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A Case Study of Area-Wide Energy Saving for Heavy Chemical Complex in Japan

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Mizushima complex is one of biggest ten heavy chemical complexes in Japan, which has been reducing energy consumption for many years and generally considers that all possible energy saving measures which could be implemented in sites have now already been completed. Conventional thinking and methodology have optimized energy consumption within a single site ("single site approach"), which considers the energy efficiency of the processes and equipment within the site itself. By using this approach, it is difficult to realize any further significant improvements in energy saving within any particular site. Area-wide approach that considers multiple sites a single entity is able to overcome this limitation by the single site approach and achieve further reductions in energy consumption. This case study for Mizushima complex applied the concept of "area-wide approach" using the methodology of "area-wide pinch technology" which had been applied to heavy chemical complexes in Japan. Area-wide pinch technology, consisting of Total Site Profile (TSP) analysis and R-curve analysis, confirmed large energy saving potential within Mizushima complex.

1. Introduction

In recent years there has been a common understanding in Japan that there is little scope for further energy saving reduction in heavy chemical complexes. A heavy chemical plant consists of a process system and a utility system. The utility system provides heat and power for all the process systems. Klemeš et al. (1997) developed and applied the Total Site Approach for energy saving studies in utility systems by using Pinch Technology, but application of this concept was still limited to a single site. This is a single site optimization ("single site approach"), which would optimize the energy efficiency only within the site itself. A fresh approach was therefore required to overcome this limitation and to achieve further improvement. A new concept ("area-wide approach") for area-wide energy saving (Matsuda et al. 2009) was developed using "Area-Wide Pinch Technology" for analysis of energy saving over multiple sites that would be considered together as if they were a single entity. Area-Wide Pinch Technology consists of R-curve analysis and Total Site Profile (TSP) analysis (Wan Alwi et al., 2014). Practical procedure of Area-Wide Pinch Technology is to apply TSP analysis and R-curve analysis separately and simultaneously based on the present operating conditions in sites because the energy saving effort is considered as the first priority in a site. Area-wide energy saving has two aspects such as area-wide heat utilization and area-wide energy efficiency improvement. When looking at the use of heat by the utilities in a site, the steam heaters and reboilers use hot utilities for heating, and coolers and steam generators use cold utilities for cooling.
It is possible to find a large temperature difference between heat supply side and heat demand side. The low-grade heat (around 150 - 200 °C) of process streams is often cooled by coolers and discarded as waste heat, but low-pressure steam (around 130 °C) could be produced from such heat. Middle-pressure steam (200 - 250 °C) is sometimes used for a reboiler but it can be replaced with the lower pressure steam if the process stream requires low level heat (around 110 °C). It is reasonable to surmise therefore, from the above information, that it should be possible to look at the energy saving potential of "area-wide heat utilization" which was identified by TSP analysis. This would make use of heat across a heavy chemical complex by utilizing surplus heat from one or more sites to provide such heat to the others. In this case

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Table 1: Collected heat exchangers in Mizushima complex

Heat exchangers		Block A, 15 sites	Block B, 10 sites	Block C, 10 sites	Total, 35 sites
Heaters	No. of unit	80	154	53	287
	Heat duty, GJ/h	960	3,132	1,370	5,462
Coolers	No. of unit	287	337	80	704
	Heat duty, GJ/h	4,222	8,793	2,488	15,503

study TSP analysis focuses on low-grade heat utilization. And it was considered that if the many utility systems in an entire complex were to be totally integrated, energy efficiency could be improved significantly by area-wide optimization in design and operation. This would be the energy saving potential of “area-wide energy efficiency improvement” which was identified by R-curve analysis. This case study was to apply area-wide pinch technology to Mizushima complex which is one of the biggest ten heavy chemical complexes in Japan and conducted the comparative evaluation to Chiba complex in Japan (Matsuda, 2008).

2. Mizushima heavy chemical complex

Mizushima complex faces onto Mizushima bay in Okayama prefecture, the western Japan. It has thirty-five sites consisting of heavy and chemical industries. Construction in the area first started in the 1950s and it was rapidly developed into one of the nation's leading heavy chemical complexes by the 1960s. The area is divided into blocks A (15 sites), B (10 sites) and C (10 sites), as shown in Figure 1, with canals between the respective blocks. Data was collected from the utility system and 991 heat exchangers, which comprised 287 heaters and 704 coolers as shown in Table 1.

3. Area-Wide Pinch Technology

3.1 TSP analysis

The utility system has to be understood and optimized in the context of a total site that consists of a number of process plants. A graphical method, so called site profiles, was first introduced by Dhole and Linnhoff (1992) and, later, Raissi (1994). Klemeš et al. (1997) considerably extended this methodology to site-wide applications. Heat recovery data for individual processes is 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 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. (2008) extended the Site Utility Grand Composite Curve (SGCC). Bandyopadhyay et al. (2009) developed the methodology to estimate the cogeneration potential of an overall site through SGCC. Ghalami et al. (2012) applied SGCC to demonstrate the potential of energy saving, cogeneration targets and promising modification in the retrofit cases.

3.2 R-curve analysis

The R-curve (Kenney, 1984) provides a target for the efficiency of a utility system converting fuel energy into heat (Q_{heat}) and power (W). The Integrated Energy Efficiency - Eq(1) is defined as a ratio of the useful

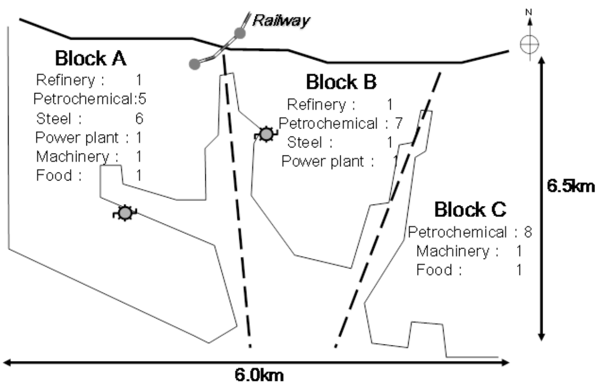

Figure 1: Mizushima complex

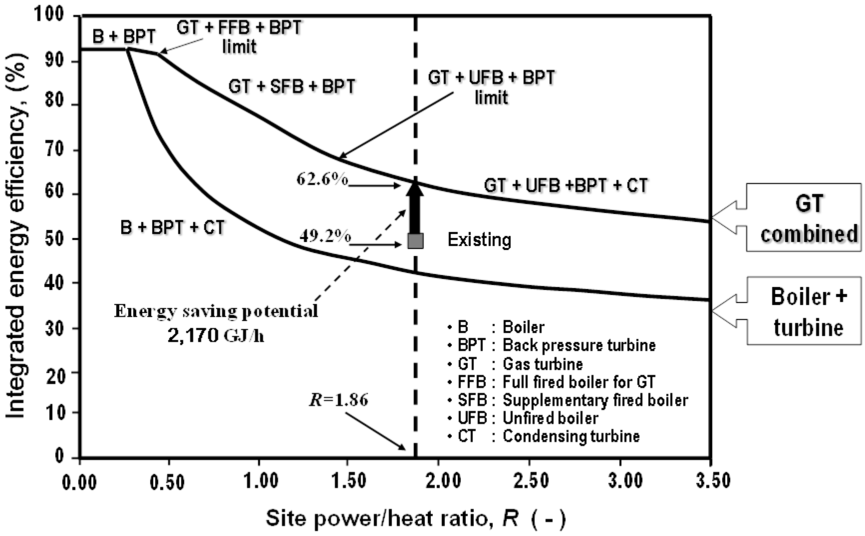

Figure 2: R-curve for block A in Mizushima

part of the energy and integrated energy consumption (Q_{fuel}). The shape of the R-curve is determined by the fact that the production of shaftwork from fuel energy requires a heat sink. In an integrated site, the process plant acts as the heat sink for power generation. The larger the heat demand relative to power demand becomes, the more efficient the overall generation becomes. This is represented by the R-ratio – the ratio of power to heat demand from the process Eq(2) at the operating condition of the site.

Integrated Energy Efficiency = (W + Q_{heat}) / Q_{fuel} (1)

R-ratio (power-to-heat ratio) = W / Q_{heat} (2)

Figure 2 shows the theoretical limit lines for two energy systems. The upper line is the “Gas Turbine combined system”, the lower one is the “Boiler and Turbine conventional system”. For the R-ratio of a given site, the R-curve shows the maximum achievable efficiency. The difference between the current efficiency and maximum efficiency reveals the scope of improvement. R-curves can be constructed for individual sites and the power and heat demand of multiple sites can be combined to determine complex-wide opportunities. Clearly the application of TSP analysis to save thermal energy consumption will interact with the R-curve analysis, as the reduced steam demand will increase the R-ratio.

4. Results

4.1 TSP analysis

TSP analysis combines the heat supply and demand using the heat exchanger data which was shown in Table1. Figure 3 shows the result of TSP analysis for blocks A in Mizushima complex. The right side of the

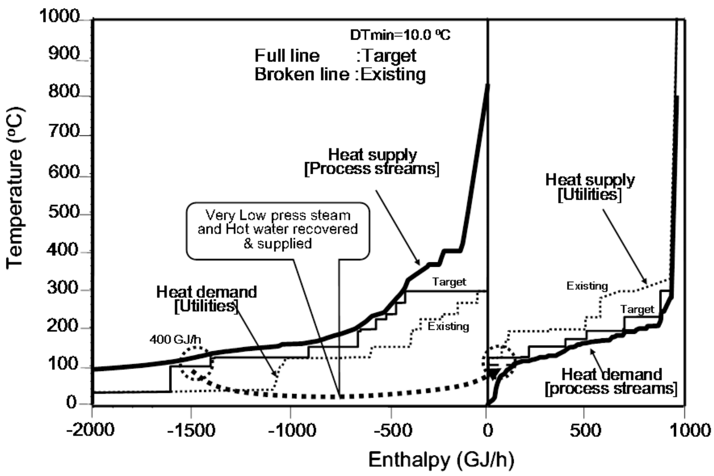

Figure 3: TSP for block A in Mizushima

Table 2: Parameters for R-curve analysis

	Block A, 15 sites	Block B, 10 sites	Block C, 10 sites
W, MW	898	489	143
Q_{heat}, GJ/h	1,740	1,620	700
Q_{fuel}, GJ/h	10,120	6,350	2,000
Integrated energy efficiency, %	49.2	53.2	60.4
Site power / heat ratio (R)	1.86	1.09	0.74

TSP analysis shows the composite curves of the process heating exchangers, such as steam-heaters and reboilers. The left side of the TSP analysis shows the composite curves of the process cooling exchangers, such as steam-generators, cooler and condensers. It was found in Table 1 that numbers of coolers were larger than that of heaters and total heat duty of coolers was also larger than that of heaters. This fact was also described in Figure 3 that the horizontal axis of the left side was longer than that of the right side. In Figure 3 the broken line showed the existing conditions and the full line showed the target conditions. It was found in the left side of Figure 3 that unutilized exhaust heat exists in the region between 100 °C to 120 °C. A combination of very low-pressure steam at 0.02 MPaG (105 °C) and hot water could be recovered. This was equivalent to 400 GJ/h. Recovering this steam and hot water would reduce the consumption of LPS from the utility plant.

4.2 R-curve analysis

Figure 2 shows the result of R-curve analysis for the existing utility consumption of block A in Mizushima complex. For example, in Figure 2, introduction of the ideal gas turbine combined system could increase the integrated energy efficiency from 49.2 % to 62.6 % while maintaining the present heat and power demand. The existing utility system was based on boilers and steam turbines, with small size gas turbines. It could be seen in Figure 2 that the integrated energy efficiency was just over the theoretical curve for a B [boiler] + BPT [back pressure turbine] + CT [condensing turbine] system and was located at the region of GT [gas turbine] + UFB [unfired boiler] + BPT + CT because the R-ratio was 1.86. This suggested that the use and generation of steam was not so efficient because large power demand reduced the efficiency due to the loss of condensing power generation. However the inadequate sizes of gas turbines in the utility plant resulted in an efficiency gap, as the existing point was substantially below the upper line that can be achieved in ideal gas turbine combined systems. The assumptions and parameters for the R-curve analysis are shown in Table 2.

4.3 Theoretical energy saving potential for Mizushima

As a result of the two analyses, it became clear that there was a huge amount of energy saving potential in block A. The results of all three blocks were summarized in Table 3. The theoretical energy saving potential for the whole of Mizushima complex was 1,020 GJ/h by TSP analysis and 5,010 GJ/h by R-curve analysis. Table 3 also shows that no energy saving potential was identified by TSP analysis in block C. It meant that low-grade heat was already being well recovered and utilized. This is because almost all sites in block C were small in energy consumption and many effort for energy saving had been implemented for long years. The conclusion was that optimizing energy use for an entire complex would theoretically yield energy saving potential in total of about 6,030 GJ/h. It was calculated that the annual energy saving potential was 48 × 10^6 GJ by 8,000 h/y. This was equivalent to almost 2 d domestic crude oil consumption in the whole of Japan because the domestic crude oil energy consumption is 23 × 10^6 GJ/d. The result of TSP analysis suggests that recovering un-utilized exhaust heat, such as very low-pressure steam and hot water, could be useful for others to satisfy a part of their heat demand and the result of R-curve analysis suggests that introducing the ideal gas turbine combined system would lift the integrated energy efficiency.

5. Discussions

5.1 Characteristic of Mizushima

Mizushima complex consists of three blocks. In general block A is larger in a size of the site and energy consumption than block B and C from Table 3. However the ratio for the energy saving potential to the integrated energy consumption is 25 % for block A, 45 % for block B and 31 % for block C. This suggested that block A was more advanced to implement the energy saving measures than block B and C. Block C had implemented heat recovery projects for many years but still had a potential to introduce the adequate size of the gas turbine combined system.

Table 3: Energy saving potential in Mizushima

	Block A, 15 sites	Block B, 10 sites	Block C, 10 sites	Total, 35 sites
Integrated energy consumption (heat + power), GJ/h	10,120	6,350	2,000	18,470
Energy saving potential by TSP analysis, GJ/h	400	620	0	1,020
Energy saving potential by R-curve analysis, GJ/h	2,170	2,230	610	5,010
Total energy saving potential, GJ/h	2,570	2,850	610	6,030

Table 4: Comparison to Chiba complex

	Chiba	Mizushima	Mizushima / Chiba
No. of sites	23	35	1.5
Integrated energy consumption (heat + power), GJ/h	13,960	18,470	1.3
Energy saving potential by TSP analysis, GJ/h	640	1,020	1.6
Energy saving potential by R-curve analysis, GJ/h	2,480	5,010	2.0
Total energy saving potential, GJ/h	3,120	6,030	
Domestic crude consumption	1 d	2 d	

5.2 Comparison of two complexes

Chiba heavy chemical complex had been studied by using area-wide pinch technology (Matsuda, 2008). Chiba complex is located on the northeastern coast of Tokyo bay. Cooperation for the study was obtained from a total of 20 companies (23 sites). The development of the area took place during the 1960s and, by the mid-1970s, production of heavy metals and chemicals was the highest of all in Japan's industrial regions. Table 4 summarizes the study result for two heavy chemical complexes, Chiba and Mizushima, and it was found that there was a huge energy saving potential in complexes although both complexes had been considering and implementing the energy saving measures for many years. Table 4 shows that Chiba had 23 sites and its integrated fuel consumption was 13,960 GJ/h. TSP analysis shows it to have a potential 640 GJ/h of energy saving, while R-curve analysis determined that Chiba had potential of 2,480 GJ/h of energy saving. Chiba therefore had the potential to save a total of 3,120 GJ/h of energy, which was equivalent to almost one day's domestic crude oil equivalent consumption in Japan. Table 4 also shows the result for Mizushima. Mizushima's energy saving potential was equivalent to almost two days crude oil consumption in Japan. In comparison, Mizushima had 1.5 times more sites than Chiba but its integrated energy consumption was only 1.3 times larger than Chiba. In contrast, the energy saving potential of Mizushima was almost twice that of Chiba. This led to the conclusion that the equipment in the energy system in Mizushima performed less efficiently than that in Chiba, which was supported by the fact that Mizushima complex was established well earlier than Chiba. For further consideration in Table 4, TSP analysis identifies a large energy saving potential by the low-grade heat utilization. R-curve analysis identifies a gas turbine introduction led to a large energy saving potential by high temperature heat utilization. The result from R-curve was 4 to 5 times larger than that from TSP analysis. It was realized that area-wide energy efficiency improvement could attain much larger energy saving than area-wide heat utilization.

5.3 Area-wide integration project idea

A number of area wide integration project ideas have been identified as a result of this study. One example is shown in Figure 4. This idea was developed from the result of TSP analysis. Site 1 recovered the low pressure steam (LPS) at 0.3 MPaG (140 °C) at one cooling water cooler and three air fin coolers. The recovered LPS was supplied to the reboiler in the adjacent Site 2. The amount in the area-wide energy saving project plan could be 22 GJ/h. The economical evaluation for this idea was expected at around five years in a simple payback period.

6. Conclusion

The case study applied the concept of area-wide approach using the methodology of Area-Wide Pinch Technology to Mizushima complex, one of the biggest heavy chemical complexes in Japan. It was found that there was a huge amount of theoretical energy saving potential in complexes despite the fact that they are very efficient plants and many energy saving measures had been implemented for long years. TSP analysis identified maximization of the heat recovery and developed the new possibility of area-wide heat utilization for low-grade heat. This resulted in proposing the heat sharing system across sites. R-curve analysis identified how much of energy efficiency increases by replacing a steam turbine with a gas turbine and resulted in proposing the energy efficiency improvement system for a whole of sites. The result from R-curve was 4 to 5 times larger than that from TSP analysis. Area-wide energy efficiency improvement was found to be able to attain much larger energy saving than area-wide heat utilization. Area-wide approach to heavy chemical complexes has made it possible to realise further significant reductions in energy consumption that were previously thought difficult to achieve.

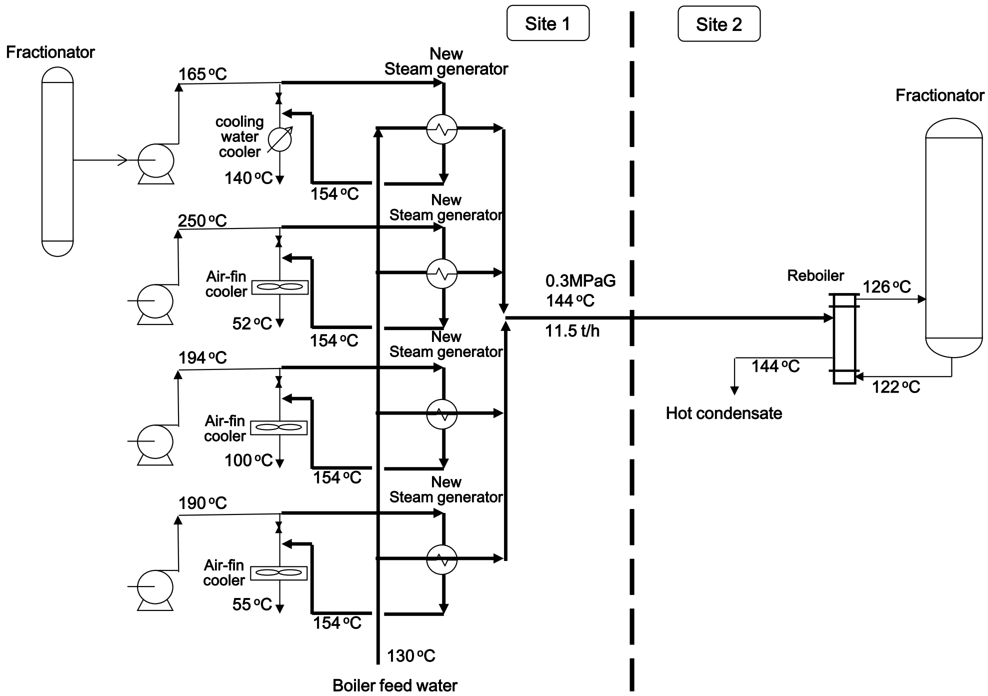

Figure 4: Area-wide energy saving idea

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