An MINLP Approach for Synthesis and Design of Multi-stream Heat Exchangers Network

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Nowadays, Multi-stream heat exchangers (MHEX) have been paid more attention to in recent years for its high efficiency and low capital. In general, the MHEXs are more compact than regular two-stream heat exchangers, this means larger heat exchanging area per unit volume and less external surface exposing in environment accompanied with MHEXs, therefore, the technology option of MHEXs is believed to bring profit in both equipment capital and operation cost. However, the design of MHEXs and their networks are much difficult because of intricate channel configuration, complicated flow arrangement, complex heat-transfer paths as well as multiple potential thermal matches among cold and hot streams.

Usually, equiment design and network synthesis are dealt and solved separately. Many methods have been proposed over the years for thermal design of multistream plate pin exchangers. See Das & Ghosh [1] for an extensive review of these methods. Most MHEXs network synthesis approaches are expanded from the two-stream heat exchangers based methodologies and could be also further divided into two categories: Pinch Technology(M. Picon-Nunez et al.[2]; Xing Luo, Wilfried Roetzel and co-workers [3-4]) and stage-wise superstructure-based optimization (Yee and Grossmann[5]; M.M. Faruque Hasan et al. [6]). However, the methods in terms of “Pinch Technology” are incapable of realizing the thermal matches spanning temperature interval and the number of equipment as well as utilities are unable to be synthesized simultaneously. Furthermore, this method cannot weigh equipment investment and utilities simultaneously, which will be achieved in mathematical programming method based on stage-wise superstructure. A series of improvements on original stage-wise superstructure are proposed in recent years and actually ameliorate the probabilities of multi-stream heat exchanging matches, but still not sufficient for the optimal match structure and streams splitting and mixing by spanning stages are still not realized thoroughly.

MHEXs are widely used in energy-intensive industrial and cryogenic processes, such as air separation/liquefaction, rectisol process in ammonia plant, cryogenic section of ethylene plants, and liquefied natural gas (LNG). Due to the large difference between ambient and operating temperatures, heat exchange between the heat exchanger and the environment can not be neglected. Unfortunately, most technologies are designed under adiabatic hypothesis and do not consider the interaction between stream arrangement and network structure which have a serious impact on utility consumption and capital cost.

In this paper, we propose a framework for simultaneous multi-stream heat exchangers network synthesis and stream arrangement optimization with considering heat transfer with the surroundings. An improved State-Space superstructure based on hierarchy matching multi-stream heat exchanger (MHEX) process operator (PO) is proposed. The rigorous heat transfer calculation between adjacent streams is implemented through temperature synergistic effect in MHEXs. Moreover, arbitrary splitting and mixing of any stream is configured by mixers and splitters embedded in distribution network (DN). The mathematical modeling of the proposed superstructure is performed with mixed integer non-linear programming (MINLP). The following key details will be highlighted:

- The effect of thermal interactions (heat loss and/or heat leakage) on the performance of MHEX and networks has been considered through detailed stream arrangement and surface area calculation.

- Effective insulation materials are used to alleviate deterioration caused by heat loss or heat leakage. New objective function are developed to capture the trade-off between utility cost, capital cost and insulation materials cost.

-The performance analysis of a series of MHEXs network configuration which have never been included within previous superstructure.

The applicability of the systematic approach is demonstrated in two case studies: a high-temperature system in petrochemical industry and a cryogenic systems in ethylene industry.

Reference:

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