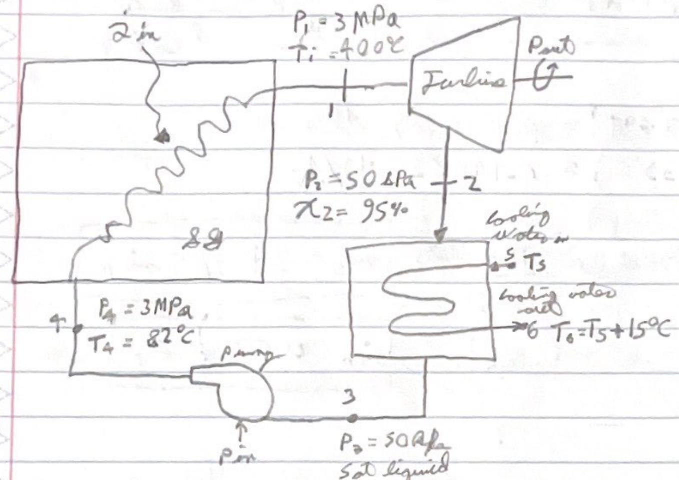
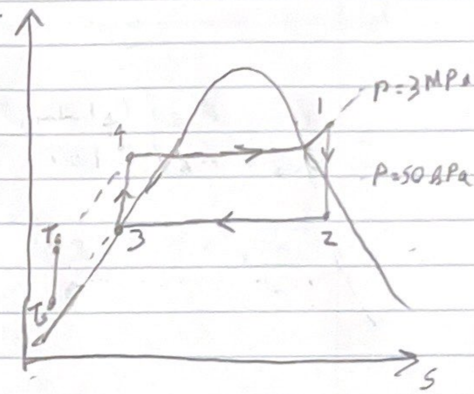
HW#5

1) wt heat sink @ NTP. assume energy loss, KE, & PE are ≈0. find (a) thermal effeciency, (b) mass flow rate of cooling water.





a) $\eta = \frac{\dot{W}_T - \dot{W}_P}{\dot{Q}} = \frac{\dot{m}_P(h_1 - h_2) - \dot{m}_P(h_4 - h_3)}{\dot{m}_P(h_1 - h_4)} = \frac{h_1 + h_3 - h_2 - h_4}{h_1 - h_4}$

$h_4 = h_f(P = 3\text{MPa}, T = 82°C) = 0.34575$ MJ/kg

$h_1 = h_g(P = 3\text{MPa}, T = 400°C) = 3.2317$ MJ/kg

$h_3 = h_{f,sat}(P = 0.05\text{MPa}, T = T_{sat} = 81.317°C) = .34054$ MJ/kg

$h_2 = h_f + x_2(h_g - h_f) = (0.34054) + 0.95(2.6452 - .34054) = 2.529967$ MJ/kg

$\eta = \frac{h_1 + h_3 - h_2 - h_4}{h_1 - h_4} = \boxed{0.24134 = 24.134\% = \eta}$

CV around secondary loop
& points 2&3

HW #5 - cont

b) find $\dot{m}_a$, $\frac{d}{dt}\int_{cv} \rho e \, dV = \sum \dot{Q} - \sum \dot{W} + \sum_i \dot{m}_i h_i \Rightarrow 0 = \sum_i \dot{m}_i h_i$

0, SS   0, no $\dot{Q}_{in}$ 0, no $\dot{W}_{in}$ neglect KE PE

$\Rightarrow \dot{m}_s (h_5 - h_6) + \dot{m}_p (h_2 - h_3) = 0 \Rightarrow \frac{\dot{m}_p}{\dot{m}_s} = \frac{h_6 - h_5}{h_2 - h_3}$

$h_5 = h_f(P = 1\,atm, T = 20°C) = 0.084007$ MJ/kg
$h_6 = h_f(P = 1\,atm, T = 35°C) = 0.14662$ MJ/kg

$\frac{\dot{m}_p}{\dot{m}_s} = 0.0286 \Rightarrow \dot{m}_s = \frac{\dot{m}_p}{0.0286} \Rightarrow \boxed{\dot{m}_s = 34.965\, \dot{m}_p}$

$\boxed{\dot{m}_p = 0.0286\, \dot{m}_s}$

$\eta_P = \frac{h_{in} - h_{out,is}}{h_{in} - h_{out}}$ $\eta_T = \frac{h_{in} - h_{out}}{h_{in} - h_{out,is}}$

HW #5 - cont

6-2) producing saturated or superheated steam @ 293°C = 566 K
condensing steam is 33°C

1) $\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}}$

$\boxed{\text{all results tabulated @ the end}}$

for first graph: $\dot{Q}_{in} = \dot{m}(h_1 - h_4)$

$\dot{W}_{net} = \dot{W}_T - \dot{W}_P$ $\dot{W}_T = \dot{m}(h_1 - h_2)$
$\dot{W}_P = \dot{m}(h_{3'} - h_3)$

$\Rightarrow \eta_{th} = \frac{\dot{m}(h_1 - h_2) - \dot{m}(h_{3'} - h_3)}{\dot{m}(h_1 - h_{3'})} = \frac{(h_1 - h_2) - (h_{3'} - h_3)}{(h_1 - h_{3'})} = \underline{0.38175}$

- use NIST for data

point 4) saturated liquid, $P_4 = 7.7725$ MPa, $T_4 = 293°C$
$h_4 = 1{,}306.3$ kJ/kg

point 1) sat vapor, $P_1 = P_4 = 7.7725$ MPa, $T_4 = 293°C$
$h_1 = 2762.0$ kJ/kg, $s_1 = 5.7605$ J/g·K

point 3) sat liquid, $P_3 = 0.0050354$ MPa, $T_3 = 33°C$
$h_3 = 138.27$ kJ/kg, $s_3 = 0.47782$ J/g·K

point 2) mixed, $s_2 = s_1 = 5.7605$ J/g·K, $P_2 = P_3 = 0.0050354$ MPa

$\Rightarrow h_g = 2561$ kJ/kg, $s_g = 8.3913$ J/gK
$h_f = h_3 = 138.27$ kJ/kg

$x = \frac{(s_2 - s_f)}{s_g - s_f} = 0.66755 \Rightarrow h_2 = h_3 + x(h_v - h_3) = 1755.575$ kJ/kg

HW#5-cont

point 3') $P_{3'} = P_4$, $s_{3'} = s_1$, $h_{3'} = 146.04$ kJ/kg

$$\eta_{th} = \frac{(h_1 - h_2) - (h_{3'} - h_3)}{h_1 - h_{3'}} = 0.38176$$

~~the~~ steam rate is $\frac{3600}{\dot{W}} = \frac{3600}{(h_1 - h_2) - (h_{3'} - h_3)} = 3.60485 \frac{kg\ steam}{kWe\text{-}h}$

graph 2 use pyXSteam for data

point 4) $T_1 = 293\,°C$, $h_4 = 1305.259$ kJ/kg , $s_1 = 3.1874$ kJ/kg·K

point 1) $T_1 = 293°C$, $h_1 = 2762.192$ kJ/kg , $s_1 = 5.7615$ kJ/kg·K

~~point~~ 3) $T_3 = 33°C$, $h_3 = 967.374$ kJ/kg , $s_3 = 3.1874$ kJ/kg·K
$x_3 = 0.34242$

point 2) $T_2 = T_3$, $h_2 = 1755.04311$ kJ/kg , $s_2 = s_1$, $x_2 = 0.66749$

$\left.\begin{array}{l} s_{f,sat}(T_2) \\ s_{g,sat}(T_2) \end{array}\right\}$ from pyXSteam $s_{fg} = s_g - s_f$

$\left.\begin{array}{l} h_{f,sat}(T_2) \\ h_{g,sat}(T_2) \end{array}\right\}$ from pyXSteam $h_{fg} = h_g - h_f$

$x_2 = \frac{s_2 - s_f}{s_{fg}}$, $x_3 = \frac{s_3 - s_f}{s_{fg}}$, $h_2 = h_f + x_2 h_{fg}$
$h_3 = h_f + x_3 h_{fg}$

η

$\eta_{th} = 0.45936$

steam gen rate $= \frac{3600}{\dot{W}} = \frac{3600}{(h_1 - h_2) - (h_4 - h_3)} = 5.37904 \frac{kg\ steam}{kWe\text{-}h}$

HW#5 - cont

graph 3 data from pyXSteam

p4) $p_4 = 5\ MPa$, $h_4 = 1154.502\ kJ/kg$

p5) $P_5 = P_4$, $h_5 = 2794.227\ kJ/kg$

p1) $P_1 = P_4$, $T_1 = 293°C$, $h_1 = 2902.507\ kJ/kg$, $s_1 = 6.1703\ J/g \cdot K$

p3) $T_3 = 33°C$, $h_3 = 137.6525\ kJ/kg$, $s_3 = 0.4759\ J/g \cdot K$

p2) $s_f = s_3$, $s_g = s_{g,sat}(T = 33°C)$, $s_{fg} = s_g - s_f$
$h_f = h_3$, $h_g = h_{g,sat}(T = 33°C)$, $h_{fg} = h_f - h_g$

$s_2 = s_1$, $x_2 = \dfrac{s_2 - s_f}{s_{fg}} = 0.71912$ $h_2 = h_f + x_2 h_{fg} = 1880.14714\ kJ/kg$

p3') $P_{3'} = P_4$, $s_{3'} = s_3$, $h_{3'} = 142.66288\ kJ/kg$

$\eta_{th} = \dfrac{\dot{W}_{net}}{\dot{Q}_{in}} = \dfrac{(h_1 - h_2) - (h_{3'} - h_3)}{h_1 - h_{3'}} = 0.368627$

steam gen rate $= \dfrac{3600}{\dot{W}} = \dfrac{3600}{(h_1 - h_2) - (h_{3'} - h_4)} = 3.53858\ \dfrac{kg\ steam}{kWe\ hr}$

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part a answers

graph	η_{th}	steam gen rate $\boxed{\frac{kg\ steam}{kWe \cdot hr}}$
1	0.38175	3.60484
2	0.45936	5.37904
3	0.36862	3.53858

HW# 5-cont

b) $\eta_c = 1 - \frac{T_c}{T_H} = \frac{33+273}{293+273} = \underline{45.936\%}$

all cycles have the same carnot efficiency. cycle 2 has the carnot efficiency & is the most efficient

c) the heat added is the difference in h, so

cycle	Q added [kJ/kg] 3'→4	4→1
1	1160.26	1455.70
2	—	1456.93
3	1016.84	1748.00

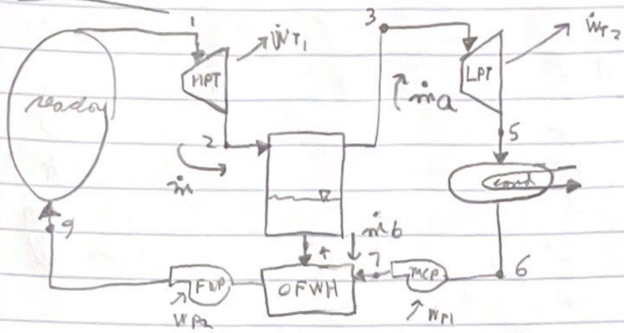
d) cycle 1 has the advantage of a moderately high steam gen rate & η_{th}, but is not physical as the outlet temp is saturated steam

cycle 2 has the best η_{th} & steam generation rate, but is not real as it is a carnot cycle

cycle 3 is the best choice as it is the most realistic, versatile & allows the most work done by the turbine, but is also the least efficient.

$$\eta_p = \frac{h_{in} - h_{out,s}}{h_{in} - h_{out}} \qquad \eta_T = \frac{h_{in} - h_{out}}{h_{in} - h_{out,s}}$$

HW #5



a) know $\eta_{th} = \dfrac{\dot{W}_{T_1} + \dot{W}_{T_2} - \dot{W}_{P_1} - \dot{W}_{P_2}}{\dot{q}_{in}}$ $\qquad \eta_p = 0.85$, $\eta_T = 0.90$

w/ $\dot{W}_{T_1} = \eta_T \,(h_1 - h_{2s})$ $\qquad \dot{W}_{T_2} = \eta_T \,(h_3 - h_{5s})$

$\dot{W}_{P_1} = \dfrac{(h_{7s} - h_6)}{\eta_p}$ $\qquad \dot{W}_{P_2} = \dfrac{(h_{9s} - h_6)}{\eta_p}$

$\dot{q}_{in} = h_1 - h_9$

next, we find the relationship b/w $\dot{m}_a, \dot{m}_b$ & $\dot{m}$

know moisture $\therefore \dot{m}_a = x_2 \dot{m}$ & $\dot{m}_b = (1 - x_2)\dot{m}$
separator does no work

$\Rightarrow$ use heater as CV & do conservation of energy

$$\underbrace{\frac{d}{dt}\int_{CV} \rho e \, dV}_{0,\ SS} = \underbrace{\sum \dot{Q}}_{0} - \underbrace{\sum \dot{W}}_{0,\text{ no work / heating}} + \sum_i \dot{m}_i \underbrace{h^{\circ}}_{\text{, too small}}$$

$\hookrightarrow 0 = \dot{m} h_8 - \dot{m}_a h_7 - \dot{m}_b h_4 \Rightarrow h_8 = \dfrac{\dot{m}_a h_7 + \dot{m}_b h_4}{\dot{m}}$

sub in $\dot{m}_a, \dot{m}_b$ $\Rightarrow h_8 = \dfrac{\dot{m} x_2 h_7 + (1 - x_2)\dot{m} h_4}{\dot{m}} = x_2 h_7 + h_4 - x_2 h_4$

$h_7 = h_6 - \dot{W}_{P_1} \Rightarrow h_8 = (1 - x_2) h_4 + x_2 (h_6 - \dot{W}_{P_1})$

$\Rightarrow$

HW#5-cont

know $h_9 = h_8 - \dot{W}_{P2}$, so find in pyXSteam

$\Rightarrow$ $\left.\begin{aligned} \dot{W}_{T_1} &= 260.495 \\ \dot{W}_{T_2} &= 792.213 \\ \dot{W}_{P_1} &= 1.608 \\ \dot{W}_{P_2} &= 6.528 \end{aligned}\right\}$ kJ/kg

$\Rightarrow \boxed{\eta = 0.33911}$

b) set all efficiencies $\approx 1 \Rightarrow \boxed{\eta = 0.37802}$

all code can be found on

github.com/jspecht3/classes/tree/main/mpre449