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Comparative study of energy saving potential for heavy chemical complex by area-wide approach

Kazuo Matsuda*

Chiyoda Corporation, 4-6-2 Minatomirai, Nishi-ku, Yokohama, 220-8765, Japan

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ABSTRACT

The thought of single site approach for energy saving in a site has been evolved to that of area-wide approach which considers multiple sites together as if they were a single entity. In area-wide approach, R-curve analysis plays an important part to evaluate the energy efficiency of the site utility system for utilizing high temperature heat, which is possible to identify energy saving potential and understand the characteristics of the utility system. R-curve analysis was applied to Mizushima complex, one of the ten largest heavy chemical complexes in Japan, and identified the characteristics and the energy saving potential for the whole of the complex. In area-wide approach, low-grade heat utilization for energy saving is also important. Total site profile analysis was used to evaluate the possibility of low-grade heat utilization. Mizushima complex was evaluated for the characterization by comparison of its energy saving potential to that of another heavy chemical complex, Chiba. It was found that the energy saving potential of Mizushima complex was twice in R-curve analysis than that of Chiba complex. This meant that the equipment in the utility system in Mizushima complex performed less efficiency than that in Chiba complex.

1. Introduction

It is very important for a site to improve energy efficincy for cost reduction, strengthening international competitiveness and environmental protection. Japanese sites have made continuous efforts to implement energy saving measures for many years and one can say that all conceivable measures have been adopted and already completed. This is, however, the case by the so-called single site approach which optimizes the energy efficiency only within one site. For further energy saving, the concept of area-wide approach is used and it has been applied to some heavy chemical complexes (Matsuda et al. [1]). Area-wide approach sees multiple sites, such as heavy chemical complex, that would be considered together as if they were a single entity by focusing on the utility system and utility heat exchangers because heat and power of utility are universally used for sites. Conducting area-wide approach employs two analyses which are R-curve analysis and Total site profile (TSP) analysis.

R-curve analysis plays very important part to evaluate the energy efficiency of the site utility system, which is possible to identify energy saving potential and understand the characteristics of the utility system. In the theory of heat cascading utilization, R-curve analysis assesses the possibility to utilize the high temperature heat which is generated from fossil fuels and TSP analysis assesses the possibility of the low-grade heat utilization which is unused heat.

The utility system provides heat and power for all the process systems in a site. Kenney [2] developed the R-curve concept of "fuel utilization curve" to evaluate the energy efficiency for the cogeneration plant. Makwana et al. [3] developed "top-level analysis" for existing total site utility systems. Kimura [4] developed the analytical method for optimization of utility systems by extending the concepts of fuel utilization curve and top-level analysis. Kimura and Zhu [5] developed the R-curve concept for the most economical modifications to existing utility systems. Manesh et al. [6] introduced the R-curve concept for optimal design of a LNG cogeneration plant. Based on the R-curve concept, Navid et al. [7] developed the environmental impact analysis for cogeneration system, Abdalisousan et al. [8] optimized thermal combined cycle gas turbine power plant with the total exergetic efficiency and Keçebaş et al. [9] evaluated the geothermal district systems.

On the other hand, Dhole and Linnhoff [10] and Raissi [11]

* Permanent address: 2-7-28 Ryoke, Izumi-ku, Yokohama, 245-0004, Japan.
E-mail address: ghg.matsudakazuo@gmail.com.

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introduced a graphical method with site profiles. Klemes et al. [12] extended this methodology to site-wide applications. Wan Alwi et al. [13] proposed a Stream Temperature vs. Enthalpy Plot (STEP) method showing pinch point to simultaneously target the multiple utilities and perform heat allocation between the utilities and the individual process streams. Sun et al. [14] applied the STEP method for cost targeting that considered different types of heat exchangers. Boldyryev and Varbanov [15] applied TSP analysis to the bromine production site to estimate energy saving potential. Chew et al. [16] maximized energy saving in total site heat integration by the Plus Minus Principles on TSP concept. Liew et al. [17] developed the extended total site problem table algorithm to target the minimum utility requirements in a steam system that considers the water sensible heat. Hackl and Harvey [18] applied total site analysis and designed the roadmap of heat integration investment for a chemical cluster in Sweden. Sun et al. [19] developed a new graphical analysis based on a Site Grand Composite Curve (SGCC) for targeting cogenerations in site utility systems.

The concept of area-wide approach was applied to a heavy chemical complex (Matsuda et al. [1]) but the identification of the characteristics for the complex was not studied. This paper implemented the comparative study of energy saving potential and the identification of the characteristics for two heavy chemical complexes macroscopically by area-wide approach. One was Mizushima complex and the other was Chiba complex (Matsuda [20]) in Japan. Furthermore the characteristics of three blocks in Mizushima complex were assessed based on the concept of comparative study.

In this study, R-curve analysis of area-wide approach was used to identify the characteristics and the energy saving potential for the complex and the characteristics of its individual sites as well. In heat cascading utilization for energy saving from area-wide approach, TSP analysis made use of heat across the complex by utilizing surplus low-grade heat from one or more sites to the others.

2. Miszushima and Chiba heavy chemical complexes

2.1. Mizushima heavy chemical complex

Mizushima heavy chemical complex is one of the ten largest heavy chemical complexes in Japan and 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), with canals between the respective blocks. Table 1a summarizes the sites data that there are various types of plants and the number of chemical plants occupies approximately 60% of the complex. Data was collected from the utility system. Major utility conditions in Mizushima complex is shown in Table 2. It is noted that some sites entrusted the management of the utility system to adjacent their parent's sites in the complex. Process-utility heat exchanger (heaters and coolers) data were also collected and summarized in Table 3. In total, 991 process-utility heat exchanger data were collected which comprised 287 heaters and 704 coolers. It is noted that power plants did not have any process-utility heat exchanger at all. Although most of companies in block C could provide the data of their utility system, only three companies in block C could provide process-utility heat exchanger data. However there was one giant chemical plant which had a large number of heat exchangers occupying a lot of heat demand of block C and heat exchanger duty of other seven companies would not give so much impact on the results.

2.2. Chiba heavy chemical complex

Chiba heavy chemical complex had been studied based on the concept of area-wide approach (Matsuda [20]). Chiba complex is located on the northeastern coast of Tokyo bay. 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. The area is also divided into three blocks, A, B and C. Cooperation for the study was obtained from a total of 20 companies (23 sites). As shown in Table 1b, chemical plants occupy most of the complex.

3. Energy saving analysis

3.1. R-curve analysis

R-curve can be constructed based on the following two equations.

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

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

Where, Q_{heat}: Heat demand for the utility system. W: Power demand for the utility system. Q_{fuel}: The integrated energy consumption which is the summation of the consumed fuel oil/gas and the purchased power in the utility system.

Fig. 1 shows the theoretical limit lines for energy system of a gas turbine combined system and a boiler and turbine conventional system. The lines goes down to the right. As the R-ratio (site power to heat ratio) increases, the integrated energy efficiency decreases. The more power demand needs to use a condensing turbine which causes the loss in condensing power generation and decreases the

Table 1
Mizushima and Chiba heavy chemical complexes.

a. Mizushima	Block A	Block B	Block C	Total
Chemical plant	5	7	8	20
Steel plant	6	1	0	7
Refinery	1	1	0	2
Machinery plant	1	0	1	2
Food factory	1	0	1	2
Power plant	1	1	0	2
Total	15	10	10	35
b. Chiba	**Block A**	**Block B**	**Block C**	**Total**
Chemical plant	3	4	11	18
Refinery	1	2	1	4
Others	1	0	0	1
Total	5	6	12	23

Table 2
Major utility conditions in Mizushima complex.

	Block A	Block B	Block C
	MPaG/°C	MPaG/°C	MPaG/°C
High pressure steam	12.0/530	12.0/325	12.9/538
	8.2/308	10.5/314	
Middle pressure steam	5.5/280	3.2/238	3.1/240
	2.7/235	1.5/200	2.8/232
	1.4/200	1.2/192	1.2/200
Low pressure steam	0.5/160	0.3/151	0.4/150
	0.4/155	0.2/133	0.3/150
	0.3/144		
	0.1/148		

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