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Review

Water and energy integration: A comprehensive literature review of non-isothermal water network synthesis

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ABSTRACT

Synthesis of non-isothermal water networks consisting of water-usage, wastewater treatment, and heat exchanger networks has been recognised as an active research field in process systems engineering. However, only brief overviews of this important field have so far been provided within the literature. This work presents a systematic and comprehensive review of papers published over the last two decades and highlights possible future directions within this field. This review can be useful for researchers and engineers interested in water and energy integration within process water networks using systematic methods based on pinch analysis, mathematical programming, and their combination. We believe that this research field will continue to be active in the near future due to the importance of simultaneous optimisation of process, water and energy integration for achieving profitability and sustainability within process industries.

Contents

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1. Introduction

1.1. Sustainable water and energy management within the industries

A typical chemical process consists of several subsystems, namely a reaction network, a separation network, a utility plant, a heat exchanger network, a water network, and a wastewater network. These subsystems are interconnected by different streams, e.g. process streams, water streams, hot and cold utilities, etc., within and between industrial processes, and also the environment (Fig. 1). The main goal of a chemical process is to transform raw materials into the desired products, thus enabling profitable and sustainable production and minimisation of water and energy consumption and waste generation into the environment.

The global consumption of water and energy is increasing and this trend will continue in the future (International Energy Outlook, 2013). Chemical Process Industries (CPIs) use large amounts of water and energy, and generate waste streams that are discharged into the environment. Pulp, paper and petroleum refining processes are amongst the larger users of water and energy within the manufacturing sector (Davé, 2004). Water and energy are usually linked within a process. Minimisation of water usage results in minimisation of wastewater generation and utility consumption for heating and cooling, and vice versa (Karuppiah et al., 2008; Ahmetović et al., 2010). Accordingly, water and energy consumption, and wastewater generation should therefore be minimised simultaneously. Discovering better alternatives for minimising water and energy usage, and waste generation satisfying environmental constraints is a global challenge for engineers and researchers (Bagatin et al., 2014). The reader is referred to some excellent handbooks/books covering these issues related to CPI such as process integration (El-Halwagi, 1997, 2006, 2012; Foo, 2013; Klemeš, 2013), sustainability in the process industry (Klemeš et al., 2010), chemical process design and integration (Smith, 2005), and systematic methods of chemical process design (Biegler et al., 1997). Also, the reader is referred to papers on process integration (Dunn and El-Halwagi, 2003), recent developments in process integration (Klemeš et al., 2013) and process synthesis (Grossmann and Guillén-Gosálbez, 2010). Systematic methods based on mathematical programming (MP) and pinch analysis (PA) have been applied over more than 40 years in order to achieve improved energy and water integration in CPI (Klemeš and Kravanja, 2013). For further details of these topics the reader is referred to comprehensive review papers relating to recent advances in chemical process optimisation (Biegler, 2014), mixed-integer nonlinear and general disjunctive programming solution methods (Trespalacios and Grossmann, 2014), heat exchanger network (HEN) synthesis (Gundersen and Naess, 1988, Furman and Sahinidis, 2002) and retrofit (Sreepathi and Rangaiah, 2014), optimal design of sustainable chemical processes and supply chains (Nikolopoulou and Ierapetritou, 2012), water network (WN) design methods using MP (Jeżowski, 2008), PA (Foo, 2009), and a combination of PA and MP (Bagajewicz, 2000; Jeżowski, 2010). Over the last two decades considerable attention has been devoted to the synthesis problem of heat integration within WNs and is expected to be an active research direction in the near future. The main goal of this synthesis problem is to perform simultaneous water and heat integration, and design an optimum combined network consisting of a WN and HEN.

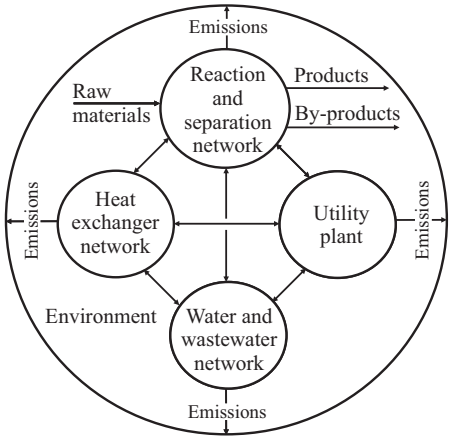

Fig. 1. The interconnections between the process subsystems and the environment.

1.2. Previous brief literature overviews on water and energy integration

The first review papers on the topic of WN synthesis using PA and MP were provided by Bagajewicz (2000), Jeżowski (2008), and Foo (2009). The main focus of those papers was on studies in which water integration was considered without heat integration. However, the importance of simultaneously considering water and energy integration was highlighted. In later review papers Jeżowski (2010), Chen and Wang (2012), Klemeš (2012), and Grossmann et al. (2014) only brief overviews were presented for some contributions on water and energy integration and the syntheses of non-isothermal WNs (see Table 1). In addition, two excellent overviews of process integration concepts and novel methods for combined energy and water integration were provided in the book's chapters (Savulescu and Kim, 2008; Savulescu and Alva-Argaez, 2013).

1.3. The purpose and structure of the paper

Over the last two decades the synthesis of non-isothermal WNs has attracted the attention of many researchers. Developments within this research field, especially over the last 5 years, and the need for updating current overviews and providing possible future directions regarding this topic have motivated the writing this review. Moreover, to the best of our knowledge there has been no comprehensive literature review of this field to date. The purpose of this paper is thus to provide such a comprehensive literature review of contributions over the last two decades within the field of synthesis of non-isothermal WNs, and to highlight possible future directions. This review is mainly limited to journal and conference papers written in English but other works are also commented on and discussed such as books and book chapters. It is hoped that this review will be useful for researchers as well as engineers in order to be up-to-date as to what is currently being done in this field, and have an overview of possible