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Sensitivity analysis, economic optimization, and configuration design of mixed refrigerant cycles by NLP techniques

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ABSTRACT

Over the past decades, increasing attention has been paid to optimal design and operation of energy intensive industries. The purpose of this paper is to present a systematic method based on a combination of mathematical methods and thermodynamic viewpoints to acquire optimized design configuration by non-linear programming techniques. Economic optimization was developed through a combination of multi-stream exchanger design and optimized operation parameters. Next, perturbations method was applied for the sensitivity analysis in the discussed refrigeration cycles in the paper. Ultimately, the results showed the one-stage cascade of mixed refrigerant refrigeration cycle (MRRC) as the best option to replace pure ethylene cycle in the olefin plant of Tabriz Petrochemical Complex.

1. Introduction

Due to the increase of energy prices, restrictions of production resources, and preservation of the environment, the necessity of energy consumption reduction as well as its consumption optimization in energy intensive industries has been revealed. Olefin plants are among the petrochemical industries with high energy consumption. Ethylene and propylene, which are the raw materials in most of the downstream petrochemical industries, are produced during thermal cracking of hydrocarbons in the furnaces of the olefin plant (Ghorbani et al., 2014).

One of the defects of the common cascade systems in different petrochemical industries is high temperature difference between refrigeration system's pure working fluid and cooled streams in the evaporator of refrigeration systems. By appropriate use of mixed refrigerant, this defect can be avoided to a large extent. In recent years, many studies have been conducted in LNG in order to develop refrigeration systems with a mixed refrigerant. Results of these studies have shown that, if mixed refrigerant were used properly, the axial work of cascade refrigeration systems would decrease in the liquefaction of natural gas. Moreover, low-temperature separation processes design is affected by the amount of axial work and refrigeration system consumption power more than anything else. Many studies are being conducted in order to decrease axial work in low-temperature refrigeration systems and diverse systems for cooling supply in low-temperature processes (Wang et al., 2013; Cao et al., 2006; Becdelievor et al., 1978; Finn et al., 1999; Ghorbani et al., 2014).

Several approaches have been developed for optimizing mixed refrigerant systems. Having combined all chosen variables such as condensation, evaporation, and intermediate pressures, flow rate, and composition of MR in the objective function, they conclude that the compressors and LNG heat exchanger contribute to the main energy losses of the liquefaction process (Mokarizadeh Haghighi Shirazi and Mowla., 2010). NLP has been also used to minimize the power consumption of a cascade MR cycle. Refrigerant composition (C1, C2, C3, and n-butane), vaporization fraction in flash tanks, as well as compressor pressure ratios are used as

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optimization variables (Vaidyaraman and Maranas, 2002). Systematic method has been conducted on the optimal design of a PRICO cycle using non-linear programming (NLP) to find the optimal operating conditions. The NLP techniques are used to optimize the refrigerant composition at a given refrigerant flow rate and pressure (Lee et al., 2002; Ghorbani et al., 2014).

On the other hand, Younas and Banat (2014) presented a steady-state model which was developed on ProMax simulation platform for determining the sensitivity of parameters affecting the absorption process. Also, the variables directly and indirectly affecting the absorption of acid gases were tested. Nemati Rouzbahani et al. (2014) studied the possibility of optimizing the whole process and performed the sensitivity analysis of the results obtained from the simulation.

The purpose of this paper is to identify and develop the best configuration of MRRC for low-temperature refrigeration systems in petrochemical industries. Three low-temperature different cycles with mixed refrigerant were employed to replace pure refrigerant refrigeration cycle. Design configuration and optimization of MRRCs are among the objects of this research. Furthermore, after identifying the effective parameters for the behavior of mixed refrigerant refrigeration cycles, a systematic method was developed for selecting the best configuration along with optimized operation parameters. Finally, these cycles were investigated by economic and sensitivity analyses.

2. Design configuration of MRRCs

Regardless of the inherent simple assortment of equipment in MRRC, different configurations can be imagined for these kinds of cycles in order to procure the needed cooling of process. Yet, how to obtain the configuration and assortment of the equipment which benefit mostly from exist complicated interaction between low-temperature process and refrigeration cycle, and to certify best configuration among the various imagined configurations, is a controversial issue. In order to answer the question and present an appropriate method to obtain the optimized configuration of MRRCs, the two presented MRRCs in Figs. 1 and 2 were developed in order to supply cooling in the olefin plant of Tabriz Petrochemical Complex. Then, the key parameters of the cycles were optimized through PSO algorithm and NLP techniques, as a combination of enumerative and direct search methods. The results showed that the cycle with configuration A performed more reversibly than configuration B, which can be attributed to better conformity between composite curves in the heat exchangers (Ghorbani et al., 2014).

The conformity between composite curves in all the heat exchangers of cycle has been investigated precisely. Moreover, it is possible to mix all the cold streams of processes and refrigerants in order to obtain one cold composite curve, representing all the cold streams. The same is true with hot streams. Since composite curves are derived by refrigerant information of cold and hot streams, the derived plot is named balanced composite curves. Furthermore, thermal integration of refrigeration cycle with a low-temperature process by a combination of both cold and hot streams of process and refrigerant is presented in these plots. Fig. 3 shows the balanced composite curves for the two MRRCs with configurations A and B with regard to Table 1 in Ghorbani et al. (2014). In these figures, due to the combination of all hot and cold curves with each other, the temperature difference between the composite curves is obtained as more than $\Delta T_{min} = 0.5$ °C.

In order to investigate the configuration of MRRCs completely and its effect on consumed power of upper refrigeration cycle, the role of which is pre-cooling for MRRC, the balanced composite

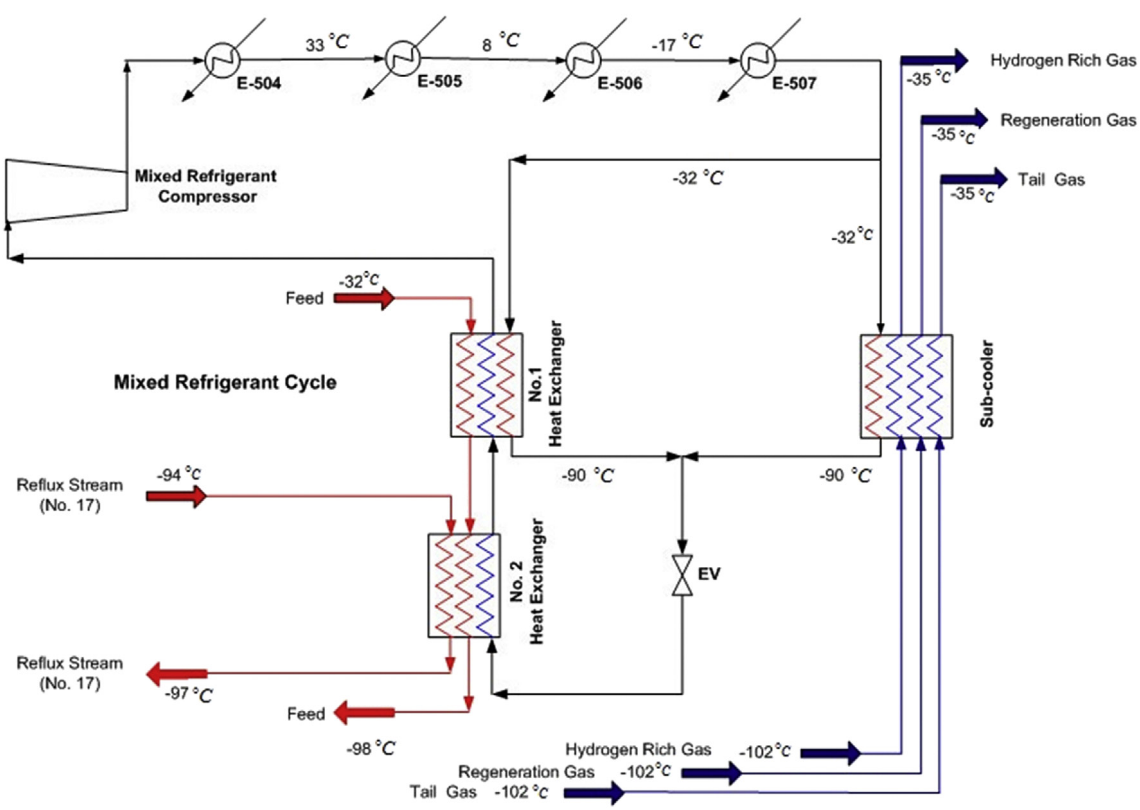

Fig. 1. Schematic diagram of MRRC (configuration A).