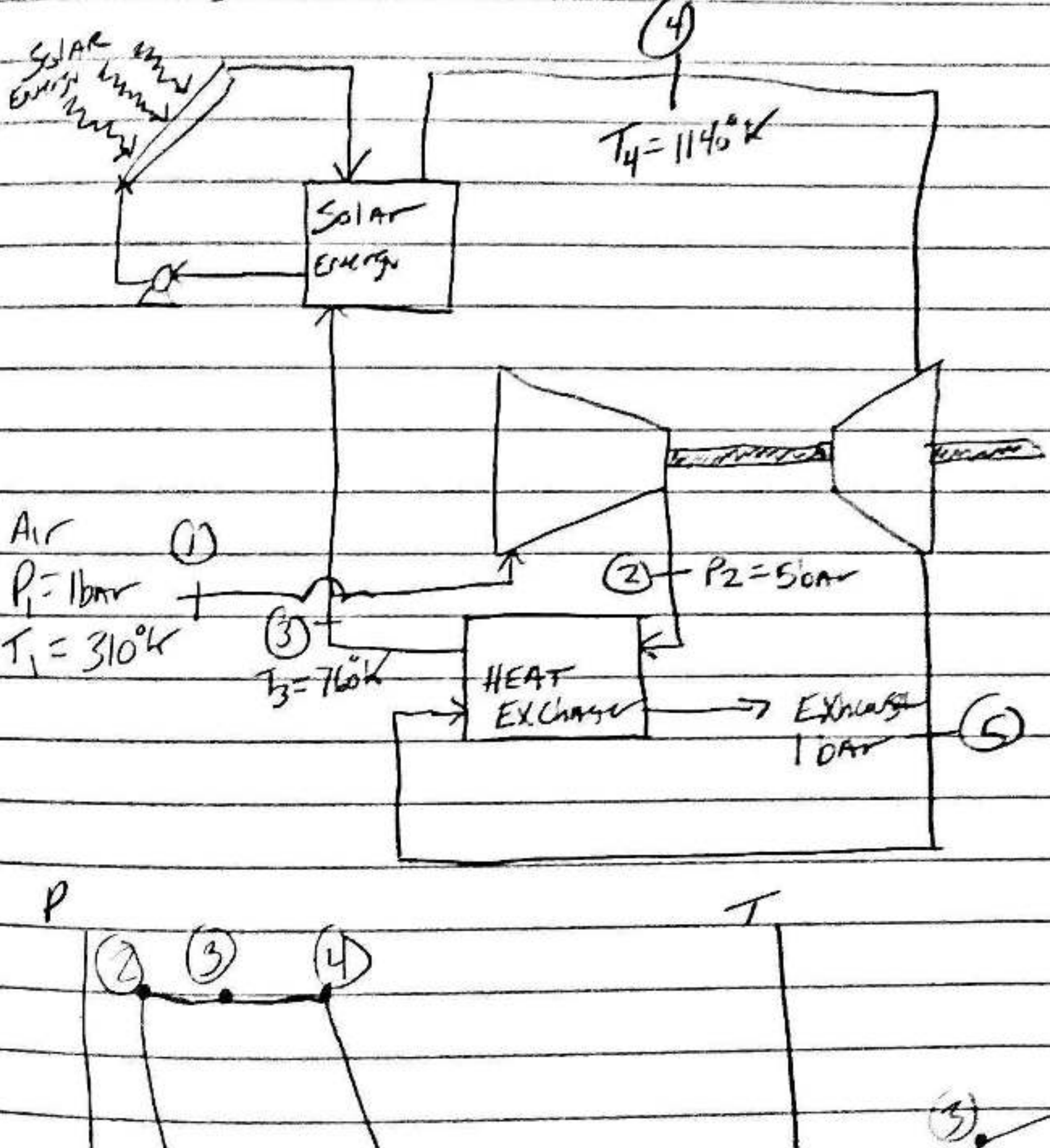
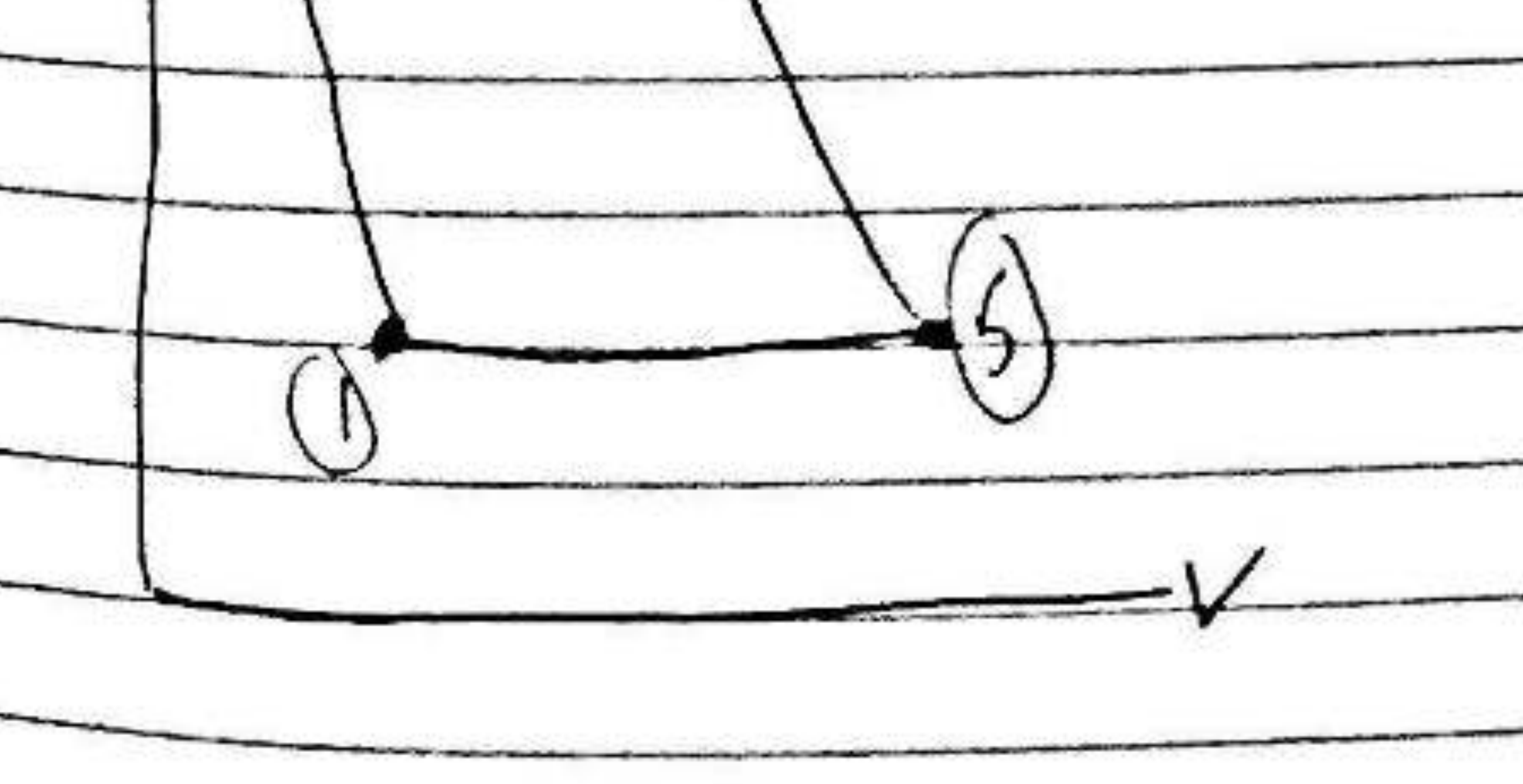
ROY SHEPARD Test #1 Question 1

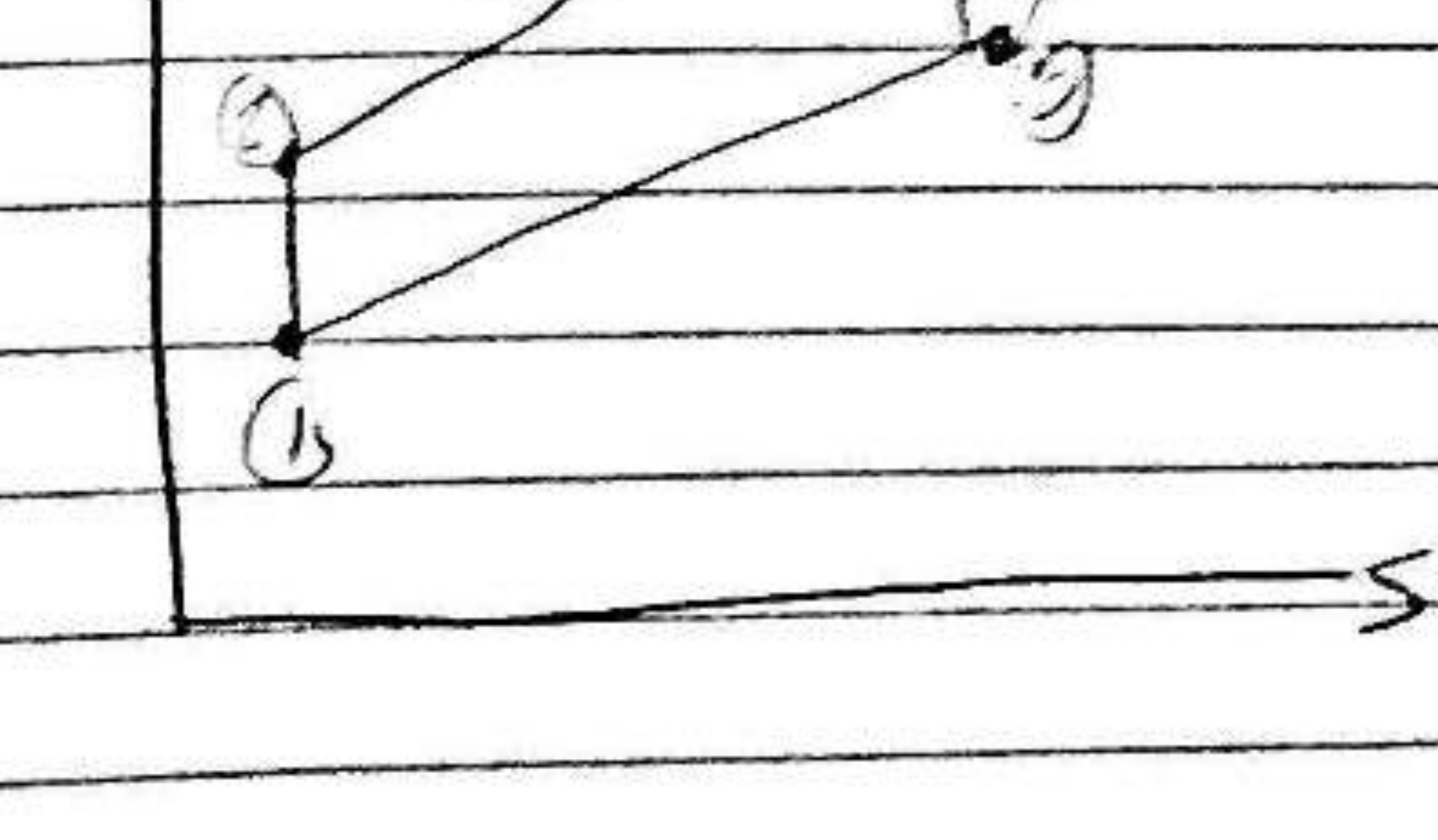
Purpose: Determine the thermal efficiency and heat exchanger effectiveness. Compare to 100% effectiveness of heat exchanger. Find the flow rate in kg/s for a net power output of 5 MW.

Diagrams:

Ideal Brayton Cycle







(2)

Sources:

- Cengel & Boles. Thermodynamic - An Engineering Approach 8th edition McGraw Hill 2015
- Crader Notes & lessons MET 350

Design Considerations:

I Assume the Following

1) Air behaves as Ideal Gas
2) C_P & C_V are constant
3) Isentropic efficiencies of the compressor and Turbines is 0.8
4) $C_P = 1.005 \frac{kJ}{kg \cdot K}$, $K = 1.4$ (Table A2)

Data & Variables:

$P_1 = 1 bar = 100 kPa$ $\quad$ $W_{net} = 500 kW$

$T_1 = 310°K$ $\quad$ $C_P = 1.005 kJ/kg \cdot K$

$P_2 = 5 bar = 500 kPa$ $\quad$ $K = 1.4$

$T_2 = 760°K$

$T_4 = 1140°K$

$\eta_t = 0.8$

Materials:

Air as an Ideal Gas

Procedures and Calculations:

I will start by solving for all states pressures & temperature then solve for part 1, next part 2 and finally part 3.

① $P_1 = 1\,bar = 100\,kPa$
$T_1 = 310K$

② $P_2 = 5\,bar = 500\,kPa$ $T_2 = T_1 \times \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 310\left(\frac{500}{100}\right)^{\frac{1.4-1}{1.4}} = 490.9 = 491K$
$T_2 = 491\,K$

③ $P_3 = 5\,bar = 500\,kPa$ $P_2 = P_3$
$T_3 = 760K$

④ $P_4 = 5\,bar = 500\,kPa$
$T_4 = 1140\,K$

⑤ $P_5 = 1\,bar = 100\,kPa$ $P_5 = P_1$
$T_5 = 720\,K$

$$T_5 = T_4 \times \left(\frac{P_6}{P_4}\right)^{\frac{k-1}{k}} = 1140\left(\frac{100}{500}\right)^{\frac{1.4-1}{1.4}} = 719.7 = 720K$$

$$W_{net} = C_p(T_4 - T_5) - C_p(T_2 - T_1)$$
$$= C_p(T_4 - T_5 - T_2 + T_1)$$
$$= 1.005(1140 - 720 - 491 + 310)$$
$$= 240.1\ kJ/kg$$

$$q_{in} = C_p(T_4 - T_3)$$
$$= 1.005(1140 - 760K)$$
$$= 381.9\ kJ/kg$$

$$\eta_{th} = \frac{W_{net}}{q_{in}} = \frac{240.1}{381.9} = \boxed{.6289}$$

$$\varepsilon = \frac{T_3 - T_2}{T_4 - T_2} = \frac{760 - 491}{1140 - 491} = \frac{269}{649} = \boxed{.5735}$$

(4)

$$W_{net} = m \cdot C_P(T_4 - T_5) - (T_2 - T_1)$$

$$500 = m \cdot 1.005 (1140 - 720)(491 - 310)$$

$$500 = m \cdot 1.005 (420) - (181)$$

$$500 = m \cdot 240.19$$

$$m = \frac{520}{240.19} = \boxed{2.08\ kg/s}$$

$$\eta_{th}\ @\ w/ \text{ with} = 1 - \frac{T_5 - T_1}{T_4 - T_1}$$

$$= \frac{720 - 310}{1140 - 310} \quad \frac{410}{830} - \boxed{.5060}$$

SUMMARY:

$\varepsilon = .5735$

$\eta_{th} = .6289$

Flow Rate @ 500 kW = 2.08 kg/s

η_{th} @ 100% = .5060

ANALYSIS:

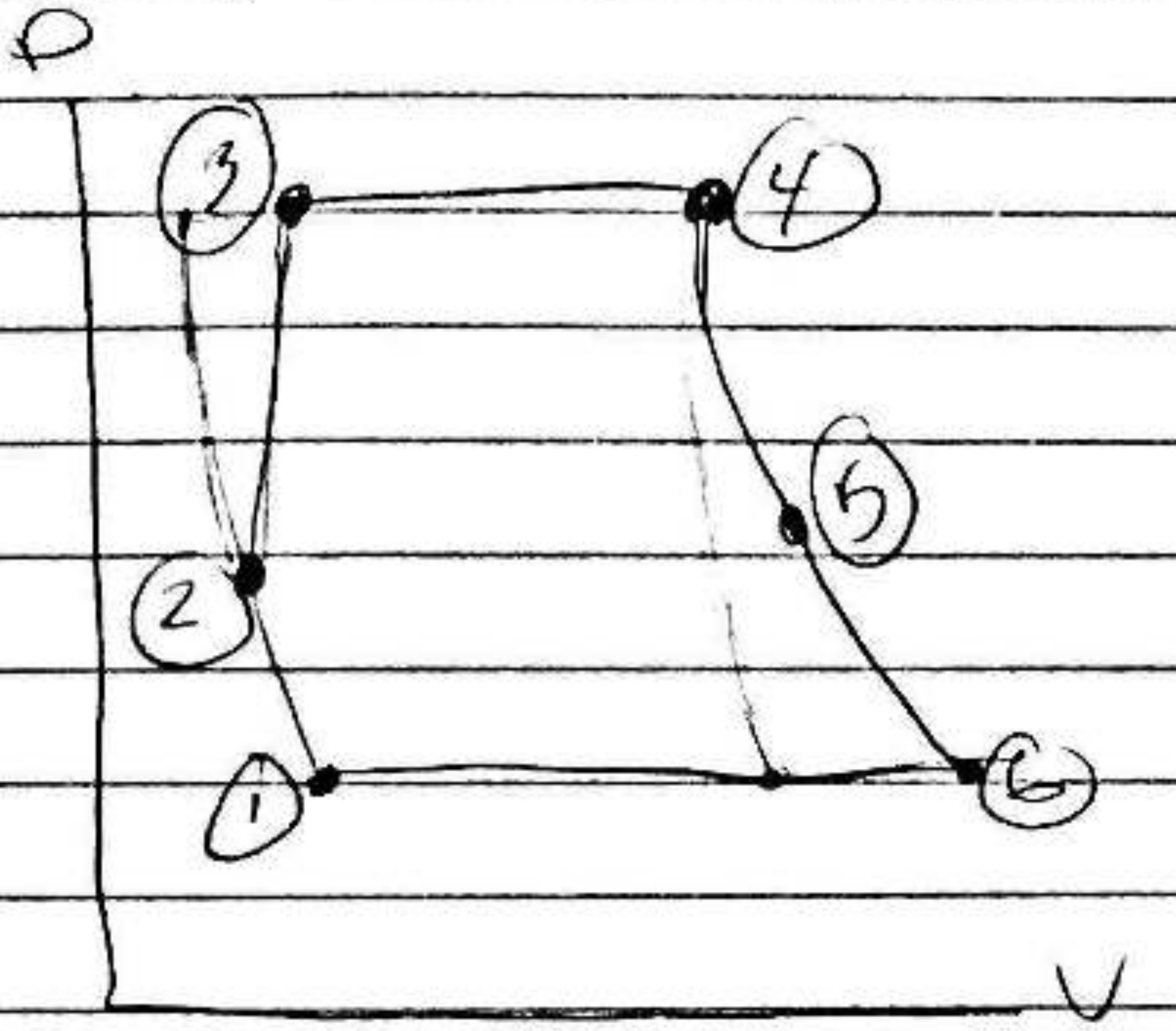
AS YOU CAN see the efficiency got worse. I WAS Not expecting that to happen. I would have expected better efficiency @ 100%. I must had MADE AN error in CALCULATIONS. BASED ON what I know with high performance vehicles it is Always better to have a more efficient heat exchanger. You will ALWAYS make more power with a more efficient heat exchanger.

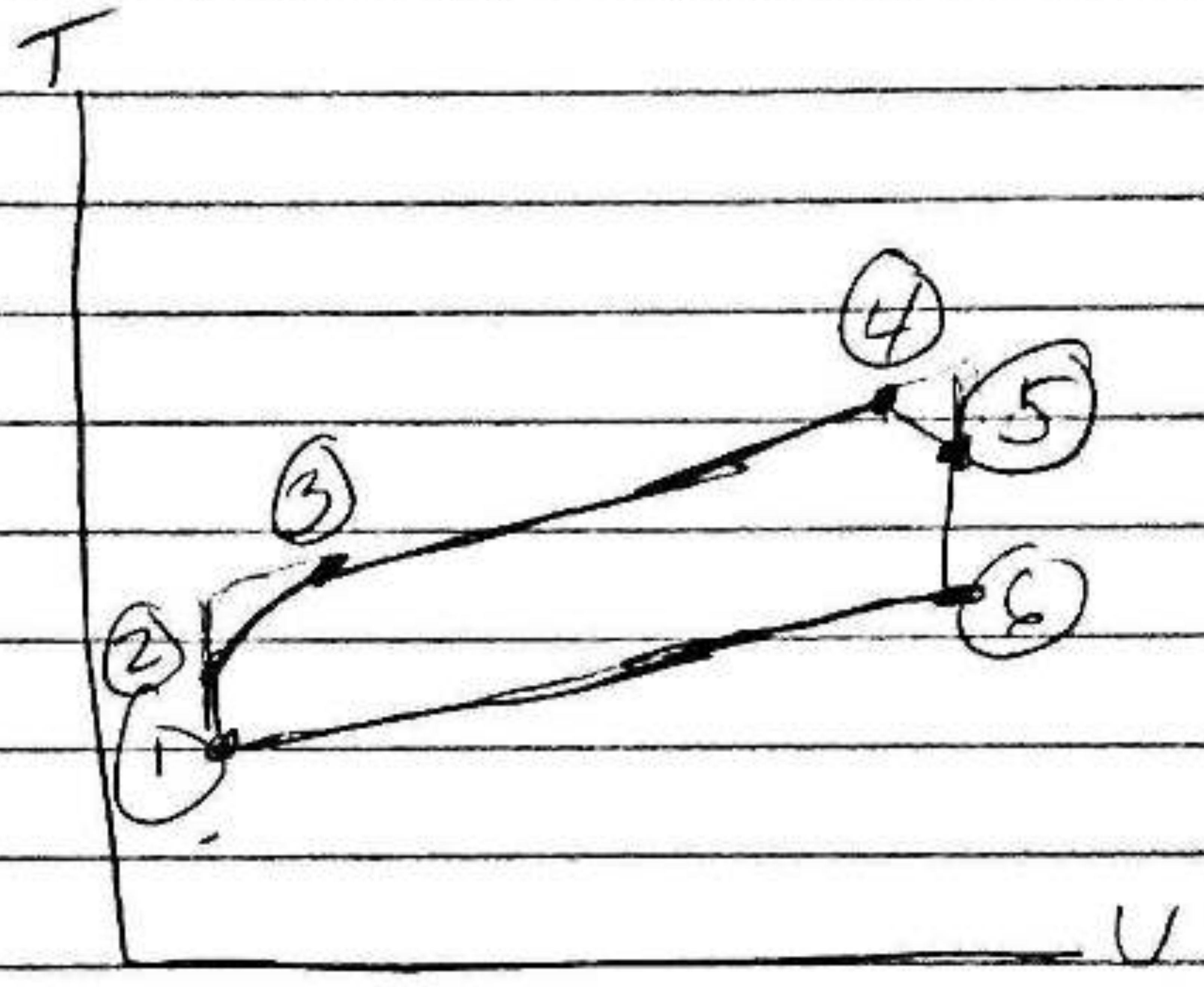
(5)

QUESTION 2 Test 1

Purpose: Find the pressure of combustion gases At the turbine exit. Find the velocity of the gasses At the nozzle exit. Find the thrust for this engine If the diffuser inlet diameter is 1.6 with A velocity of 900 km/h.

Diagrams:





Sources:

- Cengel & Boles Thermodynamic An Engineering Approach 8th edition McGraw Hill 2015
- Chapter notes & lessons MET 350

Design Considerations:

I Assume the Following

1) Air behave as Ideal gas
2) Cp & Cv Variable
3) $N_C = 0.8$
4) $N_T = 0.9$
5) Constant pressure heat

(b)

DATA & VARIABLES:

$V = 900\ km/h = 250\ m/s$

$T = -35^0C \quad P = 40\ kPa$

$T_{turb} = 950^\circ C$

$WT = 500\ kJ/kg$

$Inlet = 1,6m$

$\eta_c = 0,8$

$\eta_T = 0,9$

MATERIALS:

Air AS AN Ideal GAS

Procedural CALCULATIONS: SEE TABLE

(1) $P_1 = 40\ kPa$

$T_1 = 238,15\ K$

$V_1 = 250\ m/s$

$h_1 = 238,17\ \frac{kJ}{kg}$

$P_{r1} = 0,6192$

$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$$

$$\frac{P_2}{P_1} = \frac{P_{r2}}{P_{r1}} \quad P_2 = \frac{P_{r2}}{P_{r1}} = 61,42\ kPa$$

(2) $P_2 = 61,42\ kPa$

$T_2 = 269,3\ K$

$h_2 = 269,42\ \frac{kJ}{kg}$

$P_{r2} = 0,9608$

$$WC = 500\ kJ/kg$$

$$WC = \frac{h_3 - h_2}{WC} \quad h_3 = h_2 + WC\ in$$

$$h_3 = 669,4$$

(3) $P_3 = 1485,6\ kPa$

$T_3 = 657,4\ K$

$h_3 = 669,4\ \frac{kJ}{kg}$

$T_{3a} = 751,96$

$$\frac{P_3}{P_2} = \frac{P_{r4}}{P_{r2}} \quad P_3 = 1485,6$$

$$\eta_c = \frac{h_3 - h_2}{h_{3a} - h_2} = h_{3c} = 7?4$$

(4) $P_4 = 1485,6\ kPa$

$h_4 = 1305,03\ kJ/kg$

$P_{r4} = 257,47\ kPa$

$T_4 = 1223,1\ K$

$$P_4 = P_3$$

(7)

(5) $P_5 = 198.2$ kPa
$T_5 = 733.5$ K
$h_5 = 749.4$ kJ/kg
$P_{r5} = 34.35$
$T_{5a} = 780$ K

$w_T = \eta_T (h_4 - h_5)$
$h_5 = h_4 - \frac{w_T}{\eta_T}$
$h = 749.47$ kJ/kg

$\frac{P_5}{P_4} = \frac{P_{r5}}{P_{r4}}$

(6) $P_6 = 40$ kPa
$T_6 = 473.6$ K
$h_6 = 475.9$ kJ/kg
$P_{r6} = 6.93$

$\eta_T = \frac{h_4 - h_5}{h_4 - h_{5a}}$
$h_{5a} = 800.03$ kJ/kg
$= 780$ K

$P_6 = P_1 = 40$ kPa

$\frac{P_6}{P_5} = \frac{P_{r6}}{P_{r5}}$ $P_{r6} = 6.93$

(a) $P_{ext} = P_5 = 198.12$ kPa

(b) $h_{5a} + \frac{V_{5a}^2}{2} = h_6 + \frac{V_6^2}{2}$ $V_6 = \sqrt{2(h_{5a} - h_6)}$
$\boxed{V_6 = 805.10 \text{ m/s}}$

(c) $F = \dot{m}(V_{ext} - V_{int})$
$\dot{m} = \rho_1 V_1 A_1 = \frac{V_1}{v_1} \frac{\pi}{4} D^2$ $v_1 = \frac{RT_1}{P_1}$

$F = \frac{V_1 P_1}{RT_1} \frac{\pi}{4} D^2 (V_6 - V_1)$
$\boxed{F = 163.2 \text{ kN}}$

Summary:

(a) Turbine exit = 198.12 kPa

(b) Velocity @ exit 806.10 m/s

(c) Thrust inlet dia 1.6 = 163.29 kN

ANALYSIS:

As we can see with this answer the amount of efficiency determine the amount of thrust. For example I would expect higher efficiency would mean higher thrust.

(2)

(3)

(4)