HIGHER EFFICIENCY TARGETING IN A STEAM POWER PLANT BY USING PINCH TECHNOLOGY

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While energy productive sources continue to decrease, energy conservation remains the prime concern for many process industries. For the purpose of energy savings, the methods of analysis, synthesis and optimization are becoming more important. In this paper a computer program, which is related to a pinch technology application in steam power plants, to obtain a higher efficiency is presented. In the paper, the program ability by means of a case study is given. The results show that the efficiency of the cycle is increased, and also it is found that it is possible to reduce fuel consumption of the plant by closing pinch points.

Keywords: Pinch technology, heat exchanger network, optimization, efficiency, energy, steam power plant.

1. Introduction

According to lack of energy sources and increasing number of consumers, a need to present samples of optimization is felt. In industrial experiences, the calculation of the minimum heating and cooling requirements reveal significant energy savings. Process integration, especially pinch technology is a powerful analytical method for identifying and selecting concrete technical solution to improve efficiencies and provide an optimum manufacturing solution. The first step in the energy integration analysis is the calculation of the minimum heating and cooling requirements for heat exchanger network (HEN). A heat exchanger, exchanges heat between a hot and a cold process stream: the hot stream needs to be cooled and the cold stream needs to be heated. In steam power plants, it can be observed from cycle thermodynamics that synthesis of an optimal HEN with minimization of utilities, may improve cycle efficiency. So the design of relating HEN for optimum efficiency is a main aim of using pinch technology in a power plant optimization.

In the last decades, extensive efforts have been made in the fields of energy efficiency improvement and energy recovery technologies.

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Thermodynamic approaches in the form of *Pinch Analysis* have been first introduced in the late 1970s with the idea of setting targets prior to design and were originally developed at the ETH Zurich and Leeds University (Linnhoff and Flower 1978 [1,2]; Linnhoff 1979[3]). ICI plc took note of these promising techniques and set up research and application teams to explore and develop them [4]. Pinch analysis reports significant changes in energy savings and has established a track record of numerous successful applications in the Chemical Process Industries [5,6,7,8,9]. During last years, pinch technology has been developed in other area of process industries, including power plants and showed satisfactory results, respect to energy saving. Linnhoff and Alanis have done much research work on the using of pinch technology in various power plants. Their research model was based on modifying of an existed site [10]. Combined pinch and exergy analysis, as a second model, was introduced by Dhole and Zheng [11]. This model could use from exergy concept instead of pure thermal analysis with aid of pinch technology ability in design and targeting.

In this paper, by using of closing pinch points in HEN(first model), a new computer program is developed to achieving higher efficiency of the cycle and less fuel consumption in a case study (Shahid Rajaei steam power plant in Iran). The method has retained its simplicity and good results were obtained, however computational load has increased in comparison with the earlier works.

2. Plant description

The cycle which is selected for the examination of computer program output, is Shahid Rajaei power plant in the center of Iran. This cycle with 1000 MW includes 4 units of 250 MW. It also consists of six stages of drain extraction and one stage of steam reheater. Schematic arrangement of the cycle is shown in figure1, and the technical data and operating condition of the plant was given in table 1. Also table 2 includes the fuel information of power plant. Considering table 2, it is known necessary rate of fuel to generate 250 MW power is 13.85 kg/s. Therefore with respect to the boiler efficiency, 595.489 MW energy is shifted to the feed water.

3. Program table algorithm

In order to energy targeting and pinch point specification, a tool called "Program Table Algorithm" is used. In this way, the solution process is initiated to achieve energy targeting. After receiving inputs such as number of hot and cold streams, thermal capacity, and initial and final temperature, the program processes like this in order to get the pinch point and utilities:

At first, all the quantities of hot and cold streams are placed in two separate matrices. Then the repetitive quantities are omitted in each of them and

" $\frac{\Delta T_{\min}}{2}$ " is reduced from hot streams and is added to the cold streams. $\Delta T_{\min}$, is the minimum temperature difference between cold and hot streams. Then, repetitive quantities are omitted between the new matrixes of the cold and hot stream temperatures and all the quantities are put in one matrix. After ascending the order of numbers in the combined matrix, the cascade analysis is started. At the end, the program obtains cold and hot utility and the pinch point, also data about composite curve (CC) and grand composite curve (GCC) are the main outputs.

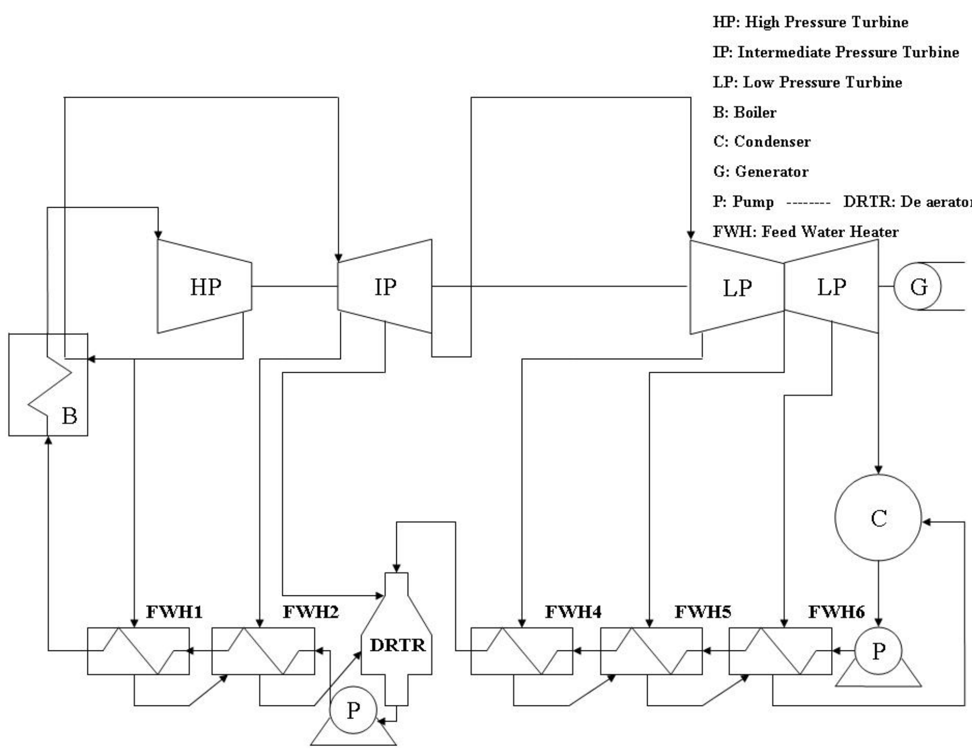

Fig. 1.Schematic arrangement of the cycle

4. Results and discussion

4.1. Data extraction- Results for the base state of the plant

In order to plan the main diagram in the pinch analysis, the cold and hot streams in the cycle must be specified, and subsequently the related information is obtained by using thermodynamic characteristics in the various parts of the cycle. In a steam turbine power plant, drain streams from turbine, which are used for feed water preheating, also outlet steam from the last part of the low pressure turbine, are supposed as power plant hot streams.

Table 1

Technical data and operating condition of the plant

Names	Value
Average flame temperature of boiler (T_f)	1443 K
Ambient temperature (T_0)	293 K
Total number of heaters	6
Number of extracted drains from IP turbine	2
Number of extracted drains from LP turbine	3
inlet pressure of boiler	16 MPa
inlet pressure of HP turbine	14 MPa
inlet temperature of HP turbine	538 ^oC
Adiabatic efficiency of HP turbine	84.21%
inlet pressure of reheater (outlet pressure of HP turbine)	3.73 MPa
inlet pressure of IP turbine	3.43 MPa
inlet temperature of IP turbine	538 ^oC
Adiabatic efficiency of IP turbine	92.88%
outlet pressure of IP turbine	0.746 MPa
inlet pressure of LP turbine	0.731 MPa
inlet temperature of LP turbine	318.45 ^oC
Adiabatic efficiency of LP turbine	91.05%
outlet pressure of LP turbine	0.01967 MPa
Exit pressure of condenser pump	0.83756 MPa
Adiabatic efficiency of condenser pump	80.00%
Adiabatic efficiency of open heater pump	80.00%
Total mass flow rate	214.845 Kg/s
TTD of heater 1	-1 ^oC
TTD of heater 2	-2 ^oC
TTD of heater 3	0
TTD of heater 4,5,6	2.8 ^oC
ITD of heater 1,2,4,5,6	5.6 ^oC
ITD of heater 3	0
Related pressure drop of heater 1	5.10%
Related pressure drop of heater 2	5.20%
Related pressure drop of heater 3	5.00%
Related pressure drop of heater 4	5.10%
Related pressure drop of heater 5	6.10%
Related pressure drop of heater 6	5.00%
Boiler thermal efficiency	94.9%
Plant fuel consumption	13.85 kg/s
Plant efficiency	41.97%

Furthermore, feed water streams, which are preheated in the heaters, and the out let steam from high pressure turbine, which is heated again, are the cold streams. Now, the physical characteristics about cold and hot streams must be defined. Generally, a thermal stream is consisted of two temperatures: Supply Temperature ($T_{\sup}$) and Target Temperature (T_{tar}). Moreover, it's necessary to define mass flow and heat capacity as well as these temperatures. For each stream in one temperature span in drawing diagrams, heat capacity, which is multiplied of mass flow in specific heat capacity, is assumed in a fix mode. In the case of the phase change, the stream is divided to smaller streams with assumed amount of CP with their input and output temperature difference is one. Then CP is obtained from following equation.

$$CP = \frac{\overset{\circ}{m} \,.\, \Delta H_{vap}}{1} \tag{1}$$

where ΔH_{vap} is the necessary heat from changing saturated liquid to saturated vapor. As a result, in order to specify heat capacity precisely, each stream is broken as possible, then the heat capacity is computed by using the equation 2:

$$\overset{\circ}{Q} = \overset{\circ}{m} C_p . \Delta T \tag{2}$$

The information about power plant cold and hot streams in the base state is given in table 3. Also the information about cold and hot streams considering CP changes in different fluid phases, which is given to the computer program, is shown in table 4. The necessary cold load for the condenser is provided by the outer cold water, and also the heat load for the boiler is provided by a furnace. With using the information of table 4, the program obtains necessary amounts for CC and GCC drawing.

Also it presents the minimum cold and hot utilities, the pinch point and the driving forces. The present curves are drawn by regarding $\Delta T_{\min} = 3.7\ ^{\circ}C$. Since considering this amount, Q_H obtains equal with boiler thermal load (595.489 MW). This means in case of designing a cycle including streams with the same specification, this minimum temperature difference would be sufficient. For the software computation in the base state and before modification, refer to table 4, figures 2, 3 are about CC and GCC. Also the program outputs are given in table 5 and 6.

4.2. Efficiency targeting- Cycle modification

After planning CC and GCC in the base mode, cycle modification is started. Table 6 specifies the lowest difference permissible temperature ($\Delta T_{\min} = 3.7\ ^{\circ}C$) which is occurred in the condensation step of the lowest pressure drain. In other condensation steps, temperature difference increases gradually until it becomes $15.9\ ^{\circ}C$ in the last one. Removal of uncoordinated distribution of the driving force in the system is the first process in order to bring the system to the optimal state and reduction of fuel consumption. Since pressure and temperature are fixed in all points of this stage, it is necessary to bring near the pinches, so the mass flows are changed in a way that in the all condensation steps, temperature difference between hot streams and cold streams be as a minimum temperature difference. For this reason, with the application of equation (3) between two consecutive pinch points, the heat balance between hot streams and cold streams will be exerted.

$$\sum_i \overset{\circ}{m}_i \cdot c_{p_i} \cdot \Delta T_i - \sum_j \overset{\circ}{m}_j \cdot c_{p_j} \cdot \Delta T_j = 0 \qquad (3)$$

index "i" in sigma represents the number of any hot stream which is placed between two consecutive pinch points and the index "j" indicates the number of any cold stream which is placed between two consecutive pinch points. In a system with six drains (such as Shahid Rajaei power plant), there are seven pinch points in drain saturated temperatures and saturated temperature correspondent with condenser pressure. The equation (3) is written between each of seven continuous points, so there are six equations with seven unknown qualities (drain mass flows and total water flow). Where as outlet power of the cycle is the same as the initial power (250 MW), there fore it's important to compute turbine outlet power. Considering that the turbine outlet work depends on the intensity of the passing mass flow from the turbine (and mass flow of feed water and all drains), by using the energy balance equation of the turbine, the total water flow is computed in a way that the total outlet load from turbine is equal to the assumed power. This equation is the seventh equation. Since these equations are linear, the solution will be easy. Table 7 presents amounts of the mass flow in optimized state which are compared to mass flows in the base state. With respect to the new quantities, input data to the program are like table 8. Results of the program computation for the power plant in optimized state are given in table 9, 10. Figures 4, 5 also show the CC and GCC after modification. Considering table 2, the use of fuel is economized. Table 11 shows related quantities of the power plant fuel consumption before and after the cycle modification. Also the power plant efficiency is obtained by the following relation.

$$\eta(\%) = \left(\frac{\overset{\circ}{W}_{net}}{\overset{\circ}{Q}_{in}}\right) \times 100 \quad (4)$$

Table 12 shows related quantities of the power plant efficiency before and after modification.

5. Conclusion

Pinch Technology is known as a powerful tool in designing and optimization of processing systems. This technology is used in power plant industries and causes appropriate application of temperature differences in the HENs and the cycle modification. As shown before, using of this technology makes an increase of total efficiency (table 12) as well as decrease of the use of fuel (table 11). In this way, the thermal load is reduced for the steam production. Also the mass flow of the input steam to low pressure turbine is reduced. This is a useful way in turbines with smaller impellers to reduce the corrosion problems. On the other hand, decrease of the fuel causes using of smaller furnace and saving in cost of power plant. Finally less fuel consumption leads to decrease in pollution.

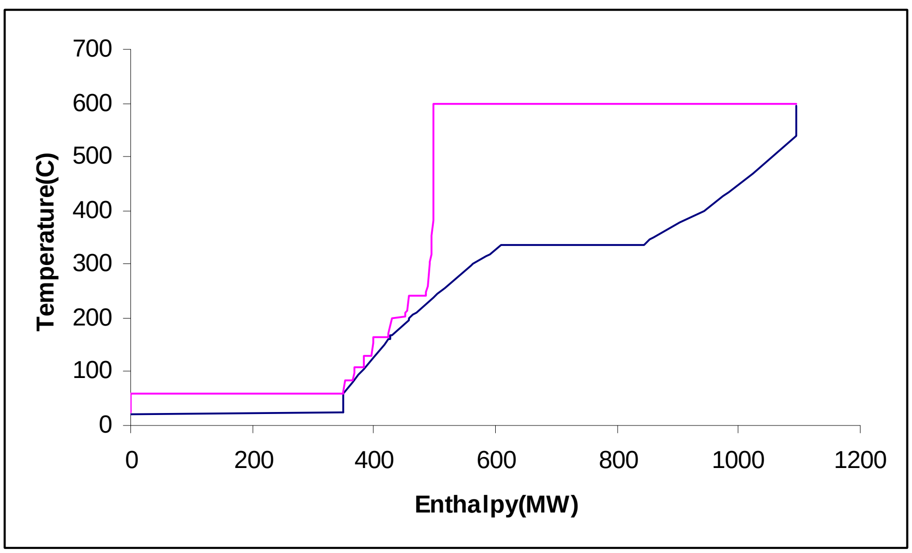

Fig. 2.Plant composite curve at the base state

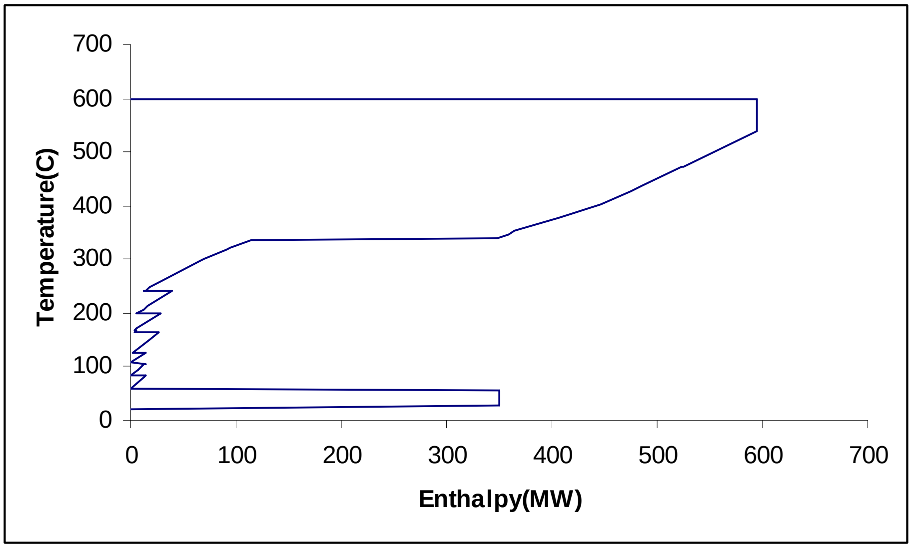

Fig. 3.Plant grand composite curve at the base state

Table 2

The fuel information of power plant [12]

Names	Value
Fuel Density	0.86 kg/m^3
Lower Heating Value	38962 kj/m^3

Table 3

The information about power plant cold and hot streams in the base state [12]

Stream	Mass flow (kg/hr)	Supp. Temp. ($^\circ C$)	Tar. Temp. ($^\circ C$)	Sat. Temp. ($^\circ C$)
Feed water(Cond. -deaerator)	628003	59.3	164.7	-
Feed water(deaerator-boiler)	772760	167.7	538	335
Steam reheater	695936	351.1	538	-
Drain 1	59374	349.1	164.7	242.1
Drain 2	42875	438.6	164.7	201.7
Drain 3	42507	323.5	164.7	164.7
Drain 4	21312	213.9	59.3	128.1
Drain 5	24173	152.9	59.3	108.5
Drain 6	23203	85.4	59.3	85.4
Condenser	558019	59.3	59.3	59.3
Gland steam	828	430	59.3	98
Ejector Steam	450	473	59.3	98

Table 4

The information about cold and hot streams considering CP changes in different fluid phases at the base state

No.	Flow(kg/s)	Supp. Temp. ($^{\circ}C$)	Tar. Temp. ($^{\circ}C$)	Heat Cap (j/kg.$^{\circ}C$)
Drain 1				
1	16.49	349.1	300	2524.02
2	16.49	300	243	3121.74
3	16.49	243	242	1755441
4	16.49	242	209.6	4574.4
5	16.49	209.6	164.7	4466.54
Drain 2				
6	11.91	438.6	380	2200.57
7	11.91	380	320	2219
8	11.91	320	260	2260.78
9	11.91	260	202	2533.74
10	11.91	202	201	1934627.8
11	11.91	201	172.7	4696.63
12	11.91	172.7	164.7	4396.14
Drain 3				
13	11.81	323.5	250	2164.6
14	11.81	250	165.7	2210.11
15	11.81	165.7	164.7	2067343
Drain 4				
16	5.92	213.9	129	2095.87
17	5.92	129	128	2179544
18	5.92	128	105.7	4242.87
19	5.92	105.7	59.3	4204.85
Drain 5				
20	6.71	152.9	109	2040.95
21	6.71	109	108	2232402.5
22	6.71	108	82.6	4242.87
23	6.71	82.6	59.3	4204.85
Drain 6				
24	6.45	85.4	84.4	2294785
25	6.45	84.4	59.3	4186.8
Gland St.				
26	0.23	430	98	2001.6
27	0.23	98	97	2264113.3
28	0.23	97	59.3	4164.3
Ejector St.				
29	0.13	473	98	2023.1

Table 4

Continued…

30	0.13	98	97	2264113.3
31	0.13	97	59.3	4164.3
Condenser				
32	155	60.3	59.3	2254826.26
Feed water				
33	174.44	59.3	164.7	4238.44
34	214.66	167.7	241.1	4564.93
35	214.66	241.1	300	4975.82
36	214.66	300	335	6363.9
37	214.66	335	336	1084385.4
38	214.66	336	400	5580.25
39	214.66	400	470	3277.67
40	214.66	470	538	2850.72
Reheater St.				
41	193.32	351.1	400	2601.98
42	193.32	400	470	2177.73
43	193.32	470	538	2216.54

Table 5

Program Exit at the base state of the plant

Hot utility(kW)	Cold utility(kW)	Pinch Point($^\circ C$)
595489.2	349841.6	83.55

Table 6

Program Exit at the base state of the plant for temperature differences between hot and cold composite curves related to each drain (Driving force)

Place	T_C(°C)	T_H(°C)	) $^\circ C$ (ΔT_{min}
Drain 6	81.7	85.4	3.7
Drain 5	104.763	109	4.237
Drain 4	123.25	129	5.75
Drain 3	157.537	165.7	8.163
Drain 2	191.981	202	10.019
Drain 1	227.122	243	15.878

Table 7

Drain mass flows and total mass flow in the base state and optimized state (kg/s)

Place	Base State	Optimized State
Drain 1	16.49	19.71
Drain 2	11.91	13.8
Drain 3	11.81	12.1
Drain 4	5.92	6.3
Drain 5	6.71	6.8
Drain 6	6.45	6.9
Total mass flow of the plant	214.66	218.4

Table 8

The information about cold and hot streams considering CP changes in different fluid phases at the optimized state

No.	Flow(kg/s)	Supp. Temp. (^oC)	Tar. Temp. (^oC)	Heat Cap. (J/kg.^oC)
Drain 1				
1	19.71	349.1	300	2524.02
2	19.71	300	243	3121.74
3	19.71	243	242	1755441
4	19.71	242	209.6	4574.4
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Table 8

Continued…

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22	6.8	108	82.6	4242.87
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Drain 6				
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25	6.9	84.4	59.3	4186.8
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27	0.228	98	97	2264113.3
28	0.228	97	59.3	4164.3
Ejector Steam				
29	0.124	473	98	2023.1
30	0.124	98	97	2264113.3
31	0.124	97	59.3	4164.3
Condenser				
32	153.1	60.3	59.3	2254826.3
Feed water				
33	173	59.3	164.7	4238.44
34	218.4	167.7	241.1	4564.93
35	218.4	241.1	300	4975.82
36	218.4	300	335	6363.9
37	218.4	335	336	1084385.4
38	218.4	336	400	5580.25
39	218.4	400	470	3277.67
40	218.4	470	538	2850.72
Reheater Steam				
41	193.997	351.1	400	2601.98
42	193.997	400	470	2177.73
43	193.997	470	538	2216.54

Table 9

Program Exit at the optimized state of the plant

Hot utility(kW)	Cold utility(kW)	Pinch Point($^{\circ}C$)
591029.2	345909.6	241.1

Table 10

Program Exit at the optimized state of the plant for temperature differences between hot and cold composite curves related to each drain (Driving force)

Place	T_C(°C)	T_H(°C)	ΔT_{min} (°C)
Drain 6	81.5705	85.4	3.83
Drain 5	105.138	109	3.86
Drain 4	124.957	129	4.04
Drain 3	160.421	165.7	5.279
Drain 2	198.279	202	3.7
Drain 1	239.3	243	3.7

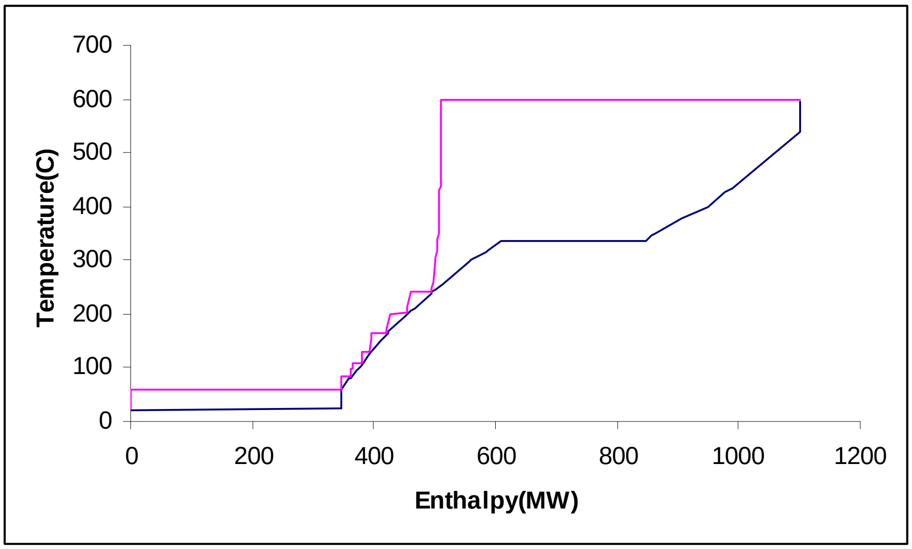

Fig. 4.Plant composite curve at the optimized state

Table 11

Quantities of the power plant fuel consumption before and after the cycle modification (kg/s)

Base State	Optimized State
13.85	13.05

Table 12

The power plant efficiency before and after the cycle modification

Cycle efficiency in the base state	Cycle efficiency in the optimized state
41.97%	42.29%

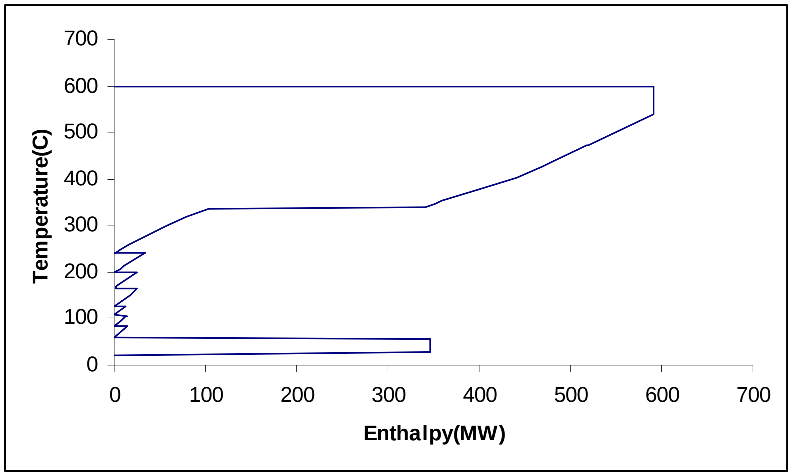

Fig. 5.Plant grand composite curve at the optimized state

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