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Application of Area-wide Pinch Technology to a Large Industrial Area in Thailand

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Area-wide pinch technology, consisting of R-Curve analysis and Total Site Profile (TSP), was applied to one of the biggest heavy chemical complexes in Thailand, Map Ta Phut industrial area. This study demonstrates that despite the recently-developed heavy chemical complex being highly efficient in energy consumption, a huge amount of energy, potentially, can be saved through energy sharing among the various sites. A mid and long term plan for area-wide energy saving has been developed on this basis.

1. Introduction

Oil refineries, petrochemical and chemical plants that have been constructed recently in the heavy chemical complexes of south east Asia are considered not to have potential for any further energy saving because their designs have been optimised for energy efficiency. However conventional designs for energy saving were based on the concept of a single site optimisation ("single site approach"), which would optimise the energy efficiency only within the site itself. 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. It has often been thought that all possible energy saving measures in heavy chemical sites within complexes had already been studied and implemented. A fresh approach was therefore required to overcome this limitation and to achieve further improvement. A new concept of area-wide energy saving ("area-wide approach") was developed using "Area-Wide Pinch technology" (Matsuda et al. 2009) for analysis of energy saving over multiple sites that would be considered together as if they were a single entity. Area-wide Pinch technology, consisting of R-Curve analysis and Total Site Profile (TSP) analysis (Hackl and Harvey, 2012) and extended by Nemet et al. (2012), was applied to one of the biggest heavy chemical complexes in Thailand, Map Ta Phut industrial area, which has been developed over the past 20 y,

2. Area-wide Pinch technology

R-Curve analysis and TSP analysis were applied independently to Map Ta Phut Industrial area.

2.1 R-Curve analysis

The R-Curve provides a target for the efficiency of utility system converting fuel energy into heat (Q_{heat}) and power (*W*). The Integrated Energy Efficiency (Eq.1), which is the fuel utilization efficiency, is defined as a ratio of the useful part of the energy and integrated energy consumption (Q_{fuel}). The shape of the R-Curve is determined by 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, 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

$$\text{Integrated Energy Efficiency} = (W + Q_{heat}) / Q_{fuel} \tag{1}$$

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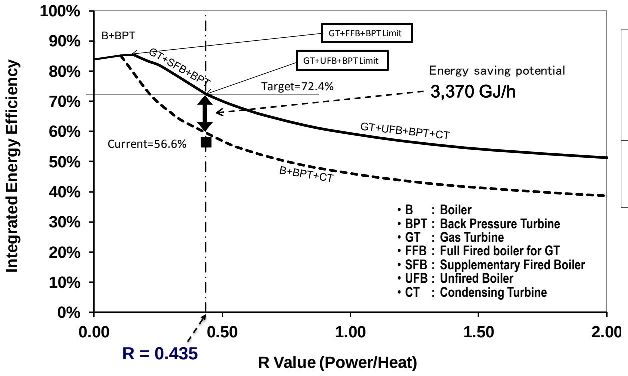

Figure 1: R-Curve analysis

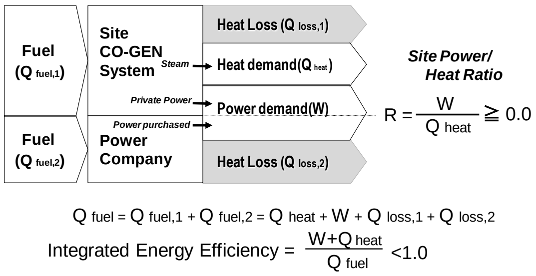

Figure 2: Two key parameters in R-Curve analysis

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

Figure 1 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” and Figure 2 illustrates graphically the definition of the two key parameters. 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 demands of multiple sites can be combined to determine complex-wide opportunities. Clearly the application of Pinch technology to save thermal energy consumption will interact with the R-Curve analysis, as the reduced steam demand will increase the R-ratio.

2.2 TSP analysis

The utility system must be understood and optimised 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 further developed by Raissi (1994). Klemeš et al. (1997) 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 Curves for the individual processes. TSP shows the energy and heat utilisation 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.

Table 1: Collected heat exchanger data

	Number	Heat duty
Heater	352	7,670 GJ/h
Cooler	639	10,148 GJ/h

Table 2: Parameters for R-Curve analysis

W , kW	733,279
Q_{heat} , GJ/h	6,067
Q_{fuel} , GJ/h	15,392
Integrated energy efficiency, %	56.6
Site Power/heat ratio (R)	0.435

3. Map Ta Phut industrial area

Map Ta Phut industrial area, located 190-kilometer southeast from Bangkok, was founded in 1990. This study covered 15 sites, each within 5 km distance of each other in the centre of Map Ta Phut industrial area. The sites consisted of a refinery, chemical plant, gas separation facility, and a utility company. Data were collected from the sites regarding the utility system and 991 heat exchangers, as shown in Table 1. It should be noted that the utility company does not have any utility heat exchanger.

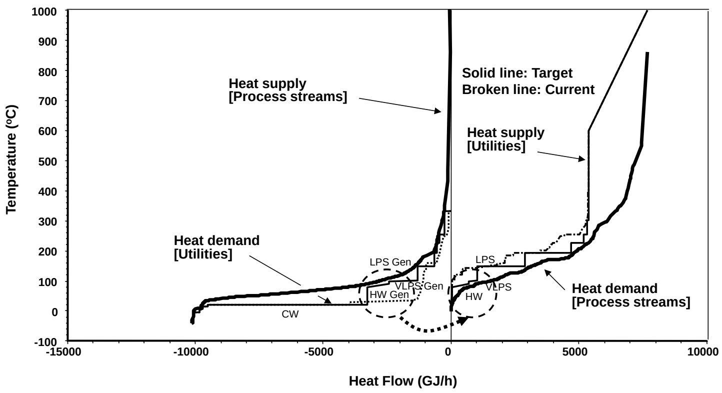

Figure 3: TSP analysis

4. Results

4.1 R-Curve analysis

Utility systems are mostly based on boilers and steam turbines, with gas turbines in sites, but all heat and power in some sites is provided by a utility company. Figure 1 shows the result of the R-Curve analysis of the existing utility consumption in Map Ta Phut industrial area, and that the utilities efficiency is close to the theoretical curve for a B[boiler] + BPT[back pressure turbine] + CT[condensing turbine] system, which suggests that the generation and use of steam is quite efficient. However the inadequate size of the gas turbines in the utility systems results in an efficiency gap as the B+BPT+CT line is significantly below the upper line that can be achieved in a gas turbine [GT] combined system. Introduction of the ideal "gas turbine combined system" could increase the integrated energy efficiency from 56. 6% to 72.4 % while maintaining the present heat and power demands. This saving potential is equivalent to 3,370 GJ/y. The assumptions and parameters for the R-Curve analysis are shown in Table 2. The R-Curve target is based on a newly installed gas turbine combined system generating 4.3 MPaG steam matching existing HPS conditions. This is because at the R-ratio in question there would be no necessity for supplementary firing.

4.2 TSP analysis

TSP analysis combines the heat supply and demand using the heat exchanger data. Figure 3 shows the result of the TSP analysis for Map Ta Phut industrial area. The right side of the TSP shows the Composite Curves of the process heat exchangers, such as steam-heater and reboiler. The left side of the TSP shows the Composite Curves of the process cooling exchangers, such as steam-generator, cooler and condenser. It was found that unutilised exhaust heat exists in the region between 100 ^oC to 200 ^oC. Two kinds of energy saving potential were identified as shown in Table 3; (1) Recovery of low-pressure steam at 0.5 MPaG equivalent to 174.5 GJ/h. (2) A combination of very low-pressure steam at 0.1 MPaG and hot water can be recovered, as shown at the left side of Figure 3 and Table 3. This is equivalent to 979.8 GJ/h and 847.6 GJ/h. Recovering this steam and hot water reduce the consumption of low-pressure steam (LPS) from the utility plant. A combined 2,001.9 GJ/h of energy can be saved by the heat recovery.

4.3 Improvement of heat recovery potential

Table 3 shows the utility conditions of heaters and coolers for the current operation case ("current case") and the targeting operation case ("targeting case"). In the whole of the industrial area, there are many kinds of utility conditions for the current case, but some adjacent utility conditions are put together as being representative for analysis. For example, FG in Table 3a consists of two flue gases (1,000 - 600 ^oC and 350 - 200 ^oC) and two hot oils (320 - 270 ^oC and 285 - 200 ^oC). It was considered in this instance that the hot oils should be included in FG for the current case because they were heated by flue gas. When targeting for energy saving, FG was defined at 1,000 - 600 ^oC because it would be used for heating the process fluids at more than 300 ^oC. For energy saving, the lower temperature regions (320 - 200 ^oC) of the FG could be replaced with high-pressure steam (HPS) and intermediate-pressure steam (IPS). Eventually an energy saving potential of 707 GJ/h could be expected in the FG.

Table 3: Utility conditions for heaters and coolers

a Utilities for Heaters	Current (GJ/h)	Targeting Utility conditions	Targeting (GJ/h)	Difference (GJ/h)
FG: Flue gas	3006.7	1000-600 °C	2299.7	707.0
HHPS: High high-pressure steam	38.6	8.7 MPaG, 301 °C	38.6	0.0
HPS: High-pressure steam	700.0	4.3 MPaG, 255 °C	131.6	568.4
IPS: Intermediate-pressure steam	215.2	2.6 MPaG, 226 °C	514.6	-299.3
MPS: Middle-pressure steam	1650.6	1.4 MPaG, 194 °C	1776.4	-125.8
LPS: Low-pressure steam	1914.6	0.5 MPaG, 148 °C	1880.4	34.1
VLPS: Very low-pressure steam	102.0	0.1 MPaG, 100 °C	324.8	-222.8
HW: Hot water	0.2	90-80 °C	661.8	-661.6
STC: Steam condensate	38.7	52-25 °C	38.7	0.0
Total	7,666.5		7,666.5	0.0

b Utilities for Coolers	Current (GJ/h)	Targeting Utility conditions	Targeting (GJ/h)	Difference (GJ/h)
VHPS Gen: Very high pressure steam	208.8	13.2 MPaG, 332 °C	259.8	51.0
HPS Gen: High-pressure steam	303.3	4.3 MPaG, 255 °C	208.3	-95.0
IPS Gen: Intermediate-pressure steam	0.0	2.6 MPaG, 226 °C	70.0	70.0
MPS Gen: Middle-pressure steam	78.1	1.4 MPaG, 194 °C	96.8	18.7
LPS Gen: Low-pressure steam	490.2	0.5 MPaG, 148 °C	664.7	174.5
VLPS Gen: Very low-pressure steam	141.9	0.1 MPaG, 100 °C	1,121.7	979.8
HW Gen: Hot water	0.0	80-90 °C	847.6	847.6
CW: Cooling water	8,288.0	20 °C	6,241.4	-2046.6
Total	9,510.3		9,510.3	0.0

Table 4: Summary of energy saving potential

Industrial area	Map Ta Phut	Chiba in Japan	Map Ta Phut/ Chiba
No. of sites	14	23	0.6
Integrated energy consumption	15,400 GJ/h	13,950 GJ/h	1.1
Theoretical energy saving potential by R-curve analysis	3,370 GJ/h	2,470 GJ/h	1.4
Theoretical energy saving potential by TSP analysis	880 GJ/h	630 GJ/h	1.4
Total	4,250 GJ/h	3,100 GJ/h	1.4

4.4 Amount of theoretical energy saving potential

R-Curve analysis can evaluate the efficiency of an energy system and TSP analysis can evaluate the possibility of recovering the waste heat. The results of the two analysis techniques showed in Table 4 that the theoretical amount of energy saving was 3,370 GJ/h by R-Curve analysis and 880 GJ/h by TSP analysis. The summation (4,250 GJ/h) was equivalent to a 28 % reduction in the integrated energy consumption (15,400 GJ/h) in the whole of the industrial area. In other words, total heat integration of all the sites would enable further energy saving, which could reduce current energy consumption by 28%, even though almost all energy saving measures thought to have been possible had already been introduced to those sites.

4.5 Area-wide integration plan

A number of area wide integration project ideas have been identified as a result of this study. One example is shown in Figure 4. Site A had a gas turbine, boilers and turbines. Site B did not have any boiler and turbine, but imported steam. Both sites wanted to increase the energy efficiency. An area-wide integration was proposed; 1) Increase the gas turbine operation load to produce the additional power (8 MW) and steam (120 t/h). 2) Install a new extraction back-pressure turbine generator (EBTG) to produce the power (21 MW). 3) Stop the condensing turbine to avoid the condensing loss. 4) Supply steam (133 t/h) from site A to site B. 5) Supply power (21 MW) from the EBTG in site A to site B. 6) Install a new boiler turbine generator to produce power (2 MW). 7) Reduce the steam import by 133 MW. Eventually this plan will achieve an energy saving of 188 GJ/h.

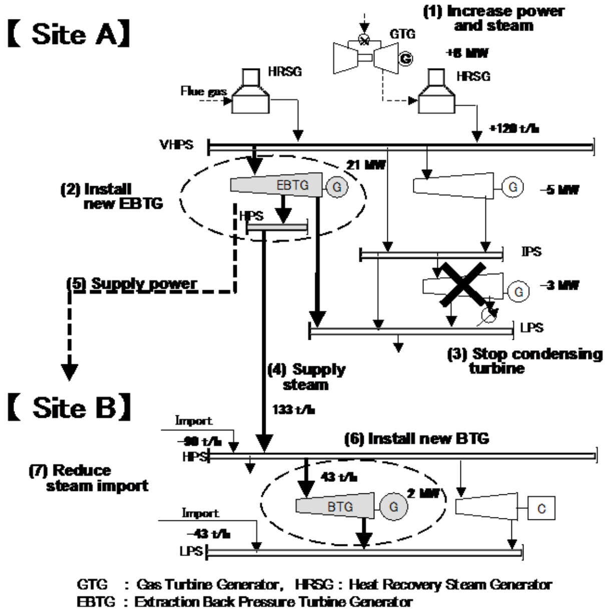

Figure 4: Area-wide integration plan

5. Discussions

5.1 Improved heat recovery (heater and cooler sides)

The left side of Figure 3 (targeting case) and the “targeting” column in Table 3 suggested very low-pressure steam (VLPS) Gen and HW Gen could be increased by 979.6 and 847.6 GJ/h in the cooler side, as shown in Table 3b. Table 3a shows that VLPS and HW were increased by 222.8 and 661.6 GJ/h in heater side and those increments were compensated sufficiently by the recovered VLPS Gen and HW Gen from cooler side.

5.2 Energy saving potential

As shown in Table 4, area-wide Pinch technology was used to study energy saving for two industrial areas, Chiba (Matsuda, 2008) and Map Ta Phut, where a huge energy saving potential was discovered to exist in heavy chemical industrial areas. Map Ta Phut industrial area has 14 sites (a utility company is not taken in account) and Chiba has 23 sites. Although the number of sites in Map Ta Phut industrial area is lower than that in Chiba, the integrated fuel consumption in Map Ta Phut industrial area was 1.1 times larger than Chiba and its theoretical energy saving potential from R-Curve and TSP analyses was 1.4 times larger. This led to the conclusion that although the plant capacity in Map Ta Phut industrial area was larger, and the recently-developed facilities had been thought to be highly efficient, Chiba, which had been established in the 1970s, had been accumulating energy saving measures through many years of effort. For further consideration in Table 4, the R-Curve analysis demonstrated that the introduction of a gas turbine led to a large energy saving potential by utilisation of high temperature heat. The result from the R-Curve was 4 times larger than that from the TSP analysis. It was realised from the TSP analysis that improvement in area-wide energy efficiency could attain much larger energy saving than utilisation of area-wide low-grade heat.

5.3 Mid and long term plan

This study targeted the development of collaborative energy saving ideas among sites (area-wide integration), such as improving energy efficiency by integrating the utility system and surplus heat sharing across the sites. In total, 17 ideas for collaborative energy saving projects were developed, including 13 ideas from the result of R-Curve analysis and 4 from the TSP analysis. The mid and long-term plan for energy saving was then studied based on the 17 ideas above, which comprised a roadmap on how to implement the practical ideas one by one and avoid dual investment. Finally 9 ideas are chosen for the mid and long term plan, which confirmed that there was 1,226 GJ/h of further energy saving potential (29 % of the theoretical energy saving potential) in the whole of the industrial area and that the overall payback period of the roadmap was less than 5 y. When trying to achieve an area-wide integration plan, several obstacles could arise, such as operability, controllability and philosophy in operation. However it is possible to solve them with forthright and comprehensive discussions among the relevant site owners.

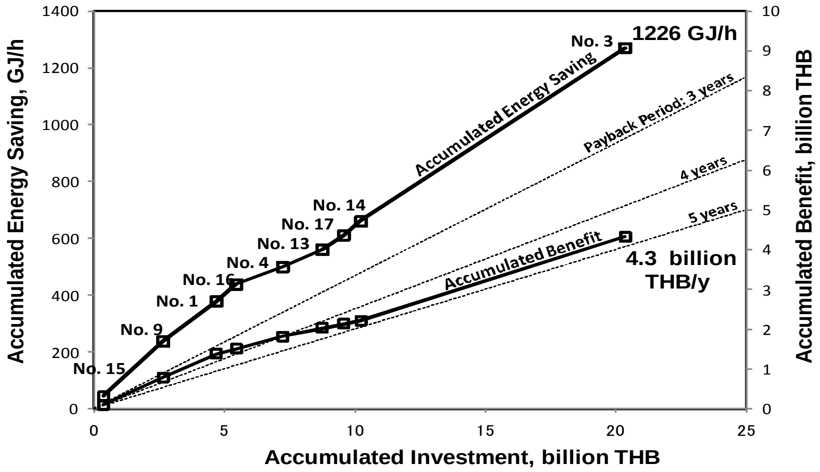

Figure 5: Mid and long term plan

6. Conclusion

“Area-wide Pinch technology" is shown to be useful for identifying the area-wide energy saving potential, even for very efficient process plants. Applying the appropriate set of techniques will allow very large and complex sites to be successfully analysed. It was found that there is a huge amount of theoretical energy saving potential, 28 % reduction of the current energy consumption, in Map Ta Phut industrial area. One area wide integration project has been shown from the result of this study. A mid and long term plan for area-wide energy saving was also developed and its energy saving potential which is equivalent to 29 % of the theoretical energy saving potential could be expected. Therefore applying “Area-wide Pinch technology” is confirmed as a practical approach for large industrial areas.

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