Research Paper

Simultaneous integrated design for heat exchanger network and cooling water system

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\textbf{ABSTRACT}

Heat exchanger network and cooling water system are two major elements of energy systems in processing plants. Such two subjects have a very close interaction with each other. However, most of current researches firstly synthesize heat exchanger network and then design cooling water system. This sequential methodology probably misses the optimum solutions, and results in some suboptimal designs from an overall perspective. To overcome this limitation of traditional methods, in present paper a simultaneous methodology is introduced to integrate heat exchanger network and cooling water system as a whole system. Unlike conventional approaches, the methodology treats cooling water as a special cold stream whose mass flow rate, initial and final temperatures are all unknown variables and require to be optimized. The methodology mainly makes use of a modified stage-wise superstructure that covers most possible configurations for integrating heat exchanger network and cooling water system. The mathematical optimization model corresponding to the superstructure is a mixed integer nonlinear programming (MINLP) problem. The total annual cost (TAC) is set as the objective function composed by utility cost, pumping cost, and capital cost of cooling tower and heat exchanger. An industrial case study is used to demonstrate the capabilities of the proposed methodology.

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\textbf{1. Introduction}

Nowadays the growing prices of fossil fuel and strict environment regulations seriously force industrial clusters to improve processing plants' energy efficiency as much as possible. Therefore, industrial energy systems, like heat exchanger networks, cooling water systems, rankine cycles and so on, have attracted high attentions from both academic and industrial practices [1]. Among these energy systems in a processing plant, a heat exchanger network and a cooling water system are two major elements which have very close relationships to energy consumption [2]. Such two subjects have been widely and deeply studied in the past few years and various kinds of design approaches have been proposed with extensive application to industrial cases.

1.1. Synthesis of heat exchanger network

The concept of heat exchanger network synthesis is initially proposed by Masso and Rudd [3] in 1970s. According to Núñez-Serna and Zamora [4], the methodologies for heat exchanger network synthesis could be classified into two categories, sequential and simultaneous approaches. In principle, the sequential methodology decomposes heat exchanger network synthesis into several sub-problems. One well-known sequential methodology for heat exchanger network synthesis is Pinch Technology (PT) proposed by Linnhoff and Hindmarsh [5]. They utilized a minimum temperature difference to find the bottlenecks for energy savings which
was also called as pinch point. Heat exchanger network synthesis is thereby divided into designing two sub-networks above and below the pinch points. Papoulias and Grossmann [6] and Cerda et al. [7] respectively developed a transshipment and a transportation model, in which heat exchanger network synthesis was implemented as a sequentially mathematical programming problem. Energy saving target, number and area of heat exchanger are sequentially optimized step by step. However, these sequential methods may not find the optimum solution, since energy saving and capital investments are not trade off simultaneously.

The other methodology for heat exchanger network synthesis is simultaneous approach that considers various factors holistically like utility expenses, pumping cost and capital investments of heat exchangers. Such methodology normally makes use of mathematical programming methods consider these costs simultaneously and operation cost simultaneously. Thus the optimum solutions may be missed and suboptimal designs may be obtained accordingly. Actually, there exist various costs in the synthesis of cooling water systems, such as pumping costs, capital costs of cooling towers and cooling water networks. Unlike graphic methods, mathematical programming methods consider these costs simultaneously and holistically. Because of this point, many researchers suggested mathematical programming methodology for the synthesis of cooling water system. Kim and Smith [14] initially developed a PT method for cooling water system synthesis by focusing on the systems’ components from an overall aspect. Due to the highly close interactions between cooling water networks and cooling tower performance, it is particularly necessary to take account into all components as a whole. Continuously, Kim et al. [15] extended their approach to cooling water system synthesis for effluent flow-rate reduction. Their method can rearrange some coolers from parallel to series configurations, rather than increasing the mass flow-rate of cooling water. However, their researches were mostly based on graphic targeting tools that cannot addressed capital investments and operation cost simultaneously. Thus the optimum solutions may be missed and suboptimal designs may be obtained accordingly.

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1.2. Synthesis of cooling water system

Cooling water system is another important element of energy systems in processing plants. It removes most waste heat rejected from hot process streams, thus the flow rate of cooling water is particularly large as well as its capital investments and operation costs. Early attempts to cooling water system synthesis were carried out through graphic targeting methods. For instance, Kim and Smith [14] initially developed a PT method for cooling water system synthesis by focusing on the systems’ components from an overall aspect. Due to the highly close interactions between cooling water networks and cooling tower performance, it is particularly necessary to take account into all components as a whole. Continuously, Kim et al. [15] extended their approach to cooling water system synthesis for effluent flow-rate reduction. Their method can rearrange some coolers from parallel to series configurations, rather than increasing the mass flow-rate of cooling water. However, their researches were mostly based on graphic targeting tools that cannot addressed capital investments and operation cost simultaneously. Thus the optimum solutions may be missed and suboptimal designs may be obtained accordingly.

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