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Synthesis of Heat Exchanger Networks Taking into Account Cost and Dynamic Considerations

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Abstract

In this work an approach is presented for the synthesis of near cost optimal heat exchanger networks with a high controllability. The presented methodology is based on a sequential approach utilizing different algorithms and mathematical models. The procedure is carried out in three steps. A genetic algorithm is used to produce a high diversity of promising structures that suffice the needs for cost reduction and controllability characteristics. For selected structures controllability evaluations are carried out, which are mainly based on relative gain array and condition number assessments. Therefore, a linear model is utilized which was further used to calculate the area adjustments and nominal bypasses for complete disturbance rejection for perfect control. As a last step simplified mathematical solution models are used to further extend insight gained for decision-making. These models are used to carry out dynamic simulations for testing the impact of different possible decentralized feedback control structure designs developed by previous methods. The application of the developed approach will be shown using an example from literature.

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1. Introduction

The implementation of heat integration strategies has a huge potential of reducing the use of primary energy carriers significantly and thus increasing the energy efficiency and cost effectiveness of a process.

The synthesis of heat exchanger networks (HENs) thus was a vital topic in the last decades and it is still a vital topic in literature today. There are numerous methods and approaches available and there are still new developments made, for example in a recent publication from Peng and Cui [1] where a simulated annealing algorithm is utilized for simultaneous synthesis of HENs. Another example is the work of Pouransari and Maréchal [2] who laid stress on large-scale industry and constraints which are inspired by layout considerations. The major synthesis problem is often reduced to the minimization of the total annual costs. These include the costs for the investment in heat exchangers and the costs for utilities like steam, thermal oil or cooling water. However, the thermal coupling of hot and cold

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streams via heat exchangers may promote the disturbance propagation throughout the HEN and could possibly cause controllability issues. The topic of controllability has been addressed in several publications. Yan et. al [3] developed an iterative procedure for the bypass design of HENs. Escobar et. al [4] introduced a computational framework for simultaneous synthesis of HENs based on the SYNHEAT model.

Following, a sequential methodology is proposed which utilizes a genetic algorithm to generate near cost optimal heat exchanger networks to create a basis of structurally different networks for the comparison with the help of characteristic numbers. These numbers are calculated with a linearized steady-state model. Furthermore, a dynamic comparison was carried out to overcome the shortcomings of the steady-state approaches.

Nomenclature

N_s	number of stages
N_h	number of hot streams
N_c	number of cold streams
u	bypass fraction
indices	
c	cold
h	hot
s	supply
t	target
hx	heat exchanger

2. Analysis and Modelling

In the following part the main algorithms and mathematical models of the applied procedure are described briefly. The first part covers the genetic algorithm followed by the linear model with the characteristic numbers and in the last part the dynamic model is explained.

2.1. Genetic algorithm

The synthesis of heat exchanger networks was carried out using a modified version of the genetic algorithm developed by Fieg et. al [5]. This algorithm derives HEN structures based on the superstructure by Yee et. al [6].The objective of the solution of a heat exchanger network synthesis problem is the minimization of the total annual costs in $/a. These include the costs for the investment in heat exchangers and the costs for utilities like steam, thermal oil or cooling water. An abbreviated form is given in equation 1:

$$\min C(x) = \sum_{n=1}^{N_h+N_c} C_{U,n} + \sum_{i=1}^{N_s}\sum_{j=1}^{N_h}\sum_{k=1}^{N_c} C_{E,ijk} \tag{1}$$

The costs for the utility heat exchangers and the costs for the supply of utilities are combined in C_U. The costs for the process to process heat exchangers are considered with the factor C_E. The algorithm is modified to carry out multiple optimizations. When carrying out these optimizations equal solutions are forbidden to generate numerous results which differ in structure.

2.2. Linear model

Apart from the consideration of costs the HENs are examined under the attention of controllability. In our case, the HENs are to be controlled by bypasses around the process to process heat exchangers and the flowrates of the utilities