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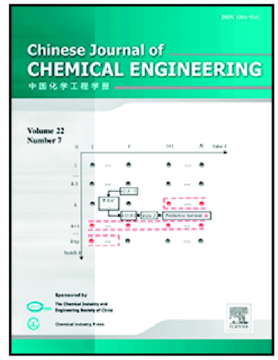

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Synthesis of Refrigeration System based on Generalized Disjunctive Programming Model

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Abstract: Refrigeration system holds an important role in process industries. The optimal synthesis can not only reduce the energy consumption, but also save the production costs. In this study, a general methodology is developed for the optimal design of refrigeration cycle and heat exchanger network (HEN) simultaneously. Taking the heat integration between the external heat sources/sinks and the refrigeration cycle into consideration, a superstructure with sub-coolers is developed. Through defining logical variables that indicate the relative temperature positions of refrigerant streams after sub-coolers, the synthesis is formulated as a Generalized Disjunctive Programming (GDP) problem based on LP transshipment model, with the target of minimizing the total compressor shaft work in the refrigeration system. The GDP model is then reformulated as a Mixed Integer Nonlinear Programming (MINLP) problem with the aid of binary variables and Big-M Constraint Method. The efficacy of the process synthesis model is demonstrated by a case study of ethylene refrigeration system. The result shows that the optimization can significantly reduce the exergy loss as well as the total compression shaft work.

Keywords refrigeration system; process synthesis; Generalized Disjunctive Programming (GDP); Mixed Integer Nonlinear Programming (MINLP)

Introduction

Refrigeration system is widely used to provide cold utilities for petrochemical processes. So it holds an important role in process industries. Generally speaking, it works by obtaining heats from low-temperature sources and passing them to high-temperature sinks, with the compression work consumed. The Fig.1 shows the diagram of a simple refrigeration loop, composed of four components: condenser, expansion valve, evaporator and compressor. The liquid refrigerant gets heat from a process stream in the evaporator section and delivers it to other process streams through the condenser. In this cycle, the refrigerant can be repeatedly compressed, condensed, expanded and evaporated to achieve the cooling requirement continuously. In addition, multiple pressure levels can simultaneously exist in the refrigeration system, according to the specific requirements. The optimization of the refrigeration system, which is a large energy consumer, can reduce the energy loss and further save the final production cost. Therefore, this issue has been widely studied in decades.

Barnes and King[1] developed one of the earlier models of refrigeration system. They used heuristics and dynamic programming simultaneously to increase intermediate pressure stages. Cheng and Math[2] improved the model, and extended the system to mixed refrigerant cycle. Because of the significant dependence on heuristics, these methods could not guarantee the solution optimality for complicated

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