Optimization of Heat Energy Network in a Boiler System Using Pinch Technology

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***Abstract* – The efficiency of the boiler system mainly depends on the effective utilization of the heat produced by the flue gas. As the flue gas temperature approaches saturation temperature of steam, the effectiveness of heat transfer reduces limiting the possibility of the flue gas heat recovery in boiler. This results in higher flue gas temperature and lower boiler efficiency. This problem is solved by using flue gas heat recovery using heat sink like feed water & combustion air. In addition to the flue gas heat, process condensate also provides heat source and need to be utilized in boiler system to increase the efficiency. If these heat sources are not effectively utilized, it can lead to higher stack loss and higher flash steam loss.**

The pinch technology is a modern technology, which can be used to develop an effective heat exchanger network. This technology can be used for the design of optimum heat recovery network for the boiler system. There is possibility to lose the opportunity of substantial heat recovery by using conventional method of heat recovery network design. Pinch analysis can provide insight for the optimum heat recovery from the various heat sources like flue gas & process condensate using various heat sinks like makeup water, feed water & combustion air.

In this paper, a present boiler system is evaluated by using pinch technology for the possibility of additional heat recovery. Flue gas and flash steam provide hot stream and make up water, feed water and combustion air provide cold stream. Enthalpy vs temperature graphs have been plotted for all hot as well as cold streams. Cold & hot composite curves are plotted to identify pinch point. This provides guidance for the designing of heat recovery network. Savings and capital cost are plotted against pinch to identify optimum pinch point. An optimum heat recovery system is designed to maximize the efficiency of boiler system. This heat recovery network is compared with the existing heat recovery system.

***Keywords* – pinch technology; boiler; flue gases; steam; effectiveness; heat exchanger**

I. INTRODUCTION

As the fossil fuel is the major source of industrial energy, depleting reserves of fossil fuel & the impact of fossil fuel combustion on pollution and global warming is a major concern. The efficient generation & utilization of energy play the vital role in the future development of the process industries. As the most of the process plant require both hot & cold utility, process integration plays a major role for the optimum utilization of these utilities. Steam is the most widely used hot utility, efficient generation & utilization of steam is very important for the efficient operation of a process plant. Pinch technology is primarily used to achieve the optimum use of steam but can be extended to achieve the efficient steam generation also. Steam is mainly generated in a steam boiler, which can be defined as the network of heat exchangers involving heat transfer among water, air, steam & flue gas. This heat exchanger network can be optimized by using pinch technology. Pinch technology provides a powerful analytical method for identifying heat recovery solution to improve efficiency of boiler.

Pinch Technology: The pinch analysis is used for the calculation of the minimum heating and cooling requirements for a process and the synthesis of optimum heat exchanger network to chive this goal. Based on thermodynamic principles, pinch technology offers a systematic approach to optimum energy integration in a process. Pinch technology establishes a temperature difference, designated as the pinch point, that separates the overall operating temperature region observed in the process into two temperature regions. Once a pinch point has been established, heat from external sources must be supplied to the process only at temperatures above the pinch and removed from the process by cooling media only at temperatures below the pinch. Such a methodology will maximize the heat recovery in the process with the establishment of a heat exchanger network based on pinch analysis principles. The best design for an energy-efficient heat exchanger network will result in a tradeoff between the energy recovered and the capital costs involved in this energy recovery. The key advantage of pinch technology over conventional design methods is the ability to set an energy target for the design. The energy target is the minimum theoretical energy demand for the overall process.

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

II. BOILER SYSTEM DESCRIPTION

The boiler under consideration is a three-pass fire tube boiler of 10 ton evaporation capacity with an operating pressure of 17.5 Kg/cm^2, and efficiency of 90 %. The fuel used in the boiler is Furnace Oil, having a calorific value of 9650Kcal/Kg. The 60 % of steam generated at the boiler outlet is utilised in the process for indirect heating, where the steam is condensed and condensate is collected at 212^0C. This condensate is collected in a flash tank placed at the outlet of a steam trap of the process heat exchanger. As the condensate cannot remain at a temperature higher than the saturation temperature, a significant portion of condensate heat is released. This heat provides latent heat to the some portion of condensate, which gets converted in to flash steam. This condensate & flash steam is collected in the feed water tank. The following table depicts the data assumed for carrying out the calculations.

Parameter	**Value**
Boiler capacity(Ton)	10
Operating pressure(Kg/cm^2)	10
Mass flow rate of fuel(Kg/hr)	687.61
Calorific value of fuel(Kcal/Kg)	9650
Evaporation capacity(Kg)	5000
Fuel composition	84%C 11%H2 3.5%S 1.5% Moisture
Efficiency of boiler	0.9
Actual mass flow rate of air	11318.67
Make up water	40%
Condensate	60%
Make up water temperature(^{o}C)	30
Condensate temperature(^{o}C)	100
Mass flow rate of make up water(Kg/hr)	3679.79
Mass flow rate of condensate(Kg/hr)	5519.69
Temperature of flash steam(^{o}C)	100
Mass flow rate of flash steam(Kg/hr)	551.969
Mass flow rate of flue gases(Kg/hr)	12006.2829
Flue gas composition	18.317%CO2 5.8876%H2O 0.4162%SO2 75.317%NO2
Adiabatic flame temperature(^{o}C)	1895.8

i. Technical data and operating conditions of boiler

III. SELECTION OF STREAMS FOR AN OPTIMUM COMPOSITE CURVE

In a boiler system there are two hot streams such as, hot streams and cold streams. The hot streams can be classified into two parts: (1). Flue Gases, (2). Flash steam. The cold streams can be divided into 3 parts: (1). Air, (2). Water, (3). Condensate. The details of the streams are given below in the table:

Stream	Stream type	T_start (^{o}C)	T_target (^{o}C)	Heat Capacity (Kw/^{o}C)	Enthalpy (KW)
1	Cold(air)	30	120	3.3012	297.11
2	Cold(water)	30	212.2	4.2796	779.74
3	Cold (condensate)	100	212.2	6.4194	720.25
4	Hot(flue gases)	1895.8	30	3.6018	6720.39
5	Hot(flash steam)	100	100		346.64

ii. Thermal data of the streams

IV. CALCULATIONS FOR COMPOSITE CURVES

For carrying out the pinch analysis, we need to assume some values like starting temperature, target temperature. The equation used for calculating the heat capacity and enthalpy were as follows:

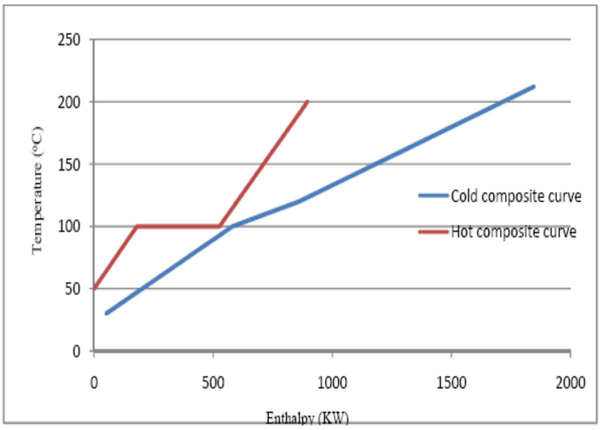
$$Q = m*C_p*D_t \text{ and } Q= H*A*D_t.$$

The data for five streams, i.e. three cold streams and two hot streams were observed and extracted. The first cold stream was air, which was entering the boiler at normal room temperature which is 30°C. And the target temperature up to which it has to be heated is 120°C. The heat capacity and enthalpy were selected as 3.30127 KW/°C and 297.115 KW respectively. The next cold stream selected was water, whose starting temperature was 30°C. And the temperature up to which it was to be heated was 212.2°C. Also the heat capacity and the enthalpy were assumed as 4.2796 KW/°C and 779.74 KW. The third cold stream-condensate water, entering the boiler at boiling temperature of water. The target temperature is 212.2°C. Also the heat capacity was 6.4194 KW/°C, and the enthalpy was taken as 720.25 KW. The flue gases, which are a part of hot stream, enters the system at 1895.8°C. This is the highest temperature of a flue gas in a boiler system theoretically. The target temperature up to which it was to be cooled is 30°C. The heat capacity and the enthalpy are 3.601 KW/°C and 6720.39 KW respectively. The last but an important hot stream is the flash steam, whose starting temperature and target temperature is the latent heat i.e. 100°C. The enthalpy was taken as 346.64°C. Based on the values, enthalpy was calculated for heat exchanger. The values are enlisted in the table shown below:

T1	T2	H1	H2
30	72	100	238.6537
72	120	238.6537329	910.6672
120	140	910.6672104	1124.647
212.2	212.2	1124.647239	8058.687

iii. Enthalpy values

From the above table we can plot a composite curve. In a composite curve, temperature vs. enthalpy curve is plotted for each stream as well as for combination of the streams. The hot stream of the heat exchanger can be cooled up to a certain temperature. This temperature is known as "**approach temperature**". This approach temperature is the minimum temperature difference between the hot and cold stream profiles known as (DT_{min}). The point at which the minimum temperature or DT_{min} is observed is known as pinch point. This pinch point helps us in designing an optimum heat exchanger with minimum energy requirement and maximum efficiency. Composite Curves consist of temperature-enthalpy (T-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. The composite curves provide a counter-current picture of heat transfer and can be used to indicate the minimum energy target for the process. This is achieved by overlapping the hot and cold composite curves, as shown in figure I. , separating them by the minimum temperature difference DT_{min}.



Composite curve

From the above curve, it is determined that the minimum temperature between hot and cold streams ie. Pinch is 7.13°C. Pinch divides the curve in two sections: one below the pinch and one above the pinch. The heat exchanger network is designed accordingly to achieve the heat transfer without violating the pinch principle. This methodology leads to efficient heat recovery which results in increase of efficiency.

V. CAPITAL ENERGY TRADE-OFF

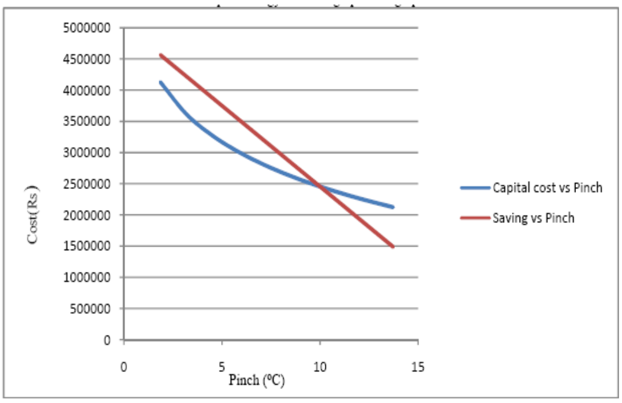
The selection of pinch point is not only based upon the composite curve. The composite curve is used to obtain a rough idea of the pinch point. The pinch point can be selected as low as desired. But it is to be kept in mind that decreasing the pinch point, increases the capital cost. Simultaneously the savings also increase. Hence an optimum pinch point is to be selected, by which we can trade the savings with initial cost of the heat exchangers. Also we need to select a point such that the payback period of the initial cost through the savings is acceptable by the owner. The following table depicts the pinch points for which the savings as well as capital cost will be:

Pinch °C	Recovery KW	Capital cost Rs.	Savings Rs.	Efficiency
1.858156	1267.267004	1835260	5071385	0.021848
3.177264	1257.005271	1606578	4691481	0.020211
4.496372	1246.743538	1453503	4311577	0.018574
5.81548	1236.481805	1337607	3931673	0.016938
7.134589	1226.220072	1244215	3551769	0.015301
8.453697	1215.958339	1166052	3171865	0.013665
9.772805	1205.696607	1098946	2791961	0.012028

11.09191	1195.434874	1040259	2412057	0.010391
12.41102	1185.173141	988211.2	2032153	0.008755
13.73013	1174.911408	941540	1652249	0.007118

iv. Pinch point with savings

From the above table we can obtain a capital energy trade off graph. The graph is as follows:

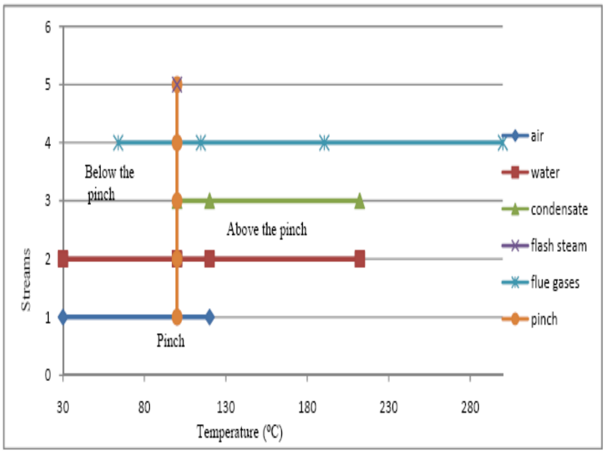


Capital cost Vs. Pinch

Thus, the above graph depicts the optimum pinch point for designing a heat exchanger which gives us a proper payback period. The optimum pinch point obtained is 7.134589 ^{o}C.

VI. HEAT EXCHANGER GRID DIAGRAM

Grid diagram is a systematic method for heat exchanger network design representation. As it is stated above heat exchanger network is designed for below the pinch and above the pinch without cross heat transfer across the pinch.



Network grid diagram

VII. CONCLUSION

By the use of pinch technology, we were able to redesign a heat exchanger network diagram. By changing the heat energy network we were able to reduce the energy losses as well as increase the savings. With the help of calculations done, we selected the optimum pinch point as 7.13459 ^{o}C. If this pinch point was used to design the heat exchanger network diagram, the savings obtained annually were 35, 51,769 rupees. Thus energy can be consumption can be reduced by increasing the savings, in the current energy crisis.

VIII. REFRENCES

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