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Simultaneous synthesis of a biogas process and heat exchanger network

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A B S T R A C T

This paper presents an energy efficient synthesis of the biogas process, performed simultaneously with the synthesis of its heat exchanger network (HEN). Its overall superstructure is composed of i) the process and ii) the HEN superstructure, and linked with iii) a proposed process stream superstructure where streams could be mixed into a smaller number of hot and cold streams, in order to obtain simpler and, yet, energy efficient solutions. The combined synthesis problem is formulated as a mixed-integer nonlinear programming (MINLP) problem. The model consists of an MINLP model for the biogas process [1] and a modified MINLP model for the simultaneous synthesis of heat-integrated HEN [2]. It enables the selection of an optimal biogas process scheme with an optimal arrangement of its HEN. The synthesis, as applied to an existing large-scale meat company, yielded a complete energy self-sufficient solution for thermophilic biogas production, closed-loop water configuration, and simple HEN arrangement.

1. Introduction

Over the last few years, waste minimization and pollution prevention have become everyday terms throughout the process industry. Rising energy costs, coupled with stringent environmental regulations regarding the accumulation of animal manure and organic matter, have forced the food industry [3–5] towards additional opportunities for the utilization of renewable resources and energy savings, by applying process integration [6,7].

A diversity of papers within the literature has dealt with heat exchanger networks that have become the subject of numerous investigations over the last 40 years. Three major approaches have been applied: the one based on thermo-dynamical insights known as ‘pinch technology’ (PT) [8], a mathematical programming approach [9,10], and a combined approach [11]. Many studies and methodologies have been proposed for making energy recovery possible within those industrial plants dealing with either the concept of heat and process integration, in general [12,13] or with the synthesis and retrofit of heat exchanger networks, in particular [14,15]. As the concept of process integration was initially applied to those plants isolated from their vicinities, it has now extended to enterprise-wide and total site integration [16], including the integration of renewables [17]. On the other hand, the scope of synthesis and the retrofit of HENs have been developed and expanded also, by considering more detailed heat exchanger designs, allowing for flexibility [18] and even simultaneously minimizing the total annual cost and the environmental impact [19]. Some recent papers have also used meta-heuristic techniques, such as genetic algorithms [20,21], and introduced global optimization techniques for the synthesis of HEN [22,23]. An excellent review with a complete timeline of HEN synthesis approaches is provided by Furman and Sahinidis [24] whilst for process integration and optimization by Friedler [25].

Mathematical optimization methods for the synthesis of HEN can be classified as sequential [26] or, as mentioned, simultaneous. The main advantages of the simultaneous approach are that the trade-offs between the capital and operating costs of the network can be handled explicitly, and that it enables the performing the simultaneous synthesis of overall systems, e.g. integrated water and HEN networks [27–30], when simultaneous models of HEN are merged with water network models, or a combined process with HEN schemes, when HEN models are included within the process models [14,31–33]. One of the better known simultaneous optimization models for the synthesis of HEN was developed by Yee & Grossmann [2]. It is based on a stage-wise superstructure and formulated as a mixed-integer nonlinear programming (MINLP) model, with the objective of simultaneously minimizing the utilities and capital costs of the network.

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