Name: ______________________________________.

MET 350 Thermal Applications
Dr. Orlando Ayala
Spring 2025
Test 2

Take home – Due Sunday March 25th, 2025, before midnight.

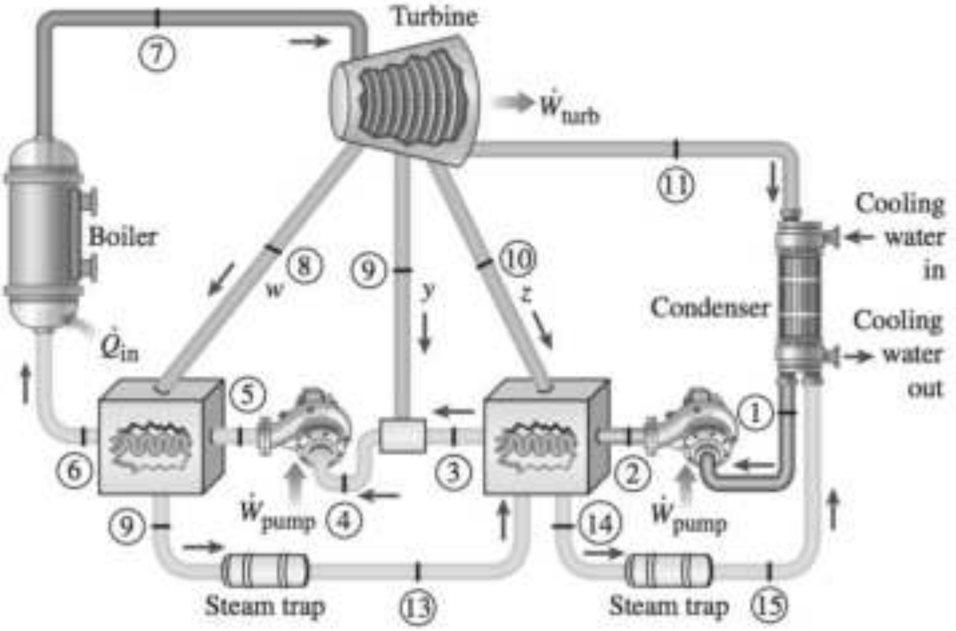
READ FIRST

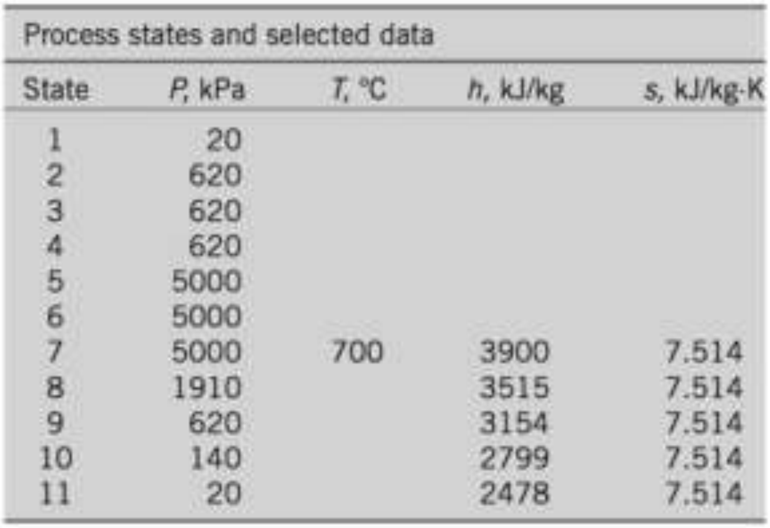
1. RELAX!!!! DO NOT OVERTHINK THE PROBLEMS!!!! There is nothing hidden. The test was designed for you to pass and get the maximum number of points, while learning at the same time. HINT: THINK BEFORE TRYING TO USE/FIND EQUATIONS (OR EVEN FIND SIMILAR PROBLEMS)
2. The total points on this test are one 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 are 2 problems. Each problem will be worth (80/2) 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.

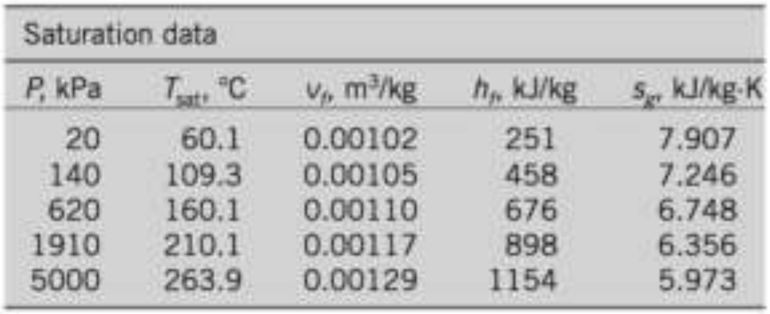
An ideal Rankine steam cycle modified with two closed feedwater heaters and one open feedwater heater is shown below. The power cycle receives 100 kg/s of steam at the high-pressure inlet to the turbine. The feedwater heater exit states for the boiler feedwater and the condensed steam are the normally assumed ideal states. The tables below provide some information for some of the states in the cycle.





Process states and selected data

State	P, kPa	T, °C	h, kJ/kg	s, kJ/kg-K
1	20			
2	620			
3	620			
4	620			
5	5000			
6	5000			
7	5000	700	3900	7.514
8	1910		3515	7.514
9	620		3154	7.514
10	140		2799	7.514
11	20		2478	7.514



Saturation data

P, kPa	T_{sat}, °C	v_f, m³/kg	h_f, kJ/kg	s_g, kJ/kg-K
20	60.1	0.00102	251	7.907
140	109.3	0.00105	458	7.246
620	160.1	0.00110	676	6.748
1910	210.1	0.00117	898	6.356
5000	263.9	0.00129	1154	5.973

1. After years of operation, the steam trap handling the fraction of mass extracted from the closed feedwater heater operating at 1910 kPa starts to malfunction and gets completely blocked. With the steam trap malfunction the mass fractions for the other feedwater heaters (“*y*” and “*z*”) got affected and the operator noted that the fluid at state 3 was saturated liquid. For such case:

   (a) Determine the fraction of extracted mass “*y*” and “*z*” for the open and closed feedwater heater respectively that guarantees the proper operation of the cycle.
   (b) Determine the cooling water temperature rise in the condenser, in ^{o}C, when the cooling water flow rate is 4200 kg/s. Assume Cp = 4.18 kJ/kg·K for cooling water.
   (c) Determine the rate of heat rejected in the condenser, the produced net power, and the thermal efficiency of the plant.

2. All of the sudden, the second steam trap starts to malfunction as well. For such case:

   (a) Determine the fraction of mass “*y*” extracted for the open feedwater heater that guarantees the proper operation of the cycle.
   (b) Determine the cooling water temperature rise in the condenser, in ^{o}C, when the cooling water flow rate is 4200 kg/s. Assume Cp = 4.18 kJ/kg·K for cooling water.
   (c) Determine the rate of heat rejected in the condenser, the produced net power, and the thermal efficiency of the plant.

Problem solution rubric

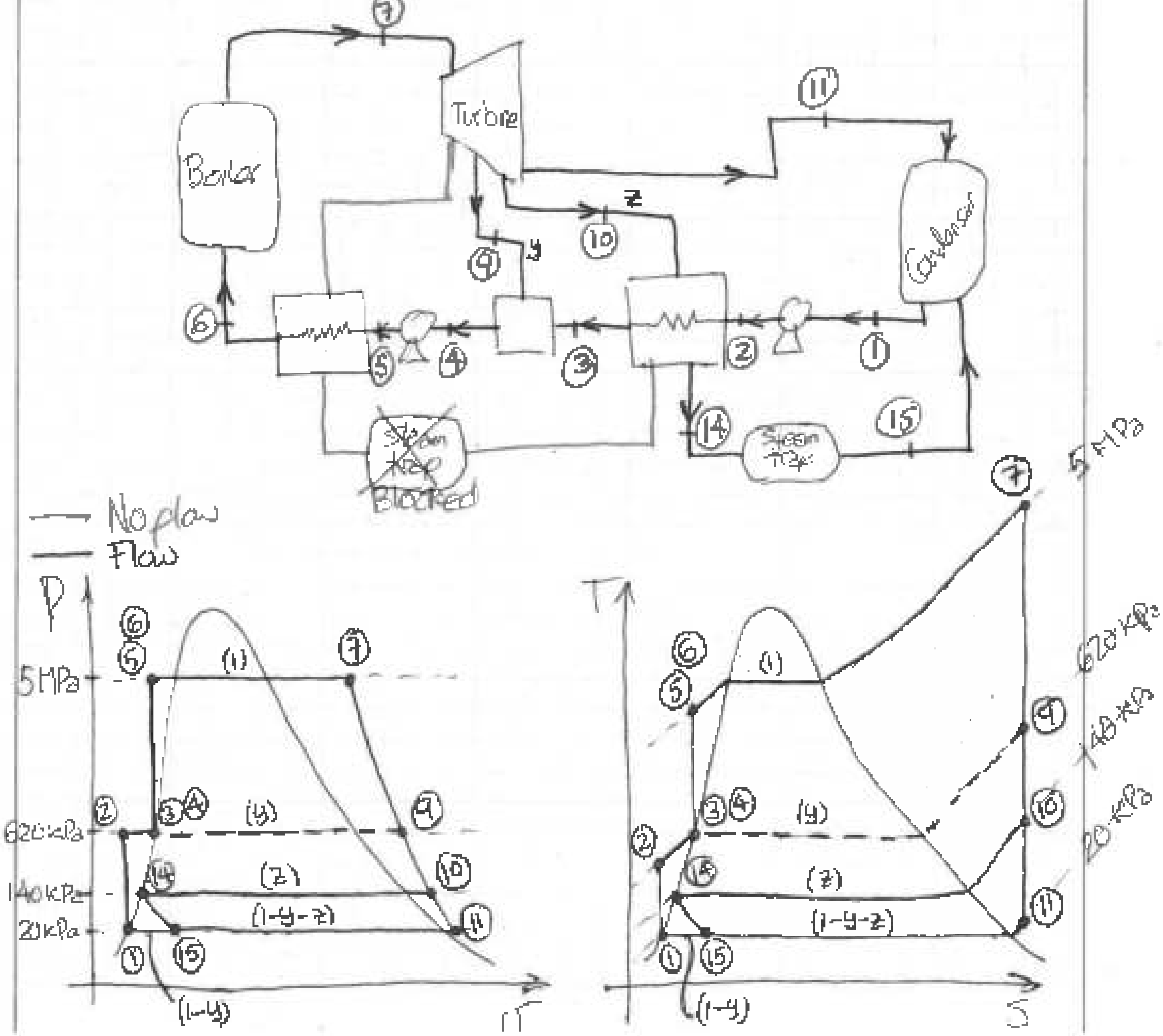
	Exceeds Standard	Meets Standard	Approaches Standard	Needs Attention
	4	3	2	1
	10 points	**7 points**	**4 points**	**0 points**
1. **Purpose** 5%	The purpose of the section to be answered is clearly identified and stated.	The purpose of the section to be answered is identified, but is stated in a somewhat 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 the mass fractions "y" and "z" extracted for the open and close-FWH in the cycle shown below when the steam trap of 2nd FWH gets clogged. Also, determine the ΔT of the cooling water in the condenser and the thermal efficiency of the plant

DIAGRAMS



SOURCES

$\boxed{B}$

Cengel and Boles. Thermodynamics - An Engineering Approach 8th edition. McGraw Hill. 2015.

DESIGN CONSIDERATIONS

I assume the following:

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

DATA & VARIABLES

$\dot{m}_T = 100$ kg/s

$\dot{m}_w = 4200$ kg/s

$C_{P_w} = 4.18 \frac{kJ}{kg \cdot K}$

$x_3 = 1$

$P_{11} = P_1 = 20$ kPa

$P_9 = P_2 = P_3 = P_4 = 620$ kPa

$P_5 = P_6 = P_7 = 5000$ kPa

$S_7 = S_9 = S_{10} = S_{11} = 7.514 \frac{kJ}{kg \cdot K}$

$h_7 = 3900 \frac{kJ}{kg}$

$h_9 = 3154$ kJ/kg

$h_{10} = 2799$ kJ/kg

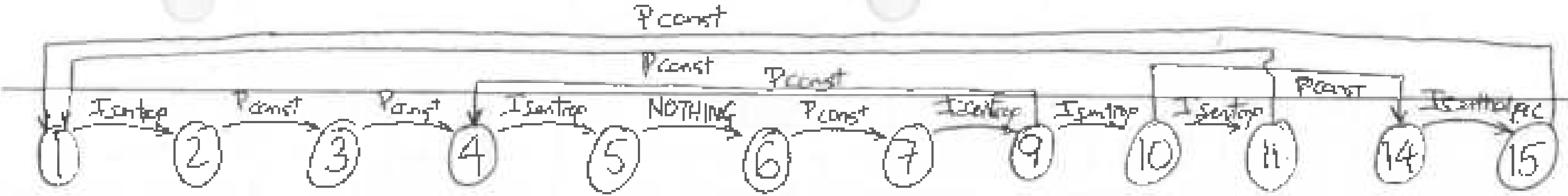
$h_{11} = 2478$ kJ/kg

MATERIALS - Fluid provided by problem

PROCEDURE

1) Get all remaining states.
2) To get "y", use 1st law at the mixing chamber.
3) To get "z", use 1st law at the FWH.
4) To get ΔT_w, compute $\dot{Q}_{out}$ in the condensar and equate it to the heat equation for the cooling water
5) To get thermal efficiancy, get the power produced by turbine and power used by pumps using 1st law

CALCULATIONS



$P_1=20kPa$
$x_1=0$
From table
$h_1=251\frac{kJ}{kg}$ ✓
$v_1=0.00102\frac{m^3}{kg}$

$P_2=620kPa$

$P_3=620kPa$
$x_3=0$
From table
$h_3=676\frac{kJ}{kg}$ ✓

$P_4=620kPa$
$x_4=0$
(MUST)
From table
$h_4=676\frac{kJ}{kg}$ ✓
$v_4=0.0011\frac{m^3}{kg}$

$P_5=5MPa$

$P_6=7MPa$

$P_7=7MPa$
$h_7=3920\ kJ/kg$ ✓
DONE

$P_9=620kPa$
$h_9=3154\ kJ/kg$ ✓
DONE

$P_{10}=140kPa$
$h_{10}=2799\ kJ/kg$ ✓
DONE

$P_{11}=20kPa$
$h_{11}=2498\ kJ/kg$ ✓
DONE

$P_{14}=140kPa$
$x_{14}=0$
(ideal out)
From table
$h_{14}=458\frac{kJ}{kg}$ ✓

$P_{15}=20kPa$

$h_2=h_1+v_1(P_2-P_1)$ ✓
$\boxed{h_2=251.612\frac{kJ}{kg}}$

$h_5=h_4+v_4(P_5-P_4)$ ✓
$\boxed{h_5=680.818\frac{kJ}{kg}}$

$h_6=h_5$ ✓
$\boxed{h_6=680.818\frac{kJ}{kg}}$

$h_{15}=h_{14}$ ✓
$\boxed{h_{15}=458\frac{kJ}{kg}}$

To get "y", apply 1st law to the mixing chamber:

$$y h_9+(1-y)h_3=h_4$$

Solving for "y":

$$y=\frac{h_4-h_3}{h_9-h_3}$$

Since $h_4=h_3$, $\cancel{\boxed{y=0}}$ This must happen ~~per~~ per proper pump operation!!!

Similarly for "z":

$$zh_{10}+(1-\overset{0}{\cancel{y}})h_2=zh_{14}+(1-\overset{0}{\cancel{y}})h_3$$

So,

$$z=\frac{h_3-h_2}{h_{10}-h_{14}}=\frac{(676-251.612)\ kJ/kg}{(2799-458)\ kJ/kg}$$

$$\cancel{\boxed{z=0.1813}}$$

C

For the cooling water increase of temperature, $\boxed{D}$

I apply 1^{st} law to the condenser:

$$\dot{m}_w c_{p_w} \Delta T_w = \dot{m}_T \left[(1-\overset{0}{\cancel{y}}-z) h_{11} + z h_{15} - (1-\overset{0}{\cancel{y}}) h_1 \right]$$

$$= \dot{m}_T \left[(1-z) h_{11} + z h_{15} - h_1 \right]$$

So,

$$\Delta T_w = \frac{\dot{m}_T}{\dot{m}_w} \frac{\left[(1-z) h_{11} + z h_{15} - h_1 \right]}{c_{p_w}}$$

$$= \frac{100 \text{ kg/s}}{4200 \text{ kg/s}} \frac{\left[(1-0.1813) 2478 + 0.1813 \times 458 - 251 \right] \text{kJ/kg}}{4.18 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}}$$

$$\boxed{\Delta T_w = 10.599 \text{ °K}}$$

For the thermal efficiency

$$\eta_{th} = \frac{W_{Turb} - W_{pump_1} - W_{pump_2}}{q_{boiler}}$$

$$W_{turb} = (h_7 - h_9) + (1-\overset{0}{\cancel{y}})(h_9 - h_{10}) + (1-\overset{0}{\cancel{y}}-z)(h_{11} - h_{10})$$

$$= (h_7 - h_{10}) + (1-z)(h_{10} - h_{11})$$

$$= (3900-2799) + (1-0.1813)(2799-2478) \ \frac{\text{kJ}}{\text{kg}}$$

$$W_{turb} = 1363.803 \text{ kJ/kg}$$

$$W_{pump_1} + W_{pump_2} = (h_2 - h_1) + (h_5 - h_4)$$

E

$$W_{pump_1} + W_{pump_2} = (251.612 - 251) + (680.88 - 676) \ kJ/kg$$

$$\underline{W_{pump_1} + W_{pump_2} = 5.43 \ kJ/kg}$$

and,

$$q_{tboiler} = h_7 - h_6 = (3900 - 680.818) \ kJ/kg$$

$$\underline{q_{tboiler} = 3219.182 \ kJ/kg}$$

Finally,

$$\eta_{th} = \frac{(1363.803 - 5.43) \ kJ/kg}{3219.182 \ kJ/kg}$$

$$\boxed{\eta_{th} = 0.422}$$

SUMMARY

a) The fractions of hot steam for the FWH system are y=0 and z=0.1813.

b) The increase in temperature of the cooling water used in the condenser is 10.60°K

c) The thermal efficiency of the cycle is 0.422.

ANALYSIS

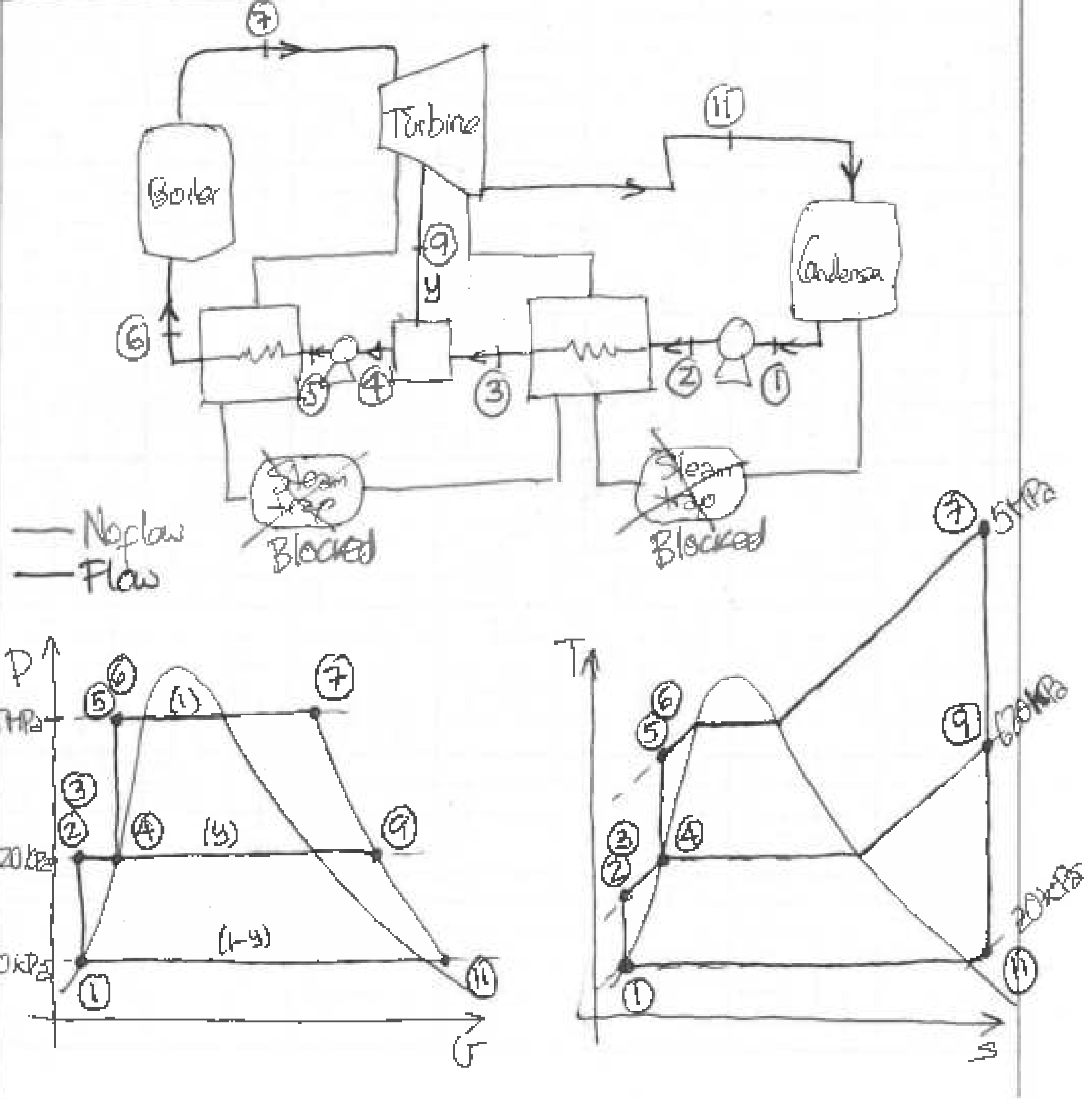
The y=0 makes perfect sense because the pump cannot have any trace of vapor. Interestingly, the thermal efficiency of the cycle slightly increased from 0.418 to 0.422 after the steam trap got clogged. This is because it is better to use vapor with less amount of enthalpy in FWH systems.

② PURPOSE

F

Determine the mass fraction "y" extracted for the open FWH in the cycle below when the steam traps get clogged. Also determine the ΔT of the cooling water in the condenser and the thermal efficiency of the plant.

DIAGRAMS



G

SOURCES

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DESIGN CONSIDERATIONS

I assume the following:

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2) Fluid is pure
3) No heat losses in connections pipes. Neether fluid flow friction losses
4) Constant pressure phase changes in boiler and condenser

DATA & VARIABLES

$\dot{m}_T = 100 \ kg/s$

$\dot{m}_w = 4200 \ kg/s$

$Cp_w = 4.18 \ kJ/kg \cdot K$

$P_{11} = P_1 = 20 \ kPa$

$P_9 = P_2 = P_3 = P_4 = 620 \ kPa$

$P_5 = P_6 = P_7 = 5000 \ kPa$

$S_7 = S_9 = S_{11} = 7.54 \ \frac{kJ}{kg \cdot K}$

$h_7 = 3900 \ kJ/kg$

$h_9 = 3154 \ kJ/kg$

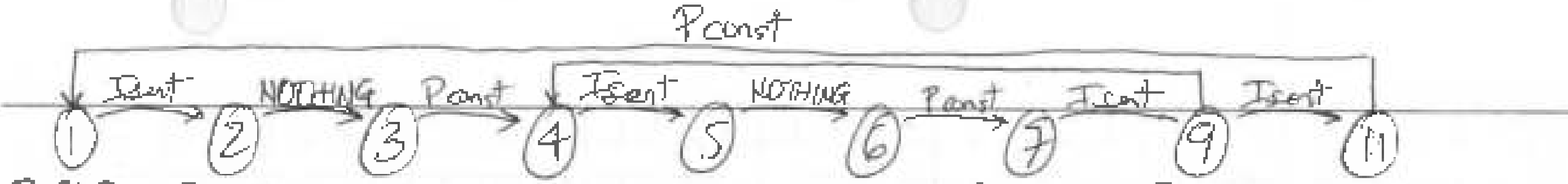
$h_{11} = 2478 \ kJ/kg$

MATERIALS: Fluid provided by problem

PROCEDURE

1) Get all remaining states
2) To get "y", use 1st law at the mixing chamber
3) To get ΔT_w, use $\dot{Q}_{out}$ in the condenser and equate it to the heat equation for the cooling water
4) To get thermal efficiency, get the power produced by turbine and power required by the pumps using 1st law

CALCULATIONS



$P_1=20kPa$
$x_1=0$

$P_2=620kPa$

$P_3=620kPa$

$P_4=620kPa$
$x_4=0$
(MUST)

$P_5=5MPa$

$P_6=5MPa$

$P_7=5MPa$
$h_9=3900\frac{kJ}{kg}$

$P_9=620kPa$
$h_9=3154\frac{kJ}{kg}$

$P_{11}=20kPa$
$h_{11}=2497.8\frac{kJ}{kg}$

DONE

DONE

DONE

From table
$h_1=251\frac{kJ}{kg}$
$v=0.00102\frac{m^3}{kg}$

$h_2=h_1+v_1(P_2-P_1)$
$h_2=251.612\frac{kJ}{kg}$

$h_3=h_2$
$h_3=251.612\frac{kJ}{kg}$

From table
$h_4=676\frac{kJ}{kg}$
$v_f=0.0011\frac{m^3}{kg}$

$h_5=h_4+v_4(P_5-P_4)$
$h_5=680.818\frac{kJ}{kg}$

$h_6=h_5$
$h_6=680.818\frac{kJ}{kg}$

To get "y", we apply 1st law to the mixing chamber:

$$y h_9+(1-y)h_3=h_4 \quad \text{so} \quad y=\frac{h_4-h_3}{h_9-h_3}$$

$$y=\frac{676\frac{kJ}{kg}-251.612\frac{kJ}{kg}}{3154\frac{kJ}{kg}-251.612\frac{kJ}{kg}}$$

$$\boxed{y=0.1462}$$

H

For the cooling water increase of temperature, $\boxed{I}$
I apply 1st law to the condenser:

$$\dot{m}_w C_{pw} \Delta T_w = \dot{m}_T (1-y)(h_{11}-h_1)$$

So,

$$\Delta T_w = \frac{\dot{m}_T}{\dot{m}_w}(1-y)\frac{(h_{11}-h_1)}{C_{pw}}$$

$$= \frac{100\ kg/s}{4200\ kg/s}(1-0.1462)\frac{(2478-251)\ kJ/kg}{4.18\ \frac{kJ}{kg \cdot K}}$$

$$\cancel{\boxed{\Delta T_w = 10.831\ K}}$$

For the thermal efficiency

$$\eta_{th} = \frac{w_{turb} - w_{pump} - w_{pump_2}}{q_{boiler}}$$

$$w_{turb} = (h_7 - h_9) + (1-y)(h_9 - h_{11})$$

$$= (3900-2799) + (1-0.1462)(2799-2478)\ kJ/kg$$

$$\underline{w_{turb} = 1375.070\ kJ/kg}$$

$$w_{pump_1} + w_{pump_2} = (h_2 - h_1) + (h_5 - h_4)$$ ← the states are the same as before!

So,

$$\underline{w_{pump_1} + w_{pump_2} = 5.43\ kJ/kg}$$

J

and,

$$q_{boiler} = h_7 - h_6 \longrightarrow \text{Same as before}$$

$$\underline{q_{boiler} = 3219.182 \ \text{kJ/kg}}$$

Finally,

$$\eta_{th} = \frac{(1375.070 - 5.43) \ \text{kJ/kg}}{3219.182 \ \text{kJ/kg}}$$

$$\boxed{\eta_{th} = 0.425}$$

SUMMARY

a) The fraction of hot steam for the open FWH is $y=0.1462$

b) The increase in temperature of the cooling water used in the condenser is 10.831°C

c) The thermal efficiency of the cycle is 0.425

ANALYSIS

Both thermal efficiency and ΔT_w changed only for about 2%. This is negligibe. The reason being that is because the only difference between the two cases is that the FWHs were open or close. Recall that $y=0$ before, now $z=0$. For both $W=0$.