Name: ______________________________________.

MET 350 Thermal Applications
Dr. Orlando Ayala
Spring 2024
Test 2

Take home – Due Tuesday March 19th, 2024, before class time.

READ FIRST

1. RELAX!!!! DO NOT OVERTHINK THE PROBLEMS!!!! There is nothing hidden. The test was designed for you to pass and get the maximum number of points, while learning at the same time. HINT: THINK BEFORE TRYING TO USE/FIND EQUATIONS (OR EVEN FIND SIMILAR PROBLEMS)

2. The total points on this test are one hundred (100). Ten (10) points are from your HW assignments, and ten (10) other points are based on the basis of technical writing. The other eighty (80) points will come from the problem solutions. For the technical writing I will follow the attached rubric.

3. There is 1 problem worth 80 points.

4. What you turn in should be only your own work. You cannot discuss the exam with anyone, except me. Call me, skype me, text me, email me, come to my office, if you have any question.

5. I do not read minds. You should be explicit and organized in your answers. Use drawings/figures. If you make a mistake, do not erase it. Rather use that opportunity to explain why you think it is a mistake and show the way to correct the problem.

6. You have to turn in your test ON TIME and ONLY through CANVAS. You must submit only one file and it has to be a pdf file. For the ePortfolio (which is optional) you are supposed to upload this artifact to your Google drive. I will provide more instructions later.

7. Do not start at the last minute so you can handle anything that could happen. Late tests will not be accepted. Test submitted through email will not be accepted either.

8. Cheating is completely wrong. The ODU Student Honor Pledge reads: "I pledge to support the honor system of Old Dominion University. I will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism." By attending Old Dominion University, you have accepted the responsibility to abide by this code. This is an institutional policy approved by the Board of Visitors. It is important to remind you the following part of the Honor Code:

    IX. PROHIBITED CONDUCT
    A. Academic Integrity violations, including:
    1. *Cheating*: Using unauthorized assistance, materials, study aids, or other information in any academic exercise (Examples of cheating include, but are not limited to, the following: using unapproved resources or assistance to complete an assignment, paper, project, quiz or exam; collaborating in violation of a faculty member's instructions; and submitting the same, or substantially the same, paper to more than one course for academic credit without first obtaining the approval of faculty).

With that said, you are NOT authorized to use any online source of any type, unless is ODU related.

1) A manufacturing facility uses a steam power plant to generate electricity and provide heating steam to the work spaces. The steam plant operates on the regenerative cycle, with one stage of feed heating. Steam enters the turbine at 5.5 MPa and 500 C, expands to 660 kPa, where extraction of y_1 steam fraction for feedwater heating occurs. The remaining steam expands through the turbine to 150 kPa, where extraction of y_2 steam fraction for space heating occurs. The system is designed in such a way that $y_2=y_1$. The remaining steam expands to 15 kPa, where it is condensed. The fluid returns from the space heating as a saturated liquid, gets throttled to condenser pressure to then enter the condenser. Determine (a) the utilization factor; (b) P-v and T-s diagrams; (c) the turbine work per kg; (d) for a 50,000 kW load, the mass flow steam entering the turbine; (e) the heat supplied to the working areas for the conditions in (d); (f) all the states in the cycle; (g) mass fractions y_2 and y_1; (h) the rate of heat removed in the condenser.

Problem solution rubric

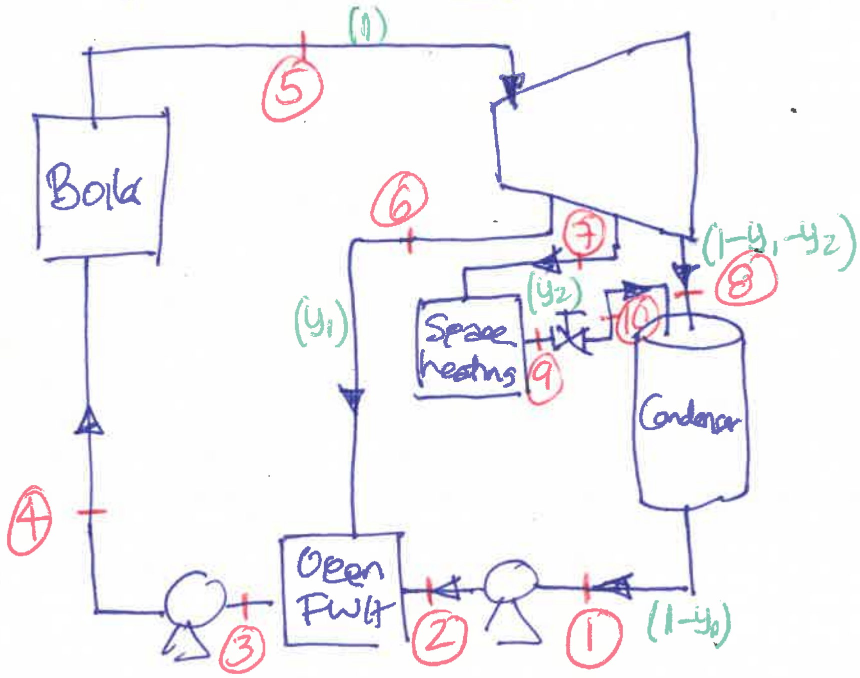
	Exceeds Standard	Meets Standard	Approaches Standard	Needs Attention
	4	3	2	1
	10 points	7 points	4 points	0 points
1. **Purpose** 5%	The purpose of the section to be answered is clearly identified and stated.	The purpose of the section to be answered is identified, but is stated in a somewhat unclear manner.	The purpose of the section to be answered is partially identified, and is stated in a somewhat unclear manner.	The purpose of the section to be answered is erroneous or irrelevant.
2. **Drawings & Diagrams** 10%	Clear and accurate diagrams are included and make the section easier to understand. Diagrams are labeled neatly and accurately.	Diagrams are included and are labeled neatly and accurately.	Diagrams are included and are labeled.	Needed diagrams are missing OR are missing important labels.
3. **Sources** 5%	Several reputable background sources were used and cited correctly.	A few reputable background sources are used and cited correctly.	A few background sources are used and cited correctly, but some are not reputable sources.	Background sources are cited incorrectly.
4. **Design considerations (assumptions, safety, cost, etc)** 10%	Design is carried out with applicable assumptions and full attention to safety and cost, etc.	Design is generally carried out with assumptions and attention to safety, cost, etc.	Design is carried out with some assumptions and some attention to safety, cost, etc.	Assumptions, safety and cost were ignored in the design.
5. **Data and variables** 5%	All data and variables are clearly described with all relevant details.	All data and variables are clearly described with most relevant details.	Most data and variables are clearly described with most relevant details.	Data and variables are not described OR the majority lack sufficient detail.
6. **Procedure** 25%	Procedure is described in clear steps. The step description is in a complete and easy to understand short paragraph.	Procedure is described in clear steps but the step description is not in a complete short paragraph.	Procedure is described in clear steps. The step description is in a complete short paragraph but it is difficult to understand.	Procedure is not described in clear steps at all.
7. **Calculations** 20%	All calculations are shown and the results are correct and labeled appropriately. The units of all values are shown.	Some calculations are shown and the results are correct and labeled appropriately.	Some calculations are shown and the results labeled appropriately.	No calculations are shown OR results are inaccurate or mislabeled.
8. **Summary** 5%	Summary describes the design, the relevant information and some future implications.	Summary describes the design and some relevant information.	Summary describes the design.	No summary is written.
9. **Materials** 5%	All materials used in the design are clearly and accurately described.	Almost all materials used in the design are clearly and accurately described.	Most of the materials used in the design are clearly and accurately described.	Many materials are described inaccurately OR are not described at all.
10. **Analysis** 10%	The design is discussed and analyzed. Argumentative predictions are made about what might happen in case of change in the operation and how the design could be change.	The design is discussed and analyzed. Argumentative predictions are made about what might happen in case of change in the operation.	The design is discussed and analyzed. No argumentative predictions are made about what might happen in case of change in the operation and how the design could be change.	The design is not discussed and analyzed.

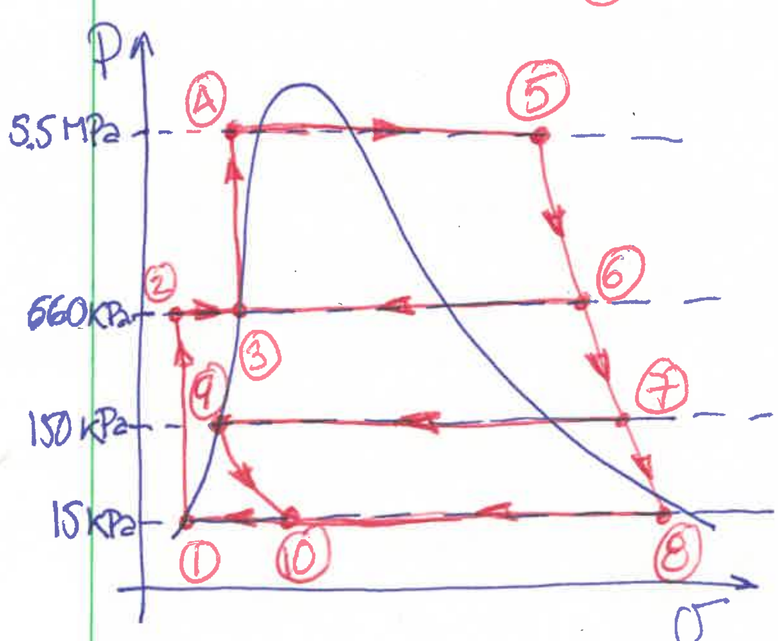
(1) PURPOSE

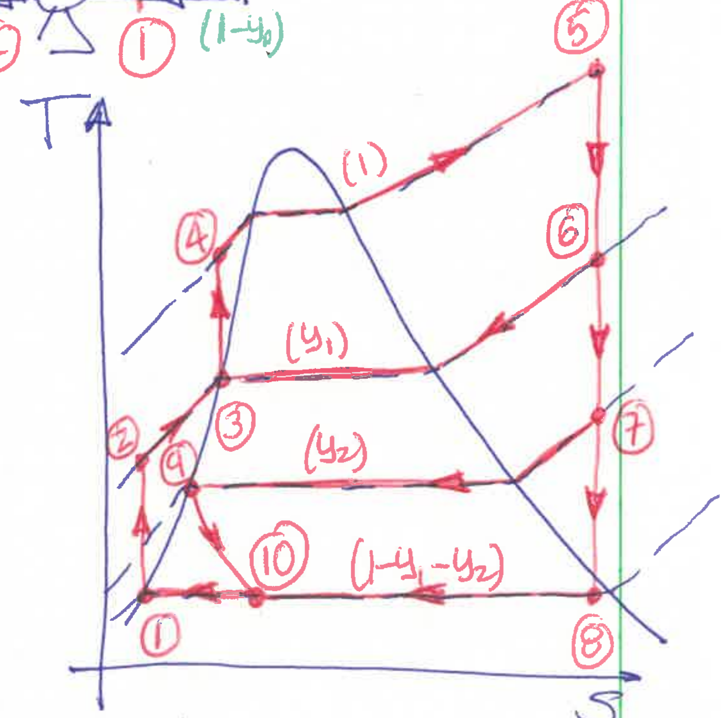
A

Determine utilization factor of the cogeneration plant shown in the figure. Also, obtain the turbine work, the mass flow entering the turbine to produce a 59,000 kW load, the heat supplied to working areas, mass fraction getting out of turbine, and the heat released in the condenser.

DRAWINGS & DIAGRAMS







SOURCES

B

Cengel & Boles. "Thermodynamics - An Engineering Approach". 8th edition, McGraw Hill. 2015.

DESIGN CONSIDERATIONS

1) Turbine and pumps work isenthropically
2) Fluid is pure
3) No heat losses in connections, pipes. Neither fluid flow losses.
4) Constant pressure phase changes in boiler and condenser.

DATA VARIABLES

$T_{turb\ inlet} = 500\ °C$ $\quad P_{FWH} = 660\ kPa$ $\quad P_{cond} = 15\ kPa$

$P_{turb\ inlet} = 5.5\ MPa$ $\quad P_{space\ heat} = 150\ kPa$ $\quad y_1 = y_2$

$\dot{W}_{out} = 50{,}000\ kW$

MATERIALS

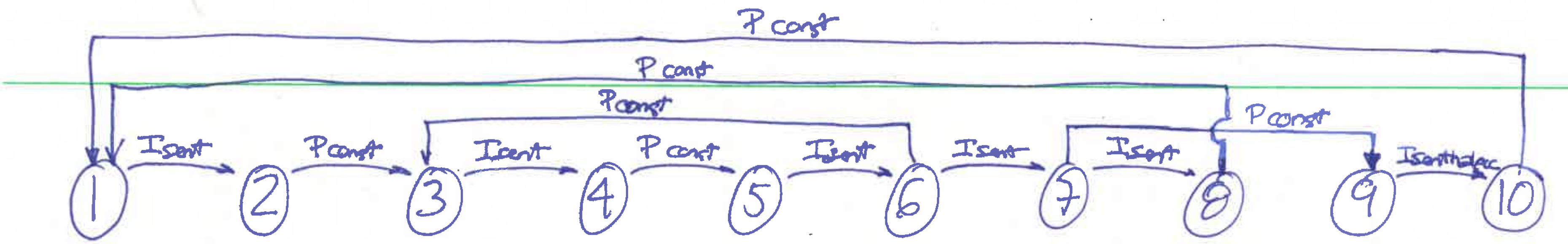
Water

PROCEDURE

1) Get all states (making use of process type)
2) Get y_1 by applying first law to FWH (then $y_2 = y_1$)
3) Get $\dot{m}$ by applying first law to turbine
4) Get $\dot{Q}_{space\ heat}$ by 1st law
5) Get $\dot{Q}_{cond}$ by 1st law

CALCULATIONS

C



$P_1 = 15\,kPa$, $x_1 = 0$ | $P_2 = 660\,kPa$ | $P_3 = 660\,kPa$, $x_3 = 0$ | $P_4 = 5.5\,MPa$ | $P_5 = 5.5\,MPa$, $T_5 = 500\,°C$ | $P_6 = 660\,kPa$ | $P_7 = 150\,kPa$ | $P_8 = 15\,kPa$ | $P_9 = 150\,kPa$, $x_9 = 0$ | $P_{10} = 15\,kPa$

Table A5
$h_1 = 225.94\ \frac{kJ}{kg}$ ✓
$T_1 = 53.97\ °C$
$v_1 = 0.001014\ \frac{m^3}{kg}$

Table A5
$h_3 = 686.664\ \frac{kJ}{kg}$ ✓
$T_3 = 162.574\,°C$
$v_3 = 0.0011048\ \frac{m^3}{kg}$
(Interpolated)

Table A6
$h_5 = 3428.90\ \frac{kJ}{kg}$ ✓
$s_5 = 6.93035\ \frac{kJ}{kg \cdot K}$
(Interpolated)

Table A5
$h_9 = 467.13\ \frac{kJ}{kg}$ ✓
$T_9 = 111.35\ °C$

$h_{10} = 467.13\ \frac{kJ}{kg}$ ✓

$h_2 = h_1 + v_1(P_2 - P_1)$

$h_2 = 226.533\ \frac{kJ}{kg}$ ✓

$h_4 = h_3 + v_3(P_4 - P_3)$

$h_4 = 692.011\ \frac{kJ}{kg}$ ✓

$s_6 = s_5$
$s_6 = 6.93035\ \frac{kJ}{kg \cdot K}$
$x_6 = \frac{s_6 - s_{f6}}{s_{fg6}}$
$= \frac{6.93035 - 1.9682}{4.75898}$
$x_6 = 1.0426$
SO IT IS SUPERHEATED
Table A6
We need double interpolation

$h_6 = 2852.159\ \frac{kJ}{kg}$

$T_6 = 217.357\,°C$

$s_7 = 6.93035\ \frac{kJ}{kg \cdot K}$
$x_7 = \frac{6.93035 - 1.4337}{5.7894}$
$x_7 = 0.9495$
MIX
$h_7 = h_{f7} + x_7 h_{fg7}$
$= 467.13 + 0.9495 \cdot 2226.0$ ✓

$h_7 = 2580.717\ \frac{kJ}{kg}$

$T_7 = 111.35\,°C$

$s_8 = 6.93035\ \frac{kJ}{kg}$
$x_8 = \frac{6.93035 - 0.7549}{7.2522}$
$x_8 = 0.85153$
MIX
$h_8 = h_{f8} + x_8 h_{fg8}$
$= 225.94 + 0.85153 \cdot 2372.3$ ✓

$h_8 = 2246.025\ \frac{kJ}{kg}$

$T_8 = 53.97\,°C$

P=0.6 MPa			P=0.8 MPa		
T (°C)	h (kJ/kg)	s (kJ/kg·K)	T (°C)	h (kJ/kg)	s (kJ/kg·K)
158.83	2756.2	6.7593	250	2839.8	6.8177
192.52	2833.46 ←	6.93035	275.31 ←	2895.79 ←	6.93035
200	2850.6	6.9683	300	2950.4	7.0402

D

Let us get y_1 (and y_2):

$$(1-y_1)h_2 + y_1 h_6 = h_3 \longrightarrow h_2 + y_1(h_6 - h_2) = h_3$$

$$y_1 = \frac{h_3 - h_2}{h_6 - h_2} = \frac{686.664 - 226.533}{2852.159 - 226.533}$$

$$\boxed{y_1 = 0.1752}$$

Thus,

$$\boxed{y_2 = 0.1752}$$

Now, the work by turbine:

$$\omega_{turb} = (h_5 - h_6) + (1-y_1)(h_6 - h_7) + (1 - y_1 - y_2)(h_7 - h_8)$$

$$= (3428.90 - 2852.159) + (1 - 0.1752)(2852.159 - 2580.717) + (1 - 2\times 0.1752)(2580.717 - 2246.025)$$

$$\boxed{\omega_{turb} = 1{,}020.042 \ \text{kJ/kg}}$$

For the mass flow rate:

$$\dot{m} = \frac{\dot{W}_{out}}{\omega_{turb}} = \frac{50{,}000 \ \text{kW}}{1{,}020.042 \ \text{kJ/kg}}$$

$$\boxed{\dot{m} = 49.018 \ \text{kg/s}}$$

The heat supplied in space heating: E

$$\dot{Q}_{space} = \dot{m}(y_2)(h_7 - h_9)$$

$$= 49.018\ \frac{kg}{s} \times 0.1752 \times (2580.717 - 467.13)\ \frac{kJ}{kg}$$

$$\boxed{\dot{Q}_{space} = 18{,}151.23\ kW}$$

The heat released in condenser:

$$\dot{Q}_{cond} = \dot{m}(1-y_1-y_2)h_8 + \dot{m}(y_2)h_{10} - \dot{m}(1-y_1)h_1$$

$$= 49.018\ \frac{kg}{s}\left[(1-2 \times 0.1752) \times 2246.025 + 0.1752 \times 467.13 - (1-0.1752)\,225.94\right]$$

$$\boxed{\dot{Q}_{cond} = 66{,}395.063\ kW}$$

Finally the utilization factor

$$\epsilon = \frac{\dot{W}_{turb} + \dot{Q}_{space} - \dot{W}_{pumps}}{\dot{Q}_{in}}$$

For this, we need $\dot{W}_{pumps}$ & $\dot{Q}_{in}$

F

$$\dot{Q}_{in} = \dot{m}(h_5 - h_4)$$

$$\boxed{\dot{Q}_{in} = 134{,}156.825 \text{ kW}}$$

$$\dot{W}_{pumps} = \dot{m}(1-y_1)(h_2 - h_1) + \dot{m}(h_4 - h_3)$$

$$\boxed{\dot{W}_{pumps} = 286.074 \text{ kW}}$$

Thus,

$$\varepsilon = \frac{50{,}000 \text{ kW} + 18{,}151.23 \text{ kW} - 286.074 \text{ kW}}{134{,}156.825 \text{ kW}}$$

$$\boxed{\varepsilon = 0.5058}$$

SUMMARY

- The utilization factor is 0.5058
- The heat released in condenser is 66,395.063 kW
- The heat given to the space is 18,151.23 kW
- The total mass flow rate is 49.018 kg/s
- The work by turbine is 1,020.042 kJ/kg
- The mass fractions leaving turbine $y_1 = y_2 = 0.1752$

ANALYSIS

- Note that the ammount of work (or power) required by the pumps in negligible. So, in this type of cycles, to improve efficiency (or utilization factor) the turbine is the element to improve.
- The mass fraction y_1 is the exact value to have state (3) on the saturated liquid curve. If that fraction is larger than 0.1752, we would have vapor in state (3), which is not good for the pump.
- If the space heating requires more than 18,151.23 kW, the state (6) will become compressed liquid. This is perfectly fine because that stream will eventually end up in the condenser.