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Pinch Analysis for Power Plant: A Novel Approach for Increase in Efficiency

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***Abstract*— Pinch technology presents a simple methodology for systematically analyzing Power Plant Processes and the surrounding utility systems with the help of the First and Second Laws of Thermodynamics. The objective of this study is to apply pinch technology for optimizing the performance of WTPS Wanakbori, Gujarat. From the Pinch analysis performed, the Composite Curves revealed that, at a minimum temperature difference of 25°C, the plant energy consumption is higher by approximately 210MW than the minimum required utility consumption. After the analysis of the plant is was concluded that the fuel consumption can be reduced by 0.19 kg/s. Hence because of the reduction of fuel consumption the efficiency of the plant can be improved to 47.19% from the present efficiency of 46.78%.**

Keyword - Pinch analysis, Current Layout of Power Plant, Hot utility Consumption, Modified Consumption rate, Increase Efficiency.

1. INTRODUCTION

Pinch Analysis is used to identify energy cost and heat exchanger network (HEN) capital cost targets for a process and recognizing the pinch point. The procedure first predicts, ahead of design, the minimum requirements of external energy, network area, and the number of units for a given process at the pinch point. Next a heat exchanger network design that satisfies these targets is synthesized. Finally the network is optimized by comparing energy cost and the capital cost of the network so that the total annual cost is minimized. **Thus, the prime objective of pinch analysis is to achieve financial savings by better process heat integration (maximizing process-to-process heat recovery and reducing the external utility loads)**.[1]

2. STEPS OF PINCH ANALYSIS

1) Identification of Hot, Cold and Utility Stream in Process.
2) Thermal Data Extraction for Process and utility stream.
3) Selection of inlet DTmin Value.
4) Construction of Composite and Grand Composite curve.
5) Estimation of minimum energy cost target.
6) Estimation of HEN Capital cost target.
7) Estimation of optimum DTmin Value.
8) Estimation of practical target for HEN design.
9) Design of HEN.[2]

Hot Streams' are those that must be cooled or are available to be cooled. e.g. product cooling before storage.

Cold Streams are those that must be heated e.g. feed preheat before a reactor.

Utility Streams' are used to heat or cool process streams, when heat exchange between process streams is not practical or economic.
A number of different **hot utilities** (steam, hot water, flue gas, etc.) and **cold utilities** (cooling water, air, refrigerant, etc.) are use in industry.

The identification of streams needs to be done with care as sometimes, despite undergoing changes in temperature, the stream is not available for heat exchange. For example, when a gas stream is compressed the stream temperature rises because of the conversion of mechanical energy into heat and not by any fluid to fluid heat exchange. Hence such a stream may not be available to take part in any heat exchange. In the context of pinch analysis, this stream may or may not be considered to be a process stream.[4]

Thermal Data Extraction for Process & Utility Streams

For each hot, cold and utility stream identified, the following thermal data is extracted from the process material and heat balance flow sheet:

Supply temperature (T_S °C): the temperature at which the stream is available.

Target temperature (T_T °C): the temperature the stream must be taken to.

Heat capacity flow rate (**CP** kW/°C): the product of flow rate (m) in kg/sec and specific heat (Cp kJ/kg °C).

CP = **m** x **Cp**

Enthalpy Change (H) associated with a stream passing through the exchanger is given by the First Law of Thermodynamics: **H = Q ± W**

In a heat exchanger, no mechanical work is being performed: **W = 0 (zero)**

The above equation simplifies to: **H = Q**,

Q= CP x (T_S **-** T_T**).**

Enthalpy Change, H = **CP x (**T_S **-** T_T**)**

The stream data and their potential effect on the conclusions of a pinch analysis should be considered during all steps of the analysis. Any erroneous or incorrect data can lead to false conclusions. In order to avoid mistakes, the data extraction is based on certain qualified principles.

Composite Curves: Temperature - Enthalpy (T - H) plots known as '**Composite curves'** have been used for many years to set energy targets ahead of design. Composite curves consist of temperature (T) – enthalpy (H) profiles of heat availability in the process (the **hot composite curve**) and heat demands in the process (the **cold composite curve**) together in a graphical representation. general any stream with a constant heat capacity (CP) value is represented on a T – H diagram by a straight line running from stream supply temperature to stream target temperature. When there are a number of hot and cold streams, the construction of hot and cold composite curves simply involves the addition of the enthalpy changes of the streams in the respective temperature intervals.[3]

Grand Composite Curve (GCC): In selecting utilities to be used, determining utility temperatures, and deciding on utility requirements, the composite curves and PTA are not particularly useful. The introduction of a new tool, the Grand Composite Curve (GCC), was introduced in 1982 by Itoh, Shiroko and Umeda. [3]

3. APPLYING THE PINCH TECHNOLOGY TO THERMAL POWER PLANT

As shown above the steam is generated in Boiler which is the steam generator which is directly sent to the high pressure turbine (HP), at the exhaust of the high pressure turbine the steam is sent back to the steam generator for the reheating purpose. This reheated steam is sent to the intermediate
pressure turbine (IP). At the exhaust of the intermediate pressure turbine (IP), the steam is sent to the low pressure turbine.

At the exhaust from the low pressure turbine (LP) the steam is sent to the condenser for condensation purpose. Here the cooling water is used as the cooling duty for the condensation of steam. From the outlet of the condenser the condensate is sent from the pump to the feed heater as shown in the above diagram. Here the heat exchange will take place between the condensate and the extracted steam from the turbines extraction. This will cause the rise in the temperature of the condensate. Similarly the condensate will be sent to further phases of heating from the different extraction of the intermediate and the high pressure turbine. Finally the condensate at the exit of the feed heater will be sent to the steam generator for generation of steam. Coal as fuel is being used as the heating utility inside the steam generator furnace. Thus the input energy of the cycle will be the fuel used in the steam generator and the output of the cycle will be the turbine work. Whereas, the cooling duty is the cooling water used for the steam condensation in the condenser.

The present Utility consumption of the plant

The present utility consumption of the plant, can be found out from the below data. The plant is a coal fired plant and the coal used is of the heating value of 20920 kJ/kg. The consumption of the coal is found to be 21.46 kg/sec. Thus from this data the hot utility consumption of the plant can be given as:

Hot Utility = Mass of coal x Heating value of coal
= 21.46 Kg/s x 20920 kJ/kg
= 448943 KJ/s = 448.943 MW.

The mass flow rate of cooling water is 5146.33 Kg/s. The temperature difference between the inlet and outlet of cooling water for the condenser is 12°C. Considering the specific heat of the cooling water to be 4.187 KJ/Kg K. the cooling duty is:

Cooling Duty = Mass flow rate of water x specific Heat x temperature difference
= 5146.33 x 4.187 x 12
= 258572.2 KJ/s
= 258.572 MW.

η = Turbine Output power / Hot utility consumption
= 210 / 448.943
= 46.78%.

Thus the plant efficiency is 46.78%.

The Hot Composite Curve

The Hot composite curve is formed by adding the m x Cp values of the entire individual hot streams together to form a single stream. The red curve in the above T-H diagram is the hot composite curve of the plant. The X-axis represents temperature in Kelvin scale and the Y-axis represents Enthalpy change in KW. Figure-2 indicates the hot composite curve. Similarly the cold Composite curve for the plant is drawn by adding the m x C p values of all the individual cold streams together to form a single stream.

The Cold Composite Curve

The blue curve in figure-3 indicates the cold composite curve. One can identify the cold composite curve as the heating cycle curve of the Rankine cycle. The axis limits of both the curves are kept the same, so that in order to superimpose the curves on each other there should not be any problem. From the above Hot Composite Curve and The Cold Composite Curve, The plant Composite curve including the both can be prepared by just combining both the curves in a single graph. [3]

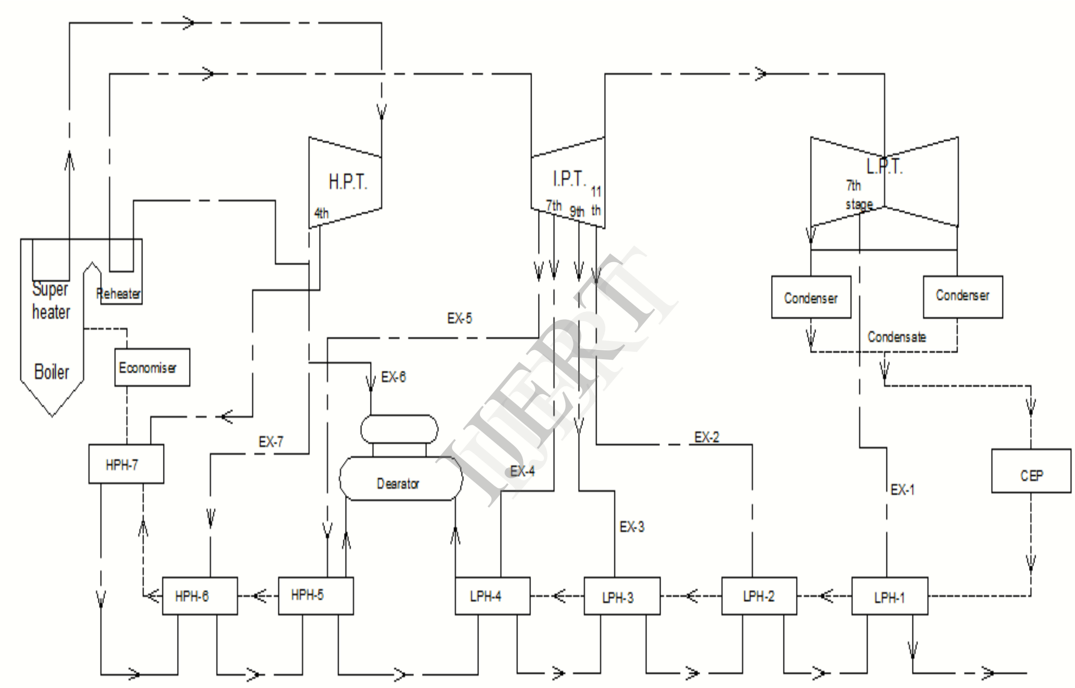

Figure-1 Schematic diagram for the functioning of a steam cycle power plant

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Table -1 the stream table of the plant

Sr. No.	Stream Name	Stream Type	Supply temp (Ts) K	Target temp (Tt) K	Heat Capacity flow rate (Kw/K)	Enthalpy Change
1	H1	Hot	442.3	294.1	5.94	879.73
2	H2	Hot	656.6	376.6	14.76	4132.84
3	H3	Hot	638.2	351.4	12.56	3603.45
4	H4	Hot	650.5	400.6	14.79	3696.06
5	H5	Hot	680.6	352.3	9.99	3279.72
6	H6	Hot	700.3	450.1	120.72	30204.94
7	H7	Hot	750.7	350.4	26.77	10715.44
8	H8	Hot	800.9	545.8	21.39	5455.88
9	C1	Cold	513.00	613.00	879.39	87939.31
10	C2	Cold	613.00	816.00	498.74	101243.56
11	C3	Cold	323.30	324.86	563.11	879.73
12	C4	Cold	324.86	330.88	686.60	4132.84
13	C5	Cold	330.88	336.12	687.74	3603.45
14	C6	Cold	336.12	341.37	704.76	3696.06
15	C7	Cold	341.37	346.00	707.11	3279.72
16	C8	Cold	346.00	383.96	795.70	30204.94
17	C9	Cold	383.96	397.28	804.44	10715.44
18	C10	Cold	397.28	404.04	808.08	5455.88
19	C11	Cold	516.00	813.00	489.64	145422.15

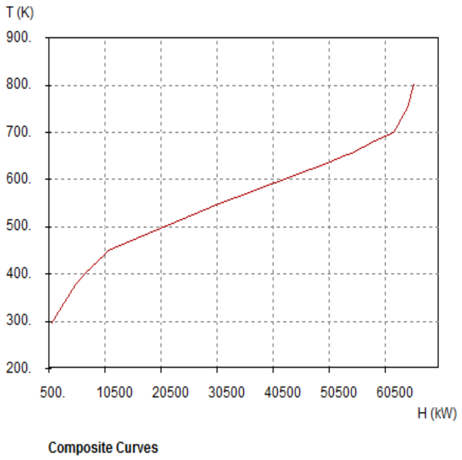

Figure -2 The Hot Composite curve

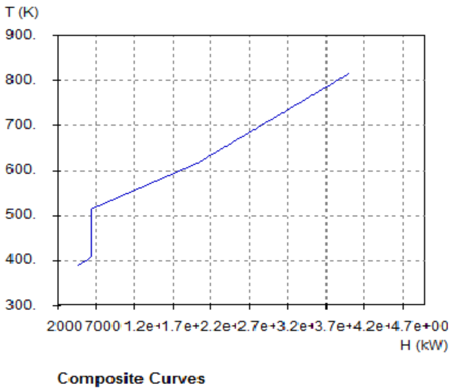

Figure -3 The Cold Composite curve

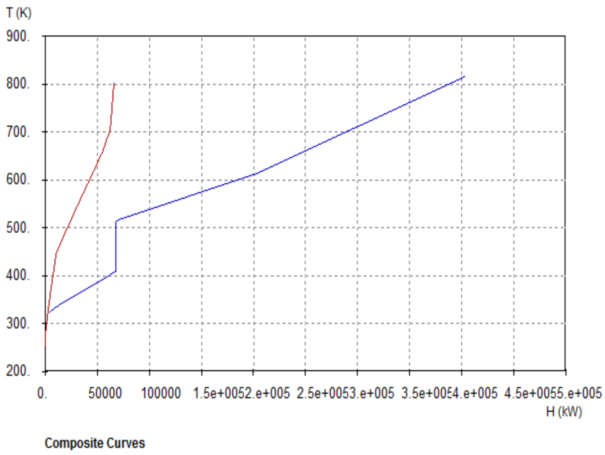

Figure -4 The Composite Curve

Figure - 4 indicates the Composite Curves. Note that the above diagram is drawn considering a minimum temperature difference as 25°C. This is taken because the least temperature difference in the plant between the hot and cold stream is at the heat exchanger no. 1 and is equal to an approximate value of 25°C.
Thus from the composite curves it can be found that the minimum utility targets for the above plant is as below:

Minimum Hot Utility requirement = 433443 KW
Minimum Cold Utility requirement = 221532 KW

From the analysis of the heat exchanger network it is very much clear that the heat exchanger no. 1 transfers the heat across the pinch. Hence it can be confirmed that this heat exchanger is the culprit for the portion of higher amount of utility consumption.

Table-2 Utility at different values of ΔT_{min}

ΔT min (°C)	Hot Utility (KW)	Cold Utility (KW)	Comments
25	448943	253572	Heat exchanger no.1 transfer heat across the pinch
20	448842	253162	Heat exchanger no.1 transfer heat across the pinch
15	448793	251672	Heat exchanger no.1 transfer heat across the pinch
10	448514	249112	Heat exchanger no.1 transfer heat across the pinch
8	448343	243231	There is no heat transfer across the pinch
5	447823	232124	There is no heat transfer across the pinch

However the network is to be studied for various values of ΔT_{min} and the utility consumption are also to be determined.

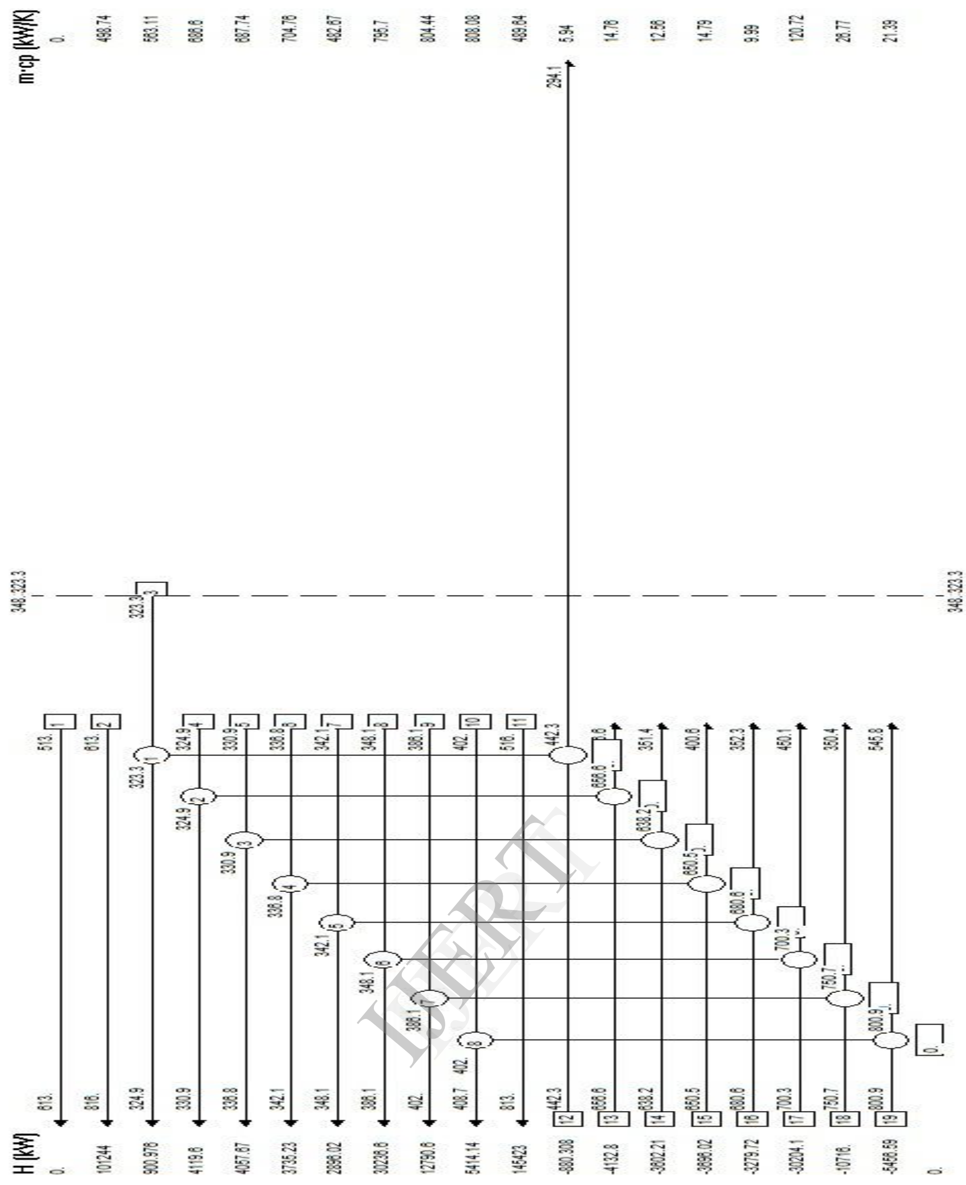

Figure- 5 Heat exchanger network at ΔT_{min} of 25 °C

From the figure- 6 it is clearly seen that now the heat exchanger no.1 do not transfer the heat across the pinch.

Thus ΔT_{min} of 8 °C is the appropriate minimum temperature difference for this plant. However to run the plant at this temperature difference the Heat Exchanger no. 1 surface area needs to be changed accordingly. This will lead to change in the outlet temperatures of the heat exchanger. That will be the new inlet temperature for the subsequent heat exchanger and further on. Thus because of the change of temperatures the entire heat exchanger network area needs to be changed and eventually there is the requirement of the retrofitting of the entire plant by changing the feed water heaters. This calls for higher investments.

Figure-7 is the grand composite curve at the minimum temperature difference of 8 °C.

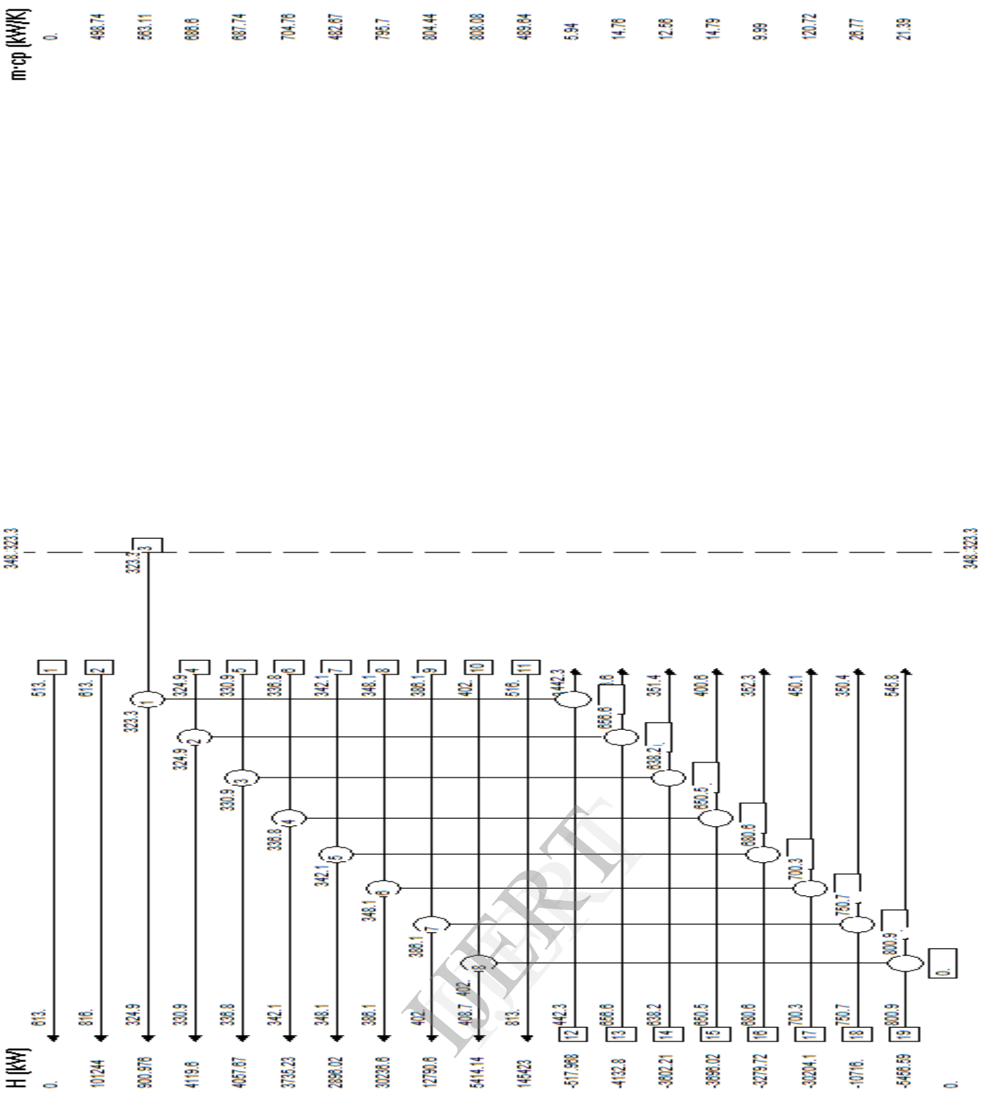

Figure- 6 Heat exchanger network diagram at ΔT_{min} of 8 °C

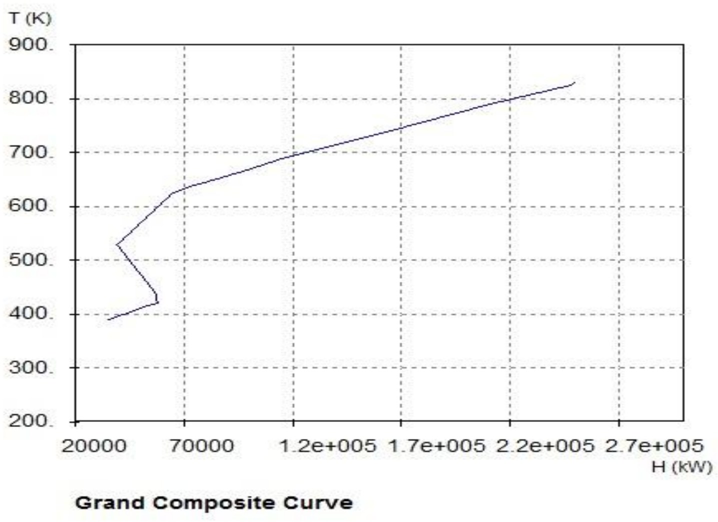

Figure- 7 Grand Composite Curve at ΔT_{min} 8 °C

Hence in order to optimize the performance of the plant, the heat recovery within the present heat exchanger network needs to be improved. i.e the process to process heat exchange should be efficient so that it leads to lower utility consumption of the plant.

In order to increase the process to process heat exchange the mass flow rate of the hot streams, i.e the turbine extraction mass flow rate needs to be increased which may lead shifting of the hot composite curve towards the cold composite curve, thereby by increasing the effectiveness of the process to process heat exchange.

But if the mass flow rate of the turbine extractions is increased, there will be loss in the output power of turbine, thereby decreasing the efficiency. Therefore in order to maintain the output power of the turbine as the same, the all over mass flow rate needs to be increased. i.e the make-up water is to be added to the cycle.

The adding of make-up water to the cycle may cause the increase in the utility consumption, but at the same time if the heat recovery within the process to process heat exchange is high enough than, this increased utility requirement can be compensated. Finally there will be the savings in the consumption of fuel and reduction in the utility requirement.

Table-3 represents the optimized mass flow rates, which are compared to the mass flow rates in the base state. Thus the new input data for the plant will be considered as given in the new stream table. Finally the composite curves and the grand composite curves can be prepared which will represent the new utility requirement of the plant

Based on the new mass flow rates considered, the plant composite curves can be prepared. From the data available from the new composite curves the new utility requirement can be estimated, which would be lesser than that of the required at the base state.

4. OPTIMIZATION OF THE PERFORMANCE

Removal of un co-ordinated 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, thereby reducing the utility consumption of the plant. Since the pressure and temperature are fixed in all the points of this stage, it is necessary that the mass flow rates are changed in a way that in all the heat exchange steps, temperature difference between hot streams and cold streams be as the minimum temperature difference. For this reason, with the application of below equation between two consecutive hot and cold streams, the heat balance can be exerted.

$$\sum m_i \times Cp_i \times \Delta T_i - \sum m_j \times Cp_j \times \Delta T_j = 0$$

Index i in sigma represents the number of any hot streams which is placed between two consecutive points and the index j indicates the number of any cold streams

Table-3 represents the optimized mass flow rates, which are compared to the mass flow rates in the base state. Thus the new input data for the plant will be considered as given in the new stream table.

Table-3 Optimized mass flow

Location	**Base state mass flow rate**	**Optimized state mass flow rate**
Extraction 1	3.00	3.25
Extraction 2	7.41	7.73
Extraction 3	6.17	8.00
Extraction 4	7.05	9.10
Extraction 5	4.63	6.18
Extraction 6	55.56	57.56
Extraction 7	11.22	11.72
Extraction 8	8.85	9.35

Table -4 stream tables with optimized mass flow rates

Sr. No.	Stream Name	Stream Type	Supply temp (Ts) K	Target temp (Tt) K	Heat Capacity flow rate (Kw/K)	Enthalpy Change
1	H1	Hot	442.3	294.1	6.44	954.63
2	H2	Hot	656.6	376.6	15.41	4313.65
3	H3	Hot	638.2	351.4	16.29	4670.71
4	H4	Hot	650.5	400.6	19.08	4768.77
5	H5	Hot	680.6	352.3	13.35	4382.41
6	H6	Hot	700.3	450.1	125.08	31294.49
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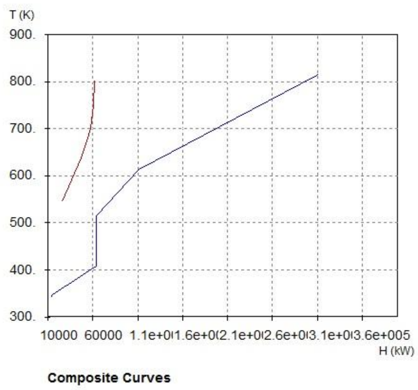

Figure -8 Optimized composite curves

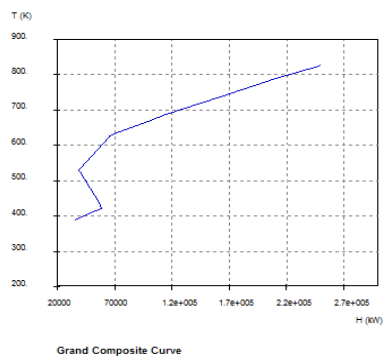

Figure -9 Optimized Grand Composite Curve

Grand Composite Curve

From the Composite Curves and the Grand Composite Curves the new utility requirement of the plant is as under.
Minimum Hot utility requirement = 431 MW
Minimum Cold utility requirement = 219 MW

The above utility requirement corresponds to the minimum temperature difference of 25 °C

Recommendations for the plant

The optimized mass flow rates have led to lower utility consumption by the plant because of the optimized process heat recovery.

Even the addition of the makeup water has not increased the utility consumption because the drain extractions streams mass flow rates have been increased keeping the total output power of the turbine constant. Hence it has led to improved process heat exchange leading to the lower utility consumption of plant. Now if the plant is operated at the optimized mass flow rates as shown in table-3, below results can be achieved.

Because of the reduction in fuel consumption the plant efficiency increases to 47.19% as compared to the previous efficiency of 46.78%.

5. CONCLUSION

The following specific conclusions are observed after this study:

- Heat and mass integration can lead to cost effective retrofitting of the existing facilities.
- Optimization of the plant using Pinch Analysis leads to the increase of total efficiency to 47.19% from the present efficiency of 46.78%.
- The fuel consumption of the plant can be reduced by 0.19 kg/s

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