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Table of contents

Steam Cycle

Steam cycle is used in steam power plants to generate a mechanical power from thermal energy that's produced from combustion, mechanical power is used to generate electricity by transferring the mechanical power to generators.

Simple steam cycle efficiency is always expected to be in range of 30-40 %, so modifications are used to increase this efficiency.

In this report, many methods will be discussed in detail with plots and tables to justify everything.

Simple Rankine Cycle

Consists of A boiler, condenser, pump, and a turbine.

Modifications expected to be used: Reheating and adding feed water heaters.

Feed water heaters have 2 kinds: Open feed water heaters and Closed feed water heaters.

OFWHs are usually used to rid of gases so it designed on a certain pressure in which these gases exit.

Advantages of Steam power station

Lower cost in built than other ones, low cost of used fuel compared to that used in nuclear and gaseous stations and getting higher electric energy from the fuel used in steam power station than from the same fuel quantity used in other stations.

Disadvantages

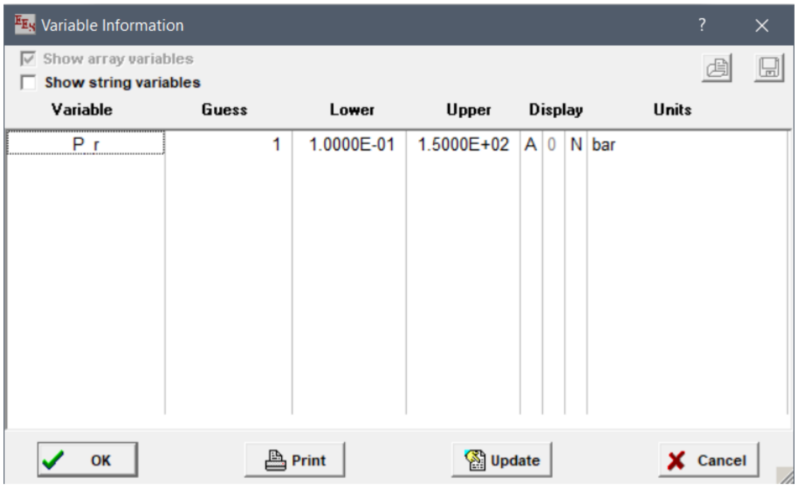
Environmental pollution, low efficiency because of continues losses in different level of operations, needs high quantity of cooling water, transporting fuel is a problem, steam power station must be built far from population areas and exhaustion of fuel by continues usage.

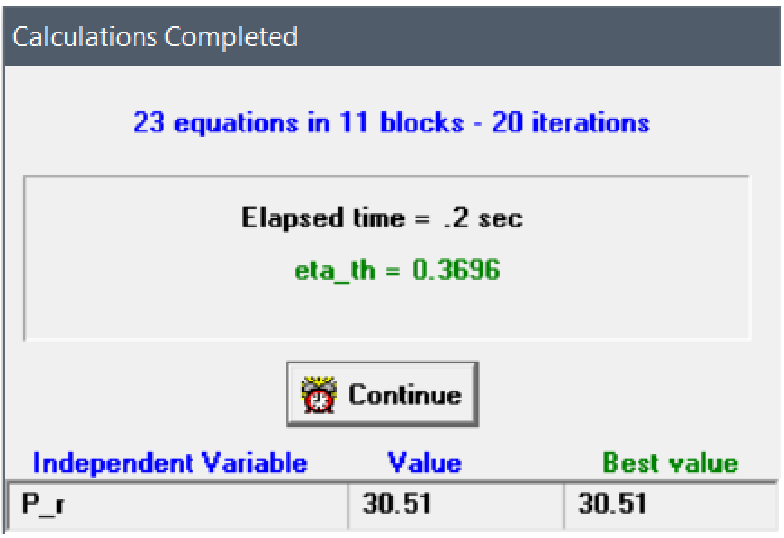
A) Reheat Rankine Cycle

Code

```
{Givens}


P_b=150;
P_c=.1;
T_max=500;
T_r=T_max
"P_r=P_c";
eta_t=0.85 ; eta_p=0.95;

{Solution}
"P1"
h_1=ENTHALPY(Steam,X=0,P=P_c)
s_1=ENTROPY(Steam,X=0,P=P_c)
"P2"
h_2s=ENTHALPY(Steam,s=s_1,P=P_b)
(h_2a - h_1)*eta_p=(h_2s - h_1)
"P3"
h_3=ENTHALPY(Steam,T=T_max,P=P_b)
s_3=ENTROPY(Steam,T=T_max,P=P_b)
"P4"
h_4s=ENTHALPY(Steam,s=s_3,P=P_r)
(h_3 - h_4s)*eta_t=(h_3 - h_4a)
"P5"
h_5=ENTHALPY(Steam,T=T_r,P=P_r)
s_5=ENTROPY(Steam,T=T_r,P=P_r)
"P6"
h_6s=ENTHALPY(Steam,s=s_5,P=P_c)
(h_5 - h_6s)*eta_t=(h_5 - h_6a)

"Requirements"
W_t=(h_3 - h_4a)+(h_5 - h_6a); W_p=h_2a - h_1;
W_net = W_t - W_p
Q_add = (h_3 - h_2a)+(h_5 - h_4a)
eta_th= W_net / Q_add
```

Varying Reheat Pressure using Max/min Tab

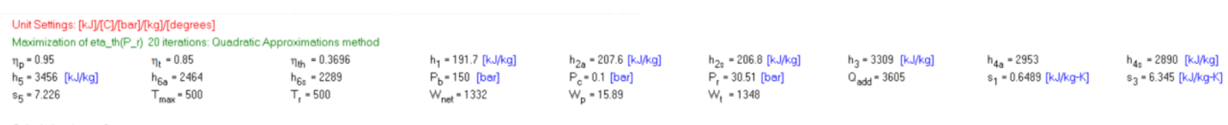


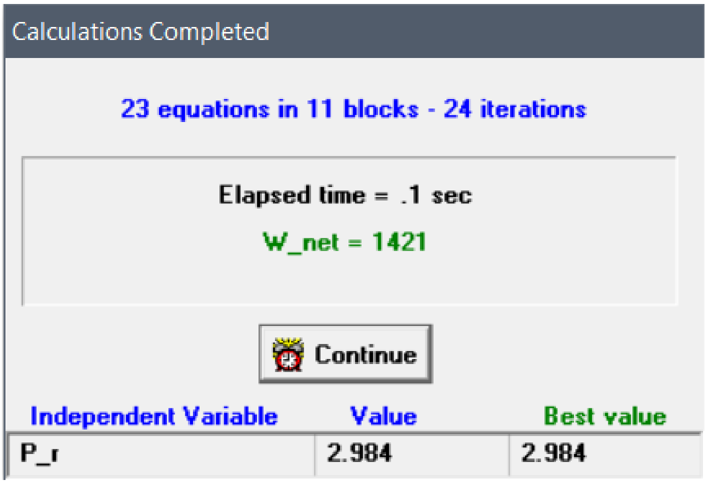


Optimum Reheat Pressure that maximizes efficiency= 30.51 bar

Maximum efficiency = 36.96%

Results tab for the maximum efficiency





Optimum Reheat Pressure that maximizes work net = 2.984 bar

Maximum Work net = 1421 kJ/kg

Results tab for maximum Work net

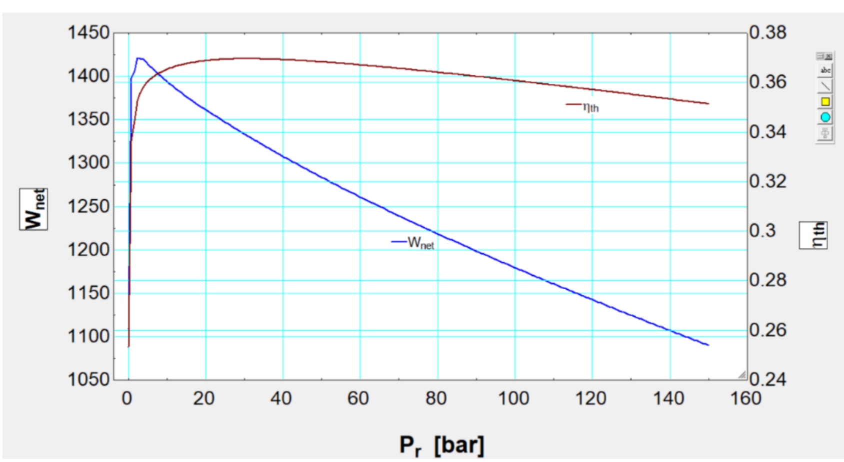
Unit Settings: [kJ]/[C]/[bar]/[kg]/[degrees]

Maximization of W_net(P_r) 24 iterations: Quadratic Approximations method

η_p = 0.95	η_t = 0.85	η_{th} = 0.3553	h_1 = 191.7 [kJ/kg]	h_{2a} = 207.6 [kJ/kg]	h_{2s} = 206.8 [kJ/kg]	h_3 = 3309 [kJ/kg]	h_{4a} = 2588	h_{4s} = 2461 [kJ/kg]
h_5 = 3486 [kJ/kg]	h_{6a} = 2770	h_{6s} = 2644	P_b = 150 [bar]	P_c = 0.1 [bar]	P_r = 2.984 [bar]	Q_{add} = 3999	s_1 = 0.6489 [kJ/kg-K]	s_3 = 6.345 [kJ/kg-K]
s_5 = 8.328	T_{max} = 500	T_r = 500	W_{net} = 1421	W_p = 15.89	W_t = 1437			

Calculation time = .1 sec

Reheat Pressure Plot against Work net and Efficiency



B) Varying P_b and getting Optimum P_r for each

Code

```
{Givens}

"P_b=120"
P_c=.1;
T_max=500;
T_r=T_max
"P_r=P_c";
eta_t=0.85 ; eta_p=0.95;

{Solution}

"P1"
h_1=ENTHALPY(Steam,X=0,P=P_c)
s_1=ENTROPY(Steam,X=0,P=P_c)

"P2"
h_2s=ENTHALPY(Steam,s=s_1,P=P_b)
(h_2a - h_1)*eta_p=(h_2s - h_1)

"P3"
h_3=ENTHALPY(Steam,T=T_max,P=P_b)
s_3=ENTROPY(Steam,T=T_max,P=P_b)

"P4"
h_4s=ENTHALPY(Steam,s=s_3,P=P_r)
(h_3 - h_4s)*eta_t=(h_3 - h_4a)

"P5"
h_5=ENTHALPY(Steam,T=T_r,P=P_r)
s_5=ENTROPY(Steam,T=T_r,P=P_r)

"P6"
h_6s=ENTHALPY(Steam,s=s_5,P=P_c)
(h_5 - h_6s)*eta_t=(h_5 - h_6a)

"Requirements"

W_t=(h_3 - h_4a)+(h_5 - h_6a); W_p=h_2a - h_1;
W_net = W_t - W_p
Q_add = (h_3 - h_2a)+(h_5 - h_4a)
eta_th= W_net / Q_add
 R= P_r/P_b
```

Parametric tables for varying P_b

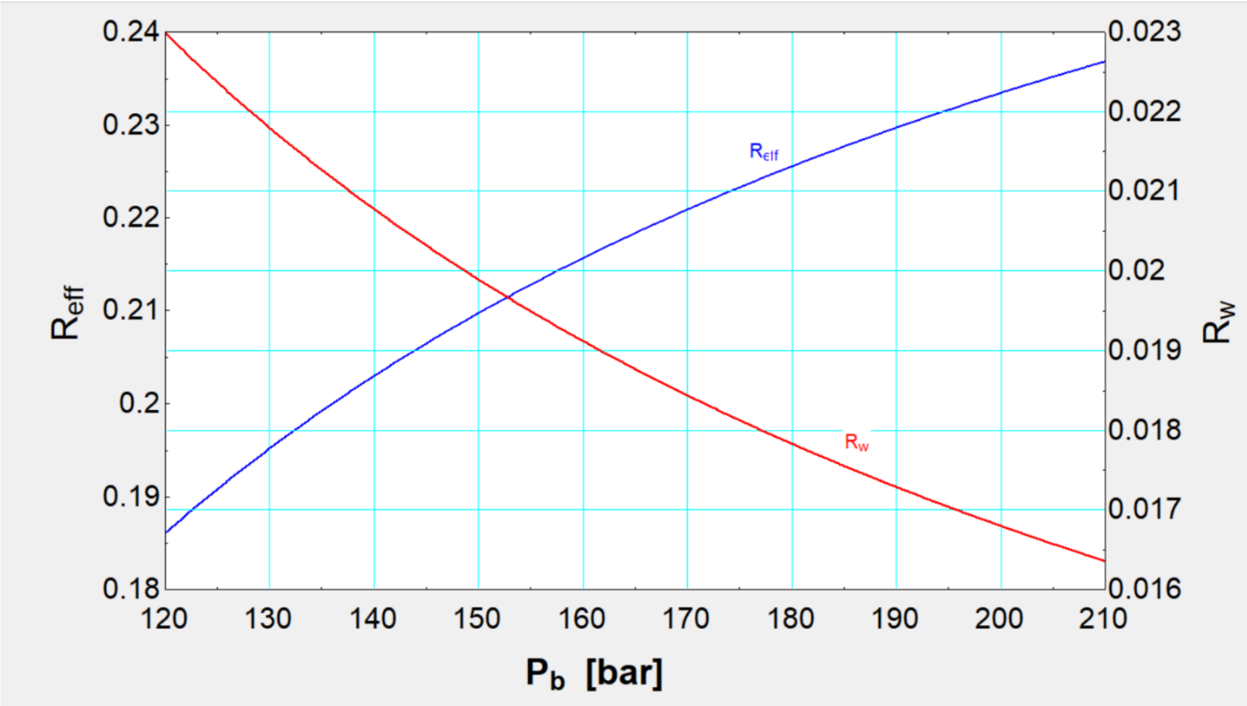
Varying P_b to get optimum P_r for max efficiency

1..1000	P_r [bar]	W_{net}	P_b [bar]	R
Run 520	3.109	1425	166.8	0.01865
Run 521	3.11	1425	166.8	0.01864
Run 522	3.111	1425	166.9	0.01863
Run 523	3.111	1425	167	0.01863
Run 524	3.112	1425	167.1	0.01862
Run 525	3.113	1425	167.2	0.01862
Run 526	3.113	1425	167.3	0.01861
Run 527	3.114	1425	167.4	0.0186
Run 528	3.115	1425	167.5	0.0186
Run 529	3.115	1425	167.6	0.01859
Run 530	3.116	1425	167.7	0.01859
Run 531	3.117	1425	167.7	0.01858
Run 532	3.117	1425	167.8	0.01857
Run 533	3.118	1425	167.9	0.01857
Run 534	3.119	1425	168	0.01856
Run 535	3.119	1425	168.1	0.01856
Run 536	3.12	1425	168.2	0.01855
Run 537	3.121	1425	168.3	0.01854
Run 538	3.121	1425	168.4	0.01854
Run 539	3.122	1425	168.5	0.01853
Run 540	3.123	1425	168.6	0.01853
Run 541	3.123	1425	168.6	0.01852
Run 542	3.124	1425	168.7	0.01851
Run 543	3.125	1425	168.8	0.01851
Run 544	3.125	1425	168.9	0.0185
Run 545	3.126	1425	169	0.0185
Run 546	3.127	1425	169.1	0.01849
Run 547	3.127	1425	169.2	0.01849
Run 548	3.128	1425	169.3	0.01848
Run 549	3.129	1425	169.4	0.01847
Run 550	3.129	1425	169.5	0.01847

Varying P_b to get optimum P_r for max work net

1..1000	η_{th}	P_r [bar]	P_b [bar]	R
Run 368	0.37	32.4	153.1	0.2117
Run 369	0.37	32.42	153.2	0.2117
Run 370	0.37	32.45	153.2	0.2118
Run 371	0.37	32.48	153.3	0.2118
Run 372	0.37	32.51	153.4	0.2119
Run 373	0.37	32.53	153.5	0.2119
Run 374	0.37	32.56	153.6	0.212
Run 375	0.37	32.59	153.7	0.212
Run 376	0.3701	32.62	153.8	0.2121
Run 377	0.3701	32.64	153.9	0.2121
Run 378	0.3701	32.67	154	0.2122
Run 379	0.3701	32.7	154.1	0.2122
Run 380	0.3701	32.72	154.1	0.2123
Run 381	0.3701	32.75	154.2	0.2124
Run 382	0.3701	32.78	154.3	0.2124
Run 383	0.3701	32.81	154.4	0.2125
Run 384	0.3702	32.83	154.5	0.2125
Run 385	0.3702	32.86	154.6	0.2126
Run 386	0.3702	32.89	154.7	0.2126
Run 387	0.3702	32.92	154.8	0.2127
Run 388	0.3702	32.94	154.9	0.2127
Run 389	0.3702	32.97	155	0.2128
Run 390	0.3702	33	155	0.2128
Run 391	0.3702	33.03	155.1	0.2129
Run 392	0.3702	33.05	155.2	0.2129
Run 393	0.3703	33.08	155.3	0.213
Run 394	0.3703	33.11	155.4	0.213
Run 395	0.3703	33.14	155.5	0.2131
Run 396	0.3703	33.16	155.6	0.2132
Run 397	0.3703	33.19	155.7	0.2132
Run 398	0.3703	33.22	155.8	0.2133

Plotting P_b against Pressure ratio for both efficiency and work net



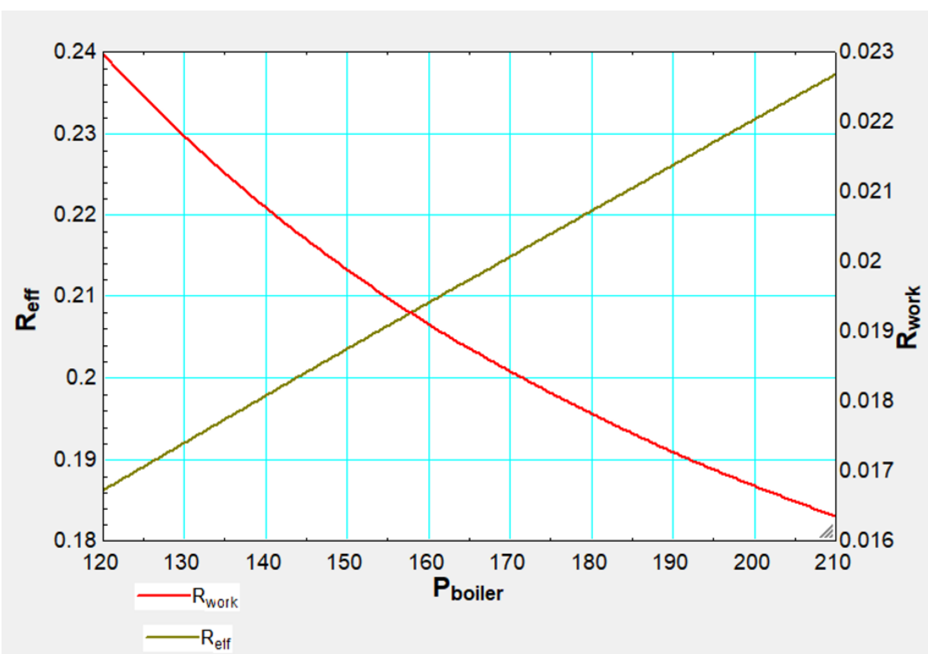
Note: method of using parametric tables has percentage of error as we assumed that the relation between the change of P_b and the change of P_r is linear.

Another method "Manually"

1..10	P_{boiler}	$P_{reheat1}$	R_{eff}	$P_{reheat2}$	R_{work}
Run 1	120	22.34	0.1862	2.756	0.02297
Run 2	130	24.96	0.192	2.833	0.02179
Run 3	140	27.69	0.1978	2.908	0.02077
Run 4	150	30.53	0.2035	2.983	0.01989
Run 5	160	33.47	0.2092	3.057	0.01911
Run 6	170	36.53	0.2149	3.132	0.01842
Run 7	180	39.69	0.2205	3.207	0.01782
Run 8	190	42.96	0.2261	3.281	0.01727
Run 9	200	46.34	0.2317	3.357	0.01679
Run 10	210	49.82	0.2372	3.433	0.01635

Here we've calculated optimum P_r at each P_b

Plotting P_b against the pressure ratio for each efficiency and work net



(C) Using the reheat pressure that maximized the efficiency in (1),

Varying the pressure of the OPWH from the Pc to the Pb to construct the maximum efficiency

1-Taking the pressure from the high-pressure turbine:

code

```
{Givens}

P_b=150

P_c=0.1

T_max=500

eta_t=0.85

eta_p=0.95

P_r=30.51

"P_ofwh=0"


{Point 1}

h_1=Enthalpy(Steam,x=0,P=P_c)

s_1=Entropy(Steam,x=0,P=P_c)


{Point 2}

s_2=s_1

h_2s=Enthalpy(Steam,s=s_2,p=P_ofwh)

(h_2-h_1)*eta_p=(h_2s-h_1)


{Point 3}

h_3=Enthalpy(Steam,x=0,P=P_ofwh)
```

```
s_3=Entropy(Steam,x=0,P=P_ofwh)


{Point 4}

s_4=s_3

h_4s=Enthalpy(Steam,s=s_4,p=P_b)

(h_4-h_3)*eta_p=(h_4s-h_3)


{Point 5}

h_5=Enthalpy(Steam,p=P_b,T=T_max)

s_5=Entropy(Steam,p=P_b,T=T_max)


{Point 6}

s_6=s_5

h_6s=Enthalpy(Steam,s=s_6,p=P_ofwh)

eta_t=(h_5-h_6)/(h_5-h_6s)


{Point 7}

s_7=s_5

h_7s=Enthalpy(Steam,s=s_7,p=P_r)

eta_t=(h_5-h_7)/(h_5-h_7s)


{Point 8}

h_8=Enthalpy(Steam,p=P_r,t=T_max)

s_8=Entropy(Steam,p=P_r,t=T_max)
```

{Point 9}

s_9=s_8

h_9s=Enthalpy(Steam,s=s_9,p=P_c)

eta_t=(h_8-h_9)/(h_8-h_9s)

{HB on ofwh}

m=(h_3-h_2)/(h_6-h_2)

{Calculations}

w_t=(h_5-h_6)+(h_6-h_7)*(1-m)+(h_8-h_9)*(1-m)

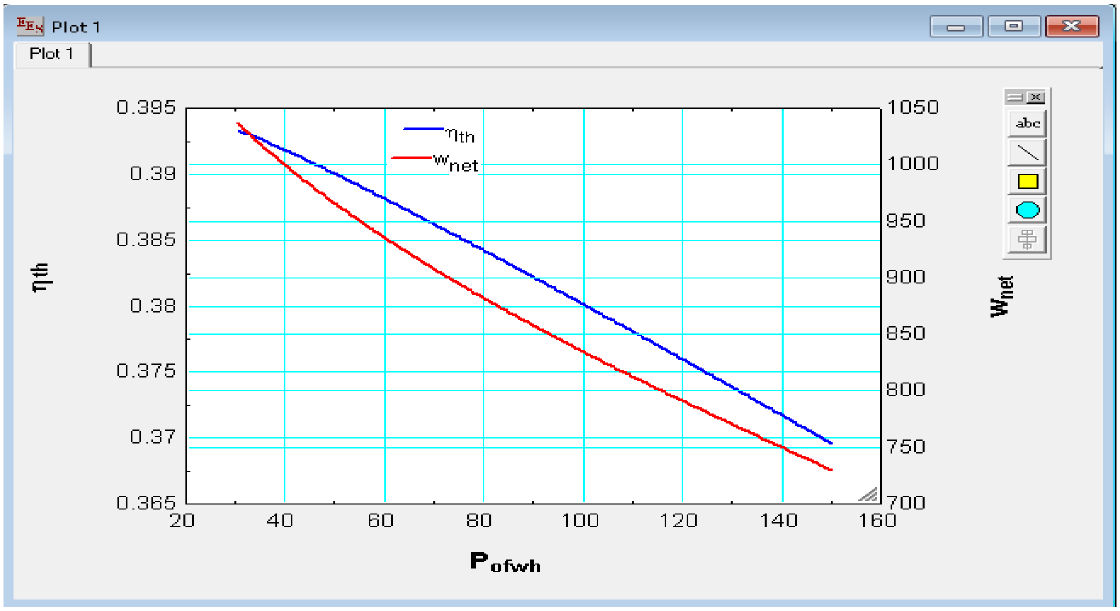
w_p=(h_2-h_1)*(1-m) + (h_4-h_3)

w_net=w_t-w_p

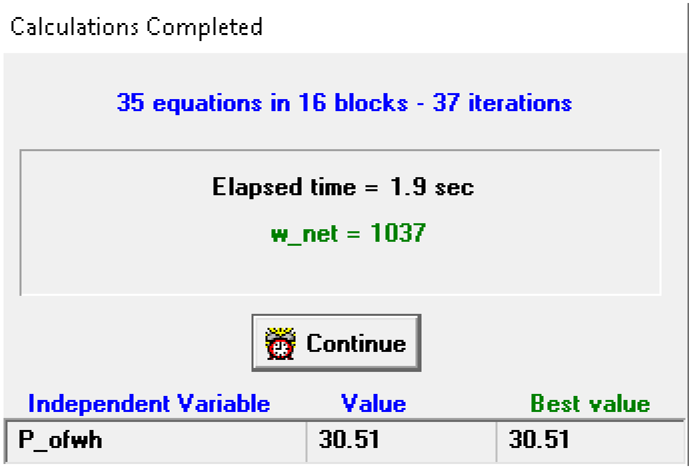
q_add=h_5-h_4+(h_8-h_7)*(1-m)

eta_th=w_net/q_add

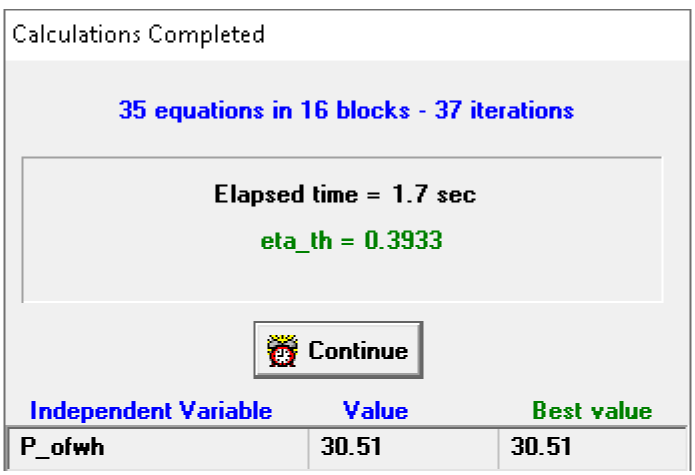
The OFWH pressure (varies from Pc to Pb) against the thermal efficiency and the net work



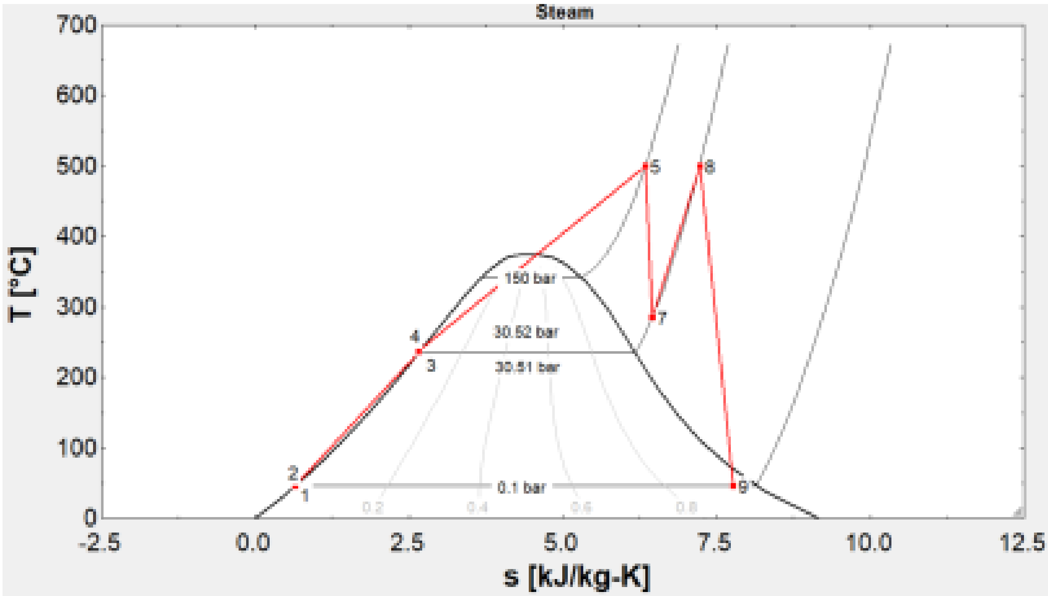
The OFWH pressure that maximized work net



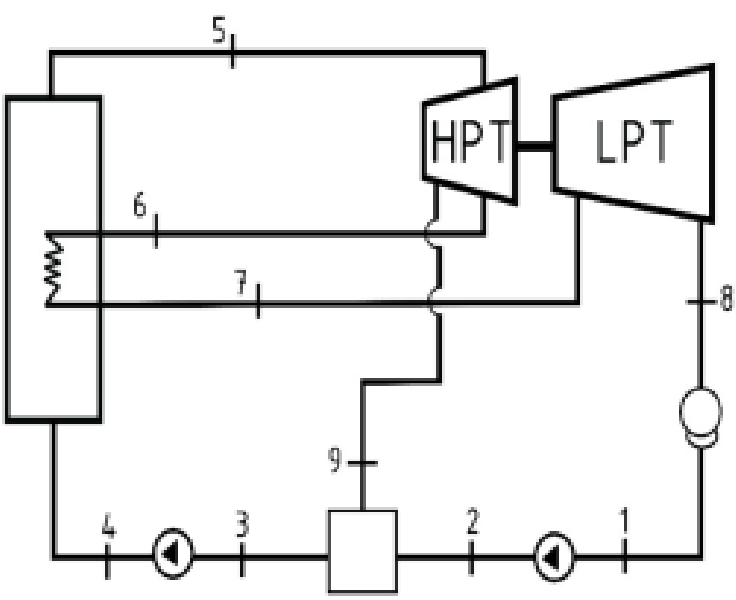
The OFWH pressure that maximized the thermal efficiency



T-s diagram



Flow diagram for this case



Note: After connecting the open feed water heater intake to the high pressure turbine and set the limits from boiler and reheat pressure we deduce that that P_{ofwh}=P_r (it's not important to try the cases of connecting the open feed water heater into the reheat pressure).

2- Taking the pressure from the low pressure turbine:

code

```
{Givens}

P_b=150

P_c=0.1

T_max=500

eta_t=0.85

eta_p=0.95

P_r=30.51

"P_ofwh=0"


{Point 1}

h_1=Enthalpy(Steam,x=0,P=P_c)

s_1=Entropy(Steam,x=0,P=P_c)


{Point 2}

s_2=s_1

h_2s=Enthalpy(Steam,s=s_2,p=P_ofwh)

(h_2-h_1)*eta_p=(h_2s-h_1)


{Point 3}

h_3=Enthalpy(Steam,x=0,P=P_ofwh)

s_3=Entropy(Steam,x=0,P=P_ofwh)
```

{Point 4}

s_4=s_3

h_4s=Enthalpy(Steam,s=s_4,p=P_b)

(h_4-h_3)*eta_p=(h_4s-h_3)

{Point 5}

h_5=Enthalpy(Steam,p=P_b,T=T_max)

s_5=Entropy(Steam,p=P_b,T=T_max)

{Point 6}

s_6s=s_8

h_6s=Enthalpy(Steam,s=s_6s,p=P_ofwh)

(h_8-h_6)=(h_8-h_6s)*eta_t

s_6=Entropy(Steam,h=h_6,p=P_ofwh)

{Point 7}

s_7=s_5

h_7s=Enthalpy(Steam,s=s_7,p=P_r)

eta_t=(h_5-h_7)/(h_5-h_7s)

{Point 8}

h_8=Enthalpy(Steam,p=P_r,t=T_max)

s_8=Entropy(Steam,p=P_r,t=T_max)

{Point 9}

s_9=s_6

h_9s=Enthalpy(Steam,s=s_9,p=P_c)

eta_t*(h_6-h_9s)=(h_6-h_9)

{HB on ofwh}

m=(h_3-h_2)/(h_6-h_2)

{Calculations}

w_t=(h_5-h_7)+(h_8-h_6)+(h_6-h_9)*(1-m)

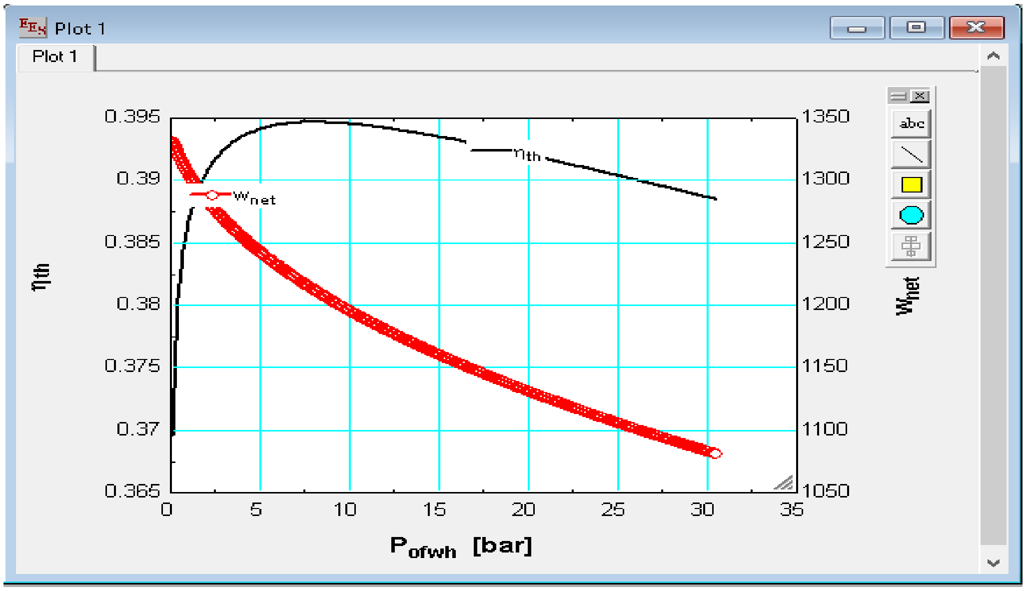
w_p=(h_2-h_1)*(1-m) + (h_4-h_3)

w_net=w_t-w_p

q_add=h_5-h_4+h_8-h_7

eta_th=w_net/q_add

The open feed water pressure (varies from P_c to P_r) against the thermal efficiency and the net work



The open feed water pressure that maximizes the efficiency

Calculations Completed

35 equations in 16 blocks - 37 iterations

Elapsed time = 1.7 sec

eta_th = 0.3933

Continue

Independent Variable	Value	Best value
P_ofwh	30.51	30.51

The open feed water pressure that maximizes the work net

Calculations Completed

36 equations in 20 blocks - 28 iterations

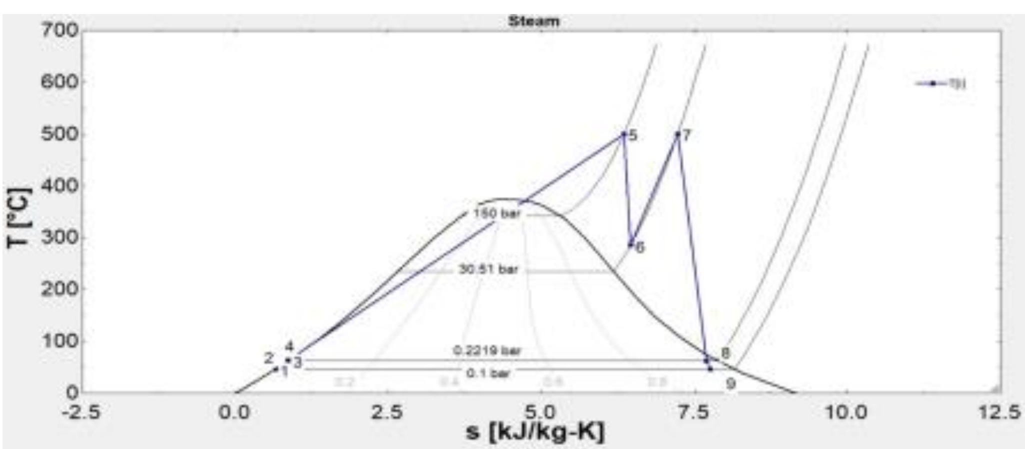
Elapsed time = 1.6 sec

w_net = 1336

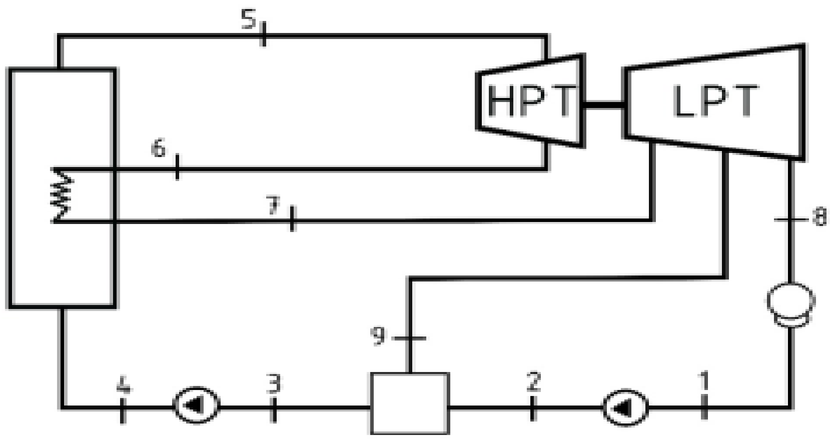
Continue

Independent Variable	Value	Best value
P_ofwh	0.2219	0.2219

T-s diagram



Flow diagram for this case:



3-Taking the pressure from the upper reheat line

Code

{Givens}

P_b=150

P_c=0.1

T_max=500

eta_t=0.85

eta_p=0.95

P_r=30.51

P_ofwh=P_r

{Point 1}

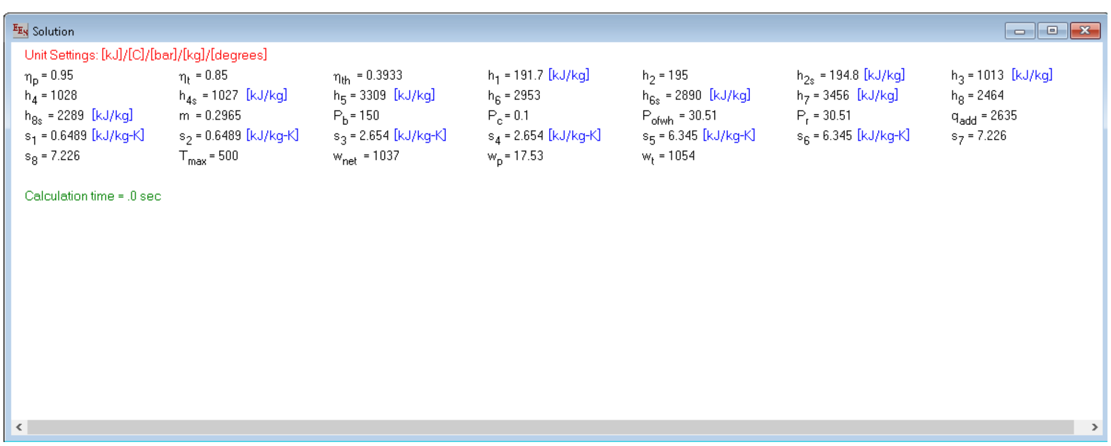
h_1=Enthalpy(Steam,x=0,P=P_c)

s_1=Entropy(Steam,x=0,P=P_c)

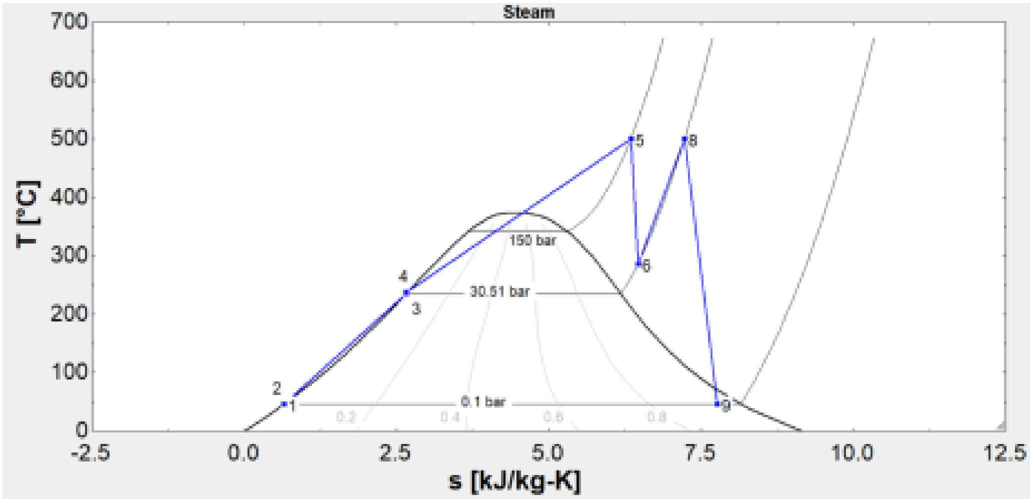
```
{Point 2}

s_2=s_1

h_2s=Enthalpy(Steam,s=s_2,p=P_ofwh)

(h_2-h_1)*eta_p=(h_2s-h_1)


{Point 3}

h_3=Enthalpy(Steam,x=0,P=P_ofwh)

s_3=Entropy(Steam,x=0,P=P_ofwh)


{Point 4}

s_4=s_3

h_4s=Enthalpy(Steam,s=s_4,p=P_b)

(h_4-h_3)*eta_p=(h_4s-h_3)


{Point 5}

h_5=Enthalpy(Steam,p=P_b,T=T_max)

s_5=Entropy(Steam,p=P_b,T=T_max)


{Point 6}

s_6=s_5

h_6s=Enthalpy(Steam,s=s_6,p=P_ofwh)

eta_t=(h_5-h_6)/(h_5-h_6s)


{Point 7}

h_7=Enthalpy(Steam,p=P_r,t=T_max)
```

```
s_7=Entropy(Steam,p=P_r,t=T_max)


{Point 8}

s_7=s_8

h_8s=Enthalpy(Steam,s=s_8,p=P_c)

eta_t=(h_7-h_8)/(h_7-h_8s)


{HB on ofwh}

m=(h_3-h_2)/(h_6-h_2)


{Calculations}

w_t=(h_5-h_6)+(h_7-h_8)*(1-m)

w_p=(h_2-h_1)*(1-m) + (h_4-h_3)

w_net=w_t-w_p

q_add=h_5-h_4+(h_7-h_6)*(1-m)

eta_th=w_net/q_add
```

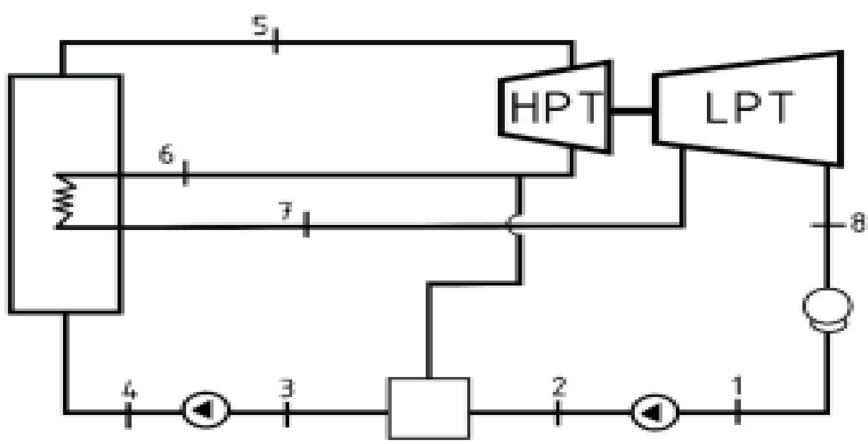
Results Tab



T-s diagram



Flow diagram



4-Taking the pressure from the lower reheat line:

code

{Givens}

P_b=150

P_c=0.1

T_max=500

eta_t=0.85

eta_p=0.95

```
P_r=30.51

P_ofwh=P_r


{Point 1}

h_1=Enthalpy(Steam,x=0,P=P_c)

s_1=Entropy(Steam,x=0,P=P_c)


{Point 2}

s_2=s_1

h_2s=Enthalpy(Steam,s=s_2,p=P_ofwh)

(h_2-h_1)*eta_p=(h_2s-h_1)


{Point 3}

h_3=Enthalpy(Steam,x=0,P=P_ofwh)

s_3=Entropy(Steam,x=0,P=P_ofwh)


{Point 4}

s_4=s_3

h_4s=Enthalpy(Steam,s=s_4,p=P_b)

(h_4-h_3)*eta_p=(h_4s-h_3)


{Point 5}

h_5=Enthalpy(Steam,p=P_b,T=T_max)

s_5=Entropy(Steam,p=P_b,T=T_max)
```

```
{Point 6}

s_6=s_5

h_6s=Enthalpy(Steam,s=s_6,p=P_ofwh)

eta_t=(h_5-h_6)/(h_5-h_6s)


{Point 7}

h_7=Enthalpy(Steam,p=P_r,t=T_max)

s_7=Entropy(Steam,p=P_r,t=T_max)


{Point 8}

s_7=s_8

h_8s=Enthalpy(Steam,s=s_8,p=P_c)

eta_t=(h_7-h_8)/(h_7-h_8s)


{HB on ofwh}

m=(h_3-h_2)/(h_7-h_2)


{Calculations}

w_t=(h_5-h_6)+(h_7-h_8)*(1-m)

w_p=(h_2-h_1)*(1-m) + (h_4-h_3)

w_net=w_t-w_p

q_add=h_5-h_4+(h_7-h_6)

eta_th=w_net/q_add
```

Results Tab

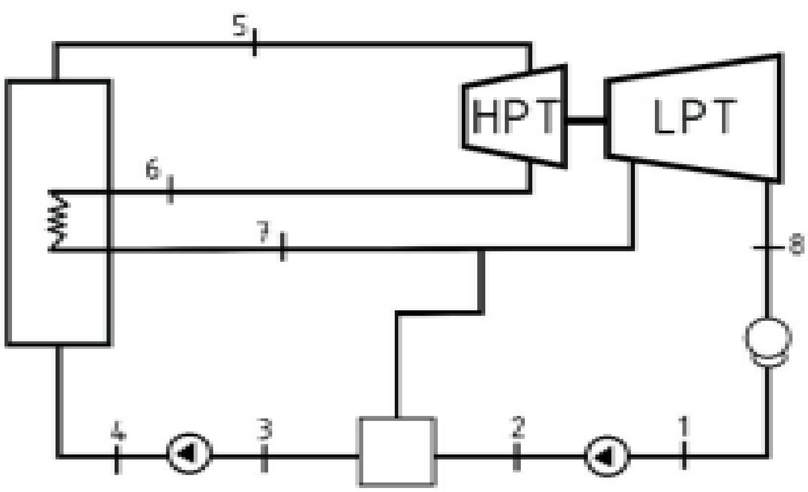
Solution

Unit Settings: [kJ]/[C]/[bar]/[kg]/[degrees]

η_p = 0.95	η_t = 0.85	η_{th} = 0.3885	h_1 = 191.7 [kJ/kg]	h_2 = 195	h_{2s} = 194.8 [kJ/kg]	h_3 = 1013 [kJ/kg]
h_4 = 1028	h_{4s} = 1027 [kJ/kg]	h_5 = 3309 [kJ/kg]	h_6 = 2953	h_{6s} = 2890 [kJ/kg]	h_7 = 3456 [kJ/kg]	h_8 = 2464
h_{8s} = 2289 [kJ/kg]	m = 0.2507	P_b = 150	P_c = 0.1	P_{ofwh} = 30.51	P_r = 30.51	q_{add} = 2784
s_1 = 0.6489 [kJ/kg-K]	s_2 = 0.6489 [kJ/kg-K]	s_3 = 2.654 [kJ/kg-K]	s_4 = 2.654 [kJ/kg-K]	s_5 = 6.345 [kJ/kg-K]	s_6 = 6.345 [kJ/kg-K]	s_7 = 7.226
s_8 = 7.226	T_{max} = 500	w_{net} = 1082	w_p = 17.67	w_t = 1099		

Calculation time = .0 sec

Flow diagram



From 1,2,3,4 we deduce that the maximum efficiency can be extracted when we intake the pressure to the open feed water from **the low pressure turbine**.

-Maximum efficiency=0.4013 at P_{ofwh}=5.913

-Maximum work net=1336 at P_{ofwh}=0.2219

(D)Adding feed water heaters to modify the cycle

D.1

"From low LP Turbine"

{Givens}

P_b=150

P_c=0.1

T_max=500

eta_t=0.85

eta_p=0.95

P_r=30.51

"P_ofwh=0"

{Point 1}

h_1=Enthalpy(Steam,x=0,P=P_c)

s_1=Entropy(Steam,x=0,P=P_c)

{Point 2}

s_2=s_1

h_2s=Enthalpy(Steam,s=s_2,p=P_ofwh)

(h_2-h_1)*eta_p=(h_2s-h_1)

{Point 3}

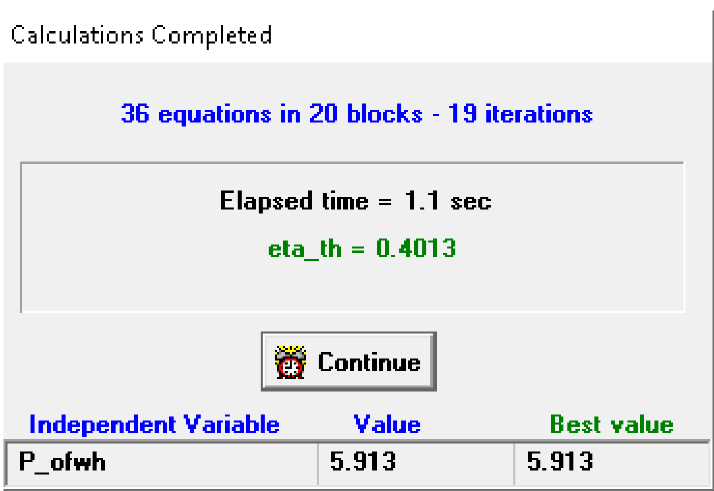
h_3=Enthalpy(Steam,x=0,P=P_ofwh)

s_3=Entropy(Steam,x=0,P=P_ofwh)

```
{Point 4}

s_4=s_3

h_4s=Enthalpy(Steam,s=s_4,p=P_b)

(h_4-h_3)*eta_p=(h_4s-h_3)


{Point 5}

h_5=Enthalpy(Steam,p=P_b,T=T_max)

s_5=Entropy(Steam,p=P_b,T=T_max)


{Point 6}

s_6s=s_8

h_6s=Enthalpy(Steam,s=s_6s,p=P_ofwh)

(h_8-h_6)=(h_8-h_6s)*eta_t

s_6=Entropy(Steam,h=h_6,p=P_ofwh)

{Point 7}

s_7=s_5

h_7s=Enthalpy(Steam,s=s_7,p=P_r)

eta_t=(h_5-h_7)/(h_5-h_7s)


{Point 8}

h_8=Enthalpy(Steam,p=P_r,t=T_max)

s_8=Entropy(Steam,p=P_r,t=T_max)


{Point 9}
```

```
s_9=s_6

h_9s=Enthalpy(Steam,s=s_9,p=P_c)

eta_t*(h_6-h_9s)=(h_6-h_9)


{HB on ofwh}

m=(h_3-h_2)/(h_6-h_2)


{Calculations}

w_t=(h_5-h_7)+(h_8-h_6)+(h_6-h_9)*(1-m)

w_p=(h_2-h_1)*(1-m) + (h_4-h_3)

w_net=w_t-w_p

q_add=h_5-h_4+h_8-h_7

eta_th=w_net/q_add
```

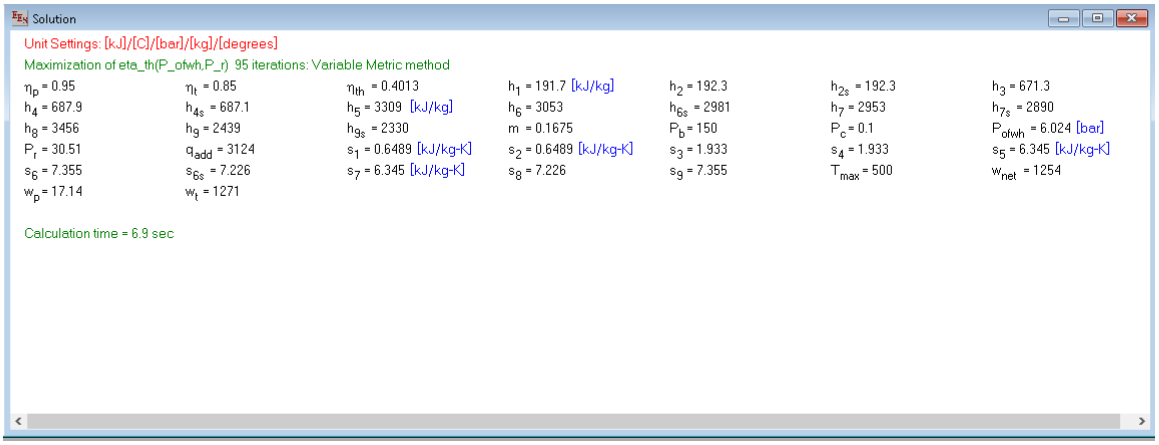
Calculations



Optimum OFWH Pressure = 5.913 bar

Maximum efficiency = 40.13%

Results Tab



Solution

Unit Settings: [kJ]/[C]/[bar]/[kg]/[degrees]

Maximization of eta_th(P_ofwh,P_r) 95 iterations: Variable Metric method

$\eta_p = 0.95$	$\eta_t = 0.85$	$\eta_{th} = 0.4013$	$h_1 = 191.7$ [kJ/kg]	$h_2 = 192.3$	$h_{2s} = 192.3$	$h_3 = 671.3$
$h_4 = 687.9$	$h_{4s} = 687.1$	$h_5 = 3309$ [kJ/kg]	$h_6 = 3053$	$h_{6s} = 2981$	$h_7 = 2953$	$h_{7s} = 2890$
$h_8 = 3456$	$h_9 = 2439$	$h_{9s} = 2330$	$m = 0.1675$	$P_b = 150$	$P_c = 0.1$	$P_{ofwh} = 6.024$ [bar]
$P_r = 30.51$	$q_{add} = 3124$	$s_1 = 0.6489$ [kJ/kg-K]	$s_2 = 0.6489$ [kJ/kg-K]	$s_3 = 1.933$	$s_4 = 1.933$	$s_5 = 6.345$ [kJ/kg-K]
$s_6 = 7.355$	$s_{6s} = 7.226$	$s_7 = 6.345$ [kJ/kg-K]	$s_8 = 7.226$	$s_9 = 7.355$	$T_{max} = 500$	$w_{net} = 1254$
$w_p = 17.14$	$w_t = 1271$					

Calculation time = 6.9 sec

Flow Diagram

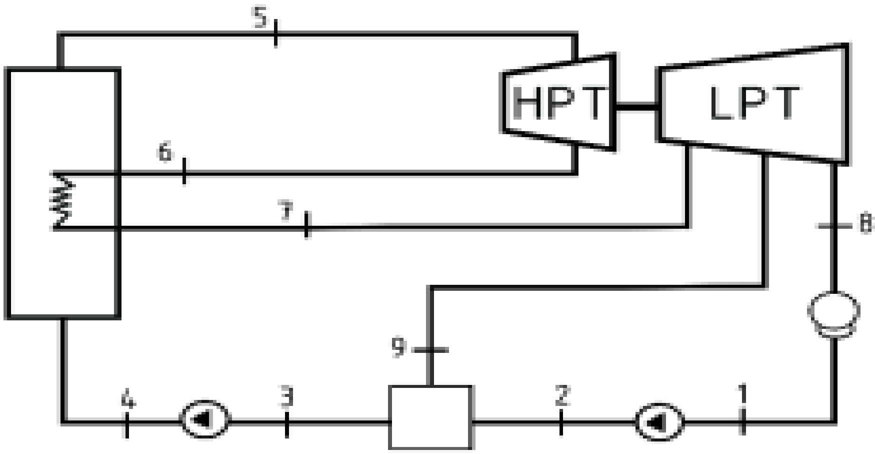
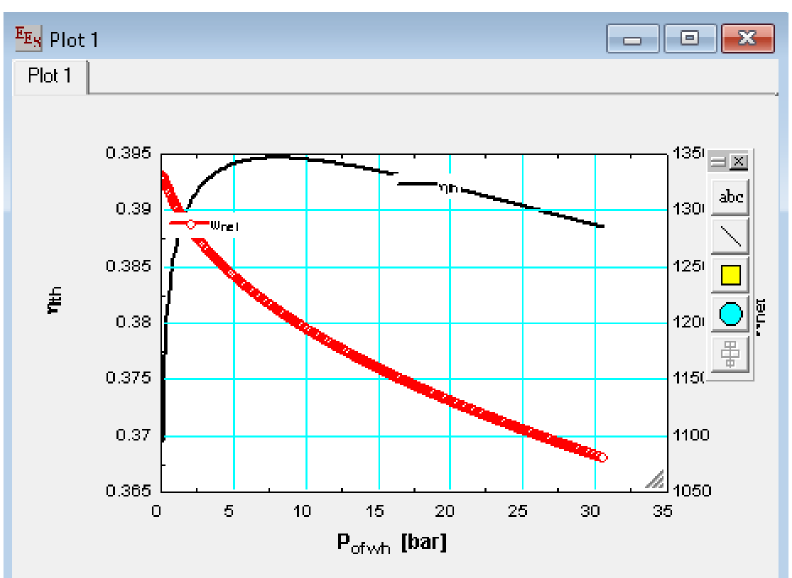


Table 1

1..1000	η_{th}	P_{ofwh} [bar]	w_{net}
Run 975	0.3888	29.75	1085
Run 976	0.3887	29.78	1085
Run 977	0.3887	29.81	1085
Run 978	0.3887	29.84	1085
Run 979	0.3887	29.87	1085
Run 980	0.3887	29.9	1084
Run 981	0.3887	29.93	1084
Run 982	0.3887	29.96	1084
Run 983	0.3887	29.99	1084
Run 984	0.3887	30.02	1084
Run 985	0.3887	30.05	1084
Run 986	0.3886	30.08	1084
Run 987	0.3886	30.11	1083
Run 988	0.3886	30.14	1083
Run 989	0.3886	30.18	1083
Run 990	0.3886	30.21	1083
Run 991	0.3886	30.24	1083
Run 992	0.3886	30.27	1083
Run 993	0.3886	30.3	1083
Run 994	0.3886	30.33	1083
Run 995	0.3885	30.36	1082
Run 996	0.3885	30.39	1082
Run 997	0.3885	30.42	1082
Run 998	0.3885	30.45	1082
Run 999	0.3885	30.48	1082
Run 1000	0.3885	30.51	1082

Parametric Table for P_{ofwh} with efficiency and work net

Plotting P_{ofwh} against efficiency and work net



Using Duplicate

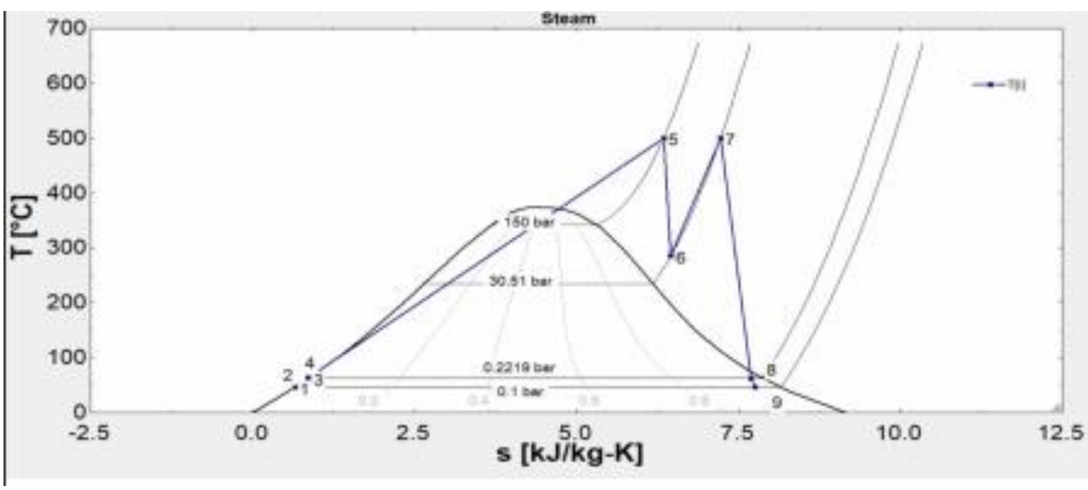
```
eta_p=0.95

P_c=0.1

P_b=150

P_r=30.51

T_max=500

eta_t=0.85

Duplicate i=1,30

P_ofwh[i]=(1)+(i-1)*(30-1)/30

h_2s[i]=enthalpy(Steam,s=s_2,P=P_ofwh[i])

h_2[i]=((h_2s[i]-h_1)/eta_p)+h_1

h_3[i]=enthalpy(Steam,x=0,P=P_ofwh[i])

s_3[i]=entropy(Steam,x=0,P=P_ofwh[i])

s_4[i]=s_3[i]

h_4s[i]=enthalpy(Steam,s=s_4[i],P=P_b)

h_4[i]=(h_4s[i]-h_3[i])/eta_p+h_3[i]

h_6s[i]=enthalpy(Steam,s=s_6s,P=P_ofwh[i])

h_6[i]=h_8-((h_8-h_6s[i])*eta_t)

s_6[i]=entropy(Steam,h=h_6[i],P=P_ofwh[i])

s_9[i]=s_6[i]

h_9s[i]=enthalpy(Steam,s=s_9[i],P=P_c)

h_9[i]=h_6[i]-((h_6[i]-h_9s[i])*eta_t)

m[i]=(h_3[i]-h_2[i])/(h_6[i]-h_2[i])

w_t[i]=(h_5-h_7)+(h_8-h_6[i])+(h_6[i]-h_9[i])*(1-m[i])

w_p[i]=(h_2[i]-h_1)*(1-m[i]) + (h_4[i]-h_3[i])
```

```
q_add[i]=h_5-h_4[i]+h_8-h_7

w_net[i]=w_t[i]-w_p[i]

eta_th[i]=w_net[i]/q_add[i]


End

h_1=enthalpy(Steam,x=0,P=0.1)

s_1=entropy(Steam,x=0,P=0.1)

s_2=s_1

{Point 5}

h_5=enthalpy(Steam,P=P_b,T=T_max)

s_5=entropy(Steam,P=P_b,T=T_max)

{Point 8}

h_8=enthalpy(Steam,P=P_r,T=T_max)

s_8=entropy(Steam,P=P_r,T=T_max)

s_6s=s_8


{Point 7}

s_7=s_5

h_7s=enthalpy(Steam,s=s_7,P=P_r)

eta_t=(h_5-h_7)/(h_5-h_7s)
```

Results tab for Duplicate

$h_{2,i}$	$h_{2s,i}$	$P_{ofwh,i}$	$h_{3,i}$	$s_{3,i}$	$\eta_{th,i}$	$h_{4,i}$	$h_{4s,i}$	$h_{6,i}$	$h_{6s,i}$	$h_{9,i}$	$h_{9s,i}$	m_i	$q_{add,i}$	$s_{4,i}$	$s_{6,i}$
192	192	1.967	502.5	1.524	0.3971	518.9	518.1	2851	2744	2441	2368	0.1168	3294	1.524	7.47
192.1	192.1	2.933	558.2	1.664	0.3995	574.7	573.9	2917	2822	2438	2354	0.1343	3239	1.664	7.42
192.2	192.2	3.9	600.7	1.767	0.4006	617.3	616.5	2968	2882	2438	2345	0.1472	3196	1.767	7.39
192.3	192.3	4.867	635.7	1.85	0.4011	652.3	651.5	3010	2932	2439	2338	0.1573	3161	1.85	7.37
192.4	192.4	5.833	665.6	1.92	0.4012	682.2	681.4	3047	2974	2439	2332	0.1658	3131	1.92	7.3
192.5	192.5	6.8	691.9	1.98	0.4011	708.5	707.7	3078	3012	2440	2328	0.173	3105	1.98	7.34
192.6	192.6	7.767	715.5	2.034	0.4009	732.1	731.3	3107	3045	2441	2324	0.1794	3081	2.034	7.33
192.7	192.7	8.733	737	2.082	0.4006	753.5	752.7	3133	3076	2442	2321	0.1851	3060	2.082	7.32
192.8	192.8	9.7	756.7	2.125	0.4002	773.2	772.4	3157	3104	2444	2318	0.1902	3040	2.125	7.31
192.9	192.9	10.67	775	2.165	0.3998	791.5	790.7	3179	3130	2445	2315	0.1949	3022	2.165	7.30
193	193	11.63	792.1	2.203	0.3993	808.6	807.8	3199	3154	2446	2313	0.1993	3005	2.203	7.29
193.1	193.1	12.6	808.2	2.237	0.3988	824.6	823.8	3219	3177	2447	2311	0.2033	2989	2.237	7.29
193.2	193.2	13.57	823.4	2.27	0.3983	839.8	839	3237	3198	2448	2309	0.2071	2973	2.27	7.28
193.3	193.3	14.53	837.8	2.3	0.3978	854.2	853.4	3254	3218	2449	2307	0.2106	2959	2.3	7.28
193.4	193.4	15.5	851.6	2.329	0.3972	867.9	867.1	3270	3237	2450	2306	0.2139	2945	2.329	7.27
193.5	193.5	16.47	864.7	2.357	0.3967	881	880.1	3286	3256	2451	2304	0.217	2932	2.357	7.27
193.6	193.6	17.43	877.3	2.383	0.3961	893.5	892.7	3301	3273	2452	2303	0.22	2920	2.383	7.26
193.7	193.7	18.4	889.4	2.408	0.3956	905.5	904.7	3315	3290	2453	2301	0.2229	2908	2.408	7.26
193.9	193.8	19.37	901.1	2.432	0.395	917.1	916.3	3328	3306	2454	2300	0.2256	2896	2.432	7.2
194	193.8	20.33	912.3	2.455	0.3944	928.3	927.5	3342	3321	2455	2299	0.2282	2885	2.455	7.25
194.1	193.9	21.3	923.2	2.477	0.3938	939.1	938.3	3354	3336	2456	2298	0.2307	2874	2.477	7.25

T-S diagram

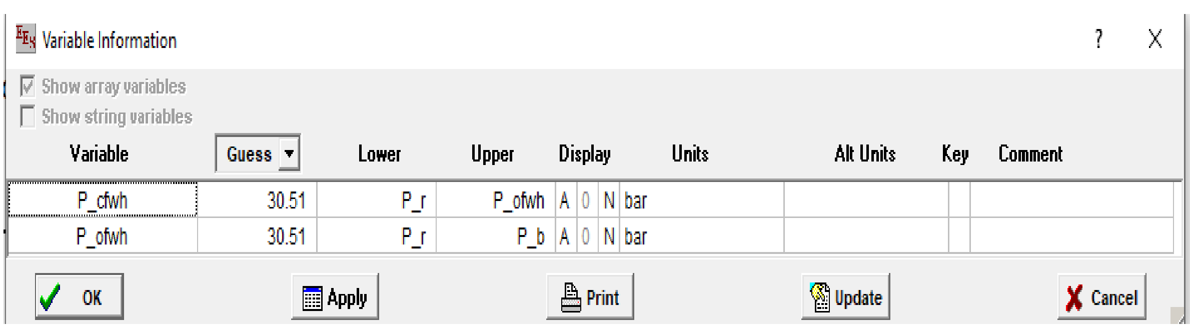


D.2 One OFWH & CFWH were added to the reheat cycle

After the Reheat Pressure

```
{Take p_ofwh&p_cfwh from HT turbine}
{given}
P_b=150
P_c=0.1
P_r=30.51
T_max=500
eta_p=0.95
eta_t=0.85
{point1}
h_1=enthalpy(Steam,x=0,P=P_c)
s_1=entropy(Steam,x=0,P=P_c)
{point2}
s_2s=s_1
h_2s=enthalpy(Steam,s=s_2s,P=P_ofwh)
eta_p=(h_2s-h_1)/(h_2-h_1)
{point11}
h_11=enthalpy(Steam,x=0,P=P_cfwh)
T_sat11=t_sat(Steam,P=P_cfwh)
{point12}
h_12=h_11
{point3}
T_3=T_sat11
h_3=4.18*T_3
{point4}
h_4=enthalpy(Steam,x=0,P=P_ofwh)
s_4=entropy(Steam,x=0,P=P_ofwh)
{point5}
s_5s=s_4
h_5s=enthalpy(Steam,s=s_5s,P=P_b)
eta_p=(h_5s-h_4)/(h_5-h_4)
{point6}
h_6=enthalpy(Steam,T=T_max,P=P_b)
s_6=entropy(Steam,T=T_max,P=P_b)
```

```
{point9}
s_9s=s_6
h_9s=enthalpy(Steam,s=s_9s,P=P_ofwh)
eta_t=(h_6-h_9)/(h_6-h_9s)
s_9=entropy(Steam,h=h_9,P=P_ofwh)
{point10}
s_10s=s_9
h_10s=enthalpy(Steam,s=s_10s,P=P_cfwh)
eta_t=(h_9-h_10)/(h_9-h_10s)
s_10=entropy(Steam,h=h_10,P=P_cfwh)
{point7}
s_7s=s_10
h_7s=enthalpy(Steam,s=s_7s,P=P_r)
eta_t=(h_10-h_7)/(h_10-h_7s)
s_7=entropy(Steam,h=h_7,P=P_r)
{piont8}
h_8=enthalpy(Steam,T=T_max,P=P_r)
s_8=entropy(Steam,T=T_max,P=P_r)
{point13}
s_13s=s_8
h_13s=enthalpy(Steam,s=s_13s,P=P_c)
eta_t=(h_8-h_13)/(h_8-h_13s)
s_13=entropy(Steam,h=h_13,P=P_c)
x_13=quality(Steam,s=s_13,P=P_c)
{HB OFWH}
m_1=(h_4-h_3)/(h_9-h_3)
{HB CFWH}
(m_2*h_10)+(1-m_1)*h_2=(m_2*h_11)+(1-m_1)*h_3
{calculation}
w_t=(h_6-h_9)+(h_9-h_10)*(1-m_1)+(h_10-h_7)*(1-m_1-m_2)+(h_8-h_13)*(1-m_1-m_2)
w_p=(h_2-h_1)*(1-m_1)+(h_5-h_4)
w_net=w_t-w_p
q_add=(h_6-h_5)+(h_8-h_7)*(1-m_1-m_2)
eta_th=w_net/q_add
```



Calculations Completed

49 equations in 31 blocks - 38 iterations

Elapsed time = 2.2 sec

eta_th = 0.3629

Continue

Independent Variable	Value	Best value
P_cfwh	30.51	30.51
P_ofwh	72.75	72.75

Optimum OFWH pressure = 72.75bar

Optimum CFWH pressure = 30.51bar

Max thermal efficiency = 0.3629 bar

Results tab

Unit Settings: SI C bar kJ mass deg

Maximization of eta_th(P_cfwh,P_ofwh) = 0.3629   38 iterations: Variable Metric method

$\eta_p = 0.95$	$\eta_t = 0.85$	$\eta_{th} = 0.3629$	$h_1 = 191.8$	$h_{10} = 2949$
$h_{13s} = 2290$	$h_2 = 199.5$	$h_{2s} = 199.1$	$h_3 = 981.4$	$h_4 = 1281$
$h_{7s} = 2949$	$h_8 = 3457$	$h_9 = 3133$	$h_{9s} = 3102$	$m_1 = 0.1395$
$P_{ofwh} = 72.75$ [bar]	$P_r = 30.51$	$q_{add} = 2279$	$s_1 = 0.6492$	$s_{10} = 6.454$
$s_4 = 3.146$	$s_{5s} = 3.146$	$s_6 = 6.348$	$s_7 = 6.454$	$s_{7s} = 6.454$
$T_{max} = 500$	$T_{sat11} = 234.8$	$w_{net} = 827$	$w_p = 17.64$	$w_t = 844.6$

$h_{10s} = 2917$	$h_{11} = 1013$	$h_{12} = 1013$	$h_{13} = 2465$
$h_5 = 1292$	$h_{5s} = 1292$	$h_6 = 3311$	$h_7 = 2949$
$m_2 = 0.3474$	$P_b = 150$	$P_c = 0.1$	$P_{cfwh} = 30.51$ [bar]
$s_{10s} = 6.395$	$s_{13} = 7.776$	$s_{13s} = 7.228$	$s_{2s} = 0.6492$
$s_8 = 7.228$	$s_9 = 6.395$	$s_{9s} = 6.348$	$T_3 = 234.8$
$x_{13} = 0.9503$			

Table 1 | Table 2 | Table 3 | Table 4

1..10	η_{th}	P_{cfwh} [bar]	P_{ofwh} [bar]
Run 1	0.3572	30	30
Run 2	0.3563	31.11	32.22
Run 3	0.3553	32.22	34.44
Run 4	0.3543	33.33	36.67
Run 5	0.3532	34.44	38.89
Run 6	0.3521	35.56	41.11
Run 7	0.3509	36.67	43.33
Run 8	0.3497	37.78	45.56
Run 9	0.3485	38.89	47.78
Run 10	0.3472	40	50

Table 1 | Table 2 | Table 3 | Table 4

1..10	η_{th}	P_{cfwh} [bar]	P_{ofwh} [bar]
Run 1	0.3472	40	50
Run 2	0.3452	41.67	52.78
Run 3	0.3431	43.33	55.56
Run 4	0.341	45	58.33
Run 5	0.3389	46.67	61.11
Run 6	0.3367	48.33	63.89
Run 7	0.3345	50	66.67
Run 8	0.3323	51.67	69.44
Run 9	0.3301	53.33	72.22
Run 10	0.3279	55	75

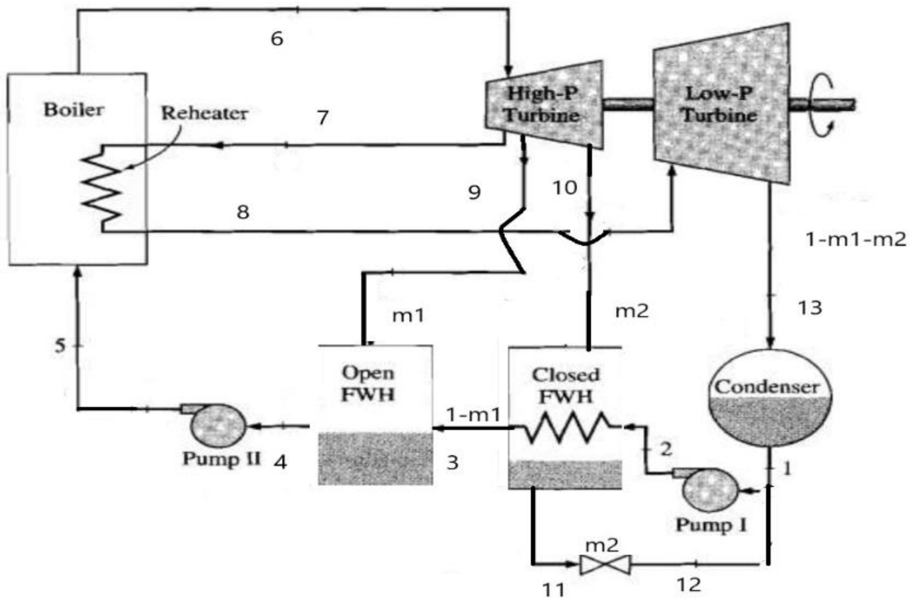
Table 1 | Table 2 | Table 3 | Table 4

1..10	η_{th}	P_{cfwh} [bar]	P_{ofwh} [bar]
Run 1	0.2924	80	100
Run 2	0.2892	82.22	105.6
Run 3	0.2859	84.44	111.1
Run 4	0.2826	86.67	116.7
Run 5	0.2793	88.89	122.2
Run 6	0.2759	91.11	127.8
Run 7	0.2724	93.33	133.3
Run 8	0.2689	95.56	138.9
Run 9	0.2653	97.78	144.4
Run 10	0.2616	100	150

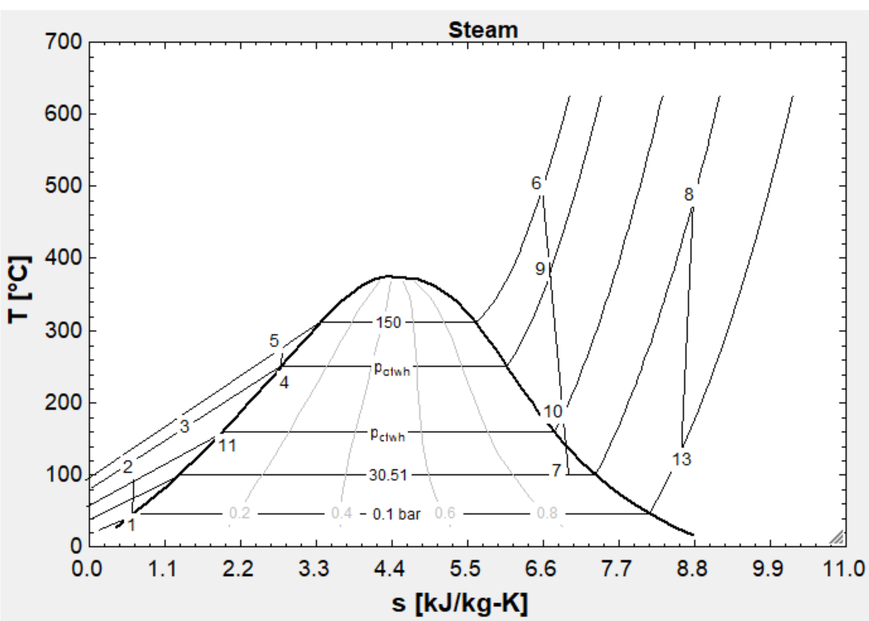
Table 1 | Table 2 | Table 3 | Table 4

1..10	η_{th}	P_{cfwh} [bar]	P_{ofwh} [bar]
Run 1	0.3279	55	75
Run 2	0.324	57.78	77.78
Run 3	0.3201	60.56	80.56
Run 4	0.3162	63.33	83.33
Run 5	0.3123	66.11	86.11
Run 6	0.3083	68.89	88.89
Run 7	0.3044	71.67	91.67
Run 8	0.3004	74.44	94.44
Run 9	0.2964	77.22	97.22
Run 10	0.2924	80	100

Flow Diagram



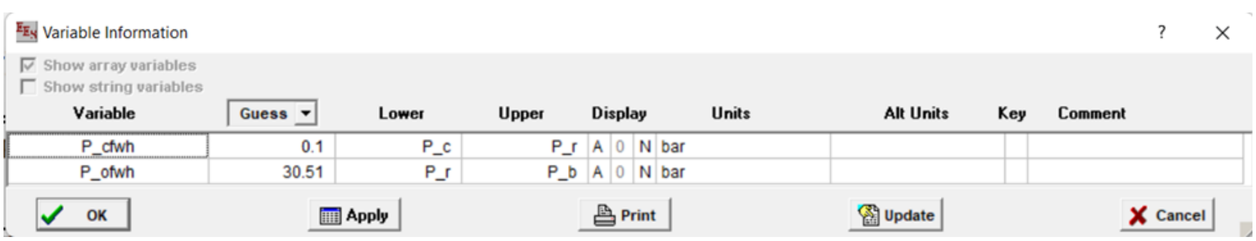
T-s Diagram



Take OFWH pressure from LT & CFWH pressure from HT

```
{Gliven}
P_b=150
P_c=0.1
P_r=30.51
T_max=500
eta_p=0.95
eta_t=0.85
{point1}
h_1=Enthalpy(Steam,x=0,P=P_c)
s_1=Entropy(Steam,x=0,P=P_c)
{point2}
s_1=s_2
h_2s=Enthalpy(Steam,s=s_2,P=P_ofwh)
eta_p=(h_2s-h_1)/(h_2-h_1)
{point12}
h_12=Enthalpy(Steam,x=0,P=P_cfwh)
h_12=h_13
T_12=T_sat(Steam,P=P_cfwh)
{point3}
T_3=T_12
h_3=T_3*4.18
{point4}
h_4=Enthalpy(Steam,x=0,P=P_ofwh)
s_4=Entropy(Steam,x=0,P=P_ofwh)
{point5}
s_5=s_4
h_5s=Enthalpy(Steam,s=s_5,P=P_b)
eta_p*(h_5-h_4)=(h_5s-h_4)
{point6}
h_6=Enthalpy(Steam,T=T_max,P=P_b)
s_6=Entropy(Steam,T=T_max,P=P_b)
```

```
s_6=s_9s
h_9s=Enthalpy(Steam,s=s_9s,P=P_ofwh)
eta_t=(h_6-h_9)/(h_6-h_9s)
s_9=Entropy(Steam,h=h_9,P=P_ofwh)
{point7}
s_7s=s_9
h_7s=Enthalpy(Steam,s=s_7s,P=P_r)
eta_t=(h_9-h_7)/(h_9-h_7s)
s_7=Entropy(Steam,h=h_7,P=P_r)
{point8}
h_8=Enthalpy(Steam,T=T_max,P=P_r)
s_8=Entropy(Steam,T=T_max,P=P_r)
{point10}
s_10s=s_8
h_10s=Enthalpy(Steam,s=s_10s,P=P_cfwh)
eta_t=(h_8-h_10)/(h_8-h_10s)
s_10=Entropy(Steam,h=h_10,P=P_cfwh)
{point11}
s_11s=s_10
h_11s=Enthalpy(Steam,s=s_11s,P=P_c)
eta_t*(h_10-h_11s)=(h_10-h_11)
s_11=Entropy(Steam,h=h_11,P=P_c)
x_11=Quality(Steam,s=s_11,h=h_11)
{mass balance}
m_1=(h_4-h_3)/(h_9-h_3)
(m_2*h_10)+(1-m_1)*h_2=(m_2*h_12)+(1-m_1)*h_3
{calculation}
w_p=(h_5-h_4)+(1-m_1)*(h_2-h_1)
w_t=(h_6-h_9)+(h_9-h_7)*(1-m_1)+(h_8-h_10)*(1-m_1)+(h_10-h_11)*(1-m_1-m_
w_net=w_t-w_p
q_add=(h_6-h_5)+(h_8-h_7)*(1-m_1)
eta_th=w_net/q_add
```



Calculations Completed

49 equations in 35 blocks - 97 iterations

Elapsed time = 3.6 sec

eta_th = 0.4109

Continue

Independent Variable	Value	Best value
P_cfwh	2.377	2.377
P_ofwh	37.78	37.78

Optimum OFWH pressure=37.78bar

Optimum CFWH pressure=2.377bar

Max thermal efficiency=0.4109bar

Results tab

Unit Settings: SI C bar kJ mass deg

Maximization of eta_th(P_cfwh,P_ofwh) = 0.4109   97 iterations: Variable Metric method

$\eta_p = 0.95$	$\eta_t = 0.85$	$\eta_{th} = 0.4109$	$h_1 = 191.8$	$h_{10} = 2881$	$h_{10s} = 2780$	$h_{11} = 2439$	$h_{11s} = 2361$	$h_{12} = 528.3$
$h_{13} = 528.3$	$h_2 = 195.8$	$h_{2s} = 195.6$	$h_3 = 525.7$	$h_4 = 1071$	$h_5 = 1086$	$h_{5s} = 1085$	$h_6 = 3311$	$h_7 = 2952$
$h_{7s} = 2944$	$h_8 = 3457$	$h_9 = 2995$	$h_{9s} = 2939$	$m_1 = 0.2209$	$m_2 = 0.1092$	$P_b = 150$	$P_c = 0.1$	$P_{cfwh} = 2.377$ [bar]

$P_{ofwh} = 37.78$ [bar]	$P_r = 30.51$	$q_{add} = 2618$	$s_1 = 0.6492$	$s_{10} = 7.451$	$s_{10s} = 7.228$	$s_{11} = 7.696$	$s_{11s} = 7.451$	$s_2 = 0.6492$
$s_4 = 2.766$	$s_5 = 2.766$	$s_6 = 6.348$	$s_7 = 6.459$	$s_{7s} = 6.445$	$s_8 = 7.228$	$s_9 = 6.445$	$s_{9s} = 6.348$	$T_{12} = 125.8$
$T_3 = 125.8$	$T_{max} = 500$	$w_{net} = 1076$	$w_p = 17.75$	$w_t = 1094$	$x_{11} = 0.9396$			

Table 1 | Table 2 | Table 3 | Table 4

1..10	η_{th}	P_{cfwh} [bar]	P_{ofwh} [bar]
Run 1	0.3931	0.1	30
Run 2	0.4017	0.3111	32.22
Run 3	0.4048	0.5222	34.44
Run 4	0.4066	0.7333	36.67
Run 5	0.4079	0.9444	38.89
Run 6	0.4088	1.156	41.11
Run 7	0.4094	1.367	43.33
Run 8	0.4098	1.578	45.56
Run 9	0.4101	1.789	47.78
Run 10	0.4102	2	50

Table 1 | Table 2 | Table 3 | Table 4

1..10	η_{th}	P_{cfwh} [bar]	P_{ofwh} [bar]
Run 1	0.4102	2	50
Run 2	0.4102	2.889	52.78
Run 3	0.4094	3.778	55.56
Run 4	0.4082	4.667	58.33
Run 5	0.4068	5.556	61.11
Run 6	0.4052	6.444	63.89
Run 7	0.4036	7.333	66.67
Run 8	0.402	8.222	69.44
Run 9	0.4003	9.111	72.22
Run 10	0.3987	10	75

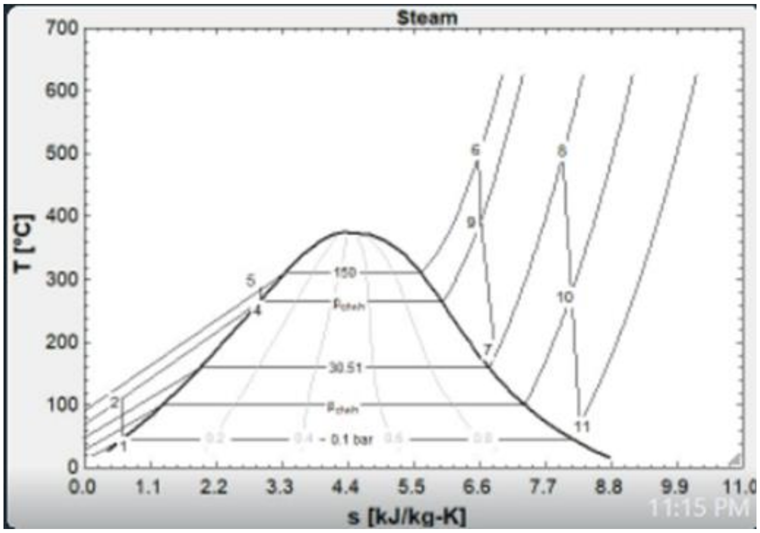
Table 1 | Table 2 | Table 3 | Table 4

1..10	η_{th}	P_{cfwh} [bar]	P_{ofwh} [bar]
Run 1	0.3987	10	75
Run 2	0.3975	10.56	77.78
Run 3	0.3964	11.11	80.56
Run 4	0.3952	11.67	83.33
Run 5	0.3941	12.22	86.11
Run 6	0.3929	12.78	88.89
Run 7	0.3918	13.33	91.67
Run 8	0.3906	13.89	94.44
Run 9	0.3895	14.44	97.22
Run 10	0.3883	15	100

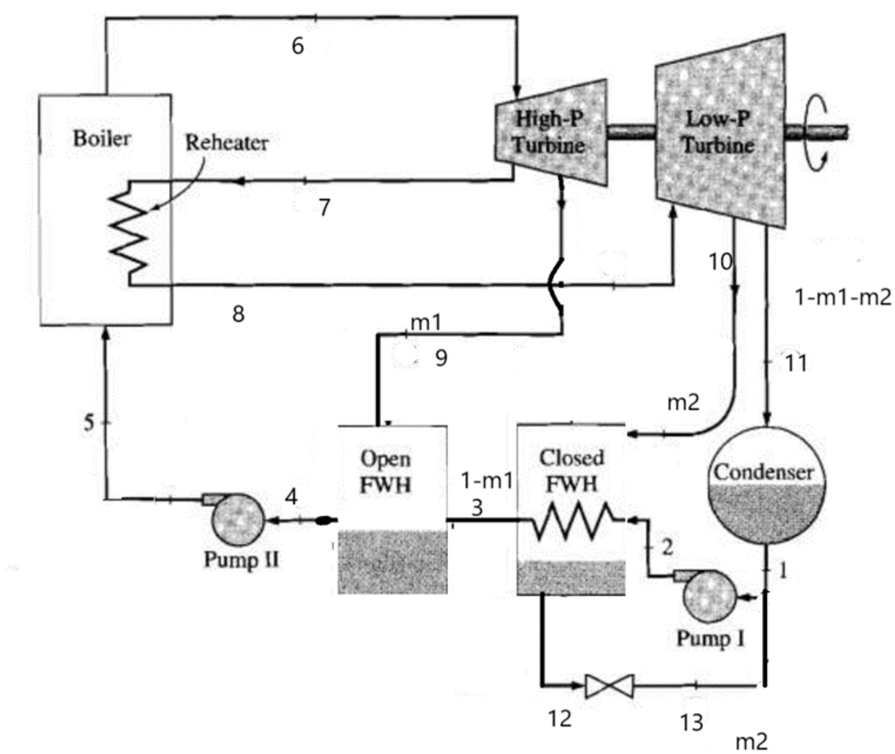
Table 1 | Table 2 | Table 3 | Table 4

1..10	η_{th}	P_{cfwh} [bar]	P_{ofwh} [bar]
Run 1	0.3883	15	100
Run 2	0.3851	16.67	105.6
Run 3	0.3819	18.33	111.1
Run 4	0.3788	20	116.7
Run 5	0.3757	21.67	122.2
Run 6	0.3726	23.33	127.8
Run 7	0.3695	25	133.3
Run 8	0.3664	26.67	138.9
Run 9	0.3634	28.33	144.4
Run 10	0.3603	30	150

T-s Diagram



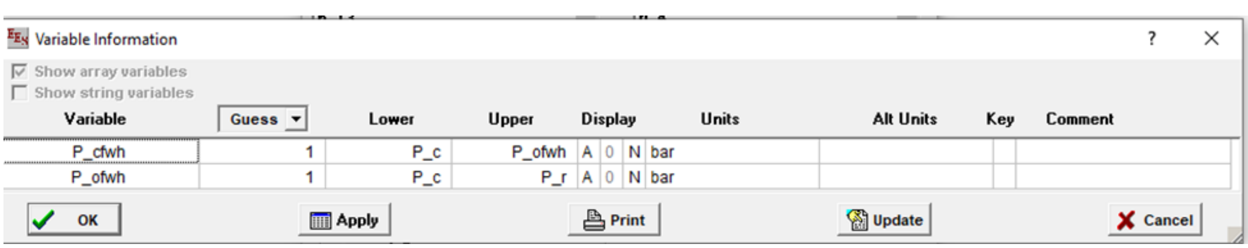
Flow Diagram



Before the reheat pressure

```
{p_ofwh&p_cfwh from LT}
{given}
P_b=150
P_c=0.1
P_r=30.51
T_max=500
eta_t=0.85
eta_p=0.95
{point1}
h_1=enthalpy(Steam,x=0,P=P_c)
s_1=entropy(Steam,x=0,P=P_c)
{point2}
s_1=s_2
h_2s=enthalpy(Steam,s=s_1,P=P_ofwh)
eta_p=(h_2s-h_1)/(h_2-h_1)
{point12}
h_12=enthalpy(Steam,x=0,P=P_cfwh)
T_sat12=t_sat(Steam,P=P_cfwh)
{point13}
h_12=h_13
{point3}
T_3=T_sat12
h_3=4.18*T_3
{point4}
h_4=enthalpy(Steam,x=0,P=P_ofwh)
s_4=entropy(Steam,x=0,P=P_ofwh)
{point5}
s_4=s_5
h_5s=enthalpy(Steam,s=s_4,P=P_b)
eta_p=(h_5s-h_4)/(h_5-h_4)
{point6}
h_6=enthalpy(Steam,T=T_max,P=P_b)
s_6=entropy(Steam,T=T_max,P=P_b)
```

```
{point7}
s_7=s_6
h_7s=enthalpy(Steam,s=s_6,P=P_r)
eta_t=(h_6-h_7)/(h_6-h_7s)
{point8}
h_8=enthalpy(Steam,T=T_max,P=P_r)
s_8=entropy(Steam,T=T_max,P=P_r)
{point9}
s_8=s_9s
h_9s=enthalpy(Steam,s=s_9s,P=P_ofwh)
eta_t=(h_8-h_9)/(h_8-h_9s)
s_9=entropy(Steam,h=h_9,P=P_ofwh)
{point10}
s_10s=s_9
h_10s=enthalpy(Steam,s=s_10s,P=P_cfwh)
eta_t=(h_9-h_10)/(h_9-h_10s)
s_10=entropy(Steam,h=h_10,P=P_cfwh)
{point11}
s_11s=s_10
h_11s=enthalpy(Steam,s=s_11s,P=P_c)
eta_t=(h_10-h_11)/(h_10-h_11s)
s_11=entropy(Steam,h=h_11,P=P_c)
x_11=quality(Steam,s=s_11,P=P_c)
{m}
m_1=(h_4-h_3)/(h_9-h_3)
(1-m_1)*h_2+(h_10*m_2)=(m_2*h_12)+(1-m_1)*h_3
{calculation}
w_t=(h_6-h_7)+(h_8-h_9)+(1-m_1)*(h_9-h_10)+(1-m_1-m_2)*(h_10-h_11)
w_p=(1-m_1)*(h_2-h_1)+(h_5-h_4)
w_net=w_t-w_p
q_add=(h_6-h_5)+(h_8-h_7)
eta_th=w_net/q_add
```


Variable Information

☑ Show array variables
☐ Show string variables

Variable	Guess	Lower	Upper	Display			Units	Alt Units	Key	Comment
P_cfwh	1	P_c	P_ofwh	A	0	N	bar			
P_ofwh	1	P_c	P_r	A	0	N	bar			

OK Apply Print Update Cancel

Calculations Completed

48 equations in 32 blocks - 141 iterations

Elapsed time = 3.3 sec

eta_th = 0.411

Continue

Independent Variable	Value	Best value
P_cfwh	1.573	1.573
P_ofwh	12.65	12.65

Optimum OFWH pressure = 12.65bar

Optimum CFWH pressure = 1.573bar

Max thermal efficiency =0.411

Results Tab

Unit Settings: SI C bar kJ mass deg

Maximization of eta_th(P_cfwh,P_ofwh) = 0.411   141 iterations: Variable Metric method

η_p = 0.95	η_t = 0.85	η_{th} = 0.411	h_1 = 191.8	h_{10} = 2803
h_{13} = 473.2	h_2 = 193.1	h_{2s} = 193.1	h_3 = 471.4	h_4 = 809
h_{7s} = 2891	h_8 = 3457	h_9 = 3220	h_{9s} = 3178	m_1 = 0.1228
P_{ofwh} = 12.65 [bar]	P_r = 30.51 [bar]	q_{add} = 2988	s_1 = 0.6492	s_{10} = 7.468
s_4 = 2.239	s_5 = 2.239	s_6 = 6.348	s_7 = 6.348	s_8 = 7.228
T_{sat12} = 112.8 [C]	w_{net} = 1228	w_p = 17.61	w_t = 1246	x_{11} = 0.9365

h_{10s} = 2729	h_{11} = 2432	h_{11s} = 2367	h_{12} = 473.2
h_5 = 825.5	h_{5s} = 824.6	h_6 = 3311	h_7 = 2954
m_2 = 0.1048	P_b = 150	P_c = 0.1	P_{cfwh} = 1.573 [bar]
s_{10s} = 7.292	s_{11} = 7.673	s_{11s} = 7.468	s_2 = 0.6492
s_9 = 7.292	s_{9s} = 7.228	T_3 = 112.8 [C]	T_{max} = 500 [C]

Table 1 | Table 2 | Table 3 | **Table 4**

1..10	η_{th}	P_{cfwh} [bar]	P_{ofwh} [bar]
Run 1	0.3953	2	2
Run 2	0.3961	2.111	2.194
Run 3	0.3967	2.222	2.389
Run 4	0.3973	2.333	2.583
Run 5	0.3978	2.444	2.778
Run 6	0.3982	2.556	2.972
Run 7	0.3986	2.667	3.167
Run 8	0.3989	2.778	3.361
Run 9	0.3992	2.889	3.556
Run 10	0.3994	3	3.75

Table 1 | Table 2 | Table 3 | Table 4

1..10	η_{th}	P_{cfwh} [bar]	P_{ofwh} [bar]
Run 1	0.3695	0.1	0.1
Run 2	0.4032	1.756	3.422
Run 3	0.4043	3.411	6.744
Run 4	0.4028	5.067	10.07
Run 5	0.4005	6.722	13.39
Run 6	0.3979	8.378	16.71
Run 7	0.3951	10.03	20.03
Run 8	0.3923	11.69	23.36
Run 9	0.3894	13.34	26.68
Run 10	0.3866	15	30

Table 1 | **Table 2** | Table 3 | Table 4

1..10	η_{th}	P_{cfwh} [bar]	P_{ofwh} [bar]
Run 1	0.3907	1	1
Run 2	0.3999	1.722	2.556
Run 3	0.4026	2.444	4.111
Run 4	0.4035	3.167	5.667
Run 5	0.4035	3.889	7.222
Run 6	0.403	4.611	8.778
Run 7	0.4023	5.333	10.33
Run 8	0.4014	6.056	11.89
Run 9	0.4004	6.778	13.44
Run 10	0.3993	7.5	15

Table 1 | Table 2 | **Table 3** | Table 4

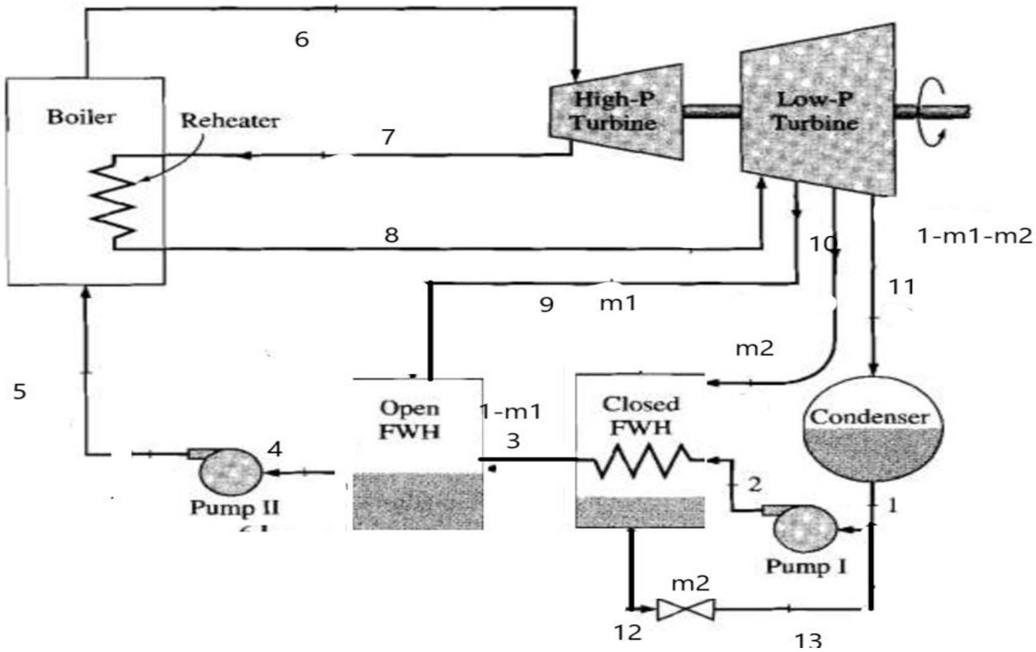
1..10	η_{th}	P_{cfwh} [bar]	P_{ofwh} [bar]
Run 1	0.3936	1.5	1.5
Run 2	0.3976	1.75	2.167
Run 3	0.4	2	2.833
Run 4	0.4015	2.25	3.5
Run 5	0.4026	2.5	4.167
Run 6	0.4033	2.75	4.833
Run 7	0.4037	3	5.5
Run 8	0.404	3.25	6.167
Run 9	0.4042	3.5	6.833
Run 10	0.4042	3.75	7.5

Duplicate Code

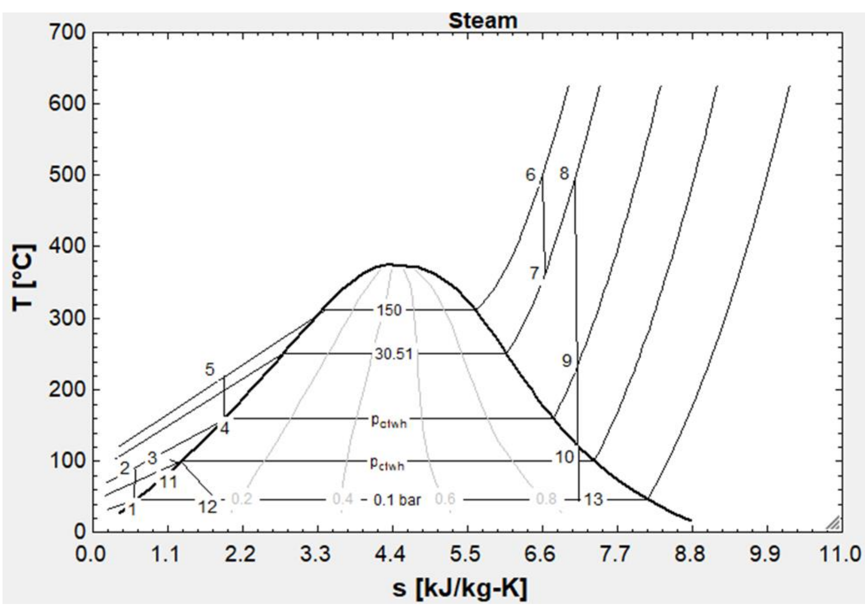
```
{given}
P_c=0.1
P_b=150
P_r=30.51
eta_p=0.95
eta_t=0.85
T_max=500

Duplicate i=1,13
P_ofwh[i]=(P_c)+((i-1)*(P_r-P_c)/13)
h_2s[i]=enthalpy(Steam,s=s_1,P=P_ofwh[i])
h_2[i]=((h_2s[i]-h_1)/eta_p)+h_1
{point4}
h_4[i]=enthalpy(Steam,x=0,P=P_ofwh[i])
s_4[i]=entropy(Steam,x=0,P=P_ofwh[i])
{point5}
h_5s[i]=enthalpy(Steam,s=s_4[i],P=P_b)
h_5[i]=((h_5s[i]-h_4[i])/eta_p)+h_4[i]
{point9}
h_9s[i]=enthalpy(Steam,s=s_8,P=P_ofwh[i])
h_9[i]=h_8-eta_t*(h_8-h_9s[i])
s_9[i]=entropy(Steam,h=h_9[i],P=P_ofwh[i])
q_add[i]=(h_6-h_5[i])+(h_8-h_7)
Duplicate j=1,13
P_cfwh[j,i]=(P_c)+((j-1)*(P_ofwh[i]-P_c)/13)
{point12}
h_12[j,i]=enthalpy(Steam,x=0,P=P_cfwh[j,i])
T_sat12[j,i]=t_sat(Steam,P=P_cfwh[j,i])
{point13}
h_12[j,i]=h_13[j,i]
{point3}
h_3[j,i]=4.18*T_sat12[j,i]
```

```
{point10}
h_10s[j,i]=enthalpy(Steam,s=s_9[i],P=P_cfwh[j,i])
h_10[j,i]=h_9[i]-eta_t*(h_9[i]-h_10s[j,i])
s_10[j,i]=entropy(Steam,h=h_10[j,i],P=P_cfwh[j,i])
{point11}
h_11s[j,i]=enthalpy(Steam,s=s_10[j,i],P=P_c)
h_11[j,i]=h_10[j,i]-eta_t*(h_10[j,i]-h_11s[j,i])
s_11[j,i]=entropy(Steam,h=h_11[j,i],P=P_c)
{m}
m_1[j,i]=(h_4[i]-h_3[j,i])/(h_9[i]-h_3[j,i])
(1-m_1[j,i])*h_2[i]+(h_10[j,i]*m_2[j,i])=(m_2[j,i]*h_12[j,i])+(1-m_1[j,i])*h_3[j,i]
{calculation}
w_t[j,i]=(h_6-h_7)+(h_8-h_9[i])+(1-m_1[j,i])*(h_9[i]-h_10[j,i])+(1-m_1[j,i]-m_2[j,i])*(h_10[j,i]-h_11[j,i])
w_p[j,i]=(1-m_1[j,i])*(h_2[i]-h_1)+(h_5[i]-h_4[i])
w_net[j,i]=w_t[j,i]-w_p[j,i]
eta_th[j,i]=w_net[j,i]/q_add[i]
End
End
{point1}
h_1=enthalpy(Steam,x=0,P=P_c)
s_1=entropy(Steam,x=0,P=P_c)
{point6}
h_6=enthalpy(Steam,T=T_max,P=P_b)
s_6=entropy(Steam,T=T_max,P=P_b)
{point7}
s_7=s_6
h_7s=enthalpy(Steam,s=s_6,P=P_r)
h_7=h_6-eta_t*(h_6-h_7s)
{point8}
h_8=enthalpy(Steam,T=T_max,P=P_r)
s_8=entropy(Steam,T=T_max,P=P_r)
```

Flow Diagram



T-s Diagram



Note: It's found that the highest efficiency obtained when the pressure of OFWH &CFWH from low turbine pressure.

D.3 One OFWH and two CFWHs were added to the reheat cycle

After the Reheat Pressure

Code

```
{given}
P_b=150
P_c=0.1
T_max=500
eta_turbine=.85;eta_pump=.95
p_reheat=30.51
"point1"
x[1]=0 "sat liq"
h_1=enthalpy(Steam,x=x[1],P=P_c)
s_1=entropy(Steam,x=x[1],P=P_c)
"point2"
s_2s=s_1
h_2s=enthalpy(Steam,s=s_2s,P=P_2)
eta_pump*(h_2-h_1)=(h_2s-h_1)
{point 16}
T_16=temperature(Steam,P=P_3,x=0)
h_16=enthalpy(Steam,x=0,P=P_3)
h_16=h_17
{h_17=enthalpy(Steam,x=0,P=P_3)}
{point 3}
T_3=T_16
{h_3=enthalpy(Steam,T=T_16,P=P_2)}
h_3=4.18*T_16
{point 4}
h_4=enthalpy(Steam,x=0,P=P_2)
s_4=entropy(Steam,x=0,P=P_2)
{point 5}
s_4=s_5s
h_5s=enthalpy(Steam,s=s_5s,P=P_b)
eta_pump*(h_5-h_4)=(h_5s-h_4)
{point 14}
T_sat_14=t_sat(Steam,P=P_1)
h_14=enthalpy(Steam,x=0,P=P_1)
h_14=h_15
{point 6}
T_sat_14=T_6
{h_6=enthalpy(Steam,T=T_sat_14,P=P_b)}
h_6=4.18*T_sat_14
```

```
{point 7}
h_7=enthalpy(Steam,T=T_max,P=P_b)
s_7=entropy(Steam,T=T_max,P=P_b)
{point 8}
s_7=s_8s
h_8s=enthalpy(Steam,s=s_8s,P=P_reheat)
eta_turbine*(h_7-h_8s)=(h_7-h_8)
s_8=entropy(Steam,h=h_8,P=P_reheat)
{point 9}
h_9=enthalpy(Steam,T=T_max,P=P_reheat)
s_9=entropy(Steam,T=T_max,P=P_reheat)
{point 10}
s_10s=s_9
h_10s=enthalpy(Steam,s=s_10s,P=P_1)
eta_turbine*(h_9-h_10s)=(h_9-h_10)
s_10=entropy(Steam,h=h_10,P=P_1)
{point 11}
s_10=s_11s
h_11s=enthalpy(Steam,s=s_11s,P=P_2)
eta_turbine*(h_10-h_11s)=(h_10-h_11)
s_11=entropy(Steam,h=h_11,P=P_2)
{point 12}
s_11=s_12s
h_12s=enthalpy(Steam,s=s_12s,P=P_3)
eta_turbine*(h_11-h_12s)=(h_11-h_12)
s_12=entropy(Steam,h=h_12,P=P_3)
{point 13}
s_12=s_13s
h_13s=enthalpy(Steam,s=s_13s,P=P_c)
eta_turbine*(h_12-h_13s)=(h_12-h_13)
s_13=entropy(Steam,h=h_13,P=P_c)
{Energy balance on CFWH2}
m_1*h_10+(1)*h_5=m_1*h_14+h_6
{Energy balance on OFWH}
m_2*h_11+m_1*h_15+(1-m_1-m_2)*h_3=h_4
{Energy balance on CFWH1}
m_3*h_12+(1-m_1-m_2)*h_2=m_3*h_16+(1-m_1-m_2)*h_3
```

```
{outputs}
w_p1=(1-m_1-m_2)*(h_2-h_1)
w_p2=h_5-h_4
w_t=(h_7-h_8)+(h_9-h_10)+(1-m_1)*(h_10-h_11)+(1-m_1-m_2)*(h_11-h_12)+(1-m_1-m_2-m_3)*(h_12-h_13)
w_net=w_t-(w_p1+w_p2)
Q_add=(h_7-h_6)+(h_9-h_8)
eta_th=w_net/Q_add
```

Variable	Guess	Lower	Upper
P_1	30	P_2	p_reheat
P_2	6	P_3	P_1
P_3	3	P_c	P_2

Calculations Completed

60 equations in 42 blocks - 244 iterations

Elapsed time = 6.6 sec

eta_th = 0.4163

Continue

Independent Variable	Value	Best value
P_1	23.09	23.09
P_2	6.896	6.896
P_3	1.158	1.158

Optimum OFWH pressure = 6.8bar

Optimum CFWH1 pressure = 23.09 bar

Optimum CFWH2 pressure =1.158 bar

Max. thermal efficiency =0.4163 bar

Results Tab

Unit Settings: SI C bar kJ mass deg

Maximization of eta_th(P_1,P_2,P_3) = 0.4163   244 iterations: Variable Metric method

$\eta_{pump} = 0.95$	$\eta_{th} = 0.4163$	$\eta_{turbine} = 0.85$	$h_1 = 191.8$
$h_{13} = 2429$	$h_{13s} = 2372$	$h_{14} = 942.5$	$h_{15} = 942.5$
$h_5 = 711$	$h_{5s} = 710.2$	$h_6 = 918.6$	$h_7 = 3311$
$P_1 = 23.09$	$P_2 = 6.896$	$P_3 = 1.158$	$P_b = 150$
$s_{11} = 7.339$	$s_{11s} = 7.247$	$s_{12} = 7.485$	$s_{12s} = 7.339$
$s_8 = 6.463$	$s_{8s} = 6.348$	$s_9 = 7.228$	$T_{16} = 103.8$

$h_{11s} = 3026$	$h_{12} = 2751$	$h_{12s} = 2693$
$h_{2s} = 192.5$	$h_3 = 433.7$	$h_4 = 694.4$
$m_1 = 0.08531$	$m_2 = 0.08214$	$m_3 = 0.08672$
$s_1 = 0.6492$	$s_{10} = 7.247$	$s_{10s} = 7.228$
$s_4 = 1.986$	$s_{5s} = 1.986$	$s_7 = 6.348$
$T_{sat,14} = 219.8$	$w_{net} = 1205$	$w_{p1} = 0.6016$

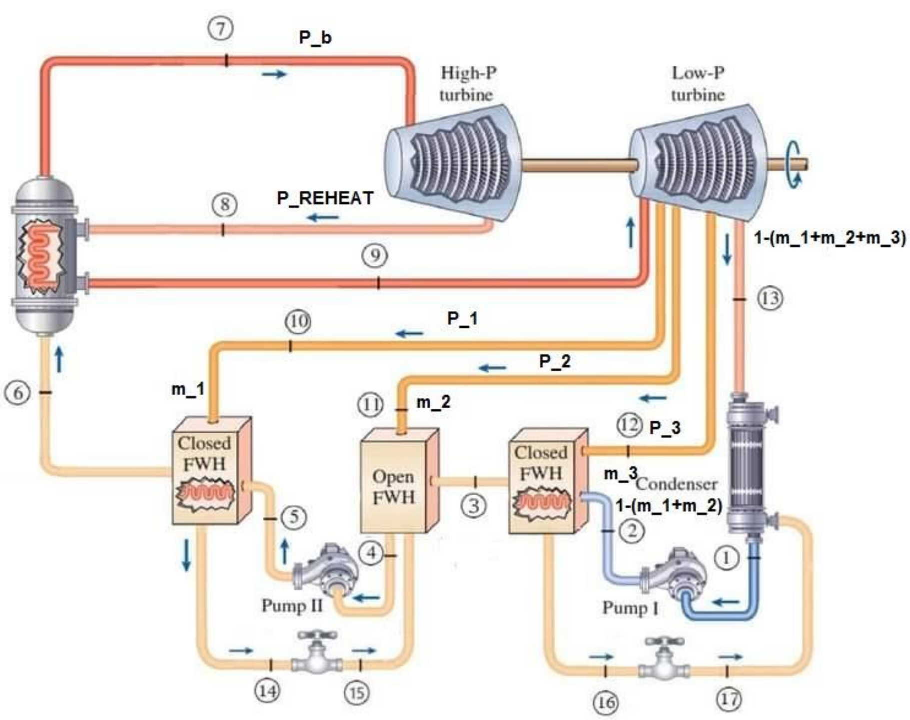
1..10	η_{th}	P_1	P_2	P_3
Run 1	0.4053	30	20	6
Run 2	0.4067	26.7	17.8	5.344
Run 3	0.408	23.4	15.6	4.689
Run 4	0.4092	20.1	13.4	4.033
Run 5	0.4103	16.8	11.2	3.378
Run 6	0.4111	13.5	9	2.722
Run 7	0.4113	10.2	6.8	2.067
Run 8	0.4104	6.9	4.6	1.411
Run 9	0.4064	3.6	2.4	0.7556
Run 10	0.3796	0.3	0.2	0.1

1..10	η_{th}	P_1	P_2	P_3
Run 1	0.4032	30	20	7
Run 2	0.4048	27.78	18.33	6.233
Run 3	0.4065	25.56	16.67	5.467
Run 4	0.4081	23.33	15	4.7
Run 5	0.4098	21.11	13.33	3.933
Run 6	0.4114	18.89	11.67	3.167
Run 7	0.4129	16.67	10	2.4
Run 8	0.414	14.44	8.333	1.633
Run 9	0.4141	12.22	6.667	0.8667
Run 10	0.407	10	5	0.1

1..10	η_{th}	P_1	P_2	P_3
Run 1	0.3967	30	20	10
Run 2	0.3989	27.56	18.33	8.9
Run 3	0.4011	25.11	16.67	7.8
Run 4	0.4033	22.67	15	6.7
Run 5	0.4055	20.22	13.33	5.6
Run 6	0.4078	17.78	11.67	4.5
Run 7	0.41	15.33	10	3.4
Run 8	0.412	12.89	8.333	2.3
Run 9	0.413	10.44	6.667	1.2
Run 10	0.4051	8	5	0.1

1..10	η_{th}	P_1	P_2	P_3
Run 1	0.4032	30	20	7
Run 2	0.4048	27.11	18	6.233
Run 3	0.4064	24.22	16	5.467
Run 4	0.4079	21.33	14	4.7
Run 5	0.4094	18.44	12	3.933
Run 6	0.4107	15.56	10	3.167
Run 7	0.4118	12.67	8	2.4
Run 8	0.4123	9.778	6	1.633
Run 9	0.4116	6.889	4	0.8667
Run 10	0.4046	4	2	0.1

Flow Diagram



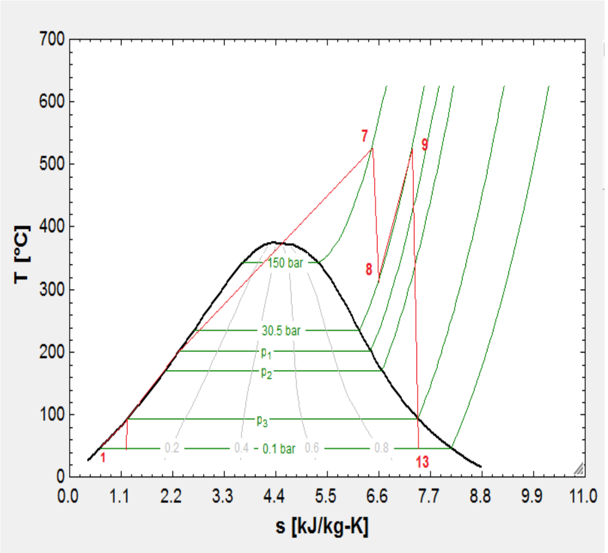
Duplicate code:

```
{Givens}
P_c=0.1[bar] (compressor pressure)
P_b=150[bar] (boiler pressure)
T_max=500 (max temperature)
eta_t=0.85 (turbine eff)
eta_p=0.95 (pump eff)
P_r=30.51[bar]
{Point 1}
h_1=ENTHALPY(Steam,x=0,P=P_c)
s_1=ENTROPY(Steam,x=0,P=P_c)
s_2s=s_1
Duplicate i=1,5
P_1[i]=(P_c)+(i-1)*(P_r-P_c)/5
{Point 10}
h_10s[i]=ENTHALPY(Steam,s=s_10s,P=P_1[i])
h_10[i]=h_9-((h_9-h_10s[i])*eta_t)
s_10[i]=ENTROPY(Steam,h=h_10[i],P=P_1[i])
{Point 14}
h_14[i]=ENTHALPY(Steam,x=0,P=P_1[i])
s_14[i]=ENTROPY(Steam,x=0,P=P_1[i])
T_14[i]=TEMPERATURE(Steam,x=0,P=P_1[i])
{point15}
h_15[i]=h_14[i]
{Point 6}
T_6[i]=T_14[i]
h_6[i]=ENTHALPY(Steam,T=T_14[i],P=P_b)

q_add[i]=(h_7-h_6[i])+(h_9-h_8)

Duplicate j=1,5
P_2[j,i]=(P_c)+(j-1)*(P_1[i]-P_c)/5
{Point 11}
s_11s[j,i]=s_10[i]
h_11s[j,i]=ENTHALPY(Steam,s=s_11s[j,i],P=P_2[j,i])
h_11[j,i]=h_10[i]-(eta_t*(h_10[i]-h_11s[j,i]))
s_11[j,i]=ENTROPY(Steam,h=h_11[j,i],P=P_2[j,i])
{Point 2}
h_2s[j,i]=ENTHALPY(Steam,s=s_2s,P=P_2[j,i])
h_2[j,i]=((h_2s[j,i]-h_1)/eta_p)+h_1
{Point 4}
h_4[j,i]=ENTHALPY(Steam,x=0,P=P_2[j,i])
s_4[j,i]=ENTROPY(Steam,x=0,P=P_2[j,i])
{Point 5}
s_5s[j,i]=s_4[j,i]
h_5s[j,i]=ENTHALPY(Steam,s=s_5s[j,i],P=P_b)
h_5[j,i]=((h_5s[j,i]-h_4[j,i])/eta_p)+h_4[j,i]
```

```
{Energy balance on CFWH1}
m_1[j,i]=(h_6[i]-h_5[j,i])/(h_10[i]-h_14[i])

Duplicate k=1,5
P_3[k,j,i]=(P_c)+(k-1)*(P_2[j,i]-P_c)/5
{Point 12}
s_12s[k,j,i]=s_11[j,i]
h_12s[k,j,i]=ENTHALPY(Steam,s=s_12s[k,j,i],P=P_3[k,j,i])
h_12[k,j,i]=h_11[j,i]-(eta_t*(h_11[j,i]-h_12s[k,j,i]))
s_12[k,j,i]=ENTROPY(Steam,h=h_12[k,j,i],P=P_3[k,j,i])
{Point 13}
s_13s[k,j,i]=s_12[k,j,i]
h_13s[k,j,i]=ENTHALPY(Steam,s=s_13s[k,j,i],P=P_c)
h_13[k,j,i]=h_12[k,j,i]-(eta_t*(h_12[k,j,i]-h_13s[k,j,i]))
{Point 16}
h_16[k,j,i]=ENTHALPY(Steam,x=0,P=P_3[k,j,i])
T_16[k,j,i]=TEMPERATURE(steam,x=0,P=P_3[k,j,i])
{Point 17}
h_17[k,j,i]=h_16[k,j,i]
{Point 3}
T_3[k,j,i]=T_16[k,j,i]
h_3[k,j,i]=ENTHALPY(Steam,T=T_3[k,j,i],P=P_2[j,i])

{Energy balance on OFWH}
m_2[k,j,i]=(h_4[j,i]-h_3[k,j,i]+(m_1[j,i]*(h_3[k,j,i]-h_15[i])))/(h_11[j,i]-h_3[k,j,i])
{Energy balance on CFWH2}
m_3[k,j,i]=(1-m_1[j,i]-m_2[k,j,i])*(h_2[j,i]-h_3[k,j,i])/(h_16[k,j,i]-h_12[k,j,i])
{Outputs}
w_t[k,j,i]=(h_7-h_8)+(h_9-h_10[i])+(1-m_1[j,i])*(h_10[i]-h_11[j,i])+(1-m_1[j,i]-m_2[k,j,i])*(h_11[j,i]-
h_12[k,j,i])+(1-m_1[j,i]-m_2[k,j,i]-m_3[k,j,i])*(h_12[k,j,i]-h_13[k,j,i])

w_p[k,j,i]=(1-m_1[j,i]-m_2[k,j,i])*(h_2[j,i]-h_1)+(h_5[j,i]-h_4[j,i])
eta_thermal[k,j,i]=(w_t[k,j,i]-w_p[k,j,i])/q_add[i]

End
End
End

{Point 9}
h_9=ENTHALPY(Steam,T=T_max,P=P_r)
s_9=ENTROPY(Steam,T=T_max,P=P_r)
s_10s=s_9
h_7=ENTHALPY(Steam,T=T_max,P=P_b)
s_7=ENTROPY(Steam,T=T_max,P=P_b)
```

{Point 8}
s_8s=s_7
h_8s=ENTHALPY(Steam,s=s_8s,P=P_r)
eta_t=(h_7-h_8)/(h_7-h_8s)
s_8=ENTROPY(Steam,h=h_8,P=P_r)
{Point 1}
h_1=ENTHALPY(Steam,x=0,P=P_c)
s_1=ENTROPY(Steam,x=0,P=P_c)
s_2s=s_1

T-s Diagram



Conclusion

max thermal efficiency	0.4167

D.4 One OFWH and three CFWHs were added to the reheat cycle

After the Reheat Pressure

Code

```
P_b=150
P_c=0.1
T_max=500
eta_t=0.85
eta_p=0.95
T_8=T_max
C_p=4.18
P_reheat=30.51
P_b=P_7
P_b=P_8
P_b=P_6
P_reheat=P_9
P_reheat=P_10
P_closed3=P_11
P_closed3=P_16
P_open=P_12
P_open=P_17
P_open=P_4
P_open=P_5
P_open=P_2
P_open=P_3
P_closed2=P_13
P_closed2=P_18
P_closed1=P_14
P_closed1=P_19
P_closed1=P_20
P_c=P_21
P_c=P_1
P_c=P_15
```

“point1 from condenser”

H_1=enthalpy(Steam,x=0,P=P_c)

S_1=entropy(Steam,x=0,P=P_c)

“point 2 to closed FWH_1”

H_2s=H_1+0.1*(P_2-P_1)

eta_p*(H_2-H_1)=(H_2s-H_1)

“point 3 from CFWH_1 to CFWH_2”

T_3=T_20

H_3=T_3*C_p

“point 4 from CFWH_2 to OFWH”

T_4=T_18

H_4=C_p*T_4

“point 5 out of OFWH”

H_5=enthalpy(Steam,x=0,P=P_open)

S_5=entropy(Steam,x=0,P=P_open)

“point 6 pumped to CFWH_3”

H_6s=H_5+0.1*(P_6-P_5)

eta_p*(H_6-H_5)=(H_6s-H_5)

“point 7 to boiler”

T_7=T_16

H_7=C_P*T_7

“point 8 from boiler”

H_8=enthalpy(Steam,T=T_max,P=P_b)

S_8=entropy(Steam,T=T_max,P=P_b)

“point 9 to be reheated”

H_9s=enthalpy(Steam,s=S_8,P=P_reheat)

eta_t*(H_9s-H_8)=(H_9-H_8)

“point 10 to LPT”

H_10=enthalpy(Steam,T=T_max,P=P_reheat)

S_10=entropy(Steam,T=T_max,P=P_reheat)

“point 11 from LPT to CFWH_3”

H_11s=enthalpy(Steam,s=S_10,P=P_closed3)

eta_t*(H_11s-H_10)=(H_11-H_10)

S_11=entropy(Steam,h=H_11,P=P_closed3)

“point 12 from LPT to open”

H_12s=enthalpy(Steam,s=S_11,P=P_open)

eta_t*(H_12s-H_11)=(H_12-H_11)

S_12=entropy(Steam,h=H_12,P=P_open)

“point 13 from LPT to CFWH_2”

H_13s=enthalpy(Steam,s=S_12,P=P_closed2)

eta_t*(H_13s-H_12)=(H_13-H_12)

S_13=entropy(Steam,h=H_13,P=P_closed2)

```
"point 14 from LPT to closed CFWH_1"
H_14s=enthalpy(Steam,s=S_13,P=P_closed1)
eta_t*(H_14s-H_13)=(H_14-H_13)
S_14=entropy(Steam,h=H_14,P=P_closed1)
"point 15 to condenser"
H_15s=enthalpy(Steam,s=S_14,P=P_c)
eta_t*(H_15s-H_14)=(H_15-H_14)
"point 16 out from closed FWH_3"
H_16=enthalpy(Steam,x=0,P=P_closed3)
S_16=entropy(Steam,x=0,P=P_closed3)
 T_16=temperature(Steam,x=0,P=P_closed3)
"point 17 throatled to OFWH"
H_16=H_17
"point 18 out from CFWH_2"
H_18=enthalpy(Steam,x=0,P=P_closed2)
S_18=entropy(Steam,x=0,P=P_closed2)
T_18=temperature(Steam,x=0,P=P_closed2)
"point 19 throatled to CFWH_1"
H_19=H_18

"point 20 out from CFWH_1"
H_20=enthalpy(Steam,x=0,P=P_closed1)
S_20=entropy(Steam,x=0,P=P_closed1)
```

T_20=temperature(Steam,x=0,P=P_closed1)

"point 21 throatled to condenser"

H_20=H_21

"energy balance"

(m_1*H_11) + H_6=(m_1*H_16) + H_7

(m_2*H_12) + (m_1*H_17) + (1 – m_1 – m_2)*H_4 = H_5

(m_3 *H_13) + ((1 – m_1 – m_2)*H_3)= ((1 – m_1 – m_2)*H_4) + (m_3 *H_18)

(m_4*H_14) + (m_3*H_19) +(1 – m_1 – m_2)*H_2 = (m_4+ m_3)*H_20 + (1 – m_1 – m_2)*H_3

"Energies"

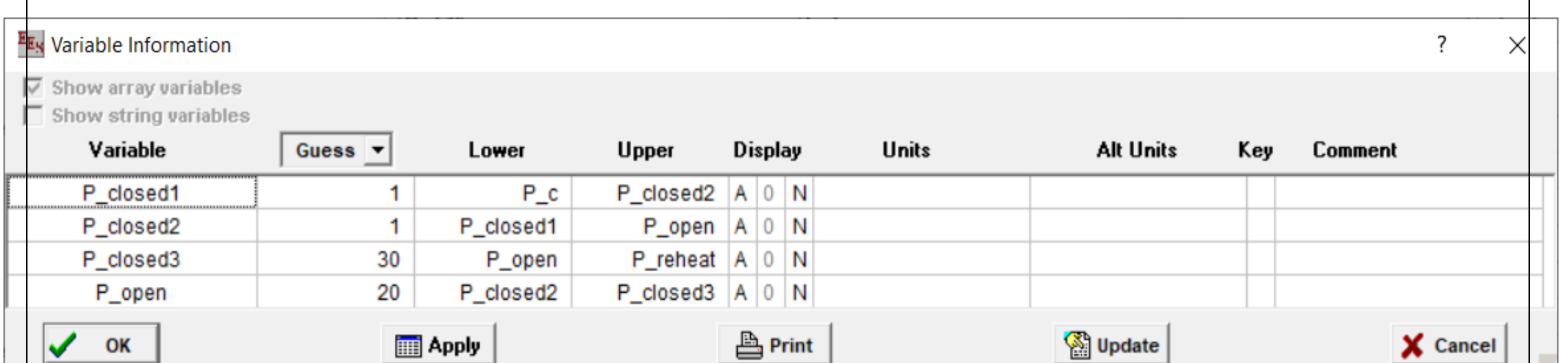
q_add = (H_8 – H_7) + (H_10 – H_9)

w_t = (H_8 – H_9) + (H_10 – H_11) + (1 – m_1)*(H_11 – H_12) + (1 – m_1 – m_2)*(H_12 – H_13) +(1 – m_1 – m_2 – m_3)*(H_13 – H_14) + (1 – m_1 – m_2 – m_3 – m_4)*(H_14 – H_15)

w_p=(H_6 – H_5) + (1 – m_1 – m_2)*(H_2 – H_1)

w_net = w_t – w_p

eta_th= w_net / q_add



Calculations Completed

84 equations in 61 blocks - 596 iterations

Elapsed time = 23.8 sec

eta_th = 0.4204

Continue

Independent Variable	Value	Best value
P_closed1	0.7589	0.7589
P_closed2	3.23	3.23
P_closed3	30.51	30.51
P_open	13.59	13.59

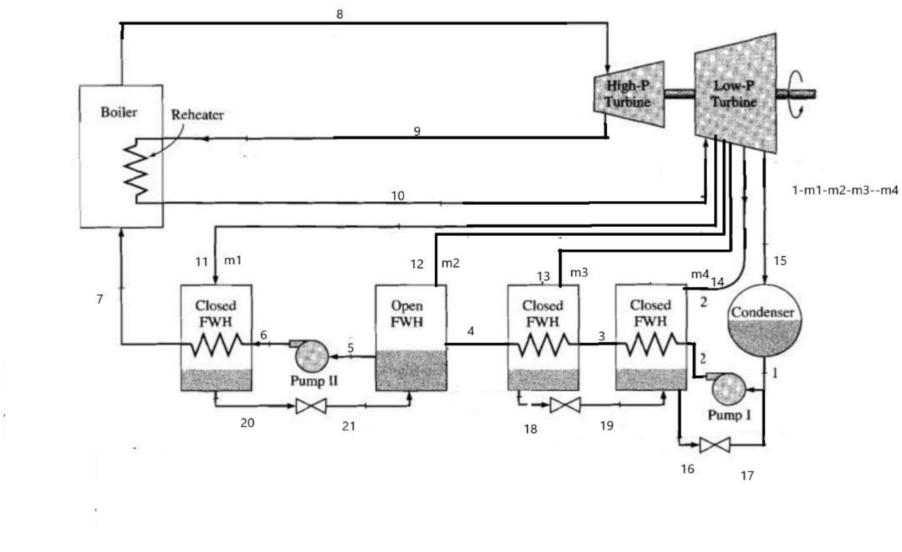
Unit Settings: SI C bar kJ mass deg

Maximization of eta_th(P_closed1,P_closed2,P_closed3,P_open) = 0.4204 574 iterations: Variable Metric method

C_p = 4.18	η_p = 0.95	η_t = 0.85	η_{th} = 0.4204	H_1 = 191.8	H_{10} = 3457
H_{11} = 3457	H_{11s} = 3457	H_{12} = 3238	H_{12s} = 3199	H_{13} = 2925	H_{13s} = 2870
H_{14} = 2684	H_{14s} = 2641	H_{15} = 2427	H_{15s} = 2382	H_{16} = 1013	H_{17} = 1013
H_{18} = 572.6	H_{19} = 572.6	H_2 = 193.2	H_{20} = 384	H_{21} = 384	H_{2s} = 193.2
H_3 = 383.1	H_4 = 569.1	H_5 = 824.1	H_6 = 838.5	H_{6s} = 837.8	H_7 = 981.4
H_8 = 3311	H_9 = 2954	H_{9s} = 2891	m_1 = 0.05848	m_2 = 0.08586	m_3 = 0.06766
m_4 = 0.06508	P_1 = 0.1	P_{10} = 30.51	P_{11} = 30.51	P_{12} = 13.61	P_{13} = 3.237
P_{14} = 0.7468	P_{15} = 0.1	P_{16} = 30.51	P_{17} = 13.61	P_{18} = 3.237	P_{19} = 0.7468
P_2 = 13.61	P_{20} = 0.7468	P_{21} = 0.1	P_3 = 13.61	P_4 = 13.61	P_5 = 13.61
P_6 = 150	P_7 = 150	P_8 = 150	P_9 = 30.51	P_b = 150	P_c = 0.1
$P_{closed1}$ = 0.7468	$P_{closed2}$ = 3.237	$P_{closed3}$ = 30.51	P_{open} = 13.61	P_{reheat} = 30.51	q_{add} = 2832
S_1 = 0.6492	S_{10} = 7.228	S_{11} = 7.228	S_{12} = 7.287	S_{13} = 7.399	S_{14} = 7.515
S_{16} = 2.654	S_{18} = 1.699	S_{20} = 1.212	S_5 = 2.271	S_8 = 6.348	T_{16} = 234.8
T_{18} = 136.1	T_{20} = 91.64	T_3 = 91.64	T_4 = 136.1	T_7 = 234.8	T_8 = 500
T_{max} = 500	w_{net} = 1190	w_p = 15.57	w_t = 1206		

Optimum pressure CFWH 1	**0.7468 Bar**
Optimum pressure CFWH 2	**3.237 Bar**
Optimum pressure CFWH 3	**30.51 Bar**
Optimum pressure OFWH	**13.61 Bar**
Max thermal efficiency	**42.04%**

Flow Diagram



T-s Diagram

Figure 81: Arrays table tab for maximum thermal efficiency

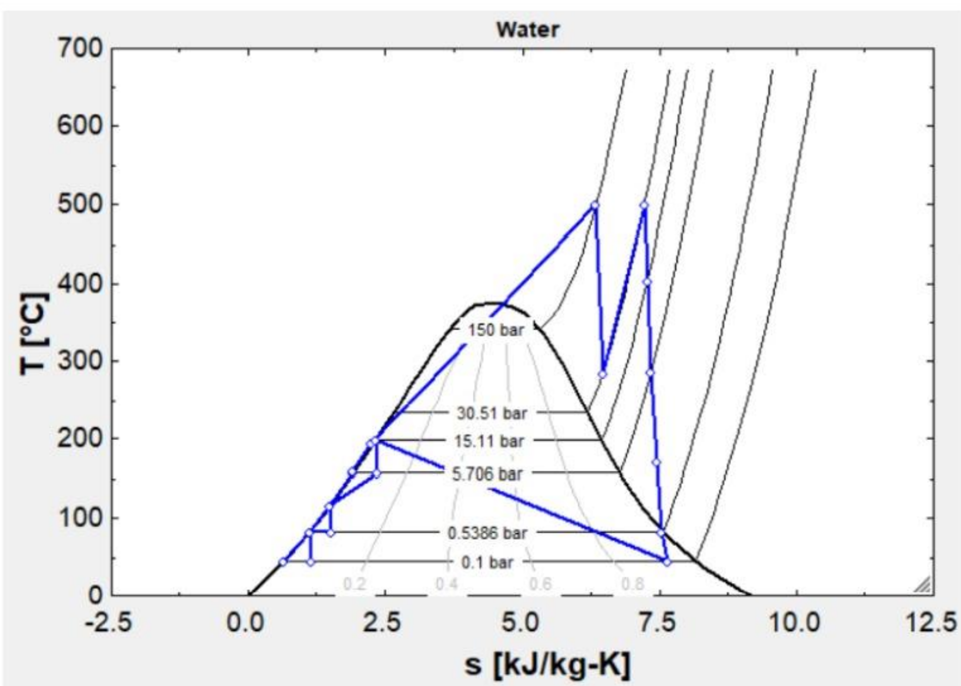


Figure 82: T-S Diagram for this case at optimized pressure values

Another soln using for loop in matlab

Code

```
clc,clear ;
addpath("steam");

%%%%%%%%%%%%%%%%%%%%%%%% the givens  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Pb = 150 ; Pc = 0.1 ;  Tmax = 500; etaT = 0.85; etaP = 0.95; Cp = 4.18; Pr =
30.53 ; x= 0;

st=.5;

format short;

%constant

%point 1
[h1,s1,P1] = point_1(Pc,x);

%point 8,9,10

[P8,h8,T8,s8,P9,h9s,h9,s9s,P10,h10,T10,s10]= point8_9_10 (Tmax,Pb,Pr,etaT);


%%%%%%%%%%%%%%%%%%%%%%%% the for loop %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

r=1;

for i=Pc:st:5%Pr
    P4f=i;
    u=1;
    for ii=(P4f+.01):st:10%Pr-.01)
        P3f=ii;
      o=1;
        for iii=(P3f+.01):st:20%(Pr-.02)
            P2f=iii;
            g=1;

            for iiii=(P2f+.01):st:Pr%(Pr-.03)
                P1f=iiii;
                %point 20,7
                [h20,T20,T7,h7,h21] = point20_7(P1f,x,Cp);

                %point 2
                [h2s,h2,h5,h6s,h6] = point_2 (P2f,Pb,h1,etaP,x,P1);

                %point 16,3
                [h16,T16,h3,T3,h17] = Point_163(P4f,x,Cp);

                %point 18,4
```

```
                [h18,T18,T4,h4,h19]= point_18_4(x,Cp,P3f);

                %point 11,12,13,14,15
                [h11s,h11,h12s,h12,h13s,h13,h14s,h14,h15s,h15] =
point_11(s10,h10,etaT,Pc,P1f,P4f);

                %mass balance
                [A,B,m1,m2,m3,m4] = mass_balance
(h2,h3,h4,h5,h6,h7,h11,h12,h13,h14,h16,h18,h19,h20,h21);

                %q,w calcs
                [Qrej(g,:),Qadd(g,:),Wt(g,:),Wp(g,:),Wnet(g,:)] = calc_QW
(h1,h2,h5,h6,h7,h8,h9,h10,h11,h12,h13,h14,h15,h17,m1,m2,m3,m4);

                % efficiency
                eta(g,:) = Wnet(g,:)/Qadd(g,:) ;
                P_4_f(g,:)=P4f;
                P_1_f(g,:)=P1f;

                P_2_f(g,:)=P2f;

                P_3_f(g,:)=P3f;
                g=g+1;
                sol=[eta,Wnet,Qadd,Qrej,Wt,Wp,P_4_f,P_3_f,P_2_f,P_1_f];
            end

           [best3(o,:),n]=max(eta);
            best_sol3(o,:)=sol(n,:);
           o=o+1;
           sol=0;
           P_4_f=0;
           P_3_f=0;
           P_2_f=0;
           P_1_f=0;
           Qrej=0;
           eta=0;
           Qadd=0;
           Wt=0;
           Wp=0;
           Wnet=0;
        end
        P_4_f;
        [best2(u,:),n]=max(best3);
        best_sol2(u,:)=best_sol3(n,:);
        u=u+1;
        best_sol3=[0 0 0 0 0 0 0 0 0 0];
        best3=0;
    end

   % h=1;
 %   [best_sol] = best_sol(Wnet,Qadd,Qrej,P_1_f,P_2_f,P_3_f,P_4_f,eta);
  %   best=best_sol;

  [best(r,:),n]=max(best2);
```

```
  best_sol(r,:)=best_sol2(n,:);
  r=r+1;
  sol=0;
  best_sol2=[0 0 0 0 0 0 0 0 0 0];
  best_sol3=[0 0 0 0 0 0 0 0 0 0];
  best2=0;
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figure(1)

plot(best_sol(:,7),best_sol(:,1),'red');
title('\eta_{th}','FontSize',14,'FontWeight','bold');
xlabel('FWH_1_{(bar)}','FontSize',12,'FontWeight','bold') ;
ylabel('\eta_{th} _{(rad)}','FontSize',12,'FontWeight','bold') ;
grid on;
grid minor;
saveas(gcf,'eta_vs_fwh_1.tiff');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figure(2)

plot((best_sol(:,2)/1000),best_sol(:,1),'red');
title('\eta_{th}&_W_n_e_t','FontSize',14,'FontWeight','bold');
xlabel('W_n_e_t_{(MW)}','FontSize',12,'FontWeight','bold') ;
ylabel('\eta_{th}','FontSize',12,'FontWeight','bold') ;
grid on;
grid minor;
saveas(gcf,'eta_vs_W_NET.tiff');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figure(3)

plot(best_sol(:,7),best_sol(:,2),'red');
title('W_n_e_t_{MW}','FontSize',14,'FontWeight','bold');
xlabel('FWH_1_{(bar)}','FontSize',12,'FontWeight','bold') ;
ylabel('W_n_e_t_{MW}','FontSize',12,'FontWeight','bold') ;
grid on;
grid minor;
saveas(gcf,'WORK_vs_fwh_1.tiff');

%%%%%%%%%%%%%%%%%%%%%%%% the excel sheet %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

excel=table(best_sol(:,1),best_sol(:,2),best_sol(:,3),best_sol(:,4),best_sol(
:,5),best_sol(:,6),best_sol(:,7),best_sol(:,8),best_sol(:,9),best_sol(:,10));
varNames={'eta','Wnet','Qadd','Qrej','Wt','Wp','P_4_f','P_3_f','P_2_f','P_1_f
'};
excel.Properties.VariableNames = varNames;

filename = 'the table.xlsx';

writetable(excel,filename);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%% functions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
function [best]=etab(eta)
best=max(eta);
end

function [h,s,Pout] = point_1(Pin,x)
      Pout = Pin;
      h = XSteam('h_px',Pin,x);
      s = XSteam('s_ph',Pin,h);
end

function [h2s,h2,h5,h6s,h6] = point_2 (P2f,Pb,h1,etaP,x,P1)


    h2s = h1 +0.1*(P2f-P1);
    h2 = h1+ (h2s-h1)/etaP;

    h5 = XSteam('h_px',P2f ,x);
    h6s = h5 +0.1*(Pb - P2f);
    h6 = h5 + (h6s -h5)/etaP;
end

function [h18,T18,T4,h4,h19]= point_18_4(x,Cp,P3f)

    h18 = XSteam('h_px',P3f,x);
    T18 = XSteam('Tsat_p',P3f);

    %point4
    T4 = T18;
    h4 = Cp*T4;

    %point19
    h19= h18;
end

function [h16,T16,h3,T3,h17] = Point_163(P4f,x,Cp)


    h16 = XSteam('h_px',P4f,x);
    T16 = XSteam('Tsat_p',P4f);

    %point3
    T3 = T16 ;
    h3 = Cp*T3 ;

    %point 17
    h17 = h16 ;

end

function [P8,h8,T8,s8,P9,h9s,h9,s9s,P10,h10,T10,s10]= point8_9_10
(Tmax,Pb,Pr,etaT)
```

```
%point 8
   P8 = Pb ; T8 = Tmax;
   h8 = XSteam('h_pt',P8 ,T8);
   s8 = XSteam('s_pT',P8 ,T8);

%point 9
   P9 = Pr ; s9s = s8;
   h9s = XSteam('h_ps',P9 ,s9s);
   h9 = h8-(h8-h9s)*etaT;

%point 10
   P10 = Pr ; T10 = Tmax;
   h10 = XSteam('h_pt',P10 ,T10);
   s10 = XSteam('s_pT',P10 ,T10);
end

function [h20,T20,T7,h7,h21] = point20_7(P1f,x,Cp)

   h20 = XSteam('h_px',P1f,x);
   T20 = XSteam('Tsat_p',P1f);
  %point 7
   T7 = T20;
   h7 = T7*Cp;

   %point 21
   h21= h20;
end

function [h11s,h11,h12s,h12,h13s,h13,h14s,h14,h15s,h15] =
point_11(s10,h10,etaT,Pc,P1f,P4f)


    h11s = XSteam('h_ps',P1f,s10);
    h11 = h10-(h10-h11s)*etaT;
    s11 = XSteam('s_ph',P1f,h11);

    %point 12

   h12s = XSteam('h_ps',P1f,s11);
   h12 = h11-(h11-h12s)*etaT;
   s12 = XSteam('s_ph',P1f,h12);

   %point 13

   h13s = XSteam('h_ps',P1f ,s12);
   h13 = h12 -(h12 -h13s)*etaT;
   s13 = XSteam('s_ph',P1f,h13);

   %point14

   h14s = XSteam('h_ps',P4f ,s13);
   h14 = h13 -(h13 -h14s)*etaT;
   s14 = XSteam('s_ph',P1f,h14);
```

```
    %point15


    h15s = XSteam('h_ps',Pc ,s14);
    h15 = h14 -(h14 -h15s)*etaT;
end

function [A,B,m1,m2,m3,m4] = mass_balance
(h2,h3,h4,h5,h6,h7,h11,h12,h13,h14,h16,h18,h19,h20,h21)

A = [(h11-h20) 0 0 0 ; (h21-h4) (h12-h4) 0 0 ; (h4-h3) (h4-h3) (h13-h18) 0 ;
(h3-h2) (h3-h2) (h19-h16) (h14-h16)];
    B = [(h7-h6) ;(h5-h4) ;(h4-h3) ;(h3-h2)];
    N = A\B;%inv(A) * B;
    m1 = N(1);
    m2 = N(2);
    m3 = N(3);
    m4 = N(4);

    m5 = 1-(m1+m2+m3+m4); % to the condenser
end

function [Qrej,Qadd,Wt,Wp,Wnet] = calc_QW
(h1,h2,h5,h6,h7,h8,h9,h10,h11,h12,h13,h14,h15,h17,m1,m2,m3,m4)
%q
    Qrej = (m3+m4)*h17 +(1-m1-m2-m3-m4)*h15 - (1-m1-m2)*h1;
    Qadd = (h8-h7)+(h10-h9);

%work
    Wt = (h8-h9)+(h10-h11)+(1-m1)*(h11-h12)+(1-m1-m2)*(h12-h13)+(1-m1-m2-
m3)*(h13-h14)+(1-m1-m2-m3-m4)*(h14-h15);
    Wp = (1-m1-m2)*(h2-h1) + (h6-h5);
    Wnet = Wt-Wp;
end
```

solution

Workspace

Name	Value
A	*4x4 double*
B	[60.6104;159.4701;123...
best	[0.5527;0.5201;0.5061;...
best2	0
best3	0
best_sol	*10x10 double*
best_sol2	[0,0,0,0,0,0,0,0,0,0]
best_sol3	[0,0,0,0,0,0,0,0,0,0]
Cp	4.1800
eta	0
etaP	0.9500
etaT	0.8500
excel	*10x10 table*
filename	'the table.xlsx'
g	23
h1	191.8123
h10	3.4565e+03
h11	3.4526e+03

Workspace

Name	Value
h11s	3.4519e+03
h12	3.4526e+03
h12s	3.4526e+03
h13	3.4526e+03
h13s	3.4526e+03
h14	2.9989e+03
h14s	2.9189e+03
h15	2.2119e+03
h15s	2.0730e+03
h16	626.7299
h17	626.7299
h18	755.0856
h19	755.0856
h2	193.8670
h20	1.0095e+03
h21	1.0095e+03
h2s	193.7643
h3	621.6528

Workspace

Name	Value
h4	744.7264
h5	904.1965
h6	917.9207
h6s	917.2345
h7	978.5311
h8	3.3108e+03
h9	2.9543e+03
h9s	2.8914e+03
i	4.6000
ii	9.6100
iii	19.6200
iiii	30.1300
m1	0.0248
m2	0.0565
m3	0.0419
m4	0.1634
n	1
o	22

Workspace

Name	Value
P1	0.1000
P10	30.5300
P1f	30.1300
P2f	19.6200
P3f	9.6100
P4f	4.6000
P8	150
P9	30.5300
P_1_f	0
P_2_f	0
P_3_f	0
P_4_f	0
Pb	150
Pc	0.1000
Pr	30.5300
Qadd	0
Qrej	0
r	11

Workspace

Name	Value
s1	0.6494
s10	7.2269
s8	6.3479
s9s	6.3479
sol	0
st	0.5000
T10	500
T16	148.7208
T18	178.1642
T20	234.0984
T3	148.7208
T4	178.1642
T7	234.0984
T8	500
Tmax	500
u	12
varNames	*1x10 cell*
Wnet	0

varNames	*1x10 cell*
Wnet	0
Wp	0
Wt	0
x	0

Variables - B

B | bes

4x1 double

	1
1	60.6104
2	159.4701
3	123.0736
4	427.7858

best

10x1 double

	1
1	0.5527
2	0.5201
3	0.5061
4	0.4964
5	0.4887
6	0.4821
7	0.4764
8	0.4713
9	0.4666
10	0.4623

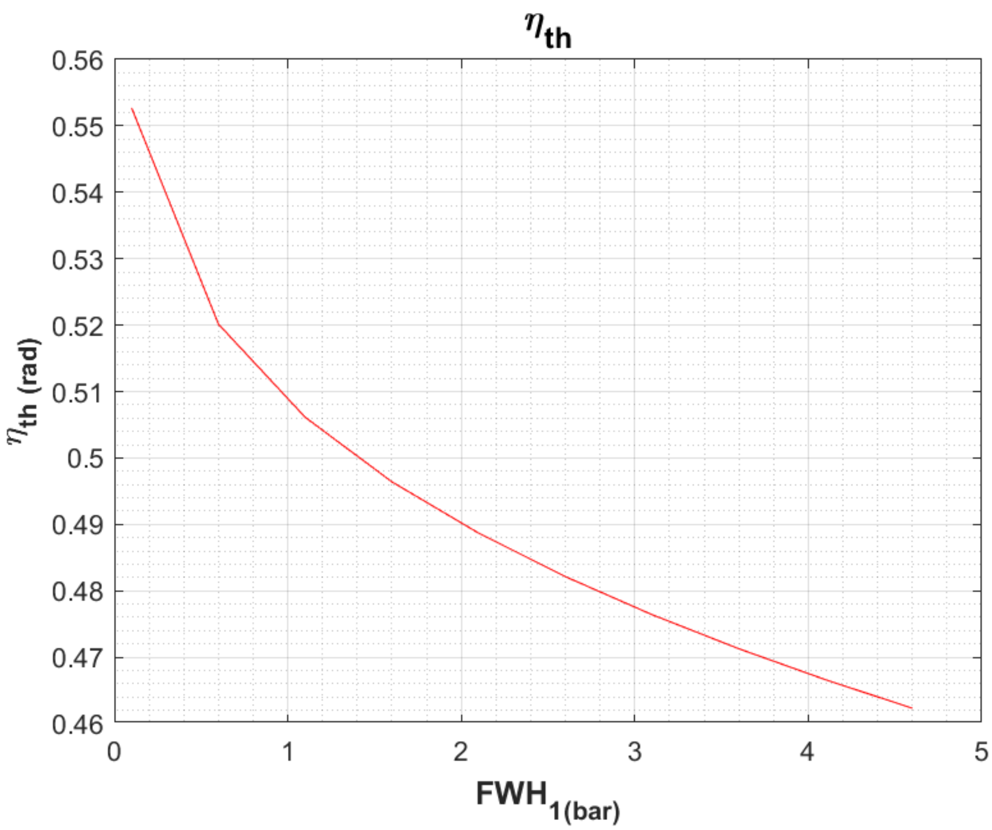
best_sol

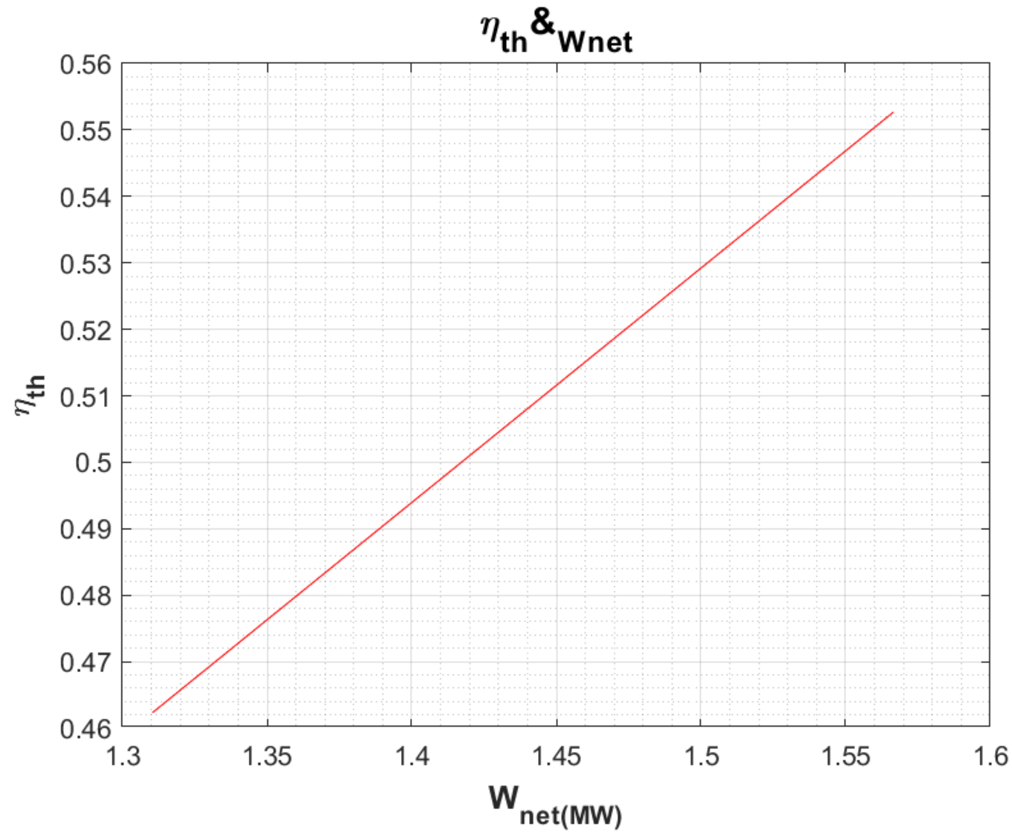
10x10 double

	1	2	3	4	5	6	7	8	9	10
1	0.5527	1.5665e+03	2.8344e+03	1.2679e+03	1.5823e+03	15.7785	0.1000	0.1100	0.1200	30.1300
2	0.5201	1.4743e+03	2.8344e+03	1.3601e+03	1.4901e+03	15.7683	0.6000	0.6100	0.6200	30.1300
3	0.5061	1.4346e+03	2.8344e+03	1.3999e+03	1.4503e+03	15.7600	1.1000	1.1100	1.1200	30.1300
4	0.4964	1.4070e+03	2.8344e+03	1.4274e+03	1.4228e+03	15.7527	1.6000	1.6100	1.6200	30.1300
5	0.4887	1.3851e+03	2.8344e+03	1.4493e+03	1.4006e+03	15.4611	2.1000	2.1100	19.6200	30.1300
6	0.4821	1.3666e+03	2.8344e+03	1.4679e+03	1.3820e+03	15.4784	2.6000	2.6100	19.6200	30.1300
7	0.4764	1.3503e+03	2.8344e+03	1.4841e+03	1.3658e+03	15.4934	3.1000	3.1100	19.6200	30.1300
8	0.4713	1.3358e+03	2.8344e+03	1.4986e+03	1.3513e+03	15.5068	3.6000	3.6100	19.6200	30.1300
9	0.4666	1.3226e+03	2.8344e+03	1.5119e+03	1.3381e+03	15.5189	4.1000	4.1100	19.6200	30.1300
10	0.4623	1.3104e+03	2.8344e+03	1.5240e+03	1.3259e+03	15.5301	4.6000	4.6100	19.6200	30.1300

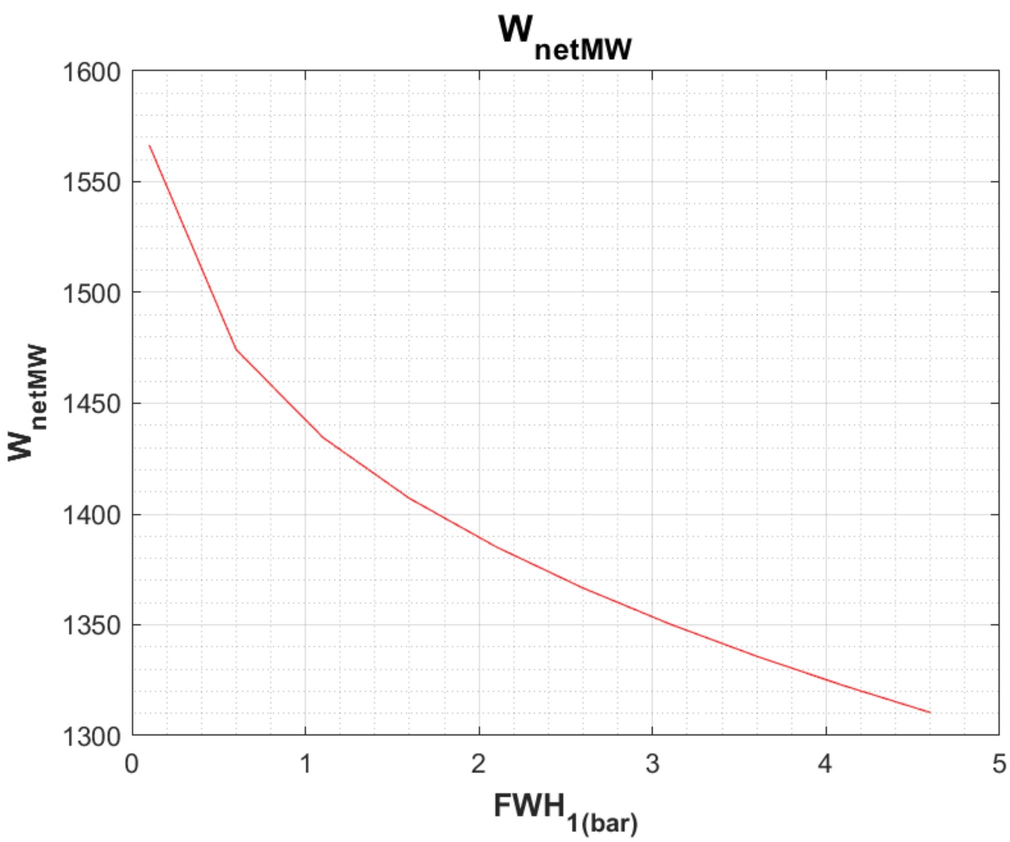
eta	Wnet	Qadd	Qrej	Wt	Wp	P_4_f	P_3_f	P_2_f	P_1_f
0.552682019	1566.539387	2834.431612	1267.892225	1582.317841	15.77845333	0.1	0.11	0.12	30.13
0.520145753	1474.317565	2834.431612	1360.114048	1490.085856	15.76829141	0.6	0.61	0.62	30.13
0.50612147	1434.566693	2834.431612	1399.864919	1450.326673	15.75997963	1.1	1.11	1.12	30.13
0.496401377	1407.015754	2834.431612	1427.415858	1422.768455	15.75270124	1.6	1.61	1.62	30.13
0.48867866	1385.126242	2834.431612	1449.30537	1400.587366	15.46112407	2.1	2.11	19.62	30.13
0.482130961	1366.567238	2834.431612	1467.864374	1382.045618	15.47837921	2.6	2.61	19.62	30.13
0.476399051	1350.320531	2834.431612	1484.111081	1365.813933	15.4934018	3.1	3.11	19.62	30.13
0.471269835	1335.782119	2834.431612	1498.649493	1351.288914	15.50679498	3.6	3.61	19.62	30.13
0.466605238	1322.560637	2834.431612	1511.870975	1338.079576	15.51893951	4.1	4.11	19.62	30.13
0.462311117	1310.389243	2834.431612	1524.042369	1325.919336	15.53009248	4.6	4.61	19.62	30.13

Best efficiency by changing the value of pressure for different FWH





η_{th}&Wnet
0.56
0.55
0.54
0.53
0.52
0.51
0.5
0.49
0.48
0.47
0.46
η_{th}
1.3
1.35
1.4
1.45
1.5
1.55
1.6
$W_{net(MW)}$



W_{netMW}
1600
1550
1500
1450
1400
1350
1300
W_{netMW}
0
1
2
3
4
5
$FWH_{1(bar)}$

D.5 One OFWH and four CFWHs were added to the reheat cycle

After the Reheat Pressure

Code

Code

```
{Givens}
P_b=150
P_c=0.1
P_re=30.51
eta_t=0.85; eta_p=0.95
T_max=500

{Point 1}
h_1=ENTHALPY(Steam,X=0,P=P_c)
s_1=ENTROPY(Steam,X=0,P=P_c)

{Point 2}
s_2s=s_1
h_2s=ENTHALPY(Steam,S=s_2s,P=P_o)
(h_2s-h_1)=(h_2-h_1)*eta_p

{Point 5}
h_5=ENTHALPY(Steam,X=0,P=P_o)
s_5=ENTROPY(Steam,X=0,P=P_o)

{Point 6}
s_6s=s_5
h_6s=ENTHALPY(Steam,S=s_6s,P=P_b)
(h_6s-h_5)=(h_6-h_5)*eta_p

{Point 9}
h_9=ENTHALPY(Steam,T=T_max,P=P_b)
s_9=ENTROPY(Steam,T=T_max,P=P_b)

{Point 10}
s_10s=s_9
h_10s=ENTHALPY(Steam,S=s_10s,P=P_re)
(h_9-h_10s)*eta_t=(h_9-h_10)

{Point 11}
h_11=ENTHALPY(Steam,T=T_max,P=P_re)
s_11=ENTROPY(Steam,T=T_max,P=P_re)

{Point 12}
s_12s=s_11
h_12s=ENTHALPY(Steam,S=s_12s,P=P_4cl)
(h_11-h_12s)*eta_t=(h_11-h_12)
```

```
s_12=ENTROPY(Steam,h=h_12,P=P_4cl)

{Point 13}
s_13s=s_12
h_13s=ENTHALPY(Steam,S=s_13s,P=P_3cl)
(h_12-h_13s)*eta_t=(h_12-h_13)
s_13=ENTROPY(Steam,h=h_13,P=P_3cl)

{Point 14}
s_14s=s_13
h_14s=ENTHALPY(Steam,S=s_14s,P=P_o)
(h_13-h_14s)*eta_t=(h_13-h_14)
s_14=ENTROPY(Steam,h=h_14,P=P_o)

{Point 15}
s_15s=s_14
h_15s=ENTHALPY(Steam,S=s_15s,P=P_2cl)
(h_14-h_15s)*eta_t=(h_14-h_15)
s_15=ENTROPY(Steam,h=h_15,P=P_2cl)

{Point 16}
s_16s=s_15
h_16s=ENTHALPY(Steam,S=s_16s,P=P_1cl)
(h_15-h_16s)*eta_t=(h_15-h_16)
s_16=ENTROPY(Steam,h=h_16,P=P_1cl)

{Point 17}
s_17s=s_16
h_17s=ENTHALPY(Steam,S=s_17s,P=P_c)
(h_16-h_17s)*eta_t=(h_16-h_17)
s_17=ENTROPY(Steam,h=h_17,P=P_c)

{Point 18}
h_18=ENTHALPY(Steam,X=0,P=P_4cl)
T_18=TEMPERATURE(Steam,h=h_18,P=P_4cl)

{Point 19}
h_19=h_18

{Point 8}
T_8=T_18
h_8=ENTHALPY(Steam,T=T_18,P=P_b)

{Point 20}
h_20=ENTHALPY(Steam,X=0,P=P_3cl)
T_20=TEMPERATURE(Steam,h=h_20,P=P_3cl)

{Point 7}
T_7=T_20
h_7=ENTHALPY(Steam,T=T_20,P=P_b)

{Point 21}
h_21=h_20

{Point 22}
h_22=ENTHALPY(Steam,X=0,P=P_2cl)
T_22=TEMPERATURE(Steam,h=h_22,P=P_2cl)
```

```
{point 23}
h_23=h_22

{Point 4}
T_4=T_22
h_4=ENTHALPY(Steam,T=T_22,P=P_o)

{Point 24}
h_24=ENTHALPY(Steam,X=0,P=P_1cl)
T_24=TEMPERATURE(Steam,h=h_24,P=P_1cl)

{Point 25}
h_25=h_24

{Point 3}
T_3=T_24
h_3=ENTHALPY(Steam,T=T_24,P=P_o)

{Energy Balance of CFWH4}
h_8+h_18*v=h_13*v+h_7

{Energy Balance of CFWH3}
h_14*w+h_19*v+h_6=h_7+h_20*(w+v)

{Energy Balance of OFWH}
h_15*x+h_21*(w+v)+h_4*(1-v-w-x)=h_5

{Energy Balance of CFWH2}
h_16*y+h_3*(1-v-x-w)=h_4*(1-v-x-w)+h_22*y

{Energy Balance of CFWH1}
h_17*z+h_23*y+h_2*(1-v-x-w)=h_3*(1-v-x-w)+h_24*(y+z)

{Calculations}

Q_add=(h_9-h_8)+(h_11-h_10)
Q_rej=(h_1-h_12)+(h_1-h_25)
W_p=(h_2-h_1)+(h_6-h_5)
W_t=(h_9-h_10)+(h_11-h_13)+(h_13-h_14)*(1-v)+(h_14-h_15)*(1-v-w)+(h_15-h_16)*(1-v-w-x)+(h_16-
h_17)*(1-v-w-x-y)+(h_17-h_12)*(1-v-w-x-y-z)
W_net=W_t-W_p
eta_th=W_net/Q_add
```

Variable	Guess	Lower	Upper	Display			Units
P_1cl	0.5	1.0000E-01	P_2cl	A	0	N	
P_2cl	3	P_1cl	P_o	A	0	N	
P_3cl	12	P_o	P_4cl	A	0	N	
P_4cl	28	P_3cl	3.0510E+01	A	0	N	
P_o	6	P_2cl	P_3cl	A	0	N	

Optimum OFWH Pressure = 5.433 bar

Optimum CFWH1 Pressure = 0.4473 bar

Optimum CFWH2 Pressure = 1.656 bar

Optimum CFWH3 Pressure = 12.72 bar

Optimum CFWH4 Pressure = 28.03 bar

Maximum Efficiency = 42.41%

Calculations Completed

78 equations in 62 blocks - 229 iterations

Elapsed time = 10.9 sec

eta_th = 0.4241

Continue

Independent Variable	Value	Best value
P_1cl	0.4473	0.4473
P_2cl	1.656	1.656
P_3cl	12.72	12.72
P_4cl	28.03	28.03
P_o	5.433	5.433

Results Tab

Unit Settings: [kJ]/[C]/[bar]/[kg]/[degrees]

Maximization of eta_th(P_1cl,P_2cl,P_3cl,P_4cl,P_o) 229 iterations: Variable Metric method

$\eta_p = 0.95$	$\eta_t = 0.85$	$\eta_{th} = 0.4241$	$h_1 = 191.7$ [kJ/kg]
$h_{13} = 3431$	$h_{13s} = 3427$ [kJ/kg]	$h_{14} = 3220$	$h_{14s} = 3182$ [kJ/kg]
$h_{17s} = 2575$ [kJ/kg]	$h_{18} = 990.7$ [kJ/kg]	$h_{19} = 990.7$ [kJ/kg]	$h_2 = 192.3$
$h_{25} = 328.9$ [kJ/kg]	$h_{2s} = 192.3$ [kJ/kg]	$h_3 = 329.3$ [kJ/kg]	$h_4 = 480$ [kJ/kg]
$h_9 = 3309$ [kJ/kg]	$P_{1cl} = 0.4473$	$P_{2cl} = 1.656$	$P_{3cl} = 12.72$
$Q_{add} = 2819$	$Q_{rej} = -2368$	$s_1 = 0.6489$ [kJ/kg-K]	$s_{10s} = 6.345$ [kJ/kg-K]
$s_{14} = 7.289$ [kJ/kg-K]	$s_{14s} = 7.231$ [kJ/kg-K]	$s_{15} = 7.352$ [kJ/kg-K]	$s_{15s} = 7.289$ [kJ/kg-K]
$s_5 = 1.893$ [kJ/kg-K]	$s_{6s} = 1.893$ [kJ/kg-K]	$s_9 = 6.345$ [kJ/kg-K]	$T_{18} = 230.1$ [C]
$T_7 = 190.6$ [C]	$T_8 = 230.1$ [C]	$T_{max} = 500$	$v = 0.07233$
$y = 0.05325$	$z = 0.04578$		

$h_{10} = 2953$	$h_{10s} = 2890$ [kJ/kg]	$h_{11} = 3456$ [kJ/kg]
$h_{15} = 3025$	$h_{15s} = 2990$ [kJ/kg]	$h_{16} = 2802$
$h_{20} = 810.4$ [kJ/kg]	$h_{21} = 810.4$ [kJ/kg]	$h_{22} = 479.7$ [kJ/kg]
$h_5 = 653.9$ [kJ/kg]	$h_6 = 670.6$	$h_{6s} = 669.7$ [kJ/kg]
$P_{4cl} = 28.03$	$P_b = 150$	$P_c = 0.1$
$s_{11} = 7.226$ [kJ/kg-K]	$s_{12} = 7.644$ [kJ/kg-K]	$s_{12s} = 7.541$ [kJ/kg-K]
$s_{16} = 7.444$ [kJ/kg-K]	$s_{16s} = 7.352$ [kJ/kg-K]	$s_{17} = 7.541$ [kJ/kg-K]
$T_{20} = 190.6$ [C]	$T_{22} = 114.3$ [C]	$T_{24} = 78.56$ [C]
$w = 0.05534$	$W_{net} = 1196$	$W_p = 17.19$

$h_{12} = 2423$	$h_{12s} = 2390$ [kJ/kg]
$h_{16s} = 2763$ [kJ/kg]	$h_{17} = 2609$
$h_{23} = 479.7$ [kJ/kg]	$h_{24} = 328.9$ [kJ/kg]
$h_7 = 816.9$ [kJ/kg]	$h_8 = 993.5$ [kJ/kg]
$P_o = 5.433$	$P_{re} = 30.51$
$s_{13} = 7.231$ [kJ/kg-K]	$s_{13s} = 7.226$ [kJ/kg-K]
$s_{17s} = 7.444$ [kJ/kg-K]	$s_{2s} = 0.6489$ [kJ/kg-K]
$T_3 = 78.56$ [C]	$T_4 = 114.3$ [C]
$W_t = 1213$	$x = 0.05177$

1..30	η_{th}	P_{1cl}	P_{2cl}	P_{3cl}	P_{4cl}	P_o
Run 1	0.419	0.1	1	6	15	2
Run 2	0.4202	0.131	1.034	6.31	15.53	2.138
Run 3	0.421	0.1621	1.069	6.621	16.07	2.276
Run 4	0.4216	0.1931	1.103	6.931	16.6	2.414
Run 5	0.4221	0.2241	1.138	7.241	17.14	2.552
Run 6	0.4224	0.2552	1.172	7.552	17.67	2.69
Run 7	0.4227	0.2862	1.207	7.862	18.21	2.828
Run 8	0.4229	0.3172	1.241	8.172	18.74	2.966
Run 9	0.4231	0.3483	1.276	8.483	19.28	3.103
Run 10	0.4232	0.3793	1.31	8.793	19.81	3.241
Run 11	0.4233	0.4103	1.345	9.103	20.35	3.379
Run 12	0.4234	0.4414	1.379	9.414	20.88	3.517
Run 13	0.4235	0.4724	1.414	9.724	21.42	3.655
Run 14	0.4235	0.5034	1.448	10.03	21.95	3.793
Run 15	0.4236	0.5345	1.483	10.34	22.49	3.931
Run 16	0.4236	0.5655	1.517	10.66	23.02	4.069
Run 17	0.4236	0.5966	1.552	10.97	23.56	4.207
Run 18	0.4236	0.6276	1.586	11.28	24.09	4.345
Run 19	0.4236	0.6586	1.621	11.59	24.63	4.483
Run 20	0.4236	0.6897	1.655	11.9	25.16	4.621
Run 21	0.4236	0.7207	1.69	12.21	25.7	4.759
Run 22	0.4235	0.7517	1.724	12.52	26.23	4.897
Run 23	0.4235	0.7828	1.759	12.83	26.77	5.034
Run 24	0.4235	0.8138	1.793	13.14	27.3	5.172
Run 25	0.4234	0.8448	1.828	13.45	27.84	5.31
Run 26	0.4234	0.8759	1.862	13.76	28.37	5.448
Run 27	0.4233	0.9069	1.897	14.07	28.91	5.586
Run 28	0.4233	0.9379	1.931	14.38	29.44	5.724
Run 29	0.4232	0.969	1.966	14.69	29.98	5.862
Run 30	0.4232	1	2	15	30.51	6

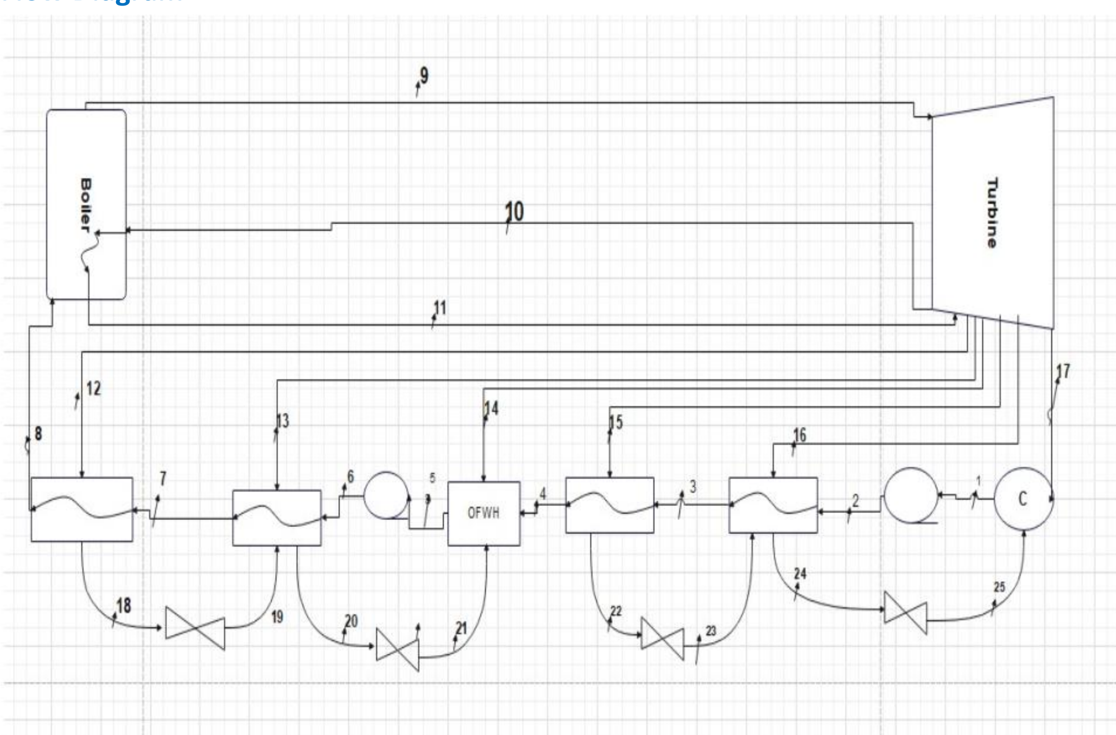
1..30	η_{th}	P_{1cl}	P_{2cl}	P_{3cl}	P_{4cl}	P_o
Run 1	0.4202	0.1	1	10	20	5
Run 2	0.4212	0.131	1.138	10.34	20.36	5.172
Run 3	0.4219	0.1621	1.276	10.69	20.72	5.345
Run 4	0.4223	0.1931	1.414	11.03	21.09	5.517
Run 5	0.4227	0.2241	1.552	11.38	21.45	5.69
Run 6	0.4229	0.2552	1.69	11.72	21.81	5.862
Run 7	0.4231	0.2862	1.828	12.07	22.17	6.034
Run 8	0.4232	0.3172	1.966	12.41	22.54	6.207
Run 9	0.4232	0.3483	2.103	12.76	22.9	6.379
Run 10	0.4233	0.3793	2.241	13.1	23.26	6.552
Run 11	0.4233	0.4103	2.379	13.45	23.62	6.724
Run 12	0.4233	0.4414	2.517	13.79	23.99	6.897
Run 13	0.4232	0.4724	2.655	14.14	24.35	7.069
Run 14	0.4232	0.5034	2.793	14.48	24.71	7.241
Run 15	0.4231	0.5345	2.931	14.83	25.07	7.414
Run 16	0.423	0.5655	3.069	15.17	25.44	7.586
Run 17	0.423	0.5966	3.207	15.52	25.8	7.759
Run 18	0.4229	0.6276	3.345	15.86	26.16	7.931
Run 19	0.4228	0.6586	3.483	16.21	26.52	8.103
Run 20	0.4227	0.6897	3.621	16.55	26.89	8.276
Run 21	0.4226	0.7207	3.759	16.9	27.25	8.448
Run 22	0.4225	0.7517	3.897	17.24	27.61	8.621
Run 23	0.4224	0.7828	4.034	17.59	27.97	8.793
Run 24	0.4223	0.8138	4.172	17.93	28.34	8.966
Run 25	0.4222	0.8448	4.31	18.28	28.7	9.138
Run 26	0.4221	0.8759	4.448	18.62	29.06	9.31
Run 27	0.422	0.9069	4.586	18.97	29.42	9.483
Run 28	0.4219	0.9379	4.724	19.31	29.79	9.655
Run 29	0.4218	0.969	4.862	19.66	30.15	9.828
Run 30	0.4217	1	5	20	30.51	10

1..30	η_{th}	P_{1cl}	P_{2cl}	P_{3cl}	P_{4cl}	P_o
Run 1	0.4198	0.1	0.8	6.3	16.6	1.9
Run 2	0.4206	0.1207	0.8345	6.652	17.08	2.048
Run 3	0.4212	0.1414	0.869	7.003	17.56	2.197
Run 4	0.4216	0.1621	0.9034	7.355	18.04	2.345
Run 5	0.422	0.1828	0.9379	7.707	18.52	2.493
Run 6	0.4224	0.2034	0.9724	8.059	19	2.641
Run 7	0.4226	0.2241	1.007	8.41	19.48	2.79
Run 8	0.4229	0.2448	1.041	8.762	19.96	2.938
Run 9	0.4231	0.2655	1.076	9.114	20.44	3.086
Run 10	0.4232	0.2862	1.11	9.466	20.92	3.234
Run 11	0.4233	0.3069	1.145	9.817	21.4	3.383
Run 12	0.4235	0.3276	1.179	10.17	21.88	3.531
Run 13	0.4236	0.3483	1.214	10.52	22.36	3.679
Run 14	0.4236	0.369	1.248	10.87	22.84	3.828
Run 15	0.4237	0.3897	1.283	11.22	23.32	3.976
Run 16	0.4237	0.4103	1.317	11.58	23.79	4.124
Run 17	0.4238	0.431	1.352	11.93	24.27	4.272
Run 18	0.4238	0.4517	1.386	12.28	24.75	4.421
Run 19	0.4238	0.4724	1.421	12.63	25.23	4.569
Run 20	0.4239	0.4931	1.455	12.98	25.71	4.717
Run 21	0.4239	0.5138	1.49	13.33	26.19	4.866
Run 22	0.4239	0.5345	1.524	13.69	26.67	5.014
Run 23	0.4239	0.5552	1.559	14.04	27.15	5.162
Run 24	0.4238	0.5759	1.593	14.39	27.63	5.31
Run 25	0.4238	0.5966	1.628	14.74	28.11	5.459
Run 26	0.4238	0.6172	1.662	15.09	28.59	5.607
Run 27	0.4238	0.6379	1.697	15.44	29.07	5.755
Run 28	0.4238	0.6586	1.731	15.8	29.55	5.903
Run 29	0.4237	0.6793	1.766	16.15	30.03	6.052
Run 30	0.4237	0.7	1.8	16.5	30.51	6.2

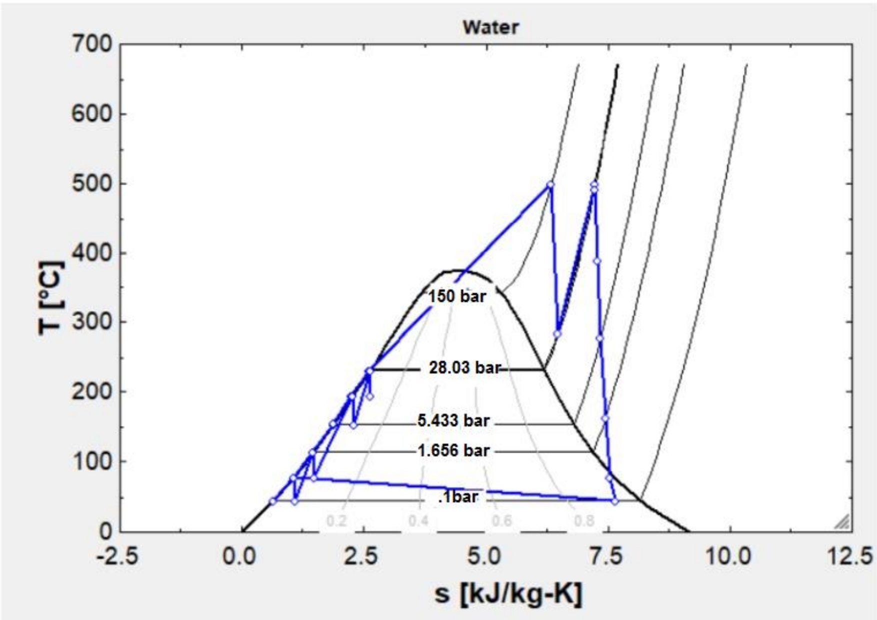
1..30	η_{th}	P_{1cl}	P_{2cl}	P_{3cl}	P_{4cl}	P_o
Run 1	0.4197	0.1	0.7	6	16	1.7
Run 2	0.4204	0.1172	0.731	6.31	16.5	1.845
Run 3	0.4209	0.1345	0.7621	6.621	17	1.99
Run 4	0.4214	0.1517	0.7931	6.931	17.5	2.134
Run 5	0.4218	0.169	0.8241	7.241	18	2.279
Run 6	0.4221	0.1862	0.8552	7.552	18.5	2.424
Run 7	0.4224	0.2034	0.8862	7.862	19	2.569
Run 8	0.4226	0.2207	0.9172	8.172	19.5	2.714
Run 9	0.4228	0.2379	0.9483	8.483	20	2.859
Run 10	0.423	0.2552	0.9793	8.793	20.5	3.003
Run 11	0.4232	0.2724	1.01	9.103	21	3.148
Run 12	0.4233	0.2897	1.041	9.414	21.5	3.293
Run 13	0.4234	0.3069	1.072	9.724	22	3.438
Run 14	0.4235	0.3241	1.103	10.03	22.5	3.583
Run 15	0.4236	0.3414	1.134	10.34	23	3.728
Run 16	0.4237	0.3586	1.166	10.66	23.51	3.872
Run 17	0.4237	0.3759	1.197	10.97	24.01	4.017
Run 18	0.4238	0.3931	1.228	11.28	24.51	4.162
Run 19	0.4238	0.4103	1.259	11.59	25.01	4.307
Run 20	0.4239	0.4276	1.29	11.9	25.51	4.452
Run 21	0.4239	0.4448	1.321	12.21	26.01	4.597
Run 22	0.4239	0.4621	1.352	12.52	26.51	4.741
Run 23	0.4239	0.4793	1.383	12.83	27.01	4.886
Run 24	0.4239	0.4966	1.414	13.14	27.51	5.031
Run 25	0.4239	0.5138	1.445	13.45	28.01	5.176
Run 26	0.4239	0.531	1.476	13.76	28.51	5.321
Run 27	0.4239	0.5483	1.507	14.07	29.01	5.466
Run 28	0.4239	0.5655	1.538	14.38	29.51	5.61
Run 29	0.4239	0.5828	1.569	14.69	30.01	5.755
Run 30	0.4239	0.6	1.6	15	30.51	5.9

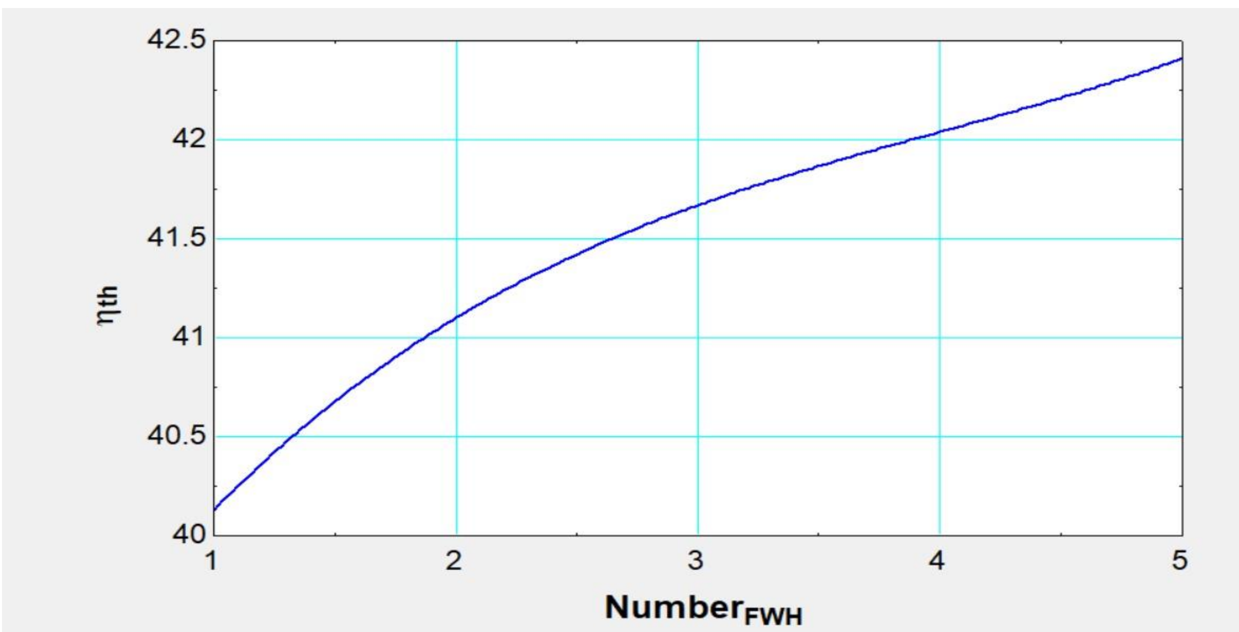
1..30	η_{th}	P_{1cl}	P_{2cl}	P_{3cl}	P_{4cl}	P_o
Run 1	0.4203	0.1	1	8	18	3
Run 2	0.4213	0.131	1.069	8.345	18.43	3.172
Run 3	0.422	0.1621	1.138	8.69	18.86	3.345
Run 4	0.4224	0.1931	1.207	9.034	19.29	3.517
Run 5	0.4228	0.2241	1.276	9.379	19.73	3.69
Run 6	0.4231	0.2552	1.345	9.724	20.16	3.862
Run 7	0.4233	0.2862	1.414	10.07	20.59	4.034
Run 8	0.4234	0.3172	1.483	10.41	21.02	4.207
Run 9	0.4235	0.3483	1.552	10.76	21.45	4.379
Run 10	0.4236	0.3793	1.621	11.1	21.88	4.552
Run 11	0.4237	0.4103	1.69	11.45	22.31	4.724
Run 12	0.4237	0.4414	1.759	11.79	22.75	4.897
Run 13	0.4238	0.4724	1.828	12.14	23.18	5.069
Run 14	0.4238	0.5034	1.897	12.48	23.61	5.241
Run 15	0.4238	0.5345	1.966	12.83	24.04	5.414
Run 16	0.4238	0.5655	2.034	13.17	24.47	5.586
Run 17	0.4237	0.5966	2.103	13.52	24.9	5.759
Run 18	0.4237	0.6276	2.172	13.86	25.33	5.931
Run 19	0.4237	0.6586	2.241	14.21	25.76	6.103
Run 20	0.4237	0.6897	2.31	14.55	26.2	6.276
Run 21	0.4237	0.7207	2.379	14.9	26.63	6.448
Run 22	0.4236	0.7517	2.448	15.24	27.06	6.621
Run 23	0.4236	0.7828	2.517	15.59	27.49	6.793
Run 24	0.4235	0.8138	2.586	15.93	27.92	6.966
Run 25	0.4235	0.8448	2.655	16.28	28.35	7.138
Run 26	0.4235	0.8759	2.724	16.62	28.78	7.31
Run 27	0.4234	0.9069	2.793	16.97	29.22	7.483
Run 28	0.4233	0.9379	2.862	17.31	29.65	7.655
Run 29	0.4233	0.969	2.931	17.66	30.08	7.828
Run 30	0.4232	1	3	18	30.51	8

Flow Diagram



T-s Diagram





Relation bn no of FWH and the efficiency

Question 2: Gas Cycle

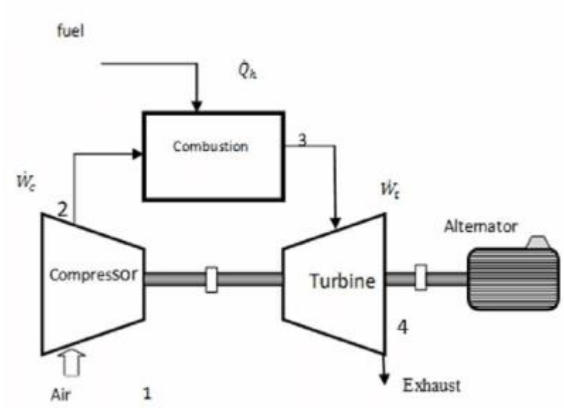
A gas turbine power plant operates on a simple gas turbine cycle with air as the working fluid. The air enters the compressor at 95 kPa and 310 K and the turbine at 1300 K. The isentropic efficiency is 80 % for the compression and 85 % for the expansion. Accounting for the variation of specific heats with temperature.

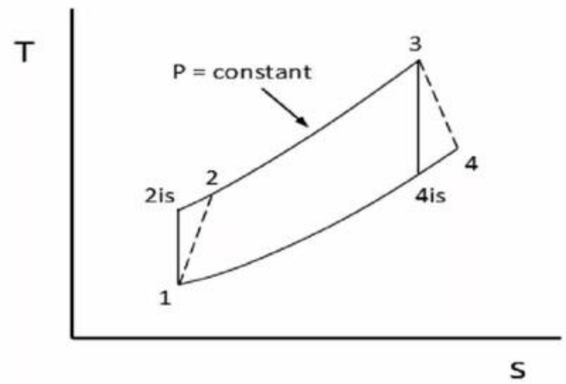
A) Find the optimum pressure ratio for maximizing network output of the cycle and plot the R_p – W_{net} relation.

B) Plot the relation between the pressure ratio and the thermal efficiency then compare it with the simple ideal cycle.

C) Use an ideal regenerator and plot the relation between the pressure ratio and the thermal efficiency to compare it with the simple ones and find out the maximum pressure ratio can be used with the regenerative cycle.

Simple gas cycle:





Code on EES

"givens"

P_1=0.95[kpa]

T_1=310[k]

T_3=1300[k]

eta_compressor=0.8

eta_turbine=0.85

rp=P_2/P_1

"point 1"

h_1=ENTHALPY(Air_ha,T=T_1,P=P_1)

s_1=ENTROPY(Air_ha,T=T_1,P=P_1)

"point 2"

s_2s=s_1

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h_2s=ENTHALPY(Air_ha,s=s_1,P=P_2)

eta_compressor=(h_2s-h_1)/(h_2-h_1)

T_2=TEMPERATURE(Air_ha,h=h_2,P=P_2)

"point 3"

h_3=ENTHALPY(Air_ha,T=T_3,P=P_2)

s_3=ENTROPY(Air_ha,T=T_3,P=P_2)

"point 4"

s_4s=s_3

h_4s=ENTHALPY(Air_ha,s=s_3,P=P_1)

eta_turbine=(h_3-h_4)/(h_3-h_4s)

T_4=TEMPERATURE(Air_ha,h=h_4,P=P_1)

"calculations"

w_t=h_3-h_4

w_c=h_2-h_1

w_net=w_t-w_c

q_add=h_3-h_2

eta_th=w_net/q_add

" ideal cycle"

w_t_s=h_3-h_4s

w_c_s=h_2s-h_1

w_net_s=w_t_s-w_c_s

q_add_s=h_3-h_2s

eta_th_s=w_net_s/q_add_s

" regeneration "

h_5=h_4
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w_t_regen=h_3-h_4

w_net_regen=w_t_regen-w_c

q_add_regen=h_3-h_5

eta_th_regen=w_net_regen/q_add_regen

Optimizing Pressure ratio for maximum work net:

1..19	rp	w_{net}
Run 1	2	117.2
Run 2	3	162.2
Run 3	4	183.8
Run 4	5	194.6
Run 5	6	199.6
Run 6	7	201.1
Run 7	8	200.4
Run 8	9	198.2
Run 9	10	195
Run 10	11	191.1
Run 11	12	186.7
Run 12	13	181.9
Run 13	14	176.9
Run 14	15	171.7
Run 15	16	166.4
Run 16	17	160.9
Run 17	18	155.4
Run 18	19	149.9
Run 19	20	144.4

Calculations Completed

33 equations in 26 blocks - 18 iterations

Elapsed time = 1.0 sec

w_net = 201.1

Continue

Independent Variable	Value	Best value
rp	7.116	7.116

Maximum pressure ratio is 7.116 bar

Results Tab

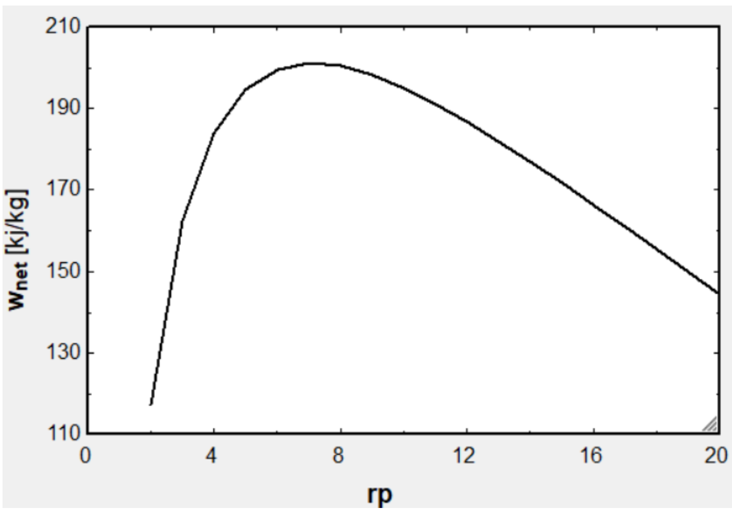
Unit Settings: [kJ]/[K]/[bar]/[kg]/[degrees]

Maximization of w_net(rp) 18 iterations: Quadratic Approximations method

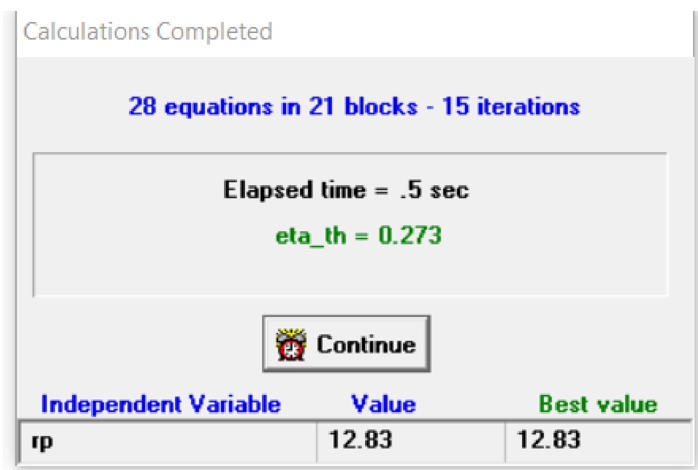
$\eta_{compressor} = 0.8$	$\eta_{th} = 0.2533$	$\eta_{th,regen} = 0.4075$	$\eta_{th,s} = 0.4067$	$\eta_{turbine} = 0.85$	$h_1 = 310.3$ [kJ/kg]	$h_2 = 602.7$	$h_{2s} = 544.2$	$h_3 = 1397$
$h_4 = 903.1$	$h_{4s} = 816$	$h_5 = 903.1$	$P_1 = 0.95$ [kpa]	$P_2 = 6.76$	$q_{add} = 793.9$	$q_{add,regen} = 493.5$	$q_{add,s} = 852.3$	$rp = 7.116$
$s_1 = 6.918$ [kJ/kg-K]	$s_{2s} = 6.918$ [kJ/kg-K]	$s_3 = 7.894$	$s_{4s} = 7.894$	$T_1 = 310$ [k]	$T_2 = 596$	$T_3 = 1300$ [k]	$T_4 = 872.8$	$w_c = 292.4$
$w_{c,s} = 233.9$	$w_{net} = 201.1$	$w_{net,regen} = 201.1$	$w_{net,s} = 346.7$	$w_t = 493.5$	$w_{t,regen} = 493.5$	$w_{t,s} = 580.6$		

Calculation time = 1.1 sec

Plotting the R_p against W_{net} relation:



Relation between pressure ratio and thermal efficiency



5- plot between pressure ratio and the thermal efficiency

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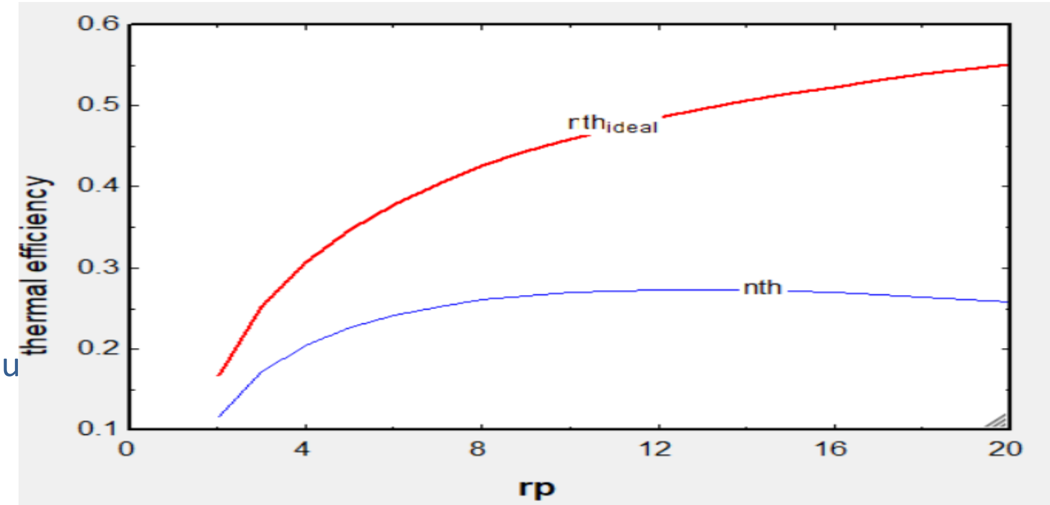
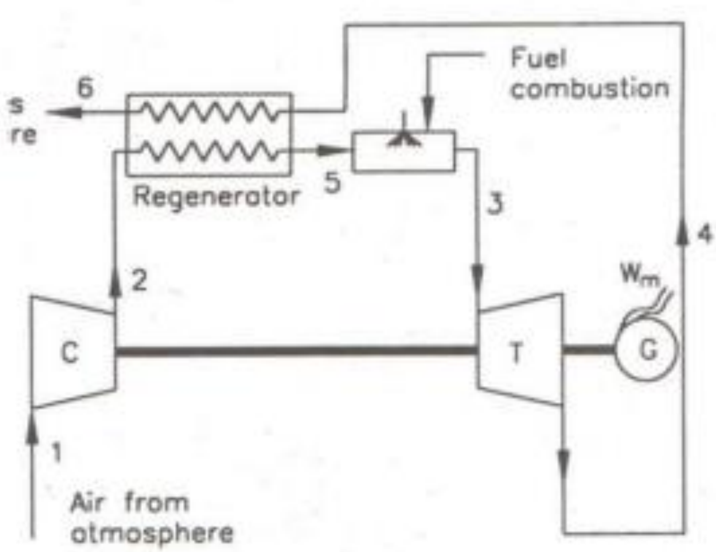
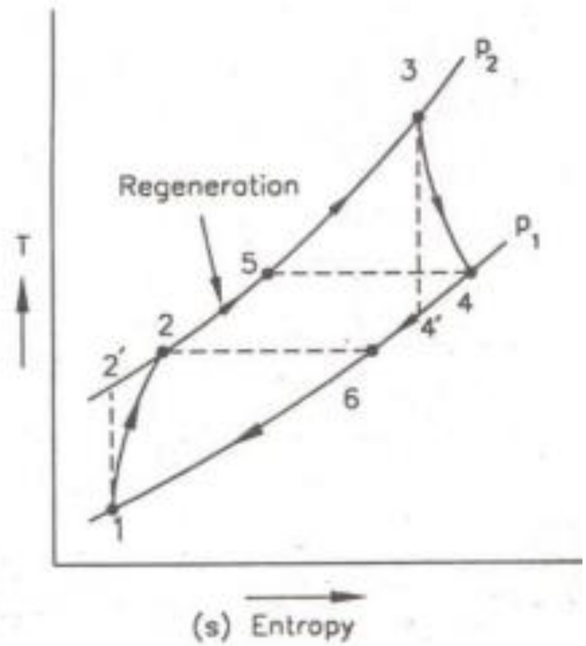
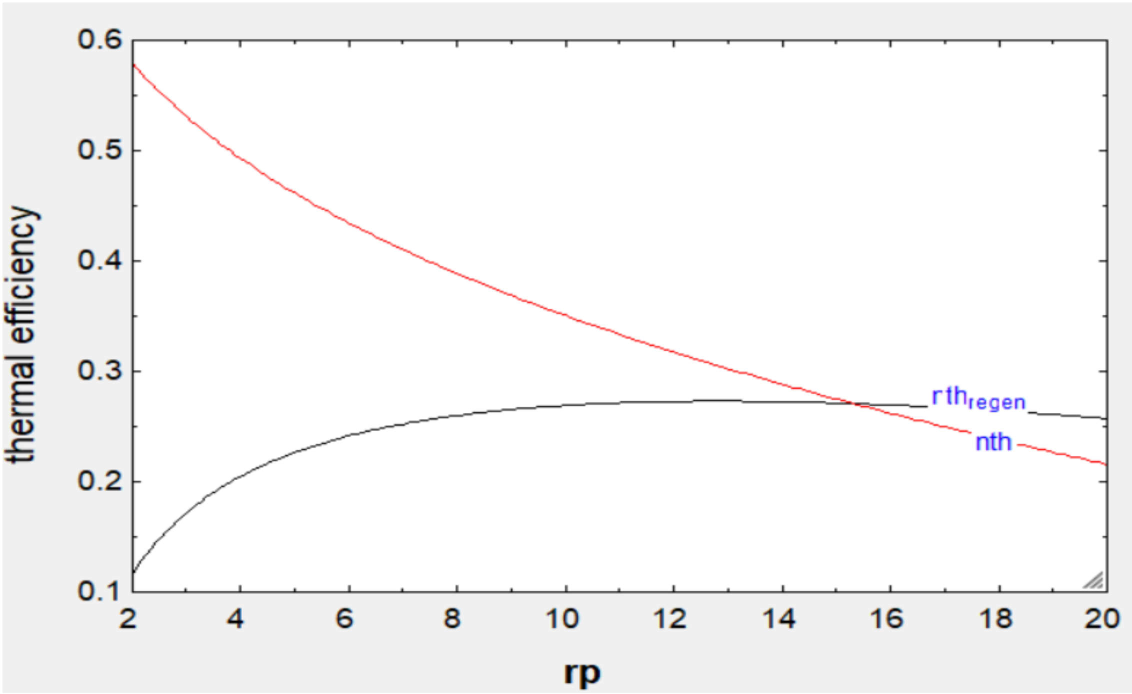


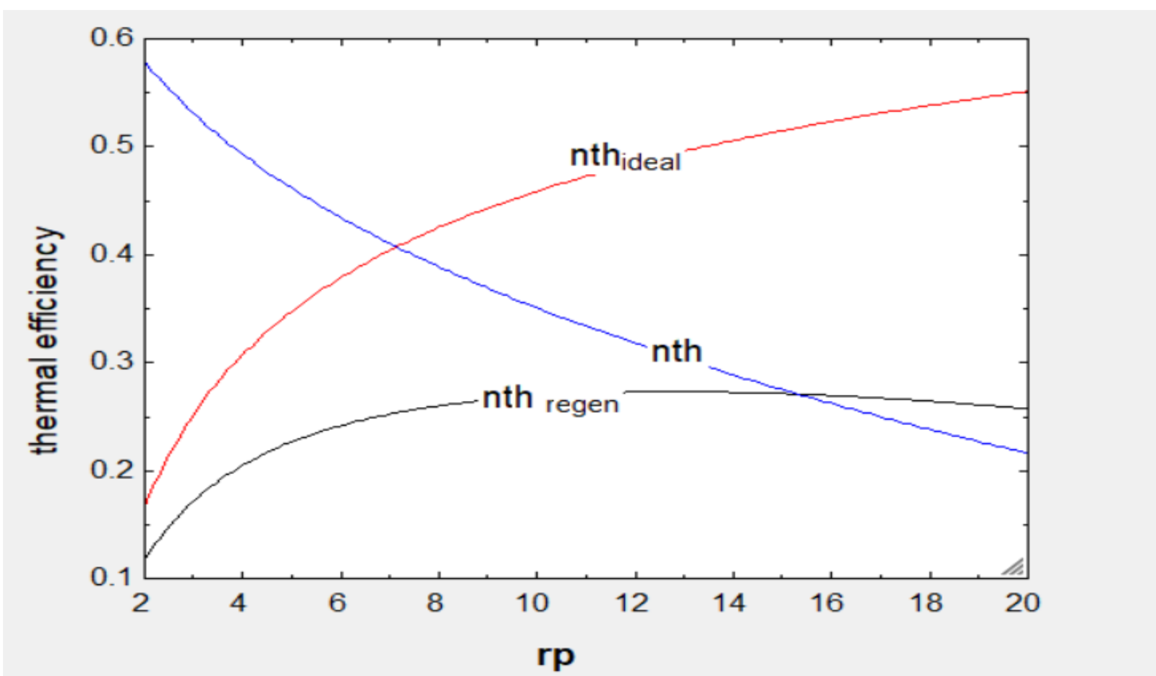




7-Plot relation between the pressure ratio and thermal efficiency:



Maximum pressure ratio is 15.2



Thank you