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Applying heat integration total site based pinch technology to a large industrial area in Japan to further improve performance of highly efficient process plants

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ABSTRACT

"Area-wide pinch technology" which consists of R-curve analysis and Site Source Sink Profile (SSSP) analysis, was applied to Kashima industrial area, one of the biggest heavy chemical complexes in Japan. This case study demonstrates that despite the very high efficiency of the individual sites in the complex, there is a huge amount of energy saving potential through energy sharing among the various sites. In addition it was found that appropriate use of the available pinch technology tools and techniques allows an industrial area of enormous scale and complexity to be analysed conveniently. This has resulted in practical area-wide energy saving projects being proposed and implemented.

1. Introduction

In the 1980s, Linnhoff et al. [1] introduced the concept of "target before design" using pinch technology for the design of individual processes. Pinch technology for Heat Exchanger Network (HEN) design was developed by Linnhoff and Hindmarsh [2]. Linnhoff and Ahmad [3], Ahmad et al. [4] evolved the methodologies to incorporate total cost targeting and block-decomposition based HEN synthesis. Later an HEN retrofit framework, based on the "process pinch" (Tjoe and Linnhoff [5]) and "network pinch" (Asante and Zhu [6]) concepts was established.

Over time pinch technology has been applied to increasingly large and complex sites. To facilitate this, a variety of tools and techniques have been developed to enhance the methodology and simplify the analysis. This case study considered one of the largest energy consuming areas yet subjected to "Area-wide pinch technology". The above-mentioned developments provide the background to the successful application of pinch technology to Kashima Industrial area.

In the context of the total site consisting of a number of process plants, the utility system must be understood and optimised. A graphical method, so called site profiles, was first introduced by Dhole and Linnhoff [7] and later extended by Raissi [8]. Klemes et al. [9] considerably extended this methodology to site-wide applications. Data for individual process heat recovery are first 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 (SSSP) analogous to the composite curves for individual processes. 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.

However, the construction of the total site profiles using the above method is difficult since a large amount of data is required. In addition, the constraints for an existing system are not taken into account, which often leads to impractical projects. To overcome these limitations top-level analysis was developed by Makwana et al. [12]. This method analyses existing total site utility systems in terms of current performance and the potential scope for improvement.

Subsequently, a method for analysing and optimising energy systems was developed by Kimura [13]. This method builds on the concepts of R-curve by Kenney [14] and top-level analysis by Makwana et al. [12]. The R-curve analysis method was further developed by Kimura and Zhu [15] to determine the most economic modifications to existing utility systems. The R-curve provides

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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 utilisation efficiency, is defined as a ratio of the useful part of energy and the integrated energy consumption (Q_{fuel}). The shape of the R-curve is determined by the fact that the production of shaft work 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.

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

$$\text{R-ratio(power-to-heat ratio)} = W/Q_{heat} \tag{2}$$

Fig. 1 shows the theoretical limit lines for two energy systems. One is "Gas turbine combined system" and the other is "Boiler and Turbine conventional system" and. Fig. 2 illustrates graphically the definition of the two key parameters.

For a given site R-ratio, the R-curve shows the maximum achievable efficiency. The difference between the existing efficiency and maximum efficiency reveals the scope of improvement. R-curves can be built up 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 reduced steam demand will increase the R-ratio.

In the conventional approach R-curve analysis is applied on the condition of the defined minimum energy requirement balance. This approach is required to determine the ultimate energy saving potential in the area-wide integration.

To perform a fully rigorous complex wide assessment requires process optimisation of each individual plant using pinch technology analysis with the resultant SSSP profiles being used to optimise the utility system and provide the basis for the R-curve analysis. This would require a very large amount of data collection and pinch analysis work.

In this study, the more practical "Grey Box Approach" (Brown [16]) was utilised. The individual sites have already been subjected to many efforts to improve energy efficiency and are believed to be among the most efficient in the world. Therefore modification of heat recovery within the individual processes was not proposed. Instead the heat exchangers of the Process–Utility interfaces (e.g. heaters, coolers and steam generators) were used to generate the SSSP curves. These curves were used as an aid to develop practicable energy saving project ideas.

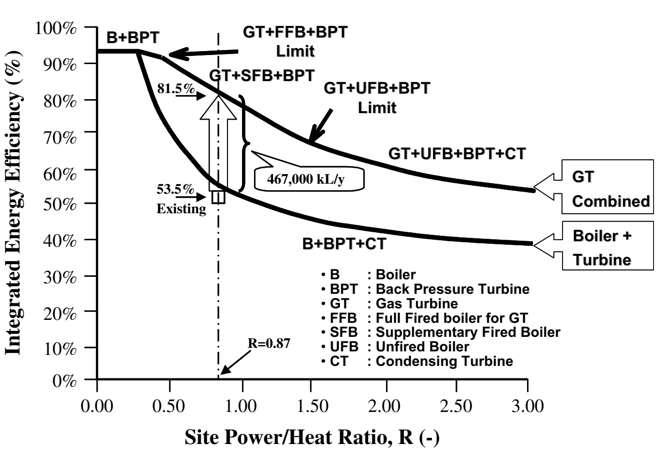

Fig. 1. R-curve analysis for block A.

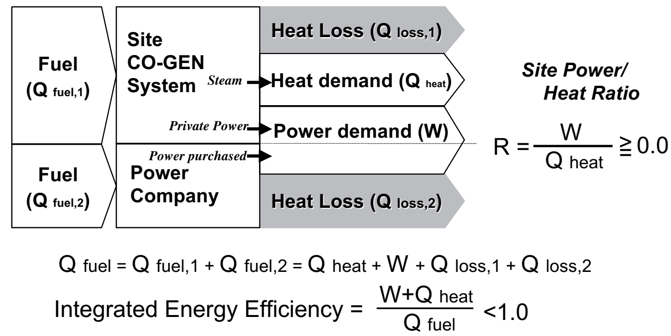

Fig. 2. Two key parameters in R-curve analysis.

R-curve analysis was used for analysing the utility system in its present condition and estimating the amount of theoretical energy saving potential. In future, if the area heat-sharing project is realised or the demand of heat and power varies, re-analysis will be required to assess the energy saving potential based on the new conditions.

R-curve analysis and SSSP analysis have been applied independently to Kashima Industrial area, one of the biggest heavy chemical complexes in Japan.

2. Kashima industrial area

Kashima industrial area is located 90-kilometer northeast from Tokyo. It has thirty-one sites consisting of process industries including petrochemical, refinery, power company, etc. as shown in Fig. 3. The area is divided into block A (17 sites) and block B (14 sites). There are north and south joint thermal power plants supplying heat and power to all the sites in both blocks. Therefore, the individual sites don't have any boiler and gas turbines.

Data were collected regarding the utility system and 1067 heat exchangers including 390 heaters and 677 coolers, as shown in Table 1. There are various utility conditions in blocks A and B, which are tabulated in Table 2.

3. Results

3.1. SSSP analysis

SSSP analysis combines the heat supply and demand using the heat exchanger data. The right side of SSSP shows the composite curves of the process heating exchangers, such as steam-heater and reboiler. The left side of SSSP shows the composite curves of the process cooling exchangers, such as steam generator, cooler and condenser. Fig. 4 shows the result of SSSP analysis for block A. It was found that unutilised exhaust heat exists in the region between 100 °C and 150 °C. Two kinds of energy saving potential were identified; (1) Recovery of Low Pressure Steam at 0.3 MPaG equivalent to 38,300 kL/y (annual crude oil equivalent) [1.5×10^6 GJ/y]. (2) A combination of very Low Pressure Steam at 0.1 MPaG and hot water can be recovered as shown in left side of Fig. 4. This is equivalent to 26,700 kL/y [1.0×10^6 GJ/y]. Recovering this steam and hot water will reduce utility consumption of Low Pressure Steam (LPS) from the utility plant. Combined there is 65,000 kL/y [2.5×10^6 GJ/y] of energy saving potential by the heat recovery in block A.

Fig. 5 shows the result of SSSP analysis for block B. Again, two kinds of energy saving potential were identified; (1) Recovery of