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Performance Evaluation of a Steam Turbine Heat Exchanger Network Using Pinch Analysis

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ABSTRACT : *This research is the performance evaluation of a steam turbine heat exchanger network using pinch and exergy analysis. The values of the parameters pertinent to this study (mass flow rates supply and target temperatures T_{supply}, and T_{target}) were obtained from the Egbin steam turbine power plant heat exchanger network. The Egbin power plant Plc is located in Egbin Town, South West Nigeria. Results obtained from the analysis showed that the minimum utility targets for the base case (15K minimum temperature difference) were 248.669MW for the hot utilities and 115.955MW for the cold utilities, the total exergy loss in the heat exchanger network was 28.3502MW, exergy efficiency was 39.59%.*

KEYWORDS - *Heat Exchanger, Exergy, Network, Pinch*

I. INTRODUCTION

Energy exploitation and use are major factors affecting nations' economic growth and industrialization. In addition to rapid population growth, electrical infrastructure has increased, making electrical energy a large part of today's life. Steam power plant is a type of power plant that has very high energy losses due to great heat loss in the boiler and condenser. More effective, reliable and profitable power plants are needed by recent market developments in the form of privatization and deregulation [1].

However, process integration, especially pinch technology is a powerful method for analyzing faults and selecting concrete technical solutions to improve efficiencies in power plants [2, 3]. [4] carried out research on enhancement of efficiency of a thermal power plant at Rajasthan State of India. Pinch analysis was applied on the steam turbine and the turbine.

An investigation was carried out [5] on thermodynamics performance evaluation in combined cycle power plant by using combined pinch and exergy analysis. In that study, exergy analysis was to assess the performance and identify which components of the system had the potential for performance improvement. The study showed that net power could be increased by 2.7% and the exergetic efficiency could be increased from 45.9% to 47.1%.

[6] carried out a study on a heat exchanger network. A model was used to optimize the heat exchanger network for a process industry and to estimate the minimum cost required for the network without compromising the energy demand by each stream as much as possible with the help of MATLAB programming software.

[7] carried out a pinch analysis on a power plant. The study presented a methodology for analyzing power plant processes and surrounding utilities with the first and second laws of thermodynamics. From the pinch analysis performed, the composite curves revealed that at a minimum temperature difference of 25ºC, the plant energy consumption was higher by 210MW than the minimum required utility consumption. Their results showed that the plant's fuel consumption could be improved by 47.19%. [8] carried out a combined pinch and exergy analysis for exergy efficiency optimization in a steam power plant. A simulation of a 325MW steam power plant was performed using a Cycle-Tempo 5.0 simulator and operational parameters of the Rankine cycle were optimized.

II. MATERIALS

The data for this study were obtained from the operational Egbin steam turbine power plant heat exchanger network. The plant is located in Egbin Town, South-West Nigeria. The values of the parameters pertinent to this study (mass flow rates and supply and target temperatures, T_{supply} and T_{target}, respectively) were obtained from the log sheet of the steam turbine power plant for an interval of five months. The Hint software was used for the analysis.

This is a software for heat exchanger network design based on the pinch method. The interface of the program has been designed focusing on getting a clear presentation of the concepts of the pinch design methods and enabling users the control of all the stages of the design.

DATA SOURCE

The steam turbine power plant heat exchanger network schematic diagram is shown in Figure 1 and the description of the process is as follows:

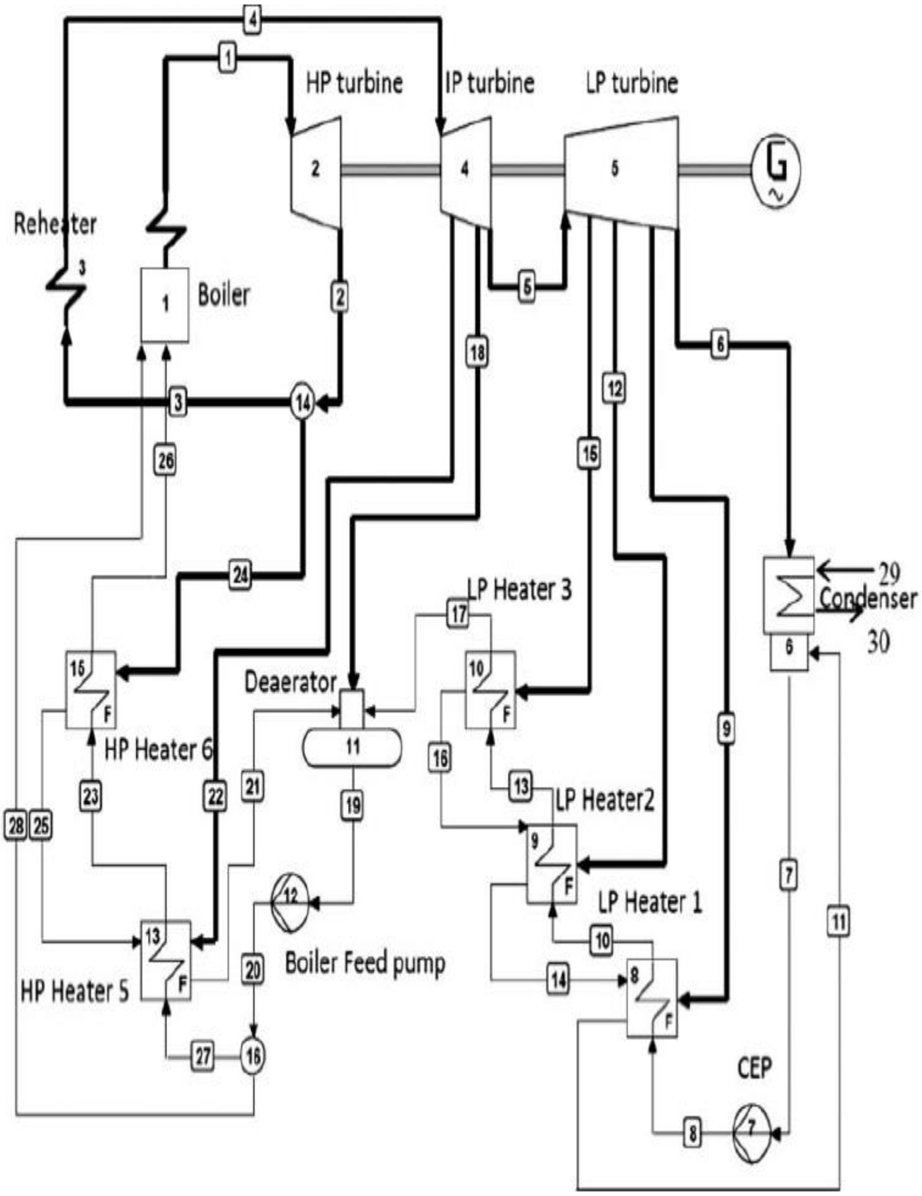

Fig 1: Schematic Drawing of Steam Turbine Heat Exchanger Network

The boiler generates steam (1), which is directly sent to a high pressure (HP) turbine (2). At the exhaust of the HP turbine, the steam is sent back to the steam generator (3) for reheating. The reheated steam is sent to an intermediate pressure (IP) turbine (4), and from the IP turbine exhaust, the steam is sent to a low-pressure (LP) turbine (5). From the LP turbine's exhaust, the steam is sent to a steam surface condenser (6). The exhaust steam from the LP turbine is condensed to its liquid state in the condenser as it transfers the latent heat to the cooling water flowing through the condenser.

The surface condenser used in the present plant is a shell and tube heat exchanger, in which the cooling water flows through the condenser tubes while the steam condenses in the shell side.

From the condenser's outlet booster pumps (7), and boiler feed pumps (12), send the condensate through the feed heating trains consisting of three LP heaters (8, 9, 10), one deaerator (11), and two HP heaters (13, 15). Here, heat is transferred from different steams extracted from the IP and HP turbines to the condensate, raising its temperature.

HEAT EXCHANGER NETWROK (HEN)

A heat exchanger network (HEN) is an arrangement of several heat exchangers that operate in an integrated manner in a process. This formation is expected to increase system efficiency. The minimum number of heat exchangers (Umin) is generally the number of process streams and utilities.

The calculation of the Umin on a HEN requires determining the minimum or maximum energy that can be recycled. This calculation can be completed by the following equation:

$$U_{min} = N - 1 \qquad (1)$$

where N = Number of process streams and utilities.

Pinch analysis is done by calculating the balance of mass and energy of the system processes based on the first and second laws of thermodynamics. The equations used are as follows: The enthalpy change (ΔH), by first Law of thermodynamics

$$\Delta H = Q - W \qquad (2)$$

Where there is no work done, W = 0, then Equation (2) is transformed into ΔH = Q, and

$$\mathrm{Q} = C_p(T_1 - T_4) \qquad (3)$$

where C_p= Specific heat capacity
T_1 =Target temperature
T_4 =Supply temperature

So that

$$\mathrm{H} = C_p(T_1 - T_4) \qquad (4)$$

The heat capacity rate (CP) is given as

$$CP = \dot{m}\, C_p \qquad (5)$$

where $\dot{m}$ = mass flowrate

The thermal efficiency (η) is defined as the ratio of network (W_{net}) generated against energy input (Q_{in}).

$$\eta = \frac{W_{net}}{Q_{in}} \times 100\% \qquad (6)$$

COMBINED PINCH AND EXERGY ANALYSIS (CPEA)

Pinch analysis is a systematic tool for investigating the possibilities of heat integration (process integration) between processes [3].

The CPEA follows the procedure of the pinch analysis, except that the curves developed are the composite curves (CCs) and the exergy composite curves (ECCs). The CC and ECC were obtained by replacing the temperature axes of the exergy composite curves with the carnot factors ηc, which are obtained with Equation (7)

$$\eta_c = 1 - \frac{T_0}{T} \qquad (7)$$

where T_0 (K) =Ambient temperature
T(K) = Temperature of the stream under consideration.

The distance between the temperature axis and the end of the hot stream curve traced down to the heat load axis gives the minimum cold utilities, while the distance between the beginning of the hot stream curves and the end of the cold stream curves traced down to the heat load axis gives maximum hot utilities in the CCs. The exergetic efficiency of a heat exchanger (HEX) is defined as the ratio of the increase in the exergy of the cold fluid to the decrease in the exergy of the hot fluid (Equation 8).

$$HEX = \frac{\sum[(\dot{m}e)_{out} - (\dot{m}e)_{in}]_{cold\ stream}}{\sum[(\dot{m}e)_{in} - (\dot{m}e)_{out}]_{hot\ stream}} \quad (8)$$

where $\sum(\dot{m}e)_{out}$ = Exergies of outgoing streams

$\sum(\dot{m}e)_{in}$ = Exergies of ingoing stream

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III. RESULTS AND DISCUSSION

The mass flow rates, supply and target temperatures of the cold (feed water) and hot (bleed steam) streams of LPH1, LPH2 and LPH3 at base case are shown in Tables 1 to 3, respectively.

Table 1: Temperature, Pressure and Enthalpy Data for LPH1 from the Turbine HEN

					LPH1					
	Feedwater				**Bleed Steam**					
Stream	**P**	**T**	**h**	**M**	**Stream**	**P**	**T**	**h**	**m**	**Tsat**
	bar	**K**	**kJ/kg**	**kg/s**		**Bar**	**K**	**kJ/kg**	**kg/s**	**K**
					LPT1 port (9)	**0.3549**	**442.3**	**2223.2**	**17.67**	
Feed water in	**22.78**	**513**	**166.3**	**293.1**	**Steam in**	**0.338**	**294.1**	**2220.9**	**17.67**	**345.0**
					Flash back			**313.1**	**66.64**	
					SSR seal steam			**2644.0**	**0.766**	
Feed water out	**20.79**	**613**	**290.9**	**293.1**	**Drain before pump**	**0.338**	**294.1**	**300.9**	**85.08**	
					Drain to FWH2	**20.79**		**303.5**	**85.08**	
Terminal temperature difference =			2.77	K						

These data were used in determining the enthalpy changes and heat flow rates and for carrying out the pinch analysis using the HINT software. Table 4 shows the stream data from the HINT software.

Table 2: Temperature Pressure and Enthalpy Data for LPH2 from the Turbine HEN

					LPH2					
	Feedwater						**Bleed Steam**			
Stream	**P**	**T**	**h**	**m**	**Stream**	**P**	**T**	**h**	**m**	**Tsat**
	bar	**K**	**kJ/kg**	**kg/s**		**Bar**	**K**	**kJ/kg**	**kg/s**	**K**
					LPT1 port (8)	**1.153**	**638.2**	**2358.7**	**20.19**	
FWH1 drain			**303.5**	**85.08**						
Feedwater in	**20.79**	**613**	**293.7**	**378.2**	**Steam in**	**1.098**	**351.4**	**2356.4**	**20.19**	**375.4**
					Flash back			**438.1**	**46.45**	
Feedwater out	**18.88**	**816**	**418.2**	**378.2**	**Drain to FWH1**	**1.098**	**347.9**	**313.1**	**66.64**	
Terminal temperature difference =				2.77	K					
Drain cooler approach =				5.00	K					

Table 3: Temperature Pressure and Enthalpy Data for LPH3 from the Turbine HEN

LPH3										
	Feedwater					**Bleed Steam**				
Stream	**P bar**	**T K**	**h kJ/kg**	**m kg/s**	**Stream**	**P Bar**	**T K**	**h kJ/kg**	**m kg/s**	**Tsat K**
					LPT1 port (7)	**3.067**	**650.5**	**2486.3**	**22.21**	
Feedwater in	**18.88**	**372.6**	**418.2**	**378.2**	**Steam in**	**2.921**	**405.8**	**2484.0**	**22.21**	**405.8**
					Flash back			**567.2**	**24.23**	
Feedwater out	**17.38**	**403.0**	**546.6**	**378.2**	**Drain to FWH2**	**2.921**	**377.6**	**438.1**	**46.45**	

Terminal temperature difference = 2.78 K
Drain cooler approach = 5.00 K

Table 4: Stream Data of the Plant

Stream	Description of Streams: Hot & Cold	Type	Heat Type	Temperature T1 (K)	Temperature T2 (K)	Heat Load H (kW)	CP= $\dot{m}c_p$ $KW/_K$
1	H1	Hot	Sensible	442.3	294.1	-879.73	5.9361
2	H2	Hot	Sensible	656.6	376.6	-4132.84	14.7601
3	H3	Hot	Sensible	638.2	351.4	-3603.45	12.5643
4	H4	Hot	Sensible	650.5	400.6	-3696.06	14.7902
5	H5	Hot	Sensible	680.6	352.3	-3279.72	9.99001
6	H6	Hot	Sensible	700.3	450.1	-30204.8	120.723
7	H7	Hot	Sensible	750.7	350.4	-10715.4	26.7684
8	H8	Hot	Sensible	800.9	545.8	-5455.88	21.3872
9	C1	Cold	Sensible	513.	613.	87939.3	879.393
10	C2	Cold	Sensible	613.	816.	101244	498.739
11	C3	Cold	Sensible	323.3	324.86	879.73	563.929
12	C4	Cold	Sensible	324.86	330.88	4132.84	686.518
13	C5	Cold	Sensible	330.88	336.12	3603.45	687.681
14	C6	Cold	Sensible	336.12	341.37	3696.06	704.011
15	C7	Cold	Sensible	341.37	346.	3279.72	708.363
16	C8	Cold	Sensible	346.	383.96	30204.9	795.703
17	C9	Cold	Sensible	383.96	397.28	10715.4	804.459
18	C10	Cold	Sensible	397.28	404.04	5455.88	807.083
19	C11	Cold	Sensible	516.	813.	145422	489.636

Composite Curves and Exergy Composite Curves for Hot and Cold Utilities at dTmin = 15K

The composite curves and the exergy composite curves for the hot and cold utilities at a minimum temperature difference of 15K are shown in Figures 2 and 3, respectively.

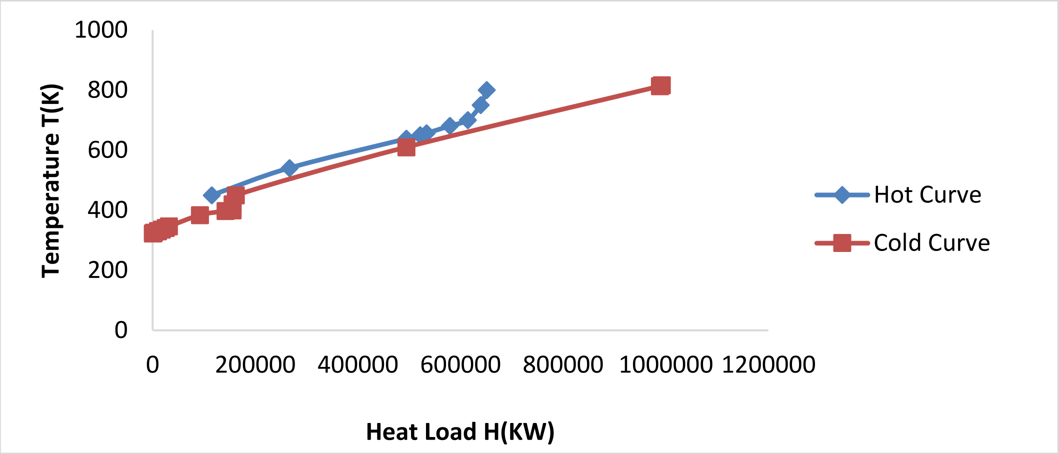

Fig 2: Composite Curves for Hot and Cold Utilities at dTmin = 15K

The temperature difference of 15k is used as the minimum temperature difference between the hot and cold streams considering the base case of the plant and it is at the heat exchanger no. 1, and is equal to an approximate value of 15k. Thus, from the composite curves it can be found that the distance between the last point on the hot stream curve and the first point on the cold stream curve along the heat load (KW) gives the maximum utility values of 248.669MW, while the distance between the first point on the hot stream curve and the last point on the cold stream curve along the heat load gives minimum utility value of 115,955MW.

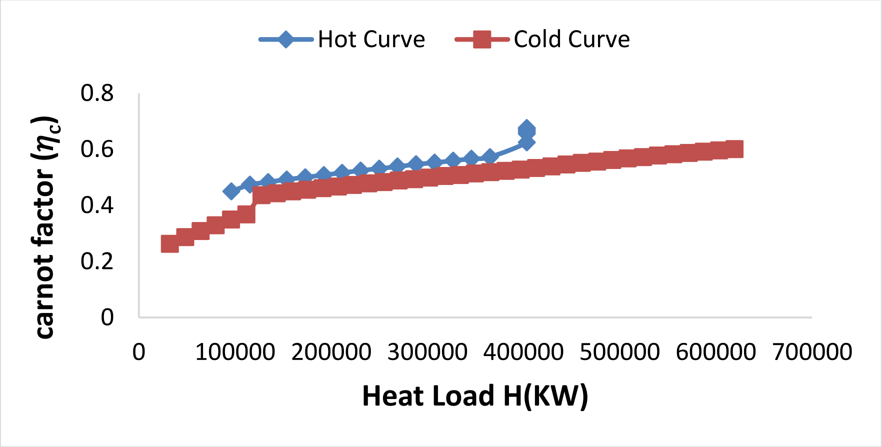

Fig 3: Exergy Composite Curves for Hot and Cold Utilities at dTmin = 15K

In Figure 3, the distance between 0 KW to the first point on the cold stream curve gives an exergy loss of 28.35KW.

EXERGY EFFICIENCY OF THE HEAT EXCHANGER NETWORK

The effect of minimum temperature difference on exergy efficiency of the heat exchanger network in the turbine are shown in Figure 4.

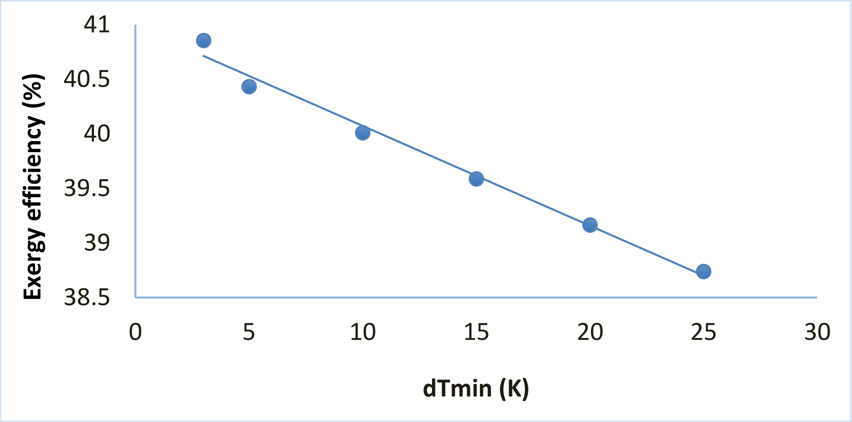

Fig 4: Exergy Efficiency of the Heat Exchanger Network

The results obtained indicate that at minimum temperature difference 15k, the exergy efficiency is 39.59%.

CONCLUSION

This study developed an effective method of evaluating the performance of a steam turbine heat exchanger network using exergy and pinch analysis. Thus, the minimum utility targets for the plant are established.

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