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Research Paper

Energy structure analysis and energy saving of complex chemical industries: A novel fuzzy interpretative structural model

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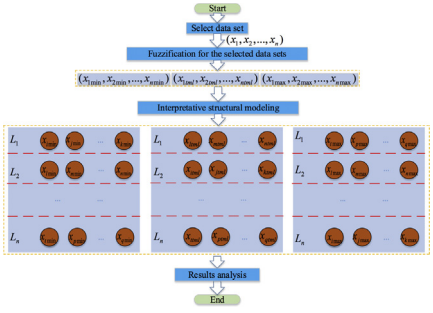
HIGHLIGHTS

- A FISM method based on the fuzzy theory is proposed.
- Energy structure and energy saving framework of complex chemical industries is obtained.
- This proposed method is efficient in energy structure analysis and energy saving of complex chemical processes.
- The raw materials can be saved about 10–30%.
- The carbon emissions can be reduced about 0.3–0.45 Ton.

GRAPHICAL ABSTRACT



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ABSTRACT

Chemical production plays a key effect in energy saving and the sustainable development. However, the uncertain data has a direct impact on the production and the energy efficiency of complex chemical industries. Therefore, in order to analyze the energy structure and improve the energy efficiency of complex chemical industries, this paper proposes a novel interpretative structural model (ISM) integrated the fuzzy theory (FISM). The production data are divided into the upper limit value, the lower limit value and the most probable value based on the data fuzzification. And then energy structures and energy saving potentials in different production configurations are obtained by using the FISM. Finally, the proposed method is applied to analyze the energy structure and obtain energy saving potentials of the ethylene production process in complex chemical industries. The experimental results show that the key impact factors of influencing the ethylene production in different production configurations can be obtained to improve the energy efficiency. Moreover, compared with the benchmarking of the best production configuration, the raw materials can be saved about 10–30% and the carbon emissions can be reduced about 0.3–0.45 Ton when producing one Ton ethylene.

1. Introduction

Nowadays, energy saving, the environmental protection and the sustainable development are paid more and more attention by human beings, especially in the complex chemical industries. The development degree of complex chemical industries has become a main sign of the industrialization process in a country. Moreover, the ethylene industry is one of the most important parts in complex chemical industries. As an industrial power, the ethylene production in China reached 17.044 million Tons in 2015 [1]. Meanwhile, the ethylene products increased around 5% per year. The change of the ethylene production in China since the 11th Five-Year is shown in Fig. 1 [1]. In 2012, the

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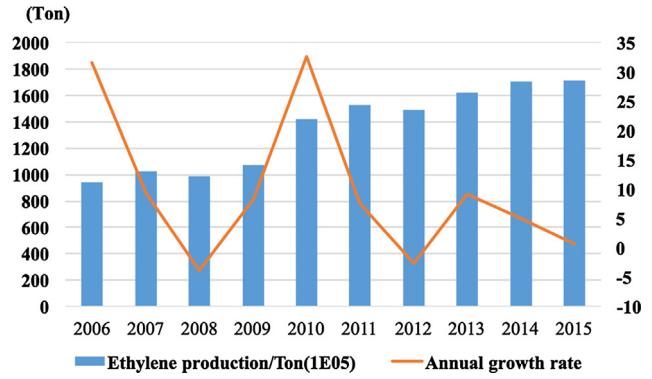

Fig. 1. Ethylene production in China.

ethylene production of China Petrochemical Corporation was 9475 kt/a, and the average fuel plus power consumption (standard oil) was 579.59 kg per Ton [2]. Energy consumptions costs of ethylene plants took up more than 50% of overall costs [3]. Although ethylene yields in China have lain in the forefront of the world, the energy efficiency still lags behind the developed countries [4]. Therefore, studying the energy structure analysis and energy saving of complex chemical industries is also beneficial for both environmental and sustainable development of the Chinese economy.

In order to analyze the energy structure and improve the energy efficiency of complex chemical industries, this paper proposes a novel energy structure analysis and energy saving method based on the ISM integrated the fuzzy set theory (FISM). First, the production data are divided into the upper limit value, the lower limit value and the most probable value based on the data fuzzification. And then the minimum eigenvalues, the most likely eigenvalues and the maximum eigenvalues are obtained. Moreover, energy structures and energy saving potentials in different production configurations are obtained by using the FISM. Finally, the proposed method is applied in the energy structure analysis and energy saving of the ethylene production process in complex chemical industries. The experimental results show that the key impact factors of influencing the ethylene production in different production configurations can be obtained to improve the energy efficiency. Moreover, compared with the benchmarking of the best production configuration, the raw materials can be saved about 10–30% and the carbon emissions can be reduced about 0.3–0.45 Ton when the ethylene is produced about one Ton.

The organization of the remaining parts is as follows: Section 2 presents the research status of the structure analysis and energy saving with the ISM and the fuzzy theory. In Section 3, the triangular fuzzy number (TFN) and the FISM are introduced in detail. The proposed method is applied in the energy structure analysis and energy saving of complex chemical industries in Section 4. Discussion and conclusion are obtained in Sections 5 and 6, respectively.

2. Related work

Nowadays, many related energy saving methods in complex chemical industries have been proposed. Zennifer et al. elaborated the importance and shortcomings of ethylene glycols in subarctic and artic regions [5]. Salkuyeh et al. proposed a novel ethylene production plant which could directly convert shale gas to ethylene with zero carbon emissions [6]. In order to attain an improvement in the overall profit, Zhao et al. optimized the production plan of the ethylene plant to save the energy [7]. Yu et al. proposed a novel multiple learning particle swarm optimization based on space transformation perturbation to improve the performance efficiency of an ethylene cracking [8]. Han et al. proposed a new linear optimization fusion model based on fuzzy C-means to analyze the energy efficiency of the ethylene production process [9]. Geng et al. applied the data fusion method to improve the energy efficiency analysis of ethylene plants. However, these methods did not take the influence of the energy consumption indicators and carbon emissions into consideration [10,11]. Meanwhile, the multi-dimensional data has a direct impact on the production and the energy efficiency of complex chemical processes [12–14]. Therefore, the energy structure analysis is beneficial for the energy saving of complex chemical industries.

The ISM was introduced by Warfield to analyze the structure of complex systems [15]. Lim et al. applied the ISM method to get the relationship of the sustained supply chain [16–18]. Dubey et al. used the total ISM to identify barriers of Green supply chain management (GSCM) [19]. Maher et al. analyzed the interaction among influential factors on the implementation of GSCM practices by using the ISM method [20]. Wu et al. used the ISM integrated the Bayesian network to attain an engineering risk factor relationship represented by a cause-effect diagram and provide the explicit risk information [21]. Venkatesha et al. proposed a new model based on the ISM for the Risk Priority Number calculation to establish interdependencies between the selective risks associated with the apparel retail supply chains [22]. In addition, Trivedi et al. used the ISM to analyze the contextual relationship among some key factors, which play an influential role in the disaster waste [23]. Yadav et al. interpreted the interdependency among the selected critical success factors based on the ISM method [24]. Han et al. applied the ISM integrated the extreme learning machine to analyze the energy efficiency and reduced the energy consumption of the ethylene industry [25].

However, the statistical data have the characteristics of multi-dimension, noise and uncertainty. Thus, it is not objective and accurate to evaluate the energy efficiency production situation of each plant based on the statistical data. Meanwhile, because the adjacency matrix of the ISM is obtained by using expert experiences and affected by the uncertain data, the results are inconclusive and not objective. Therefore, the fuzzy theory is introduced into the ISM to obtain the energy structure and energy saving potentials.

The fuzzy theory was originally proposed by Zadeh and applied in quality management and risk management [26]. Coppi et al. compared two kinds of clustering models by using the left and right fuzzy data to analyze the empirical information affected by imprecision or vagueness [27]. Chen et al. realized comprehensive and quantitative evaluation of environ-economic benefits of anaerobic digestion technology by using the fuzzy evaluation method based on life cycle assessment and cost-benefit analysis [28]. Molinari et al. presented a weak preference relation to establish a total order on the family of TFN [29]. Wang et al. used TFN to facilitate the knowledge management performance evaluation with a group support system [30]. In order to predict the nonlinear fuzzy system more precise, Wu et al. proposed a new fuzzy support vector machine with multi-dimensional input variables [31]. Based on the grey model and neural networks, Zeng et al. built the TFN grey model (TFGM) integrated the neural network to accurately forecast the TFN series [32]. Based on the distance between two TFNs, Zeng et al. constructed a fuzzy least absolute liner regression model to evaluate the fitting effect of the observed and estimated values [33]. Akbas et al integrated fuzzy set theory and quality function deployment to maintain the sustainable development at wastewater treatment plants [34]. In order to improve the ethylene production conditions and guide the efficiency of energy utilization, Han et al. introduced fuzzy data envelopment analysis cross model [35]. Based on the fuzzy grey model (FGM) and multicriteria decision making model (MCDM), Wang et al. proposed FG-MCDM to improve energy efficiency and protect environment [36]. Based on the above analysis, the energy structure of complex chemical industries can be simplified based on the ISM, and the uncertain data can be disposed by using the effective TFN in the fuzzy theory. Therefore, this paper proposes a novel energy structure analysis and energy saving method based on the FISM.