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A multistream heat exchanger model with enthalpy feasibility

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ABSTRACT

A temperature feasibility constraint is an important part of multistream heat exchanger (MSHE) modeling. However, temperature feasibility of an MSHE model makes a numerical issue when a physical property package is used to obtain highly accurate temperature-enthalpy relationships in equation-oriented modeling environment. To resolve the issue, this study proposes a new MSHE model with enthalpy feasibility using the fact that enthalpy is a monotonically increasing function of temperature. A natural gas liquefaction process, called a single mixed refrigeration process, is optimized using the proposed MSHE model under an equation-oriented modeling environment with a physical property package as a case study.
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1. Introduction

In cryogenic processes, such as air separation operation, natural gas (NG) liquefaction and separations for effluent gases in petrochemical plants, ensuring an efficient heat exchange is of significant importance. Multistream heat exchangers (MSHEs) have been applied in cryogenic processes because they enable compact and well-insulated designs (Kamath et al., 2012). According to Austbo and Gundersen (2015), the temperature gap between hot and cold streams in heat exchangers should decrease as the temperature decreases so as to improve efficiency. Therefore, MSHEs have, in general, a temperature difference of 1–3 K in large heat transfer processes (Lee et al., 2002). Preferable types of MSHEs that allow for a small temperature gap between the hot and cold streams are plate-fin and spiral-wound MSHEs (Pattison and Baldea, 2015).

In an MSHE, simultaneous heat exchange processes between multiple hot and cold streams take place; therefore, it is difficult to develop an MSHE model. In the literature, MSHEs have been modeled using energy balance equations with temperature feasibility constraints for process optimization analyses. As expressed in Eq. (1), the temperature feasibility condition implies that the temperature difference between the hot and cold composite curves at any internal point must be greater than the minimum internal temperature approach value. Thus, the pinch concept, which is mainly used in heat exchanger network synthesis (HENS) problems, is also applied to MSHE modeling.

$$T_k - t_k \geq T_{MITA} \tag{1}$$

One of the limitations of the general HENS problems is the use of a constant heat capacity (Fieg et al., 2009; Peng and Cui, 2015). This is not suitable in the case of large temperature variations of streams with a small temperature difference between the hot and cold streams. On top of that, if phase change occurs in MSHEs, the use of rigorous and accurate physical property calculations is mandatory (Lee et al., 2002). Wu et al. (2015) adopted a temperature-dependent function for the heat capacity for HENS problems. They expressed the heat capacity as a cubic function of the temperature to check temperature feasibility at the end point only. Liao et al. (2017, 2018) also checked temperature feasibility at only both end points although they correlated enthalpy with temperature, pressure, and compositions. However, temperature feasibility should be checked at internal points as well as at the inlet and outlet points of heat exchangers to consider the variable nature of the thermal properties of streams in HENS problems. Hasan et al. (2010) assumed that the temperature of a stream is a cubic function of enthalpy. They verified temperature feasibility for the whole temperature range for each heat exchanger by means of differential analysis.

Another limitation of general HENS problems is that all the stream conditions are fixed: the inlet and outlet temperatures and pressures, heat capacity, flow rate, and composition. Although some conditions were defined as variables in the literature, the other conditions were still fixed. Hasan et al. (2010) consid-

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