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MET 350
Test 2

Purpose:

The purpose of this problem is to evaluate the performance & operational characteristics of a regenerative cycle steam power plant by calculating the utilization factor of the plant, which is a measure of efficiency, creating PV & T-S diagrams, determing the work produced by the turbine, calculating the mass flow rate of steam for a given power load, identifying all the states, and calculating mass fractions & the rate of heat removal in the condenser.

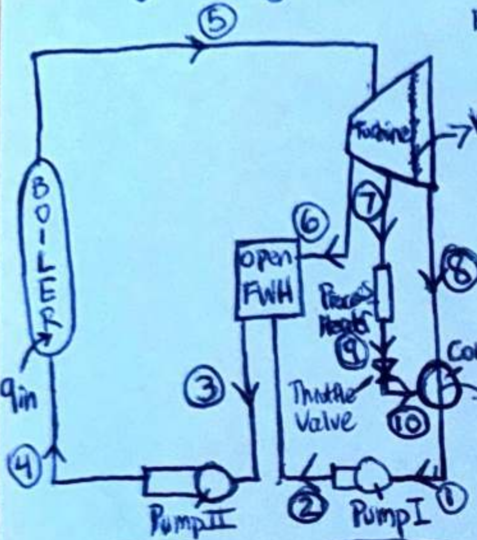
Sources:

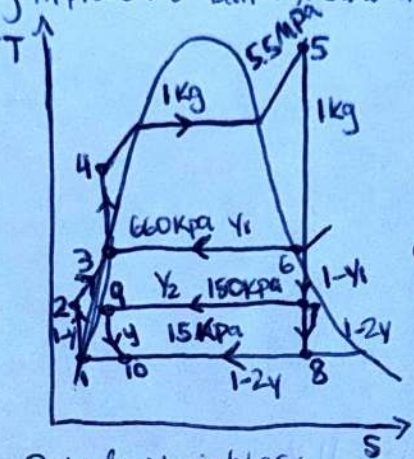
Cengel & Boles. "Thermodynamics - An Engineering Approach 8th Edition, McGraw Hill. 2015

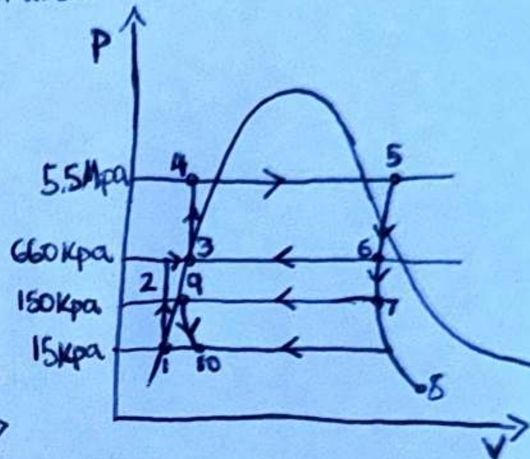
Material:

Steam

Drawing & Diagrams







Data & Variables:

(1)

$P_1 = 15\,kpa$

$h_1 = h_f @ 15\,kpa$

$h_1 = 225.94\,\frac{KJ}{kg}$

$V_1 = V_f = 0.001014\,\frac{m^3}{kg}$

(2)

$P_2 = 660\,kpa$

$h_2 = h_1 + W_{pump,in\,I}$

$h_2 = 0.225.94 + 0.65$

$h_2 = 226.59\,KJ/kg$

(3)

$P_3 = 660\,kpa$

$X_3 = 0$

$h_3 = 684.08 + \frac{697 - 684.08}{700 - 650}(660 - 650)$

$h_3 = 686.66\,KJ/kg$

$V_3 = 0.001104 + \frac{0.001108 - 0.001104}{700 - 650}(660 - 650)$

$V_3 = 0.0011048\,m^3/kg$

(4)

$W_{pump,in\,II} = V_3(P_4 - P_3)$

$= 0.0011048(5500 - 660)$

$= 5.35\,KJ/kg$

$h_4 = h_3 + W_{pump,in\,II}$

$= 686.66 + 5.35$

$= 692.01\,KJ/kg$

(5)

$P_5 = 5.5\,Mpa$

$T_5 = 500°C$

$h_5 = 3428.9\,KJ/kg$

$S_5 = 6.93035\,\frac{KJ}{kg\,K}$

(6)

$S_6 = S_5 = 6.93035\,\frac{KJ}{kg\,K}$

$P_6 = 660\,kpa$

From superheated tables:

$h_6 = 2853\,KJ/kg$

(7)

$S_7 = S_6 = 6.9305\,\frac{KJ}{kg\,K}$

$P_7 = 150\,kpa$

@ $P_7 = 150\,kpa$

$S_7 = S_f + X_7 \cdot S_{fg}$

$6.93035 = 1.4337 + X_7 \cdot 5.7894$

$X_7 = 0.9494$

$h_7 = h_f + x_7 \cdot h_{fg}$

$467.13 + 0.9494 \cdot 2226$

$h_7 = 2580.57\,KJ/kg$

(8)

$S_8 = S_6 = 6.93035\,\frac{KJ}{kg\,K}$

$P_8 = 15\,kpa$

@ $P_8 = 15\,kpa$

$S_8 = S_f + X_8 \cdot S_{fg}$

$6.93035 = 0.7549 + X_8 \cdot 7.2522$

$X_8 = 0.85$

$h_8 = h_f + x_8 \cdot h_{fg}$

$225.94 + 0.85 \cdot 2372.3$

$h_8 = 2246.02\,KJ/kg$

(9)

$P_9 = 150\,kpa$

$X_9 = 0$

$h_9 = h_f @ 150\,kpa$

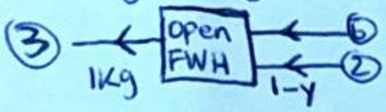
$h_9 = 467.13\,KJ/kg$

(10)

$h_{10} = h_9$ (throttling)

$h_{10} = 467.13\,KJ/kg$

Applying energy balance to feedwater heater:



$y_1 = y_2 = y$

$y h_6 + (1-y) h_2 = 1 \cdot h_3$

$y \cdot 2853 + (1-y) 226.59 = 686.66$

$2626.41 y = 460.07$

$y = 0.1752$

$\boxed{y_1 = y_2 = 0.1752}$

d) Work input to pumps =

$= (1-y)\, W_{pump,in\,I} + W_{pump,in\,II}$

$W_{in} = (1-0.1752) \cdot 0.65 + 5.35$

$W_{in} = 5.886$ kJ/kg

Net work output $= \dot{m}(W_{out} - W_{in})$

$5000 = \dot{m}(837.92 - 5.886)$

$\boxed{\dot{m} = 60.09 \text{ kg/s}}$

a) process heat $(\dot{Q}_p) = \dot{m}(y(h_7 - h_9))$

$\dot{Q}_p = 60.09 \cdot 0.1752 \cdot (2580.57 - 467.13)$

$\dot{Q}_p = 22249.806$ KW

Utilization factor $(\varepsilon_u) = \dfrac{\dot{W}_{net} + \dot{Q}_p}{Q_{in}}$

$= \dfrac{50000 + 22249.806}{164459.72}$

$\boxed{\varepsilon_u = 0.4393}$

c) Turbine work per kg (W_{out}) =

$= 1 \cdot (h_5 - h_6) + (1-y)(h_6 - h_7) + (1-2y)(h_7 - h_8)$

$W_{out} = (3428.9 - 2853) + (1-0.1752)(2853 - 2580.57) +$

$(1 - 2 \cdot 0.1752)(2580.57 - 2246.02) =$

$= 395.9 + 224.7 + 217.32$

$\boxed{W_{out} = 837.92 \text{ kJ/kg}}$

e) Heat supplied to the working areas $(Q_{in}) = \dot{m}(h_5 - h_4)$

$Q_{in} = 60.09(3428.9 - 692.01)$

$\boxed{Q_{in} = 164459.72 \text{ KW}}$

h) Rate of heat removed in the condenser:

$Q_{out} = \dot{m}(y h_{10} + (1-2y) h_8 - (1-y) h_1)$

$Q_{out} = 60.09(0.1752 \cdot 467.13 + (1 - 2 \cdot 0.1752)(2246.02) -$

$(1-0.1752)(225.94)$

$= 60.09(81.84 + 1459.01 - 186.355)$

$\boxed{Q_{out} = 81391.58 \text{ KW}}$

Analysis:

The plant would likely display high efficiency in both power generation and space heating. The utilization factor indicates the proportion of the heat added that is converted to work, which, in an ideal cycle, should be high. The heat supplied for space heating would be effictively utilized, suggesting good coregeneration capability.

Design Considerations:

- The system operates on a regenerative cycle, which improves efficiency by preheating the feedwater before it enters the boiler
- The problem states $y_2 = y_1$, which suggests that the system is designed to use equal fractions of steam for feedwater heating & space heating
- The pumps & turbines are assumed to be isentropic
- The system is assumed to have perfect insulation w/ no heat losses to the surroundings