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Energy saving study on a large steel plant by total site based pinch technology

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ABSTRACT

The total site approach using a "Total Site Profile (TSP) analysis" (based on pinch technology) was applied to a large scale steel plant. And it was confirmed, despite the very high efficiency of the individual process systems of the plant, that there would be a huge energy saving potential by adopting this approach. It became apparent that the available pinch technology tools and techniques lend themselves very well to the analysis of a steel plant. The heat (thermal energy) under 300 °C has previously not been well utilized in steel plants. But TSP analysis was able to identify the distribution and the quantity of such heat, from which energy saving plans could be developed.

1. Introduction

A steel plant consumes a huge amount of energy. Energy saving has been studied for long years by many well-respected, professional engineers and a great deal of equipment has also been introduced to significantly improve energy efficiency (Bisio and Rubatto [1], Chan et al. [2], XU and Cang [3]). These approaches concentrated on the study of individual process systems (Worrell et al. [4]) but a total site approach has previously not been considered.

Pinch technology (Kemp [5]), an analytical methodology, has however been applied in heavy chemical complexes, such as refineries and petrochemical plants, to analyze the heat recovery system with the objective of reducing energy consumption in a plant or a complex of plants. It is well known that engineers in heavy chemical complexes study energy saving, not only by using a single process system approach but also by a total site approach of TSP analysis based on pinch technology. Tian et al. [6] studied the integration approach in a steel plant from the aspect of industrial water saving.

Pinch technology needs and makes use of the data obtained from many heat exchangers in the pressurized system of a heavy chemical complex. However, most of the process systems in a steel plant are operated under atmospheric pressure and originally the concept of using heat exchangers for heat recovery in the steel plant was hardly recognized, despite improved heat recovery systems. On the contrary pinch technology is based on the data obtained from heat exchangers. In order to analyze the heat recovery systems in a steel plant by total site approach, the data equivalent to that obtained for heat exchangers was essentially required. A procedure for the preparation of such data was newly established. It was important for the procedure to analyze and understand how the heat was utilized in each process system. Firstly all the process systems that consumed and recovered the heat were extracted. And then it was confirmed how the heat was transferred to heat and cool the process streams, even without any heat exchanger. After confirmation of the heat balance, each fluid was identified as to whether it was a utility fluid or a process fluid. For TSP analysis, the data of the utility/process fluids in heat exchanging are used, but not the process/process fluids. Thus the procedure was developed to extract adequate heat data for pinch technology analysis. A large steel plant was then studied with the extracted heat data by using the total site approach of TSP analysis.

2. TSP analysis and data

2.1. TSP analysis

In the context of a total site consisting of a number of process plants, the utility system must be understood and optimized. A graphical method, so called site profiles, was first introduced by Dhole and Linnhoff [7] and later Raissi [8]. Klemes et al. [9] considerably extended this methodology to site-wide applications. Heat recovery data for individual processes are firstly converted to grand composite curves (GCCs). GCCs are combined to form a site heat source profile and a site sink profile. These two profiles form total site profiles (TSP) analogous to the composite

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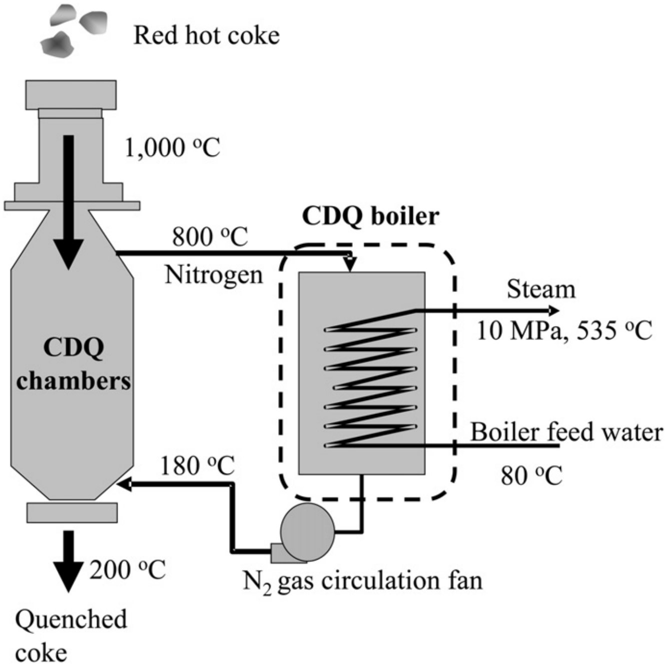

Fig. 1. Coke dry quench (CDQ) unit.

curves for the individual processes. TSP shows the energy and heat utilization profile of the whole plant. TSP analysis can identify the opportunities for inter-process integration via the utility system and the preparation of the appropriate integration strategy. Perry et al. [10] extended the site utility grand composite curve (SGCC). Bandyopadhyay et al. [11] developed the methodology to estimate the cogeneration potential of an overall site through SGCC.

2.2. Steel plant

A large scale steel plant was studied, with an annual production capacity of 8,000,000 tons of crude steel. The plant consisted of a raw material preparation process (coke oven and sintering), an iron making process (blast furnace), a steel making process (converter and continuous casting machine), and a rolling and finishing process (hot and cold strip mill). An adjacent thermal power plant received fuel gas that was a by-product of the steel plant, and generated electricity and heat which were then sent back to the steel plant.

2.3. Data for analysis

Most of the process systems in a steel plant are operated under atmospheric pressure and heat exchangers are not much used despite improved heat recovery systems. It was confirmed how the heat was utilized in each process. Fig. 1 shows a coke dry quench (CDQ) unit, one of the most effective heat recovery systems equipped with a coke oven process. This unit cools the red hot coke from the coke oven process and recovers the heat of the red hot coke. The red hot coke (1000 °C) in the heat recovery system is initially charged into the CDQ chambers (sealed vessels) and the heat is recovered by inert gas (nitrogen), which is heated to about 800 °C. The hot nitrogen is then introduced into the CDQ boiler (waste heat boiler) to produce high pressure steam (HPS). Finally the very high temperature hot coke produces HPS through the nitrogen. There are two heat exchanging systems (Fig. 2) in the CDQ unit. One, the CDQ chambers, treats the heat of the red hot coke and the nitrogen. And the other, the CDQ boiler, treats the heat of the nitrogen and the steam. TSP analysis uses the data of the utility/process fluids in the heat exchangers. In the first exchanger (CDQ chambers), it appeared that the nitrogen is a utility fluid but its operating condition is fixed like that of a process fluid. It was considered that the first heat exchanger treated a process/process fluid and that the data from such exchanger was not suitable for TSP analysis. It was eventually decided to use the data of the second exchanger (CDQ boiler). In this way, all the heat exchanging systems in the steel plant were checked and the input data of the heat exchangers (heaters and coolers) was chosen for TSP analysis.

2.4. Utility conditions

Five utility conditions are used for heaters and three are used for coolers. Utilities for heaters are two kinds of flue gases (FG-H and FG-L), two pressure levels of steam and a steam condensate. FG-H and FG-L are the flue gases at the heating unit and furnaces, which are combusted gases of the by-product gases from the steel plant. Utilities for coolers are two pressure levels of generated steam and a hot water.

3. Results

The “current” column in Table 1 summarizes the utility conditions of heaters and coolers for the current operation case (“current case”) after determination of the appropriate data from the heat exchangers for TSP analysis. There are five utilities for heaters (Table 1a) and three utilities for coolers (Table 1b). The data zero for IPS (intermediate pressure steam) indicates that IPS is not used. In Table 1b, the terms ‘HPS Gen’ and ‘MPS Gen’ were used to differentiate them from mere high and middle pressure steam conditions. For example, HPS Gen means the range from supplied cold boiler feed water (100 °C) up to superheated high pressure steam (10 MPa, 535 °C).

3.1. Current case

Fig. 3 shows the TSP chart which is based on the current data for heaters and coolers as shown in Table 1. The right side of Fig. 3

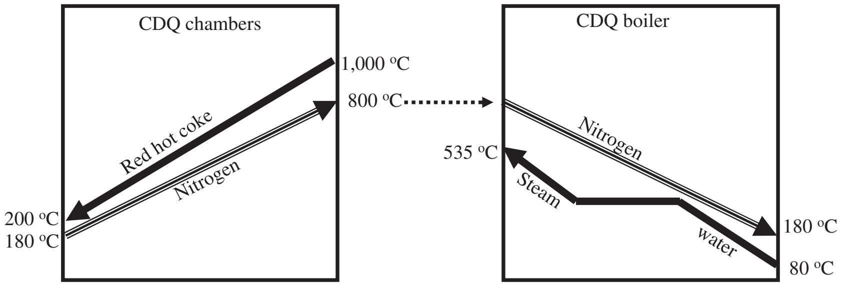

Fig. 2. Temperature–heat diagram of CDQ unit.

Table 1
Utility conditions for heaters and coolers in current and targeting cases.

Utilities for heaters		Current (GJ/h)	Targeting (GJ/h)	Difference (GJ/h)
a				
FG-H (1900–850 °C)	Flue gas at steel material heating	734.4	0.0	−734.4
FG-L (1400–230 °C)	Flue gas at Blast Furnace	1431.9	2070.7	638.8
IPS (235 °C)	Intermediate pressure steam (3 MPa)	0.0	42.4	42.4
MPS (180 °C)	Middle pressure steam (1 MPa)	71.2	11.6	−59.6
LPS (151 °C)	Low pressure steam (0.5 MPa)	49.4	162.2	112.8
STC (140 °C)	Steam condensate	27.6	27.6	0.0
	Total	2314.5	2314.5	0.0
Utilities for coolers		Current (GJ/h)	Targeting (GJ/h)	Difference (GJ/h)
b				
VHPS Gen (100–535 °C)	Very high pressure steam (12 MPa)	0.0	1041.5	1041.5
HPS Gen (100–535 °C)	High pressure steam (10 MPa)	630.1	0.0	−630.1
IPS Gen (80–235 °C)	Intermediate pressure steam (3 MPa)	0.0	31.6	31.6
MPS Gen (90–180 °C)	Middle pressure steam (1 MPa)	350.9	0.0	−350.9
LPS Gen (80–151 °C)	Low pressure steam (0.5 MPa)	0.0	0.0	0.0
HW Gen (76–98 °C)	Hot water	92.1	0.0	−92.1
	Total	1073.1	1073.1	0.0

shows the information of the heaters and the left side shows that of the coolers. It is acknowledged that the heaters duty (2314.5 GJ/h) is almost twice as large as that of the coolers (1073.1 GJ/h). A large scale steel plant consumes a huge amount of energy but only half of the consumed heat is recovered, which means that despite the very high efficiency of the individual processes in the plant, there is a huge energy saving potential. The difference in duty between the heater duty and the cooler duty is considered as unrecovered heat. When the heat recovery technology is significantly improved, the amount of the unrecovered heat will be greatly reduced. There is also a large gap between two composite curves for heaters (heating media and heating demand) as shown on the right side of Fig. 3, which suggests that the lower temperature heating media can be used instead of the present heating media. Simultaneously, due to the large gap between two composite curves as shown on the left side of Fig. 3, the higher temperature cooling media for coolers can be used.

3.2. Targeting case

The targeting case for energy saving was studied by changing the utility conditions for heating and cooling as shown in Fig. 4. For heaters, the present FG-H (1900–850 °C) can be replaced by FG-L (1400–230 °C) because the heating demand level is adequately satisfied by the lower level utility, FG-L. On the other hand for coolers, the present HPS Gen condition causes the large gap from the cooling demand composite curve. It is therefore possible to produce a new utility such as VHPS (very high pressure steam) Gen. The result of the targeting case study is summarized in the "targeting" column of Table 1.

4. Discussion

The process integration in a steel plant was studied by Elfgren et al. [12] using a mathematical programming method. The study was to improve the efficiency of the energy system in the steel plant, a local CHP using process gases from the plant and the district heating system, but it did not consider the total site approach that would make the best use of energy across a large steel plant. The total site approach for a large industrial area was recently studied by Matsuda et al. [13] and a large amount of energy saving potential was identified despite it being a highly efficient process plants. It is important to use the concept of the total site approach in a large steel plant.

4.1. Heater side

In Table 1a, it can be seen that FG-H can be totally replaced by FG-L. This suggests that the original fuel gas of FG-H would not need to be used at steel material heating, but would be able to be sent to an adjacent thermal power plant for power generation (Modesto and Nabra [14], Wang et al. [15]).

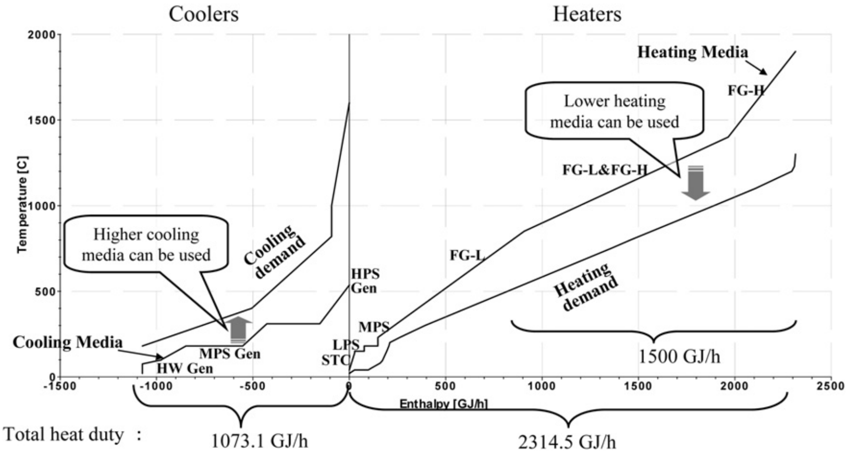

Fig. 3. Current case.

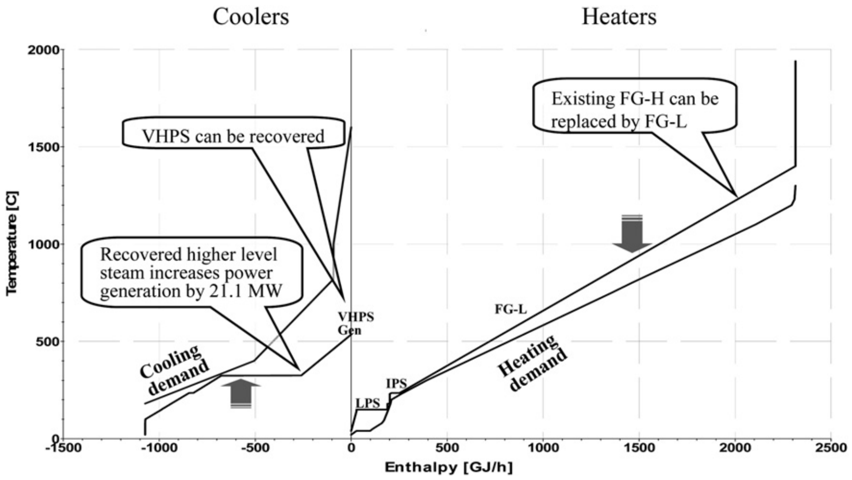

Fig. 4. Targeting case.

A steel plant uses very high temperature heat in large quantities. The heating demand more than 500 °C (approximately 1500 GJ/h read on the right side of Fig. 3) occupies 70% of the total demand (2314.5 GJ/h). The lower level heating media can be used in Fig. 4. Newly installed IPS can be used for a lower part of current FG-L user and LPS can be used for a part of current MPS user. Fig. 5 shows an enlarged view of the heaters on the right side of Fig. 3. Looking at the heating demand under 100 °C, three utilities (MPS, LPS and steam condensate) are used. Their heat duties (71.2, 49.4 and 27.6 GJ/h) are small in the total heat duty (2314.5 GJ/h) in Table 1. But the area heated by MPS can be replaced by LPS, which could lead to power generation increase by 0.6 MW because the thermal pressure drop around a steam turbine generator will be larger when the pressure of the exhaust steam is reduced.

4.2. *Cooler side*

The left side of Fig. 4 (targeting case) and the "targeting" column in Table 1 suggested that new VHPS Gen could be generated in the cooler side, as shown in Table 1b, instead of the present HPS Gen and MPS Gen. The generated VHPS Gen shifted from MPS Gen would be able to produce power generation of 21.1 MW because the suction steam pressure for the steam turbine generator is increased and the thermal pressure drop is increased. However the VHPS Gen shifted from HPS Gen would generate little power increase because their operating conditions are close each other. The current HW Gen will be a preheating part of the IPS Gen.

4.3. *Utilization of un-utilized heat*

Fig. 6 shows an enlarged view of the coolers from the left side of Fig. 3. The heat under 300 °C in Fig. 6 is approximately 330 GJ/h which is now used to produce only HW Gen and a little MPS Gen. But this is not considered to be optimum, suggesting that there would be a large amount of un-utilized heat in the steel plant. It was therefore considered that there was a potential for energy saving. In the case of a single power generation system, Walsh and Thornley [16], who studied ORC (Organic Rankine Cycle) using Benzene at 221 °C, expected that 11% of power generation efficiency could be achieved. In this study, there was a requirement to supply heat of around 150 °C to the reboiler for the CO_2 removal system. The utilization plan of the un-utilized heat was then

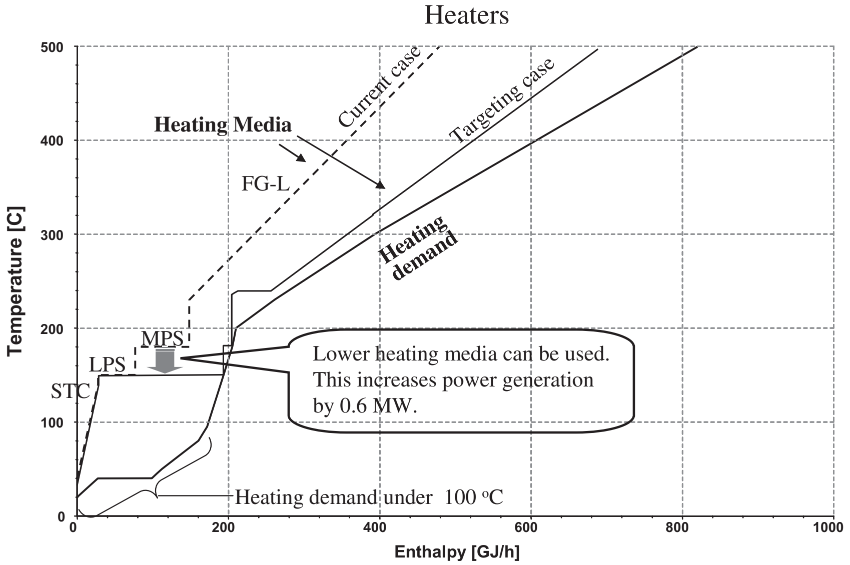

Fig. 5. Enlarged view of heaters.

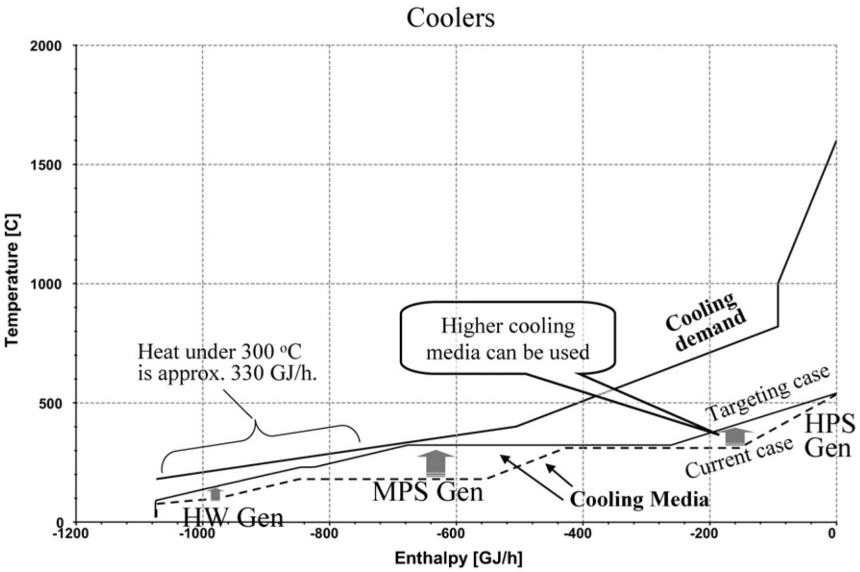

Fig. 6. Enlarged view of coolers.

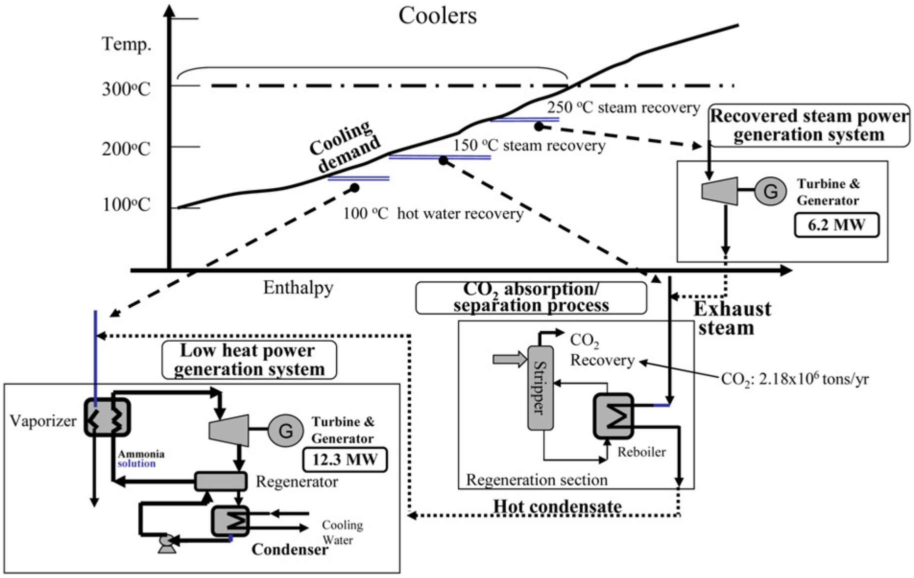

Fig. 7. Combined low grade heat power generation and utilization (under 300 °C).

developed as shown in Fig. 7, which was a combination of power generation and heat utilization. It consisted of three systems. The first was a power generation system (6.2 MW) using recovered steam (approximately 250 °C). The second was to supply exhaust steam (approximately 150 °C) from the above mentioned power generation system to the reboiler in the CO_2 removal system (capacity: 2 million tons of removal CO_2/year). The last was a low heat power generation system (12.3 MW) using highly concentrated NH_3 solution [17] as an operating fluid, exchanged with hot condensate (100 °C) discharged from the reboiler. The power generation efficiency of the low heat power generation system was 8%, but it is well considered to be a good numeric value of the efficiency because the exergy rate at 100 °C is basically small. The cost performance of two power generation systems was roughly estimated in a unit price (investment cost/generated power). The recovered steam generating system is approximately 1000 US$/kW and the low heat power generation system is approximately 3500 US$/kW, with payback periods of approximately two years and seven years respectively. The low heat power generation system itself is expensive due to the efficiency being lower than the recovered steam generating system. In order to improve the economic efficiency the combined system of two power generating systems was studied, in which electric devices were commonly used. The unit price of the combined system was expected to be reduced to about 2600 US$/kW and it is understood that if it were to reach around 2000 US$/kW, its broad use would be encouraged.

5. Conclusion

It was generally believed that there was no further potential for energy saving in a steel plant because almost all energy saving measures thought to be possible had already been developed and introduced. However it became clear that the concept for energy saving studies had been limited only to the individual process systems in the plant. TSP analysis based on the total site approach for a large steel plant was able to identify that there was a large energy saving potential, especially in cooler side (power generation of 21.1 MW). Furthermore the quantity of the heat under 300 °C showed that there was a possibility to develop a combined system of two power generation systems (6.2 MW and 12.3 MW) and a heat utilization system for the removal of CO_2.

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