Ben Smithson Thermal Test 2

Purpose: The purpose of this test is to show understanding of a regenerative steam power plant. The test allows individuals to show their understanding for drawing a system as well.

Sources: Cengel & Boles, Thermodynamics, An Engineering approach 9th edition

Design considerations

1) Feedwater heater (open)
2) condenser
3) $Y_2 = Y_1$
4) regenerative cycle
5) one stage feed heating

Data & Variables

1) 5.5 mpa & 500°C
2) 50,000 kw load
3) 15 kpa lowest

materials:

1) Steam
2) saturated liquid
3) system w/ pump, super heater, turbine, condenser, throttle

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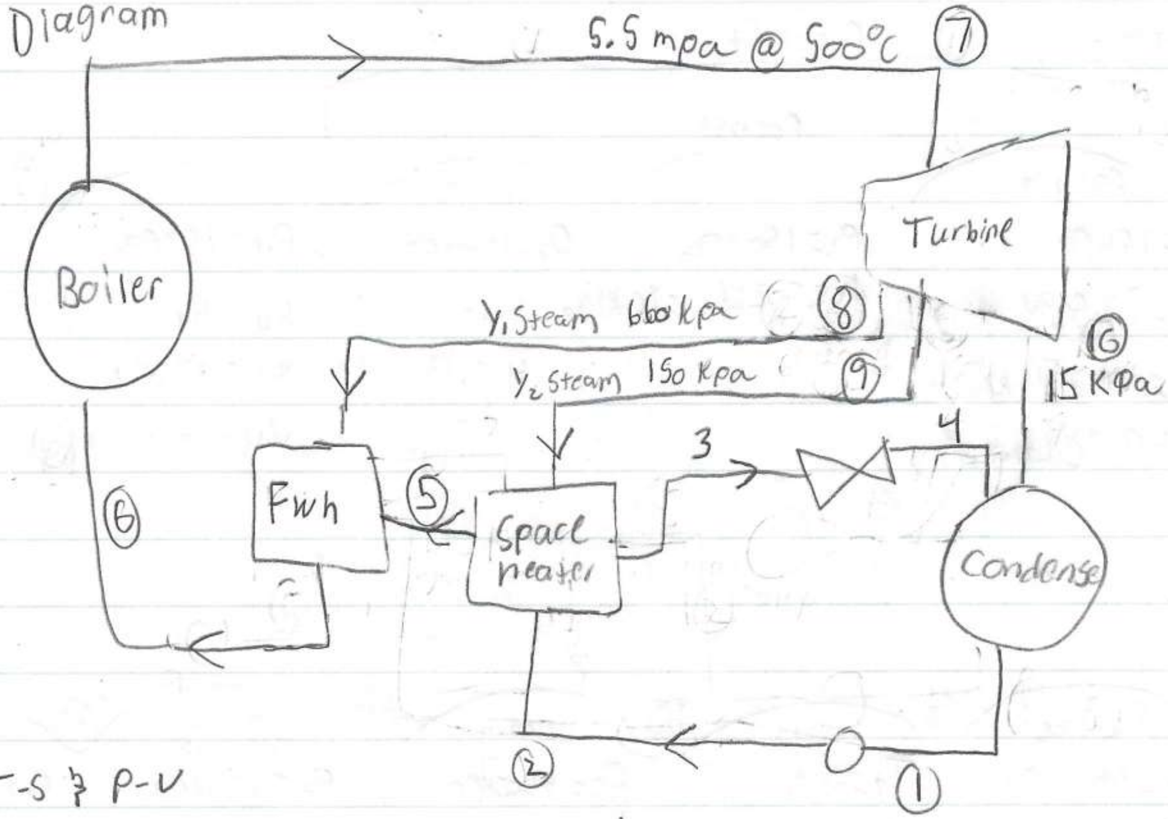
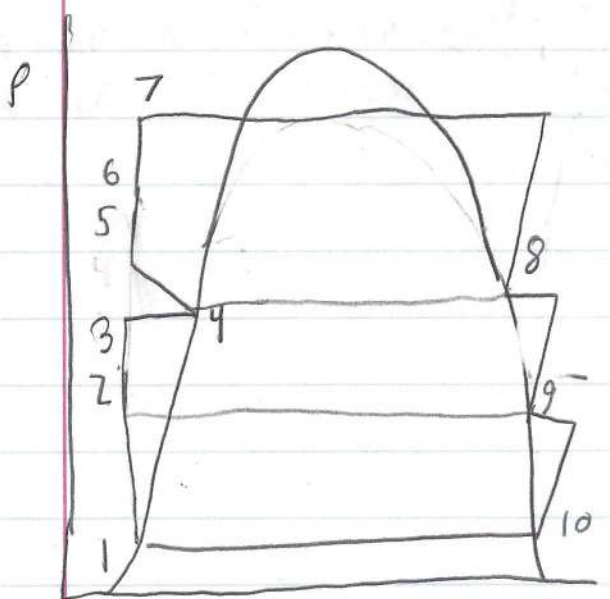
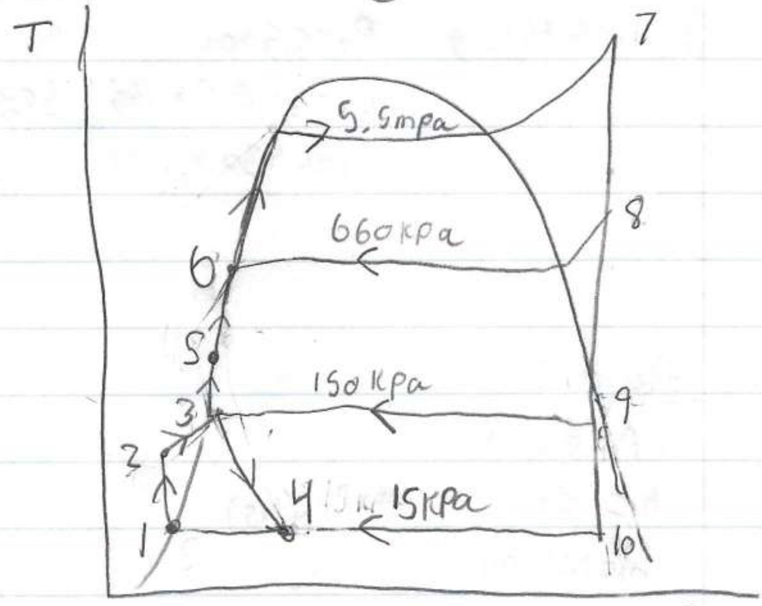
Diagram



T-S & P-V





calculations:

States

p const

Pconst

(1) sat liq

$P_1 = 15 kPa$

$h_1 = 225.94$ kJ/kg

$V_1 = V_f @ 15 kPa$

$V_1 = 0.001014\ m^3/kg$

(2)

$P_2 = 150 kPa$

$h_2 = 226.076$ kJ/kg

(3) sat liq

$P_3 = 150 kPa$

$h_4 =$ 467.13 kJ/kg

(4)

$P_4 = 15 kPa$

$h_4 = h_1$

$h_4 = 225.94$

$v_4 = 0.01014$

(5) sat liq

$P_5 = 660 kPa$

$h_5 = 232.48$

(6) sat liq

$P_6 = 660 kPa$

$h_6 = 686.66$ kJ/kg

(7) steam

$T_7 = 500°C$

$P_7 = 5.5 mpa$

$h_7 = 3428.9$ kJ/kg

$s_7 = 6.930$ kJ/kg·K

(8) steam

$P_8 = 660 kPa$

$h_8 = 2760.24$ kJ/kg

$s_8 = s_7$

(9) sat liq

$P_9 = 150 kPa$

$h_9 = 2693.1$ kJ/kg

$s_9 = s_7$

(10) steam

$P_{10} = 15 kPa$

$h_{10} = 2697.8$

$s_{10} = s_7$

State 1

P_1 = given

h_1 = sat water table (h_s)

$h_1 = 225.94$

State 2

$P_2 = 150 kPa$ (example 10-53 hw)

$w_{p,in} = v_1 (P_2 - P_1) = 0.001014 (150 - 15) = 0.13689$

$w_p + h_1 = h_2 = 0.13689 + 225.94 = 226.076$

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State 3

h_3 @ 150kpa $= 467.13$ kJ/kg

State 4 = State 1

State 5:

$W_{P,in} = V_4 (P_5 - P_4)$

$w = 0.01014 (660 - 15) = 6.54$

$W_P + h_4 = h_5$

$h_5 = 232.48$ kJ/kg

State 6:

table @ 660kpa

interpolate

$h_6 = 686.66$ kJ/kg

State 7:

Superheated water

table A-6 interpolate between (5.0 mpa & 6.0mpa) @ 500°C

$h_7 = 3428.90$ kJ/kg

$S_7 = 6.930$ kJ/kg·K

State 8: @ 660kpa

table A-5 Sat vapor interpolate

$h_8 = 2760.240$ kJ/kg

$S_8 = S_7 = 6.930$ kJ/kg·K

State 9: @ 150kpa

$h_9 = 2693.1$ kJ/kg

$s_9 = s_7 = 6.930$ kJ/kg·K

State 10

$P_{10} = 15$ kpa (example 10-53)

$s_{10} = s_7 = 6.930$ kJ/kg·K

$$x_{10} = \frac{s_{10} - s_f}{s_{fg}} = \frac{6.930 - 1.968}{4.759}$$ ← interpolate

$x_{10} = 1.042$

$h_{10} = h_f + x_{10} h_{fg} = 225.94 + 1.042 \cdot 2372.3 =$

$h_{10} = 2697.87$ kJ/kg

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a. Utilization factor (pg 573)

$$\epsilon_u = \frac{\text{Net power output} + \text{Process heat delivered}}{\text{total heat input}}$$

$$\frac{w_{net} + Q_p}{Q_{in}}$$

$Q_p = h_9 - h_5 = 2693.1 - 232.48 = 2460.62$

$$\frac{730.93 + 2460.62}{2742.24} = \boxed{1.1638}$$

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c. Wout (turbine work)

$$w_{out} = (h_7 - h_8) + (1-y)(h_8 - h_9) + (1-2y)(h_9 - h_{10})$$

$$y = \frac{h_5 - h_2}{h_9 - h_3} = \frac{232.48 - 226.076}{2693.1 - 467.13} = 0.00287$$

$$w_{out} = (3428.9 - 2760.24) + (1 - 0.00287)(2760.24 - 2693.1) + (1 - 2\cdot 0.00287)(2693.1 - 2697.8)$$

$$\boxed{w_{out} = 730.93 \text{ kJ/kg}}$$

d. 50,000 load into system

$$\frac{50{,}000 \text{ kW}}{730.93} = 68.4 \text{ kg/second}$$

e. $q_{in} = h_7 - h_6 =$

$3428.9 - 686.66 = 2742.42$ kJ/kg

g. mass fractions

$Y_1 = 0.00287 = 0.28\%$

$Y_1 = Y_2$

$Y = \frac{h_5 - h_2}{h_9 - h_3} = \frac{232.48 - 226.076}{2693.1 - 467.1} = 0.00287$

$Y_2 = 0.28\%$

h mass flow rate = (pg 558)

$W_{net} = \dot{m} w_{net} \rightarrow \dot{m} \frac{W_{net}}{w_{net}} = \frac{90000kw}{130.93} = 68.406$

$Q_L = \dot{m}(h_{10} - h_1) = 68.406(2697.8 - 225.94)$

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Summary: The turbine is doing work at a rate of 730 kJ/kg & puts out 3 out puts to be condensed & heated the system is able to be self sufficient and allows the steam to go through stages back to itself.

Analysis: Since the heat supplied to each system occurs & the work is 730, the system is able to operate. Also, the utilization factor is decent, so the system is able to regenerate the steam & work properly. In a real life scenario when designing a system based on the parts that you are given, this test/problem will be helpful to know where each piece should go to be effective.