 585.29K)}{(555.84K - 585.29K)} = \boxed{1.33}$$

B)

① —ISENT→ ② —P CONST→ ③ —ISENT→ ④ —P CONST→

$T_1 = 30°C = 303.15 K$
$P_1 = 100 kPa$

$P_2 = (r_p) P_1$
$= 10 (100 kPa)$
$= 1000 kPa$

$T_3 = 800°C = 1073.15 K$
$P_3 = P_2$
$P_3 = 1000 kPa$

$P_4 = P_1$
$P_4 = 100 kPa$

$T_2 = T_1 (r_p)^{\frac{k-1}{k}}$
$= 303.15 (10)^{\frac{k-1}{k}}$
$= 585.29 K$

$T_4 = T_3 \left(\frac{1}{10}\right)^{\frac{1.4-1}{1.4}}$
$= 555.84 K$

NET WORK

$W_{net} = W_{out} - W_{in} = c_p(T_3 - T_4) - c_p(T_2 - T_1)$
$= 1.005(1073.15K - 555.84K) - 1.005(585.29K - 303.15K)$
$= \boxed{236.34 \text{ kJ/kg}}$

HEAT ADDITION + REJECTION

$q_{in} = c_p(T_3 - T_2)$
$= 1.005(1073.15K - 585.29K)$
$= \boxed{490.299 \text{ kJ/kg}}$

$q_{out} = c_p(T_4 - T_1)$
$= 1.005(555.84K - 303.15K)$
$= \boxed{253.95 \text{ kJ/kg}}$

HEAT EXCHANGER EFFECTIVENESS

N/A

THERMAL EFFICIENCY

$\eta_{th} = \frac{W_{net}}{q_{in}} = .4820 = \boxed{48.2\%}$

$r_p = 8.58$

c)

1 →(ISENT)→ 2 →(P CONST)→ 5 →(P CONST)→ 3 →(ISENT)→ 4 →(P CONST)→ 6 →(P CONST)→

State 1: $T_1 = 30°C = 303.15\,K$, $P_1 = 100\,kPa$

State 2: $P_2 = (r_p)P_1 = (8.58)(100\,kPa) = 858\,kPa$

State 5: $P_5 = P_2$, $P_5 = 858\,kPa$

State 3: $T_3 = 800°C = 1073.15\,K$, $P_3 = P_5$, $P_3 = 858\,kPa$

State 4: $P_4 = P_6$, $P_4 = 100\,kPa$

State 6: $P_6 = P_4$, $P_6 = 100\,kPa$

$$T_2 = T_1 (r_p)^{\frac{k-1}{k}} = 303.15(8.58)^{\frac{1.4-1}{1.4}} = 560.23\,K$$

$$T_4 = T_3 \left(\frac{1}{8.58}\right)^{\frac{1.4-1}{1.4}} = 1073.15\,K \left(\frac{1}{8.58}\right)^{\frac{1.4-1}{1.4}} = 580.69\,K$$

$$T_5 = T_4 - 10 = 570.69\,K$$

$$h_5 - h_2 = h_4 - h_6$$

$$c_p(T_5 - T_2) = c_p(T_4 - T_6)$$

$$T_6 = T_4 - (T_5 - T_2)$$

$$T_6 = 570.23\,K$$

NET WORK

$$w_{net} = w_{out} - w_{in} = c_p(T_3 - T_4) - c_p(T_2 - T_1) = \boxed{236.56\ kJ/kg}$$

HEAT ADDITION + REJECTION

$$q_{in} = c_p(T_3 - T_5) = \boxed{504.97\ kJ/kg}$$

$$q_{out} = c_p(T_6 - T_1) = \boxed{268.42\ kJ/kg}$$

THERMAL EFFICIENCY

$$\eta_{th} = \frac{w_{net}}{q_{in}} = .4684 = \boxed{46.84\%}$$

HEAT EXCHANGER EFFECTIVENESS

$$\varepsilon = \frac{T_5 - T_2}{T_4 - T_2} = \boxed{0.511}$$

DJ

→ ① —ISENT→ ② —P_{CONST}→ ⑤ —P_{CONST}→ ③ —ISENT→ ④ —P_{CONST}→ ⑥ —P_{CONST}→

State 1: $T_1 = 30°C = 303.15K$, $P_1 = 100\ kPa$

State 2: $P_2 = (r_p)P_1 = (10)(100kPa) = 1000\ kPa$

State 5: $P_5 = P_2 = 1000\ kPa$

State 3: $T_3 = 895.48°C = 1168.63K$, $P_3 = P_5$, $P_3 = 1000\ kPa$

State 4: $P_4 = P_6$, $P_4 = 100\ kPa$

State 6: $P_6 = P_1$, $P_6 = 100\ kPa$

$$T_2 = T_1 (r_p)^{\frac{k-1}{k}} = 585.29K$$

$$T_5 = T_4 - 10 = 595.28\ K$$

$$T_4 = T_3 \left(\frac{1}{10}\right)^{\frac{k-1}{k}} = 605.28\ K$$

$$T_6 = T_4 - (T_5 - T_2) = 595.29\ K$$

NET WORK

$$W_{net} = W_{out} - W_{in} = c_p(T_3 - T_4) - c_p(T_2 - T_1) = \boxed{282.62\ kJ/kg}$$

HEAT ADDITION & REJECTION

$$q_{in} = c_p(T_3 - T_5) = \boxed{576.22\ kJ/kg}$$

$$q_{out} = c_p(T_6 - T_1) = \boxed{293.60\ kJ/kg}$$

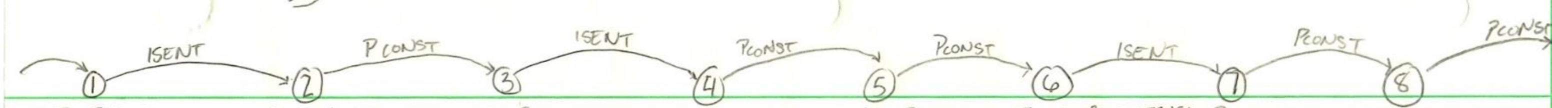
THERMAL EFFICIENCY

$$\eta_{TH} = \frac{W_{net}}{q_{in}} = 0.4904 = \boxed{49.04\ \%}$$

HEAT EXCHANGER EFFECTIVENESS

$$\varepsilon = \frac{T_5 - T_2}{T_4 - T_2} = \boxed{.499}$$

E)



State 1

$T_1 = 30°C = 303.15\ K$

$P_1 = 100\ kPa$

State 2

$P_2 = r_P(P_1)$

$= 1000\ kPa$

$T_2 = T_1 (r_P)^{\frac{k-1}{k}}$

$= 585.29\ K$

State 3

$P_3 = P_2$

$P_3 = 1000\ kPa$

$T_3 = 303.15\ K$

State 4

$P_4 = r_P(P_3)$

$= 10{,}000\ kPa$

$T_4 = T_3 (r_P)^{\frac{k-1}{k}}$

$= 585.29\ K$

State 5

$P_5 = P_4$

$= 10{,}000\ kPa$

$T_5 = T_7 - 10$

$T_5 = 277.9\ K$

State 6

$T_6 = 800°C = 1073.15\ K$

$P_6 = P_3$

$= 10000\ kPa$

State 7

$P_7 = P_8$

$P_7 = 100\ kPa$

$T_7 = T_5 + 10$

$T_7 = \left(\frac{P_7}{P_6}\right)^{\frac{k-1}{k}} \times T_6$

$= \left(\frac{100\ kPa}{10000\ kPa}\right)^{\frac{1.4-1}{1.4}} \times 1073.15\ K$

$T_7 = 287.9\ K$

State 8

$P_8 = P_1$

$P_8 = 100\ kPa$

$h_5 - h_4 = h_7 - h_8$

$c_p(T_5 - T_4) = c_p(T_7 - T_8)$

$T_8 = T_7 - T_5 + T_4$

$T_8 = 595.3\ K$

NET WORK

$W_{net} = W_{out_{6-7}} - W_{in_{1-2}} + W_{pn_{3-4}}$

$= c_p(T_6 - T_7) - c_p(T_2 - T_1) + c_p(T_4 - T_3)$

$= 787.6 - 283 + 283 =$

$= \boxed{789.17\ kJ/kg}$

HEAT ADDITION + REJECTION

$q_{in} = c_p(T_6 - T_5)$

$= \boxed{799.22\ kJ/kg}$

$q_{out} = q_{out_{8-1}} + q_{out_{2-3}}$

$= c_p(T_8 - T_1) + c_p(T_2 - T_3)$

$= \boxed{576.62\ kJ/kg}$

THERMAL EFFICIENCY

$\eta_{TH} = \frac{W_{net}}{q_{in}} = \frac{789.17}{799.22}$

$= 0.9869$

$= \boxed{98.69\ \%}$

HEAT EXCHANGER EFFECTIVENESS

$\epsilon = \frac{T_5 - T_4}{T_7 - T_4}$

$= \boxed{1.03}$

SUMMARY

	W_{net}	q_{in}	q_{OUT}	η_{TH}	ε
A	236.34 kJ/kg	529.94 kJ/kg	293.4 kJ/kg	44.59%	1.33
B	236.34 kJ/kg	490.29 kJ/kg	253.95 kJ/kg	48.2%	N/A
C	236.56 kJ/kg	504.97 kJ/kg	268.42 kJ/kg	46.84%	0.511
D	282.62 kJ/kg	576.22 kJ/kg	293.60 kJ/kg	49.04%	.499
E	789.17 kJ/kg	799.62 kJ/kg	576.62 kJ/kg	98.69%	1.03

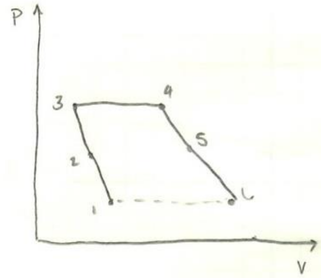
ANALYSIS

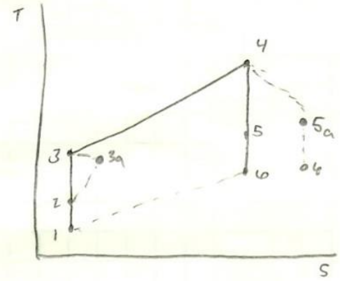
FOR THIS PROBLEM, THE ORIGINAL DESIGN AND THE ONE WITH TWO STAGE COMPRESSOR AS THEY EXCEED THE EFFECTIVENESS THRESHOLD OF 1.00. THE ONE WITH A PRESSURE RATIO OF 8.58 HAD THE GREATEST HEAT EXCHANGER EFFECTIVENESS WITHIN THE PARAMETERS BUT WAS LESS EFFICIENT. THE BEST OPTION WAS A MAXIMUM CYCLE TEMPERATURE OF 895.40 °C AS IT WAS EFFECTIVE AND EFFICIENT WHILE PRODUCING MORE WORK.

2) PURPOSE: DETERMINE THE PRESSURE OF COMBUSTION GASES AT THE TURBINE EXIT, THE VELOCITY OF THE GASES AT THE NOZZLE EXIT + THE THRUST FOR THE ENGINE IF THE DIFFUSER INLET DIAMETER IS 1.6m

SOURCES: CENGEL + BOLES, THERMODYNAMICS - AN ENGINEERING APPROACH 8TH EDITION MCGRAW HILL 2015

DIAGRAMS:





DATA AND VARIABLES

$T_1 = -35°C = 238.15K$

$P_1 = 40\ kPa$

$T_4 = 950°C$

$\eta_T = 90\%$

$\eta_C = 80\%$

DESIGN CONSIDERATIONS

1) AIR BEHAVES AS AN IDEAL GAS
2) CP + CV ARE VARIABLE

MATERIALS

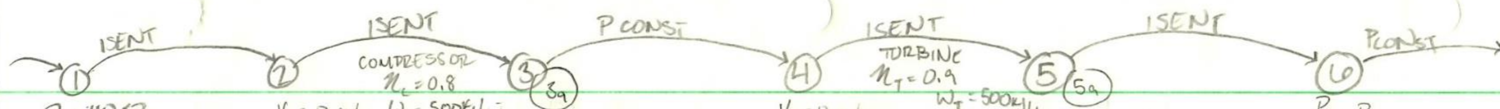
AIR AS IDEAL GAS

PROCEDURE

1) SOLVE FOR STATES

2) SOLVE FOR VELOCITY + PRESS

3) SOLVE FOR THRUST



State 1

$P_1 = 40$ kPa

$T_1 = -35°C = 238.15$ K

$v_1 = \frac{RT_1}{P_1}$

$= 1.71$ m³/kg

$V_1 = 900$ km/h :

$\frac{900\text{ km}}{h} \cdot \frac{1\text{ h}}{3600\text{ s}} \cdot \frac{1000\text{ m}}{1\text{ km}}$

$= 250$ m/s

$h_1 = 238.17$
USING INTERPOLATION A-17

$P_{r_1} = .6194$

$h_2 = h_1 + \frac{V_1^2}{2}$

$= 269.42$ kJ/kg

$P_2 = P_1 \left(\frac{P_{r_2}}{P_{r_1}}\right)$

$= 61.4$ kPa

State 2

$V_2 = 0$ m/s $w_c = 500$ kJ/kg

$T_2 = 269.81$ } INTERPOLATED
$P_{r_2} = .9508$ } A-17

State 3

$w_c = \frac{h_3 - h_2}{\eta_c}$

$h_3 = h_2 + w_c \times \eta_c$

$= 269.42 + 500(.8)$

$= 669.42$ kJ/kg

$T_3 = 659.01$ K } INTERPOLATED
$P_{r_3} = 23.00$ } A-17

$P_3 = P_2 \left(\frac{P_{r_3}}{P_{r_2}}\right)$

$= 1485.69$ kPa

$\eta_c = \frac{h_3 - h_2}{h_{3a} - h_2}$

$0.8 = \frac{669.42 - 269.42}{h_{3a} - 269.42}$

$h_{3a} = 769.42$ kJ/kg

$T_{3a} = 751.96$ K - INTERPOLATED A17

State 4

$V_4 = 0$ m/s

$T_4 = 950°C = 1223.15$ K

$P_4 = P_3$

$P_4 = 1485.69$ kPa

$h_4 = 1305.03$ kJ/kg } INTERPOLATED
$P_{r_4} = 257.472$ } A-17

State 5

$w_T = 500$ kJ/kg $V_5 = 0$ m/s

$w_T = \eta_T (h_4 - h_5)$

$h_5 = h_4 - \frac{w_T}{\eta_T}$

$= 1305.03 - \frac{500}{0.9}$

$= 749.47$ kJ/kg

$T_5 = 733.56$ } INTERPOLATED
$P_{r_5} = 34.35$ } A-17

$P_5 = P_4 \left(\frac{P_{r_5}}{P_{r_4}}\right)$

$= 198.21$ kPa

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

$0.9 = \frac{1305.03 - 749.47}{1305.03 - h_{5a}}$

$h_{5a} = 800.03$ kJ/kg

$T_{5a} = 780.0$ K - INTERPOLATED A17

State 6

$P_6 = P_1$

$P_6 = 40$ kPa

$\frac{P_6}{P_5} = \frac{P_{r_6}}{P_{r_5}}$

$P_{r_6} = P_{r_5}\left(\frac{P_6}{P_5}\right)$

$= 6.932$

$T_6 = 473.61$ K } INTERPOLAT
$h_6 = 475.94$ kJ/kg } A-17

PRESSURE AT TURBINE EXIT

$P_5 = 198.12$ KPa

VELOCITY OF GASES AT NOZZLE EXIT

$$h_{5a} + \frac{V_{5a}^2}{2} \approx 0 = h_6 + \frac{V_6^2}{2}$$

$$V_6 = \sqrt{2(h_{5a} - h_6)}$$

$$= \sqrt{2(800.03 - 475.94)}$$

$$= 805.10 \text{ m/s}$$

THRUST

$$F = \dot{m}\,(V_{exit} - V_{inlet})$$

$$\dot{m} = \frac{V_1}{v_1} \frac{\pi}{4} D^2$$

$$F = \frac{V_1}{v_1} \frac{\pi}{4} D^2 (V_6 - V_1)$$

$$= \frac{250}{1.71} \frac{\pi}{4} (1.6)^2 (805.10 - 250)$$

$$= 163171.75 \text{ N}$$

$$= 163.17 \text{ KN}$$

SUMMARY

PRESSURE AT TURBINE EXIT = 198.12 KPa

VELOCITY AT NOZZLE EXIT = 805.10 m/s

THRUST = 163.17 KN

ANALYSIS

FOR THIS PROBLEM, THERE WAS A SIGNIFICANT PRESSURE DROP AT THE TURBINE EXIT.