Test 2

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Steps

① purpose, diagrams, sources ④ technical analysis

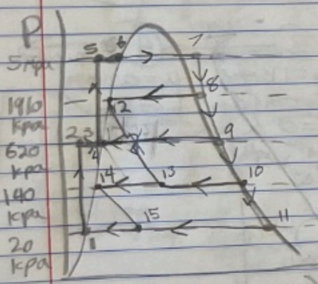
② states, summarys

③ calculations, sources,

① purpose:

1) Determine mass fraction "y" & "z", cooling water temp rise in condenser, and rate of heat rejected, net work, thermal efficiency

2) mass fraction of "y", cooling water temp rise, and rate of heat rejected, Network and thermal efficiency



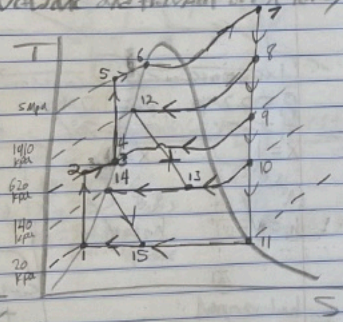
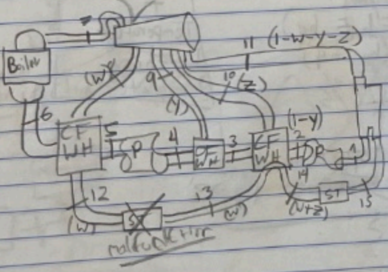


Diagram:



2 pumps

2 Closed FW HeatX

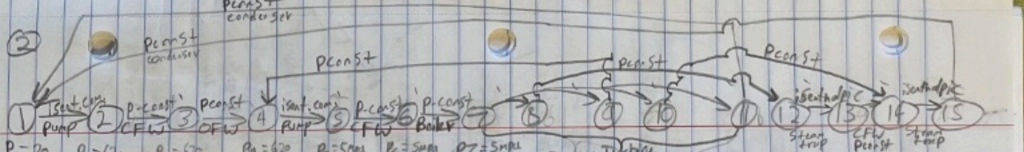
1 mixing chamber

1 turbine

2 steam traps → case 1: 1 broken case 2: both broken

1 condenser

(2)



$P_1 = 20$ kPa, $h_1 = 251.42 \frac{kJ}{kg}$ ✓

$P_2 = 620$ kPa, $h_2 = 252.03 \frac{kJ}{kg}$ ✓

$P_3 = 620$ kPa, $h_3 = h_4$, $h_3 = 676 \frac{kJ}{kg}$ ✓

$P_4 = 620$ kPa, $h_4 = 676 \frac{kJ}{kg}$ ✓

$P_5 = 5$ MPa, $h_5 = 680.687 \frac{kJ}{kg}$ ✓

$P_6 = 5$ MPa, $h_6 = 1154 \frac{kJ}{kg}$ ✓

$P_7 = 5$ MPa, $T_7 = 700°C$, $h_7 = 3900 \frac{kJ}{kg}$ ✓

$P_8 = 1910$ kPa, $h_8 = 3515 \frac{kJ}{kg}$ ✓

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

$P_{10} = 140$ kPa, $h_{10} = 2799 \frac{kJ}{kg}$ ✓

$P_{11} = 20$ kPa, $h_{11} = 2478$ ✓

$s_7 = s_8 = s_9 = s_{10} = s_{11}$

$P_{12} = 1910$ kPa, $h_{12} = 878 \frac{kJ}{kg}$ ✓

$P_{13} = 140$ kPa, $h_{13} = 878 \frac{kJ}{kg}$ ✓

$P_{14} = 140$ kPa, $h_{14} = 458 \frac{kJ}{kg}$ ✓

$P_{15} = 20$ kPa, $h_{15} = 458 \frac{kJ}{kg}$ ✓

The first step is to use the given information for states in a saturated liquid state. followed by recognizing the isentropic process for states 7-11 and use the given data or find through interpolation.

For states 2 & 5 b/c they are connected to pumps using Bernoulli's trick w/pumps learned from Ayala's class $h_2 - h_1 = v_1(P_2 - P_1)$ can be used.

For states 12 - 15 they work through steam traps which cool the temp. of the fluid but don't lose enthalpy. making them (12-13), (14-15) isenthalpic processes.

Source:
O. Ayala
Thermal Application Lecture
tues-thurs.

③ Case 1

Assuming "W" is steam trap is blocked completely, the mass feeds into the nearest output line in this case "y" feeding into the open FWHX. B/c state 13 is blocked and Not transporting mass to state 14 and 13 is cooling to maintain a temp. below saturation. Now that it is blocked state 10 is Not cooled as much resulting in state 3 being much hotter and Now saturated.

"y" → "w+y" → New "y"

Mass Fractions

1st CFWHX 1st law

$\cancel{q_{in}}-\cancel{q_{out}}+\cancel{w_{in}}-\cancel{w_{out}}=\Delta h \rightarrow 0=h_{out}-h_{in}$

$h_{in}=h_{out}$

$(1-y)h_3-h_2=z(h_{10}-h_{14})$

1st law OFWHX

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

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

$0=y$

$y+w=y' \rightarrow \boxed{y=0.181}$ ⓐ

$\frac{(1-.181)h_3-h_2}{h_{10}-h_{14}}=z$

$\frac{(0.181)(676\frac{kJ}{kg}-252.03\frac{kJ}{kg})}{2799\frac{kJ}{kg}-458\frac{kJ}{kJ}}=\boxed{0.033=z}$ ⓐ

1st law around 2nd CFWHX

$\frac{h_6-h_5}{h_8-h_{12}}=\frac{w(h_8-h_{12})}{h_8-h_{12}}$

$w=\frac{1163\frac{kJ}{kg}-680.687\frac{kJ}{kg}}{3515\frac{kJ}{kg}-848\frac{kJ}{kg}}$ $W=0.181$

$\dot{m}_c=4200\,kg/s$ $cp=4.18\frac{kJ}{kg\cdot K}$

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

1st law → Condenser

$0=\Delta h \Rightarrow (1-y)h_1=(1-w-y-z)h_{11}+zh_{15}$

$$\frac{\dot{m}[(1-w-y-z)h_{11}+zh_{15}-(1-y)h_1]}{\dot{m}_c\cdot cp}=T$$

$$\frac{100\frac{kg}{s}((1-.181-0-0.033)2478\frac{kJ}{kg}+0.033(458\frac{kJ}{kg})-(1-0)251.42\frac{kJ}{kg})}{4200\frac{kg}{s}\cdot 4.18\frac{kJ}{kg\cdot K}}=T$$

$\boxed{T=11.18°C}$ ⓑ

Source
thermodynamics
an engineering approach
ed. 8
Canvas HW
Solutions 1.2

Calculations (3)

State 1 — Sat. Liquid table @ $P_1 = 20\ kPa \rightarrow h_1 = 251.42\ \frac{kJ}{kg}$ (table A-5)

$\hookrightarrow v_1 = 0.001017\ m^3/kg$

State 2 — compressed liquid → for a pump use → 1st law → $h_2 - h_1 = v_1(P_2 - P_1)$

$h_2 = 251.42\ \frac{kJ}{kg} + 0.001017\ m^3/kg\ (620\ kPa - 20\ kPa)$

$h_2 = 252.03\ \frac{kJ}{kg}$

State 4 — Sat. Liquid table @ $P_4 = 620\ kPa \rightarrow$ interpolate $\boxed{y_2 = y_1 + \frac{(x_2 - x_1)(y_3 - y_1)}{(x_3 - x_1)}}$

Pump → must be at least

table A-5

$x_1 = 600\ kPa$ $y_3 = 684.08\ \frac{kJ}{kg}$ $x_2 = 620$

$x_3 = 650\ kPa$ $y_1 = 670.38\ \frac{kJ}{kg}$

$y_2 = 670.38\ \frac{kJ}{kg} + \frac{(20)(13.7)}{(50)}$

$y_2 = h_4 = 675.86\ \frac{kJ}{kg}$

State 5 — compressed liquid → pump → 1st law → $h_5 - h_4 = v_4(P_5 - P_4)$

interpolate for $v_4 = y_2 = y_1 + \frac{(x_2 - x_1)(y_3 - y_1)}{(x_3 - x_1)}$ $y_3 = .001104\ m^3/kg$ $y_1 = .001101\ \frac{m^3}{kg}$

$y_2 = .001101\ \frac{m^3}{kg} + \frac{(20)(0.000003)}{50}$

$y_2 = v_4 = 0.0011022\ m^3/kg$

$h_5 = 675.86\ \frac{kJ}{kg} + 0.0011022\ \frac{m^3}{kg}(5000\ kPa - 620\ kPa)$

$h_5 = 680.687\ \frac{kJ}{kg}$

State 7 — given → $h_7 = 3900\ \frac{kJ}{kg}$

State 8 — $\hookrightarrow h_8 = 3515\ \frac{kJ}{kg}$

State 9 — $\hookrightarrow h_9 = 3154\ \frac{kJ}{kg}$

State 10 — $\hookrightarrow h_{10} = 2799\ \frac{kJ}{kg}$

State 11 — $\hookrightarrow h_{11} = 2478\ \frac{kJ}{kg}$

$h_{12} = y_2 = \frac{(160)(30.31)}{(250)} + 878.16\ \frac{kJ}{kg} = h_{12}$

$y_3 = 908.47\ \frac{kJ}{kg}$ $x_3 = 2000\ kPa$ $x_2 = 1910\ kPa$

$y_1 = 878.16\ \frac{kJ}{kg}$ $x_1 = 1750\ kPa$

$h_{12} = 898\ \frac{kJ}{kg}$

$h_{14} = y_2 = 444.36\ \frac{kJ}{kg} + \frac{(15)\cdot(22.77)}{(25)}$

$y_3 = 467.13\ \frac{kJ}{kg}$ $x_3 = 150\ kPa$ $x_2 = 140\ kPa$

$y_1 = 444.36\ \frac{kJ}{kg}$ $x_1 = 125\ kPa$

$h_{14} = 458\ \frac{kJ}{kg}$

State 12 — $h_{12} = h_{13}$ → isenthalpic

$h_{12} \Rightarrow$ Sat. liquid → interpolate @ $P_{12} = 1910\ kPa$ Sat. liquid tables

State 14 — $h_{14} = h_{15}$ it is an isenthalpic process → assume h_{14} → Sat. liquid around the first CFWHX $\hookrightarrow h_{14} \Rightarrow$ interpolate @ $P_{14} = 140\ kPa$ & sat. liquid values

State 3 → Sat. liquid @ 620 kPa $\rightarrow 676\ \frac{kJ}{kg} = h_3$

State 6 → assuming state 6 is a Sat. Liquid due to HX and the previous states 3, 4, 5 being Sat. Liquid → h_6 → Sat. Liquid

given $h_6 @ P_6 = 5000\ kPa \rightarrow h_6 = 1154\ \frac{kJ}{kg}$

③ calculations continued for cases 1 and case 2

$\eta_{th} = \frac{W_{net}}{q_{in}} \rightarrow W_{net} = W_{out_{7-11}} - W_{in_{2-1}} - W_{in_{5-4}}$

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

1st law

$W_{out_{7-11}} = h_7 - W(h_8) - y(h_9) - z(h_{10}) - (1-w-y-z)h_{11}$

$= 3900\frac{kJ}{kg} - 0.181(3515\frac{kJ}{kg}) - (0) - (0.033)2799\frac{kJ}{kg} - (0.786)(2478\frac{kJ}{kg})$

$3900\frac{kJ}{kg} - 636.215\frac{kJ}{kg} - 92.36\frac{kJ}{kg}\ 1947.708\frac{kJ}{kg}$

$W_{out} = 1223.71\frac{kJ}{kg}$

1st law

pump 1 $W_{in_{2-1}} = h_2 - h_1 = 252.03\frac{kJ}{kg} - 251.42\frac{kJ}{kg} = 0.61\frac{kJ}{kg}$

pump 2 $W_{in\,5-4} = h_5 - h_4 = 680.687\frac{kJ}{kg} - 676\frac{kJ}{kg} = 4.687\frac{kJ}{kg}$

$+ \quad 5.297\frac{kJ}{kg}$

$W_{net} = 1223.7\frac{kJ}{kg} - 5.297\frac{kJ}{kg}$

$W_{net} = 1218.403\frac{kJ}{kg}$

1st law Boiler $= q_{in}$ $\quad q_{in} = h_7 - h_6 = 3900\frac{kJ}{kg} - 1154\frac{kJ}{kg} = 2746\frac{kJ}{kg}$

$\eta_{th} = \frac{W_{net}}{q_{in}} = \frac{1218.403\frac{kJ}{kg}}{2746\frac{kJ}{kg}} = \boxed{0.44 = \eta}$ ©

heat rejected in condenser 1st law

$q_{out} = h_{11} - h_1 = 2478\frac{kJ}{kg} - 251.42\frac{kJ}{kg} = 2226.6\frac{kJ}{kg}$ } 2433.18

case 1 only added $= h_{15} - h_1 = 458\frac{kJ}{kg} - 251.42\frac{kJ}{kg} = 206.58\frac{kJ}{kg}$

$Q_{out} = \dot{m} \cdot q_{out} = 100 kg/s \cdot 2433.18\frac{kJ}{kg}$

$\boxed{\dot{Q}_{out} = 243.3\ MW}$ ©

$\dot{W}_{net} = \dot{m} \cdot W_{net}$

$= 100 kg/s \cdot 1218.403\frac{kJ}{kg} = \boxed{121.8\ MW = \dot{W}}$ ©

③

Case 2

Both steam traps are broken meaning his leading to the condenser is not anymore and the mass of z is runs through the CFWHX but stops at the steam trap. The remainder of mass from the turbine does not combine with z as it should but continues with it missing.

mass fraction

OFWHX 1st law

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

Source thermodynamics an engineering approach W. 8 cengel boles, kanoglu

Condenser 1st law

$(1-w-y-z)h_1 = (1-w-y+z)h_{11}$

w is the same and z is the same as case 1 b/c the tracks flow w/ their mass but they just add to the nearest track in the next part of the process. can't flow backwards in a turbine

$y \rightarrow w+y \rightarrow y'$ remainder $(1-y-w-z) \rightarrow 1-y'$

$(1-0.033)676\frac{kJ}{kg} = (0.181+y)3154\frac{kJ}{kg} + (1-0.181-y-0.033)676$

$653.692\frac{kJ}{kg} = 570.874 - 3154y + 676 - 122.356 - 22.308 + 676y$

$\frac{-449.52}{-2478} = \frac{-2478y}{-2478}$

ⓐ $\boxed{0.181 = y}$

cool water flow $\dot{m}_c = 4200\,kg/s$ $\dot{m} = 100\,kg/s$ $c_p = 4.18\frac{kJ}{kg\cdot K}$

$\frac{\dot{m}((1-w-y-z)h_{11} - (1-w-y-z)h_1)}{\dot{m}_c \cdot c_p} = T$

$\frac{100\frac{kg}{s}((0.605)2478\frac{kJ}{kg} - (0.605)251.42\frac{kJ}{kg})}{4200\frac{kg}{s} \cdot 4.18\frac{kJ}{kg\cdot K}} = \boxed{7.67°C = T}$ ⓑ

$q_{out,tot} = h_{11} - h_1 = 2478\frac{kJ}{kg} - 251.42\frac{kJ}{kg} = 2226.6\frac{kJ}{kg}$

$\dot{Q}_{out} = q_{out} \cdot \dot{m} = 2226.6\frac{kJ}{kg} \cdot 100\frac{kg}{s} = \boxed{222\,MW = \dot{Q}_{out}}$ ⓒ

Work net is the same in case 1 and case 2

Same w/ $\dot{Q}_{in}$ $\boxed{\dot{W}_{net} = 121.8\,MW}$ ⓒ

$\boxed{\eta^{th} = 0.44}$ ⓒ

Technical writing:

(4)

The design of the Rankine Steam cycle w/out any malfuction is a functional and ideal system. In the problem, the question proposed in the design that the steam trap was blocked. In such a case, the fluid which passes through "w" line becomes stopped, and is halted from cooling in steam trap, and from entering the closed FW HX which would help maintain a temp balance for the resulting state 3. As a result of the malfunction, State 3 is of a higher temp. as a sat. liquid. Which is problematic b/c State 3 combines State 9 (Vapor) from the turbine maintaining a constant pressure, this will heat up to state 4 which is a sat. Liquid / mixed vapor due to temp increase, and goes into a pump. This is very bad for the pumps. Similarly the mass of water vapor being backed up in the tubes from the heat exchanger could turn back into a mixed vapor after giving some heat in the CHX and feed back up the tubes due to backflow from the cycles continuous running despite the malfunction. if the mixed vapor goes back into the turbine it could ruin the turbine. This is the same in case 2 w/ both steam traps broken as in the aforementioned case 1. To avoid these problems a potential solution would be to install a pressure gage which when a pressure is exceeded a valve is opened releasing the built up mixed vapor into a condenser for reuse. As for the potential overheating in State 3, to fix, add in an extension in the tubing to cool down the fluid through increased surface area.