

**PRAIRIE VIEW A&M UNIVERSITY
ROY G. PERRY COLLEGE OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING
MCEG 3023 THERMODYNAMICS II
FALL 2021**

- I. COURSE DESCRIPTION IN ABET FORMAT**
- II. ASSESSMENT RESULTS FOR CURRENT AND PAST THREE PERIODS**
Program Outcomes Assessed in Course
Assessment Summary of Class Semester Averages for Outcomes
End of Semester Course Outcomes Assessment Reports
- III. TESTS**
Summary of Topics covered by Test
Original Test Questions & Master Solution/grading scheme used
(Summary of topics can be a separate page or include on the assignment itself)
 - Above Average (Graded original work)
 - Average (Graded original work)
 - Below Average (Graded original work)
- IV. DESIGN ASSIGNMENT**
Summary of Topics covered By Design Assignment
 - Above Average (Graded original work)
 - Average (Graded original work)
 - Below Average (Graded original work)
- V. QUIZZES/HOME ASSIGNMENTS**
Summary of Topics covered by Quiz
Original Quiz Questions & Master Solution/grading scheme used
 - Above Average (Graded original work)
 - Average (Graded original work)
 - Below Average (Graded original work)

Course Description in ABET Format

MECHANICAL ENGINEERING DEPARTMENT MCEG 3023 THERMODYNAMICS II

Please use the following format for the course syllabi (2 pages maximum in Times New Roman 12 point font)

1.	Course number and name:	MCEG 3023 THERMODYNAMICS II
2.	Credits and contact hours:	3 credit hours; 3 contact hours
3.	Instructor's or course coordinator's name:	Dr. Ziaul Huque
4.	Text book: Title:	Thermodynamics, An Engineering Approach
	Author:	Yunus A. Çengel, and Michael A. Boles
	Publisher, Year & Edition:	9 th Edition, McGraw-Hill, Higher Education, 2019: ISBN 978-1-259-82267-4
	a. Other Supplemental material	1. "Funds of Engineering Thermodynamics," by Michael Moran, 5th Edition, Wiley & Sons, 2004. 2. "Fundamentals of Thermodynamics," Richard Sonntag, Claus Borgnakke, and Gordon J. Van Wylen, 6th Edition, John Wiley & Sons, 2003. 3. Thermodynamics, Edward E. Anderson, PWS Publishing Company, 1994. 4. Thermodynamics, Concepts and Applications by Stephen R. Turns, Cambridge University Press, New York, 2006. 5. Engineering Thermodynamics, by Dwight C. Look, Jr., PWS Publishing, Boston, 1986
5.	Specific course information	
	a. Brief description of the content of the course (catalog description)	MCEG 3023. Thermodynamics II. (3-0) Credit 3 semester hours. Continuation of Thermodynamics I, including various power cycles, refrigeration cycles, fluid flow, combustion process, and advanced concepts of gas dynamic such as shock waves.
	b. Prerequisites or Co-requisites	MCEG 2013 Thermodynamics I MATH 2024 Calculus II
	c. *Indicate whether a required, elective, or selected elective (as per definition provided) course in the program	Required course
6.	Specific goals for the course	Students will be able to :
	a. Specific outcomes of instruction (e.g. The student will be able to explain the significance of current	i. Solve the energy and exergy balance problems. ii. Identify, formulate, solve intermediate, advanced and complex thermodynamic engineering problems.

	research about a particular topic.)	
	b. Explicitly indicate which of the student outcomes listed in Criterion 3 or any other outcomes are addressed by the course.	This course addresses: Outcome 2 An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
7	Brief list of topics to be covered	Overview of Thermodynamics Exergy and Irreversibility Vapor Power Systems Gas Power Systems Mixtures and Psychometrics Reacting Mixtures and Combustion Refrigeration & Heat Pump Thermodynamic Relations

***Required** courses are required of all students in the program, **elective** courses (often referred to as open or free electives) are optional for students, and **selected elective** courses are those for which students must take one or more courses from a specified group.

THERMODYNAMICS II
FALL 2021

Title of Assignment: TEST 1

TOPICS COVERED IN TEST 1

Test 1 covered the following topics:

1. Change of Exergy.
2. Exergy Destructions.
3. Exergetic Efficiency.
4. Gas Power Cycle.

THERMODYNAMICS II
FALL 2021

**SAMPLE TEST QUESTIONS, SOLUTION,
AND GRADING SCHEME FOR TEST 1**

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3302 Y01 : Thermodynamics II
Fall 2021
Exam #1

Name: Solution Score: _____

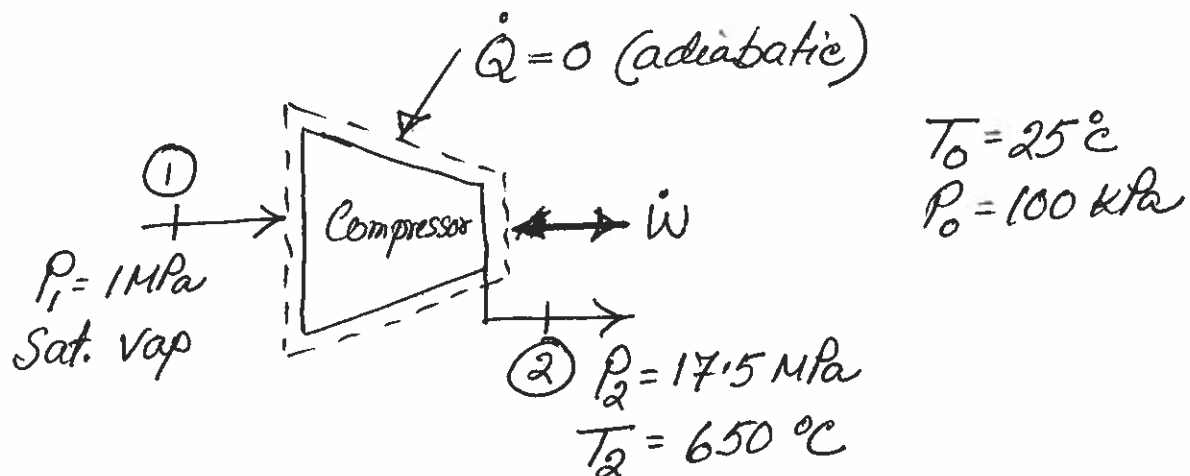
- (1) An adiabatic compressor is used to bring saturated water vapor at 1 MPa up to 17.5 MPa, where the actual exit temperature is 650 °C. Let $T_o = 25\text{ °C}$, $p_o = 100\text{ kPa}$.
- (i) Draw the schematic of the problem (4 pts)
 - (ii) Determine specific volume, enthalpy, and entropy at the inlet (9 pts)
 - (iii) Determine the specific volume, enthalpy, and entropy at the exit (9 pts)
 - (iv) What is the change of exergy between the exit and the inlet of the compressor (10 pts)
 - (v) What is the work supplied to the compressor (6 pts)
 - (vi) What is the minimum work the compressor requires (5 pts)
 - (vii) What is the exergy destroyed in the turbine (5 pts)
 - (viii) What is the 2nd Law efficiency or the exergetic efficiency of the compressor (2 pts)
- (2) Air enters the compressor of an air-standard Brayton Cycle with a volumetric flow rate of 60 m³/s at 0.8 bars and 280 K. The pressure ratio of the cycle is 20 and the maximum cycle temperature is 2300 K.
- (i) Draw the P-v and the T-s diagram of the cycle with the input conditions shown in the figures (4 pts)
 - (ii) Mass flow rate of air in the system (4 pts)
 - (iii) P, T, and v at the beginning of the compressor. (6 pts)
 - (iv) P, T, and v at the exit of the compressor (6 pts)
 - (v) P, T, and v at the exit of the combustor (6 pts)
 - (vi) P, T, and v at the exit of the turbine (6 pts)
 - (vii) Heat addition in combustor (4 pts)
 - (viii) Heat rejection in condenser (4 pts)
 - (ix) The net work of the cycle (5 pts)
 - (x) Thermal efficiency of the cycle (5 pts)

Note:

1. Show detailed steps to get full credit
2. Show unit conversions

#1

(i)



(ii) open system/control volume
working fluid $\rightarrow$ steam $\rightarrow$ need phase at each state

Inlet is state ①

at $P_1 = 1 \text{ MPa} = 1000 \text{ kPa}$ (from Pressure Saturation Table A-5)

$$v_1 = v_{g,1} = 0.19436 \text{ m}^3/\text{kg}$$

$$h_1 = h_{g,1} = 2777.1 \text{ kJ/kg}$$

$$s_1 = s_{g,1} = 6.5850 \text{ kJ/kg}\cdot\text{K}$$

(iii) Exit is state ②

At $P_2 = 17.5 \text{ MPa} = 17500 \text{ kPa}$, $T_{2,\text{sat}} = 354.64^\circ \text{C}$
since $T_2 = 650^\circ \text{C} > T_{2,\text{sat}} = 354.64^\circ \text{C} \rightarrow$ superheated

From superheat Table A-6

at $P_2 = 17.5 \text{ MPa}$ and $T_2 = 650^\circ \text{C}$

$$v_2 = 0.022742 \text{ m}^3/\text{kg}; \quad h_2 = 3693.8 \text{ kJ/kg}$$

$$s_2 = 6.7366 \text{ kJ/kg}\cdot\text{K}$$

①

$$(iv) \dot{X}_2 - \dot{X}_1 = \dot{m} \left[(h_2 - h_1) - T_0 (s_2 - s_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1) \right]$$

$V_2^2 - V_1^2$ not given

$$\Rightarrow \frac{\dot{X}_2 - \dot{X}_1}{\dot{m}} = (h_2 - h_1) - T_0 (s_2 - s_1)$$

$$\begin{aligned} \Rightarrow \psi_2 - \psi_1 &= (3693.8 - 2777.1) \frac{\text{kJ}}{\text{kg}} - 298 \text{ K} (6.7366 - 6.5850) \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \\ &= (916.7 - 45.18) \text{ kJ/kg} \\ &= \boxed{871.52 \text{ kJ/kg}} \end{aligned}$$

(v) To find the work we use the energy balance equation

$$\dot{Q} - \dot{W} = \dot{m} [(h_2 - h_1) + \cancel{\Delta KE} + \cancel{\Delta PE}]$$

$$\Rightarrow - \frac{\dot{W}}{\dot{m}} = h_2 - h_1 = (3693.8 - 2777.1) \text{ kJ/kg} \\ = \boxed{916.7 \text{ kJ/kg}}$$

(vi) The minimum work the compressor requires is the reversible work which we can get from energy balance

$$\dot{Q} \left(1 - \frac{T_0}{T} \right) - \dot{W}_u - \cancel{T_0 \dot{S}_{gen}} = \dot{X}_2 - \dot{X}_1$$

adiabatic to get reversible work

$$\therefore - \dot{W}_{rev} = \dot{X}_2 - \dot{X}_1$$

$$\Rightarrow - \dot{m} W_{rev} = \dot{m} (\psi_2 - \psi_1)$$

$$\Rightarrow - W_{rev} = 871.52 \text{ kJ/kg} \quad \left[\dot{W}_u = \dot{W} \text{ for an open system} \right]$$

(2)

$$\therefore \boxed{W_{rev} = -871.52 \text{ kJ/kg}}$$

(vii) Energy destroyed can be obtained in two ways: (a) from exergy balance eqn and (b) from $T_0 S_{gen}$.

$$(a) \dot{Q} \left(1 - \frac{T_0}{T}\right) - \dot{W} - T_0 \dot{S}_{gen} = \dot{X}_2 - \dot{X}_1$$

$$\Rightarrow -\dot{W} - T_0 \dot{S}_{gen} = \psi_2 - \psi_1$$

$$\Rightarrow -(-916.7 \text{ kJ/kg}) - T_0 \dot{S}_{gen} = 871.52 \text{ kJ/kg}$$

$$\Rightarrow T_0 \dot{S}_{gen} = (871.52 - 916.7) \text{ kJ/kg} = -45.18 \text{ kJ/kg}$$

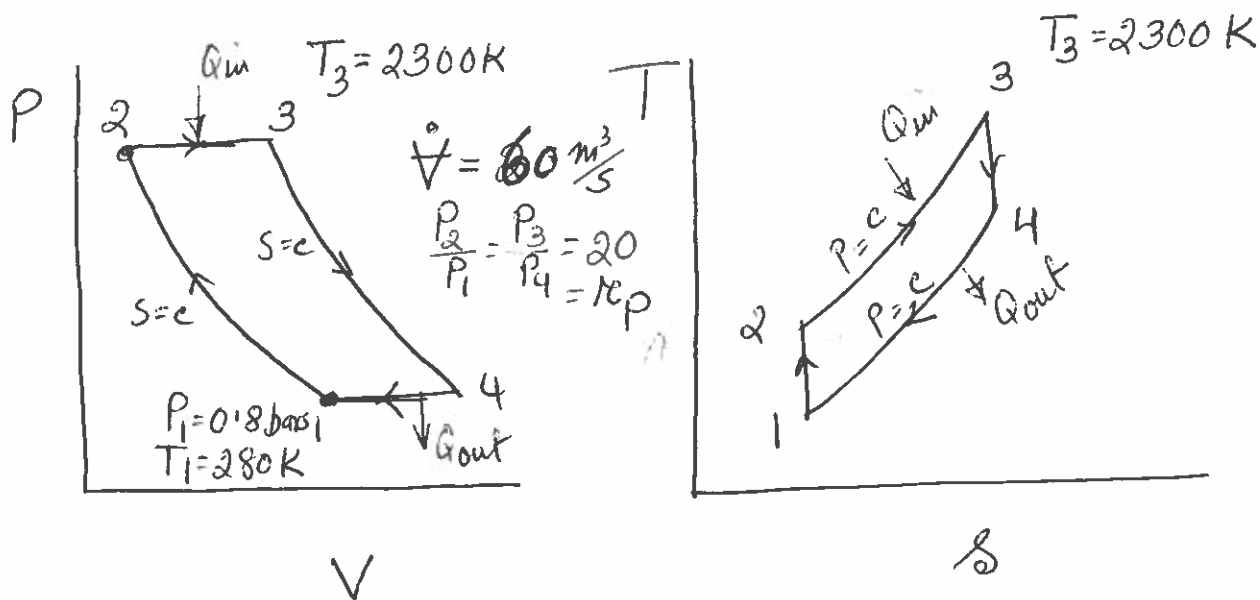
$$\Rightarrow T_0 \dot{S}_{gen} = X_{destroyed} = \boxed{45.18 \text{ kJ/kg}}$$

(viii) 2nd Law efficiency

$$\eta_{II} = \frac{W_{rev}}{W} = \frac{871.52 \text{ kJ/kg}}{916.7 \text{ kJ/kg}} = \boxed{0.951}$$

#2

(i)



(ii) $\dot{m} = \frac{\dot{V}}{v}$

at state ① $P_1 v_1 = R T_1$

$R_{\text{air}} = 0.287 \frac{\text{KJ}}{\text{kg} \cdot \text{K}}$

$$\Rightarrow v_1 = \frac{R T_1}{P_1} = \frac{(0.287 \frac{\text{KJ}}{\text{kg} \cdot \text{K}})(280 \text{ K})}{0.8 \text{ bars} \frac{100 \text{ kPa}}{1 \text{ bar}}} = \frac{1 \text{ KPa} \cdot \text{m}^3}{1 \text{ KJ}} = \boxed{1.0045 \frac{\text{m}^3}{\text{kg}}}$$

$$\therefore \dot{m} = \frac{\dot{V}}{v} = \frac{60 \frac{\text{m}^3}{\text{s}}}{1.0045 \frac{\text{m}^3}{\text{kg}}} = \boxed{59.73 \text{ kg/s}}$$

(iii) $P_1 = 0.8 \text{ bars} = 80 \text{ kPa}$ (given)

$T_1 = 280 \text{ K}$ (given)

$v_1 = 1.0045 \text{ m}^3/\text{kg}$ (from (i))

(iv) exit of the compressor is state ②

$\frac{P_2}{P_1} = \kappa_p = 20$

$\therefore P_2 = P_1 \times 20 = 80 \text{ kPa} \times 20 = \boxed{1600 \text{ kPa}}$

(4)

Process 1-2 is an isentropic process. Therefore we use the isentropic relation

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(K-1)/K} \quad K = 1.4 \text{ for air}$$

$$\Rightarrow T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{K-1/K} = (280 \text{ K})(20)^{\frac{1.4-1}{1.4}} = \boxed{659 \text{ K}}$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^K \Rightarrow \frac{V_1}{V_2} = \left(\frac{P_2}{P_1}\right)^{1/K} = (20)^{1/1.4} = 8.498$$

$$\therefore V_2 = V_1 / 8.498 = \frac{1.0045 \text{ m}^3/\text{kg}}{8.498} = \boxed{0.1182 \text{ m}^3/\text{kg}}$$

(v) Exit of combustor is state ③.

$$P_3 = P_2 = \boxed{1600 \text{ kPa}}$$

$$T_3 = \boxed{2300 \text{ K}} \text{ given}$$

apply ideal gas relation for state ③

$$P_3 V_3 = RT_3 \Rightarrow V_3 = \frac{RT_3}{P_3} = \frac{0.287 \times 2300}{1600} = \boxed{0.4126 \text{ m}^3/\text{kg}}$$

(vi) Exit of the turbine is state 4.

Process 3-4 is an isentropic process. Therefore we will apply isentropic relation

$$P_4 = P_1 = \boxed{80 \text{ kPa}}$$

$$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{K-1}{K}} \Rightarrow T_4 = T_3 \left(\frac{1}{20}\right)^{\frac{1.4-1}{1.4}} = (2300 \text{ K})(0.4249)$$

$$\Rightarrow \boxed{T_4 = 977.2 \text{ K}}$$

$$\frac{P_4}{P_3} = \left(\frac{V_3}{V_4}\right)^K \Rightarrow P_4 = P_3 \left(\frac{V_3}{V_4}\right)^K = (1600) \left(\frac{0.4126}{V_4}\right)^{1.4}$$

or

$$\frac{V_3}{V_4} = \left(\frac{P_4}{P_3}\right)^{\frac{1}{K}} \Rightarrow \frac{0.4126}{V_4} = \left(\frac{80}{1600}\right)^{\frac{1}{1.4}} \Rightarrow \boxed{V_4 = 3.506 \text{ m}^3/\text{kg}}$$

$$(vii) \quad Q_{in} = \dot{m}(h_3 - h_2)$$

$$h_3 @ T_3 = 2300 = 2629.6 \text{ kJ/kg after extrapolation}$$

$$h_2 @ T_2 = 659 \text{ K} = 670.47 \text{ kJ/kg}$$

$$\therefore Q_{in} = (59.73 \text{ kg/s})(2629.6 - 670.47) \text{ kJ/kg} = \boxed{117,018 \text{ kJ/sec}}$$

$$(viii) \quad Q_{out} = \dot{m}(h_4 - h_1)$$

$$h_4 @ T_4 = 977.2 \text{ K} \Rightarrow \frac{977.2 - 960}{980 - 960} = \frac{h_4 - 1000.55}{1023.25 - 1000.55}$$

$$\Rightarrow h_4 = 1020.1 \text{ kJ/kg}$$

$$h_1 @ T_1 = 280 \text{ K} = 280.13 \text{ kJ/kg}$$

$$\therefore Q_{out} = (59.73)(1020.1 - 280.13) = \boxed{44,198.4 \text{ kJ/s}}$$

$$(ix) \quad \text{Net work of the cycle}$$

$$W_{cycle} = Q_{in} - Q_{out} = (117,018 - 44,198) \text{ kJ/s} = \boxed{72,820 \text{ kJ/s}}$$

$$(x) \quad \eta_{th} = \frac{W_{cycle}}{Q_{in}} = \frac{72,820 \text{ kJ/s}}{117,018 \text{ kJ/s}} = 0.6223 = \boxed{62.23\%}$$

ABOVE AVERAGE

Above Average Student Original Graded Assignment

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3302 Y01 : Thermodynamics II
Fall 2021
Exam #1

Name: Heba Afzal Score: 85

- (1) An adiabatic compressor is used to bring saturated water vapor at 1 MPa up to 17.5 MPa, where the actual exit temperature is 650 °C. Let $T_o = 25$ °C, $p_o = 100$ kPa.
- (i) Draw the schematic of the problem (4 pts) ✓
 - (ii) Determine specific volume, enthalpy, and entropy at the inlet (9 pts) ✓
 - (iii) Determine the specific volume, enthalpy, and entropy at the exit (9 pts) ✓
 - (iv) What is the change of exergy between the exit and the inlet of the compressor (10 pts) ✓
 - (v) What is the work supplied to the compressor (6 pts) ?
 - (vi) What is the minimum work the compressor requires (5 pts) ✓
 - (vii) What is the exergy destroyed in the turbine (5 pts) $X_{dest} = T_o S_{gen}$ ✓ $\Delta S = \int \frac{\delta Q}{T} + S_{gen}$
 - (viii) What is the 2nd Law efficiency or the exergetic efficiency of the compressor (2 pts) ✓ $S_{gen} = \Delta S$
- (2) Air enters the compressor of an air-standard Brayton Cycle with a volumetric flow rate of 60 m³/s at 0.8 bars and 280 K. The pressure ratio of the cycle is 20 and the maximum cycle temperature is 2300 K.
- (i) Draw the P-v and the T-s diagram of the cycle with the input conditions shown in the figures (4 pts)
 - (ii) Mass flow rate of air in the system (4 pts)
 - (iii) P, T, and v at the beginning of the compressor. (6 pts)
 - (iv) P, T, and v at the exit of the compressor (6 pts)
 - (v) P, T, and v at the exit of the combustor (6 pts)
 - (vi) P, T, and v at the exit of the turbine (6 pts)
 - (vii) Heat addition in combustor (4 pts)
 - (viii) Heat rejection in condenser (4 pts)
 - (ix) The net work of the cycle (5 pts)
 - (x) Thermal efficiency of the cycle (5 pts)

Note:

1. Show detailed steps to get full credit
2. Show unit conversions

72 → 85

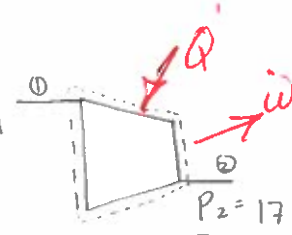
① - Adiabatic Compressor $Q=0$

- working Fluid - Sat water vapor

- open system [usc h] so values @ $h_g, h_g, v_g, \dots$

i)

$P_1 = 1 \text{ MPa}$



$T_0 = 25^\circ\text{C}$
 $P_0 = 100 \text{ kPa}$
 $Q = 0$
 $P_2 = 17.5 \text{ MPa}$
 $T_2 = 650^\circ\text{C}$

II) Det. v_1, h_1, s_1

$$v_g)_{1000 \text{ kPa}} = 0.19436 \text{ m}^3/\text{kg} = v_1$$

$$T_{\text{sat}})_{1000 \text{ kPa}} = 179.88^\circ\text{C}$$

$$1 \text{ MPa} = 1000 \text{ kPa}$$

$$\begin{aligned} \phi - w &= \Delta h \\ 0 &= h_2 - h_1 \\ h_1 &= h_2 \end{aligned}$$

$$h_g)_{1000 \text{ kPa}} = 2777.1 \text{ kJ/kg} = h_1$$

$$h = h_f + x h_{fg}$$

$$s_g)_{1000 \text{ kPa}} = 6.585 \text{ kJ/kg K} = s_1$$

$$v = \frac{V}{m}$$

$$T_0 = 25 + 273 = 298$$

III) Det. v_2, h_2, s_2

$$v_2)_{17.5 \text{ MPa}} = 0.022742 \text{ m}^3/\text{kg}$$

low?
what
phase?

$$P_0 = 100 \text{ kPa} \frac{1 \text{ MPa}}{1000 \text{ kPa}} =$$

$$P_0 = 0.1 \text{ MPa}$$

$$T_0 = 298 \text{ K}$$

open?
closed?

$$h_2)_{17.5 \text{ MPa}} = 3693.8 \text{ kJ/kg}$$

$$s_2)_{17.5 \text{ MPa}} = 6.7366 \text{ kJ/kg K}$$

$$\text{IV) } \Delta X = m \left[h_2 - h_1 - T_0 (s_2 - s_1) + P_0 (v_2 - v_1) \right] + m \left[\frac{v_2^2 - v_1^2}{2} + (z_2 - z_1) \right]$$

$$\frac{\Delta X}{m} = (h_2 - h_1) - T_0 (s_2 - s_1) + P_0 (v_2 - v_1)$$

$$\frac{\Delta X}{m} = (3693.8 \text{ kJ/kg} - 2777.1 \text{ kJ/kg}) - (25^\circ + 273)(6.7366 \text{ kJ/kg K} - 6.585 \text{ kJ/kg K})$$

$$\frac{\Delta X}{m} = 699.9052 \text{ kJ/kg}$$

$$+ 1000 \text{ kPa} (0.022742 \text{ m}^3/\text{kg} - 0.19436 \text{ m}^3/\text{kg})$$

$$\text{V) } \phi - w = m \left(h_2 - h_1 + \frac{v_2^2 - v_1^2}{2} + g(z_2 - z_1) \right)$$

$$-\frac{w}{m} = (h_2 - h_1) + \frac{v_2^2 - v_1^2}{2}$$

$$-\frac{w}{m} = (3693.8 \text{ kJ/kg} - 2777.1 \text{ kJ/kg}) + \frac{(0.022742 \text{ m}^3/\text{kg})^2 - (0.19436 \text{ m}^3/\text{kg})^2}{2}$$

$$916.7 + (-0.01862) = 916.68$$

$$w = 916.68 \text{ kJ/kg}$$

$$\text{VI) } \frac{W_{\text{min}}}{m} = \frac{\Delta X}{m} = 699.9052 \text{ kJ/kg}$$

①

$$\text{VI) } X_{\text{dest}} = T_0 S_{\text{gen}}$$

$$\Delta S = \int \frac{\delta Q}{T} + S_{\text{gen}}$$

$$S_2 - S_1 = S_{\text{gen}}$$

$$\Delta_2 - \Delta_1 = S_{\text{gen}}$$

$$6.7366 \text{ kJ/kgK} - 6.585 \text{ kJ/kgK} = S_{\text{gen}}$$

$$0.1516 \text{ kJ/kgK} = S_{\text{gen}}$$

$$X_{\text{dest}} = T_0 S_{\text{gen}}$$

$$= 298 \text{ K} (0.1516 \text{ kJ/kgK})$$

$$= 45.1768 \text{ kJ/kg}$$

$$\text{VIII) } \eta = \frac{W_{\text{rev}}}{W} = \frac{699.9052 \text{ kJ/kg}}{916.68 \text{ kJ/kg}} = 0.764 \approx 76.4\%$$

$$T_0 = 25^\circ\text{C} + 273$$

$$T_0 = 298 \text{ K}$$

36

$$\dot{V} = 60 \text{ m}^3/\text{s}$$

$$P_1 = 0.8 \text{ bar}$$

$$T_1 = 280 \text{ K}$$

$$r_p = 20$$

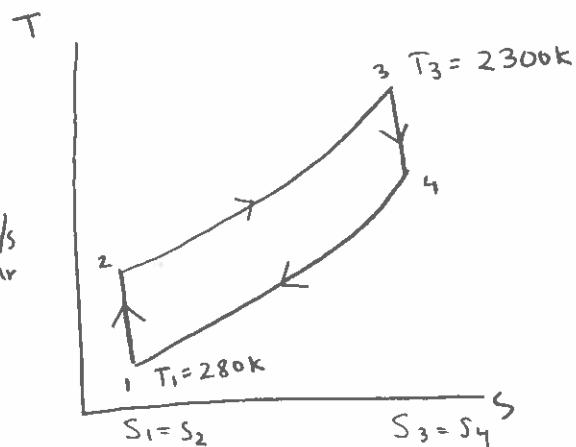
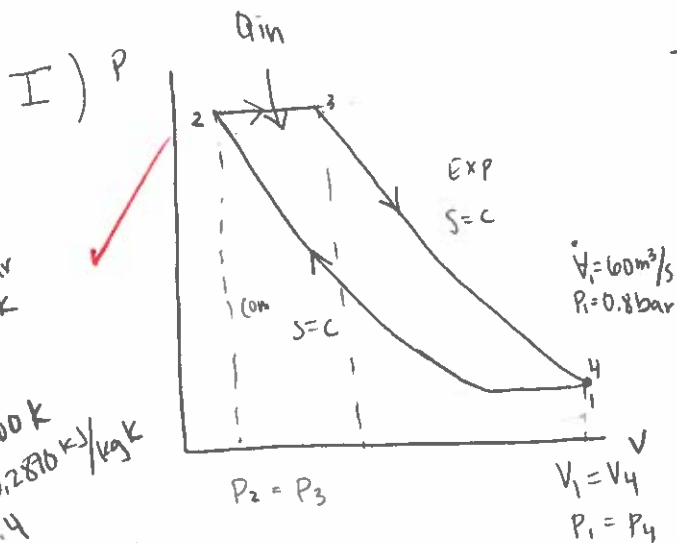
$$T_3 = 2300 \text{ K}$$

$$R_{\text{air}} = 0.2870 \text{ kJ/kgK}$$

$$k = 1.4$$

- isentropic B/ 1-2, 3-4 (use relations)

$S = c$ isentropic



II) find $\dot{m}$

$$PV = mRT \quad \frac{P_1 \dot{V}_1}{RT_1} = \dot{m}$$

$$\frac{80 \text{ kPa} (60 \text{ m}^3/\text{s})}{(0.2870 \text{ kJ/kgK})(280 \text{ K})} = \dot{m}$$

$$59.73 \text{ kg/s} = \dot{m}$$

$$0.8 \text{ bar} \times \frac{100 \text{ kPa}}{1 \text{ bar}} = 80 \text{ kPa}$$

$$\frac{P_4}{P_3} = r_p$$

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

$$v = \frac{\dot{V}}{\dot{m}}$$

$$= \frac{60 \text{ m}^3/\text{s}}{59.73 \text{ kg/s}}$$

$$= 1.0045 \text{ m}^3/\text{kg}$$

III) $P_1 = 0.8 \text{ bar}$ or 80 kPa
 $V_1 = 1.0045 \text{ m}^3/\text{kg}$
 $T_1 = 280 \text{ K}$

$$PV = RT$$

$$V_1 = \frac{RT}{P} = \frac{0.2870 \text{ kJ/kgK} (280 \text{ K})}{80 \text{ kPa}} = 1.0045 \text{ m}^3/\text{kg}$$

IV) $P_2 = 1600 \text{ kPa}$ or 16 Bar
 $V_2 = 0.118 \text{ m}^3/\text{kg}$
 $T_2 = 658.99 \text{ K}$

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

$$20 = \frac{P_2}{80 \text{ kPa}}$$

$$1600 \text{ kPa} = P_2$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}}$$

$$T_2 = \left(\frac{1600}{80 \text{ kPa}} \right)^{\frac{1.4-1}{1.4}} (280 \text{ K})$$

$$T_2 = 658.99 \text{ K}$$

V) $P_3 = P_2 = 1600 \text{ kPa}$
 $V_3 = 0.4125$
 $T_3 = 2300 \text{ K}$

$$V = \frac{RT}{P}$$

$$V = \frac{0.2870 (2300 \text{ K})}{1600 \text{ kPa}}$$

$$V_2 = \frac{RT}{P}$$

VI) $V_4 = V_1 = 1.0045 \text{ m}^3/\text{kg}$
 $P_4 = P_1 = 80 \text{ kPa}$
 $T_4 = 280 \text{ K}$

$$T = PV/R$$

$$(3) = \frac{80 (1.0045)}{0.2870}$$

$$V_2 = \frac{0.2870 (658.99)}{1600}$$

$$\text{VII) } Q_{in} = \dot{m} C_v \Delta T \quad C \text{ is not constant.}$$

$$59.73 (1.005) (2300 - 658.99)$$

$$= 1649.215$$

$$\text{VIII) } Q_{out} = m C_v \Delta T$$

$$= 59.73 (1.005) ($$

$$= 0 \quad \text{X}$$

~~IX~~

$$\text{IX) } W_{cycle} = Q_{in} - Q_{out} = 1649.215$$

$$\text{X) } \eta = \frac{W_{cycle}}{Q_{in}} = \dots$$

$$W_{cycle} = Q_{in} - Q_{out}$$

$$Q - W =$$

$$C_v = 1.005$$

AVERAGE

Average Student Original Graded Assignment

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3302 Y01 : Thermodynamics II
Fall 2021
Exam #1

Name: Caleb Combs Score: 79

- (1) An adiabatic compressor is used to bring saturated water vapor at 1 MPa up to 17.5 MPa, where the actual exit temperature is 650 °C. Let $T_o = 25$ °C, $p_o = 100$ kPa.
- (i) Draw the schematic of the problem (4 pts)
 - (ii) Determine specific volume, enthalpy, and entropy at the inlet (9 pts)
 - (iii) Determine the specific volume, enthalpy, and entropy at the exit (9 pts)
 - (iv) What is the change of exergy between the exit and the inlet of the compressor (10 pts)
 - (v) What is the work supplied to the compressor (6 pts)
 - (vi) What is the minimum work the compressor requires (5 pts)
 - (vii) What is the exergy destroyed in the turbine (5 pts)
 - (viii) What is the 2nd Law efficiency or the exergetic efficiency of the compressor (2 pts)
- (2) Air enters the compressor of an air-standard Brayton Cycle with a volumetric flow rate of 60 m³/s at 0.8 bars and 280 K. The pressure ratio of the cycle is 20 and the maximum cycle temperature is 2300 K.
- (i) Draw the P-v and the T-s diagram of the cycle with the input conditions shown in the figures (4 pts)
 - (ii) Mass flow rate of air in the system (4 pts)
 - (iii) P, T, and v at the beginning of the compressor. (6 pts)
 - (iv) P, T, and v at the exit of the compressor (6 pts)
 - (v) P, T, and v at the exit of the combustor (6 pts)
 - (vi) P, T, and v at the exit of the turbine (6 pts)
 - (vii) Heat addition in combustor (4 pts)
 - (viii) Heat rejection in condenser (4 pts)
 - (ix) The net work of the cycle (5 pts)
 - (x) Thermal efficiency of the cycle (5 pts)

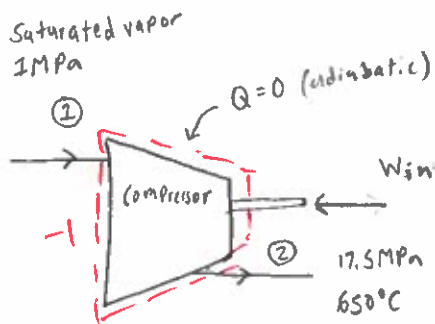
Note:

1. Show detailed steps to get full credit
2. Show unit conversions

(1)

(i)

47



$$T_0 = 25^\circ\text{C}$$

$$P_0 = 100\text{ kPa}$$

62 $\rightarrow$ (79)

(ii)

$$v_g = 0.19436\text{ m}^3/\text{kg}, \quad h_g = 2777.1\text{ kJ/kg}, \quad s_g = 6.5850\text{ kJ/kg}\cdot\text{K}$$

(iii)

From table A-6, at 17.5 MPa and 650°C (need to show the phase at state 2!)

$$v_2 = 0.022742\text{ m}^3/\text{kg}, \quad h_2 = 3693.8\text{ kJ/kg}, \quad s_2 = 6.7366\text{ kJ/kg}\cdot\text{K}$$

(iv)

$$\dot{X}_2 - \dot{X}_1 = \dot{m}[(h_2 - h_1) - T_0(s_2 - s_1)] + \cancel{\dot{m} \frac{v_2^2 - v_1^2}{2}} + \cancel{\dot{m}g(z_2 - z_1)}$$

$$\dot{X}_2 - \dot{X}_1 = \dot{m}[(3693.8\text{ kJ/kg} - 2777.1\text{ kJ/kg}) - (298.15\text{ K})(6.7366\text{ kJ/kg}\cdot\text{K} - 6.5850\text{ kJ/kg}\cdot\text{K})]$$

$$\dot{X}_2 - \dot{X}_1 = \dot{m}(871.500\text{ kJ/kg})$$

$\downarrow$ unit conversion

$$\dot{X}_2 - \dot{X}_1 = 871.500\text{ kJ/kg}$$

(1)

(V) $\dot{Q} - \dot{W} = \dot{m}(h_2 - h_1)$ open system.

$\dot{Q} - \dot{W} = (3693.8 - 2777.1) \text{ (KJ/Kg)}$

$\dot{W} = 916.7 \text{ KJ/Kg}$

(vi) $W_{rev} = X_2 - X_1 = 871.500 \text{ KJ/Kg}$ Should show this relation from exergy balance

(vii) $X_{destroyed} = T_0 S_{gen}$

$S_2 - S_1 = \int_1^2 \frac{\dot{Q}}{T_b} + S_{gen}$

$S_{gen} = (6.7366 \text{ KJ/Kg} \cdot \text{K}) - (6.5850 \text{ KJ/Kg} \cdot \text{K})$

$= 0.1516 \text{ KJ/Kg} \cdot \text{K}$

$X_{destroyed} = T_0 S_{gen} = (298.15 \text{ K})(0.1516 \text{ KJ/Kg} \cdot \text{K}) = 45.1995 \text{ KJ/Kg}$

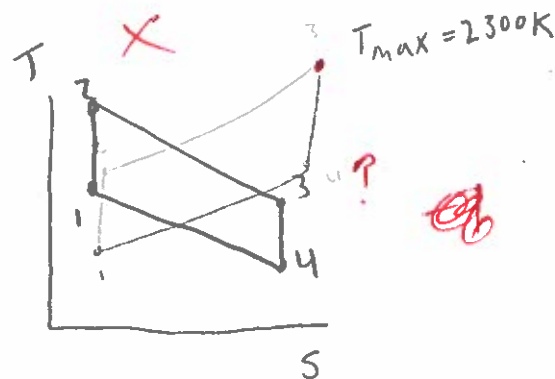
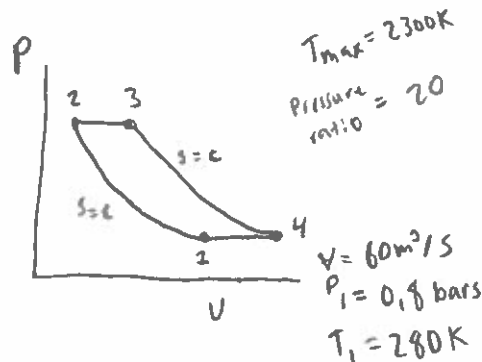
(viii) $\eta_{2nd\ law} = \frac{W_{rev}}{W} = \frac{871.500 \text{ KJ/Kg}}{916.7 \text{ KJ/Kg}} = 0.95 \rightarrow 95\%$

②

2.

15

(i)



(ii)

$$\dot{m} = \frac{\dot{V}}{v_1}$$

(iii)

$$P_1 = 0.8\text{ bars}, T_1 = 280\text{K}, v_1 = ?$$

$$P_1 v_1 = R T_1$$

$$(80\text{ kPa}) v_1 = (0.287\text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(280\text{K})$$

$$v_1 = \frac{(0.287\text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(280\text{K})}{80\text{ kPa}}$$

$$v_1 = 1.0045\text{ m}^3/\text{kg}$$

$$\frac{x}{0.8\text{ bars}} = \frac{101.325\text{ kPa}}{1.01325\text{ bars}}$$

$$x = 80\text{ kPa}$$

(iv)

$$\left(\frac{T_2}{T_1}\right) = \left(\frac{v_1}{v_2}\right)^{\kappa-1}$$

$$\left(\frac{2300\text{K}}{280\text{K}}\right) = \left(\frac{1.0045\text{ m}^3/\text{kg}}{v_2}\right)^{1.4-1}$$

$\Rightarrow$

$$\frac{115}{14} = \frac{(1.0045\text{ m}^3/\text{kg})^{0.4}}{v_2^{0.4}}$$

$$v_2^{0.4} = 0.12196$$

3

$$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^K$$

$$\frac{1600 \text{ KPa}}{80 \text{ KPa}} = 20, \quad \boxed{P_2 = 1600 \text{ KPa}} \quad \checkmark$$

$$\frac{1600 \text{ KPa}}{80 \text{ KPa}} = \left(\frac{1.0045 \text{ m}^3/\text{kg}}{v_2}\right)^{1.4}$$

$$(v_2)^{1.4} = \frac{(1.0045 \text{ m}^3/\text{kg})^{1.4}}{20}$$

$$\boxed{v_2 = 0.1182 \text{ m}^3/\text{kg}}$$

$$\boxed{T_2 = T_{\max} = 2300 \text{ K}} \quad \times$$

(vi) $Pv = RT$

(vii) $\boxed{Q_{\text{in}} = C_p (T_3 - T_2)}$

(viii) $\boxed{Q_{\text{out}} = C_p (T_1 - T_4)}$

(ix)

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

(x)

$$\eta_{\text{th}} = \frac{W}{Q_{\text{in}}}$$

BELOW AVERAGE

Below Average Student Original Graded Assignment

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3302 Y01 : Thermodynamics II
Fall 2021
Exam #1

Name: IVAN CORONADO Score: 68

- (1) An adiabatic compressor is used to bring saturated water vapor at 1 MPa up to 17.5 MPa, where the actual exit temperature is 650 °C. Let $T_o = 25$ °C, $p_o = 100$ kPa.
- (i) Draw the schematic of the problem (4 pts)
 - (ii) Determine specific volume, enthalpy, and entropy at the inlet (9 pts)
 - (iii) Determine the specific volume, enthalpy, and entropy at the exit (9 pts)
 - (iv) What is the change of exergy between the exit and the inlet of the compressor (10 pts)
 - (v) What is the work supplied to the compressor (6 pts)
 - (vi) What is the minimum work the compressor requires (5 pts)
 - (vii) What is the exergy destroyed in the turbine (5 pts)
 - (viii) What is the 2nd Law efficiency or the exergetic efficiency of the compressor (2 pts)
- (2) Air enters the compressor of an air-standard Brayton Cycle with a volumetric flow rate of 60 m³/s at 0.8 bars and 280 K. The pressure ratio of the cycle is 20 and the maximum cycle temperature is 2300 K.
- (i) Draw the P-v and the T-s diagram of the cycle with the input conditions shown in the figures (4 pts)
 - (ii) Mass flow rate of air in the system (4 pts)
 - (iii) P, T, and v at the beginning of the compressor. (6 pts)
 - (iv) P, T, and v at the exit of the compressor (6 pts)
 - (v) P, T, and v at the exit of the combustor (6 pts)
 - (vi) P, T, and v at the exit of the turbine (6 pts)
 - (vii) Heat addition in combustor (4 pts)
 - (viii) Heat rejection in condenser (4 pts)
 - (ix) The net work of the cycle (5 pts)
 - (x) Thermal efficiency of the cycle (5 pts)

Note:

1. Show detailed steps to get full credit
2. Show unit conversions

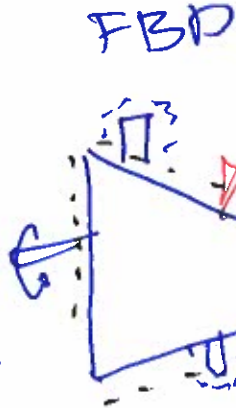
①

OPEN SYSTEM

WORKING FLUID:

VAPOR
SATURATED
WATER
VAPOR

ADIABATIC
 $Q=0$



①

DEAD STATE
 $T_0 = 25^\circ\text{C}$
 $P_0 = 100\text{ kPa}$

STATE 2

$P_2 = 17.5\text{ MPa} \rightarrow 17500\text{ kPa}$

$T_2 = 650^\circ\text{C}$

PHASE 2

$T_2 > T_{\text{sat}}(17500\text{ kPa})$
→ SUPERHEATED VAPOR

$V_2 = 0.022742\text{ m}^3/\text{kg}$

$h_2 = 3693.8\text{ kJ/kg}$

$s_2 = 6.7366\text{ kJ/kg}\cdot\text{K}$

state 1
PHASE 1
SATURATED WATER
VAPOR

$P_1 = 1\text{ MPa} / 1000\text{ kPa}$

$v_1 = 0.19436\text{ m}^3/\text{kg}$

$T_1 = 179.88^\circ\text{C}$

$h_1 = 2777.1\text{ kJ/kg}$

$s_1 = 6.5850\text{ kJ/kg}\cdot\text{K}$

$$\frac{x_2}{m} - \frac{x_1}{m} = \left[(h_2 - h_1) - T_0 (s_2 - s_1) \right] + \frac{V_2 - V_1}{2v_{\text{avg}}} + g(z_2 - z_1)$$

$$= \left[(3693.8 - 2777.1) - 298\text{ K} (6.7366 - 6.5850) \right]$$

$$= [916.7 - 45.1768]$$

$$= 871.5232\text{ kJ/kg}$$

vi) $\phi_2 - \phi_1 = 871.5232\text{ kJ/kg}$
minimum work

v) work supplied
Energy destroyed = $w_{\text{max}} - w_{\text{act}}$
 $45.17 = x - 871.5232$
 $x = 826.353\text{ kJ/kg}$

$x_{\text{destroy}} = T_0 S_{\text{gen}}$
 $= (298\text{ K}) (6.7366 - 6.5850)$
 $x_{\text{destroyed}} = 45.17\text{ kJ/kg}$

①

Cont... Problem 1

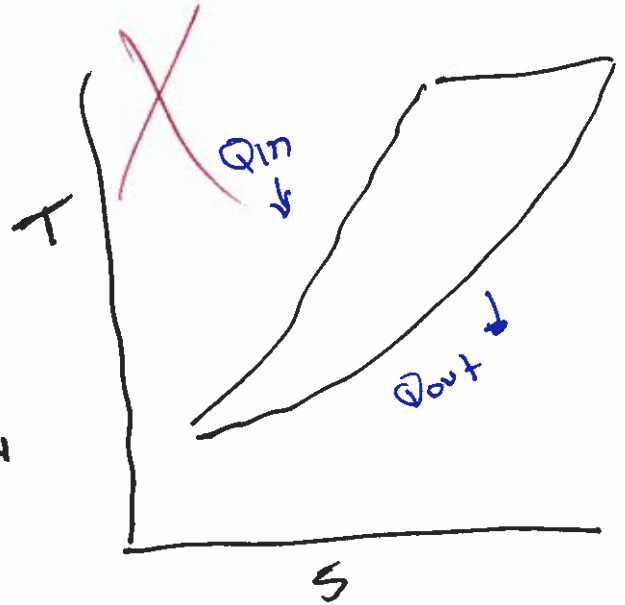
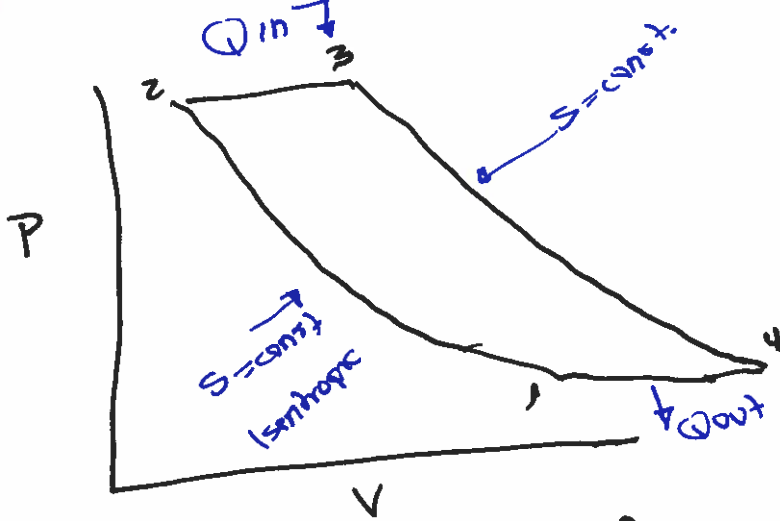


η_{thermal}

$$\frac{826.353}{871.52} \times 100 = 94.81\%$$

Problem 2

Breton



$\dot{m} = 60 \text{ m}^3/\text{s}$
 $P_1 = .8 \text{ bar}$
 $T_1 = 280 \text{ K}$
 $P_r = 20$
 $T_2 = 658.99 \text{ K}$
 $T_3 = 2300 \text{ K}$

$T_4 = 543.16 \text{ K}$

$P_2 = P_3$

1 to 2
Isentropic
relation

$$\eta_T = 1 - \frac{1}{r_p^{\frac{k-1}{k}}} \rightarrow 1 - \frac{1}{20^{.2857}} = 1 - \frac{1}{2.3534} \rightarrow 57.50\%$$

3

Cont... Problem Z

Net power
work

$$W_{net} = W_T - W_C$$

$$C_p = 1.005$$

$$W_C = \dot{m} \times C_p (T_2 - T_1) \rightarrow 6 \times 1.005 (658.99 - 280)$$

$$W_T = \dot{m} \times C_p (T_3 - T_4) \rightarrow 6 \times 1.005 (2300 - 5413.16)$$

$$W_C = 2285.30$$

$$W_T = 18772.35$$

$$W_{net} = 2285.30 + 18772.35$$

$$W_{net} = 21057.65$$

**THERMODYNAMICS II
FALL 2021**

Title of Assignment: TEST 2

TOPICS COVERED IN TEST 2

Test 2 covered the following topics:

1. Vapor Power Cycle
2. Refrigeration Cycle

THERMODYNAMICS II
FALL 2021

**SAMPLE TEST QUESTIONS, SOLUTION,
AND GRADING SCHEME FOR TEST 2**

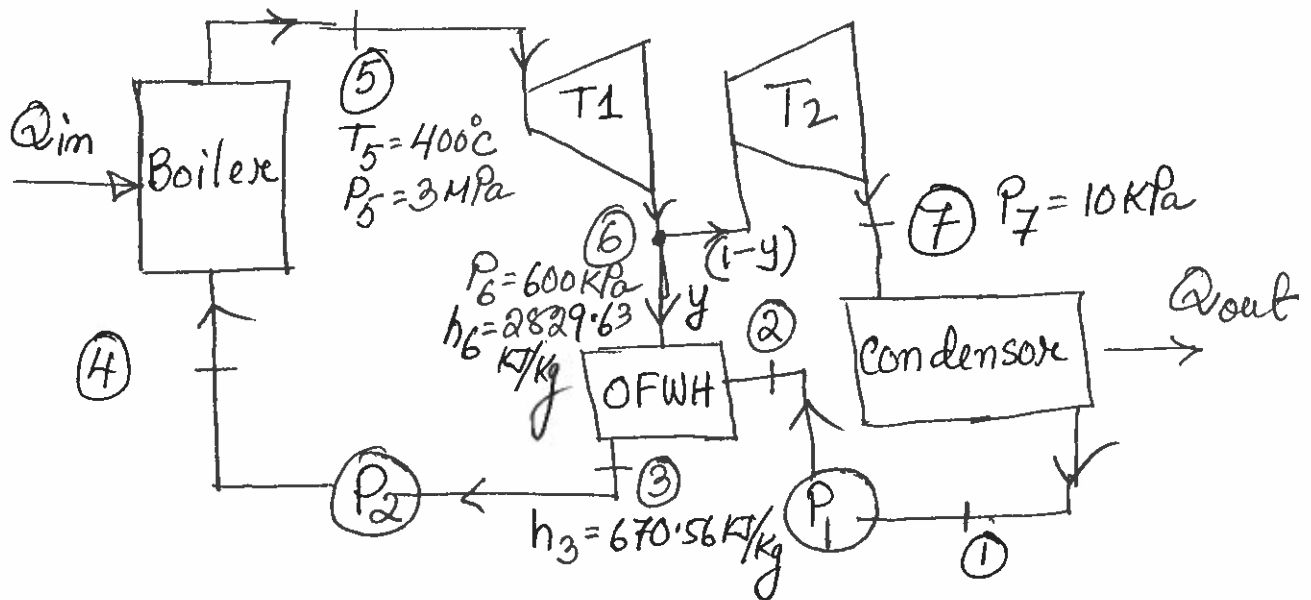
Prairie View A&M University
Department of Mechanical Engineering
MCEG 3302 Y01 : Thermodynamics II
Fall 2021
Exam #2

Name: Solution Score: _____

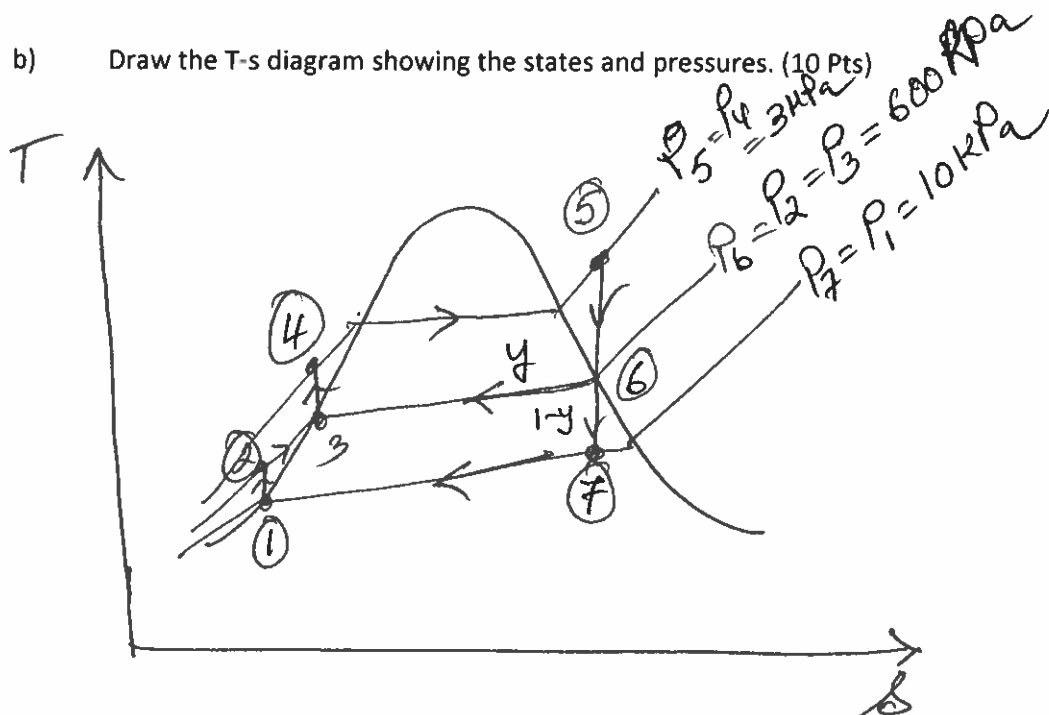
Note:

1. Show detailed steps to get full credit
2. Show unit conversions

- (1) A steam power plant is based on ideal regenerative Rankine cycle. Steam enters the 1st turbine at 400 °C and 3 MPa and exits at 600 kPa. At this point a fraction of steam, y , is extracted for open feedwater heater (OFWH). The rest of the steam enters the 2nd turbine and exits at the condenser pressure of 10 kPa. The enthalpy at the exit of the OFWH is given as 670.56 kJ/kg and the enthalpy at the point of extraction is given as 2829.63 kJ/kg. Determine the following:
- a) Draw the schematic of the plant. Number each state. On the schematic at each state write down the given values. (10 Pts)



- b) Draw the T-s diagram showing the states and pressures. (10 Pts)



- c) Determine the work done by pump 1 at the inlet of the OFWH in kJ/kg. (10 Pts)

Inlet to pump 1 (inlet to OFWH) is state ①
The phase is saturated liquid at $P_1 = 10 \text{ kPa}$

$$w_{P1} = v_1(P_2 - P_1) \approx v_{f1}(P_2 - P_1)$$

$$v_{f1} = 0.001010 \text{ m}^3/\text{kg} @ P_1 = 10 \text{ kPa}$$

$$\therefore w_{P1} = 0.001010 \text{ m}^3/\text{kg} (680 - 10) \text{ kPa} \cdot \frac{\text{kJ}}{1 \text{ kPa} \cdot \text{m}^3} = \boxed{0.5959 \frac{\text{kJ}}{\text{kg}}}$$

- d) Determine the enthalpy at the exit of pump 1 in kJ/kg. (10 Pts)

$$w_{P1} = (h_2 - h_1) = 0.5959 \text{ kJ/kg}$$

$$\therefore h_2 = h_1 + 0.5959 \text{ kJ/kg}$$

$$h_1 = h_{f1} @ P_1 = 10 \text{ kPa} = 191.81 \text{ kJ/kg}$$

$$\therefore h_2 = (191.81 + 0.5959) \text{ kJ/kg} = \boxed{192.41 \text{ kJ/kg}}$$

- e) The fraction of steam extracted for OFWH. (10 Pts)

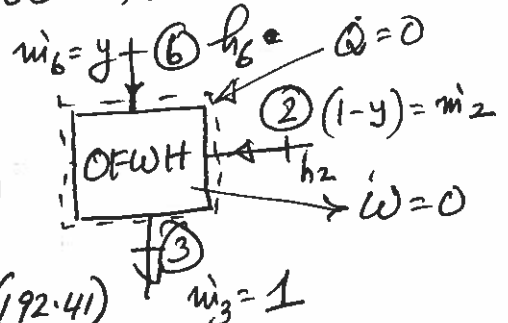
Apply energy balance across the OFWH

$$\dot{m}_3 h_3 = \dot{m}_6 h_6 + \dot{m}_2 h_2$$

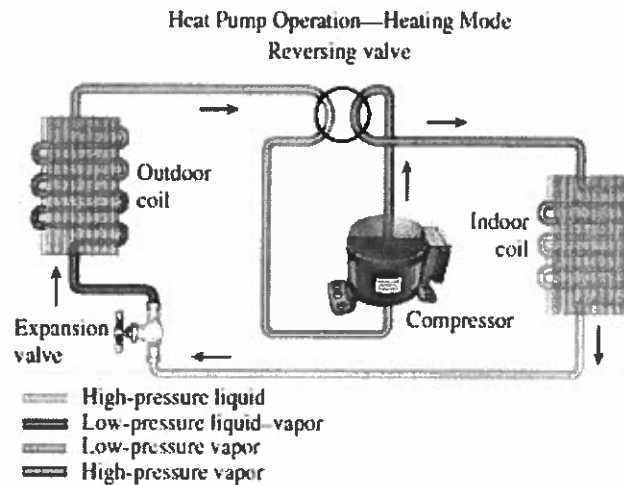
$$\Rightarrow (1) (670.56 \text{ kJ/kg}) = y (2829.63 \text{ kJ/kg}) + (1-y) (192.41 \text{ kJ/kg})$$

$$\Rightarrow 670.56 = 2829.63 y + 192.41 - y (192.41)$$

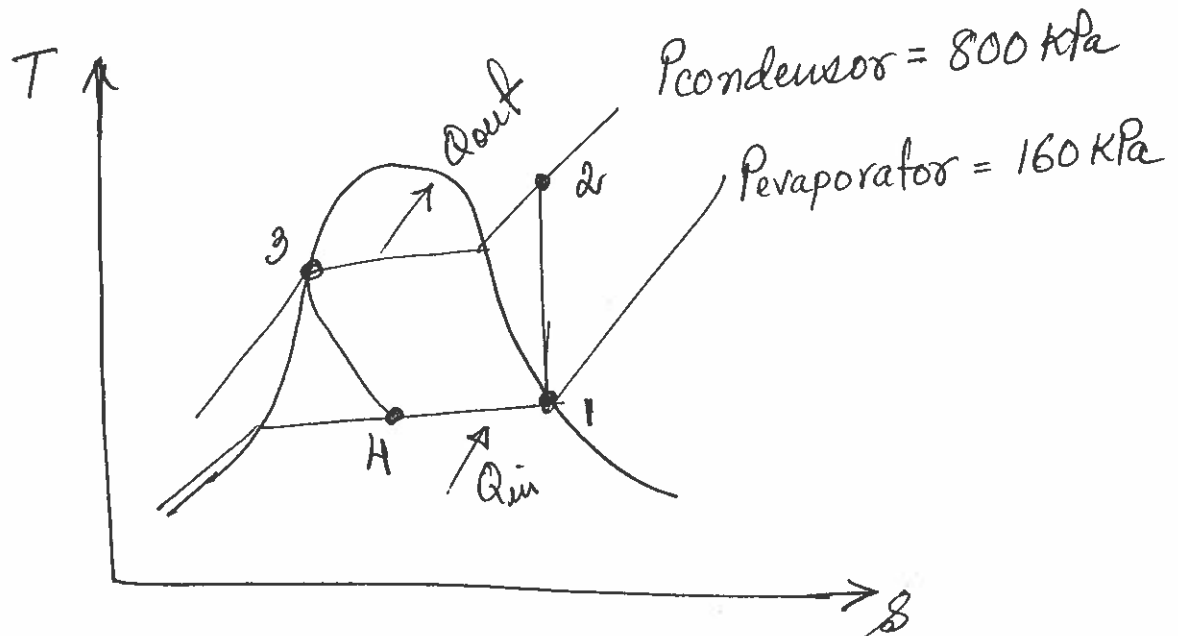
$$\Rightarrow \boxed{y = 0.1813}$$



- (2) The figure below shows a Heat Pump operating on an ideal refrigeration cycle in winter to heat a building. Outdoor coil works as an evaporator and getting heat from cold outside air. The evaporator pressure is 160 kPa. The indoor coil works as a condenser operating at a pressure of 800 kPa. The working fluid is Refrigerant 134a. Determine the following:



- (i) Draw the T-s Diagram with appropriate labeling (10 Pts.)



Ideal refrigeration cycle
Working fluid - R134a.

(ii) Enthalpies at every state (20 Pts)

State ① is saturated vapor at 160 kPa
 $\therefore h_1 = h_{1g} = 241.14 \text{ kJ/kg}$ (Table A-12)
 $s_1 = s_{1g} = 0.94202 \text{ kJ/kg}\cdot\text{K}$

State ②
 $P_2 = 800 \text{ kPa}$ and $s_2 = s_1 = 0.94202 \text{ kJ/kg}\cdot\text{K}$
 $s_{g2} @ P_2 = 800 \text{ kPa} = 0.91853 \text{ kJ/kg}\cdot\text{K}$
 Since $s_2 = 0.94202 > s_{g2} = 0.91853 \rightarrow$ State ②
 is superheated
 we get h_2 from superheat table by interpolation

$$P = 0.80 \text{ MPa} = 800 \text{ kPa}$$

$h = \frac{267.34}{246.82}$	0.9185	$h_2 - 246.82$	$= \frac{0.94202 - 0.9185}{0.9481 - 0.9185}$
$h = \frac{276.46}{254.84}$	0.9481	$h_2 - 246.82$	$= \frac{0.02352}{0.0296} = 0.7946$

$$\Rightarrow h_2 = 246.82 + (800)(0.7946)$$

$$\Rightarrow h_2 = 253.19 \text{ kJ/kg}$$

$$\Rightarrow h_2 = 274.59 \text{ kJ/kg}$$

State ③ is at saturated liquid at $P_3 = 800 \text{ kPa}$.

$$\therefore h_3 = h_{3f} @ P_3 = 800 \text{ kPa} = 171.86 \text{ kJ/kg}$$

State ④: $h_4 = h_3 = 171.86 \text{ kJ/kg}$ $\rightarrow$ Throttling process.

(iii) COP of the heat pump (10 Pts)

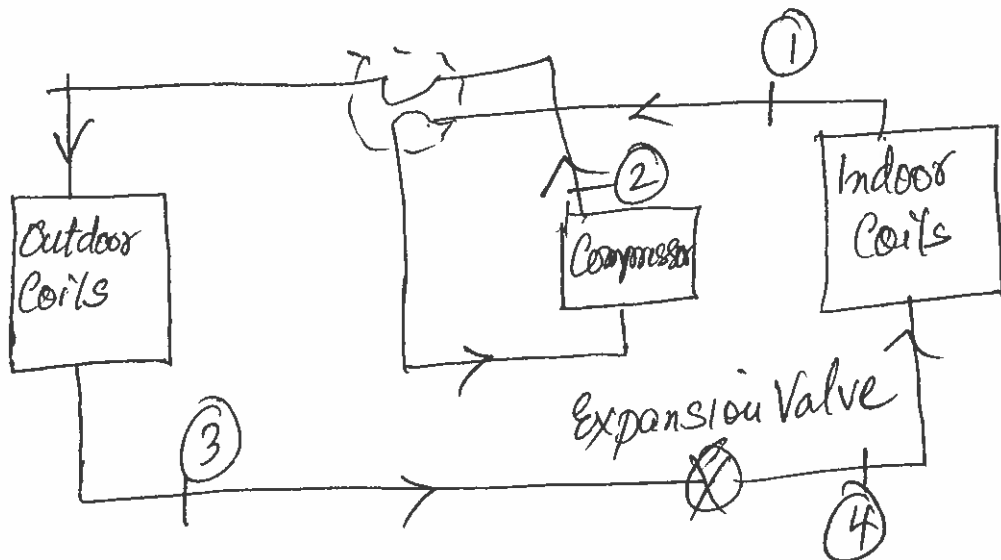
$$COP_{HP} = \frac{Q_{out}}{W_{cycle}} = \frac{Q_{out}}{Q_{out} - Q_{in}}$$

$$Q_{out} = h_2 - h_3 = (274.59 - 171.86) \text{ kJ/kg} = 102.73 \text{ kJ/kg}$$

$$Q_{in} = h_1 - h_4 = (241.14 - 171.86) \text{ kJ/kg} = 69.28 \text{ kJ/kg}$$

$$\therefore COP_{HP} = \frac{102.73 \text{ kJ/kg}}{(102.73 - 69.28) \text{ kJ/kg}} = 3.07$$

(iv) Draw the schematic of the system if the same unit is to be used for cooling the building (10 Pts)



ABOVE AVERAGE

Above Average Student Original Graded Assignment

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3302 Y01 : Thermodynamics II
Fall 2021
Exam #2

Name: Caleb Combs Score: 89

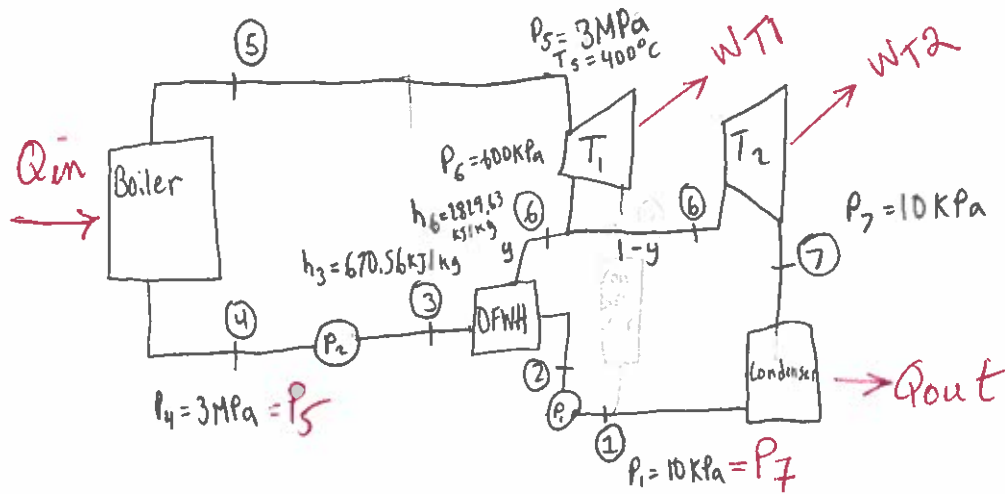
Note:

1. Show detailed steps to get full credit
2. Show unit conversions

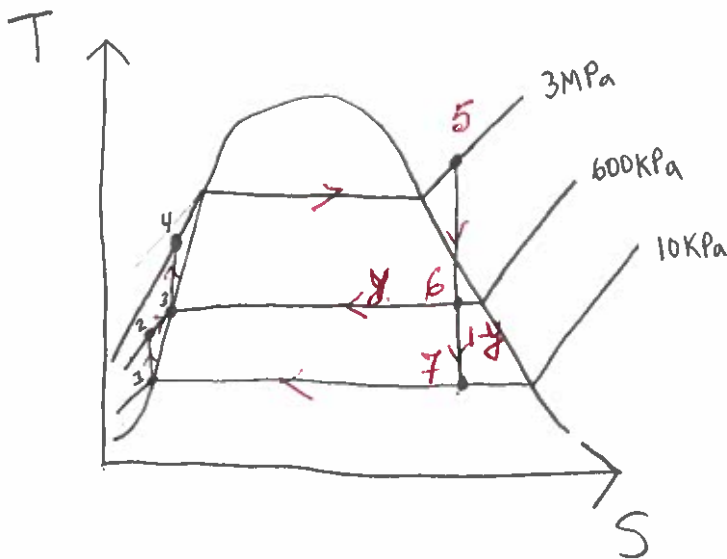
89

- (1) A steam power plant is based on ideal regenerative Rankine cycle. Steam enters the 1st turbine at 400 °C and 3 MPa and exits at 600 kPa. At this point a fraction of steam, y , is extracted for open feedwater heater (OFWH). The rest of the steam enters the 2nd turbine and exits at the condenser pressure of 10 kPa. The enthalpy at the exit of the OFWH is given as 670.56 kJ/kg and the enthalpy at the point of extraction is given as 2829.63 kJ/kg. Determine the following:

- a) Draw the schematic of the plant. Number each state. On the schematic at each state write down the given values. (10 Pts)



- b) Draw the T-s diagram showing the states and pressures. (10 Pts)



- c) Determine the work done by pump 1 at the inlet of the OFWH in kJ/kg. (10 Pts)

From "Table A-5",

$$h_1 = h_{\text{sat}@10\text{KPa}} = 191.81 \text{ kJ/kg}$$

$$V_1 = V_{\text{sat}@10\text{KPa}} = 0.001010 \text{ m}^3/\text{kg} = V$$

$$W_{\text{pump},in} = h_2 - h_1$$

$$W_{\text{pump},in} = V(P_2 - P_1)$$

$$W_{\text{pump},in} = (0.001010 \text{ m}^3/\text{kg})(600\text{KPa} - 10\text{KPa})$$

$$W_{\text{pump},in} = 0.5959 \text{ kJ/kg}$$

unit conversion

- d) Determine the enthalpy at the exit of pump 1 in kJ/kg. (10 Pts)

$$W_{\text{pump},in} = h_2 - h_1$$

$$0.5959 \text{ kJ/kg} = h_2 - 191.81 \text{ kJ/kg}$$

$$h_2 = 192.4059 \text{ kJ/kg}$$

- e) The fraction of steam extracted for OFWH. (10 Pts)

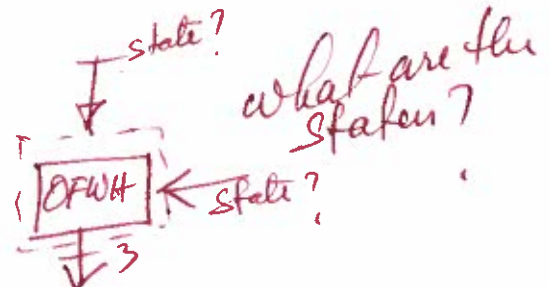
$$P_2 = 600 \text{ kPa}$$

$$h_3 = 670.56 \text{ kJ/kg}$$

$$h_6 = 2829.63 \text{ kJ/kg}$$

$$\dot{E}_{in} = \dot{E}_{out}$$

around OFWH



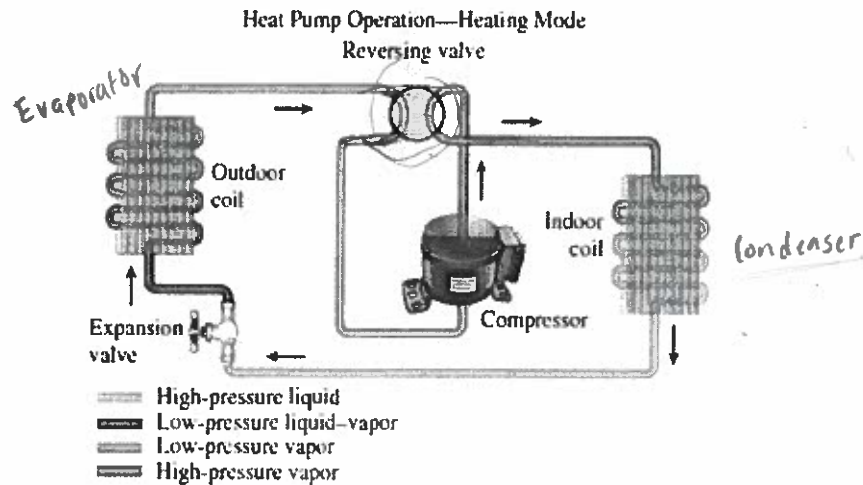
$$y(2829.63 \text{ kJ/kg}) + (1-y)(192.4059 \text{ kJ/kg}) = (1)(670.56 \text{ kJ/kg})$$

$$2829.63y - 192.4059y + 192.4059 = 670.56$$

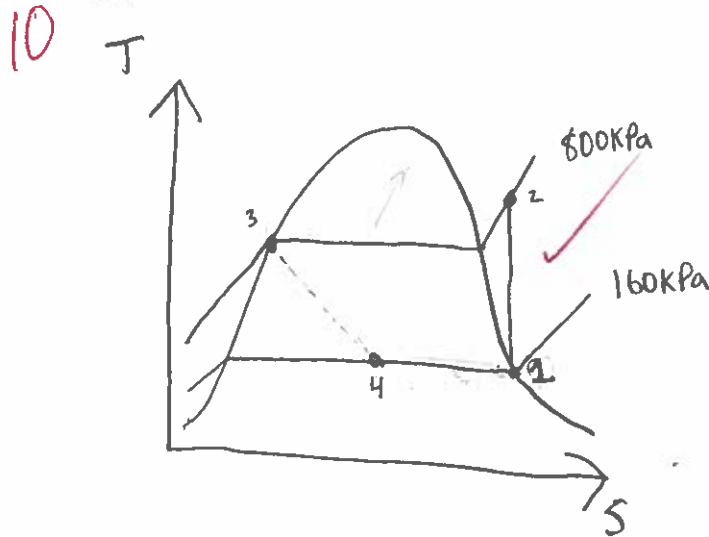
$$2637.2241y = 478.1541$$

$$y = 0.1813$$

- (2) The figure below shows a Heat Pump operating on an ideal refrigeration cycle in winter to heat a building. Outdoor coil works as an evaporator and getting heat from cold outside air. The evaporator pressure is 160 kPa. The indoor coil works as a condenser operating at a pressure of 800 kPa. The working fluid is Refrigerant 134a. Determine the following:



- (i) Draw the T-s Diagram with appropriate labeling (10 Pts.)



(ii) Enthalpies at every state (20 Pts)

From "Table A-12",

18

$$h_1 = h_{g@160\text{kPa}} = 241.14 \text{ kJ/kg}, \quad S_1 = S_{g@160\text{kPa}} = 0.94202 \text{ kJ/kg}\cdot\text{K}$$

$$S_1 = S_2 = 0.94202 \text{ kJ/kg}\cdot\text{K}$$

$$\frac{276.46 - 267.34}{0.9481 - 0.9185} = \frac{h_2 - 267.34}{0.9420 - 0.9185}$$

$$h_2 = 274.581 \text{ kJ/kg}$$

$$h_3 = h_{s@100\text{kPa}} = \underline{95.48 \text{ kJ/kg}} \quad ?$$

Throttling process, therefore, $h_3 = h_4$

$$h_3 = h_4 = 95.48 \text{ kJ/kg}$$

$$h_4 = 95.48 \text{ kJ/kg}$$

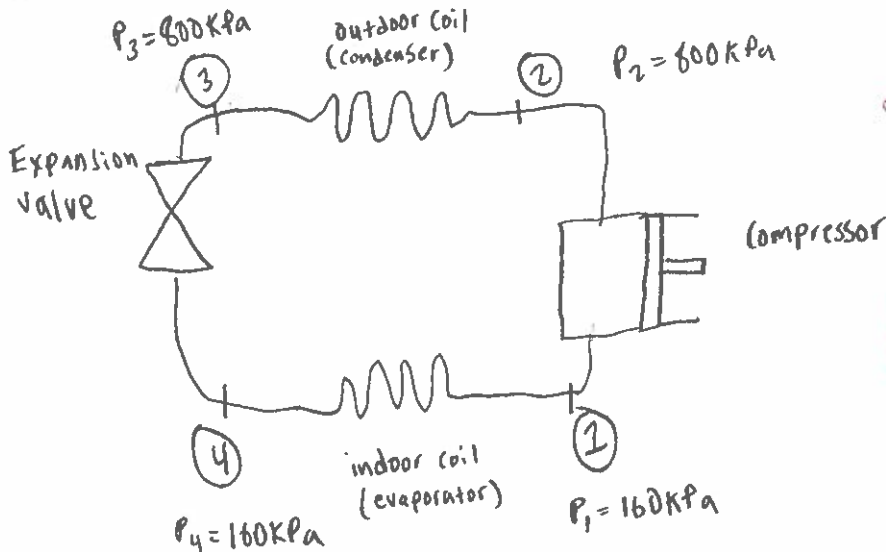
(iii) COP of the heat pump (10 Pts)

10

$$\text{COP}_{\text{HP}} = \frac{Q_{\text{condenser}}}{W_{\text{compressor}}} = \frac{h_2 - h_3}{h_2 - h_1} = \frac{274.581 \text{ kJ/kg} - 95.48 \text{ kJ/kg}}{274.581 \text{ kJ/kg} - 241.14 \text{ kJ/kg}}$$

$$\text{COP}_{\text{HP}} = 5.356$$

(iv) Draw the schematic of the system if the same unit is to be used for cooling the building (10 Pts)



Drawing should be based on the given figure!

AVERAGE

Average Student Original Graded Assignment

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3302 Y01 : Thermodynamics II
Fall 2021
Exam #2

Name: Thomas Carroll III Score: 76

Note:

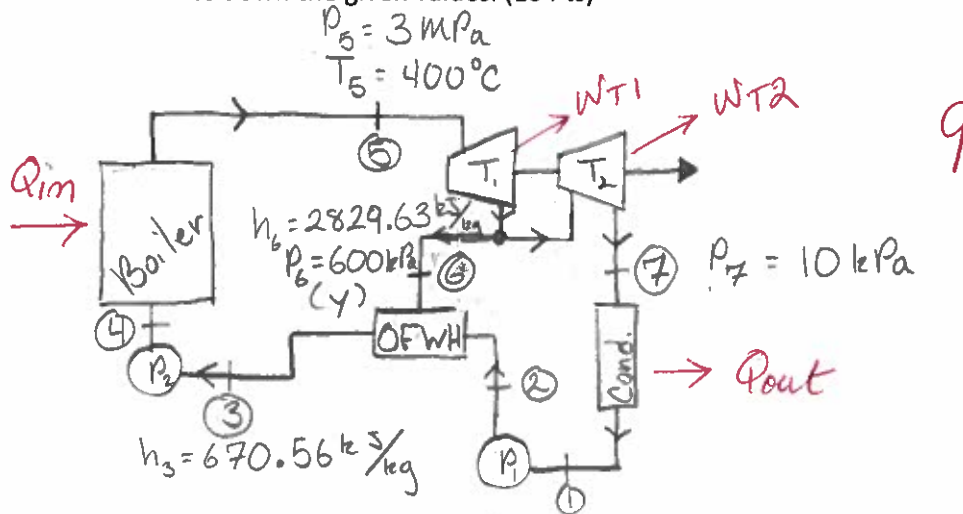
1. Show detailed steps to get full credit
2. Show unit conversions

76

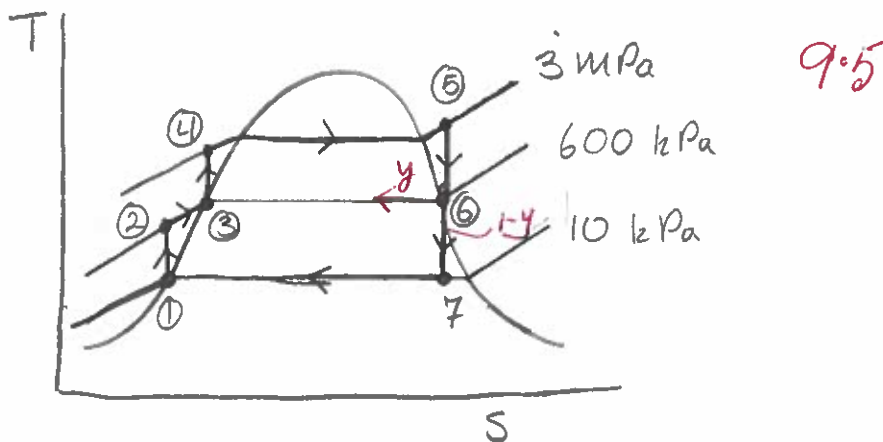
39

- (1) A steam power plant is based on ideal regenerative Rankine cycle. Steam enters the 1st turbine at 400 °C and 3 MPa and exits at 600 kPa. At this point a fraction of steam (y) is extracted for open feedwater heater (OFWH). The rest of the steam enters the 2nd turbine and exits at the condenser pressure of 10 kPa. The enthalpy at the exit of the OFWH is given as 670.56 kJ/kg and the enthalpy at the point of extraction is given as 2829.63 kJ/kg. Determine the following:

- a) Draw the schematic of the plant. Number each state. On the schematic at each state write down the given values. (10 Pts)



- b) Draw the T-s diagram showing the states and pressures. (10 Pts)



c) Determine the work done by pump 1 at the inlet of the OFWH in kJ/kg. (10 Pts)

9 $w_p = ?$

$P_1 = P_7 = 10 \text{ kPa}$

$P_2 = P_6 = 600 \text{ kPa}$

$v_{f1} = 0.001010 \text{ m}^3/\text{kg}$
at inlet

$w_p = v_{f1} (P_2 - P_1) \rightarrow V_1 \neq V_{f1} @ P_1 \text{ inlet to pump.}$

$\Rightarrow w_p = (0.001010 \frac{\text{m}^3}{\text{kg}})(600 \text{ kPa} - 10 \text{ kPa})$

$w_p = 0.5959 \text{ kJ/kg}$

unit conversion?

d) Determine the enthalpy at the exit of pump 1 in kJ/kg. (10 Pts)

9 $h_2 = ?$, $h_1 = h_{f1} = 191.81 \frac{\text{kJ}}{\text{kg}}$, $w_p = 0.5959 \frac{\text{kJ}}{\text{kg}}$

① $\dot{Q}_2 = 0$, $\dot{W}_2 = \dot{m}(h_2 - h_1)$

$\Rightarrow (-w_p) = h_2 - h_1$

$\Rightarrow w_p = h_1 - h_2 \Rightarrow 0.5959 \frac{\text{kJ}}{\text{kg}} = 191.81 \frac{\text{kJ}}{\text{kg}} - h_2$

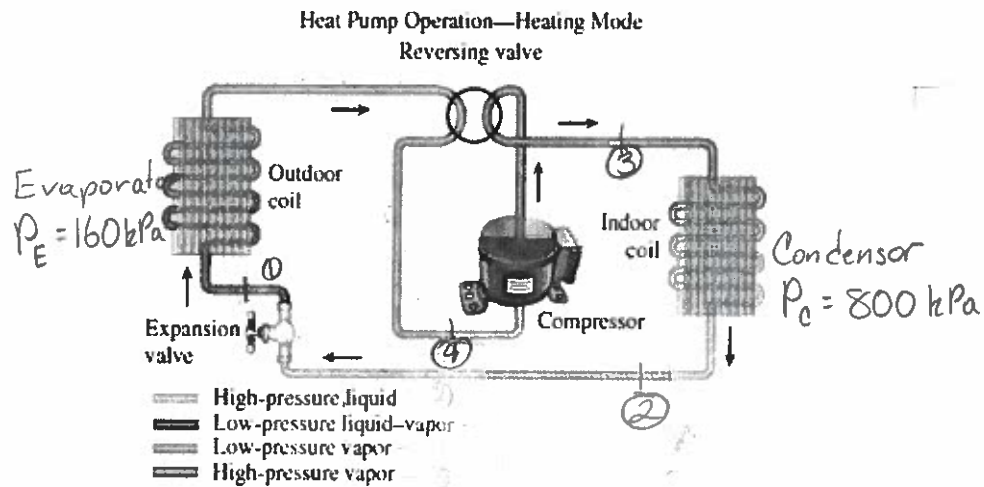
$\Rightarrow h_2 = 191.21 \frac{\text{kJ}}{\text{kg}}$

e) The fraction of steam extracted for OFWH. (10 Pts)

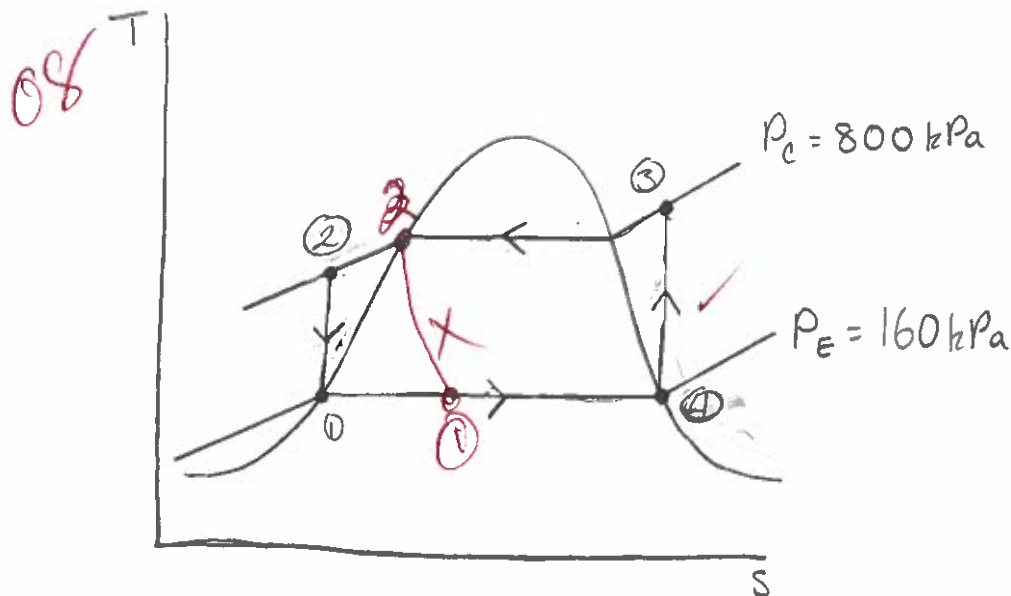
2 $\dot{Q} - \dot{W} = \dot{m}_2 h_2 - \dot{m}_6 h_6$

$\Rightarrow 0 = (1-y)h_2 - (y)h_6$

- (2) The figure below shows a Heat Pump operating on an ideal refrigeration cycle in winter to heat a building. Outdoor coil works as an evaporator and getting heat from cold outside air. The evaporator pressure is 160 kPa. The indoor coil works as a condenser operating at a pressure of 800 kPa. The working fluid is Refrigerant 134a. Determine the following:



- (i) Draw the T-s Diagram with appropriate labeling (10 Pts.)



(ii) Enthalpies at every state (20 Pts)

12

$$P_1 = P_4 = 160 \text{ kPa}$$

$$S_1 = S_{f1} = 0.12686 \text{ kJ/kg}\cdot\text{K}$$

$$h_1 = h_{f1} = 31.18 \text{ kJ/kg}$$

$$v_{f1} = 0.0007435 \text{ m}^3/\text{kg}$$

$$P_3 = P_2 = 800 \text{ kPa}$$

$$S_3 = S_4 = 0.94202 \text{ kJ/kg}\cdot\text{K}$$

$$\frac{h_3 - h_a}{h_b - h_a} = \frac{S_3 - S_a}{S_b - S_a} \Rightarrow \frac{h_3 - 267.34 \text{ kJ/kg}}{276.46 \text{ kJ/kg} - 267.34 \text{ kJ/kg}} = \frac{(0.94202 - 0.9185) \text{ kJ/kg}\cdot\text{K}}{(0.9481 - 0.9185) \text{ kJ/kg}\cdot\text{K}}$$

$$\Rightarrow h_3 = 274.59 \text{ kJ/kg}$$

$$P_2 = 800 \text{ kPa}$$

$$S_2 = S_1 = 0.12686 \text{ kJ/kg}\cdot\text{K}$$

$$h_1 - h_4 = h_1 - h_2$$

$$\Rightarrow h_2 = h_1 = 31.18 \text{ kJ/kg}$$

* This is due to throttling

$$P_4 = 160 \text{ kPa}$$

$$S_4 = 0.94202 \text{ kJ/kg}\cdot\text{K}$$

$$h_4 = 241.14 \text{ kJ/kg}$$

Assume to be Sat. vap

$S_3 > S_g \rightarrow$ superheated

$S_4 > S_2 \rightarrow$ compressed

$h_2 = ?$

Ans:

$$h_1 = 31.18 \text{ kJ/kg}$$

$$h_2 = 31.18 \text{ kJ/kg}$$

$$h_3 = 274.59 \text{ kJ/kg}$$

$$h_4 = 241.14 \text{ kJ/kg}$$

(iii) COP of the heat pump (10 Pts)

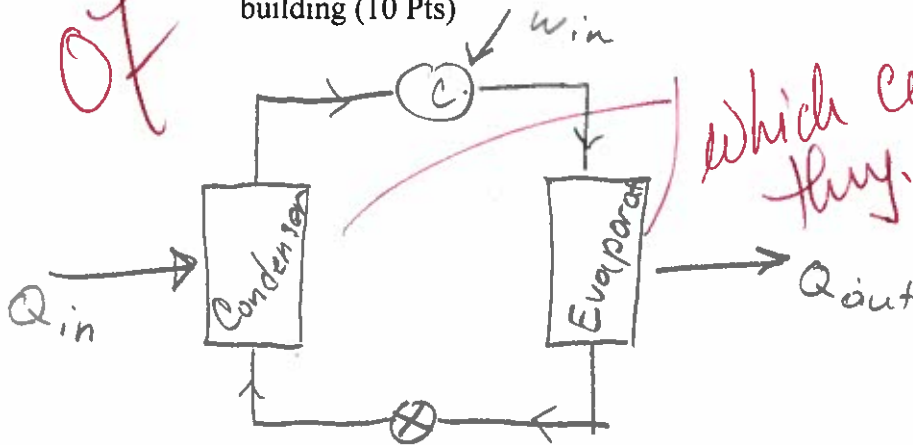
10

$$(COP)_{HP} = \frac{Q_{out}}{W_{in}} = \frac{(243.41 \text{ kJ/kg})}{33.45 \text{ kJ/kg}} = 7.277$$

$$\begin{aligned} W_{in} &= h_3 - h_4 \\ &= (274.59 - 241.14) \text{ kJ/kg} \\ &= 33.45 \text{ kJ/kg} \end{aligned}$$

$$\begin{aligned} Q_{out} &= h_2 - h_3 \\ &= (31.18 - 274.59) \text{ kJ/kg} \\ &= -243.41 \text{ kJ/kg} \end{aligned}$$

(iv) Draw the schematic of the system if the same unit is to be used for cooling the building (10 Pts)



Which coils are they. Should be based on the figure given

BELOW AVERAGE

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3302 Y01 : Thermodynamics II
Fall 2021
Exam #2

Name: Heba Afzal **Score:** _____

Note:

1. Show detailed steps to get full credit
2. Show unit conversions

- c) Determine the work done by pump 1 at the inlet of the OFWH in kJ/kg. (10 Pts)

8

$$w_p =$$

$$h_1)_{10 \text{ kPa}} = 191.81 = h_f$$

$$w_p = 0.001010(590)$$

$$w_p = 0.5959 \text{ kJ/kg.}$$

$$w_p = v_{f1} \Delta P$$

$$v_{f1)_{10 \text{ kPa}} = 0.001010 \text{ unit}$$

$$P_2 - P_1 = 600 - 10 \text{ unit.}$$

- d) Determine the enthalpy at the exit of pump 1 in kJ/kg. (10 Pts)

9

$$w_p = 0.5959 = h_2 - h_1$$

$$h_1 = h_f)_{10 \text{ kPa}} = 191.81 \text{ unit}$$

$$0.5959 = h_2 - 191.81$$

$$h_2 = 0.5959 + 191.81$$

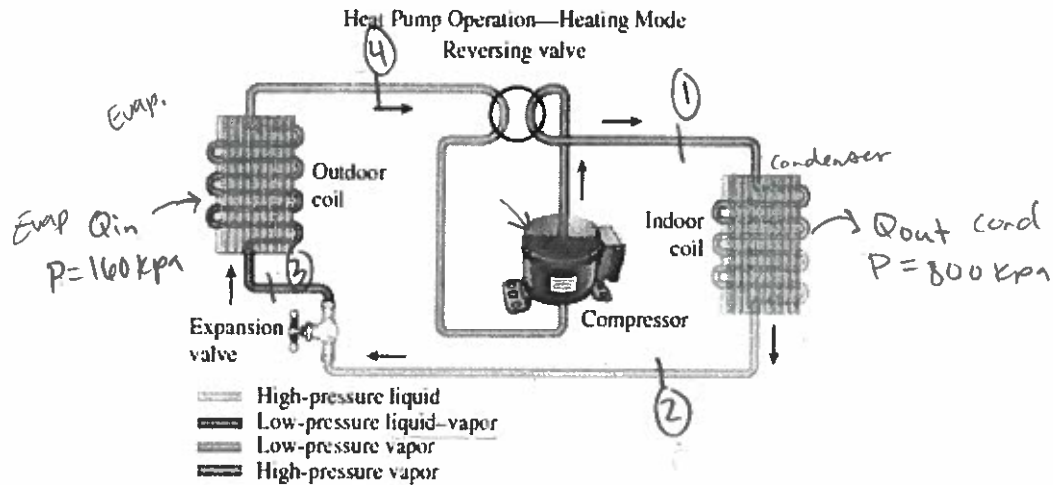
$$h_2 = 192.4059 \text{ unit.}$$

00

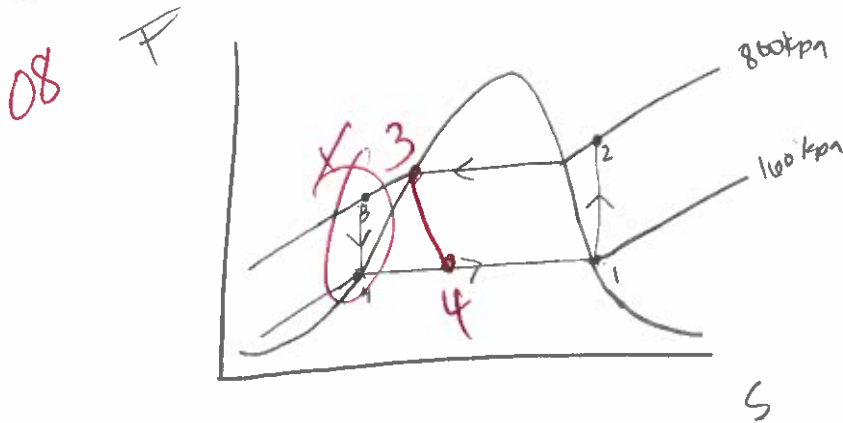
- e) The fraction of steam extracted for OFWH. (10 Pts)

1
0

- (2) The figure below shows a Heat Pump operating on an ideal refrigeration cycle in winter to heat a building. Outdoor coil works as an evaporator and getting heat from cold outside air. The evaporator pressure is 160 kPa. The indoor coil works as a condenser operating at a pressure of 800 kPa. The working fluid is Refrigerant 134a. Determine the following:



- (i) Draw the T-s Diagram with appropriate labeling (10 Pts.)



(ii) Enthalpies at every state (20 Pts)

12

saturated vapor

$$h_1)_{P=160 \text{ kPa}} = h_g = \underline{241.14 \text{ kJ/kg}} \quad \checkmark$$

$$s_1 = s_g)_{160 \text{ kPa}} = 0.94202 \quad \checkmark$$

$$s_2 = s_1 = 0.94202 \text{ kJ/kg} \quad \checkmark$$

$$P_2 = 800 \text{ kPa}$$

$$s_g)_{800 \text{ kPa}} = 0.918 \quad s_2 > s_g = \text{Superheated} \quad \checkmark$$

$$h_2)_{0.8 \text{ MPa}} = \frac{0.942 - 0.918}{0.948 - 0.918} = \frac{h_2 - 267.34}{276.416 - 267.34}$$

$$h_2 = \underline{274.636 \text{ kJ/kg}} \quad \checkmark$$

$$h_2 = h_3 \quad \text{throttling process}$$

$$s_3 = 0.35408$$

$$s_3)_{800 \text{ kPa}}$$

$$s_3 = s_4$$

$$h_4)_{160 \text{ kPa}} = 31.18 \text{ kJ/kg}$$

$$h_3 = h_{f3} @ P_3 = 800 \text{ kPa}$$

$$h_4 = h_3 \quad \text{throttling process}$$

$$P = 160 \text{ kPa}$$

$$s_4 = 0.35408$$

(iii) COP of the heat pump (10 Pts)

04

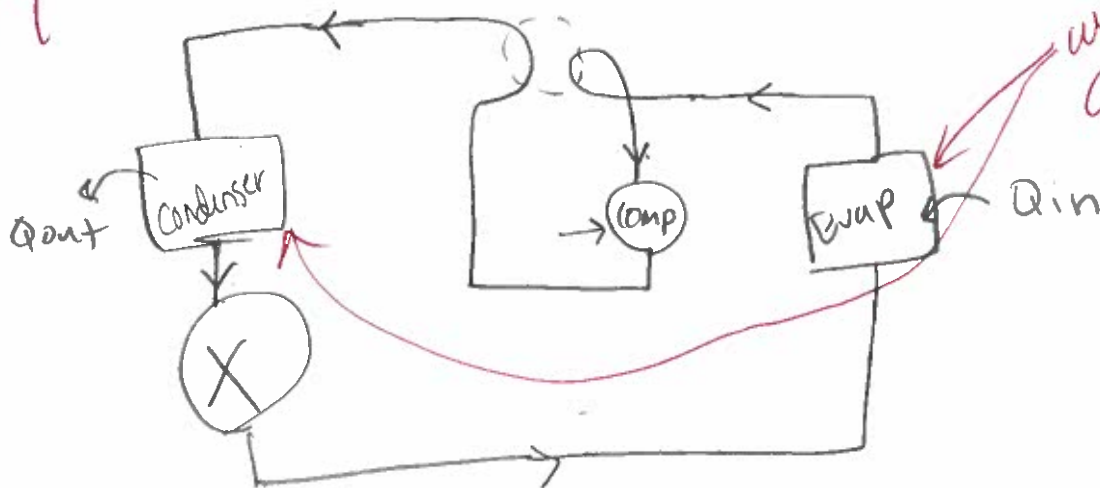
$$COP = \frac{Q_{cond}}{W_{comp}} = \frac{h_2 - h_1}{h_1 - h_4} = \frac{274.636 - 241.14}{241.14 - 31.18} =$$

1

0

(iv) Draw the schematic of the system if the same unit is to be used for cooling the building (10 Pts)

07



which coils are they?

THERMODYNAMICS II

FALL 2021

Title of Assignment: TEST 3

TOPICS COVERED IN TEST 3

Test 3 covered the following topics:

1. Combustion Processes
2. Gas-Vapor Mixture & Psychrometry

THERMODYNAMICS II
FALL 2021

**SAMPLE TEST QUESTIONS, SOLUTION,
AND GRADING SCHEME FOR TEST 3**

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3023 Y01 : Thermodynamics II
Exam #3

Name: Solution Score: _____

Note:

1. Show detailed steps to get full credit
2. Show unit conversions

1. The components of the exhaust gas of a spark ignition engine (gasoline engine) using a fuel mixture represented as C_8H_{17} have a dry molar analysis of 8.7% CO_2 , 8.9% CO , 0.3% O_2 , 3.7% H_2 , 0.3% CH_4 and 78.1% N_2 . Determine the following:
 - (i) Determine the stoichiometric balanced equation for the fuel C_8H_{17} . (20 pts)
 - (ii) Determine the balanced equation based on the dry product analysis as given in the problem. (30 pts.)
 - (iii) Determine the equivalence ratio Φ , defined as the ratio of mass of fuel for the actual reaction (ii) to the mass of fuel for the stoichiometric reaction (i) (10 pts)

2. Atmospheric air at 35 °C and a relative humidity of 70% is cooled to 20 °C and a relative humidity of 50% for a residential home. Determine the following:
 - a) The amount of water added or removed during the process.
 - b) The amount of energy added or removed during the process.
 - c) The dew point temperature of the outside air.
 - d) The dew point temperature of the room air.

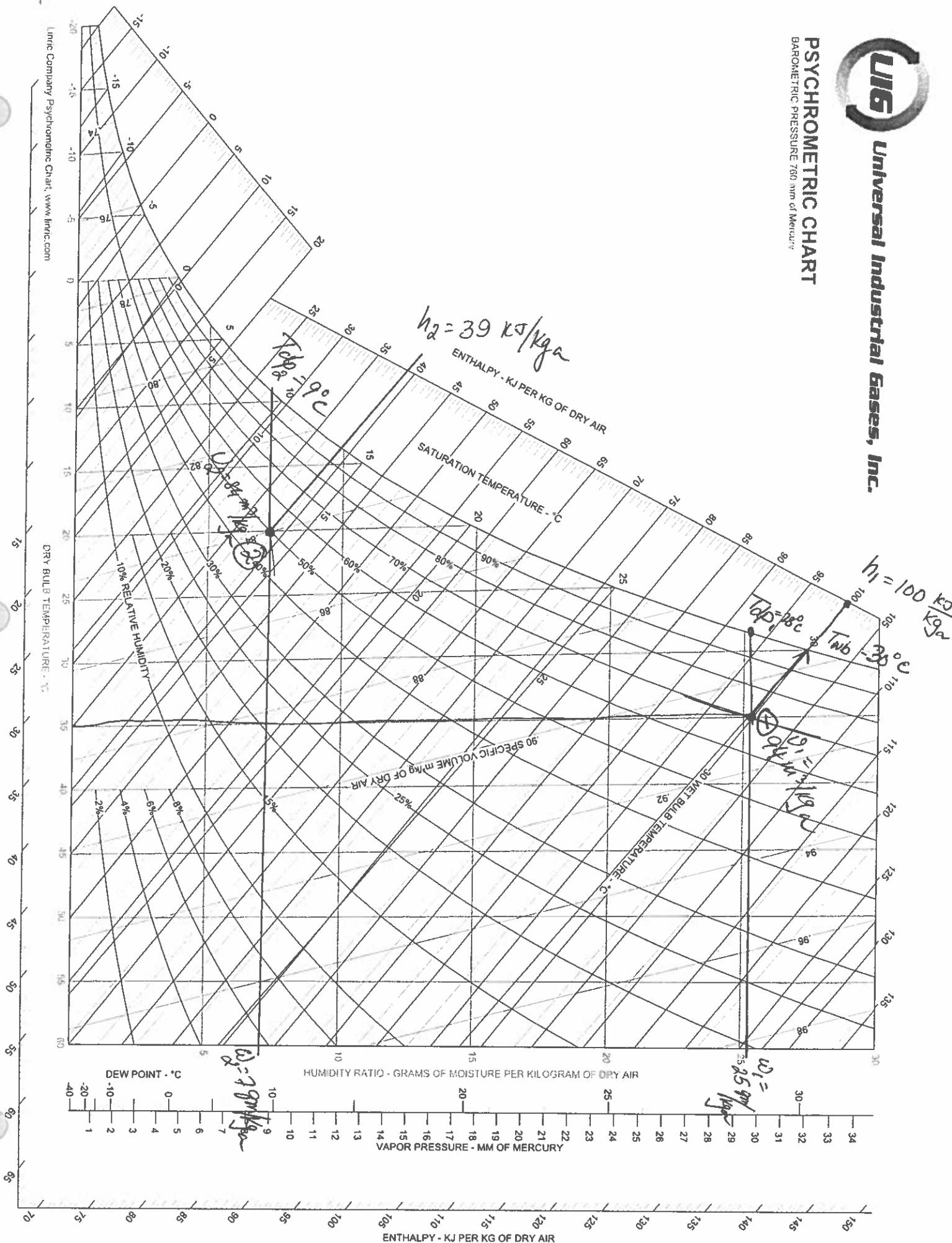
Note: You must use the psychrometric chart provided and **show on the chart how and what values** you obtained to determine the answers for (a), (b), (c), and (d) to get credit.



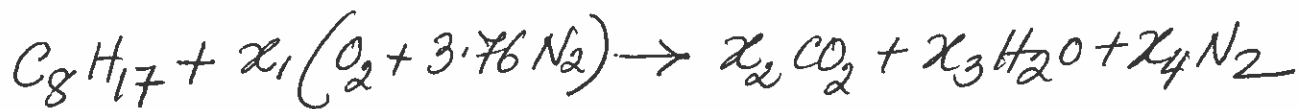
Universal Industrial Gases, Inc.

PSYCHROMETRIC CHART

BAROMETRIC PRESSURE 760 mm of Mercury



#1 (i) Stoichiometric balanced equation



C balance:

~~$$8 = x_2 \Rightarrow x_2 = 8$$~~

$$8 = x_2$$

$$O: 2x_1 = 2x_2 + x_3 = 2(8) + x_3 = 16 + x_3$$

$$H: 17 = 2x_3 \Rightarrow x_3 = \frac{17}{2} = 8.5 = x_3$$

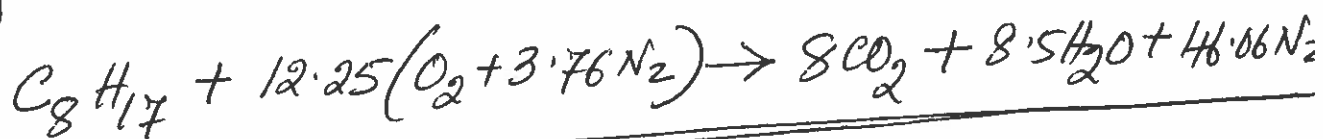
$$\therefore 2x_1 = 16 + x_3 \Rightarrow 2x_1 = 16 + 8.5 = 24.5$$

$$\Rightarrow x_1 = \frac{24.5}{2} = 12.25 = x_1$$

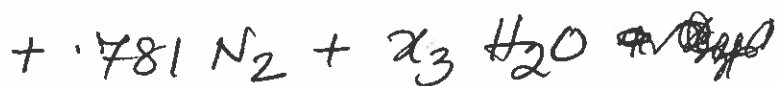
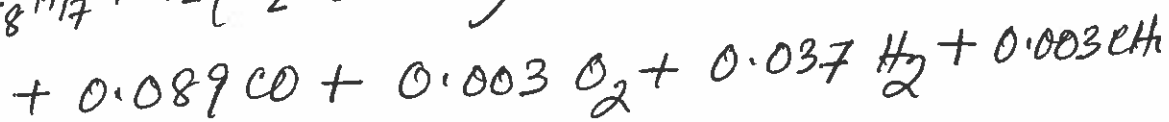
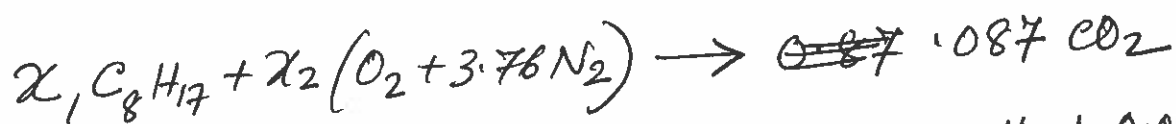
$$N: 3.76 \times 2 \times x_1 = 2x_4$$

$$\Rightarrow 3.76 \times 2 \times 12.25 = 2x_4 \Rightarrow x_4 = 46.06$$

Therefore the stoichiometric balanced equation is



(ii) actual reaction



Atom balances

$$C: \quad 8x_1 = 0.087 + 0.089 + 0.003$$

$$\Rightarrow \underline{x_1 = 0.0224}$$

$$O: \quad 2x_2 = (2)(0.087) + 0.089 + (2)(0.003) + x_3$$

$$\Rightarrow 2x_2 = 0.269 + x_3 \quad \text{--- (1)}$$

$$H: \quad 17x_1 = (2)(0.037) + (4)(0.003) + 2x_3$$

$$\Rightarrow 17x_1 = 0.086 + 2x_3 \quad \text{--- (2)}$$

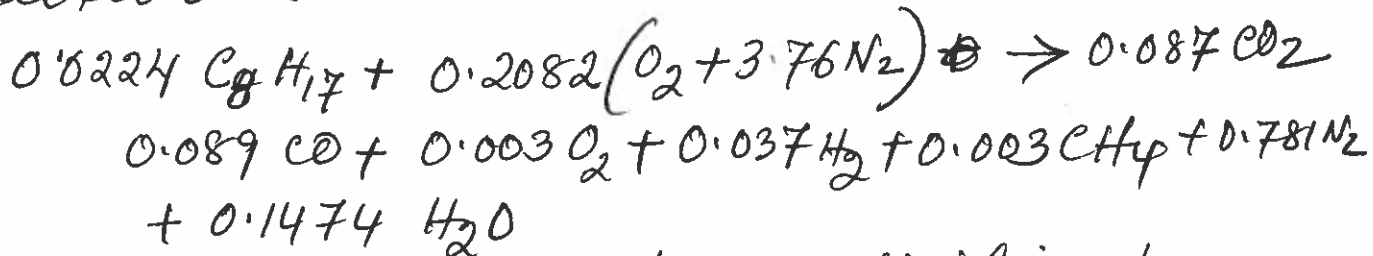
$$\Rightarrow (17)(0.0224) = 0.086 + 2x_3$$

$$\Rightarrow 2x_3 = 0.2948 \Rightarrow \underline{x_3 = 0.1474}$$

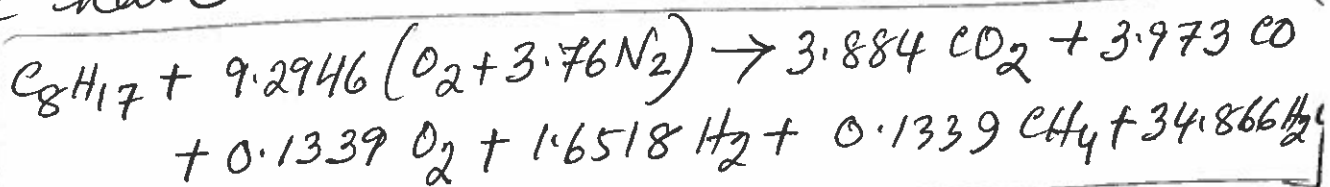
$$\text{Now from eq (1)} \quad 2x_2 = 0.269 + x_3 = 0.269 + 0.1474$$

$$\Rightarrow \underline{x_2 = 0.2082}$$

Therefore the balanced equation for actual reaction is



On per mole of fuel basis, dividing by 0.0224 we have



ABOVE AVERAGE

Above Average Student Original Graded Assignment

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3023 Y01 : Thermodynamics II
Exam #3

Name: Heba Afzal **Score:** 180

Note:

1. Show detailed steps to get full credit
2. Show unit conversions

- 60
1. The components of the exhaust gas of a spark ignition engine (gasoline engine) using a fuel mixture represented as C_8H_{17} have a dry molar analysis of 8.7% CO_2 , 8.9% CO , 0.3% O_2 , 3.7% H_2 , 0.3% CH_4 and 78.1% N_2 . Determine the following:

- Determine the stoichiometric balanced equation for the fuel C_8H_{17} . (20 pts)
- Determine the balanced equation based on the dry product analysis as given in the problem. (30 pts.)
- Determine the equivalence ratio Φ , defined as the ratio of mass of fuel for the actual reaction (ii) to the mass of fuel for the stoichiometric reaction (i) (10 pts)

- 40
2. Atmospheric air at $35^\circ C$ and a relative humidity of 70% is cooled to $20^\circ C$ and a relative humidity of 45% for a residential home. Determine the following:

- The amount of water added or removed during the process.
- The amount of energy added or removed during the process.
- The dew point temperature of the outside air.
- The dew point temperature of the room air.

Note: You must use the psychrometric chart provided and **show on the chart how and what values** you obtained to determine the answers for (a), (b), (c), and (d) to get credit.

$$\begin{array}{ll}
 T_1 = 35^\circ C & T_2 = 20^\circ C \\
 \phi_1 = 70\% & \phi_2 = 45\% \\
 h_1 = 99.5 \text{ kJ/kg} & h_2 = 36.5 \text{ kJ/kg} \\
 T_{wb1} = 29.9^\circ C & T_{wb2} = 13^\circ C \\
 v_1 = 0.908 \text{ m}^3/\text{kg} & v_2 = 0.839 \text{ m}^3/\text{kg} \\
 \text{Humidity ratio } \omega_1 = 25.2 \frac{\text{grams } H_2O}{\text{kg dry air}} & \text{Humidity ratio } \omega_2 = 6.5 \frac{\text{grams } H_2O}{\text{kg dry air}} \\
 T_{dp1} = 28.6^\circ C & T_{dp2} = 8^\circ C
 \end{array}$$

a) water was removed during the process $\omega_2 - \omega_1 \Rightarrow 6.5 \frac{\text{g } H_2O}{\text{kg Air}} - 25.2 \frac{\text{g } H_2O}{\text{kg Air}} = -18.7 \frac{\text{g } H_2O}{\text{kg Air}}$

so $18.7 \frac{\text{g } H_2O}{\text{kg Air}}$ were removed from Air

b) $Q = h_2 - h_1 \Rightarrow Q = 36.5 \text{ kJ/kg} - 99.5 \text{ kJ/kg}$

$Q = -63 \text{ kJ/kg}$ which tells Energy was removed @ a rate of 63 kJ/kg

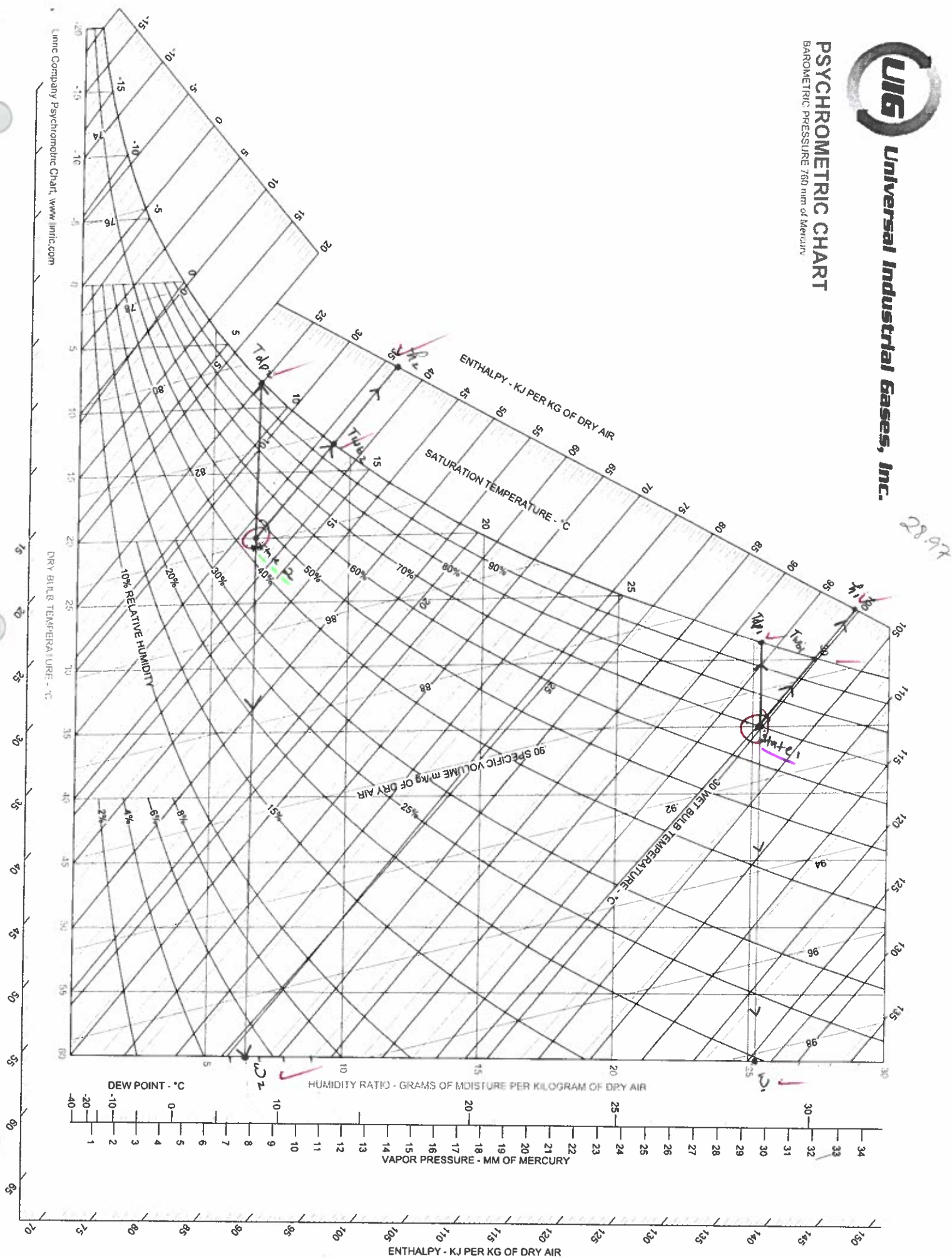
c) $T_{dp(\text{outside Air})} = 28.6^\circ C$

d) $T_{dp(\text{room Air})} = 8^\circ C$



PSYCHROMETRIC CHART

BAROMETRIC PRESSURE 760 mm of Mercury



$$C = 12 \quad H = 1 \quad \text{Air} = x(O_2 + 3.76 N_2)$$

$$N = 14$$

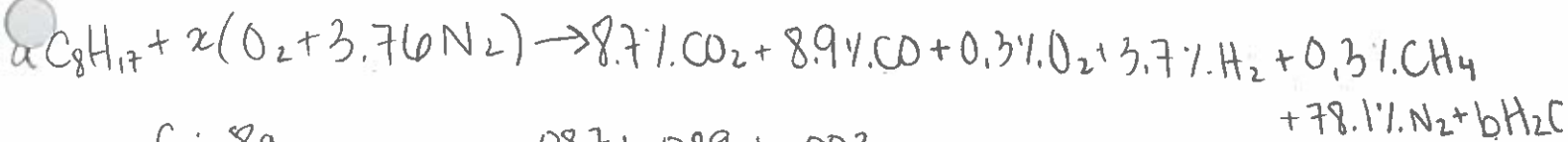
$$O = 16$$

$$CO_2$$

$$H_2O$$

$$N_2$$

ii)



$$C: 8a = .087 + .089 + .003$$

$$30 \quad H: 17a = 0.037(2) + .003(4) + 2b$$

$$O: 2x = .087(2) + .089 + .003(2) + b$$

$$N: 3.76(2)x = .781(2)$$

$$C: 8a = .087 + .089 + .003$$

$$a = 0.022$$

$$O: x = \frac{.087(2) + .089 + .003(2) + 0.147}{2} = .208 \checkmark$$

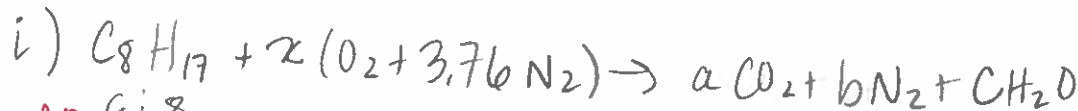
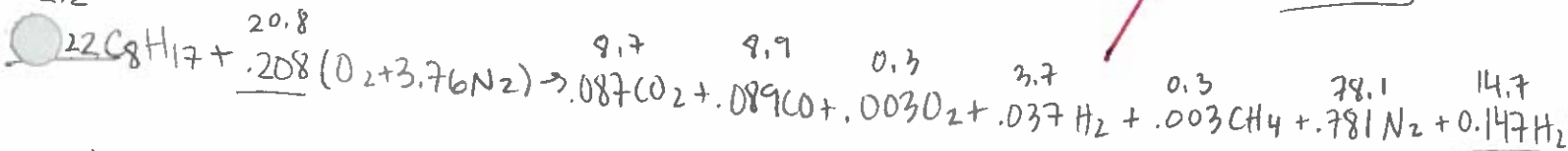
$$H: 17(0.022) = .037(2) + .003(4) + 2b$$

$$b = 0.147$$

$$N: 3.76(2)x = .781(2)$$

$$x = 0.208 \checkmark$$

2.2



$$20 \quad C: 8 = a$$

$$H: 17 = 2c$$

$$O: 2x = 2a + c$$

$$N: 3.76(2)x = 2b$$

$$C: a = 8$$

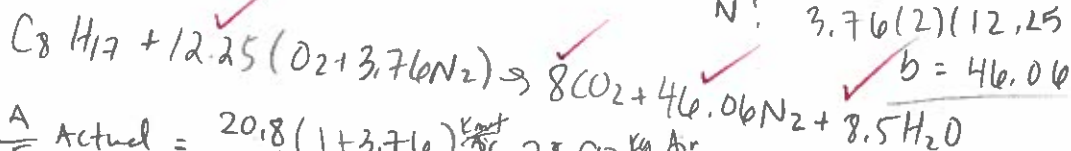
$$H: c = 8.5$$

$$O: 2x = 2(8) + 8.5$$

$$x = 12.25$$

$$N: 3.76(2)(12.25) = 2b$$

$$b = 46.06$$



$$\frac{\text{kg Air}}{\text{kmol Air}}$$

$$8(12) + 17 = 113$$

$$28.97$$

$$ii) \frac{A}{F} \text{ Actual} = \frac{20.8(1 + 3.76) \frac{\text{kg Air}}{\text{kmol Air}}}{2.2 \text{ kmol F}} \times \frac{28.97 \frac{\text{kg Air}}{\text{kmol Air}}}{113 \frac{\text{kg Fuel}}{\text{kmol F}}} = 11.53 \frac{\text{kg Air}}{\text{kg Fuel}}$$

$$\frac{A}{F} \text{ Actual} / \frac{A}{F} \text{ Stoich}$$

$$10 \quad \frac{A}{F} \text{ Stoich} = \frac{12.25(4.76) \text{ kmol Air}}{1 \text{ kmol Fuel}}$$

$$\times \frac{28.97 \frac{\text{kg Air}}{\text{kmol Air}}}{113 \frac{\text{kg Fuel}}{\text{kmol Air}}} = 14.949 \frac{\text{kg Air}}{\text{kg Fuel}}$$

$$= \frac{11.53}{14.949} = 0.77$$

AVERAGE

Average Student Original Graded Assignment

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3023 Y01 : Thermodynamics II
Exam #3

Name: Anette Lira Score: 78

Note:

1. Show detailed steps to get full credit
2. Show unit conversions

III Equivalence Ratio $\phi = \frac{2.37}{1.22} = \boxed{\frac{1.94 \text{ Kg (Air)}}{\text{Kg (fuel)}}}$ ✓
mass basis

- ✓ 1. The components of the exhaust gas of a spark ignition engine (gasoline engine) using a fuel mixture represented as C_8H_{17} have a dry molar analysis of 8.7% CO_2 , 8.9% CO , 0.3% O_2 , 3.7% H_2 , 0.3% CH_4 and 78.1% N_2 . Determine the following:
- Determine the stoichiometric balanced equation for the fuel C_8H_{17} . (20 pts)
 - Determine the balanced equation based on the dry product analysis as given in the problem. (30 pts.)
 - Determine the equivalence ratio Φ , defined as the ratio of mass of fuel for the actual reaction (ii) to the mass of fuel for the stoichiometric reaction (i) (10 pts)
2. Atmospheric air at 30 °C and a relative humidity of 80% is cooled to 25 °C and a relative humidity of 50% for a residential home. Determine the following:
- The amount of water added or removed during the process.
 - The amount of energy added or removed during the process.
 - The dew point temperature of the outside air.
 - The dew point temperature of the room air.

Note: You must use the psychrometric chart provided and **show on the chart how and what values** you obtained to determine the answers for (a), (b), (c), and (d) to get credit.

State 1

$\phi = \text{relative humidity} = 80\%$
 $T_{db} = 30^\circ C$
 relative humidity = 80%

Psychrometric chart
 $\begin{cases} h_1 = 85 \text{ kJ/kg} \\ T_{wb} = 27^\circ C \\ v = 0.865 \text{ m}^3/\text{kg} \end{cases}$
 humidity ratio = 22 grams of moisture / 1 kg of dry air
 $w = 22$
 dew point = 26 °C

State 2

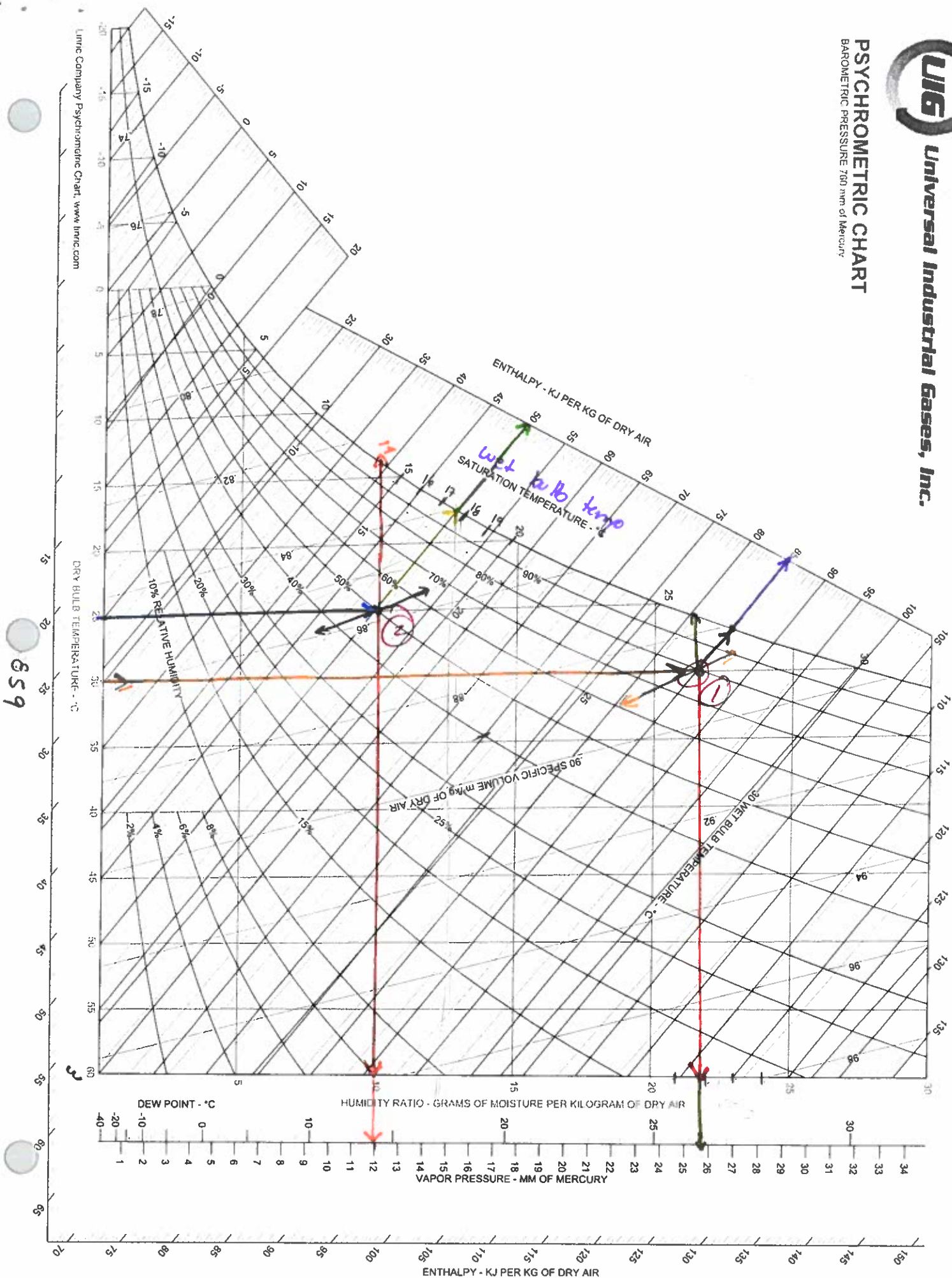
$T_{db} = 25^\circ C$
 relative humidity = 50%
 Psych. Ch $\begin{cases} h_2 = 50 \text{ kJ/kg} \\ T_{wb} = 17.7^\circ C \\ w = 10 \text{ grams of moisture} \cdot \text{Kg of dry Air} \\ v = 0.859 \text{ m}^3/\text{kg} \end{cases}$
 dew point = 12 °C

a) $w = w_2 - w_1 = w_1 - w_2 = 22 - 10 = 12 \text{ g of moisture} \cdot \text{Kg of dry Air}$
 being removed during the process because the air is also being cooled
 b) $Q = h_2 - h_1 =$



PSYCHROMETRIC CHART

BAROMETRIC PRESSURE 760 mm of Mercury



BELOW AVERAGE

Below Average Student Original Graded Assignment

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3023 Y01 : Thermodynamics II
Exam #3

Name: Thomas Carroll^{III} **Score:** 65

Note:

1. Show detailed steps to get full credit
2. Show unit conversions

- 25
1. The components of the exhaust gas of a spark ignition engine (gasoline engine) using a fuel mixture represented as C_8H_{17} have a dry molar analysis of 8.7% CO_2 , 8.9% CO , 0.3% O_2 , 3.7% H_2 , 0.3% CH_4 and 78.1% N_2 . Determine the following:

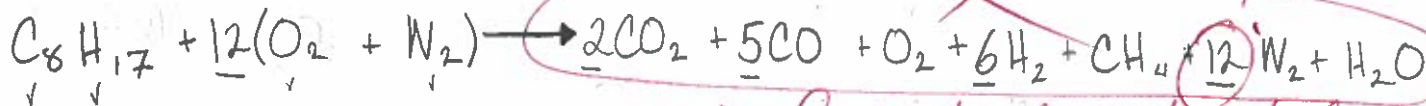
- Determine the stoichiometric balanced equation for the fuel C_8H_{17} . (20 pts)
- Determine the balanced equation based on the dry product analysis as given in the problem. (30 pts.)
- Determine the equivalence ratio Φ , defined as the ratio of mass of fuel for the actual reaction (ii) to the mass of fuel for the stoichiometric reaction (i) (10 pts)

- 40
2. Atmospheric air at 35 °C and a relative humidity of 70% is cooled to 20 °C and a relative humidity of 40% for a residential home. Determine the following:

- The amount of water added or removed during the process.
- The amount of energy added or removed during the process.
- The dew point temperature of the outside air.
- The dew point temperature of the room air.

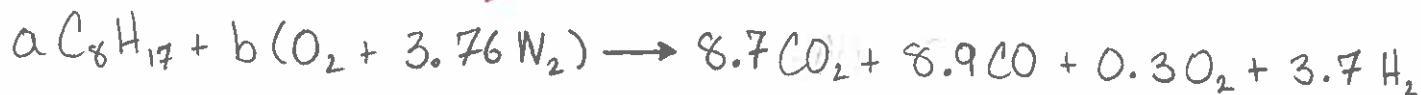
Note: You must use the psychrometric chart provided and **show on the chart how and what values** you obtained to determine the answers for (a), (b), (c), and (d) to get credit.

(i)



X you need to find stoichiometric balanced equation first.

(ii)



$$a = 1$$



$$b + 3.76b = 12 \Rightarrow \frac{4.76b}{4.76} = \frac{12}{4.76}$$

$$c = 3.52$$

$$b = 2.52$$

$$a + b = c \Rightarrow 1 + 2.52 = 3.52$$





Universal Industrial Gases, Inc.

PSYCHROMETRIC CHART

Outside Barometric Pressure: 760 mm of Mercury

Inside

$T_1 = 35^\circ\text{C}$
 $T_2 = 20^\circ\text{C}$

$\phi_1 = 70\% \Rightarrow \phi_2 = 40\%$

$v_1 = 25.3 \text{ g/kg}$
 $w_2 = 6.0 \text{ g/kg}$

$h_1 = 99.5 \text{ kJ/kg}$
 $h_2 = 35 \text{ kJ/kg}$

$v_1 = 91 \text{ m}^3/\text{kg}$
 $v_2 = 83.6 \text{ m}^3/\text{kg}$

a)

$\Delta w = -19.3 \text{ g/kg}$

b)

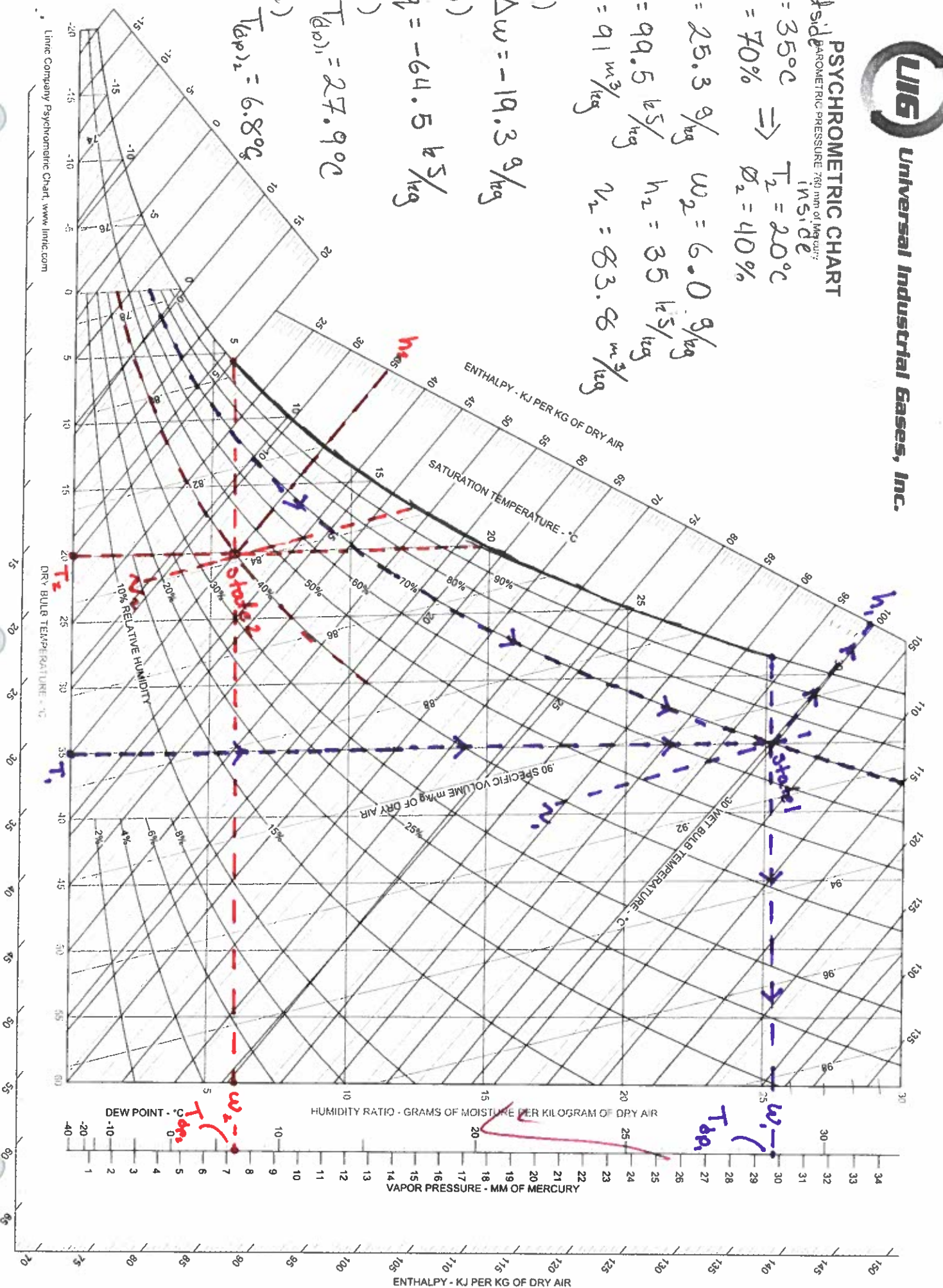
$q = -64.5 \text{ kJ/kg}$

c)

$T_{db1} = 27.9^\circ\text{C}$

d)

$T_{dpt2} = 6.8^\circ\text{C}$



2.)

$$\begin{aligned} T_1 = 35^\circ\text{C} &\Rightarrow T_2 = 20^\circ\text{C} \\ \phi_1 = 70\% &\Rightarrow \phi_2 = 40\% \end{aligned}$$

(a)

$$\begin{aligned} \Delta w &= w_2 - w_1 \\ &= (6.0 - 25.3) \text{ g/kg} \\ &= -19.3 \text{ g/kg} \quad (\text{loss of water}) \end{aligned}$$

(b)

$$\begin{aligned} \dot{Q} - \dot{W} &= \dot{m} \left(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} \right) \\ \Rightarrow q &= (h_2 - h_1) \\ &= (35 \text{ kJ/kg} - 99.5 \text{ kJ/kg}) \\ &= -64.5 \text{ kJ/kg} \end{aligned}$$

(c)

$$T_{(dp)_1} = 27.9^\circ\text{C}$$

(d)

$$T_{(dp)_2} = 6.8^\circ\text{C}$$

THERMODYNAMICS II

FALL 2021

Title of Assignment: Final Exam

TOPICS COVERED IN Final Exam

Final exam covered the following topics:

1. Exergy and 2nd Law efficiency
2. Vapor Power Cycle
3. Gas Power Cycle
4. Combustion

THERMODYNAMICS II
FALL 2021

**SAMPLE TEST QUESTIONS, SOLUTION,
AND GRADING SCHEME FOR FINAL EXAM**

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3023 Y01 : Thermodynamics II
Final Exam

Solution

Print your name (Last name first)

Signature and Date

Score

100

Signing your name in the space provided above signifies that you will abide by the Prairie View A&M University Code of Student Conduct. It also signifies that you understand that you will get zero for this test if there is any indication of copying from other students or from other source.

Note:

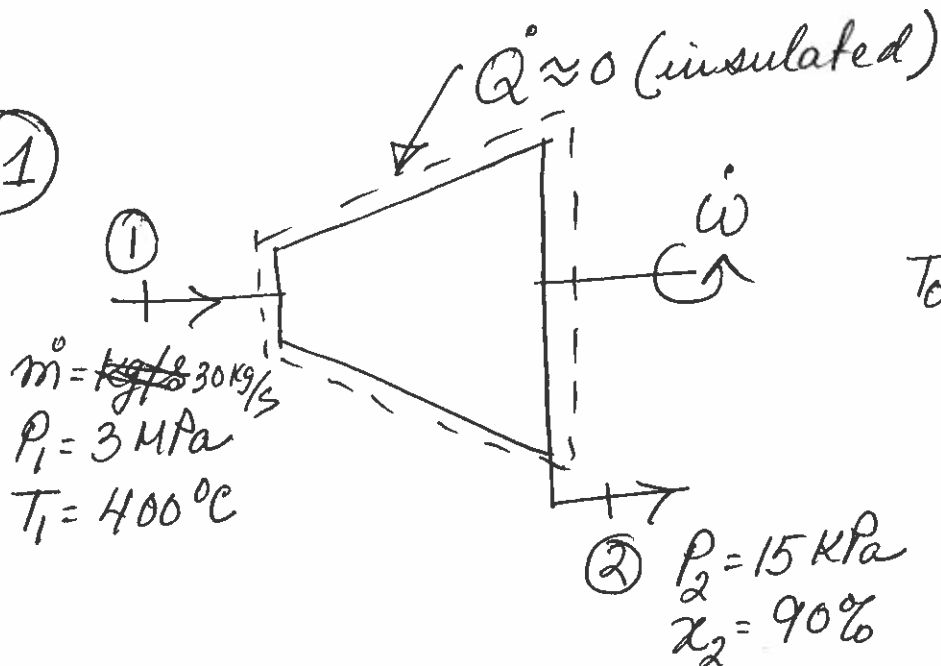
1. Show detailed steps to get full credit
2. Show units and unit conversions

1. An insulated steam turbine receives 30 kg of steam per second at 3 MPa, 400 °C and leaves at 15 kPa, 90% quality. Determine the change in availability and the second-law efficiency for the process. (25 pts.)
2. Consider a regenerative cycle using steam as the working fluid. Steam leaves the boiler and enters the turbine at 4 MPa, 500 °C. After expansion to 400 kPa, some of the steam is extracted from the turbine for the purpose of heating the feedwater in an open feedwater heater. The pressure in the feedwater heater is 400 kPa, and the water leaving it is saturated liquid at 400 kPa. The steam not extracted expands to 10 kPa. Determine the fraction of the mass of steam that is extracted. (25 pts.)
3. Consider a gas turbine with air entering the compressor at 0.1 MPa and 20 °C. The pressure leaving the compressor is 1.0 MPa, and the maximum temperature in the cycle is 1100 °C. Assume a compressor efficiency of 80%. Determine the compressor work. (20 pts.)
4. Octane (C_8H_{18}) is burned with atmospheric air. The analysis of the products on a dry basis is as follows: (20 pts.)

CO_2	10.00%
O_2	2.37%
CO	0.53%
N_2	87.10%

- (i) Complete the balanced equation on per kmol of fuel.
- (ii) Determine the air-fuel ratio on a mass basis

#1



$$T_0 = 25^\circ\text{C} = 25 + 273 = 298^\circ\text{K}$$

Determine: (a) change availability/energy
(b) 2nd law efficiency

$$(a) \Delta X = \dot{m} \Delta \psi$$

$$= \dot{m} \left[(h_2 - h_1) - T_0 (s_2 - s_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1) \right]$$

$$\Delta X = \dot{m} \left[(h_2 - h_1) - T_0 (s_2 - s_1) \right] \quad \text{--- (1)}$$

$\Delta KE \approx 0$ (Since no velocity information is given)

$\Delta PE \approx 0$ (no height information is given).

State 1

$$\text{at } P_1 = 3 \text{ MPa}, T_{1,\text{sat}} = 233.85^\circ\text{C}$$

Since $T_1 = 400^\circ\text{C} > T_{1,\text{sat}} = 233.85^\circ\text{C}$, state ① is at superheated state

From superheat table A-6, @ $P_1 = 3 \text{ MPa}$ & $T_1 = 400^\circ\text{C}$,

$$h_1 = 3231.7 \text{ kJ/kg and } s_1 = 6.9235 \text{ kJ/kg}\cdot\text{K}$$

State 2

State ② is at saturated mixture state.

$$\therefore \text{At } P_2 = 15 \text{ kPa, } h_{f2} = 225.94 \text{ kJ/kg, } h_{g2} = 2598.3 \text{ kJ/kg}$$

$$s_{f2} = 0.7549 \text{ kJ/kg}\cdot\text{K, } s_{g2} = 8.0071 \text{ kJ/kg}\cdot\text{K}$$

$$\therefore h_2 = h_{f2} + x_2(h_{g2} - h_{f2})$$

$$= 225.94 + 0.9(2598.3 - 225.94) \text{ kJ/kg}$$

$$\Rightarrow h_2 = 2361.06 \text{ kJ/kg}$$

$$s_2 = s_{f2} + x_2(s_{g2} - s_{f2}) = 0.7549 + 0.9(8.0071 - 0.7549) \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

$$\Rightarrow s_2 = 7.28188 \text{ kJ/kg} \cdot \text{K}$$

$$\therefore \Delta X = m[(h_2 - h_1) - T_0(s_2 - s_1)]$$

$$= (30 \frac{\text{kg}}{\text{s}}) \left[(2361.06 - 3231.7) \frac{\text{kJ}}{\text{kg}} - 298 \text{ K} (7.28188 - 6.9235) \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \right]$$

$$= -29323.1 \text{ kJ/s}$$

$$\therefore \boxed{\Delta X = -29,323.1 \text{ kW}}$$

Therefore there is a decrease of 29,323 kW of exergy.

$$\textcircled{b} \quad \eta_{II} = \frac{W_{\text{actual}}}{W_{\text{reversible}}} = \frac{\dot{W}_a}{\dot{W}_{\text{rev}}}$$

$$\dot{W}_{\text{rev}} = \Delta X = 29,323.1 \text{ kW}$$

$\dot{W}_a$ is obtained from energy balance equation

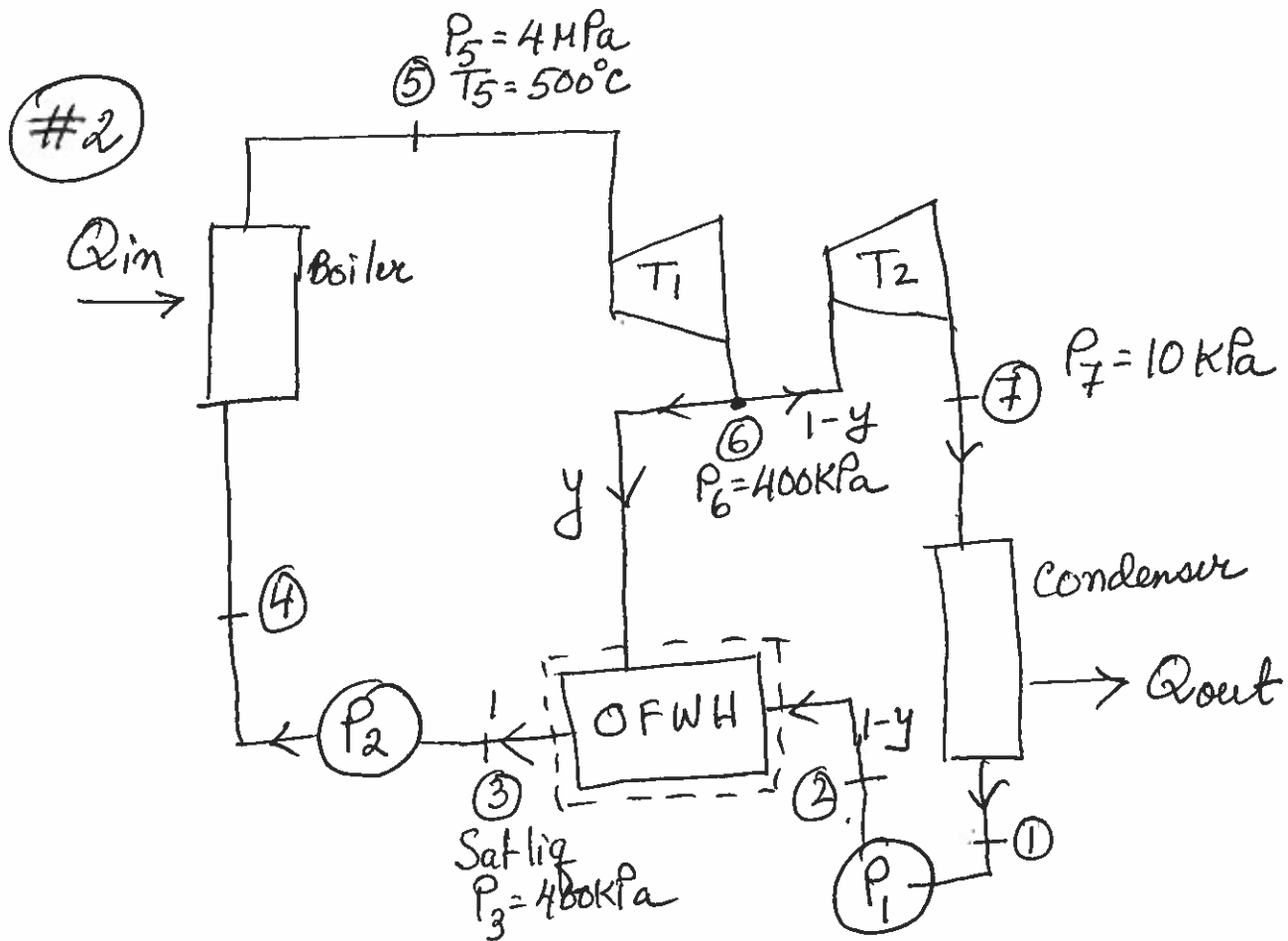
$$\dot{Q} - \dot{W}_a = m[(h_2 - h_1) + \cancel{\Delta KE} + \cancel{\Delta PE}]$$

$$\therefore \dot{W}_a = (30 \frac{\text{kg}}{\text{s}}) (2361.06 - 3231.7) \frac{\text{kJ}}{\text{kg}}$$

$$= -26119.2 \text{ kJ/s}$$

$$\Rightarrow \dot{W}_a = 26,119.2 \text{ kJ/s}$$

$$\therefore \eta_{II} = \frac{\dot{W}_a}{\dot{W}_{\text{rev}}} = \frac{26,119.2 \text{ kJ/s}}{29,323.1 \text{ kJ/s}} = 0.89 = \boxed{89\%}$$



Determine y :

To determine y , apply energy balance around the open feedwater heater

$$\dot{Q} - \dot{W} = \dot{m}_3 h_3 - y \dot{m}_6 h_6 - (1-y) \dot{m}_2 h_2$$

$$\Rightarrow h_3 - y h_6 - (1-y) h_2 = 0$$

$$\Rightarrow h_3 - y h_6 - h_2 + y h_2 = 0$$

$$\Rightarrow y(h_2 - h_6) + h_3 - h_2 = 0$$

$$\Rightarrow y = \frac{h_2 - h_3}{h_2 - h_6} \quad \text{--- (1)}$$

We need the values of h_2 , h_3 & h_6 .

State ②:

$$P_1 = P_7 = 10 \text{ kPa} \text{ and } P_2 = P_6 = P_3 = 400 \text{ kPa}.$$

State ① is saturated liquid at 10 kPa because it is the inlet to pump 1.

$$\therefore h_1 = h_{f@P_1 = 10 \text{ kPa}} = 191.81 \text{ kJ/kg}$$

$$v_1 = v_{f1} = 0.001010 \text{ m}^3/\text{kg}.$$

$$\begin{aligned} w_{pI} &= v_1 (P_2 - P_1) \approx v_{f1} (P_2 - P_1) = 0.001010 \frac{\text{m}^3}{\text{kg}} (400 - 10) \text{ kPa} \\ &= 0.3939 \frac{\text{m}^3 \cdot \text{kPa}}{\text{kg}} \frac{\text{kJ}}{\text{kPa} \cdot \text{m}^3} = 0.3939 \frac{\text{kJ}}{\text{kg}}. \end{aligned}$$

$$\text{again } w_{pI} = (h_2 - h_1) = 0.3939 \text{ kJ/kg}$$

$$\begin{aligned} \therefore h_2 &= (h_1 + 0.3939) \text{ kJ/kg} = (191.81 + 0.3939) \text{ kJ/kg} \\ &\Rightarrow \underline{h_2 = 192.20 \text{ kJ/kg}} \end{aligned}$$

State ③: saturated liquid at 400 kPa

$$\therefore h_3 = h_{f3@400 \text{ kPa}} = \underline{\underline{604.66 \text{ kJ/kg}}} = h_6$$

State ⑤: At $P_5 = 4 \text{ MPa}$, $T_{5,\text{sat}} = 250.35^\circ\text{C}$

Since $T_5 = 500^\circ\text{C} > T_{5,\text{sat}} = 250.35^\circ\text{C} \rightarrow$ Superheated
From superheat table, at $P_5 = 4 \text{ MPa}$ and $T_5 = 500^\circ\text{C}$,

$$s_5 = 6.9781 \text{ kJ/kg} \cdot \text{K}$$

Assuming ^{adiabatic and} reversible turbine, $s_6 = s_5 = 6.9781 \text{ kJ/kg} \cdot \text{K}$

at $P_6 = 4 \text{ MPa}$, $s_{g6} = 6.8955 \text{ kJ/kg} \cdot \text{K}$

Since $s_6 = 6.9781 > s_{g6} = 6.8955 \rightarrow$ superheated.

From superheat table, at $P_g = 400 \text{ kPa}$, $s_g = 6.9781$
 we determine h_g by interpolation

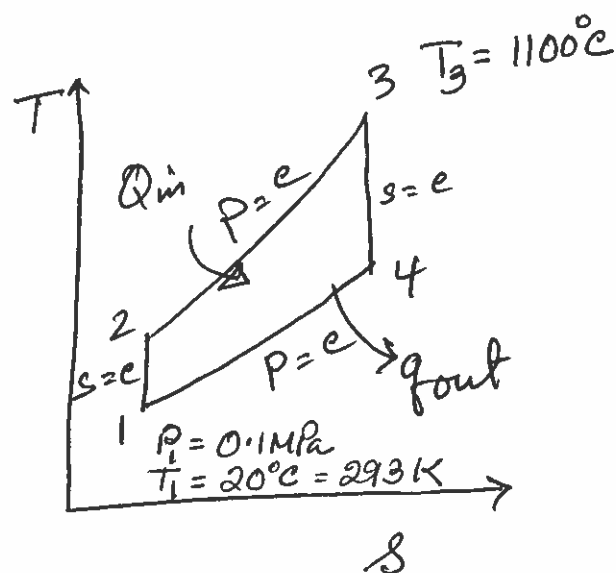
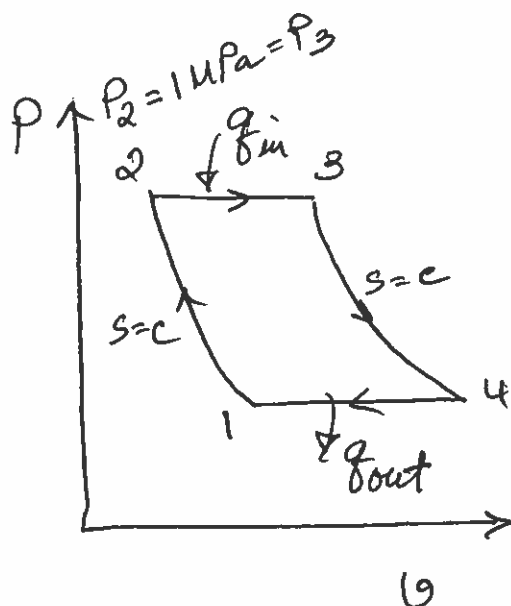
<u>$P = 0.4 \text{ MPa}$</u>		$\frac{h_g - 2752.8}{2860.9 - 2752.8} = \frac{6.9781 - \overset{6.9306}{\cancel{2752}}}{7.1723 - 6.9306}$
<u>h</u>	<u>s</u>	
2752.8	6.9306	
h_g	6.9781	
2860.9	7.1723	

$$\Rightarrow \underline{h_g = 2774.04 \text{ kJ/kg}}$$

Therefore from eq ①

$$y = \frac{192.20 - 604.66}{192.20 - 2774.04} = \boxed{0.1598} \text{ answer.}$$

#3



$$\eta_{\text{comp}} = 80\%$$

$$W_{\text{comp}} = ?$$

$$W_{\text{comp}} = h_2 - h_1 \quad \text{--- ①}$$

We need enthalpy at states ① and ②. In order to get enthalpy we need temperatures at ① and ②.

$$T_1 = 293 \text{ K}$$

From Ideal gas table of air, at $T_1 = 293 \text{ K}$ we get h_1 by interpolation (Table A-17)

$$\frac{h}{T} \quad \frac{290.16 - 290}{295.17 - 290.16} = \frac{293 - 290}{295 - 290}$$

$$h_1 - 293 \Rightarrow \underline{\underline{h_1 = 293.17 \text{ kJ/kg}}}$$

In order to get h_2 , we first assume an isentropic process and get T_{2s} and h_{2s}

using isentropic relation we have

$$\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}} \quad K \text{ for air} = 1.4$$

$$\Rightarrow T_{2s} = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}} = (293 \text{ K}) \left(\frac{1000 \text{ kPa}}{100 \text{ kPa}}\right)^{\frac{1.4-1}{1.4}}$$

$$\Rightarrow T_{2s} = 565.7 \text{ K}$$

$\therefore h_{2s}$ @ 565.7 K from Table A-17 is

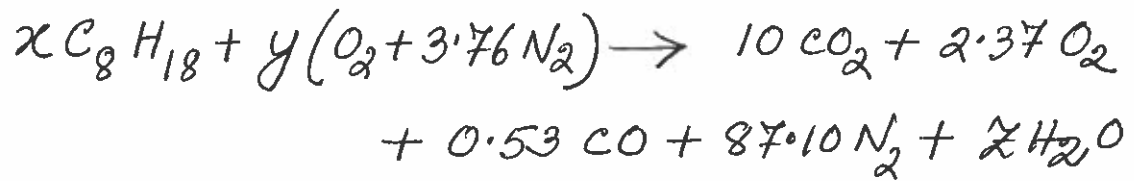
$$\begin{array}{rcl} \frac{T}{h_{2s}} & & \\ 560 & - & 565.17 \\ 565.7 & - & h_{2s} \\ 570 & - & 575.59 \end{array} \quad \frac{h_{2s} - 565.17}{575.59 - 565.17} = \frac{565.7 - 560}{570 - 560}$$
$$\Rightarrow h_{2s} = 571.11 \frac{\text{kJ}}{\text{kg}}$$

$$\therefore w_{\text{comp},s} = (h_{2s} - h_1) = (571.11 - 293.17) \text{ kJ/kg}$$
$$= 277.9 \text{ kJ/kg}$$

$$\therefore \cancel{w_{\text{comp}}} \eta_{\text{comp}} = \frac{w_{\text{comp},s}}{w_{\text{comp},a}} = 0.8$$

$$\therefore w_{\text{comp},a} = \frac{277.9}{0.8} = 347.4 \text{ kJ/kg}$$

#4



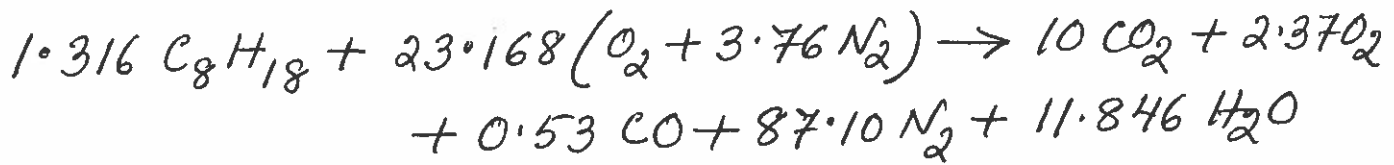
(i)

Atom balance

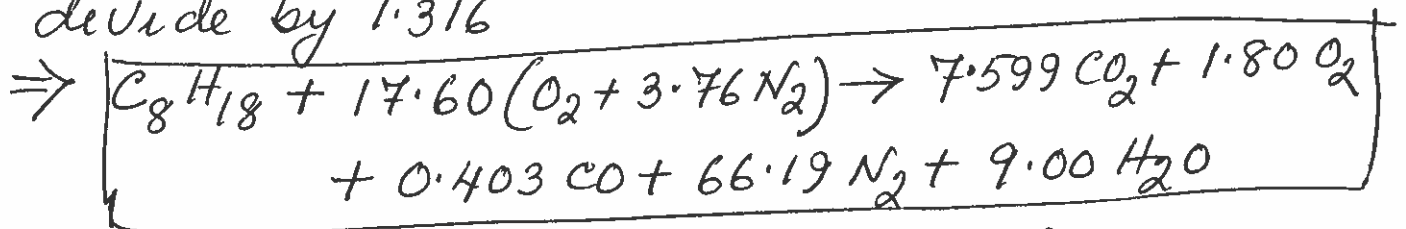
$$C: 8x = 10 + 0.53 \Rightarrow 8x = 10.53 \Rightarrow x = 1.31625$$

$$H: 18x = 2z \Rightarrow (18)(1.31625) = 2z \Rightarrow z = 11.846$$

$$N: (2)(y)(3.76) = 2 \times 87.10 \Rightarrow y = 23.168$$



divide by 1.316



$$(ii) \quad A_{\text{air}}/F_{\text{fuel}} \Big|_{\text{mole mass}} = \frac{(17.60)(4.76)(28.97)}{(1)[(12 \times 8) + (1 \times 18)]} = \boxed{21.3}$$

$$\boxed{A/F \Big|_{\text{mass}} = 21.3}$$

ABOVE AVERAGE

Above Average Student Original Graded Assignment

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3023 Y01 : Thermodynamics II
Final Exam

Combs Caleb

Print your name (Last name first)

Caleb Combs 12/7/2021

Signature and Date

Score

~~90~~ 97

100

Signing your name in the space provided above signifies that you will abide by the Prairie View A&M University Code of Student Conduct. It also signifies that you understand that you will get zero for this test if there is any indication of copying from other students or from other source.

Note:

1. Show detailed steps to get full credit
2. Show units and unit conversions

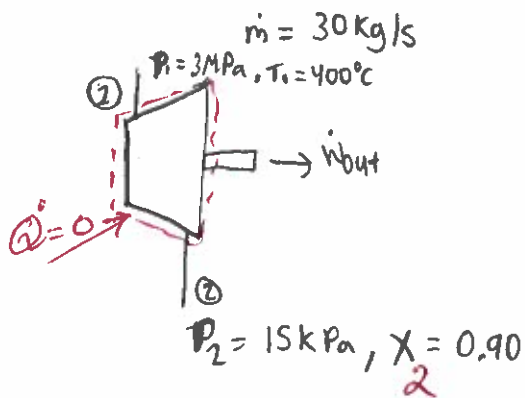
1. An insulated steam turbine receives 30 kg of steam per second at 3 MPa, 400 °C and leaves at 15 kPa, 90% quality. Determine the change in availability and the second-law efficiency for the process. (25 pts.)
2. Consider a regenerative cycle using steam as the working fluid. Steam leaves the boiler and enters the turbine at 4 MPa, 500 °C. After expansion to 400 kPa, some of the steam is extracted from the turbine for the purpose of heating the feedwater in an open feedwater heater. The pressure in the feedwater heater is 400 kPa, and the water leaving it is saturated liquid at 400 kPa. The steam not extracted expands to 10 kPa. Determine the fraction of the mass of steam that is extracted. (25 pts.)
3. Consider a gas turbine with air entering the compressor at 0.1 MPa and 20 °C. The pressure leaving the compressor is 1.0 MPa, and the maximum temperature in the cycle is 1100 °C. Assume a compressor efficiency of 80%. Determine the compressor work. (20 pts.)
4. Octane (C_8H_{18}) is burned with atmospheric air. The analysis of the products on a dry basis is as follows: (20 pts.)

CO_2	10.00%
O_2	2.37%
CO	0.53%
N_2	87.10%

- (i) Complete the balanced equation on per kmol of fuel.
- (ii) Determine the air-fuel ratio on a mass basis

1.

24



(a) Change in availability

Since it is given that there is steam at state 1, refer to Superheated table

At $P_1 = 3 \text{ MPa}$ and $T_1 = 400^\circ\text{C}$,

Need to show the phase at state 1.

$$h_1 = 3231.7 \text{ kJ/kg} \checkmark$$

$$S_1 = 6.9235 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \checkmark$$

Since at exit of turbine $X = 0.90$, it is a saturated mixture. Therefore, refer to table A-5

At $P_2 = 15 \text{ kPa}$ and $X = 0.90$

$$\begin{aligned} h_2 &= h_f + X h_{fg} \\ &= (225.94 \text{ kJ/kg}) + (0.90)(2372.3 \text{ kJ/kg}) \\ &= 2361.01 \text{ kJ/kg} \checkmark \end{aligned}$$

$$\begin{aligned} S_2 &= S_f + X S_{fg} \\ &= (0.7549 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}) + (0.90)(7.2522 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}) \\ &= 7.28188 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \checkmark \end{aligned}$$

$$\Delta \dot{X} = \dot{m} \left[(h_2 - h_1) - T_0 (S_2 - S_1) + \frac{v_2^2 - v_1^2}{2} + g(z_2 - z_1) \right]$$

why? why?

$$\Delta \dot{X} = (30 \text{ kg/s}) \left[(2361.01 \text{ kJ/kg} - 3231.7 \text{ kJ/kg}) - (298.15 \text{ K})(7.28188 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} - 6.9235 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}) \right]$$

1. Continued

$$\eta_{II} = \frac{W_u}{W_{rev}}$$

$$\dot{W}_{rev} = \Delta \dot{X}$$

$$\dot{W}_{rev} = -29.326 \text{ MW} \quad \checkmark$$

Energy balance eqn.

$$\dot{Q} + \dot{W} = \dot{m} \left[(h_2 - h_1) + \frac{v_2^2 - v_1^2}{2} + g(z_2 - z_1) \right]$$

$$+W = (30 \text{ kg/s}) [2361.01 \text{ kJ/kg} - 3231.7 \text{ kJ/kg}]$$

$$W = -26150.7 \frac{\text{kJ}}{\text{s}}$$

$$W_u = -26.150 \text{ MW} \quad \checkmark$$

$$\eta_{II} = \frac{W_u}{W_{rev}} \quad \checkmark$$

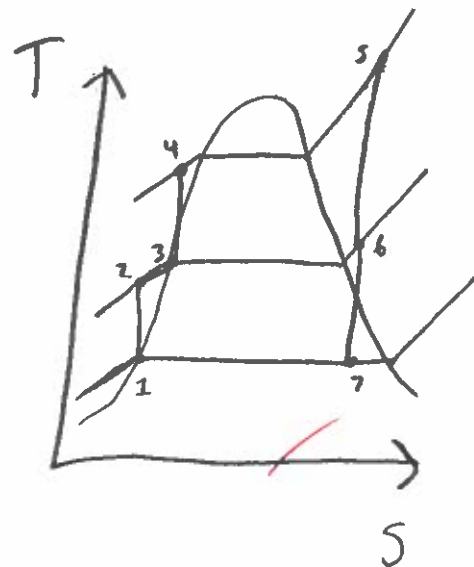
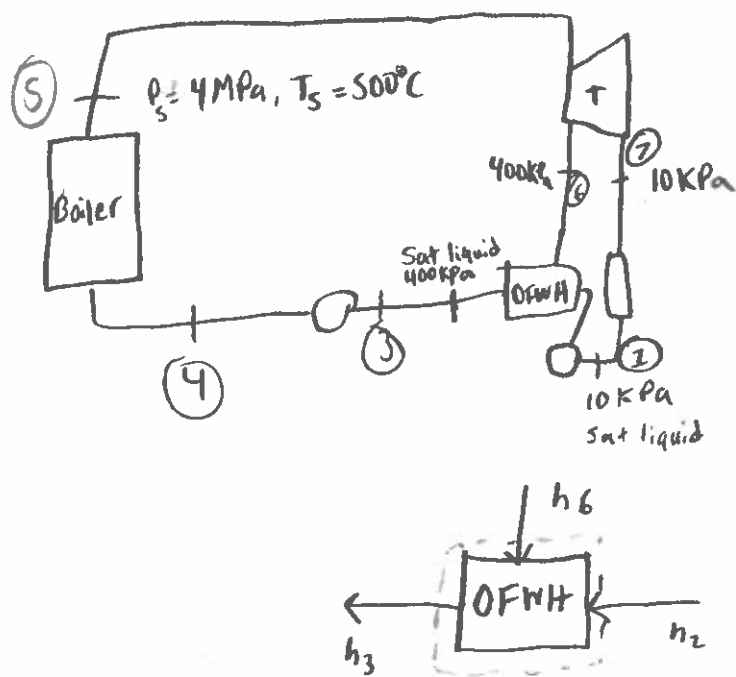
$$\eta_{II} = \frac{-26.151 \text{ MW}}{-29.326 \text{ MW}} \quad \checkmark$$

$$\eta_{II} = 0.8917$$

$$\boxed{\eta_{II} = 89.17\%} \quad \checkmark$$

2.

25



At 4 MPa and 500°C , Since $T_5 > T_{\text{sat}}$, it is Superheated so refer to table A-6

$$S_5 = 7.0922 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

$$S_5 = S_6$$

At 400 kPa and $S_6 = 7.0922 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$, Since $S_6 > S_g$ it is Superheated so refer to table A-6

$$\frac{7.1723 - 6.9306}{2860.9 - 2752.8} = \frac{7.0922 - 6.9306}{h_6 - 2752.8}$$

$$h_6 = 2825.075 \frac{\text{kJ}}{\text{kg}}$$

At 10 kPa and Saturated liquid, refer to table A-S,

$$h_1 = 191.81 \frac{\text{kJ}}{\text{kg}}$$

$$W_{\text{pump}} = v (P_2 - P_1)$$

$$W_{\text{pump}} = (0.001010 \text{ m}^3/\text{kg})(400 \text{ kPa} - 10 \text{ kPa}) \left(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3} \right)$$
$$= 0.3939 \frac{\text{kJ}}{\text{kg}}$$

$$W_{\text{pump}} = h_2 - h_1$$

$$0.3939 \frac{\text{kJ}}{\text{kg}} = h_2 - 191.81 \frac{\text{kJ}}{\text{kg}}$$

$$h_2 = 192.2039 \frac{\text{kJ}}{\text{kg}}$$

At 400 kPa and Saturated liquid, refer to table A-S

$$h_g = 604.66 \frac{\text{kJ}}{\text{kg}}$$



$$\sum \dot{E}_{\text{in}} = \sum \dot{E}_{\text{out}}$$

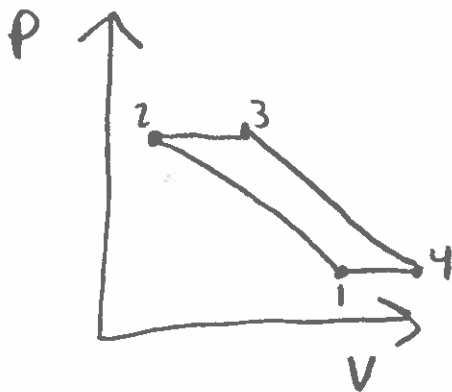
$$y h_g + (1-y) h_2 = 1 h_3 \Rightarrow y (2625.075 \frac{\text{kJ}}{\text{kg}}) + (192.2039 \frac{\text{kJ}}{\text{kg}}) - y (192.2039 \frac{\text{kJ}}{\text{kg}})$$
$$= 604.66 \frac{\text{kJ}}{\text{kg}}$$

$$\Rightarrow 2432.8711 y + 192.2039 = 604.66$$

$$y = 0.1695$$

3,

18



$$P_1 = 0.1 \text{ MPa}, T_1 = 20^\circ\text{C}$$

$$P_2 = 1.0 \text{ MPa}, T_{\text{max}} = 1100^\circ\text{C}$$

$$\eta_{\text{th}} = 0.80$$

$$W_{\text{comp, in}} = h_2 - h_1$$

At $P_1 = 0.1 \text{ MPa}$ and $T_1 = 20^\circ\text{C}$, refer to table A-17

$$\frac{295 - 290}{295.17 - 290.16} = \frac{293.15 - 290}{h_1 - 290.16}$$

$$h_1 = 293.3163 \frac{\text{kJ}}{\text{kg}}$$

$$\left(\frac{T_2}{T_1} \right) = \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}}$$

$$T_2 = \left(\frac{1.0 \text{ MPa}}{0.1 \text{ MPa}} \right)^{\frac{1.4-1}{1.4}} (293.15 \text{ K})$$

$$T_2 = 565.984$$

At $T_2 = 565.984$, refer to table A-17.

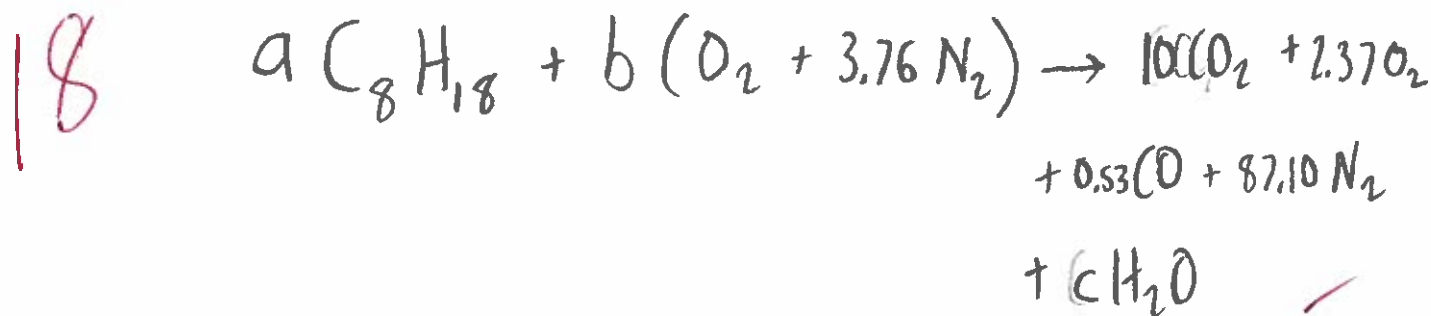
$$\frac{570 - 560}{575.59 - 565.17} = \frac{565.984 - 560}{h_2 - 565.17} \Rightarrow h_2 = 571.405 \frac{\text{kJ}}{\text{kg}}$$

$$W_{\text{comp, in}} = (571.405 - 293.316) \left(\frac{\text{KJ}}{\text{Kg}} \right)$$

$$W_{\text{comp, in}} = 278.089 \frac{\text{KJ}}{\text{Kg}}$$

↑ This is reversible work.
need to use efficiency to
get W_{act}

4.



$$C: 8a = 10 + 0.53 \Rightarrow$$

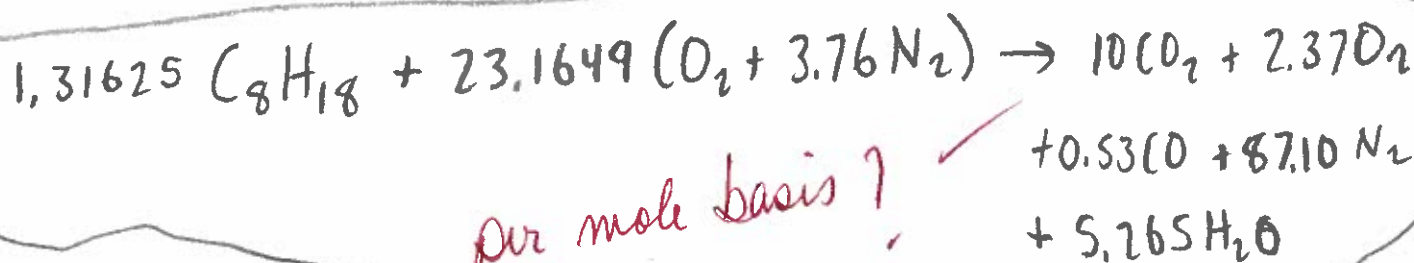
$$a = 1.31625$$

$$H: 18a = 2C$$

$$\Rightarrow 18(1.31625) = 2C \Rightarrow C = 5.265$$

$$N: 28 \times 3.76 \times b = 87.10 \times 2 \Rightarrow b = \frac{87.10}{3.76} = 23.1649$$

Balanced equation:



(b)

$$\text{Air-fuel ratio (mass basis)} = \frac{(23.1649 \times 10^3 \text{ mol}) \times \left(\frac{32g}{\text{mol}} \right) + (87.1 \times 10^3 \text{ mol}) \times \left(\frac{28g}{\text{mol}} \right)}{(1.31625 \times 10^3 \text{ mol}) \times \left(\frac{((8 \times 12) + (18 \times 1))g}{\text{mol}} \right)}$$

$$= \frac{741.2768 \text{ Kg} + 2438.8 \text{ Kg}}{150.0525 \text{ Kg}} = 21.193 \frac{\text{kg(air)}}{\text{kg(fuel)}}$$

AVERAGE

Average Student Original Graded Assignment

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3023 Y01 : Thermodynamics II
Final Exam

Carroll III, Thomas

Print your name (Last name first)

Thomas Carroll III 12-7-21

Signature and Date

Score 85
100

Signing your name in the space provided above signifies that you will abide by the Prairie View A&M University Code of Student Conduct. It also signifies that you understand that you will get zero for this test if there is any indication of copying from other students or from other source.

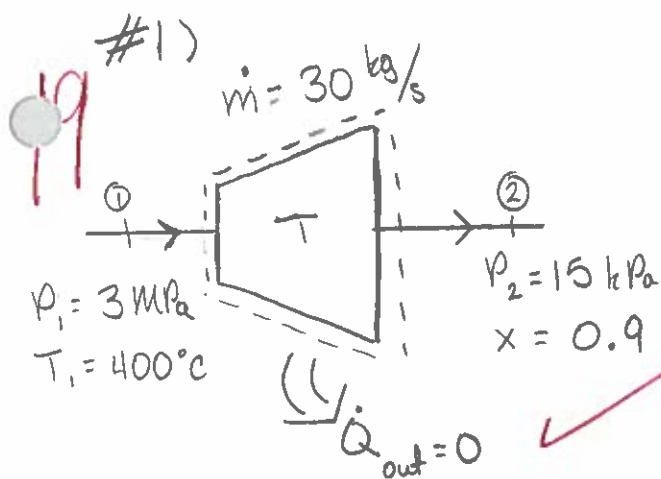
Note:

1. Show detailed steps to get full credit
2. Show units and unit conversions

1. An insulated steam turbine receives 30 kg of steam per second at 3 MPa, 400 °C and leaves at 15 kPa, 90% quality. Determine the change in availability and the second-law efficiency for the process. (25 pts.)
2. Consider a regenerative cycle using steam as the working fluid. Steam leaves the boiler and enters the turbine at 4 MPa, 500 °C. After expansion to 400 kPa, some of the steam is extracted from the turbine for the purpose of heating the feedwater in an open feedwater heater. The pressure in the feedwater heater is 400 kPa, and the water leaving it is saturated liquid at 400 kPa. The steam not extracted expands to 10 kPa. Determine the fraction of the mass of steam that is extracted. (25 pts.)
3. Consider a gas turbine with air entering the compressor at 0.1 MPa and 20 °C. The pressure leaving the compressor is 1.0 MPa, and the maximum temperature in the cycle is 1100 °C. Assume a compressor efficiency of 80%. Determine the compressor work. (20 pts.)
4. Octane (C_8H_{18}) is burned with atmospheric air. The analysis of the products on a dry basis is as follows: (20 pts.)

CO_2	10.00%
O_2	2.37%
CO	0.53%
N_2	87.10%

- (i) Complete the balanced equation on per kmol of fuel.
- (ii) Determine the air-fuel ratio on a mass basis



- open system
 - insulated
 - steam
- Find:
 $\sqrt{\Delta X} = ?$
 $\sqrt{\eta_{\text{th}}} = ?$

66 → 73

①
 $P_1 = 3 \text{ MPa} = 3,000 \text{ kPa}$
 $T_1 = 400^\circ\text{C} > T_{\text{sat},P} = 233.85$
 (super heated)

$h_1 = 3231.7 \text{ kJ/kg}$

$s_1 = 6.9235 \text{ kJ/kg}\cdot\text{K}$

$v_1 = 0.09938 \text{ m}^3/\text{kg}$

②
 $P_2 = 15 \text{ kPa}$
 $x_2 = 0.9$ } sat. mix

$T_2 = T_{\text{sat},P} = 53.97^\circ\text{C}$

$h_2 = h_f + x h_{fg}$

$= (225.94 \text{ kJ/kg}) + (0.9)(2372.3 \text{ kJ/kg})$
 $= 2361.01 \text{ kJ/kg}$

$s_2 = s_f + x s_{fg}$

$= (0.7549 \text{ kJ/kg}\cdot\text{K}) + (0.9)(7.2522 \text{ kJ/kg}\cdot\text{K})$
 $= 7.2819 \text{ kJ/kg}\cdot\text{K}$

$v_2 = v_f + x v_{fg}$

$= (0.001014 \text{ m}^3/\text{kg}) + (0.9)(10.019 \text{ m}^3/\text{kg})$
 $= 9.019 \text{ m}^3/\text{kg}$

⑤

$\eta_{\text{th,turb}} = \frac{W_{\text{out}}}{W_{\text{rev,out}}} = \frac{h_1 - h_2}{\Delta \psi}$

$= \frac{(3231.7 - 2361.01) \text{ kJ/kg}}{(870.69 \text{ kJ/kg})}$

$= 0.99 = \boxed{99\%}$

③
 $\dot{Q} = 0$
 $\dot{Q} - \dot{W} = \dot{m}(h_2 - h_1) + \frac{v_2^2 - v_1^2}{2} + \dot{m}gz$

$-\dot{W} = \dot{m}(h_2 - h_1)$

$-\dot{W} = (30 \text{ kg/s})(2361.01 - 3231.7) \text{ kJ/kg}$

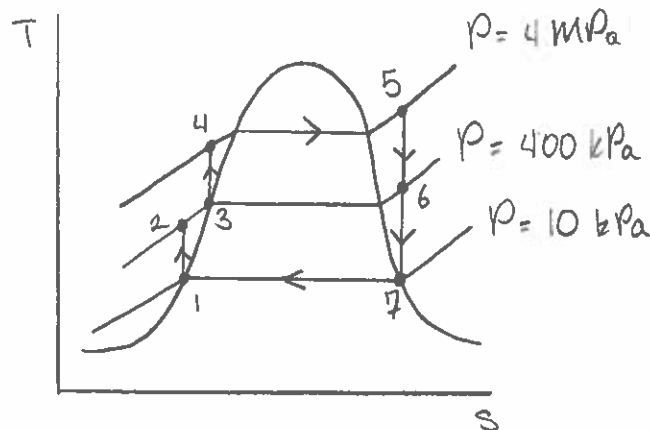
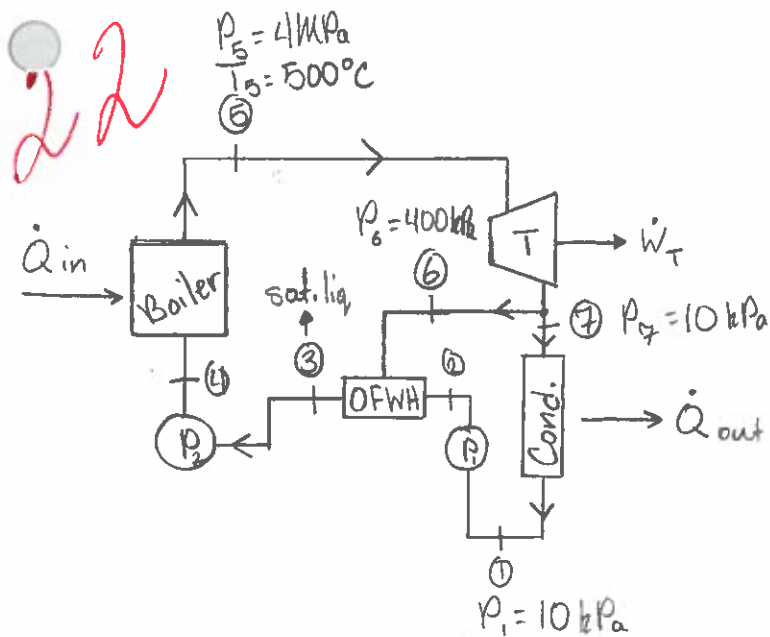
$\dot{W} = 26120.7 \text{ kJ/s}$

④
 $\frac{\dot{W}_{\text{rev}}}{\dot{m}} = \frac{\dot{m}(\psi_1 - \psi_2)}{\dot{m}} + \dot{Q} \left(1 - \frac{T_0}{T_1}\right)$

$\frac{26120.7 \text{ kJ/s}}{30 \text{ kg/s}} = \Delta \psi$

$\Delta \psi = 870.69 \text{ kJ/kg}$, $\Delta X = 26120.7 \text{ kJ/s}$

#2)



$P_1 = 10 \text{ kPa}$
 $T_1 = T_{\text{sat},p} = 45.81^\circ\text{C}$
 $v_1 = v_{f,p} = 0.001010 \text{ m}^3/\text{kg}$
 $h_1 = h_{f,p} = 191.81 \text{ kJ/kg}$
 $s_1 = s_{f,p} = 0.6492 \text{ kJ/kg}\cdot\text{K}$

$P_2 = 400 \text{ kPa}$
 $s_1 = s_2 = 0.6492 \text{ kJ/kg}\cdot\text{K}$
 $w_p = v_1(P_2 - P_1)$
 $= (0.001010 \text{ m}^3/\text{kg})(400 \text{ kPa} - 10 \text{ kPa})(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3})$
 $= 0.3939 \text{ kJ/kg}$

$w_{p1} = h_2 - h_1$
 $\Rightarrow h_2 = w_{p1} + h_1$
 $= (0.3939 \text{ kJ/kg}) + (191.81 \text{ kJ/kg})$

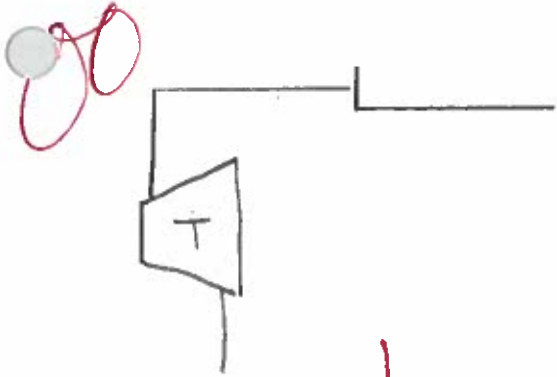
$P_3 = 400 \text{ kPa}, T_3 = T_{\text{sat},p} = 143.61^\circ\text{C}$
 sat. liq.
 $h_3 = h_{f,p} = 604.66 \text{ kJ/kg}$
 $s_3 = s_{f,p} = 1.7765 \text{ kJ/kg}\cdot\text{K}$
 $v_3 = v_{f,p} = 0.001084 \text{ m}^3/\text{kg}$

$P_4 = P_5 = 4 \text{ MPa}$
 $s_4 = s_3 = 1.7765 \text{ kJ/kg}\cdot\text{K}$
 $w_{p2} = v_3(P_4 - P_3)$
 $= (0.001084 \text{ m}^3/\text{kg})(4000 \text{ kPa} - 400 \text{ kPa})$
 $= 3.902 \text{ kJ/kg}$
 $h_4 = w_{p2} + h_3 = (3.902 \text{ kJ/kg} + 604.66 \text{ kJ/kg})$
 $= 608.56 \text{ kJ/kg}$

$P_5 = 4 \text{ MPa}$
 $T_5 = 500^\circ\text{C} > T_{\text{sat},p} = 263.94^\circ\text{C}$
 (super heated)

$h_5 = 3446.0 \text{ kJ/kg}$
 $s_5 = 7.0922 \text{ kJ/kg}\cdot\text{K}$

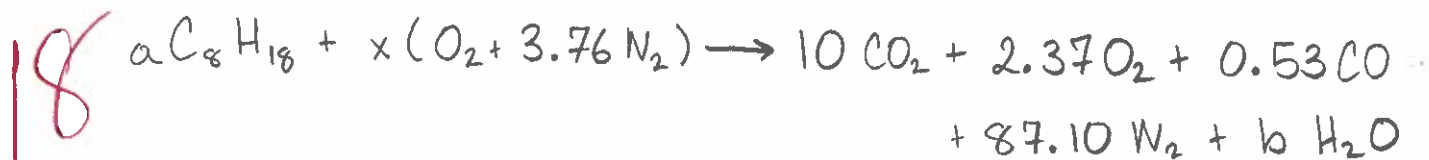
#3.)



0

#4.)

(i)

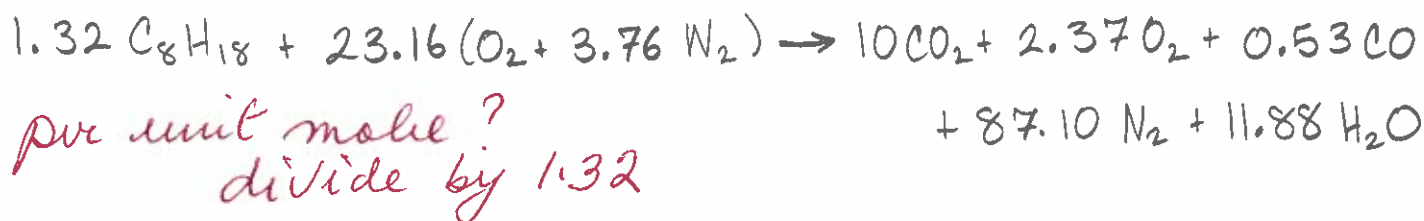


$$C - 8a = 10 + 0.53 \Rightarrow a = 1.32$$

$$H - 18a = 2b \Rightarrow b = 11.88$$

$$O = 2x = 10(2) + 2.37(2) + 0.53 + b$$

$$N = (3.76)(2x) = 87.10(2) \Rightarrow x = 23.16$$



(ii)

$$AF = \frac{m_{air}}{m_{fuel}} = \frac{(23.16 \times 4.76 \text{ kmol})_{air}}{(1.32 \times 8 \text{ kmol}) + (11.88 \times 2 \text{ kmol})_{fuel}} = \boxed{3.212 \text{ kg air / kg fuel}}$$

*mole basis
need per mass
basis.*

BELOW AVERAGE

Below Average Student Original Graded Assignment

Prairie View A&M University
Department of Mechanical Engineering
MCEG 3023 Y01 : Thermodynamics II
Final Exam

Santiago Sanchez, Emanuel

Print your name (Last name first)

Emanuel Sanchez 12/07/2021

Signature and Date

Score 72
100

Signing your name in the space provided above signifies that you will abide by the Prairie View A&M University Code of Student Conduct. It also signifies that you understand that you will get zero for this test if there is any indication of copying from other students or from other source.

Note:

1. Show detailed steps to get full credit
2. Show units and unit conversions

1. An insulated steam turbine receives 30 kg of steam per second at 3 MPa, 400 °C and leaves at 15 kPa, 90% quality. Determine the change in availability and the second-law efficiency for the process. (25 pts.)

x

- ✓ 2. Consider a regenerative cycle using steam as the working fluid. Steam leaves the boiler and enters the turbine at 4 MPa, 500 °C. After expansion to 400 kPa, some of the steam is extracted from the turbine for the purpose of heating the feedwater in an open feedwater heater. The pressure in the feedwater heater is 400 kPa, and the water leaving it is saturated liquid at 400 kPa. The steam not extracted expands to 10 kPa. Determine the fraction of the mass of steam that is extracted. (25 pts.)

y

- ✓ 3. Consider a gas turbine with air entering the compressor at 0.1 MPa and 20 °C. The pressure leaving the compressor is 1.0 MPa, and the maximum temperature in the cycle is 1100 °C. Assume a compressor efficiency of 80%. Determine the compressor work. (20 pts.)

x = 80%

4. Octane (C_8H_{18}) is burned with atmospheric air. The analysis of the products on a dry basis is as follows: (20 pts.)

CO ₂	10.00%
O ₂	2.37%
CO	0.53%
N ₂	87.10%

mass air

mass fuel

- ✓ (i) Complete the balanced equation on per kmol of fuel.
✓ (ii) Determine the air-fuel ratio on a mass basis

1) $\dot{m} = 30 \text{ kg/s}$

04 $\left. \begin{array}{l} P_5 = 3 \text{ MPa} \\ T_5 = 400^\circ\text{C} \end{array} \right\} \begin{array}{l} h_5 = 3231.7 \text{ kJ/kg} \\ s_5 = 6.92 \text{ kJ/kg} \cdot \text{K} \end{array} \right\} \text{phase?}$

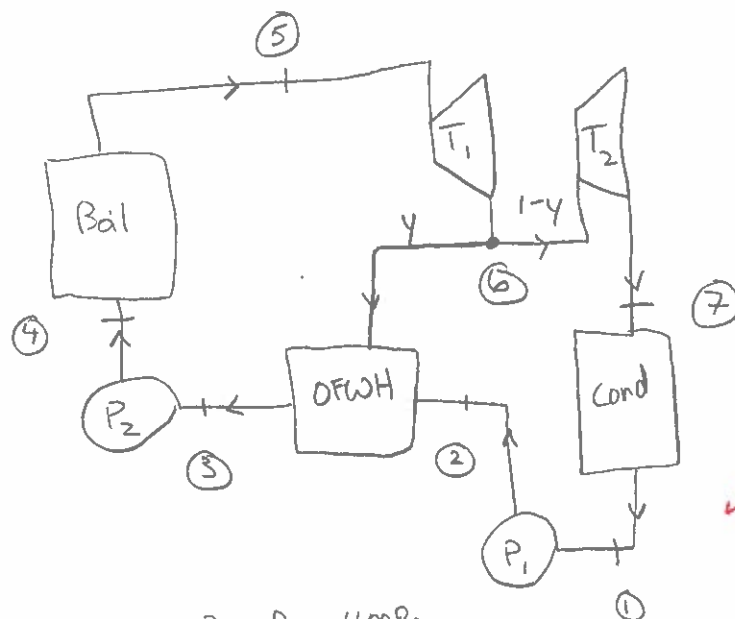
$\left. \begin{array}{l} P_6 = 15 \text{ kPa} \\ x = 90\% \end{array} \right\} \begin{array}{l} h_6 = \dots \\ s_6 = \dots \end{array}$

$$\Delta X = ? = \dot{m} [(h_2 - h_1) - T_0 (s_2 - s_1)]$$
$$= \dot{m} [(h_6 - h_5) - T_0 (s_6 - s_5)]$$

47 → 52

②

15



$$P_5 = 4 \text{ MPa}$$

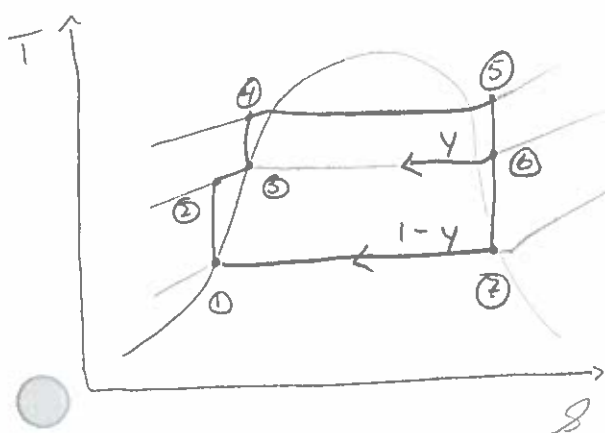
$$T_5 = 500^\circ\text{C}$$

$$P_6 = 400 \text{ kPa}$$

$$P_2 = P_3 = 400 \text{ kPa}$$

$$P_7 = 10 \text{ kPa}$$

$$\dot{m} h_i = \dot{m} h + \dot{m} h$$



$$P_5 = P_4 = 4 \text{ MPa}$$

$$P_6 = P_2 = P_3 = 400 \text{ kPa}$$

$$P_7 = P_1 = 10 \text{ kPa}$$

$$(1) (h_3) = y(h_6) + (1-y)(h_7)$$

$$h_3 = h_f @ 400 \text{ kPa} = 604.66 \text{ kJ/kg}$$

$$h_6 @ 4 \text{ MPa}, 500^\circ\text{C} = 3446 \text{ kJ/kg}$$

$$h_7 = h_f @ 10 \text{ kPa} = 191.81 \text{ kJ/kg}$$

? needs interpolation

$$604.66 = y(3446) + (1-y)(191.81)$$

$$= 3446y + 191.81 - 191.81y$$

$$3254.19y = 604.66 - 191.81$$

$$y = 0.127$$

③ Working fluid: air

$$s_1 = s_2$$

$$s_{2g} \Rightarrow s_2$$

12

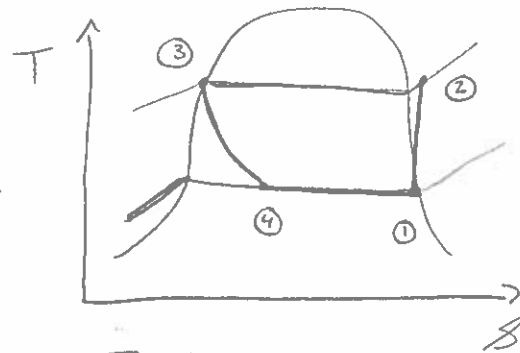
$$P_1 = .1 \text{ MPa}$$

$$T_1 = 20^\circ\text{C} = 293 \text{ K}$$

$$T_H = 1100^\circ\text{C} = T_2 = 1373 \text{ K}$$

$$P_2 = 1 \text{ MPa}$$

$$x = 80\%$$



$$T_4 = T_1 = 293 \text{ K}$$

$$W_{\text{comp}} = x(h_2 - h_1)$$

@ State 1

$$h_1 @ 293 \text{ K}$$

T A-17

=> interpolation

K	h
290	290.16
293	x
295	295.17

$$\frac{x - 290.16}{295.17 - 290.16} = \frac{293 - 290}{295 - 290}$$

$$x = 293.17$$

$$h_1 = 293.17 \text{ kJ/kg}$$

@ State 2

$$h_2 @ 1373 \text{ K}$$

=> interpolate

K	h
1360	1467.49
1373	x
1380	1491.44

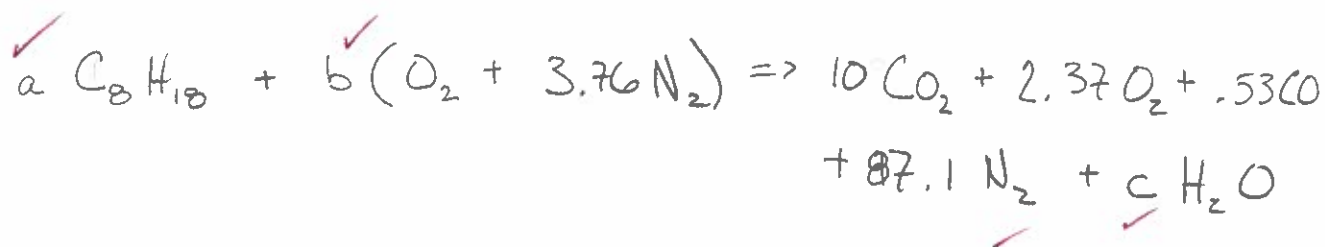
$$\frac{x - 1467.49}{1491.44 - 1467.49} = \frac{13}{20}$$

$$x = 1483.06$$

$$h_2 = 1483.06 \text{ kJ/kg}$$

↓↓

4) 16



$$C: 8a = 10 + .53$$

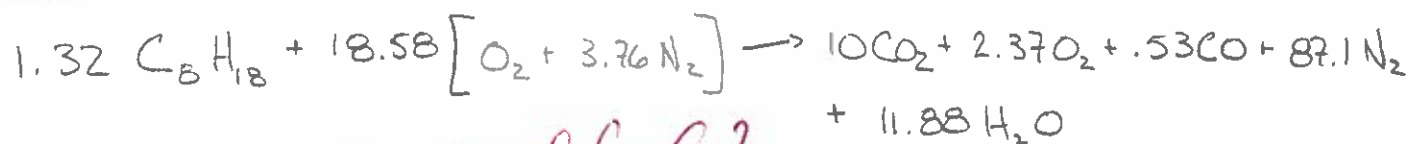
$$a = 1.32$$

$$H: 18a = 2c$$

$$c = \frac{18a}{2} = 11.88$$

$$O: 2b = 2.37(2) + 20 + .53 + c$$

$$b = 18.58$$



per mole of fuel?

$$1.32 [8(12) + 18(1)] = 150.48 \text{ g} \Rightarrow \text{Fuel}$$

$$18.58 [2(16) + 3.76(2)(14)] = 2550.66 \text{ g} \Rightarrow \text{air}$$

$$AF \text{ Ratio} \Rightarrow \frac{2550.66}{150.48} = 16.95 \text{ g air / g Fuel}$$

THERMODYNAMICS II
FALL 2021

Title of Assignment: Design Project

TOPICS COVERED IN DESIGN PROJECT

Design Project covered the following topics:

Optimum compression ratio of a Brayton Cycle gas turbine

THERMODYNAMICS II
FALL 2021

Title of Assignment: DESIGN PROJECT

Sample solution of the design project

In this project the students should calculate the thermal efficiency and net work with different compression ratios.

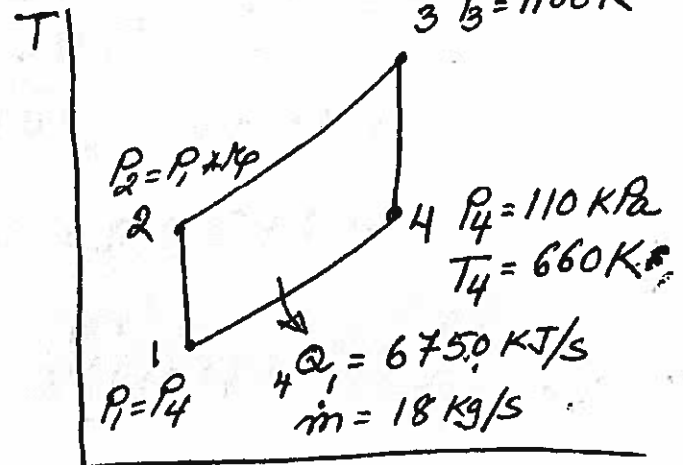
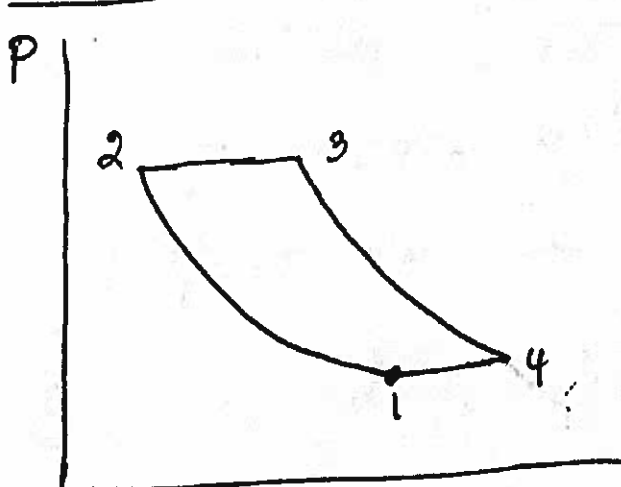
They will then plot η vs r_p and w vs r_p in the same plot and conclude about the best or optimum conditions.

Below is the solution with compressor pressure ratio of 8.

Assumptions:

- Steady operating conditions
- Air-standard assumption
- Kinetic & potential energy changes are negligible
- Air is an ideal gas with variable specific heats.

Solution:



Assume a compression pressure ratio of 8

$$\therefore P_2/P_1 = 8$$

$$P_1 = P_4 = 110 \text{ kPa}$$

$$\therefore P_2 = P_1 \times 8 = 110 \text{ kPa} \times 8 = 880 \text{ kPa} = P_3$$

From Table A-17, ideal gas properties of air

$$\text{at } T_3 = 1100 \text{ K} \rightarrow h_3 = 1161.07 \text{ kJ/kg}$$

$$\text{at } T_4 = 660 \text{ K} \rightarrow h_4 = 670.47 \text{ kJ/kg}$$

$$\dot{Q}_{\text{out}} = \dot{m}(h_4 - h_1)$$

$$\Rightarrow 6740 \text{ kJ/s} = 18 \text{ kg/s} (670.47 - h_1) \text{ kJ/kg}$$

$$\Rightarrow h_1 = 296.03 \text{ kJ/kg}$$

Process 1-2 is isentropic compression

$$\therefore \frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}}$$

$$\Rightarrow T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}} ; \text{ assume } k_{\text{air}} = 1.4$$

Determine the value of T_1 corresponding to h_1 from table A-17 by interpolation

$$\frac{T_1 - 295}{298 - 295} = \frac{296.03 - 295.17}{298.18 - 295.17} \rightarrow T_1 = 295.86 \text{ K}$$

$$\therefore T_2 = (295.86 \text{ K}) (8)^{\frac{1.4-1}{1.4}} = 535.9 \text{ K} = T_2$$

$$\therefore \text{at } T_2 = 535.9 \text{ K} \rightarrow h_2 = ~~543.98~~ 540.09 \text{ kJ/kg}$$

$$\therefore \dot{Q}_{\text{in}} = {}_2\dot{Q}_3 = \dot{m}(h_3 - h_2) = 18 \text{ kg/s} (1161.07 - 540.09) \text{ kJ/kg} = \underline{11,177.64 \text{ kJ/s}}$$

$$\dot{W}_{\text{comp, in}} = \dot{m}(h_2 - h_1) = (18 \frac{\text{kg}}{\text{s}})(540.09 - 296.03) \text{ kJ/kg}$$

$$= 4393.08 \text{ kJ/s}$$

$$\dot{W}_{T, \text{out}} = \dot{m}(h_3 - h_4) = 18(1161.07 - 670.47) = 8830.8 \text{ kJ/s}$$

$$\therefore \dot{W}_{\text{net, out}} = \dot{W}_{T, \text{out}} - \dot{W}_{\text{comp, in}} = 8830.8 - 4393.08$$

$$= 4437.72 \text{ kJ/s.}$$

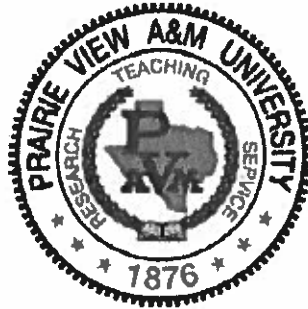
$$\therefore \underline{\dot{W}_{\text{net, out}} = 4437.72 \text{ kJ/s}}$$

$$\eta = \frac{\dot{W}_{\text{net, out}}}{\dot{Q}_{\text{in}}} = \frac{4437.72 \text{ kJ/s}}{11177.64 \text{ kJ/s}} = 0.3970 = 39.7\%$$

ABOVE AVERAGE

Above Average Student Original Graded Assignment

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



85

**MCEG 3302-Y01
Thermodynamics II
Fall 2021**

COVER PAGE

**REPORT ON
“Design of a Gas-Turbine Power Plant”**

**Submitted by
Mohammed Hashimi
Austin Smith**

85

**On
December 05, 2021
To
Dr. Ziaul Huque**

PROJECT DESCRIPTION

In a gas-turbine power plant, there is a limit on the maximum temperature at the turbine inlet imposed by metallurgical considerations of the turbine blades. In order to increase the efficiency, one consideration is to increase the compressor pressure ratio keeping the turbine inlet temperature constant. Increasing the compressor pressure ratio will also decrease the net work developed per unit mass flow rate.

Consider a gas-turbine power plant operating on a simple Brayton Cycle with air as the working fluid. The air enters the turbine at 1100 K and leaves at 110 kPa and 660 K. Heat is rejected to the surroundings at a rate of 6750 kJ/s, and air flows through the cycle at a rate of 18 kg/s. Assuming both the turbine and the compressor to be isentropic, determine the best compression ratio for optimum efficiency and net work per unit mass flow rate of the plant.

To solve this problem, you are asked to design a compression ratio of a gas-turbine power plant that will provide the best combination of plant thermal efficiency and net work output per unit mass flow rate. Complete the following tasks for this design project.

- (a) Discuss your new design of the compression ratio to satisfy the problems requirement.
- (b) Compute the thermal efficiencies and net work per unit mass flow rates for several compression ratios keeping the turbine inlet temperature constant at 1100 K. Plot the thermal efficiency and the flow work vs pressure ratio on a single plot. Analyze the results and suggest an optimum compressor pressure based on your plot. Account for the variation of specific heats with temperature in evaluating the air properties. Clearly list all the assumptions you use for your calculations. Show all steps in your calculations and type equations directly in Microsoft Word.

ABSTRACT

Gas-turbine power plant follows the Brayton cycle. Steady state and isentropic case is taken for the calculations of the processes. Specific heat is also accounted for with respect to temperature. Sample calculations are done for pressure ratio of $r_p = 10$. Efficiency and work output are calculated for different values of pressure ratios. Efficiency increases with the increase of pressure ratio of the gas cycle. Work output first increases with the increase of pressure ratio but after pressure ratio of 17, the work output decreases at the gas turbine power plant. But the increase in pressure ratio has some limitations e.g. compressor specification to compress gas and the tubes in which the gas flows that affect their ability to withstand the high pressure. The graph shows that the pressure ratio $r_p = 17$ is optimum pressure ratio for maximum power and cycle efficiency under the material limitations for the power plant.

Abstract should contain a brief description of process and summary of important results

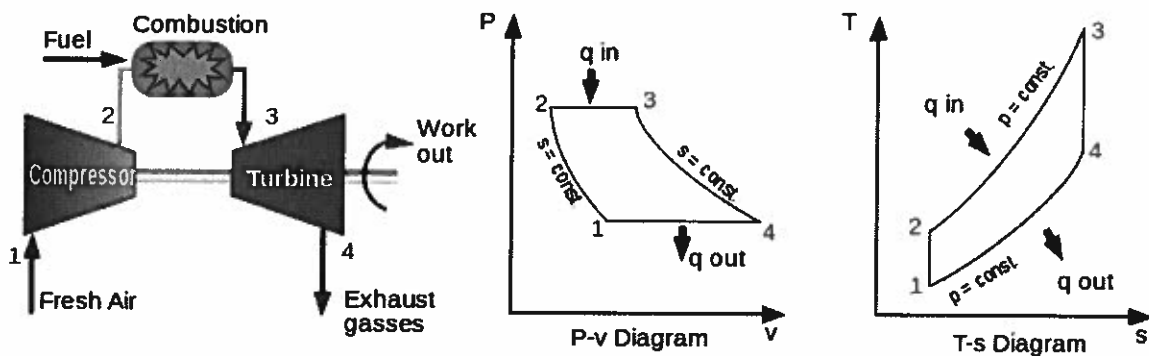
Project Design

GAS-TURBINE POWER PLANT

GAS-TURBINE POWER PLANT follows the Brayton cycle. The working principle and schematic diagram of Bryton cycle are given as follows

- 1-2 Isentropic Compression of gas in compressor
- 2-3 Heat addition in the gas at Constant pressure in combustion chamber
- 3-4 Isentropic Expansion of gas in gas turbine
- 4-1 Heat rejection from gas at Constant pressure through HRSG

T-S diagram of the gas turbine power plant is given as follows;



Design Parameters FOE SAMPLE CALCULATION

Given Data:

Pressure of air at turbine exit = $P_1 = 110 \text{ kPa}$

Temperature of air at compressor Inlet = $T_1 = 298 \text{ K}$

Compression ratio of air compressor = $r_p = 10$

Maximum temperature of cycle (at gas turbine Inlet) = $T_3 = 1100 \text{ K}$

Calculation Procedure

State 1

$T_1 = 298 \text{ K}$

$P_1 = 110 \text{ kPa}$

$R_p = 10$

From Ideal gas Properties of air table, on above conditions;

$C_p = 1.005 \text{ kJ/kgK}$

$k = 1.4$

State 2

As Process 1-2 is isentropic, hence from an ideal gas the following relation is used.

For air, heat capacity ratio $k = 1.4$ at 298 K

$$T_2/T_1 = P_2/P_1^{k-1}$$

$$T_2/T_1 = r_p^{k-1}$$

$$T_2/298 = 101.4/11.4$$

$$T_2 = 575.3 \text{ K}$$

use word equation.

From Ideal gas Properties of air table, at T_2 ;

$$C_p = 1.045 \text{ kJ/kgK}$$

$$k = 1.379$$

State 3

$$T_3 = 1100 \text{ K}$$

$$R_p = 10$$

From Ideal gas Properties of air table, on above conditions;

$$C_p = 1.155 \text{ kJ/kgK}$$

$$k = 1.331$$

State 4

$$R_p = 10$$

$$C_p = 1.155 \text{ kJ/kgK}$$

$$k = 1.331$$

As Process 3-4 is isentropic, hence from an ideal gas the following relation is used.

$$T_4/T_3 = P_4/P_3^{k-1}$$

$$T_4/T_3 = 1/r_p^{k-1}$$

For an ideal gas, combustion gasses at 1100°C and pressure of 1100 kPa has heat capacity ratio $k = 1.331$

$$T_4/1100 = 1/10^{1.331-1}$$

$$T_4 = 620.51 \text{ K}$$

Assumptions for Bryton Cycle

As all four processes of the cycle are executed in the steady flow devices under steady state condition. The change in Potential and kinetic energies are neglected for all these devices. The energy balance equation for the Brayton cycle is expressed as;

$$q_{in} - q_{out} + w_{in} - w_{out} = T_{out} C_p - T_{in} C_p$$

Gas Compressor Analysis

As the process 1-2 is isentropic, therefore no heat is exchanged, so, change in heat is excluded. Only work input is given to the compressor so energy balance equation for compressor becomes;

$$\begin{aligned} w_{in \text{ compressor}} &= C_p(T_2 - T_1) \\ w_{in \text{ compressor}} &= 1.005(575.31 - 298) \\ w_{in \text{ compressor}} &= 278.69 \text{ kJ/kg} \end{aligned}$$

use h from table

Combustion Chamber analysis

As the process 2-3 is constant pressure heat addition in combustion chamber, change in work is excluded for this process as no exchange of work in combustion chambers, thus, energy balance equation for combustion chamber becomes;

$$\begin{aligned} q_{in} &= C_p(T_3 - T_2) \\ q_{in} &= 1.045(1100 - 575.31) \\ q_{in} &= 548.54 \text{ kJ/kg} \end{aligned}$$

Gas Turbine Analysis

As the process 3-4 is isentropic, therefore no heat is exchanged, so, change in heat is excluded. Only work output is given by the turbine so energy balance equation for the turbine becomes;

$$\begin{aligned} w_{gas \text{ turbine}} &= C_p(T_3 - T_4) \\ w_{gas \text{ turbine}} &= 1.155(1100 - 620.5) \\ w_{gas \text{ turbine}} &= 553.9 \text{ kJ/kg} \end{aligned}$$

As the process 4-1 is constant pressure heat rejection to atmosphere, change in work is excluded for this process as no exchange of work, thus, energy balance equation becomes;

$$\begin{aligned} q_{out \text{ gas}} &= C_p(T_4 - T_1) \\ q_{out \text{ gas}} &= 375 \text{ kJ/kg} \end{aligned}$$

Work output of cycle

$$\begin{aligned} w_{out} &= C_p T_3 - T_2 - C_p(T_4 - T_1) \\ w_{out} &= 1.155(1100 - 575.35) - 1.045(620.45 - 298) \\ w_{out} &= 268.9 \text{ kJ/kg} \end{aligned}$$

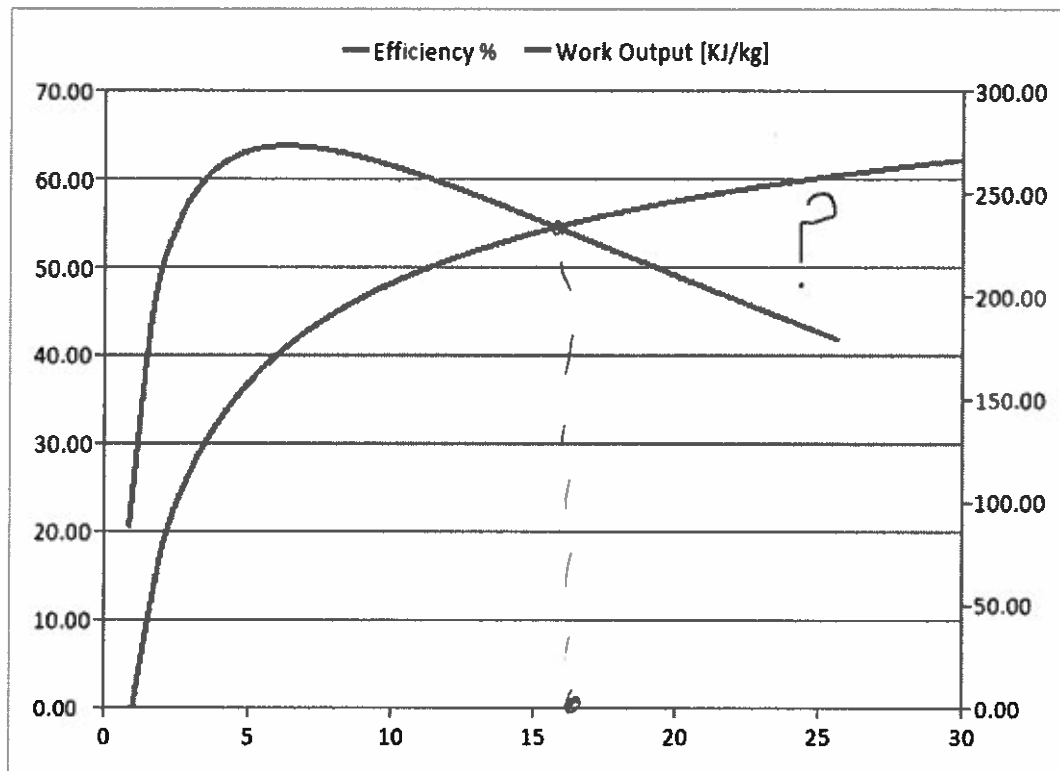
Thermal efficiency of Gas cycle

For ideal case, taking $k = 1.4$ for ideal gas;

$$\begin{aligned} \eta_{th} &= 1 - \frac{1}{r_p^{k-1}} \\ \eta_{th} &= 1 - \frac{1}{11^{1.4-1}} \\ \eta_{th} &= 48.21 \% \end{aligned}$$

CALCULATIONS FOR DIFFERENT PRESSURE RATIOS

Cp at 1100 K	1.1551 [KJ/kgK]	k at 1100 K	1.33	for ideal Case k=1.4	T3=1100[K]	T1=298[K]
P2[[Kpa]	P1[Kpa]	rp=P2/P1	Efficiency %	Temperature at Compressor Exit T2[K]	Temperature at turbine Exit T4[K]	Work Output [KJ/kg]
110	110	1	0.00	298.00	1100.00	87.89
220	110	2	17.97	363.27	925.83	194.60
330	110	3	26.94	407.88	837.03	235.90
440	110	4	32.70	442.83	779.24	255.96
550	110	5	36.86	471.98	737.17	266.27
660	110	6	40.07	497.22	704.50	271.28
770	110	7	42.65	519.60	678.00	273.12
880	110	8	44.80	539.81	655.85	272.93
990	110	9	46.62	558.29	636.92	271.39
1100	110	10	48.21	575.35	620.45	268.90
1210	110	11	49.60	591.23	605.92	265.75
1320	110	12	50.83	606.11	592.95	262.12
1430	110	13	51.95	620.13	581.26	258.14
1540	110	14	52.95	633.40	570.65	253.91
1650	110	15	53.87	646.01	560.94	249.49
1760	110	16	54.71	658.04	552.01	244.94
1870	110	17	55.49	669.53	543.75	240.30
1980	110	18	56.21	680.56	536.07	235.59
2090	110	19	56.88	691.15	528.91	230.84
2200	110	20	57.51	701.36	522.21	226.06
2310	110	21	58.10	711.20	515.91	221.27
2420	110	22	58.65	720.72	509.98	216.48
2530	110	23	59.17	729.93	504.37	211.70
2640	110	24	59.67	738.86	499.06	206.94
2750	110	25	60.14	747.53	494.02	202.20
2860	110	26	60.58	755.95	489.23	197.48
2970	110	27	61.00	764.15	484.66	192.79
3080	110	28	61.41	772.13	480.29	188.13
3190	110	29	61.79	779.91	476.12	183.51
3300	110	30	62.16	787.50	472.12	178.92



Gas Turbine Power Plant efficiency and Work output at different Pressure ratios

Pressure Ratio of Brayton Cycle

Pressure ratio of gas cycle has a positive effect on cycle efficiency of gas power plants. Efficiency increases with the increase of pressure ratio of the gas cycle. But the increase in pressure ratio has some limitations e.g. compressor specification to compress gas and the tubes in which the gas flows that affect their ability to withstand the high pressure.

Pressure ratio of the gas cycle has a positive effect on the work output of the gas power plant. Work output first increases with the increase of pressure ratio but after pressure ratio of 17, the work output decreases at the gas turbine power plant. This shows the turbine limitation for power production.

Hence, pressure ratio $rp = 17$ is optimum pressure ratio for maximum power and cycle efficiency.

CONCLUSION

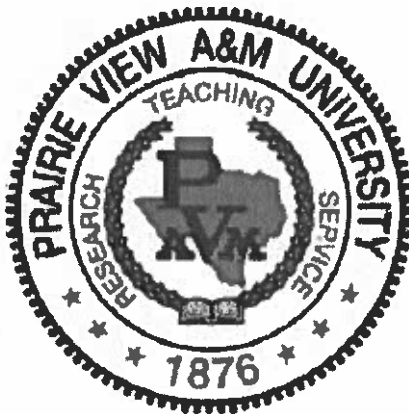
Efficiency increases with the increase of pressure ratio of the gas cycle. But the increase in pressure ratio has some limitations e.g. compressor specification to compress gas and the tubes in which the gas flows that affect their ability to withstand the high pressure. Work output first increases with the increase of pressure ratio but after pressure ratio of 17, the work output decreases at the gas turbine power plant. This shows the turbine limitation for power production. Thus pressure ratio $r_p = 17$ is optimum pressure ratio for maximum power and cycle efficiency under the material limitations for the power plant.

AVERAGE

Average Student Original Graded Assignment

**Mechanical
Engineering
Department
MCEG 3302**

Thermodynamics II



“Design of a Gas-Turbine Power Plant”

**Prepared by
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12/6/2021

**Prairie View A&M University
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Abstract

This project focuses on the design of a gas-turbine power plant. The design of the hardware theoretically used in this assignment is crucial in finding viable real-life values for this application. The material taught throughout this Thermodynamics II course was used to find, calculate and analyze the use and design of this particular design derived from our detailed calculations. The equations for the net work per unit mass flow rate and the compression ratio were utilized to complete required design tasks. The results from the calculated analysis of this application are demonstrated throughout this report.

TABLE OF CONTENTS

ABSTRACT	i
LIST OF FIGURES.	ii
LIST OF TABLES	iii
1. PROJECT BACKGROUND	1
1.1 Design Tasks of the Project.....	1
1.2 Introduction	1
1.3 Project Description	1
2. PROJECT PROCESS	2
2.1 Detailed Description of Design Tasks	2
3. PROJECT DATA ANALYSIS	6
3.1 Discussion of Results	6
3.2 Conclusions Based on each Objective and Results.....	6
3.3 Recommendations	6

LIST OF FIGURES

Figure 3.1 Thermal Efficiency and Flow Work vs Pressure Ratio Plot	6
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LIST OF TABLES

Table 2.1 Given Parameters	2
Table 2.2 Summary of Detailed Calculations.....	5

CHAPTER 1

PROJECT BACKGROUND

1.1 Design Tasks of the Project

The design tasks of this project are:

1. Discuss your new design of the compression ratio to satisfy the problems requirement.
2. Compute the thermal efficiencies and net work per unit mass flow rates for several compression ratios keeping the turbine inlet temperature constant at 1100 K.
3. Plot the thermal efficiency and the flow work vs pressure ratio on a single plot.
4. Analyze the results and suggest an optimum compressor pressure based on your plot. Account for the variation of specific heats with temperature in evaluating the air properties.
5. Show all steps in your calculations and type equations directly in Microsoft Word. Clearly list all the assumptions you use for your calculations.

1.2 Introduction

This is an open-ended design project related to the compression ratio of a power plant. Requirements for this project involved to design a compression ratio of a gas-turbine power plant that will provide the best combination of plant thermal efficiency and net work output per unit mass flow rate. This includes performing detailed calculations and analyses learned throughout the time of this Thermodynamics II course.

1.3 Problem Description

In a gas-turbine power plant, there is a limit on the maximum temperature at the turbine inlet imposed by metallurgical considerations of the turbine blades. In order to increase the efficiency, one consideration is to increase the compressor pressure ratio keeping the turbine inlet temperature constant. Increasing the compressor pressure ratio will also decrease the net work developed per unit mass flow rate.

Consider a gas-turbine power plant operating on a simple Brayton Cycle with air as the working fluid. The air enters the turbine at 1100 K and leaves at 110 kPa and 660 K. Heat is rejected to the surroundings at a rate of 6750 kJ/s, and air flows through the cycle at a rate of 18 kg/s. Assuming both the turbine and the compressor to be isentropic, determine the best compression ratio for optimum efficiency and net work per unit mass flow rate of the plant.

CHAPTER 2

PROJECT PROCESS

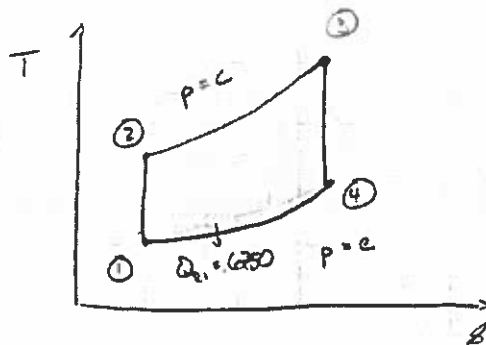
2.1 Detailed Description of Design Tasks

First of all, we need to understand what the problem is asking and what information is available or given. The essence of the problem is to increase the efficiency of the gas- turbine having some restraints in consideration such as if we increase the compressor ratio, it will decrease our net work per unit mass.

- **System** - Gas Turbine
- **Cycle** - Brayton Power Cycle
- **Working Fluid** - Air

Table 2.1 – Given Parameters

INPUTS PROVIDED			
Description			Units
Lower Pressure	P_4	110	KPa
Turbine Inlet Temperature	T_3	1100	K
Turbine exit Temperature	T_4	660	K
Heat Rejected1	Q_R	6750	KW
Mass Flow	m	18	Kg/s



$$\begin{aligned}
 P &= 110 \text{ kPa} & \gamma_{\text{air}} &= 1.4 & C_p &= 1.005 \\
 T_3 &= 1100 \text{ K} & T_4 &= 660 \text{ K} \\
 Q_R &= 6750 \text{ kW} & m &= 18 \text{ kg/s}
 \end{aligned}$$

$$m C_p (T_4 - T_1) = 6750$$

$$18 (1.005) (660 - T_1) = 6750$$

$$T_1 = -\left(\frac{6750}{18.09} - 660\right) = 286.87 \text{ K}$$

$$\begin{aligned}
 w_{\text{net}} &= C_p (\sqrt{T_3} - \sqrt{T_1})^2 \\
 &= C_p (\sqrt{1100} - \sqrt{286.87})^2 \\
 &= 264.70 \text{ kJ/kg}
 \end{aligned}$$

$$\begin{aligned}
 r_c &= \left(\frac{T_3}{T_1}\right)^{\frac{\gamma}{\gamma-1}} \Rightarrow \frac{1.4}{2(1.4-1)} = 1.75 \\
 &= \left(\frac{1100}{286.87}\right)^{1.75} = 10.51
 \end{aligned}$$

$$r_c = 10.51$$

$$\eta_o = 1 - \sqrt{\frac{T_n}{T_3}}$$

$$\begin{aligned} T_{n1} &= 270 \text{ K} \\ T_{n2} &= 280 \text{ K} \end{aligned}$$

$$\begin{aligned} T_{n3} &= 290 \text{ K} \\ T_{n4} &= 300 \text{ K} \end{aligned}$$

$$\eta_{o1} = 1 - \sqrt{\frac{270}{1100}} = .5046 = 50.46\%$$

$$\eta_{o2} = 1 - \sqrt{\frac{280}{1100}} = .4955 = 49.55\%$$

$$\eta_{o3} = 1 - \sqrt{\frac{290}{1100}} = .4865 = 48.65\%$$

$$\eta_{o4} = 1 - \sqrt{\frac{300}{1100}} = .4778 = 47.78\%$$

$$w_{net} = 1.005 (\sqrt{T_3} - \sqrt{T_n})^2$$

$$w_{net1} = 1.005 (\sqrt{1100} - \sqrt{270})^2 = 281.45 \text{ kJ/kg}$$

$$w_{net2} = 1.005 (\sqrt{1100} - \sqrt{280})^2 = 271.40 \text{ kJ/kg}$$

$$w_{net3} = 1.005 (\sqrt{1100} - \sqrt{290})^2 = 261.70 \text{ kJ/kg}$$

$$w_{net4} = 1.005 (\sqrt{1100} - \sqrt{300})^2 = 252.34 \text{ kJ/kg}$$

$$r_c = \left(\frac{T_3}{T_n} \right)^{\frac{\gamma}{\gamma-1}}$$

$$r_{c1} = \left(\frac{1100}{270} \right)^{1.75} = 11.68$$

$$r_{c2} = \left(\frac{1100}{280} \right)^{1.75} = 10.96$$

$$r_{c3} = \left(\frac{1100}{290} \right)^{1.75} = 10.31$$

$$r_{c4} = \left(\frac{1100}{300} \right)^{1.75} = 9.72$$

Thermal Efficiencies and Net Work per Unit Mass Flow Rates at Turbine Inlet Temperature

Table 2.2 – Summary of Detailed Calculations

T_{min}	n_o	W_{net}	r_c
270	0.5046	281.45	11.68
280	0.4955	271.4	10.96
290	0.4865	261.7	10.31
300	0.4778	252.34	9.72

CHAPTER 3

PROJECT DATA ANALYSIS

3.1 Discussion of Results

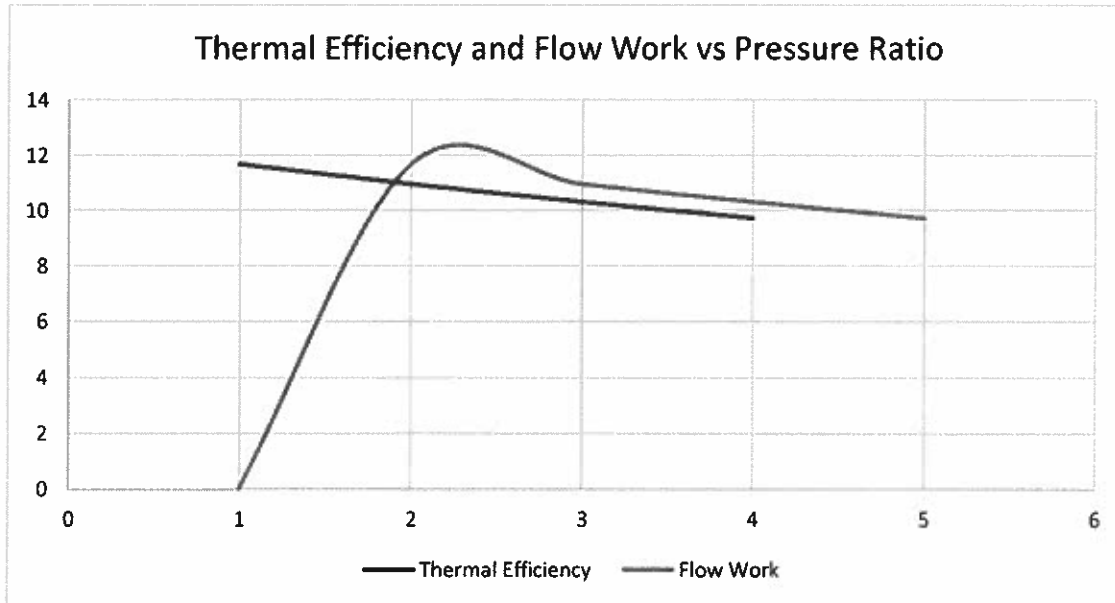


Figure 3.1 - Thermal Efficiency and Flow Work vs Pressure Ratio Plot

The design tasks were completed by applying and utilizing the calculated parameters from the detailed calculations. As a result, we were able to calculate the best compression ratio for optimum efficiency to be 10.51. Along with the compression ratio, we were also able to calculate the net work for the compression ratio to be 264.70 KJ/Kg. Figure 1.1 demonstrates the relationship between our net work, pressure ratio, and our efficiency percentage. Thermal efficiency and Flow Work are also demonstrated in our figure.

3.2 Conclusions Based on each Objective and Results

This project was successfully executed by completing all the design tasks a compression ratio of a gas-turbine power plant. Correct calculations throughout the project proved crucial to ensuring the results provided and discussed are accurate. With the collection of measurement data from the project description, the thermal efficiencies and net works per unit mass flow rates seem to be accurate with the provided parameter data.

3.3 Recommendations

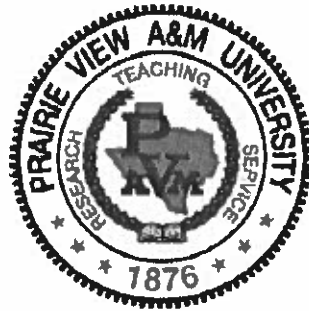
Using new parameter values might prove to be beneficial to the application to further understand and improve the results of the project. Provided there is a further understanding of the theory through research and development, then we could be able to find and suggest design changes to further enhance the applied use of the project.

References

BELOW AVERAGE

Below Average Student Original Graded Assignment

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



**MCEG 3302-Y01
Thermodynamics II
Fall 2021**

80

COVER PAGE

**REPORT ON
“Design of a Gas-Turbine Power Plant”**

**Submitted by
Caleb Combs and Thomas Carroll III**

**On
December 06, 2021**

**To
Dr. Ziaul Huque**

PROJECT DESCRIPTION

In a gas-turbine power plant, there is a limit on the maximum temperature at the turbine inlet imposed by metallurgical considerations of the turbine blades. In order to increase the efficiency, one consideration is to increase the compressor pressure ratio keeping the turbine inlet temperature constant. Increasing the compressor pressure ratio will also decrease the net work developed per unit mass flow rate.

Consider a gas-turbine power plant operating on a simple Brayton Cycle with air as the working fluid. The air enters the turbine at 1100 K and leaves at 110 kPa and 660 K. Heat is rejected to the surroundings at a rate of 6750 kJ/s, and air flows through the cycle at a rate of 18 kg/s. Assuming both the turbine and the compressor to be isentropic, determine the best compression ratio for optimum efficiency and net work per unit mass flow rate of the plant.

To solve this problem, you are asked to design a compression ratio of a gas-turbine power plant that will provide the best combination of plant thermal efficiency and net work output per unit mass flow rate. Complete the following tasks for this design project.

- (a) Discuss your new design of the compression ratio to satisfy the problems requirement.
- (b) Compute the thermal efficiencies and net work per unit mass flow rates for several compression ratios keeping the turbine inlet temperature constant at 1100 K. Plot the thermal efficiency and the flow work vs pressure ratio on a single plot. Analyze the results and suggest an optimum compressor pressure based on your plot. Account for the variation of specific heats with temperature in evaluating the air properties. Clearly list all the assumptions you use for your calculations. Show all steps in your calculations and type equations directly in Microsoft Word.

ABSTRACT

The goal of this project was to design a Brayton cycle with a pressure ratio that would result in the best balance of net work output and thermal efficiency. To do this, we tested various pressure ratios and then calculated the net work output and thermal efficiency. Our net work and thermal efficiency was then plotted against pressure ratio. Our goal was to find the point of intersection of the two curves and find the pressure ratio to which it corresponds; this pressure ratio would be the optimum pressure ratio for the cycle. However, when net work and thermal efficiency was plotted versus pressure ratio, we discovered no point of intersection. This led us to believe that the calculation of enthalpies at each state of the cycle would be a more appropriate method of solving the given problem.

PRESENTATION OF TECHNICAL COMPONENTS

(a)

To solve this problem, we aimed to find a compression ratio of a gas-turbine power plant that will provide the best combination of plant thermal efficiency and net work output per unit mass flow rate. To do this, we tested different pressure ratios and used them to calculate the net work output and the thermal efficiency using the thermodynamic relations shown below.

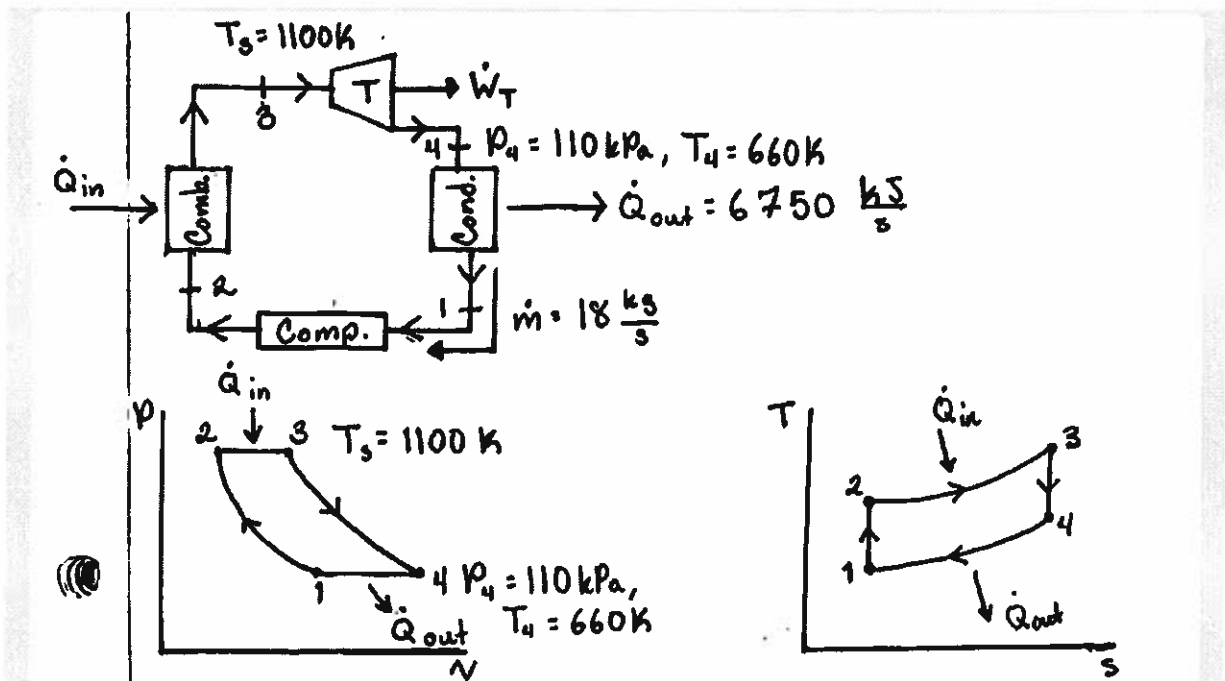
$$\eta_{th} = 1 - \frac{1}{(\tau_p)^{\frac{k-1}{k}}}$$

$$\eta_{th} = 1 - \frac{Q_{out}}{Q_{in}}$$

$$W_{net} = (Q_{out})(\eta_{th})$$

From there we plotted the data on a graph and found that both the net work output and thermal efficiency had a positive correlation with pressure ratio. This can be seen in our graph. With this information, we do believe that finding the values of enthalpy at each state of the cycle to determine our net work and thermal efficiency would be a more appropriate method of solving the given problem.

(b)



$$\frac{P_3}{P_4} = \left(\frac{T_3}{T_4}\right)^{\frac{k-1}{k}} \rightarrow \frac{P_3}{100 \text{ kPa}} = \left(\frac{1100\text{K}}{660\text{K}}\right)^{\frac{1.4-1}{1.4}} \rightarrow P_3 = 657.5 \text{ kPa}$$

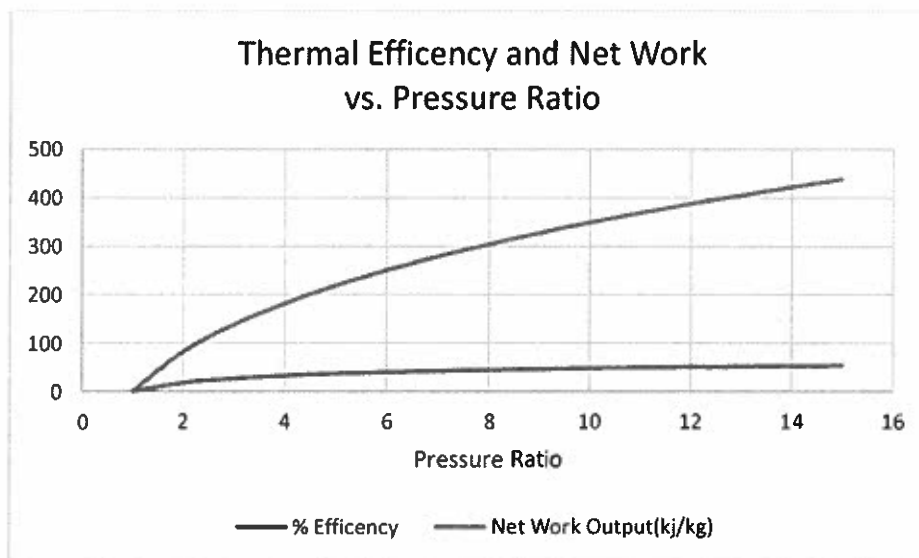
$$r_p = \frac{P_3}{P_4} = \frac{657.5\text{kPa}}{110\text{kPa}} = 5.98$$

$$\eta_{th} = 1 - \frac{1}{(r_p)^{\frac{k-1}{k}}} = 1 - \frac{1}{(5.98)^{\frac{1.4-1}{1.4}}} = 0.40 = 40\%$$

$$\eta_{th} = 1 - \frac{Q_{out}}{Q_{in}} \rightarrow 0.4 = 1 - \frac{6750 \left(\frac{\text{kJ}}{\text{s}}\right)}{Q_{in}} \rightarrow Q_{in} = 11,250 \left(\frac{\text{kJ}}{\text{s}}\right)$$

$$\eta_{th} = \frac{W_{net}}{Q_{in}} \rightarrow W_{net} = (\eta_{th})(Q_{in}) = (0.40) \left(11,250 \frac{\text{kJ}}{\text{s}}\right) = 4500 \frac{\text{kJ}}{\text{s}}$$

explain how you did the subsequent calculations?



*Net work found in our calculations was divided by the given mass flow rate of 18 kg/s to allow for a more readable graph

The calculations done above were repeated for pressure ratios ranging from 1 to 15. As can be seen in the graph above, both net work and efficiency increase with pressure ratio. No intersection of the two curves can be found. Therefore, no optimum compressor ratio can be determined.

CONCLUSION

In conclusion, the results of our work are not what we expected. Based on our knowledge of thermodynamic principles, we anticipated a net work curve to increase, reach a maximum, and then decrease. Our net work curve, however, increases infinitely as pressure ratio increases. This leads us to believe that our method used is at least to some degree erroneous. We believe that determining the enthalpy values at each state of the brayton cycle process and then using those values to find net work and efficiency would be a better course of action. Using this method would allow us to account for the constant turbine inlet temperature that is given in the problem statement.