Spring2024

ALEXANDRIA UNIVERSITY

جامعة الإسكندرية

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MEC212 Thermodynamics II

Alexandria University – FOE

Thermodynamics II Course Project

(1) In the preliminary design stage of a steam power plant that is working on reheat Rankine cycle, the following specifications are considered:

- The boiler pressure = 15 MPa
- The condenser pressure = 10 kPa
- The maximum temperature is 500 ºC
- The isentropic efficiency of all turbine sections is 0.85
- The isentropic efficiency of the pumps is 0.95

A. Plot the reheat pressure against the thermal efficiency and net work on the same graph to determine the optimum reheat pressure that maximizes the efficiency and the optimum reheat pressure that maximizes the net work.

B. In order to obtain a relation between the boiler pressure and its optimum reheat pressure, vary P_b from 120 to 210 bar to get the optimum reheat pressure for each P_b. Then Plot P_b against ratio $P_{r,opt}/P_b$.

The maximum obtainable efficiency of the previous plant was not adequate, in order to increase the plant efficiency, 5 proposals were investigated:

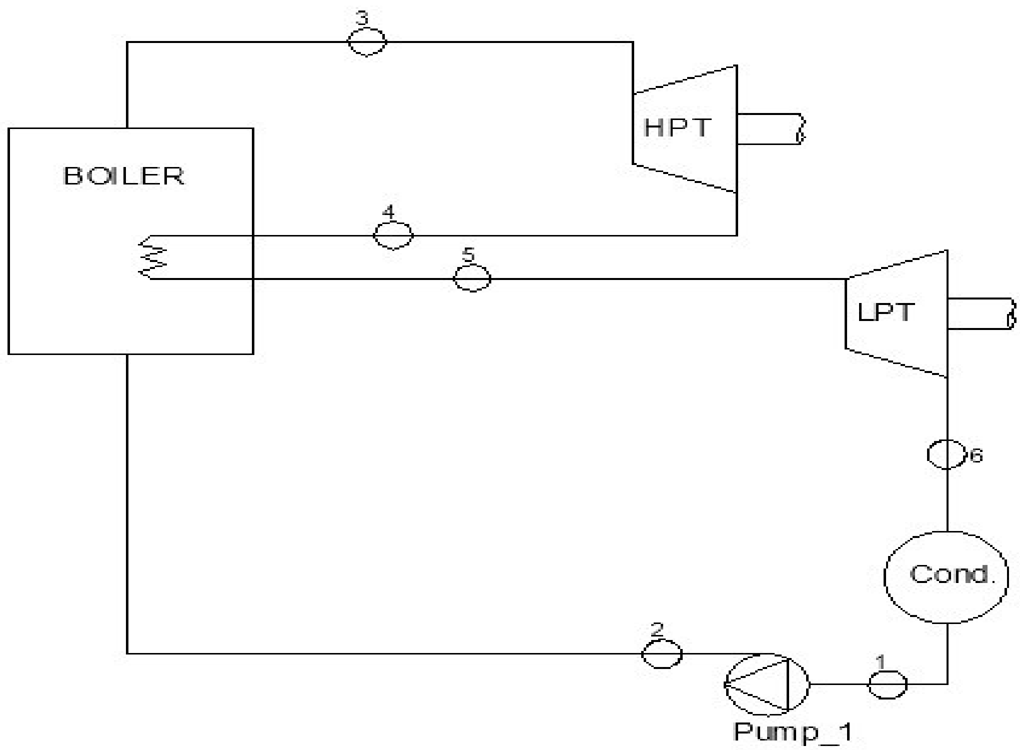
1) One OFWH was added to the reheat cycle.
2) One OFWH and one CFWH were added to the reheat cycle.
3) One OFWH and two CFWHs were added to the reheat cycle.
4) One OFWH and three CFWHs were added to the reheat cycle.
5) One OFWH and four CFWHs were added to the reheat cycle.

C. For the 1st proposal, use the reheat pressure that maximized the efficiency in **(1) A**, and plot the OFWH pressure (vary the pressure from P_c to P_b) against the thermal efficiency and the net work on the same graph to determine the optimum OFWH pressure that maximizes the efficiency and the pressure that maximizes the net work at that reheat pressure.

D. Determine the best layout for each of the aforementioned five proposals, and use EES or any other software to obtain the optimum operating pressures of the various components to maximize the efficiency, then plot the number of FWHs against the optimum efficiency.

E. Bonus (2 degrees) will be granted if you can approach the maximum number of feed water heaters considering the pressure drops (7 bars) in closed FWHs.

Requirement (A)



Flow Diagram

Givens:

$p_b = 150\ bar$, $p_c = 0.1\ bar$, $T_{Max} = 500°C$

$\eta_p = 0.95$, $\eta_T = 0.85$, $p_R = p_c \rightarrow p_b$

$\rightarrow h_1 = h_f \text{ @ } p_c$

$\rightarrow s_{2s} = \ s_1$

$h_{2s} \rightarrow (from\ steam\ chart)\ @P = p_b\ \&\ @S = (S_{2s} = S_1)$

$$\rightarrow \ \eta_p = \frac{h_{2s} - \ h_1}{h_2 - \ h_1} \rightarrow \ h_2 = \frac{h_{2s} - \ h_1}{\eta_p} + h_1$$

$\rightarrow h_3, s_3 \rightarrow (from\ steam\ chart)\ @P = p_b\ \&\ @T = T_{Max}$

$\rightarrow s_{4s} = \ s_3$

$\rightarrow h_{4s} \rightarrow (from\ steam\ chart)\ @P = p_R\ \&\ @\ S = (S_{4s} = S_3)$

$$\rightarrow \eta_T = \frac{h_3 - \ h_4}{h_3 - \ h_{4s}} \rightarrow \ h_4 = h_3 - \left(\eta_T \times (h_3 - \ h_{4s})\right)$$

$\rightarrow h_5, s_5 \rightarrow (from\ steam\ chart)\ @P = p_R\ \&\ @T = T_{Max}$

$\rightarrow s_{6s} = \ s_5$

$\rightarrow h_{6s} \rightarrow (from\ steam\ chart)\ @P = p_C\ \&\ @\ S = (S_{6s} = S_5)$

$$\rightarrow \eta_T = \frac{h_5 - \ h_6}{h_5 - \ h_{6s}} \rightarrow \ h_6 = h_5 - \left(\eta_T \times (h_5 - \ h_{6s})\right)$$

Requirements

$\rightarrow W_{Turbine} = (h_5 - h_6) + (h_3 - h_4)$

$\rightarrow W_{Pump} = (h_2 - h_1)$

$\rightarrow W_{Net} = W_{Turbine} - W_{Pump}$

$\rightarrow Q_{Add} = (h_3 - h_2) + (h_5 - h_4)$

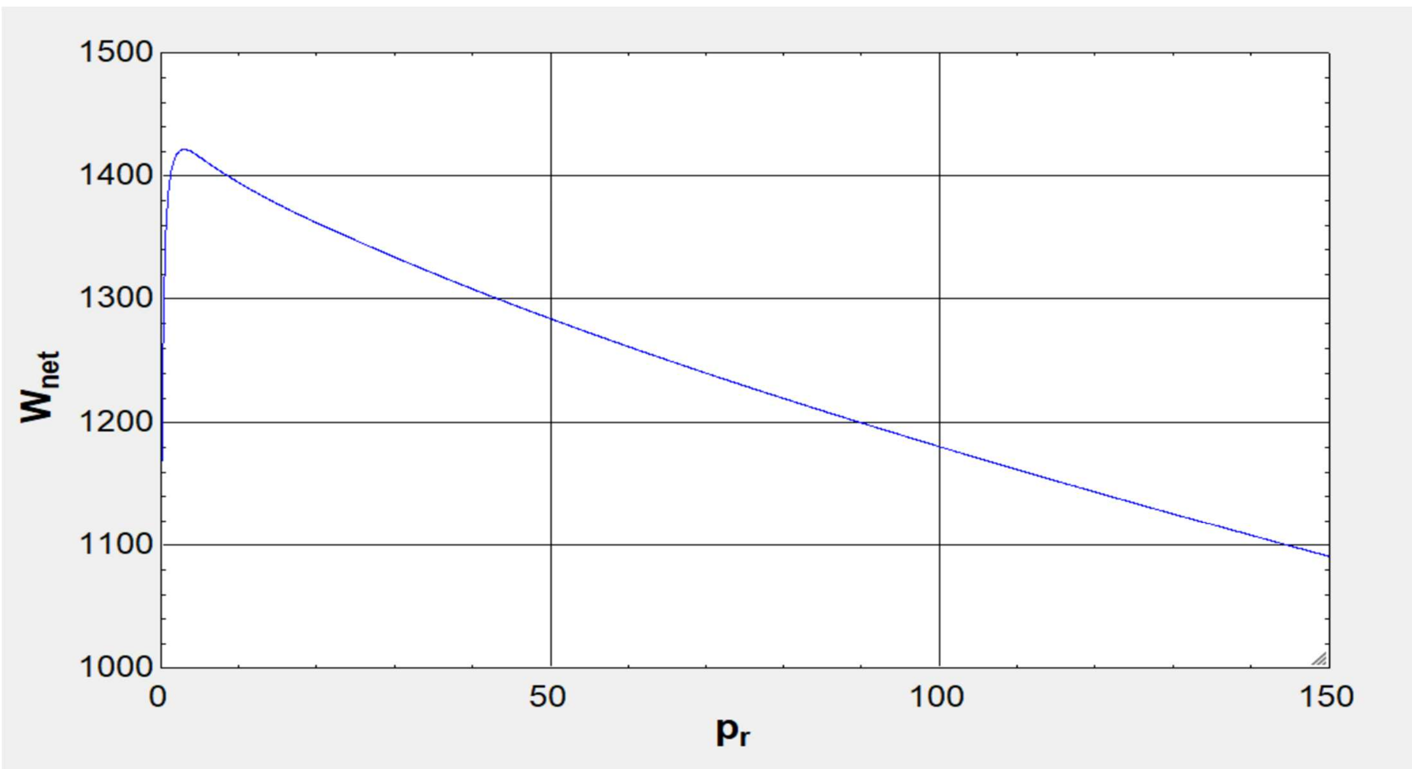
$$\eta_{th} = \frac{W_{Net}}{Q_{Add}}$$

Case (A)

Unit Settings: SI C bar kJ mass deg

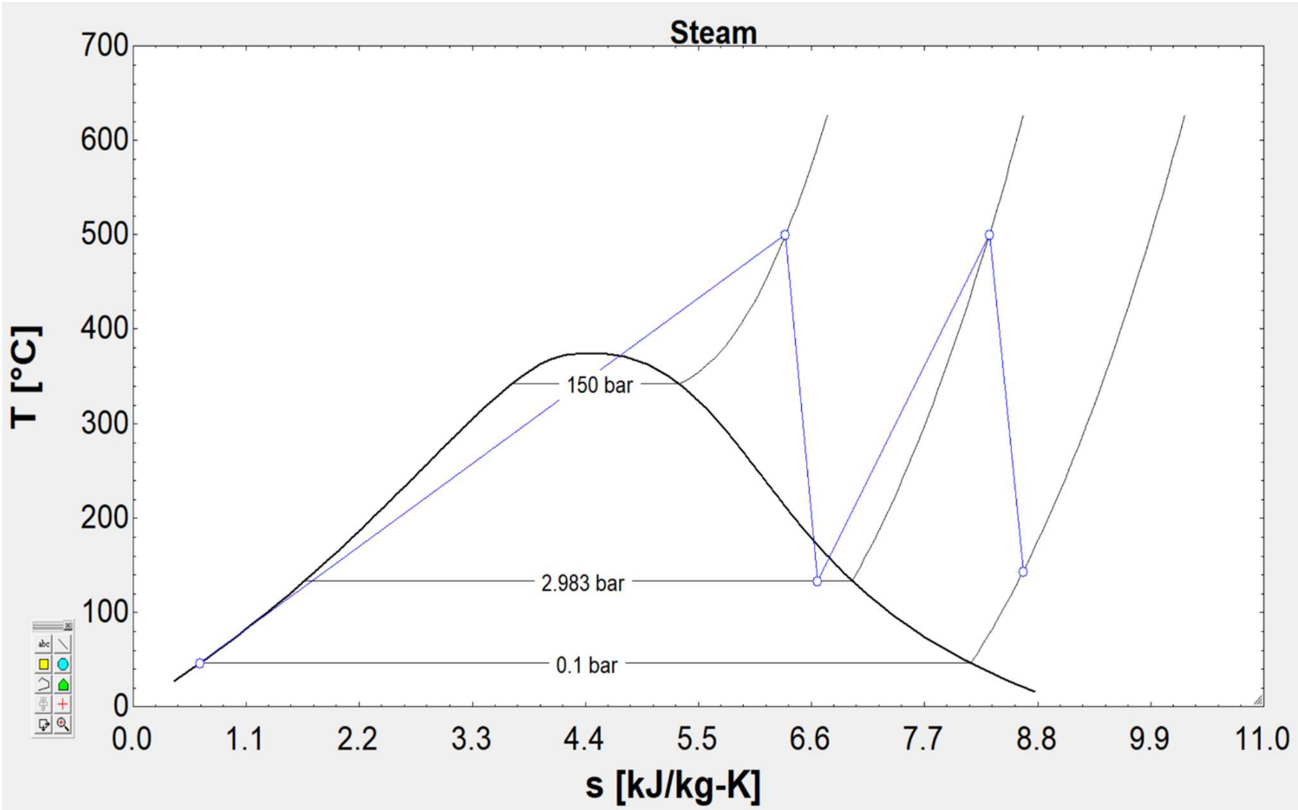
Maximization of W_net(p_r) = 1421   25 iterations: Quadratic Approximations method

efficiency = 0.3553	$efficiency_{pump}$ = 0.95	$efficiency_{turbine}$ = 0.85	h_1 = 191.8	h_2 = 207.6	h_{2s} = 206.8	h_3 = 3311
h_4 = 2589	h_{4s} = 2462	h_5 = 3487	h_6 = 2771	h_{6s} = 2644	p_b = 150 [bar]	p_c = 0.1 [bar]
p_r = 2.983	Q_{in} = 4000	Q_{out} = 2579	s_1 = 0.6492	s_2 = 0.6513	s_{2s} = 0.6489	s_3 = 6.348
s_4 = 6.661	s_{4s} = 6.348	s_5 = 8.33	s_6 = 8.66	s_{6s} = 8.33	T_1 = 45.8	T_2 = 46.47
T_{2s} = 46.28	T_3 = 500	T_4 = 133.3	T_{4s} = 133.3	T_5 = 500	T_6 = 143.6	T_{6s} = 77.39
T_{max} = 500 [c]	W_{net} = 1421					



The optimum $p_R = 2.983\ bar \ \rightarrow p_{R1}$

(for maximum W_{Net})

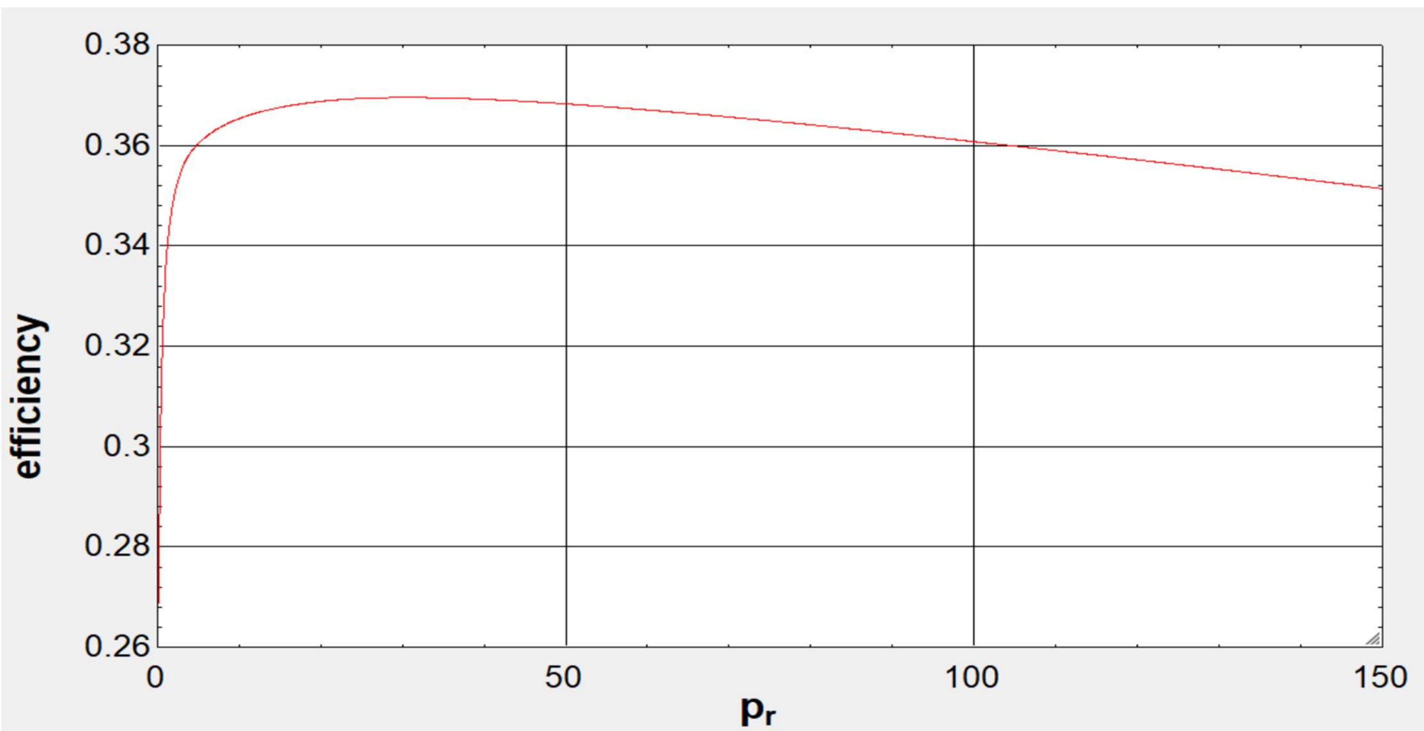

Steam
T [°C]
s [kJ/kg-K]
150 bar
2.983 bar
0.1 bar
0
100
200
300
400
500
600
700
0.0
1.1
2.2
3.3
4.4
5.5
6.6
7.7
8.8
9.9
11.0

Case (B)

Unit Settings: SI C bar kJ mass deg

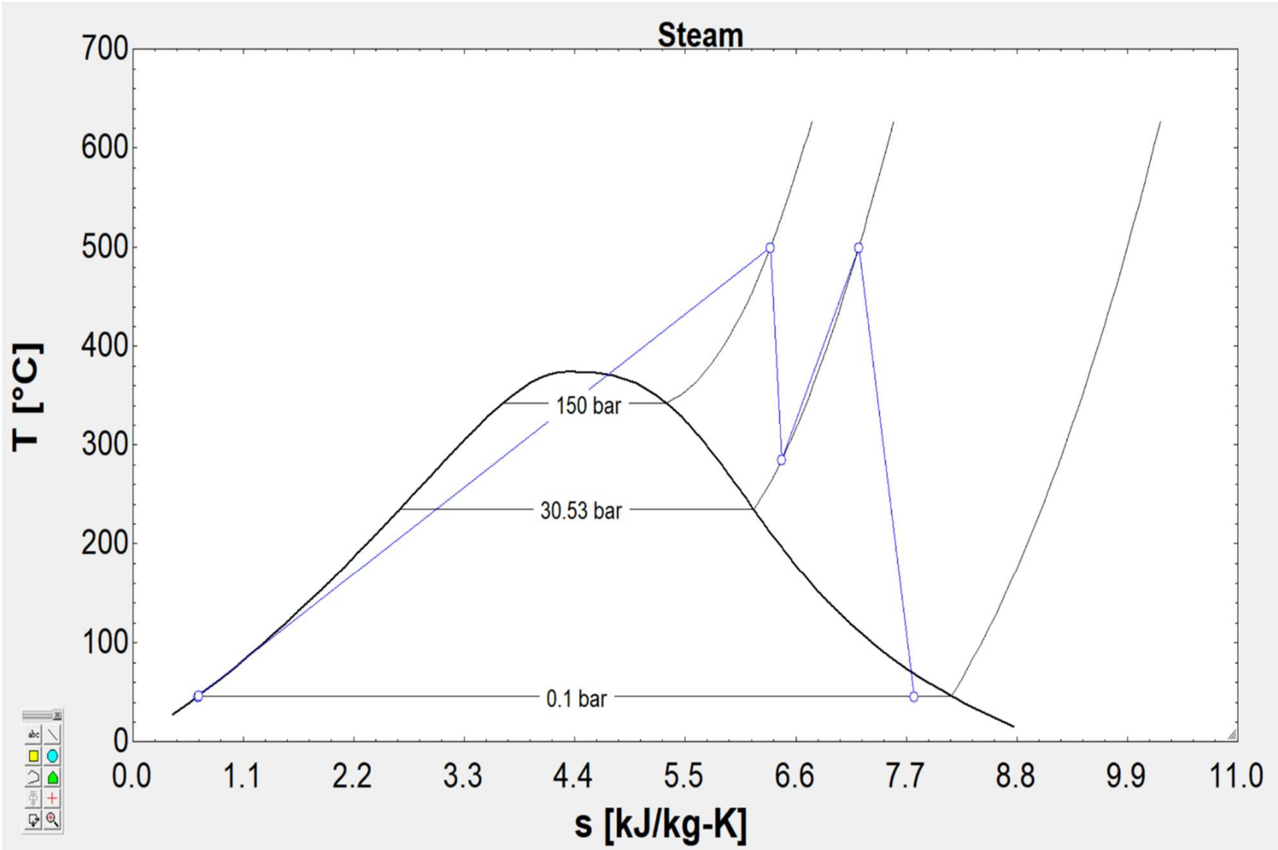
Maximization of efficiency(p_r) = 0.3695   21 iterations: Quadratic Approximations method

efficiency = 0.3695	$efficiency_{pump}$ = 0.95	$efficiency_{turbine}$ = 0.85	h_1 = 191.8	h_2 = 207.6	h_{2s} = 206.8	h_3 = 3311
h_4 = 2954	h_{4s} = 2891	h_5 = 3457	h_6 = 2465	h_{6s} = 2290	p_b = 150 [bar]	p_c = 0.1 [bar]
p_r = 30.53	Q_{in} = 3606	Q_{out} = 2273	s_1 = 0.6492	s_2 = 0.6513	s_{2s} = 0.6489	s_3 = 6.348
s_4 = 6.463	s_{4s} = 6.348	s_5 = 7.227	s_6 = 7.776	s_{6s} = 7.227	T_1 = 45.8	T_2 = 46.47
T_{2s} = 46.28	T_3 = 500	T_4 = 285.2	T_{4s} = 262.5	T_5 = 500	T_6 = 45.81	T_{6s} = 45.81
T_{max} = 500 [c]	W_{net} = 1332					

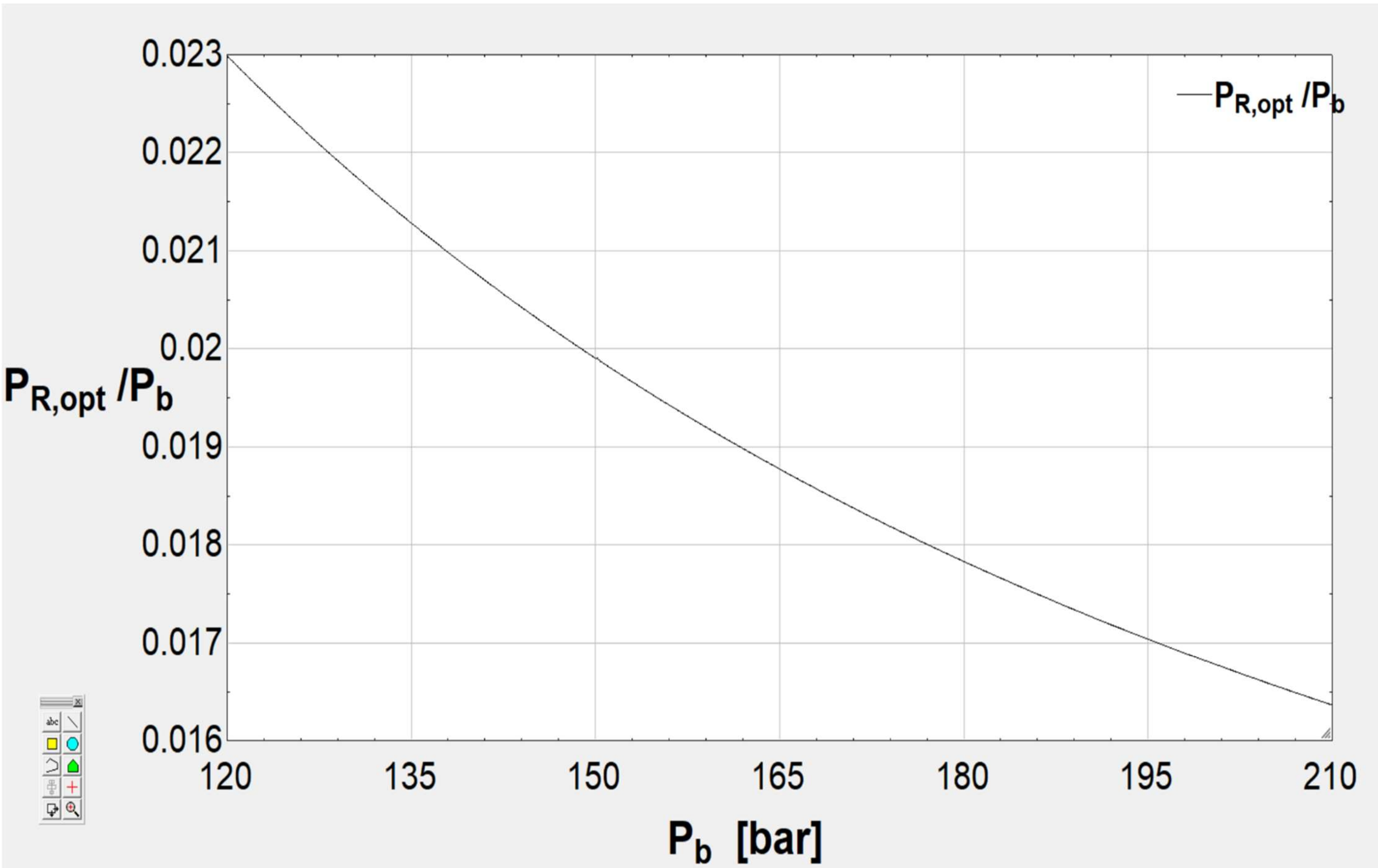


The optimum $p_R = 30.53\ bar \rightarrow p_{R2}$

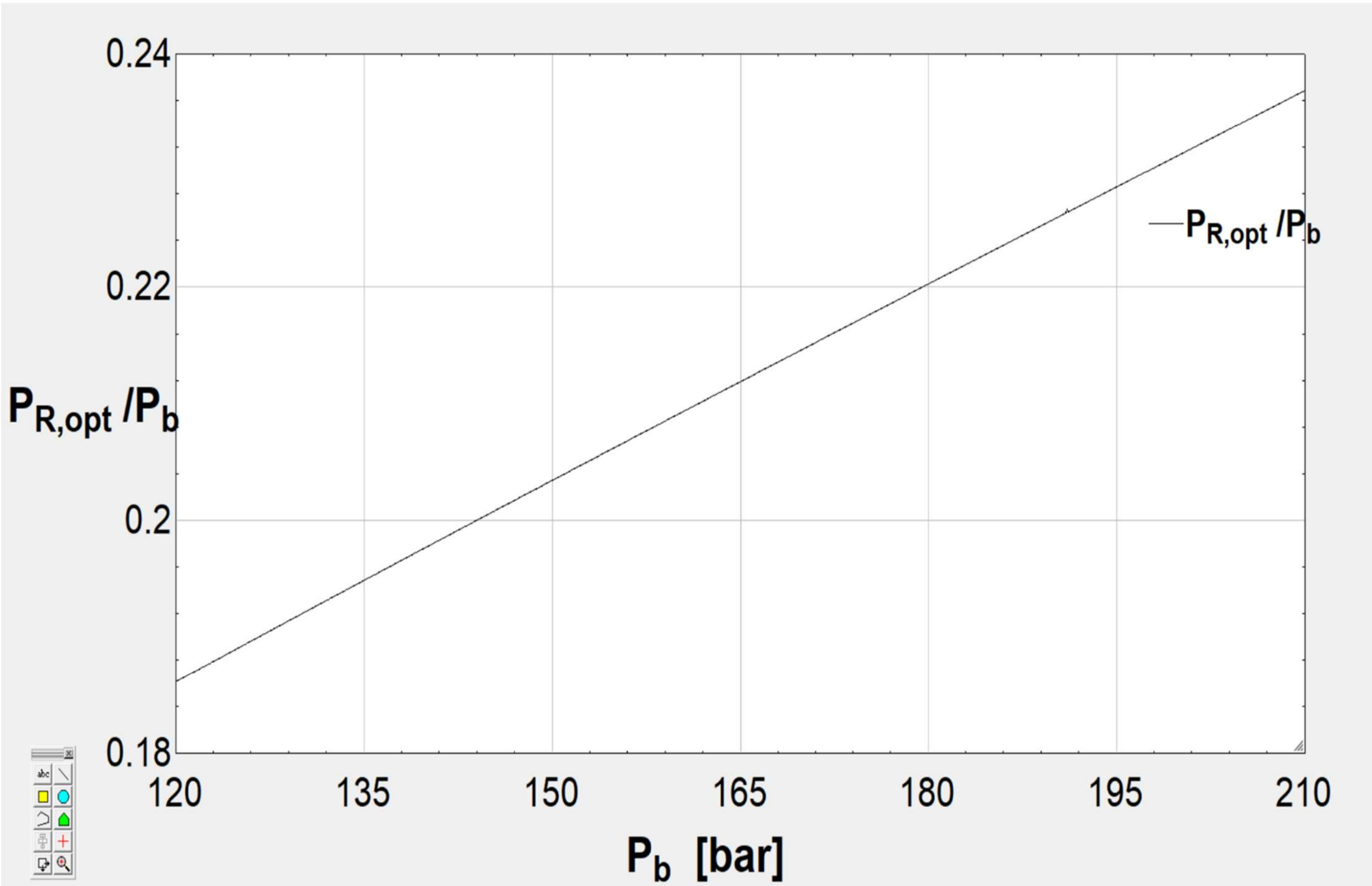
(for maximum efficiency)


Steam
T [°C]
s [kJ/kg-K]
150 bar
30.53 bar
0.1 bar
0
100
200
300
400
500
600
700
0.0
1.1
2.2
3.3
4.4
5.5
6.6
7.7
8.8
9.9
11.0

Requirement (B)

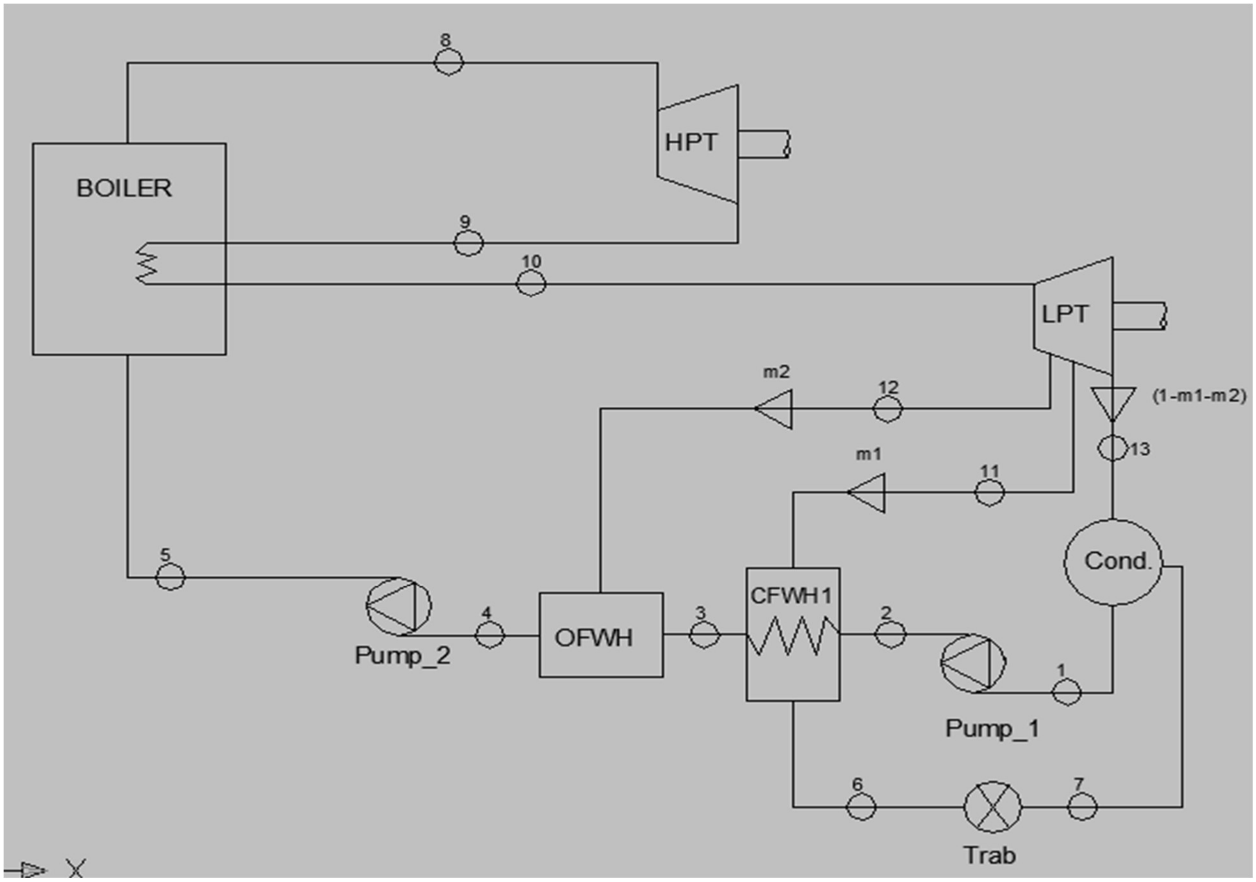


The relation according to maximum Work Net



The relation according to maximum Efficiency

Requirement (C)



First $P_{OFWH} < P_{Reheater}$

h_1 *from table 2 at* $P_{Condenser}$ *at saturated point*

$S_1 = S_f \text{ at } P_C$

h_{2s} *from steam chart at* P_{OFWH} *and* S_1

$$h_2 = \frac{h_{2s} - h_1}{0.95} + h_1$$

h_3 *from table 2 at* P_{OFWH} *at saturated point*

$S_3 = S_f \text{ at } P_{OFWH}$

h_{4s} *from steam chart at* P_{Boiler} *and* S_3

$$h_4 = \frac{h_{4s} - h_3}{0.95} + h_3$$

h_5 *from steam chart at* P_{Boiler} *and* T_{max}

S_5 *from steam chart at* P_{Boiler} *and* T_{max}

h_{6s} *from steam chart at* $P_{Reheater}$ *and* S_5

$$h_6 = -(((h_5 - h_{6s}) \times 0.85) - h_5)$$

h_7 *from steam chart at* $P_{Reheater}$ *and* T_{max}

S_7 *from steam chart at* $P_{Reheater}$ *and* T_{max}

h_{8s} *from steam chart at* P_{OFWH} *and* S_7

$$h_8 = -(((h_7 - h_{8s}) \times 0.85) - h_7)$$

S_8 *from steam chart at* P_{OFWH} *and* h_8

h_{9s} *from steam chart at* $P_{Condenser}$ *and* S_8

$$h_9 = -(((h_8 - h_{9s}) \times 0.85) - h_8)$$

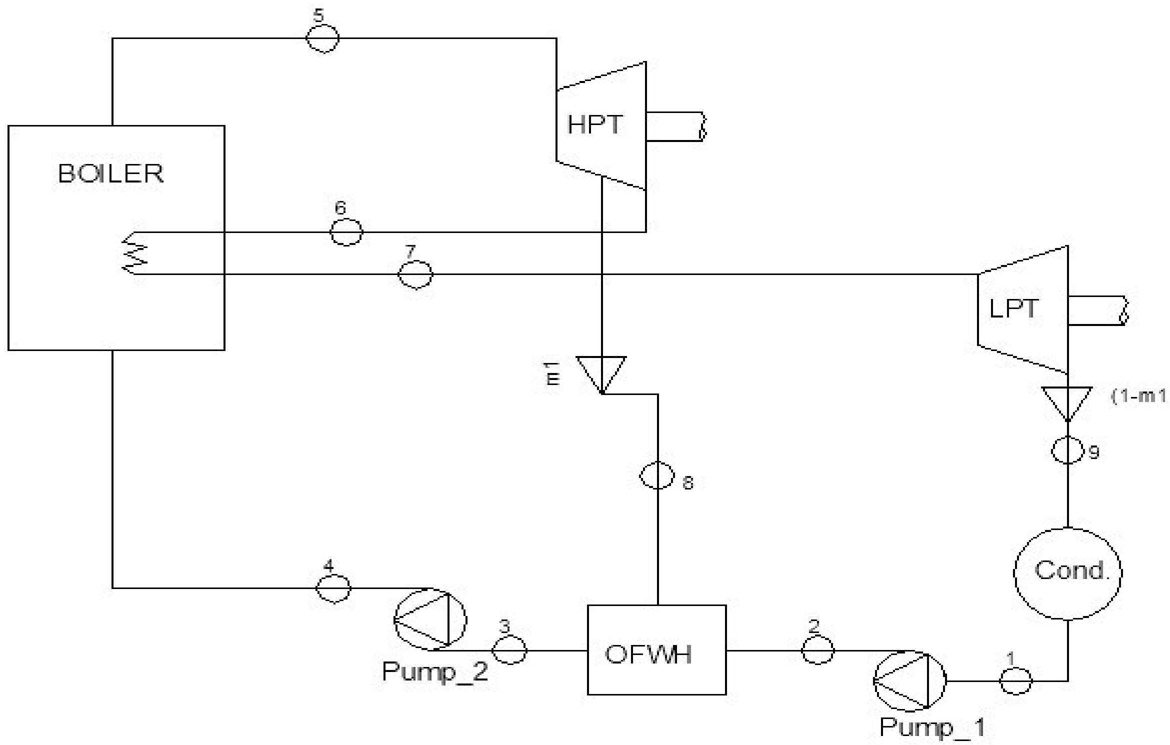
$$x = \frac{h_3 - h_2}{h_8 - h_2}$$

$$q_{Reject} = (1 - x) \times (h_9 - h_1)$$

$$q_{in} = (h_5 - h_4) \times (h_7 - h_6)$$

$$W_{net} = \left(q_{in} - q_{Reject}\right)$$

Thermal efficiency = $1 - \frac{q_{Reject}}{q_{in}}$



second $P_{OFWH} > P_{Reheater}$

h_1 *from table 2 at* $P_{Condenser}$ *at saturated point*

$S_1 = S_f$ *at* P_C

h_{2s} *from steam chart at* P_{OFWH} *and* S_1

$$h_2 = \frac{h_{2s} - h_1}{0.95} + h_1$$

h_3 *from table 2 at* P_{OFWH} *at saturated point*

$S_3 = S_f$ *at* P_{OFWH}

h_{4s} *from steam chart at* P_{Boiler} *and* S_3

$$h_4 = \frac{h_{4s} - h_3}{0.95} + h_3$$

$h_5\ from\ steam\ chart\ at\ P_{Boiler}\ and\ T_{max}$

$S_5\ from\ steam\ chart\ at\ P_{Boiler}\ and\ T_{max}$

$h_{6s}\ from\ steam\ chart\ at\ P_{OFWH}\ and\ S_5$

$h_6 = -(((h_5 - h_{6s}) \times 0.85) - h_5)$

$S_6 from\ steam\ chart\ at\ P_{OFWH}\ and\ h_6$

$h_{7s}\ from\ steam\ chart\ at\ P_{Reheater}\ and\ S_6$

$h_7 = -(((h_6 - h_{7s}) \times 0.85) - h_6)$

$h_8\ from\ steam\ chart\ at\ P_{Reheater}\ and\ T_{max}$

$S_8\ from\ steam\ chart\ at\ P_{Reheater}\ and\ T_{max}$

$h_{9s}\ from\ steam\ chart\ at\ P_{Condenser}\ and\ S_8$

$h_9 = -(((h_8 - h_{9s}) \times 0.85) - h_8)$

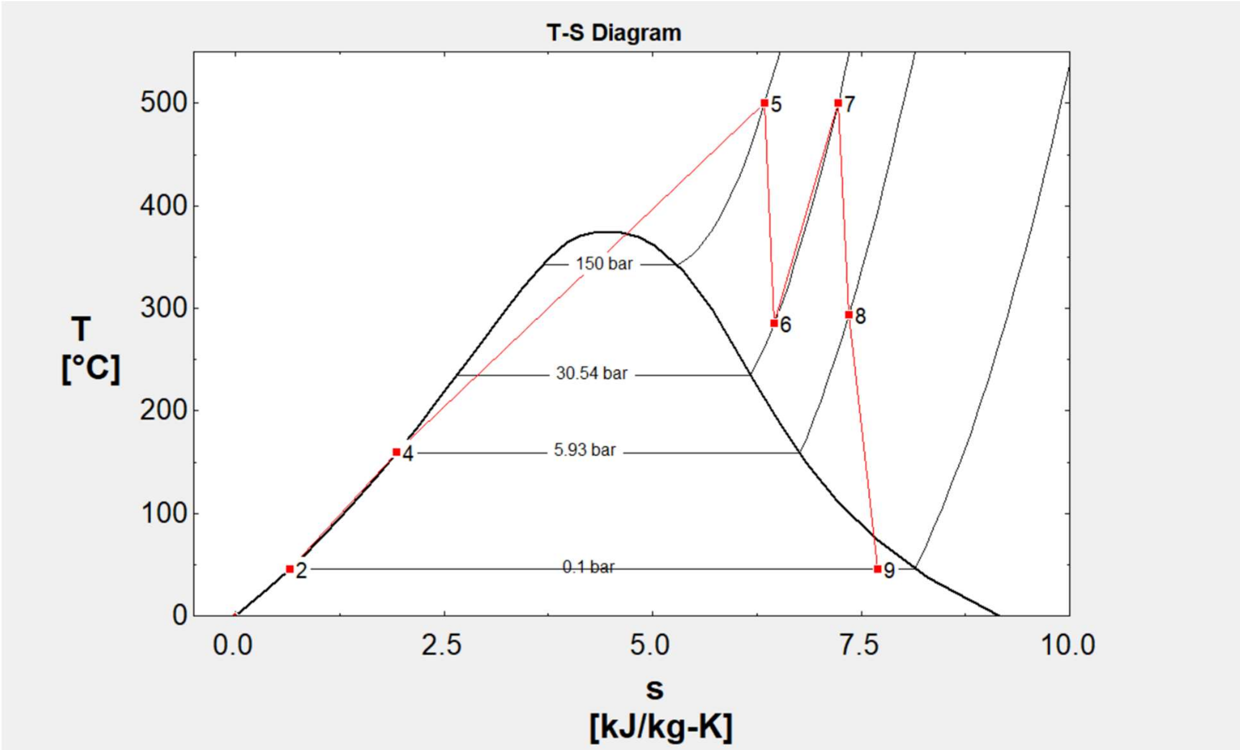
$$x = \frac{h_3 - h_2}{h_6 - h_2}$$

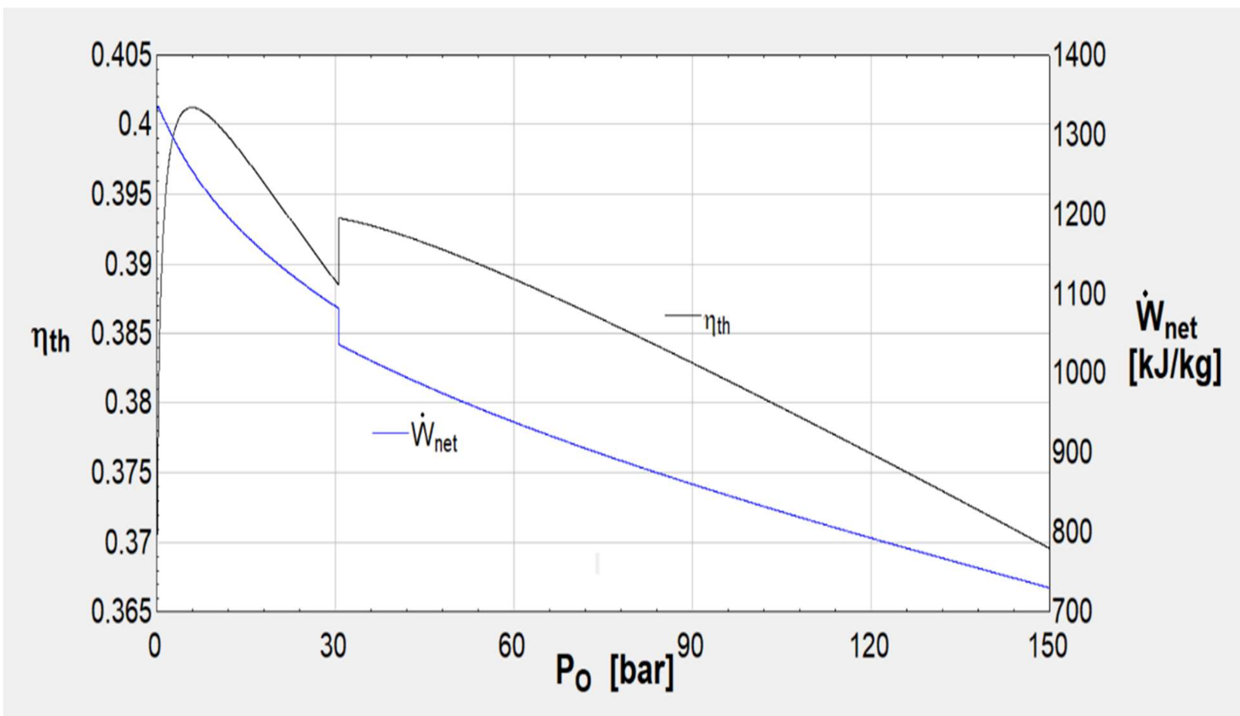
$q_{Reject} = (1 - x) \times (h_9 - h_1)$

$q_{in} = (h_5 - h_4) + ((1 - x) \times (h_7 - h_6))$

$W_{net} = \left(q_{in} - q_{Reject}\right)$

Thermal efficiency = $1 - \frac{q_{Reject}}{q_{in}}$





Maximization of eta_th(P_O) 23 iterations: Quadratic Approximations method

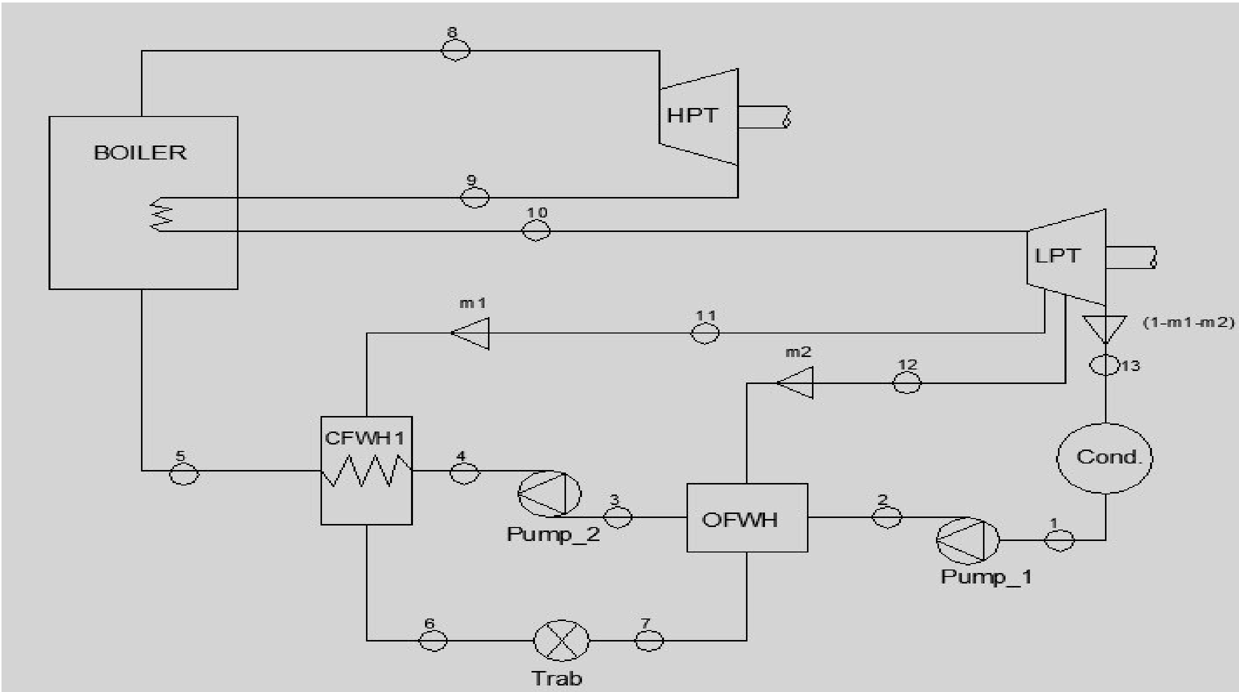
η_{th} = 0.4012 P_O = 5.917 [bar] $\dot{W}_{net}$ = 1254.74 [kJ/kg]

Maximization of W_dot_net(P_O) 33 iterations: Quadratic Approximations method

η_{th} = 0.3778 P_O = 0.222 [bar] $\dot{W}_{net}$ = 1335.65 [kJ/kg]

Requirement (D)

1-1st proposal one OFWH & one CFWH-1st case



$h_1 = h_f \,\&\, s_1 = s_f \;@\; P_{Cond.}$

$s_{2S} = s_1$

$h_{2S} \;@\; s_{2s} \,\&\, P_O$

$h_2 = \frac{1}{\eta_P} * (h_{2S} - h_1) + h_1$

$h_3 = h_f \;\&\; s_3 = s_f \;@\; P_O$

$s_{4S} = s_3$

$h_{4S} \;@\; s_{3S} \,\&\, P_B$

$h_4 = \frac{1}{\eta_P} * (h_{4S} - h_3) + h_3$

$h_6 = h_f \;@\; P_{Clos\ \ 1}$

$T_{6(sat.)} \;@\; P_{Cl\ \ \ 1}$

$T_5 = T_{6(sat.)}$ as $TTD = zero$

h_5 @ P_B & $T_{6(sat.)}$

$h_6 = h_7$

h_8 @ P_B & T_{max} From TS diagram

h_{9s} From TS diagram

$h_9 = h_8 + \eta_t * (h_8 - h_{9s})$

h_{10} P_R & T_{max} From TS diagram

h_{11s} From TS diagram

$h_{11} = h_{10} + \eta_t * (h_{10} - h_{11s})$

h_{12s} From TS diagram

$h_{12} = h_{11} + \eta_t * (h_{11} - h_{12s})$

h_{13s} From TS diagram

$h_{13} = h_{12} + \eta_t * (h_{12} - h_{13s})$

$$m_1 = \frac{h_5 - h_4}{h_{11} - h_6}$$

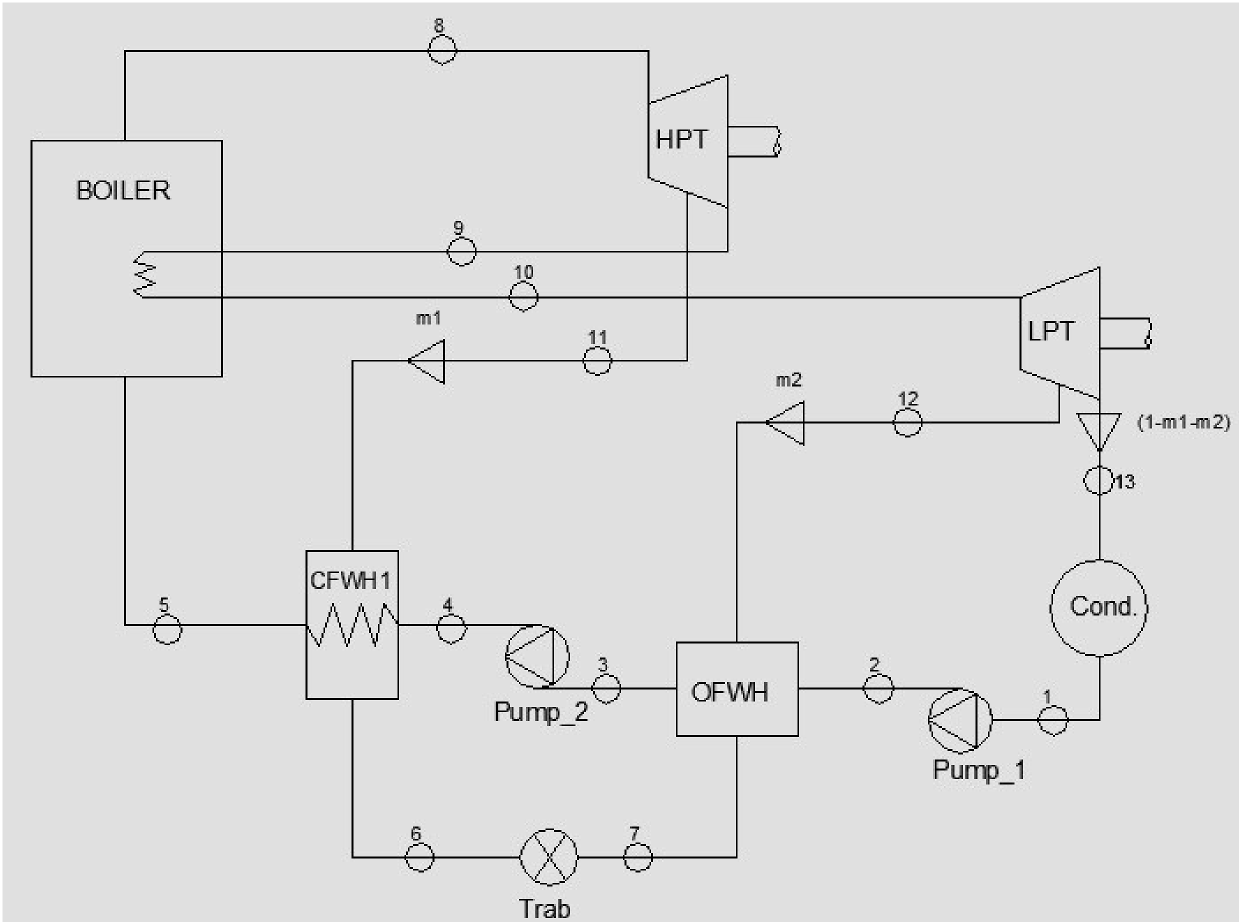
$$m_2 = \frac{h_3 - (1 - m_1)h_2 - m_1 h_7}{h_{12} - h_2}$$

$$\boldsymbol{Q_{add}} = (h_8 - h_5) + (h_{10} - h_9)$$

$$\boldsymbol{Q_{rej.}} = (1 - m_1 - m_2) * (h_{13} - h_1)$$

$$\eta_{\boldsymbol{P}} = 1 - \frac{\boldsymbol{Q_{rej.}}}{\boldsymbol{Q_{add}}}$$

1-1st proposal OFWH & one CFWH-2nd case



$h_1 = h_f$ & $s_1 = s_f$ @ $P_{Cond.}$

$s_{2S} = s_1$

h_{2S} @ s_{2s} & P_O

$h_2 = \frac{1}{\eta_P} * (h_{2S} - h_1) + h_1$

$h_3 = h_f$ & $s_3 = s_f$ @ P_O

$s_{4s} = s_3$

h_{4s} @ s_{3s} & P_B

$h_4 = \frac{1}{\eta_P} * (h_{4S} - h_3) + h_3$

$h_6 = h_f$ @ $P_{Clos\ \ 1}$

$T_{6(sat.)}$ @ P_{Close_1}

$T_5 = T_{6(sat.)}$ as $TTD = zero$

h_5 @ P_B & $T_{6(sat.)}$

$h_6 = h_7$

h_8 @ P_B & T_{max} From TS diagram

h_{9s} From TS diagram

$h_9 = h_8 + \eta_t * (h_8 - h_{9s})$

h_{10} P_R & T_{max} From TS diagram

h_{11s} From TS diagram

$h_{11} = h_{10} + \eta_t * (h_{10} - h_{11s})$

h_{12s} From TS diagram

$h_{12} = h_{11} + \eta_t * (h_{11} - h_{12s})$

h_{13s} From TS diagram

$h_{13} = h_{12} + \eta_t * (h_{12} - h_{13s})$

$$m_1 = \frac{h_5 - h_4}{h_{11} - h_6}$$

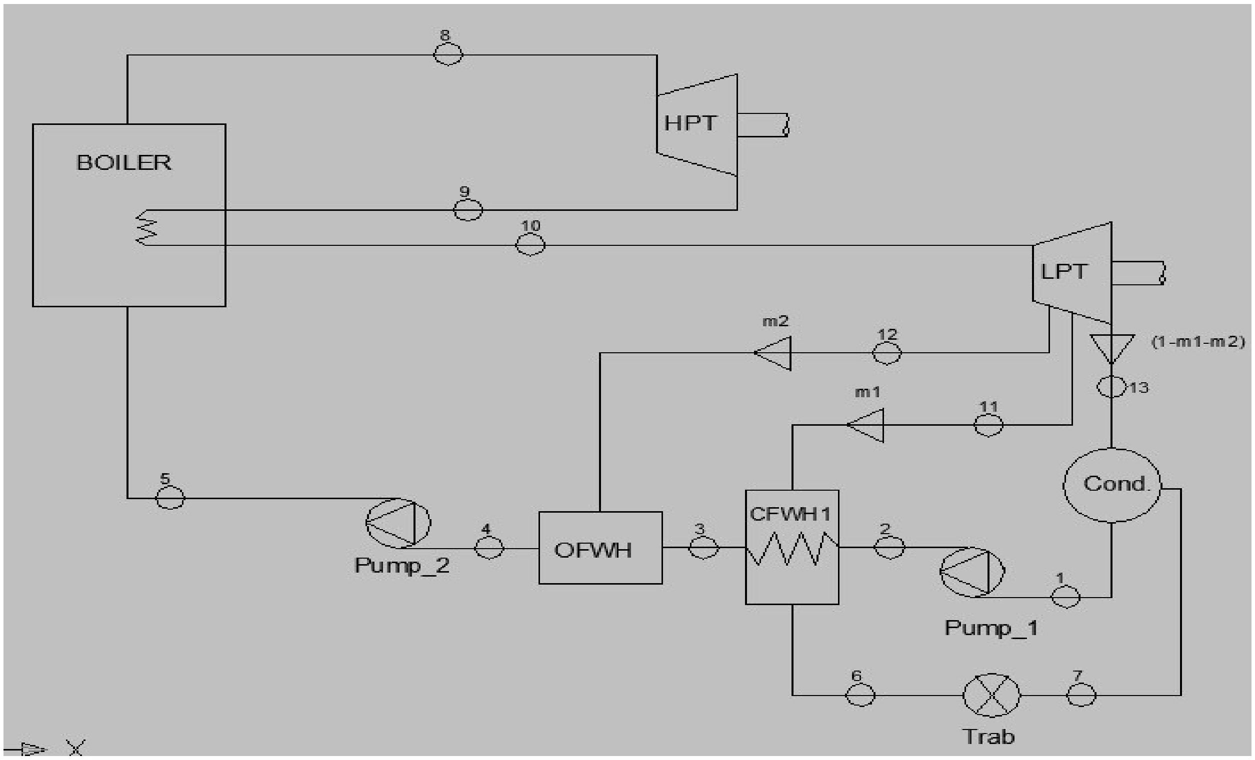
$$m_2 = \frac{h_3 - (1 - m_1)h_2 - m_1 h_7}{h_{12} - h_2}$$

$$\boldsymbol{Q_{add}} = (h_8 - h_5) + (1 - m_1)(h_{10} - h_9)$$

$$\boldsymbol{Q_{rej.}} = (1 - m_1 - m_2) * (h_{13} - h_1)$$

$$\eta_{\boldsymbol{P}} = 1 - \frac{\boldsymbol{Q_{rej.}}}{\boldsymbol{Q_{add}}}$$

1-1st proposal OFWH & one CFWH-3rd case



$h_1 = h_f \;\&\; s_1 = s_f \;@\; P_{Cond.}$

$s_{2S} = s_1$

$h_{2S} \;@\; s_{2s} \;\&\; P_O$

$$h_2 = \frac{1}{\eta_P} * (h_{2S} - h_1) + h_1$$

$T_{6(sat.)} \;@\; P_{Close_1}$

$T_5 = T_{6(sat.)}$ as $TTD = zero$

$h_3 \;@\; P_O \;\&\; T_{6(sat.)}$

$h_4 = h_f \;\&\; s_4 = s_f \;@\; P_O$

$s_{5s} = s_4$

$h_{5s} \;@\; s_{3s} \;\&\; P_B$

$h_5 = \frac{1}{\eta_P} * (h_{5S} - h_4) + h_4$

$h_6 = h_f$ @ $P_{Clos\ 1}$

$h_6 = h_7$

h_8 @ P_B & T_{max} From TS diagram

h_{9s} From TS diagram

$h_9 = h_8 + \eta_t * (h_8 - h_{9s})$

h_{10} P_R & T_{max} From TS diagram

h_{12s} From TS diagram

$h_{12} = h_9 + \eta_t * (h_{19} - h_{12s})$

h_{11s} From TS diagram

$h_{11} = h_{12} + \eta_t * (h_{12} - h_{11s})$

h_{13s} From TS diagram

$h_{13} = h_{11} + \eta_t * (h_{11} - h_{13s})$

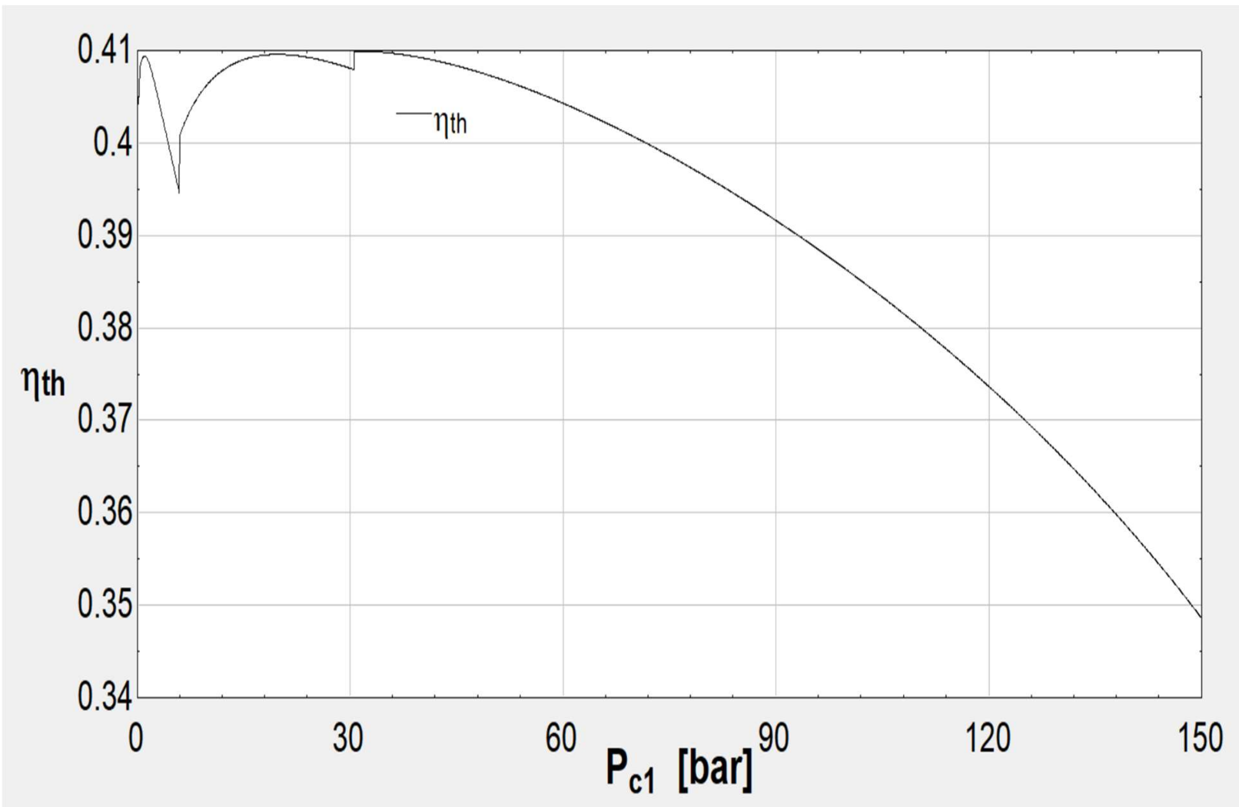
$$m_2 = \frac{h_4 - h_3}{h_{12} - h_3}$$

$$m_1 = \frac{(1 - m_1)(h_3 - h_2)}{h_{11} - h_6}$$

$$\boldsymbol{Q_{add}} = (h_8 - h_5) + (h_{10} - h_9)$$

$$\boldsymbol{Q_{rej.}} = (1 - m_1 - m_2) * (h_{13} - h_1) + m_1 * (h_7 - h_1)$$

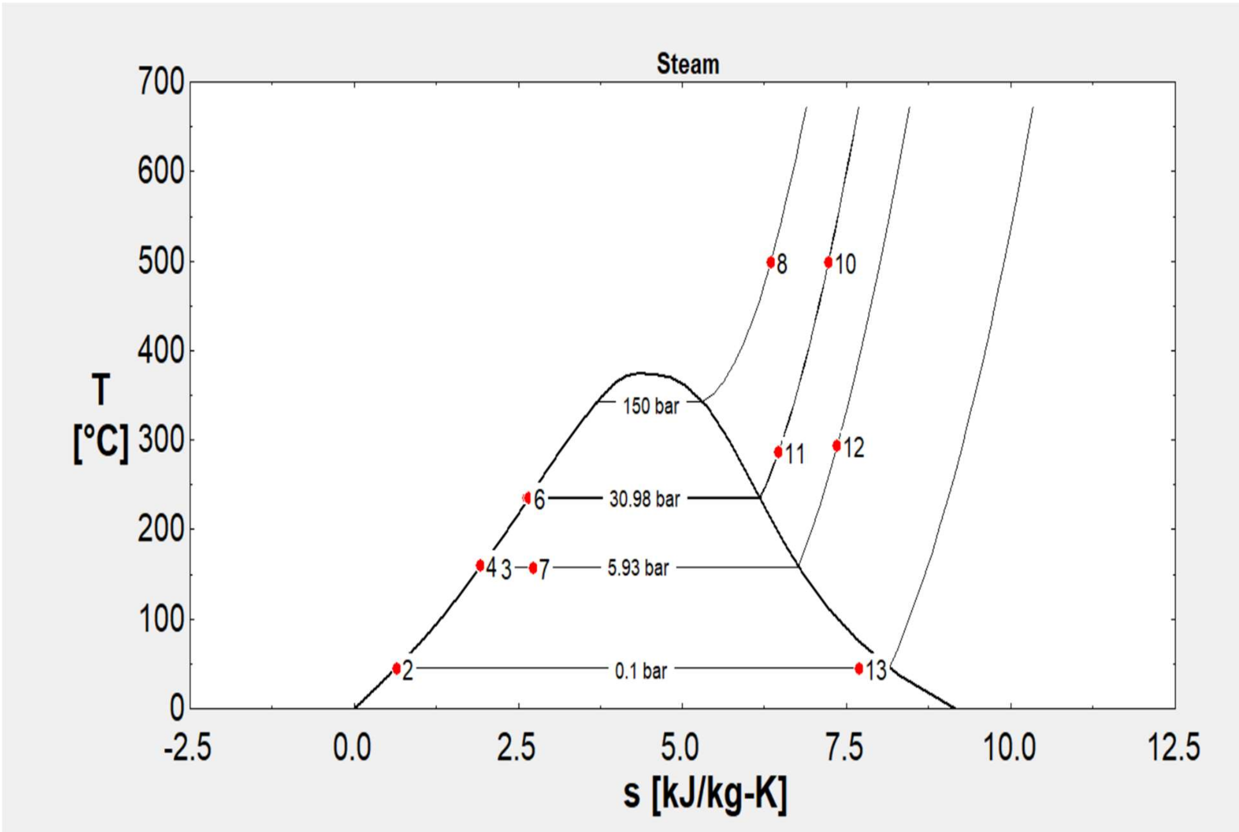
$$\eta_{\boldsymbol{P}} = 1 - \frac{\boldsymbol{Q_{rej.}}}{\boldsymbol{Q_{add}}}$$

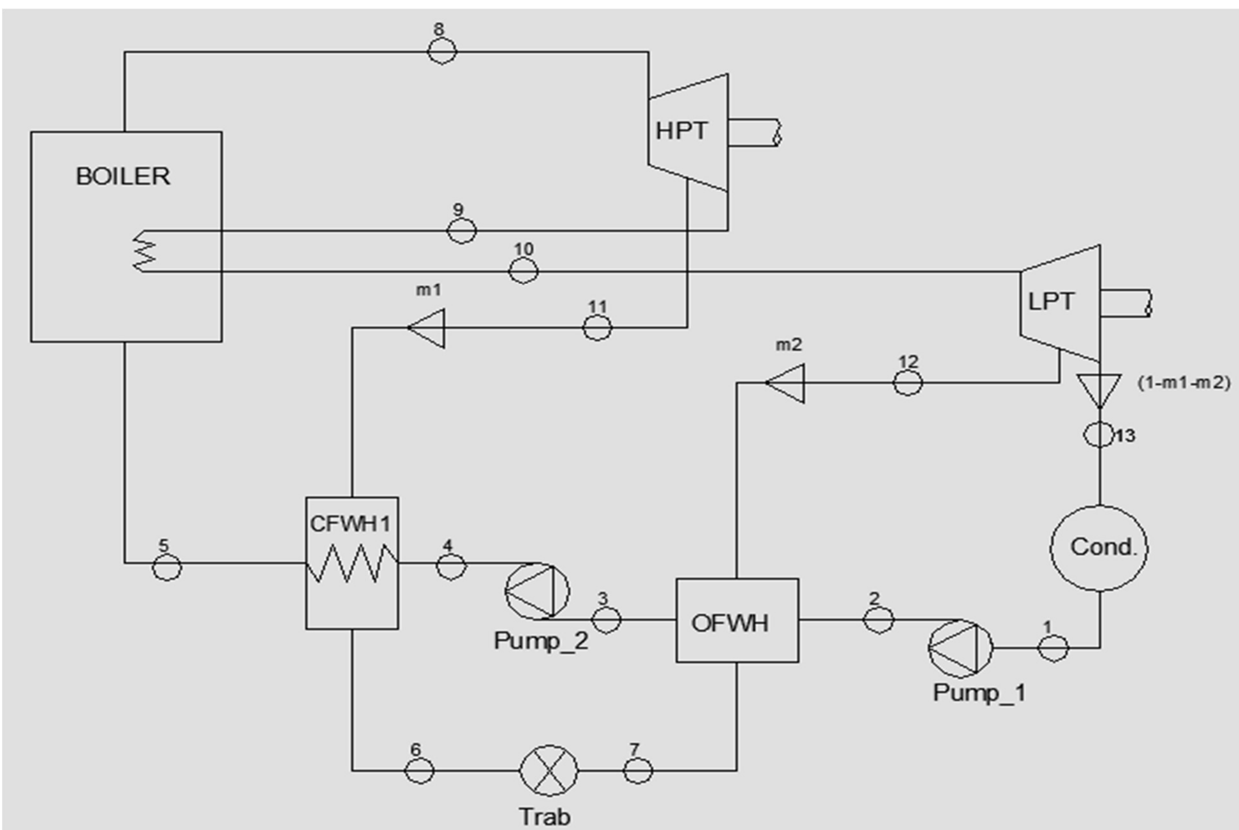


Maximization of eta_th(P_c1) 20 iterations: Quadratic Approximations method

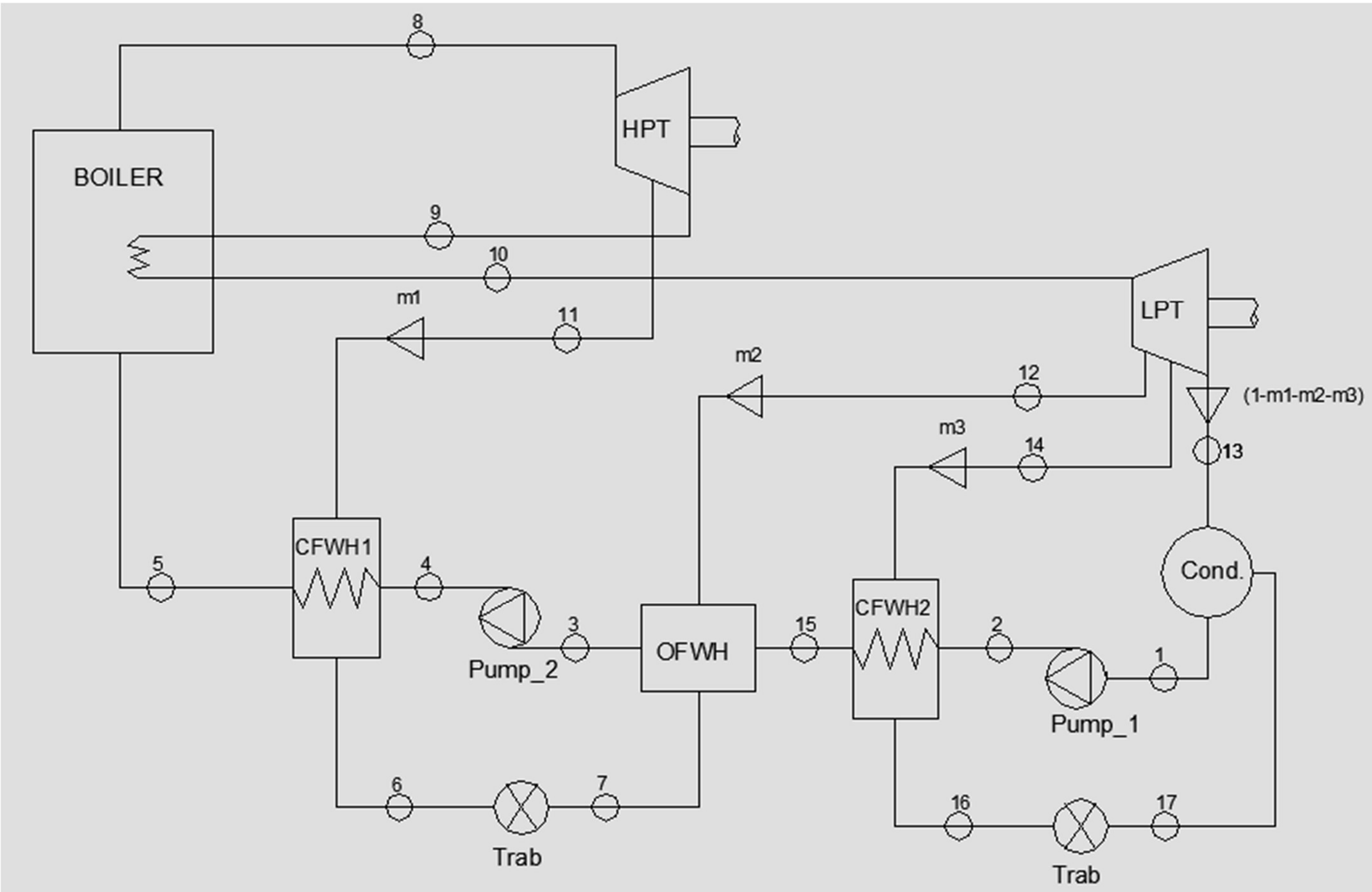
η_{th} = 0.4099 P_{c1} = 30.95 [bar] $\dot{W}_{net}$ = 1109.787 [kJ/kg]

The best layout





1-2nd proposal one OFWH &TWO CFWH-1st case



$$h_1 = h_f \;\&\; s_1 = s_f \text{ @ } P_{Cond.}$$

$$s_{2S} = s_1$$

$$h_{2S} \text{ @ } s_{2s} \;\&\; P_O$$

$$h_2 = \frac{1}{\eta_P} * (h_{2S} - h_1) + h_1$$

$$T_{16} = T_{(sat.)} \text{ as } TTD = zero$$

$$h_{16} = h_f \text{ @ } P_{clos\ 2}$$

$$h_{16} = h_{17}$$

h_{15} @ P_O & T_{16}

$h_3 = h_f$ & $s_3 = s_f$ @ P_O

h_{4s} @ s_3 & P_O

$h_4 = \frac{1}{\eta_P} * (h_{4S} - h_3) + h_3$

$h_6 = h_f$ & $T_6 = T_{sat.}$ @ P_{Close_1}

h_5 @ P_B & T_6

$h_6 = h_7$

h_8 @ P_B & T_{max} From TS diagram

h_{11s} From TS diagram

$h_{11} = h_8 - \eta_t * (h_8 - h_{11s})$

h_{9s} From TS diagram

$h_9 = h_{11} - \eta_t * (h_{11} - h_{9s})$

h_{10} @ P_B & T_{max} From TS diagram

h_{12s} From TS diagram

$h_{12} = h_{10} - \eta_t * (h_{10} - h_{12s})$

h_{14s} From TS diagram

$h_{14} = h_{12} - \eta_t * (h_{12} - h_{14s})$

h_{13s} From TS diagram

$h_{13} = h_{14} - \eta_t * (h_{14} - h_{13s})$

$$m_1 = \frac{h_5 - h_4}{h_{11} - h_6}$$

$$m_2 = \frac{h_3 - (1 - m_1)h_{15} - m_1 h_7}{h_{12} - h_{15}}$$

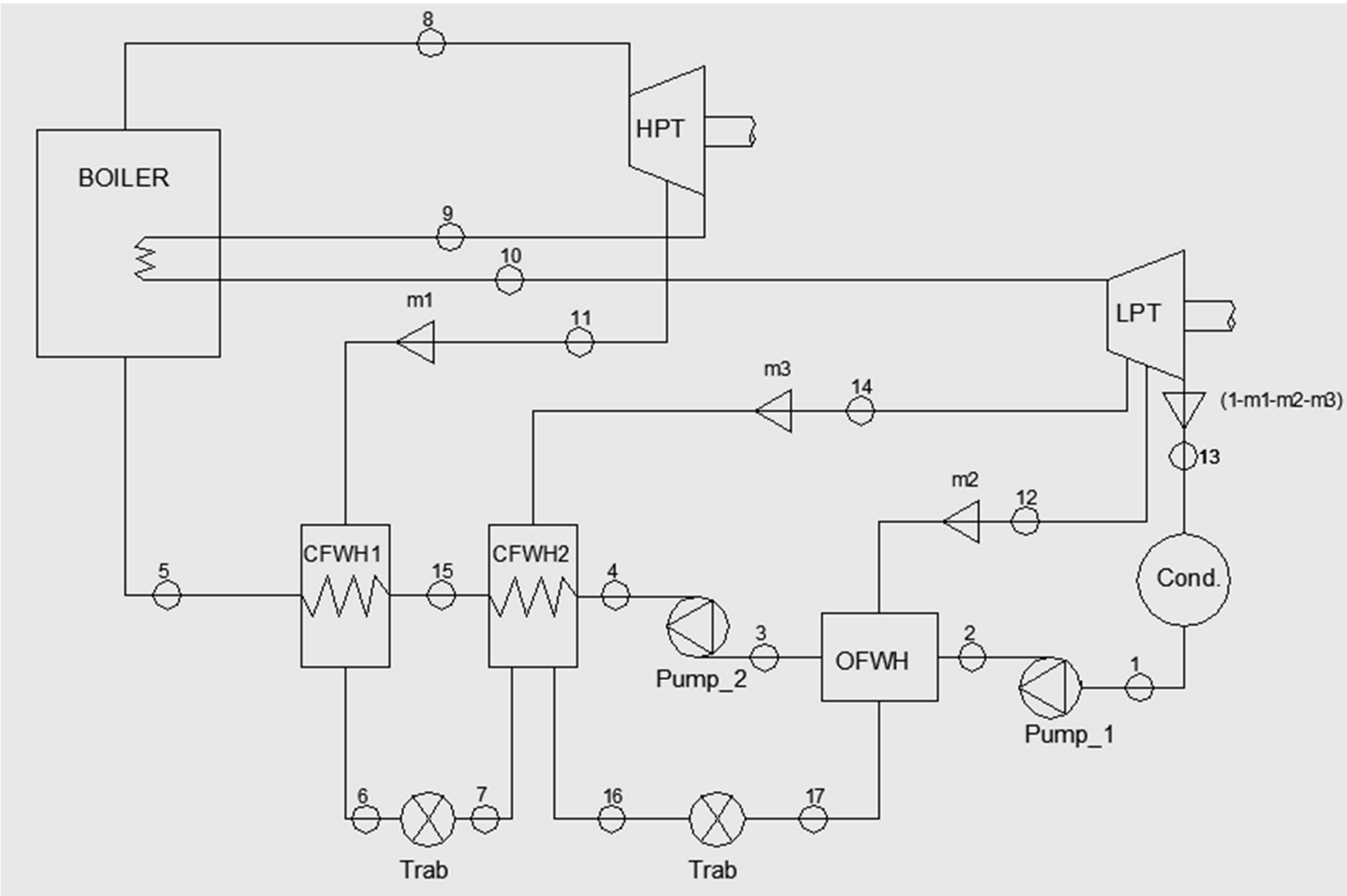
$$m_3 = \frac{(\mathrm{h}_{15} - \mathrm{h\_2})(1 - \mathrm{m}_1 - \mathrm{m}_2)}{h_{14} - h_{16}}$$

$$\boldsymbol{Q_{add}} = (h_8 - h_5) + (1 - m_1)(h_{10} - h_9)$$

$$\boldsymbol{Q_{rej.}} = (1 - m_1 - m_2 - m_3)(h_{13} - h_1) + m_3(h_{17} - h_1)$$

$$\eta_{\boldsymbol{P}} = 1 - \frac{\boldsymbol{Q_{rej.}}}{\boldsymbol{Q_{add}}}$$

1-2nd proposal one OFWH &TWO CFWH-2nd case



$$h_1 = h_f \,\&\, s_1 = s_f \text{ @ } P_{Cond.}$$

$$s_{2S} = s_1$$

$$h_{2S} \text{ @ } s_{2s} \,\&\, P_O$$

$$h_2 = \frac{1}{\eta_P} * (h_{2S} - h_1) + h_1$$

$$h_3 = h_f \,\&\, s_3 = s_f \text{ @ } P_O$$

$$h_{4s} \text{ @ } s_3 \,\&\, P_O$$

$$h_4 = \frac{1}{\eta_P} * (h_{4S} - h_3) + h_3$$

$h_{16} = h_f \;\; @ \; P_{close_2} \& T_{16} = T_{(sat.)}$

$h_{16} = h_{17}$

$\mathrm{T}_{15} = \mathrm{T}_{16}$ as $TTD = zero$

h_{15} @ P_O & T_{16}

$h_6 = h_f$ & $\mathrm{T}_6 = \mathrm{T}_{\mathrm{sat.}}$ @ P_{Close_1}

h_5 @ P_B & T_6

$h_6 = h_7$

h_8 @ P_B & T_{max} From TS diagram

$h_{11\mathrm{s}}$ From TS diagram

$h_{11} = h_8 - \eta_t * (h_8 - h_{11\mathrm{s}})$

$h_{9\mathrm{s}}$ From TS diagram

$h_9 = h_{11} - \eta_t * (h_{11} - h_{9\mathrm{s}})$

h_{10} @ P_B & T_{max} From TS diagram

$h_{14\mathrm{s}}$ From TS diagram

$h_{14} = h_{10} - \eta_t * (h_{10} - h_{14\mathrm{s}})$

$h_{12\mathrm{s}}$ From TS diagram

$h_{12} = h_{14} - \eta_t * (h_{14} - h_{12\mathrm{s}})$

$h_{13\mathrm{s}}$ From TS diagram

$h_{13} = h_{12} - \eta_t * (h_{12} - h_{13\mathrm{s}})$

$$m_1 = \frac{h_5 - h_{15}}{h_{11} - h_6}$$

$$m_3 = \frac{h_{15} - h_4 + m_1(h_{16} - h_7)}{h_{14} - h_{14}}$$

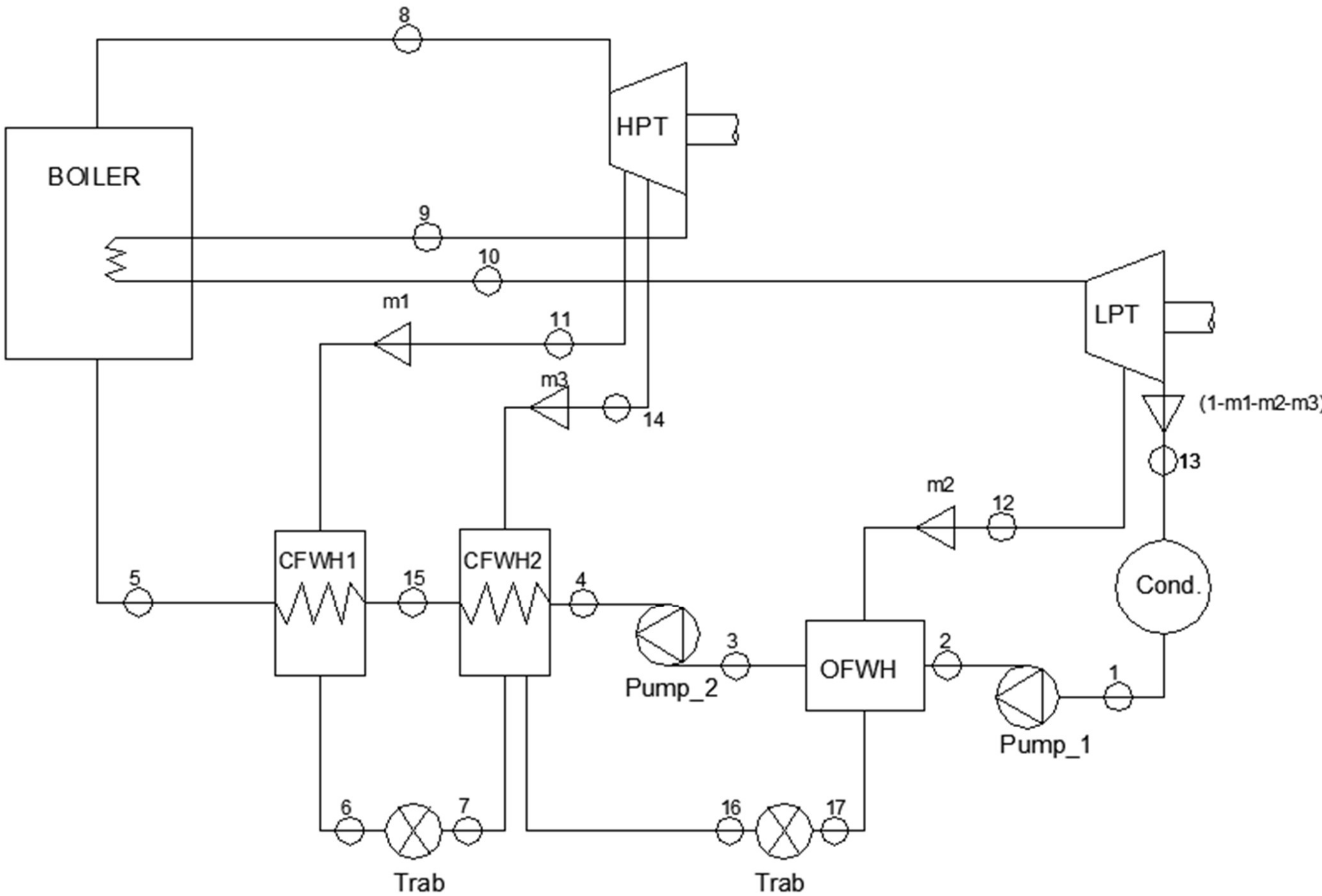
$$m_2 = \frac{\mathrm{h}_3 - (\mathrm{m}_1 + \mathrm{m}_2)\mathrm{h}_{17} - (1 - m_1 - m_3)h_2}{h_{12} - h_2}$$

$$\boldsymbol{Q_{add}} = (h_8 - h_5) + (1 - m_1)(h_{10} - h_9)$$

$$\boldsymbol{Q_{rej.}} = (1 - m_1 - m_2 - m_3)(h_{13} - h_1)$$

$$\eta_{\boldsymbol{P}} = 1 - \frac{\boldsymbol{Q_{rej.}}}{\boldsymbol{Q_{add}}}$$

1-2nd proposal one OFWH &TWO CFWH-3rd case



$h_1 = h_f \,\&\, s_1 = s_f$ @ $P_{Cond.}$

$s_{2S} = s_1$

h_{2S} @ s_{2s} & P_O

$$h_2 = \frac{1}{\eta_P} * (h_{2S} - h_1) + h_1$$

$h_3 = h_f \,\&\, s_3 = s_f$ @ P_O

h_{4s} @ s_3 & P_O

$$h_4 = \frac{1}{\eta_P} * (h_{4S} - h_3) + h_3$$

$h_{16} = h_f$ @ P_{close_2}&$T_{16} = T_{(sat.)}$

$h_{16} = h_{17}$

$T_{15} = T_{16}$ as $TTD = zero$

h_{15} @ P_O & T_{16}

$h_6 = h_f$ & $T_6 = T_{sat.}$ @ $P_{Clos\ 1}$

h_5 @ P_B & T_6

$h_6 = h_7$

h_8 @ P_B & T_{max} From TS diagram

h_{11s} From TS diagram

$h_{11} = h_8 - \eta_t * (h_8 - h_{11s})$

h_{14s} From TS diagram

$h_{14} = h_{11} - \eta_t * (h_{11} - h_{14s})$

h_{9s} From TS diagram

$h_9 = h_{14} - \eta_t * (h_{14} - h_{9s})$

h_{10} @ P_B & T_{max} From TS diagram

h_{12s} From TS diagram

$h_{12} = h_{10} - \eta_t * (h_{10} - h_{12s})$

h_{13s} From TS diagram

$h_{13} = h_{12} - \eta_t * (h_{12} - h_{13s})$

$$m_1 = \frac{h_5 - h_{15}}{h_{11} - h_6}$$

$$m_3 = \frac{h_{15} - h_4 + m_1(h_{16} - h_7)}{h_{14} - h_{14}}$$

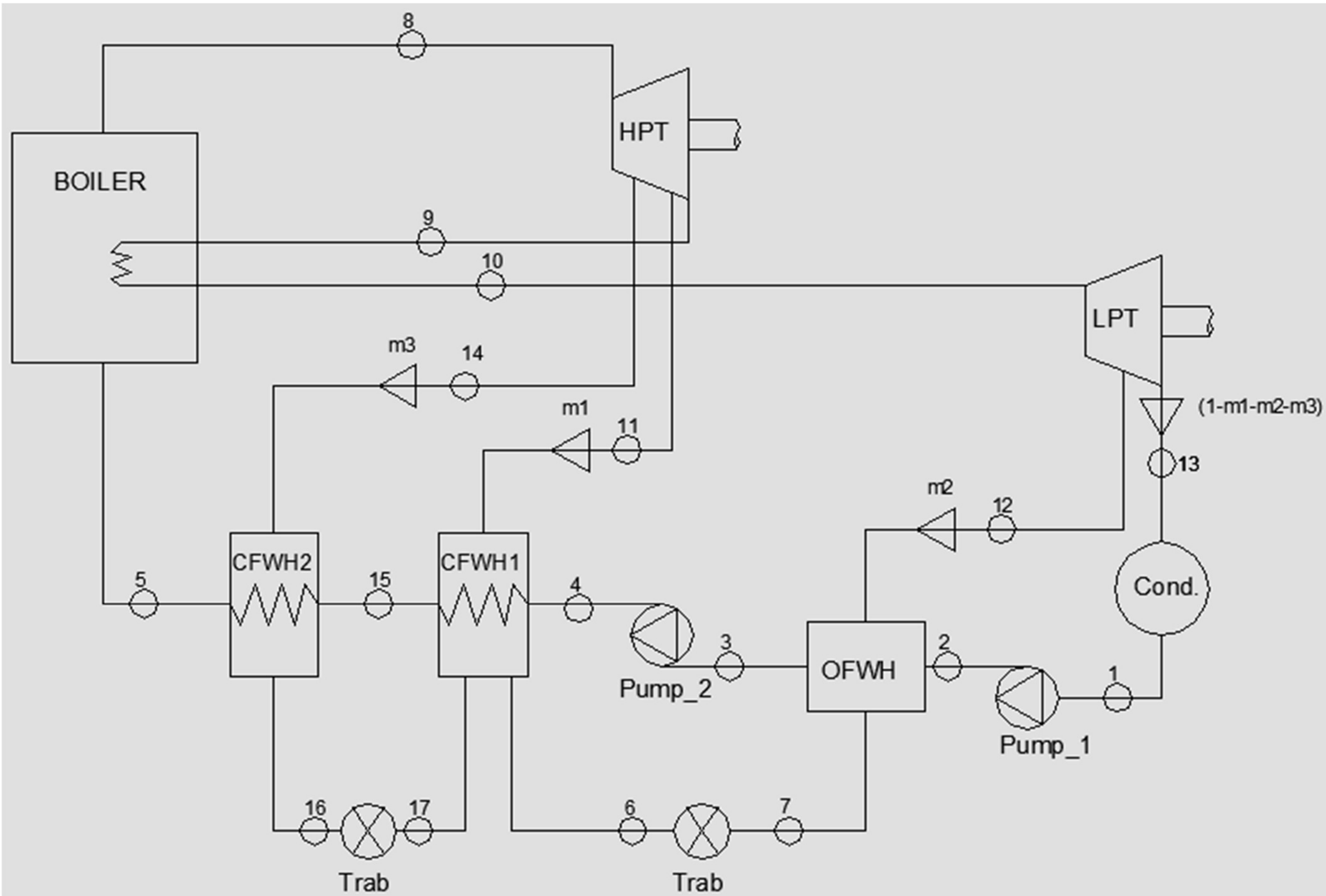
$$m_2 = \frac{\mathrm{h}_3 - (\mathrm{m}_1 + \mathrm{m}_2)\mathrm{h}_{17} - (1 - m_1 - m_3)h_2}{h_{12} - h_2}$$

$$\boldsymbol{Q_{add}} = (h_8 - h_5) + (1 - m_1 - m_3)(h_{10} - h_9)$$

$$\boldsymbol{Q_{rej.}} = (1 - m_1 - m_2 - m_3)(h_{13} - h_1)$$

$$\eta_{\boldsymbol{P}} = 1 - \frac{\boldsymbol{Q_{rej.}}}{\boldsymbol{Q_{add}}}$$

1-2nd proposal one OFWH &TWO CFWH-4th case



$$h_1 = h_f \,\&\, s_1 = s_f \;@\; P_{Cond.}$$

$$s_{2S} = s_1$$

$$h_{2S} \;@\; s_{2s} \,\&\, P_O$$

$$h_2 = \frac{1}{\eta_P} * (h_{2S} - h_1) + h_1$$

$$h_3 = h_f \,\&\, s_3 = s_f \;@\; P_O$$

$$h_{4s} \;@\; s_3 \,\&\, P_O$$

$$h_4 = \frac{1}{\eta_P} * (h_{4S} - h_3) + h_3$$

$h_6 = h_f$ & $T_6 = T_{sat.}$ @ $P_{Clo\ \ 1}$

$h_6 = h_7$

$T_{15} = T_6$ as $TTD = zero$

h_{15} @ P_B & T_6

$h_{16} = h_f$ @ P_{close_2}&$T_{16} = T_{(sat.)}$

$h_{16} = h_{17}$

$T_{15} = T_{16}$ as $TTD = zero$

h_5 @ P_O & T_{16}

h_8 @ P_B & T_{max} From TS diagram

h_{14s} From TS diagram

$h_{14} = h_8 - \eta_t * (h_8 - h_{14s})$

h_{11s} From TS diagram

$h_{11} = h_{14} - \eta_t * (h_{14} - h_{11s})$

h_{9s} From TS diagram

$h_9 = h_{11} - \eta_t * (h_{11} - h_{9s})$

h_{10} @ P_B & T_{max} From TS diagram

h_{12s} From TS diagram

$h_{12} = h_{10} - \eta_t * (h_{10} - h_{12s})$

h_{13s} From TS diagram

$h_{13} = h_{12} - \eta_t * (h_{12} - h_{13s})$

$$m_3 = \frac{h_5 - h_{15}}{h_{14} - h_{16}}$$

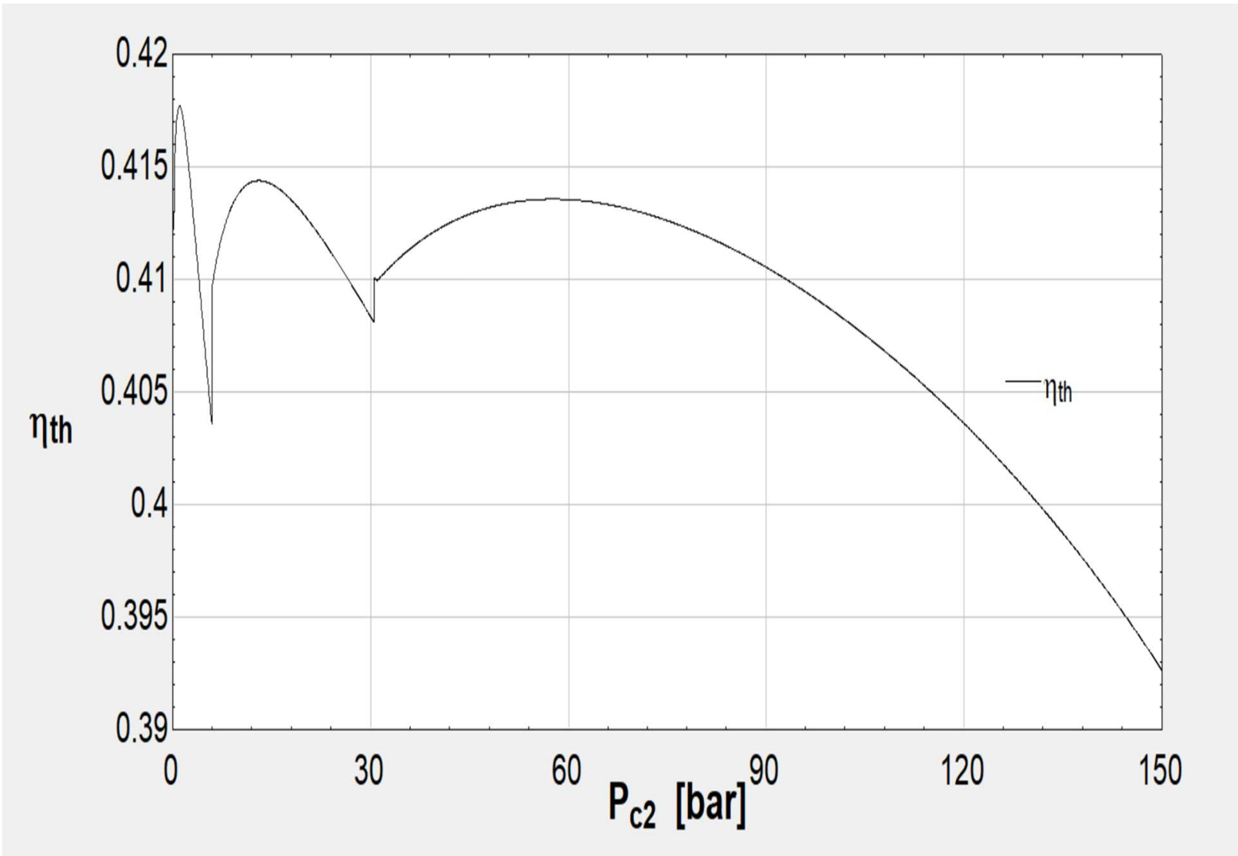
$$m_1 = \frac{h_{15} - h_4 + m_3(h_6 - h_{17})}{h_{11} - h_6}$$

$$m_2 = \frac{\mathrm{h}_3 - (\mathrm{m}_1 + \mathrm{m}_2)\mathrm{h}_7 - (1 - m_1 - m_3)h_2}{h_{12} - h_2}$$

$$\boldsymbol{Q_{add}} = (h_8 - h_5) + (1 - m_1 - m_3)(h_{10} - h_9)$$

$$\boldsymbol{Q_{rej.}} = (1 - m_1 - m_2 - m_3)(h_{13} - h_1)$$

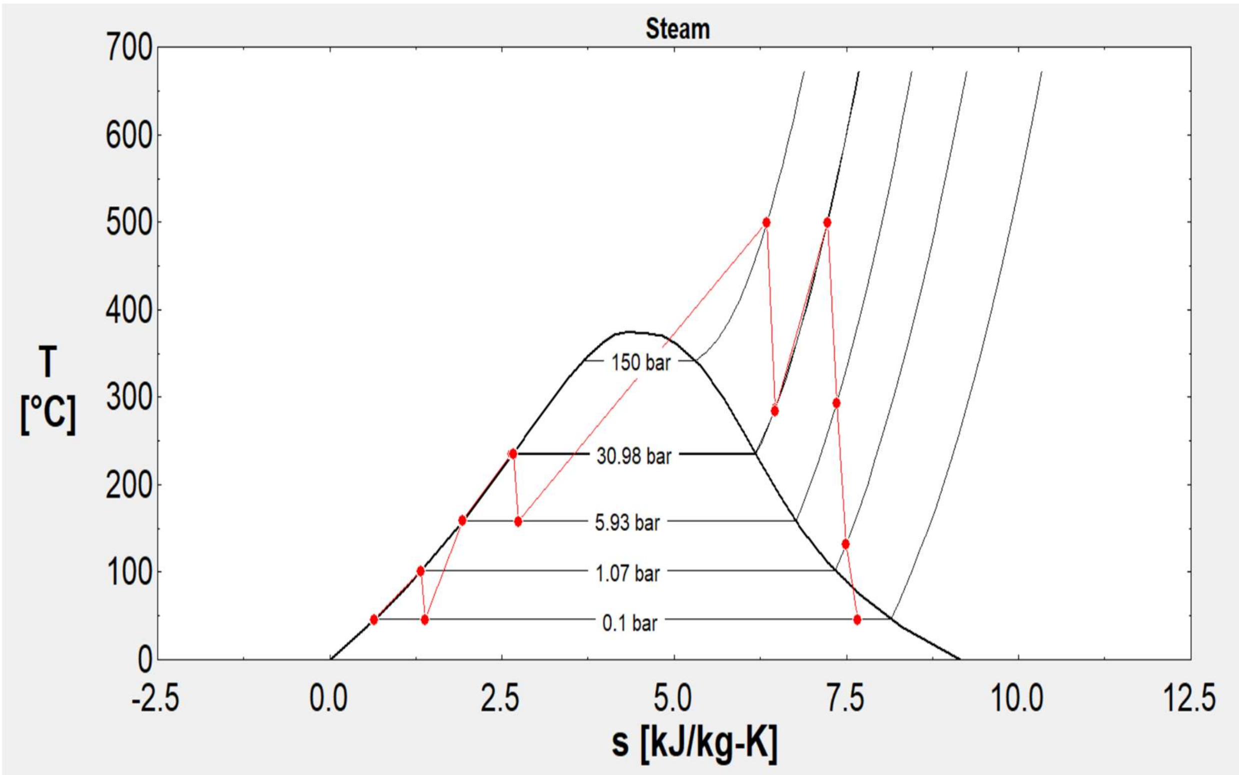
$$\eta_{\boldsymbol{P}} = 1 - \frac{\boldsymbol{Q_{rej.}}}{\boldsymbol{Q_{add}}}$$

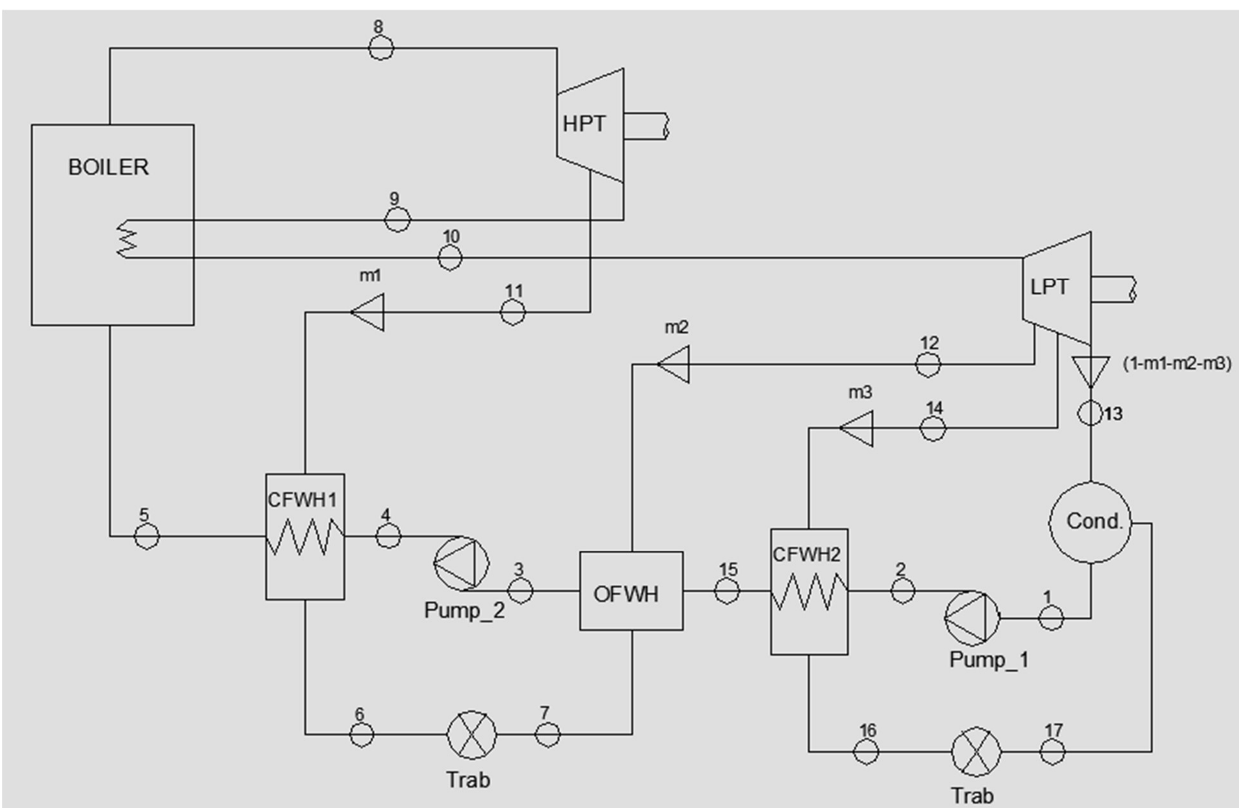


Maximization of eta_th(P_c2) 19 iterations: Quadratic Approximations method

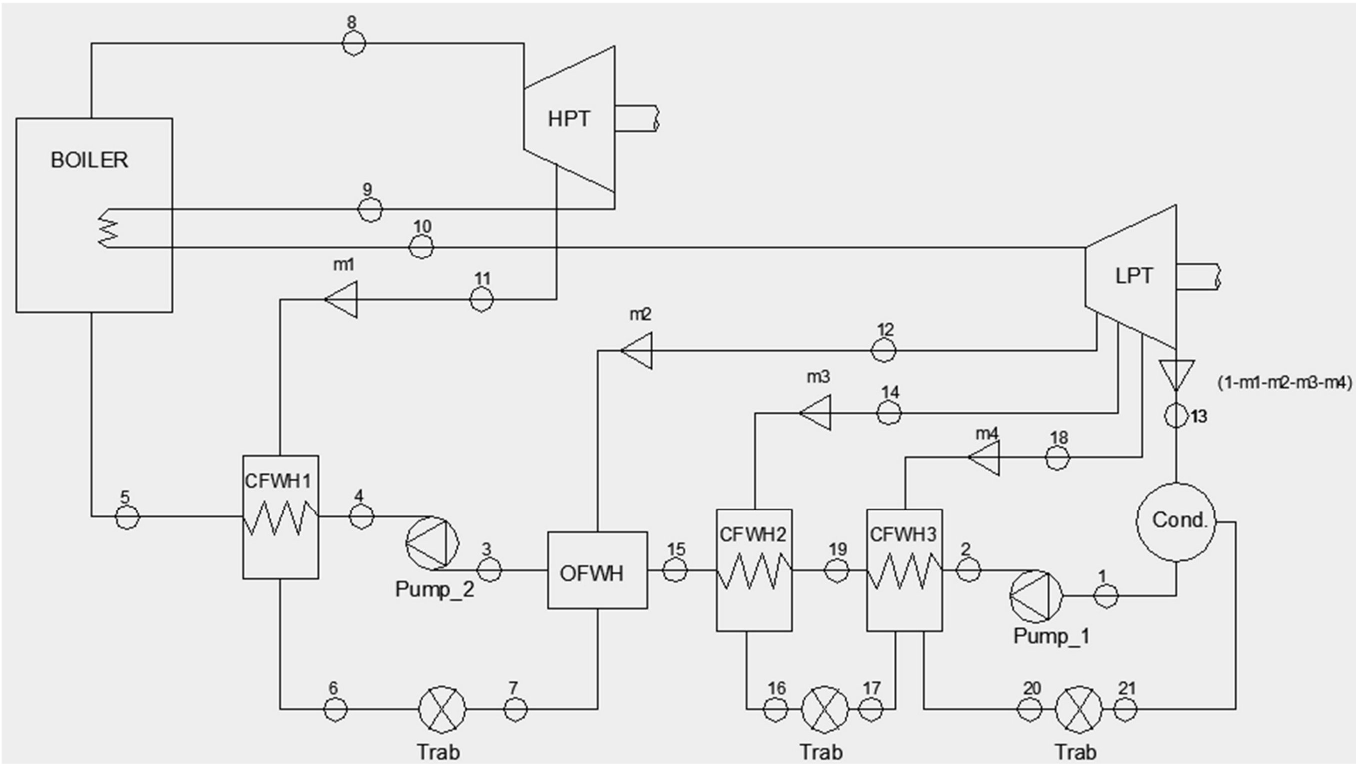
η_{th} = 0.4177 P_{c2} = 1.0705 [bar] $\dot{W}_{net}$ = 1130.685 [kJ/kg]

The best layout





1-3rd proposal one OFWH &THREE CFWH-1st case



$$h_1 = h_f \;\&\; s_1 = s_f \;@\; P_{Cond.}$$

$$s_{2S} = s_1$$

$$h_{2S} \;@\; s_{2s} \;\&\; P_O$$

$$h_2 = \frac{1}{\eta_P} * (h_{2S} - h_1) + h_1$$

$$h_{20} = h_f \;\&\; T_{20} = T_{sat}. \;@P_{close_3}$$

$$h_{21} = h_{20} \; as \; TTD = Zero$$

$$h_{19} \;@\; P_B \;\&\; T_{20}$$

$$h_{16} = h_f \;\&\; T_{16} = T_{sat}. \;@P_{close_2}$$

$$h_{17} = h_{16}$$

$h_{15} = h_f @ P_O \& T_{16}$

$h_3 = h_f \ \& \ s_3 = s_f \ @ \ P_O$

$h_{4s} \ @ \ s_3 \ \& \ P_O$

$$h_4 = \frac{1}{\eta_P} * (h_{4S} - h_3) + h_3$$

$h_6 = h_f \ \& \ \mathrm{T}_6 = \mathrm{T}_{\mathrm{sat.}} \ @ \ P_{Close_1}$

$h_6 = h_7$

$\mathrm{T}_5 = \mathrm{T}_6$ as $TTD = zero$

$h_5 \ @ \ P_B \ \& \ T_6$

h_8 @ $P_B \ \& \ T_{max}$ From TS diagram

$h_{11\mathrm{s}}$ From TS diagram

$h_{11} = h_8 - \eta_t * (h_8 - h_{11\mathrm{s}})$

$h_{9\mathrm{s}}$ From TS diagram

$h_9 = h_{11} - \eta_t * (h_{11} - h_{9\mathrm{s}})$

$h_9 = h_{11} - \eta_t * (h_{11} - h_{9\mathrm{s}})$

h_{10} @ $P_B \ \& \ T_{max}$ From TS diagram

$h_{12\mathrm{s}}$ From TS diagram

$h_{12} = h_{10} - \eta_t * (h_{10} - h_{12\mathrm{s}})$

$h_{14\mathrm{s}}$ From TS diagram

$h_{14} = h_{12} - \eta_t * (h_{12} - h_{14\mathrm{s}})$

$h_{18\mathrm{s}}$ From TS diagram

$h_{18} = h_{14} - \eta_t * (h_{14} - h_{18\mathrm{s}})$

$h_{13\mathrm{s}}$ From TS diagram

$$h_{13} = h_{18} - \eta_t * (h_{18} - h_{13s})$$

$$m_1 = \frac{h_5 - h_4}{h_{11} - h_6}$$

$$m_2 = \frac{h_3 - (1 - m_1)h_{15} + m_1 \mathrm{h}_7}{h_{12} - h_{15}}$$

$$m_3 = \frac{(1 - m_1 - m_2)(h_{15} - h_{19})}{h_{14} - h_{16}}$$

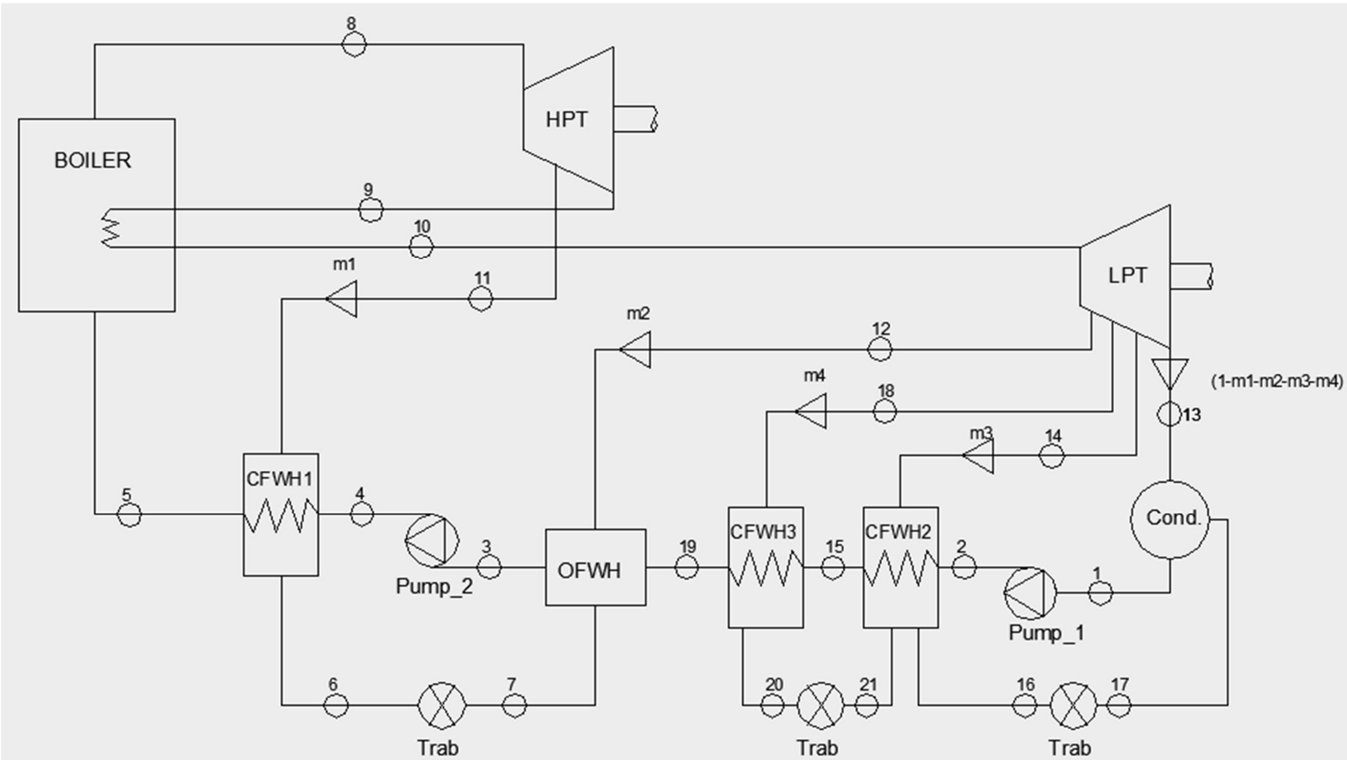
$$m_4 = \frac{(1 - m_1 - m_2)(h_{19} - h_2) + m_3(h_{20} - h_{17})}{h_{18} - h_{20}}$$

$$\boldsymbol{Q_{add}} = (h_8 - h_5) + (1 - m_1)(h_{10} - h_9)$$

$$\boldsymbol{Q_{rej.}} = (1 - m_1 - m_2 - m_3 - m_4)(h_{13} - h_1) + (m_3 + m_4)(h_{21} - h_1)$$

$$\eta_{\boldsymbol{P}} = 1 - \frac{\boldsymbol{Q_{rej.}}}{\boldsymbol{Q_{add}}}$$

-3rd proposal one OFWH &THREE CFWH-2nd case



$h_1 = h_f \;\&\; s_1 = s_f \;@\; P_{Cond.}$

$s_{2S} = s_1$

$h_{2S} \;@\; s_{2s} \;\&\; P_O$

$h_2 = \dfrac{1}{\eta_P} * (h_{2S} - h_1) + h_1$

$h_{16} = h_f \;\&\; T_{16} = T_{sat}. \;@P_{close_2}$

$h_{17} = h_{16}$

$\mathrm{T}_{15} = \mathrm{T}_{16}$ as $TTD = zero$

$h_{15} \;@\; P_O \;\&\; T_{16}$

$h_{20} = h_f \;\&\; T_{20} = T_{sat}. \;@P_{close_3}$

$h_{21} = h_{20}$

$h_{19} = h_f @ P_O \& T_{16}$

$h_3 = h_f \;\&\; s_3 = s_f \;@\; P_O$

$h_{4s} \;@\; s_3 \;\&\; P_O$

$$h_4 = \frac{1}{\eta_P} * (h_{4S} - h_3) + h_3$$

$h_6 = h_f \;\&\; \mathrm{T}_6 = \mathrm{T}_{\mathrm{sat.}} \;@\; P_{Close_1}$

$h_6 = h_7$

$\mathrm{T}_5 = \mathrm{T}_6$ as $TTD = zero$

$h_5 \;@\; P_B \;\&\; T_6$

$h_8 \;@\; P_B \;\&\; T_{max}$ From TS diagram

$h_{11\mathrm{s}}$ From TS diagram

$h_{11} = h_8 - \eta_t * (h_8 - h_{11\mathrm{s}})$

$h_{9\mathrm{s}}$ From TS diagram

$h_9 = h_{11} - \eta_t * (h_{11} - h_{9\mathrm{s}})$

$h_9 = h_{11} - \eta_t * (h_{11} - h_{9\mathrm{s}})$

$h_{10} \;@\; P_B \;\&\; T_{max}$ From TS diagram

$h_{12\mathrm{s}}$ From TS diagram

$h_{12} = h_{10} - \eta_t * (h_{10} - h_{12\mathrm{s}})$

$h_{18\mathrm{s}}$ From TS diagram

$h_{18} = h_{12} - \eta_t * (h_{12} - h_{18\mathrm{s}})$

$h_{14\mathrm{s}}$ From TS diagram

$h_{14} = h_{18} - \eta_t * (h_{18} - h_{14\mathrm{s}})$

$h_{13\mathrm{s}}$ From TS diagram

$$h_{13} = h_{14} - \eta_t * (h_{14} - h_{13s})$$

$$m_1 = \frac{h_5 - h_4}{h_{11} - h_6}$$

$$m_2 = \frac{h_3 - (1 - m_1)h_{19} + m_1 \mathrm{h}_7}{h_{12} - h_{19}}$$

$$m_4 = \frac{(1 - m_1 - m_2)(h_{19} - h_{15})}{h_{18} - h_{20}}$$

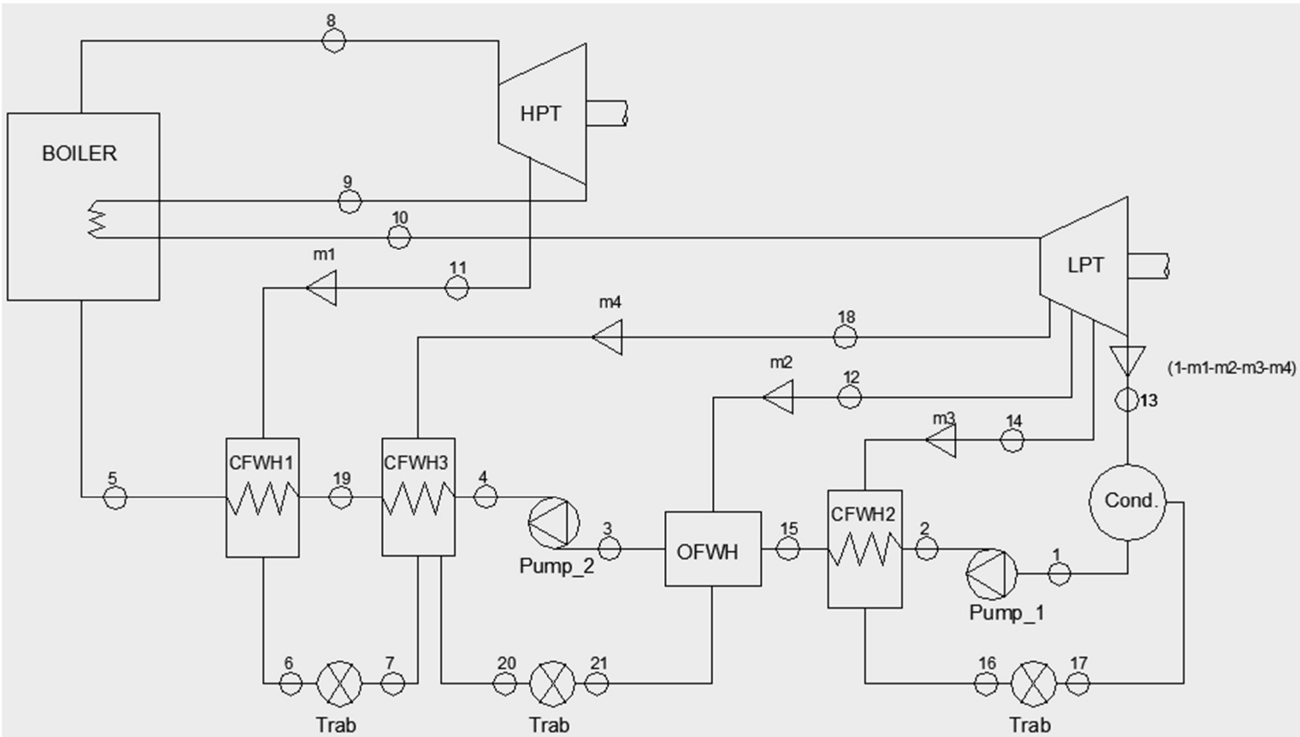
$$m_3 = \frac{(1 - m_1 - m_2)(h_{15} - h_2) + m_3(h_{20} - h_{17})}{h_{14} - h_{16}}$$

$$\boldsymbol{Q_{add}} = (h_8 - h_5) + (1 - m_1)(h_{10} - h_9)$$

$$\boldsymbol{Q_{rej.}} = (1 - m_1 - m_2 - m_3 - m_4)(h_{13} - h_1) + (m_3 + m_4)(h_{17} - h_1)$$

$$\eta_{\boldsymbol{P}} = 1 - \frac{\boldsymbol{Q_{rej.}}}{\boldsymbol{Q_{add}}}$$

-3rd proposal one OFWH &THREE CFWH-3rd case



$h_1 = h_f \,\&\, s_1 = s_f \text{ @ } P_{Cond.}$

$s_{2S} = s_1$

$h_{2S} \text{ @ } s_{2s} \,\&\, P_O$

$$h_2 = \frac{1}{\eta_P} * (h_{2S} - h_1) + h_1$$

$h_{16} = h_f \,\&\, T_{16} = T_{sat}. \text{ @} P_{close_2}$

$h_{17} = h_{16}$

$\mathrm{T}_{15} = \mathrm{T}_{16}$ as $TTD = zero$

$h_{15} \text{ @ } P_O \& T_{16}$

$h_3 = h_f \,\&\, s_3 = s_f \text{ @ } P_O$

$h_{4s} \text{ @ } s_3 \,\&\, P_O$

$$h_4 = \frac{1}{\eta_P} * (h_{4S} - h_3) + h_3$$

$h_6 = h_f$ & $T_6 = T_{sat.}$ @$P_{close\,3}$

$h_7 = h_6$

$h_{19} = h_f$@ P_O& T_6

$h_{20} = h_f$ & $\mathrm{T}_{20} = \mathrm{T}_{\mathrm{sat.}}$ @ P_{Close_1}

$h_{21} = h_{20}$

$\mathrm{T}_5 = \mathrm{T}_{20}$ as $TTD = zero$

h_5 @ P_B & T_{20}

h_8 @ P_B & T_{max} From TS diagram

$h_{18\mathrm{s}}$ From TS diagram

$h_{18} = h_8 - \eta_t * (h_8 - h_{18\mathrm{s}})$

$h_{11\mathrm{s}}$ From TS diagram

$h_{11} = h_{18} - \eta_t * (h_{18} - h_{11\mathrm{s}})$

$h_{9\mathrm{s}}$ From TS diagram

$h_9 = h_{11} - \eta_t * (h_{11} - h_{9\mathrm{s}})$

h_{10} @ P_B & T_{max} From TS diagram

$h_{12\mathrm{s}}$ From TS diagram

$h_{12} = h_{10} - \eta_t * (h_{10} - h_{12\mathrm{s}})$

$h_{14\mathrm{s}}$ From TS diagram

$h_{14} = h_{12} - \eta_t * (h_{12} - h_{14\mathrm{s}})$

$h_{13\mathrm{s}}$ From TS diagram

$h_{13} = h_{14} - \eta_t * (h_{14} - h_{13\mathrm{s}})$

$$m_1 = \frac{h_5 - h_{19}}{h_{11} - h_6}$$

$$m_4 = \frac{h_{19} - (h_{20} - h_7)m_1 - h_4}{h_{18} - h_{20}}$$

$$m_2 = \frac{h_3 - (1 - m_1 - m_4)h_{15} - h_{21}(m_1 + m_4)}{h_{12} - h_{15}}$$

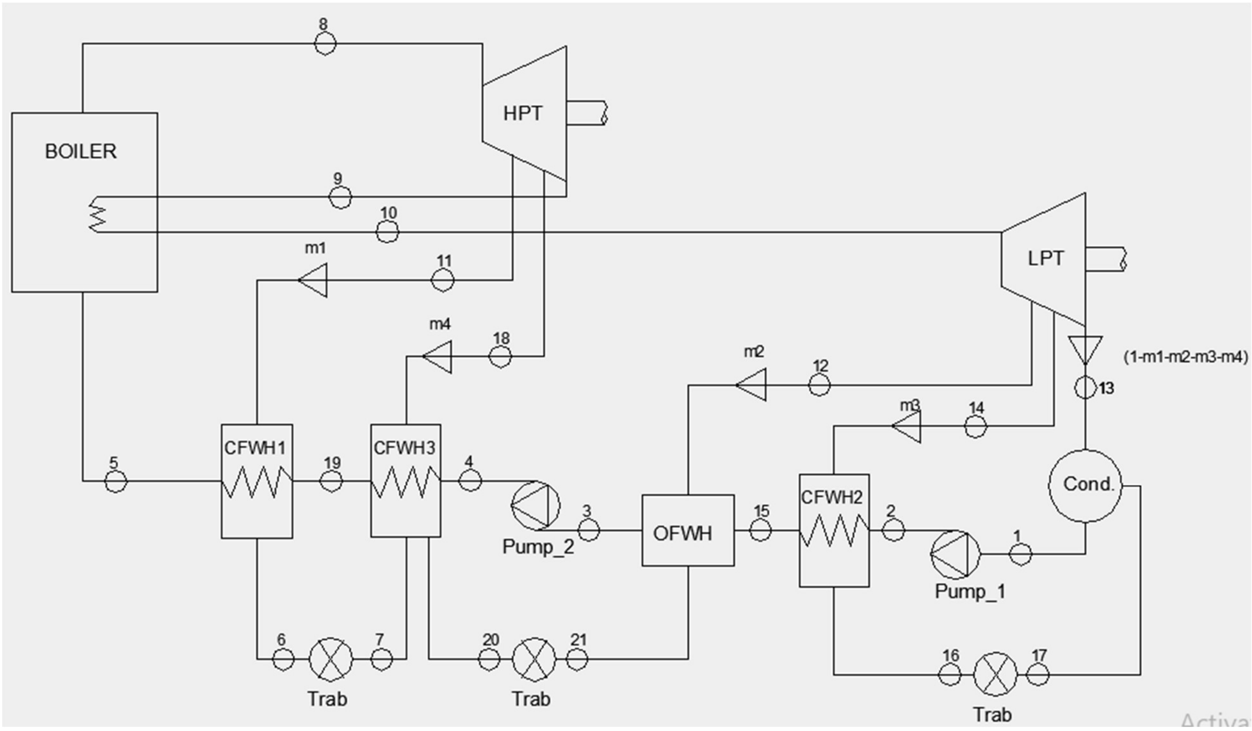
$$m_3 = \frac{(1 - m_1 - m_2 - m_4)(h_{15} - h_2)}{h_{14} - h_{16}}$$

$$\boldsymbol{Q_{add}} = (h_8 - h_5) + (1 - m_1)(h_{10} - h_9)$$

$$\boldsymbol{Q_{rej.}} = (1 - m_1 - m_2 - m_3 - m_4)(h_{13} - h_1) + (m_3)(h_{17} - h_1)$$

$$\eta_{\boldsymbol{P}} = 1 - \frac{\boldsymbol{Q_{rej.}}}{\boldsymbol{Q_{add}}}$$

3rd proposal one OFWH &THREE CFWH 4th case



$$h_1 = h_f \;\&\; s_1 = s_f \;@\; P_{Cond.}$$

$$s_{2S} = s_1$$

$$h_{2S} \;@\; s_{2s} \;\&\; P_O$$

$$h_2 = \frac{1}{\eta_P} * (h_{2S} - h_1) + h_1$$

$$h_{16} = h_f \;\&\; T_{16} = T_{sat}. \;@P_{close_2}$$

$$h_{17} = h_{16}$$

$$\mathrm{T}_{15} = \mathrm{T}_{16} \text{ as } TTD = zero$$

$$h_{15} \;@\; P_O \;\&\; T_{16}$$

$$h_3 = h_f \;\&\; s_3 = s_f \;@\; P_O$$

$$h_{4s} \;@\; s_3 \;\&\; P_O$$

$$h_4 = \frac{1}{\eta_P} * (h_{4S} - h_3) + h_3$$

$h_{20} = h_f$ & $T_{20} = T_{sat}.$ $@P_{close\,3}$

$h_{21} = h_{20}$

$h_{19} = h_f @\, P_O$ & T_{20}

$h_6 = h_f$ & $\mathrm{T}_6 = \mathrm{T}_{\mathrm{sat.}}$ $@\, P_{Clos\ 1}$

$h_6 = h_7$

$\mathrm{T}_5 = \mathrm{T}_6$ as $TTD = zero$

$h_5 @\, P_B$ & T_6

h_8 @ P_B & T_{max} From TS diagram

$h_{11\mathrm{s}}$ From TS diagram

$h_{11} = h_8 - \eta_t * (h_8 - h_{11\mathrm{s}})$

$h_{18\mathrm{s}}$ From TS diagram

$h_{18} = h_{11} - \eta_t * (h_{11} - h_{18\mathrm{s}})$

$h_{9\mathrm{s}}$ From TS diagram

$h_9 = h_{18} - \eta_t * (h_{18} - h_{9\mathrm{s}})$

h_{10} @ P_B & T_{max} From TS diagram

$h_{12\mathrm{s}}$ From TS diagram

$h_{12} = h_{10} - \eta_t * (h_{10} - h_{12\mathrm{s}})$

$h_{14\mathrm{s}}$ From TS diagram

$h_{14} = h_{12} - \eta_t * (h_{12} - h_{14\mathrm{s}})$

$h_{13\mathrm{s}}$ From TS diagram

$h_{13} = h_{14} - \eta_t * (h_{14} - h_{13\mathrm{s}})$

$$m_1 = \frac{h_5 - h_{19}}{h_{11} - h_6}$$

$$m_4 = \frac{h_{19} - (h_{20} - h_7)m_1 - h_4}{h_{18} - h_{20}}$$

$$m_2 = \frac{h_3 - (1 - m_1 - m_4)h_{15} - h_{21}(m_1 + m_4)}{h_{12} - h_{15}}$$

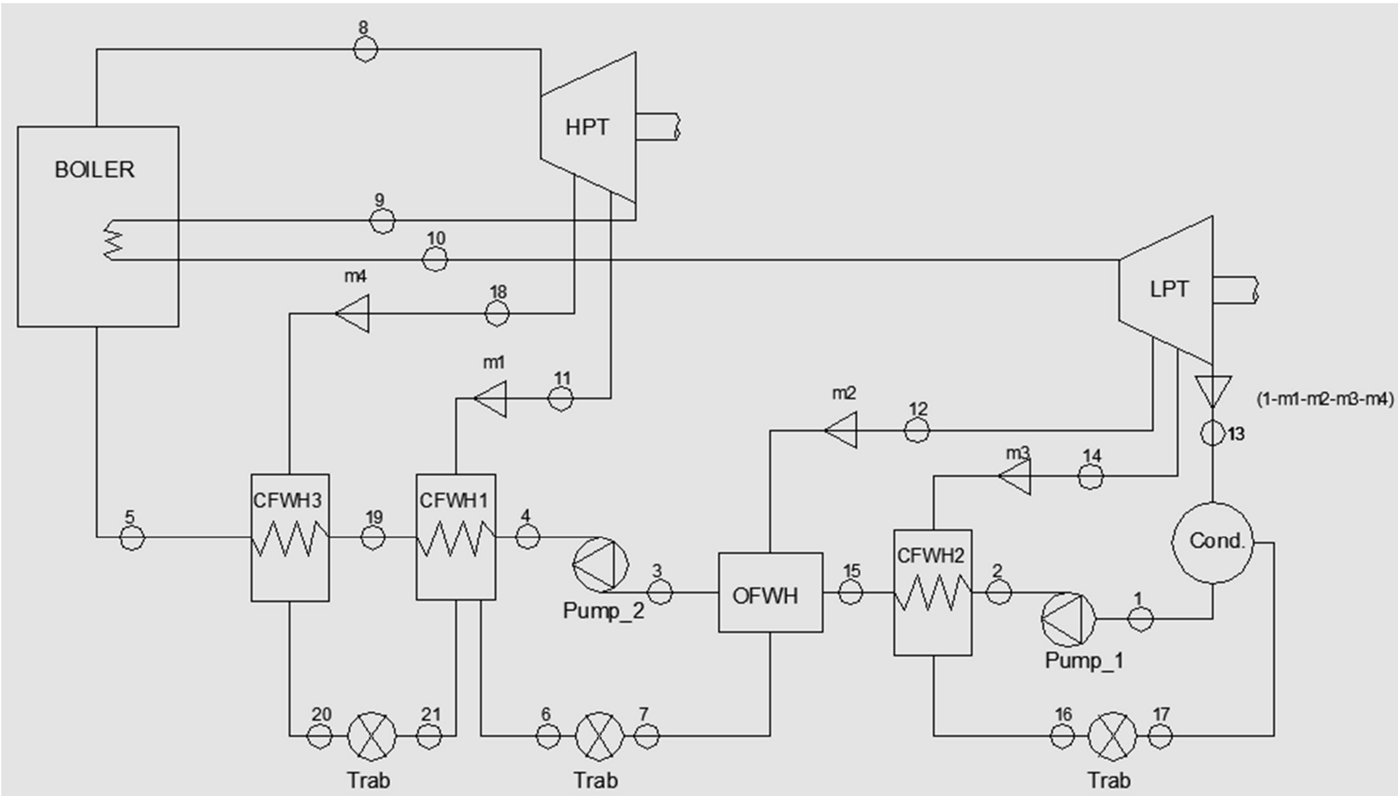
$$m_3 = \frac{(1 - m_1 - m_2 - m_4)(h_{15} - h_2)}{h_{14} - h_{16}}$$

$$\boldsymbol{Q_{add}} = (h_8 - h_5) + (1 - m_1 - m_4)(h_{10} - h_9)$$

$$\boldsymbol{Q_{rej.}} = (1 - m_1 - m_2 - m_3 - m_4)(h_{13} - h_1) + (m_3)(h_{17} - h_1)$$

$$\eta_{\boldsymbol{P}} = 1 - \frac{\boldsymbol{Q_{rej.}}}{\boldsymbol{Q_{add}}}$$

3rd proposal one OFWH &THREE CFWH 5th case



$$h_1 = h_f \;\&\; s_1 = s_f \;@\; P_{Cond.}$$

$$s_{2S} = s_1$$

$$h_{2S} \;@\; s_{2s} \;\&\; P_O$$

$$h_2 = \frac{1}{\eta_P} * (h_{2S} - h_1) + h_1$$

$$h_{16} = h_f \;\&\; T_{16} = T_{sat.} \;@P_{close_2}$$

$$h_{17} = h_{16}$$

$$\mathrm{T}_{15} = \mathrm{T}_{16} \;\text{ as }\; TTD = zero$$

$$h_{15} \;@\; P_O \& \, T_{16}$$

$h_3 = h_f$ & $s_3 = s_f$ @ P_O

h_{4s} @ s_3 & P_O

$$h_4 = \frac{1}{\eta_P} * (h_{4S} - h_3) + h_3$$

$h_{20} = h_f$ & $T_{20} = T_{sat}.$ @P_{close_3}

$h_{21} = h_{20}$

$h_{19} = h_f$@ P_O& T_{20}

$h_6 = h_f$ & $\mathrm{T}_6 = \mathrm{T}_{\mathrm{sat.}}$ @ $P_{Clos\ 1}$

$h_6 = h_7$

$\mathrm{T}_5 = \mathrm{T}_6$ as $TTD = zero$

h_5 @ P_B & T_6

h_8 @ P_B & T_{max} From TS diagram

$h_{11\mathrm{s}}$ From TS diagram

$h_{11} = h_8 - \eta_t * (h_8 - h_{11\mathrm{s}})$

$h_{18\mathrm{s}}$ From TS diagram

$h_{18} = h_{11} - \eta_t * (h_{11} - h_{18\mathrm{s}})$

$h_{9\mathrm{s}}$ From TS diagram

$h_9 = h_{18} - \eta_t * (h_{18} - h_{9\mathrm{s}})$

h_{10} @ P_B & T_{max} From TS diagram

$h_{12\mathrm{s}}$ From TS diagram

$h_{12} = h_{10} - \eta_t * (h_{10} - h_{12\mathrm{s}})$

$h_{14\mathrm{s}}$ From TS diagram

$h_{14} = h_{12} - \eta_t * (h_{12} - h_{14\mathrm{s}})$

h_{13s} From TS diagram

$$h_{13} = h_{14} - \eta_t * (h_{14} - h_{13s})$$

$$m_4 = \frac{h_5 - h_{19}}{h_{18} - h_{20}}$$

$$m_1 = \frac{h_{19} - (h_{21} - h_6)m_4 - h_4}{h_{11} - h_6}$$

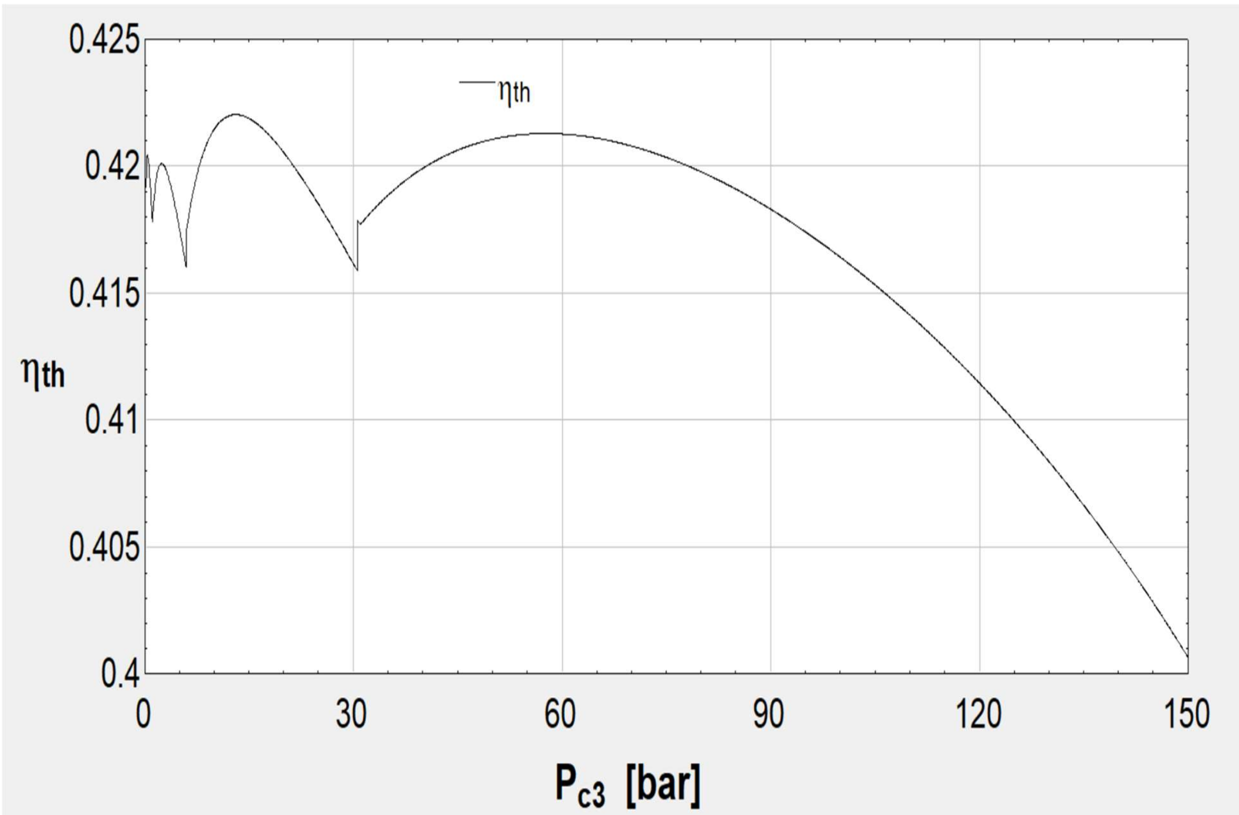
$$m_2 = \frac{h_3 - (1 - m_1 - m_4)h_{15} - h_{21}(m_1 + m_4)}{h_{12} - h_{15}}$$

$$m_3 = \frac{(1 - m_1 - m_2 - m_4)(h_{15} - h_2)}{h_{14} - h_{16}}$$

$$\boldsymbol{Q_{add}} = (h_8 - h_5) + (1 - m_1 - m_4)(h_{10} - h_9)$$

$$\boldsymbol{Q_{rej.}} = (1 - m_1 - m_2 - m_3 - m_4)(h_{13} - h_1) + (m_3)(h_{17} - h_1)$$

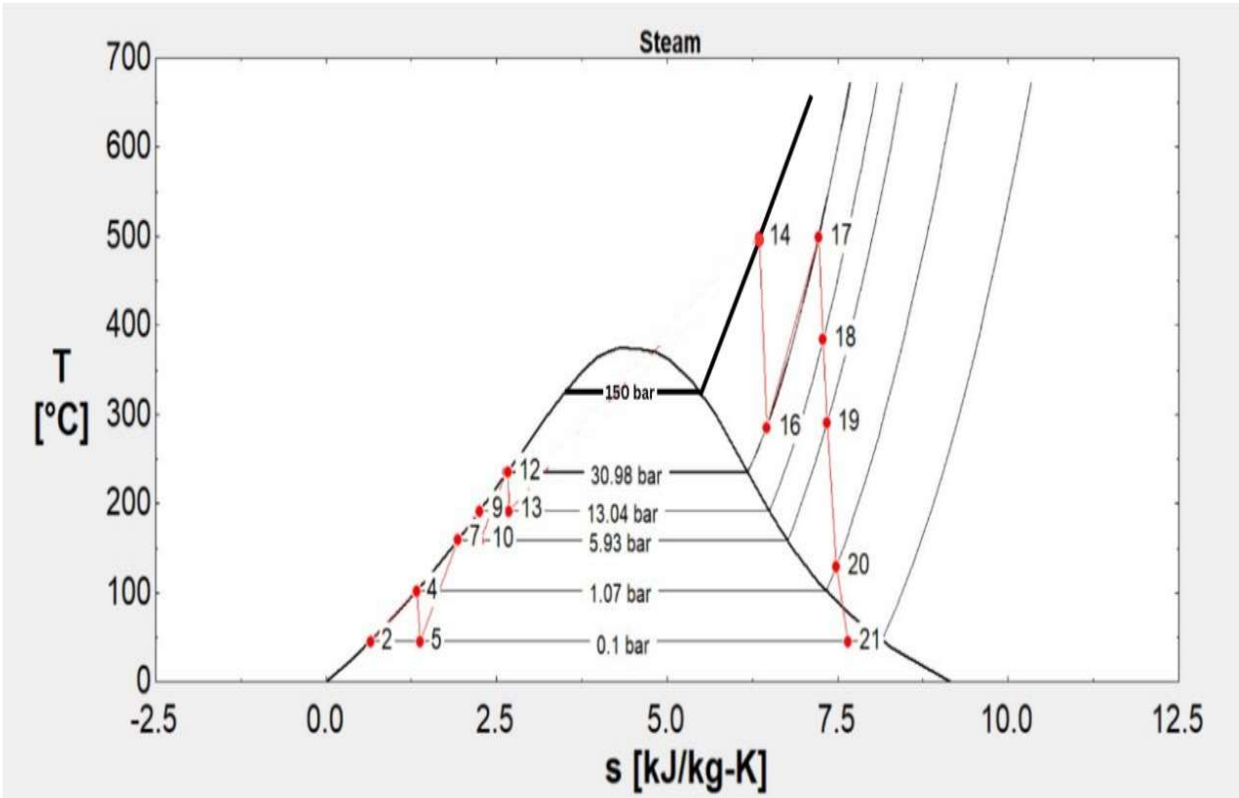
$$\eta_{\boldsymbol{P}} = \mathbf{1} - \frac{\boldsymbol{Q_{rej.}}}{\boldsymbol{Q_{add}}}$$

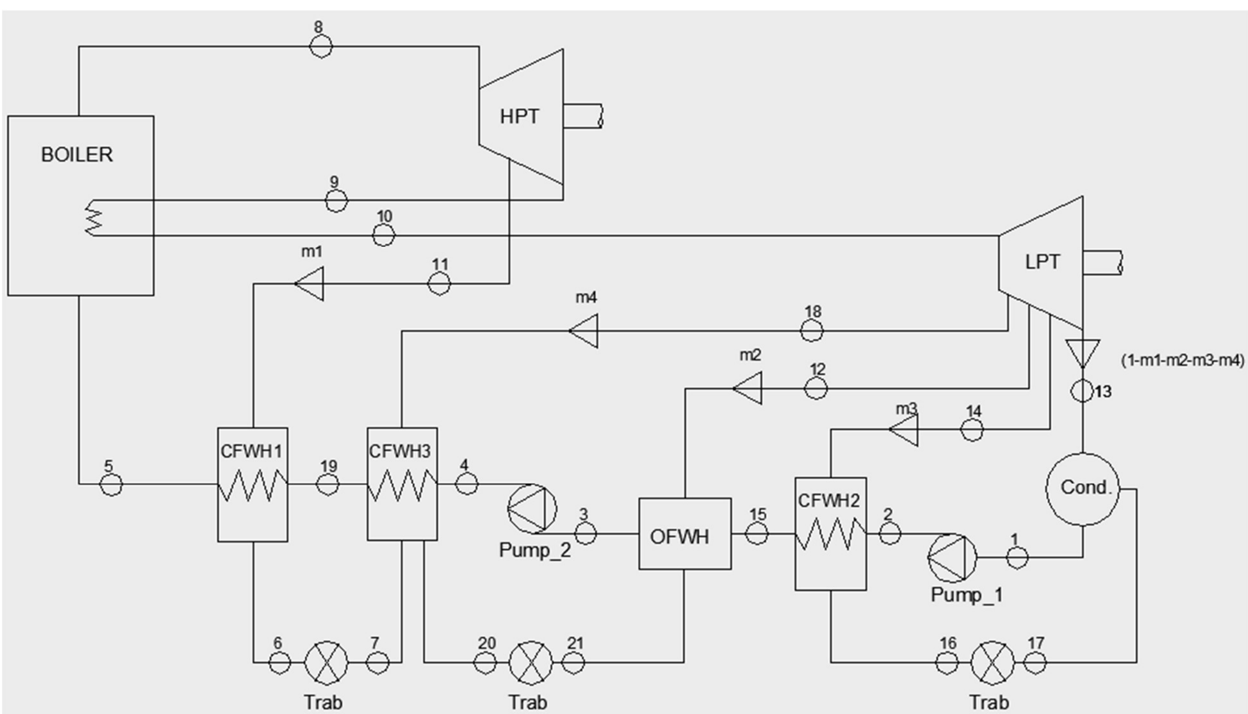


Maximization of eta_th(P_c3) 21 iterations: Quadratic Approximations method

$\eta_{th} = 0.4220$ $P_{c3} = 13.04$ [bar] $\dot{W}_{net} = 1157.353$ [kJ/kg]

The best layout





1-4th Proposal one OFWH & Four CFWH.

In this proposal we have six cases we will start with the…

<u>properties that are independent of P_{C4}:</u>

$h_1 = h_f$ @ P_c

$S_1 = S_f$ @ P_c

$h_{2S} = h$ @P_o & S_1

$h_2 = h_1 + \frac{h_{2S} - h_1}{\eta_P}$

$h_7 = h_f$ @ P_{c2}

$h_8 = h_7$

$T_7 = T$ @ P_{C2} &h_7

$T_6 = T_7$

$h_6 = h$ @ T_6 & P_o

$h_9 = h_f$ @ P_o

$S_9 = S_f$ @ P_o

$h_{10s} = h$ @ P_B & S_9

$h_{10} = h_9 + \frac{h_{10S} - h_9}{\eta_P}$

$h_{12} = h_f$ @ P_{C3}

$h_{13} = h_{12}$

$T_{12} = T$ @ P_{C3} &h_{12}

$T_{11} = T_{12}$

$h_{11} = h$ @ P_B & T_{11}

$h_{15} = h_f$ @P_{C1}

$h_{16} = h_{15}$

$T_{15} = T$ @ P_{C1}&h_{15}

$T_{14} = T_{15}$

$h_{14} = h$ @ P_B & T_{14}

$h_{17} = h$ @ T_{MAX} & P_B

$S_{17} = S$ @ P_B & h_{17}

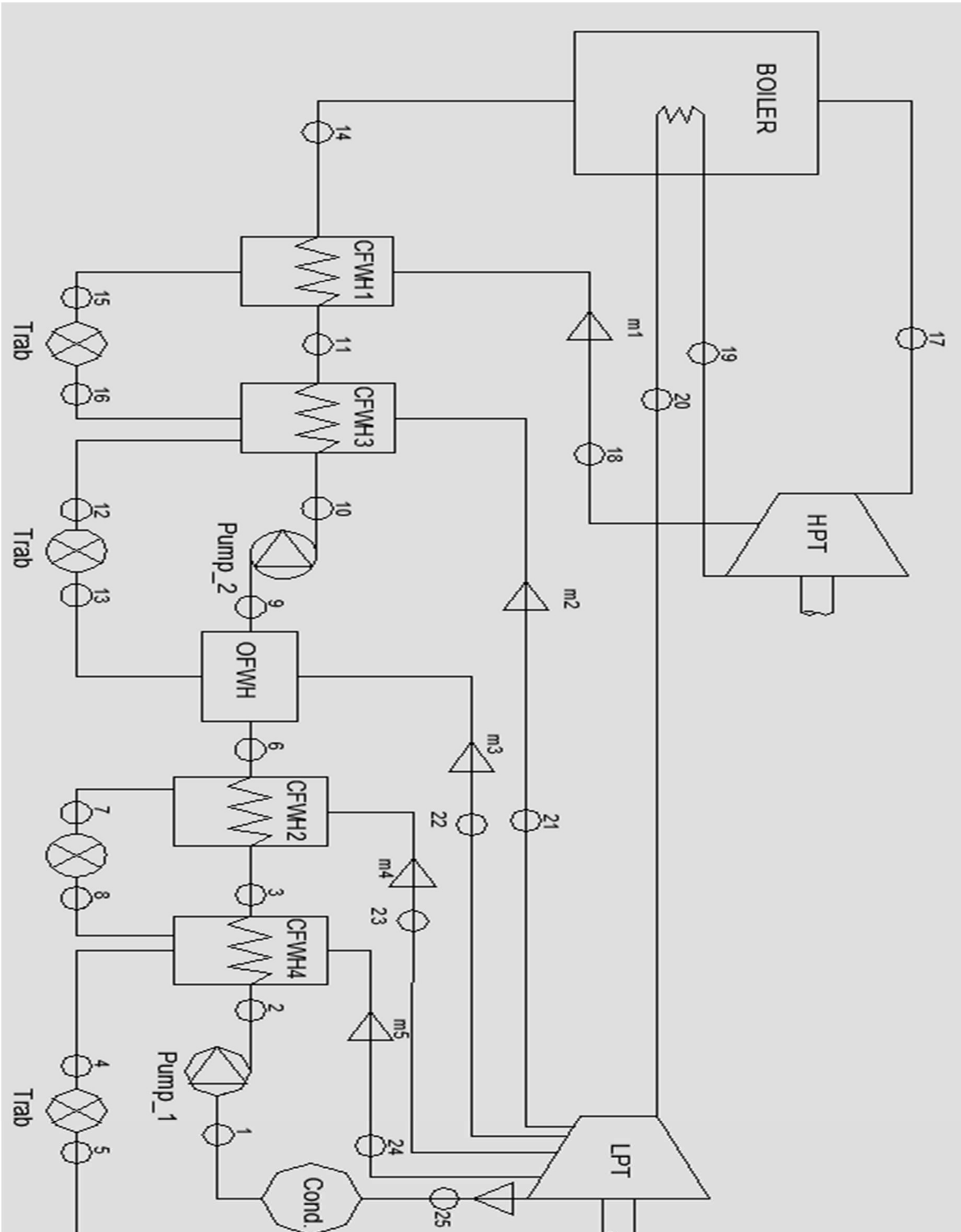
$h_{20} = h$ @ T_{MAX} & P_R

$S_{20} = S$ @ P_R & h_{20}

Note: we will remain the indexing of the 4th CFWH constant

- 24 is the inlet.
- 3 is the outlet.
- 4&5 are the backward branch.

<u>Case 1:</u> $P_{C4} < P_{C2}$



$h_4 = h_f$ @ P_{C4}

$h_5 = h_4$

$T_4 = T$ @ P_{C4} & h_4

$T_3 = T_4$

$h_3 = h$ @ T_3 & P_o

$h_{18S} = h$ @ P_{C1} & S_{17}

$$h_{18} = h_{17} + \frac{h_{18s} - h_{17}}{\eta_T}$$

$S_{18} = S$ @ P_{C1} & h_{18}

$h_{19s} = h$ @ P_R & S_{18}

$$h_{19} = h_{18} - \frac{h_{18} - h_{19s}}{\eta_T}$$

$h_{21S} = h$ @ P_{C3} & S_{20}

$$h_{21} = h_{20} - \frac{h_{20} - h_{21s}}{\eta_T}$$

$S_{21} = S$ @ P_{C3} & h_{21}

$H_{22S} = h$ @ P_O & S_{21}

$$h_{22} = h_{21} - \frac{h_{21} - h_{22s}}{\eta_T}$$

$S_{22} = S$ @ P_O & h_{22}

$H_{23S} = h$ @ P_{C2} & S_{22}

$$H_{23} = h_{22} - \frac{h_{22} - h_{23s}}{\eta_T}$$

$S_{23} = S$ @ P_{C2} & h_{23}

$H_{24S} = h$ @ P_{C4} & S_{23}

$$H_{24} = h_{23} - \frac{h_{23} - h_{24s}}{\eta_T}$$

$S_{24} = S$ @ P_{C4} & h_{24}

$H_{25s} = h$ @ P_C & S_{24}

$$H_{25} = h_{24} - \frac{h_{24} - h_{25s}}{\eta_T}$$

$$\mathbf{m_1} = \frac{h_{14} - h_{11}}{h_{18} - h_{15}}$$

$$\mathbf{m_2} = \frac{h_{11} - h_{10} + m_1(h_{12} - h_{16})}{h_{21} - h_{12}}$$

$$\mathbf{m_3} = \frac{h_9 - h_6 + (m_1 + m_2)(h_6 - h_{13})}{h_{22} - h_6}$$

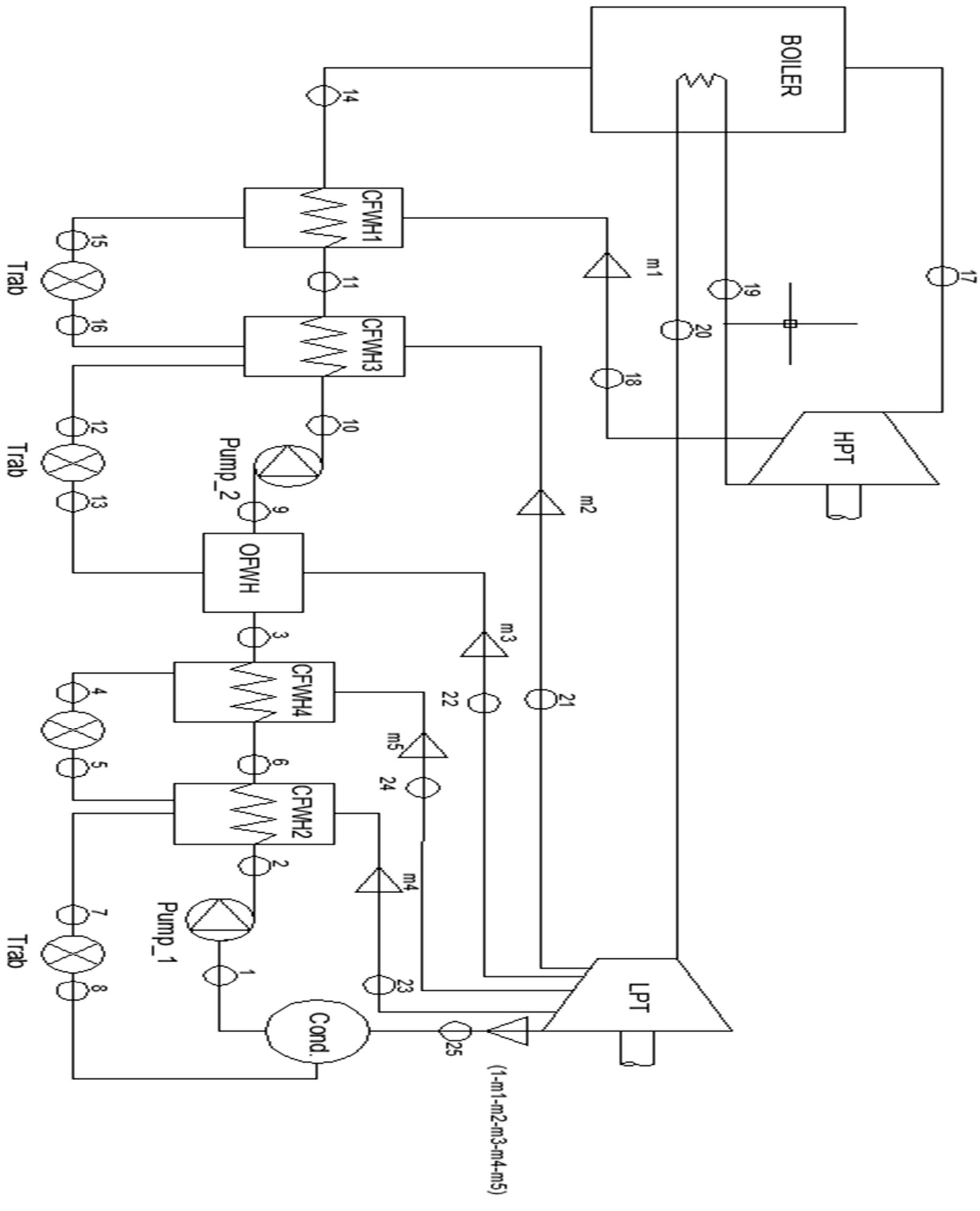
$$\mathbf{m_4} = \frac{(1 - m_1 - m_2 - m_3)(h_6 - h_3)}{h_{23} - h_7}$$

$$\mathbf{m_5} = \frac{m_4(h_4 - h_8) + (1 - m_1 - m_2 - m_3)(h_3 - h_2)}{h_{24} - h_4}$$

$$\dot{Q}_{rej} = (1 - m_1 - m_2 - m_3 - m_4 - m_5)h_{25} + (m_4 + m_5)h_5 - (1 - m_1 - m_2 - m_3)h_1$$

$$\dot{Q}_{add} = h_{17} - h_{14} + (h_{20} - h_{19}) * (1 - m_1)$$

Case 2: $P_{C4} < P_O$


BOILER
HPT
LPT
CFWH1
CFWH3
CFWH4
CFWH2
OFWH
Pump_1
Pump_2
Cond.
Trab
Trab
Trab
m1
m2
m3
m4
m5
(1-m1-m2-m3-m4-m5)
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3
4
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7
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25

$h_4 = h_f\ @P_{C4}$

$h_5 = h_4$

$T_4 = T\ @\ P_{C4}\&h_4$

$T_3 = T_4$

$h_3 = h\ @\ T_3\ \&\ P_o$

$h_{18S} = h\ @\ P_{C1}\ \&S_{17}$

$h_{18} = h_{17} + \frac{h_{18}\ - h_{17}}{\eta_T}$

$S_{18} = S\ @\ P_{C1}\ \&\ h_{18}$

$h_{19s} = h\ @\ P_R\ \&\ S_{18}$

$h_{19} = h_{18} - \frac{h_{18} - h_{19s}}{\eta_T}$

$h_{21S} = h\ @\ P_{C3}\ \&S_{20}$

$h_{21} = h_{20} - \frac{h_{20} - h_{21s}}{\eta_T}$

$S_{21} = S\ @\ P_{C3}\ \&\ h_{21}$

$H_{22S} = h\ @\ P_O\ \&S_{21}$

$h_{22} = h_{21} - \frac{h_{21} - h_{22s}}{\eta_T}$

$S_{22} = S\ @\ P_O\ \&\ h_{22}$

$H_{24S} = h\ @\ P_{C4}\ \&S_{22}$

$H_{24} = h_{22} - \frac{h_{22} - h_{24s}}{\eta_T}$

$S_{24} = S\ @\ P_{C4}\ \&\ h_{24}$

$H_{23S} = h\ @\ P_{C2}\ \&S_{24}$

$H_{23} = h_{24} - \frac{h_{24} - h_{23s}}{\eta_T}$

$S_{23} = S\ @\ P_{C2}\ \&\ h_{23}$

$H_{25s} = h\ @\ P_C\ \&\ S_{23}$

$H_{25} = h_{23} - \frac{h_{23} - h_{25s}}{\eta_T}$

$$\mathbf{m_1} = \frac{h_{14}-h_{11}}{h_{18}-h_{15}}$$

$$\mathbf{m_2} = \frac{h_{11}-h_{10}+m_1(h_{12}-h_{16})}{h_{21}-h_{12}}$$

$$\mathbf{m_3} = \frac{h_9-h_3+(m_1+m_2)(h_3-h_{13})}{h_{22}-h_3}$$

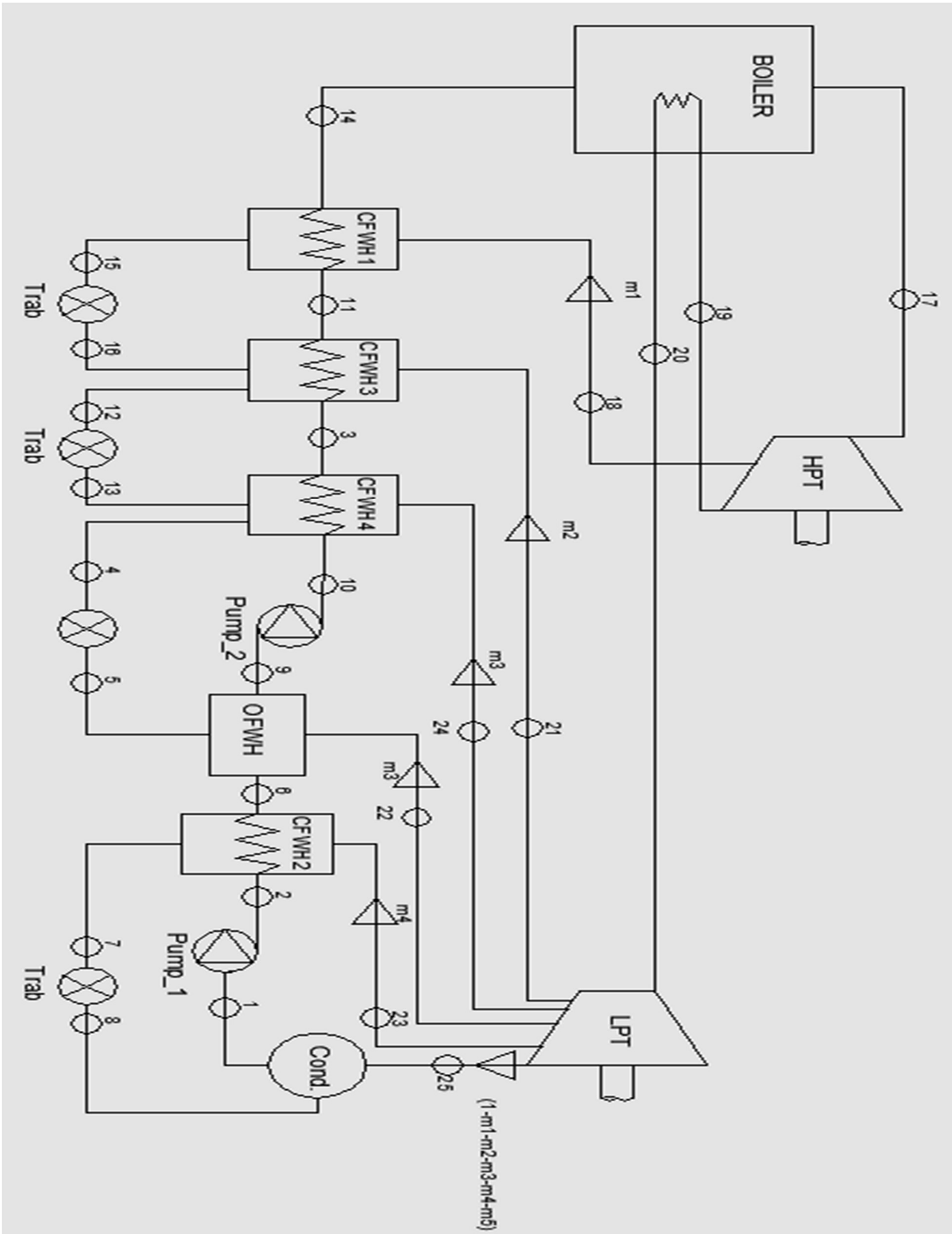
$$\mathbf{m_5} = \frac{(1-m_1-m_2-m_3)(h_3-h_6)}{h_{24}-h_4}$$

$$\mathbf{m_4} = \frac{m_5(h_7-h_5)+(1-m_1-m_2-m_3)(h_6-h_2)}{h_{23}-h_7}$$

$$\dot{Q}_{rej} = (\mathbf{1} - \mathbf{m_1} - \mathbf{m_2} - \mathbf{m_3} - \mathbf{m_4} - \mathbf{m_5})\mathbf{h_{25}} + (\mathbf{m_4} + \mathbf{m_5})\mathbf{h_8} - (\mathbf{1} - \mathbf{m_1} - \mathbf{m_2} - \mathbf{m_3})\mathbf{h_1}$$

$$\dot{Q}_{add} = \mathbf{h_{17}} - \mathbf{h_{14}} + (\mathbf{h_{20}} - \mathbf{h_{19}}) * (\mathbf{1} - \mathbf{m_1})$$

<u>Case 3:</u> $P_{C4} < P_{C3}$



$h_4 = h_f\ @P_{C4}$

$h_5 = h_4$

$T_4 = T\ @\ P_{C4}\&h_4$

$T_3 = T_4$

$h_3 = h\ @\ T_3\ \&\ P_B$

$h_{18S} = h\ @\ P_{C1}\ \&S_{17}$

$h_{18} = h_{17} + \frac{h_{18s} - h_{17}}{\eta_T}$

$S_{18} = S\ @\ P_{C1}\ \&\ h_{18}$

$h_{19s} = h\ @\ P_R\ \&\ S_{18}$

$h_{19} = h_{18} - \frac{h_{18} - h_{19s}}{\eta_T}$

$h_{21S} = h\ @\ P_{C3}\ \&S_{20}$

$h_{21} = h_{20} - \frac{h_{20} - h_{21s}}{\eta_T}$

$S_{21} = S\ @\ P_{C3}\ \&\ h_{21}$

$H_{24S} = h\ @\ P_{C4}\ \&S_{21}$

$H_{24} = h_{21} - \frac{h_{21} - h_{24s}}{\eta_T}$

$S_{24} = S\ @\ P_{C4}\ \&\ h_{24}$

$H_{22S} = h\ @\ P_O\ \&S_{24}$

$h_{22} = h_{24} - \frac{h_{24} - h_{22s}}{\eta_T}$

$S_{22} = S\ @\ P_O\ \&\ h_{22}$

$H_{23S} = h\ @\ P_{C2}\ \&S_{22}$

$H_{23} = h_{22} - \frac{h_{22} - h_{23s}}{\eta_T}$

$S_{23} = S\ @\ P_{C2}\ \&\ h_{23}$

$H_{25s} = h\ @\ P_C\ \&\ S_{23}$

$H_{25} = h_{23} - \frac{h_{23} - h_{25s}}{\eta_T}$

$$\mathbf{m_1} = \frac{\boldsymbol{h_{14}-h_{11}}}{\boldsymbol{h_{18}-h_{15}}}$$

$$\mathbf{m_2} = \frac{\boldsymbol{h_{11}-h_3+m_1(h_{12}-h_{16})}}{\boldsymbol{h_{21}-h_{12}}}$$

$$\mathbf{m_5} = \frac{\boldsymbol{h_3-h_{10}+(m_1+m_2)(h_4-h_{13})}}{\boldsymbol{h_{24}-h_4}}$$

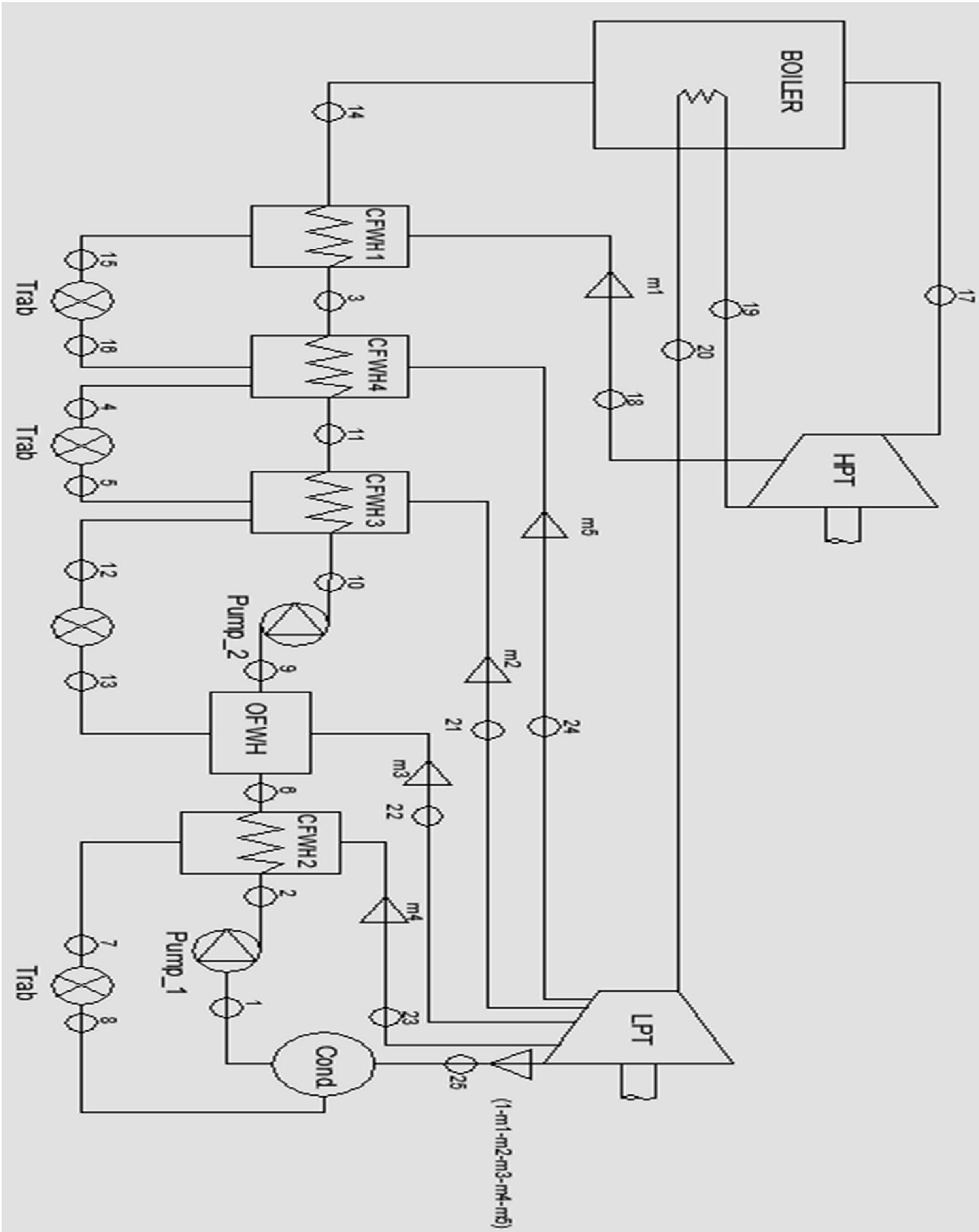
$$\mathbf{m_3} = \frac{\boldsymbol{h_9-h_6+(m_1+m_2+m_5)(h_6-h_5)}}{\boldsymbol{h_{22}-h_6}}$$

$$\mathbf{m_4} = \frac{\boldsymbol{(1-m_1-m_2-m_3-m_5)(h_6-h_2)}}{\boldsymbol{h_{23}-h_7}}$$

$$\dot{\boldsymbol{Q}}_{\boldsymbol{rej}} = (\mathbf{1}-\mathbf{m_1}-\mathbf{m_2}-\mathbf{m_3}-\mathbf{m_4}-\mathbf{m_5})\mathbf{h_{25}}+\mathbf{m_4h_8}-(\mathbf{1}-\mathbf{m_1}-\mathbf{m_2}-\mathbf{m_3}-\mathbf{m_5})\mathbf{h_1}$$

$$\dot{\boldsymbol{Q}}_{\boldsymbol{add}} = \mathbf{h_{17}}-\mathbf{h_{14}}+(\mathbf{h_{20}}-\mathbf{h_{19}})*(\mathbf{1}-\mathbf{m_1})$$

<u>Case 4:</u> $P_{C4} < P_R$



$h_4 = h_f$ @ P_{C4}

$h_5 = h_4$

$T_4 = T$ @ P_{C4} & h_4

$T_3 = T_4$

$h_3 = h$ @ T_3 & P_B

$h_{18S} = h$ @ P_{C1} & S_{17}

$h_{18} = h_{17} + \frac{h_{18s} - h_{17}}{\eta_T}$

$S_{18} = S$ @ P_{C1} & h_{18}

$h_{19s} = h$ @ P_R & S_{18}

$h_{19} = h_{18} - \frac{h_{18} - h_{19s}}{\eta_T}$

$H_{24S} = h$ @ P_{C4} & S_{20}

$H_{24} = h_{20} - \frac{h_{20} - h_{24s}}{\eta_T}$

$S_{24} = S$ @ P_{C4} & h_{24}

$h_{21S} = h$ @ P_{C3} & S_{24}

$h_{21} = h_{24} - \frac{h_{24} - h_{21s}}{\eta_T}$

$S_{21} = S$ @ P_{C3} & h_{21}

$H_{22S} = h$ @ P_O & S_{21}

$h_{22} = h_{21} - \frac{h_{21} - h_{22s}}{\eta_T}$

$S_{22} = S$ @ P_O & h_{22}

$H_{23S} = h$ @ P_{C2} & S_{22}

$H_{23} = h_{22} - \frac{h_{22} - h_{23s}}{\eta_T}$

$S_{23} = S$ @ P_{C2} & h_{23}

$H_{25s} = h$ @ P_C & S_{23}

$H_{25} = h_{23} - \frac{h_{23} - h_{25s}}{\eta_T}$

$$\mathbf{m_1} = \frac{\boldsymbol{h_{14} - h_{11}}}{\boldsymbol{h_{18} - h_{15}}}$$

$$\mathbf{m_5} = \frac{\boldsymbol{h_3 - h_{11} + m_1(h_4 - h_{16})}}{\boldsymbol{h_{24} - h_4}}$$

$$\mathbf{m_2} = \frac{\boldsymbol{h_{11} - h_{10} + (m_1 + m_5)(h_{12} - h_5)}}{\boldsymbol{h_{21} - h_{12}}}$$

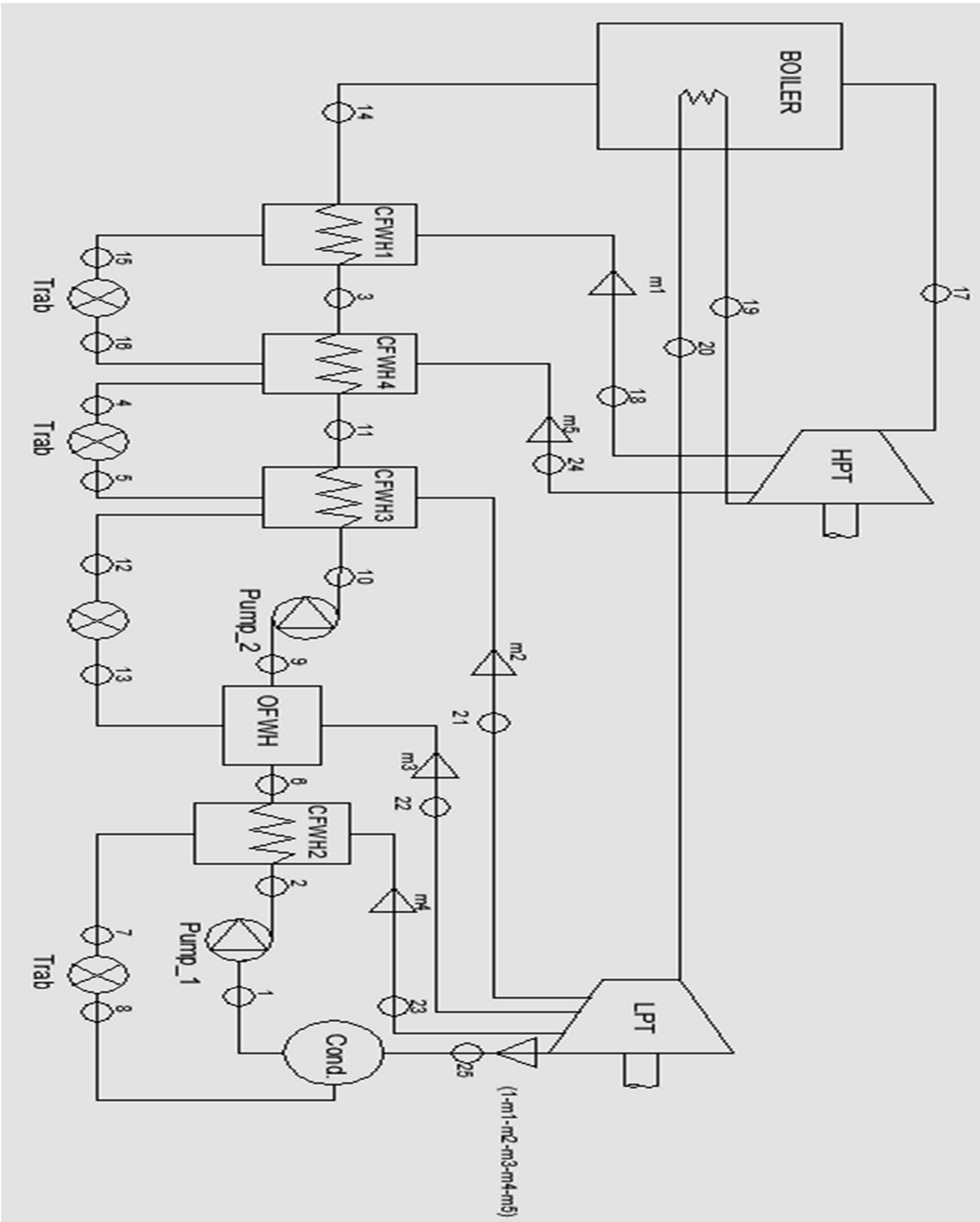
$$\mathbf{m_3} = \frac{\boldsymbol{h_9 - h_6 + (m_1 + m_2 + m_5)(h_6 - h_{13})}}{\boldsymbol{h_{22} - h_6}}$$

$$\mathbf{m_4} = \frac{\boldsymbol{(1 - m_1 - m_2 - m_3 - m_5)(h_6 - h_2)}}{\boldsymbol{h_{23} - h_7}}$$

$$\dot{Q}_{rej} = (\mathbf{1} - \mathbf{m_1} - \mathbf{m_2} - \mathbf{m_3} - \mathbf{m_4} - \mathbf{m_5})\mathbf{h_{25}} + \mathbf{m_4 h_8} - (\mathbf{1} - \mathbf{m_1} - \mathbf{m_2} - \mathbf{m_3} - \mathbf{m_5})\mathbf{h_1}$$

$$\dot{Q}_{add} = \mathbf{h_{17}} - \mathbf{h_{14}} + (\mathbf{h_{20}} - \mathbf{h_{19}}) * (\mathbf{1} - \mathbf{m_1})$$

<u>Case 5:</u> $P_{C4} < P_{C1}$



$h_4 = h_f\ @P_{C4}$

$h_5 = h_4$

$T_4 = T\ @\ P_{C4} \& h_4$

$T_3 = T_4$

$h_3 = h\ @\ T_3\ \&\ P_B$

$h_{18S} = h\ @\ P_{C1}\ \& S_{17}$

$h_{18} = h_{17} + \frac{h_{18}\ - h_{17}}{\eta_T}$

$S_{18} = S\ @\ P_{C1}\ \&\ h_{18}$

$H_{24S} = h\ @\ P_{C4}\ \& S_{18}$

$H_{24} = h_{18} - \frac{h_{18} - h_{24s}}{\eta_T}$

$S_{24} = S\ @\ P_{C4}\ \&\ h_{24}$

$h_{19s} = h\ @\ P_R\ \&\ S_{24}$

$h_{19} = h_{24} - \frac{h_{24} - h_{19s}}{\eta_T}$

$h_{21S} = h\ @\ P_{C3}\ \& S_{24}$

$h_{21} = h_{24} - \frac{h_{24} - h_{21s}}{\eta_T}$

$S_{21} = S\ @\ P_{C3}\ \&\ h_{21}$

$H_{22S} = h\ @\ P_O\ \& S_{21}$

$h_{22} = h_{21} - \frac{h_{21} - h_{22s}}{\eta_T}$

$S_{22} = S\ @\ P_O\ \&\ h_{22}$

$H_{23S} = h\ @\ P_{C2}\ \& S_{22}$

$H_{23} = h_{22} - \frac{h_{22} - h_{23s}}{\eta_T}$

$S_{23} = S\ @\ P_{C2}\ \&\ h_{23}$

$H_{25s} = h\ @\ P_C\ \&\ S_{23}$

$H_{25} = h_{23} - \frac{h_{23} - h_{25s}}{\eta_T}$

$$\mathbf{m_1} = \frac{h_{14}-h_3}{h_{18}-h_{15}}$$

$$\mathbf{m_5} = \frac{h_3-h_{11}+m_1(h_4-h_{16})}{h_{24}-h_4}$$

$$\mathbf{m_2} = \frac{h_{11}-h_{10}+(m_1+m_5)(h_{12}-h_5)}{h_{21}-h_{12}}$$

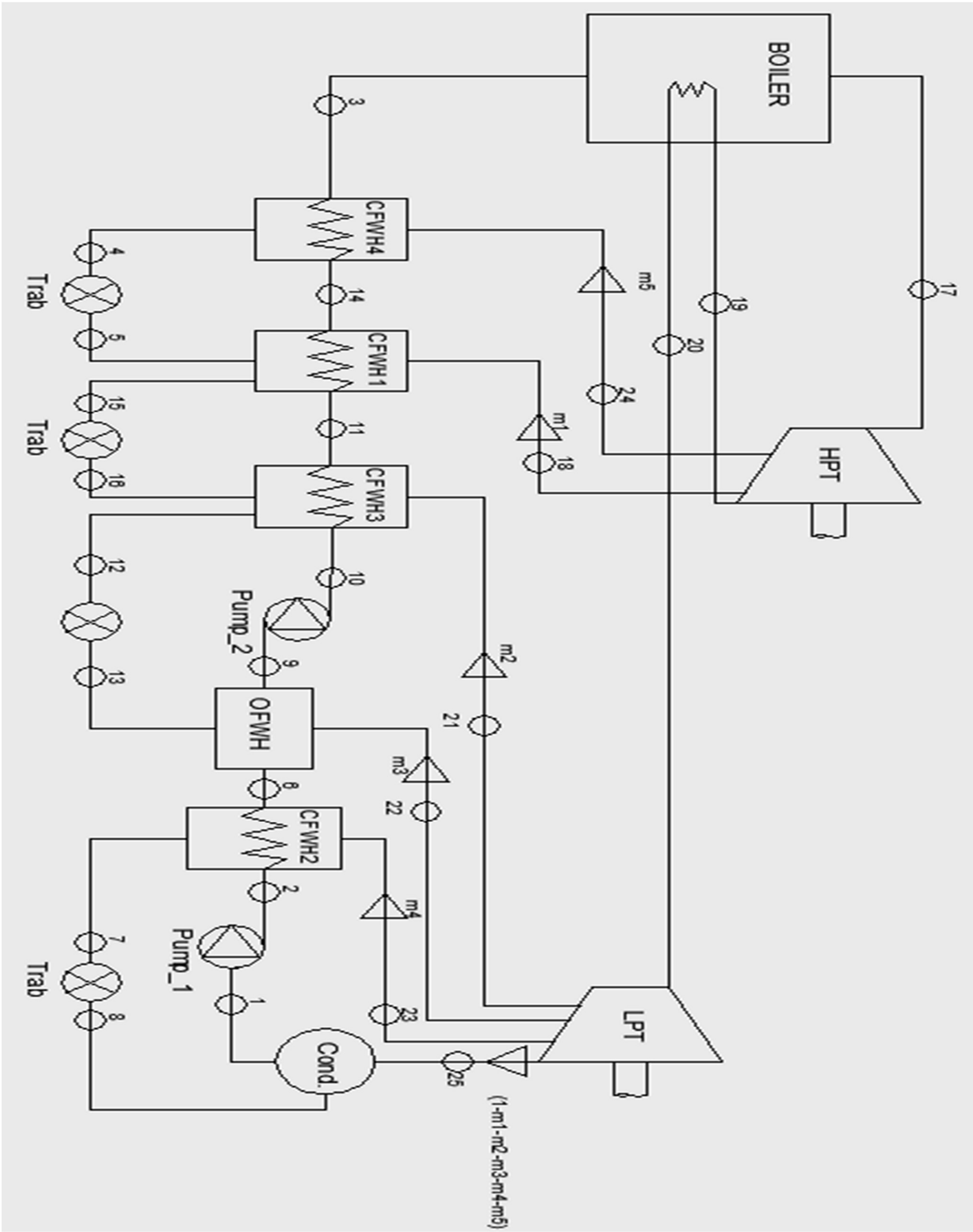
$$\mathbf{m_3} = \frac{h_9-h_6+(m_1+m_2+m_5)(h_6-h_{13})}{h_{22}-h_6}$$

$$\mathbf{m_4} = \frac{(1-m_1-m_2-m_3-m_5)(h_6-h_2)}{h_{23}-h_7}$$

$$\dot{Q}_{rej} = (\mathbf{1} - \mathbf{m_1} - \mathbf{m_2} - \mathbf{m_3} - \mathbf{m_4} - \mathbf{m_5})\mathbf{h_{25}} + \mathbf{m_4 h_8} - (\mathbf{1} - \mathbf{m_1} - \mathbf{m_2} - \mathbf{m_3} - \mathbf{m_5})\mathbf{h_1}$$

$$\dot{Q}_{add} = \mathbf{h_{17}} - \mathbf{h_{14}} + (\mathbf{h_{20}} - \mathbf{h_{19}}) * (\mathbf{1} - \mathbf{m_1} - \mathbf{m_5})$$

Case 6: $P_{C4} < P_B$


BOILER
HPT
LPT
CFWH4
CFWH1
CFWH3
CFWH2
OFWH
Cond.
Pump_1
Pump_2
Trab
Trab
Trab
m1
m2
m3
m4
m5
(1-m1-m2-m3-m4-m5)
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24
25

$h_4 = h_f$ @ P_{C4}

$h_5 = h_4$

$T_4 = T$ @ P_{C4} & h_4

$T_3 = T_4$

$h_3 = h$ @ T_3 & P_B

$H_{24S} = h$ @ P_{C4} & S_{17}

$H_{24} = h_{17} - \frac{h_{17} - h_{24s}}{\eta_T}$

$S_{24} = S$ @ P_{C4} & h_{24}

$h_{18S} = h$ @ P_{C1} & S_{24}

$h_{18} = h_{24} + \frac{h_{18s} - h_{24}}{\eta_T}$

$S_{18} = S$ @ P_{C1} & h_{18}

$h_{19s} = h$ @ P_R & S_{18}

$h_{19} = h_{18} - \frac{h_{18} - h_{19s}}{\eta_T}$

$h_{21S} = h$ @ P_{C3} & S_{24}

$h_{21} = h_{24} - \frac{h_{24} - h_{21s}}{\eta_T}$

$S_{21} = S$ @ P_{C3} & h_{21}

$H_{22S} = h$ @ P_O & S_{21}

$h_{22} = h_{21} - \frac{h_{21} - h_{22s}}{\eta_T}$

$S_{22} = S$ @ P_O & h_{22}

$H_{23S} = h$ @ P_{C2} & S_{22}

$H_{23} = h_{22} - \frac{h_{22} - h_{23s}}{\eta_T}$

$S_{23} = S$ @ P_{C2} & h_{23}

$H_{25s} = h$ @ P_C & S_{23}

$H_{25} = h_{23} - \frac{h_{23} - h_{25s}}{\eta_T}$

$$\mathbf{m_5} = \frac{h_3 - h_{14} + m_1(h_{24} - h_4)}{h_{24} - h_4}$$

$$\mathbf{m_1} = \frac{h_{14} - h_{11} + m_5(h_{15} - h_5)}{h_{18} - h_{15}}$$

$$\mathbf{m_2} = \frac{h_{11} - h_{10} + (m_1 + m_5)(h_{12} - h_{16})}{h_{21} - h_{12}}$$

$$\mathbf{m_3} = \frac{h_9 - h_6 + (m_1 + m_2 + m_5)(h_6 - h_{13})}{h_{22} - h_6}$$

$$\mathbf{m_4} = \frac{(1 - m_1 - m_2 - m_3 - m_5)(h_6 - h_2)}{h_{23} - h_7}$$

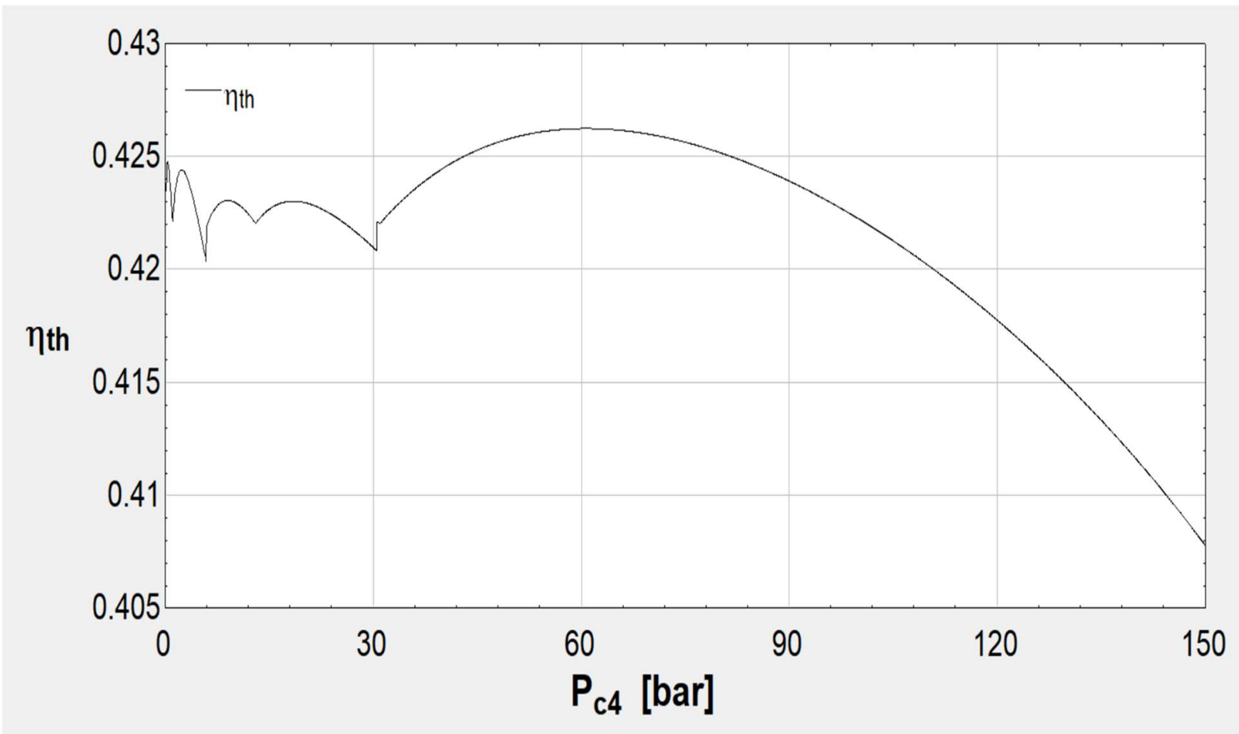
$$\dot{Q}_{rej} = (\mathbf{1} - \mathbf{m_1} - \mathbf{m_2} - \mathbf{m_3} - \mathbf{m_4} - \mathbf{m_5})\mathbf{h_{25}} + \mathbf{m_4 h_8} - (\mathbf{1} - \mathbf{m_1} - \mathbf{m_2} - \mathbf{m_3} - \mathbf{m_5})\mathbf{h_1}$$

$$\dot{Q}_{add} = \mathbf{h_{17}} - \mathbf{h_3} + (\mathbf{h_{20}} - \mathbf{h_{19}}) * (\mathbf{1} - \mathbf{m_1} - \mathbf{m_5})$$

For all cases:

$W_{net} = \dot{Q}_{add} - \dot{Q}_{rej}$

$\eta_{TH} = 1 - \dfrac{\dot{\boldsymbol{Q}}_{\boldsymbol{rej}}}{\dot{\boldsymbol{Q}}_{\boldsymbol{add}}}$



Maximization of eta_th(P_c4) 18 iterations: Quadratic Approximations method

$\eta_{th} = 0.4262$ $P_{c4} = 60.69$ [bar] $\dot{W}_{net} = 1067.337$ [kJ/kg]

The best layout