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Reduction of water usage in industry by using the MINLP coordinates technique

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ABSTRACT

Natural resources are limited, so we need to handle them carefully. Wastewater also belongs as a significant natural resource. The re-usage of wastewater is to save fresh water and for the preparation of raw materials or/and utilities. The wastewater re-usage distribution can be optimised using mixed-integer nonlinear programming (MINLP), as a tool in combinations using the coordinates technique. The main goal of this MINLP coordinates technique was: i) wastewater and condensate, as produced during different industrial processes, could be collected for: utilities for steam-generation, and the preparations of raw materials; ii) wastewater and condensate could be collected within the main reservoir; iii) distributions from the main reservoir could be used with including different alternatives, which can reduce pollution, based on the re-usage of wastewater. Alternatives included in the optimization model represent potential solutions, which need to be evaluated on appropriate way.

The MINLP coordinates technique for wastewater re-usage distribution was tested on existing formalin and methanol industrial processes, thus allowing the saving of water and generated by 280 kEUR/a profit.

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1. Introduction

Water is an essential element throughout the chemical industry during normal functioning. Water is amongst the more important raw materials and utilities, therefore it is reasonable to re-use water within process industries.

The simplicity of pinch methodology, together with certain similarities between water minimisation and energy minimisation problems, have spawned the developments of conceptually designed approaches within the field of water minimisation (Majozi et al., 2006; Wang and Smith, 1994).

Lee et al. presented a mathematical programming technique to solve water minimisation problems for fixed schedule and cyclic operation batch processes (Lee et al., 2014).

Liu et al. proposed a superstructure and a mathematical programming model for optimization of a water network with both single and two outflow water-using processes (Liu et al., 2012). Optimization of industrial water networks made up of several water-using processes can reduce freshwater usage and wastewater production.

Hallale presented a new graphical method for targeting fresh water and wastewater minimisation (Hallale, 2002). The new approach is based upon a new representation of water composite curves and the concept of water surplus. This is used to construct a water surplus diagram, which is similar to the grand composite curve in heat pinch analysis.

Poplewski and Jezowski developed a simultaneous method to solve wastewater treatment network design problem with wastewater treatment technology choice (Poplewski and Jeżowsk, 2009). The approach consists in solving optimization model of a superstructure. Adaptive random search (ARS) method has been used as optimization technique.

Manan et al. presented a new technique for simultaneous minimisation of water and energy in process plants through a combination of numerical and graphical tools (Manan et al., 2009). The technique consists of three main steps, namely, setting the minimum water and wastewater targets; design of minimum water utilisation network, and heat recovery network design.

Tan et al. proposed a new systematic technique for the retrofit of water network with regeneration based on water pinch analysis (Tan et al., 2007). The procedure consists of two parts: retrofit targeting and design for a water network with regeneration units.

An important realisation about all these systems is, that in the absence of regeneration systems are pinched at the lowest (inlet) temperature. In addition, what makes the design challenging is that the mixing of streams is part of the design, especially if it is used to

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achieve target temperatures, and therefore avoiding the uses of heat exchangers or utilities. It has been shown that clever mixing can reduce the number of exchangers within a system (Bagajewicz et al., 2002; Savulescu et al., 2002).

Bagajewicz (Bagajewicz, 2000) carried out research work into solving the water minimisation problem for heat exchanger network (HEN) synthesis technologies.

The analogy between heat and mass transfer phenomena from the direct transposition of the classical thermal Pinch analysis to the so called mass pinch method. Based on the analogy between heat and mass exchangers, El-Halwagi et al (El-Halwagi and Manousiouthakis, 1989). first proposed an optimization method that was a direct extension of thermal pinch and which they called 'mass pinch analyses'. On the basis of the observed analogies between the mechanisms involved in the heat transfer and mass transfer, a unified vision of transport phenomena was proposed by Bird and co-workers (Bird et al., 1996).

Dhole et al. proposed a method (Dhole et al., 1996) analysis based on the minimum water requirement by each process operation in order to perform its function, called 'water demand', and the quantity of water simultaneously extracted or rejected by the same operations called 'water sources'.

Water sources can be used at other points during a process in order to satisfy other water demands, provided that the concentrations and other constraints are met (Shafiei et al., 2003). Their operation can tolerate a certain degree of variation regarding the purity of the wash water but imposes certain constraints.

The former always consists of a two-step approach (targeting and design) when synthesising a batch-water network that features minimum freshwater and wastewater flows for a given production schedule. On the other hand, mathematical methods (Ng et al., 2009; Gabriel and El-Halwagi, 2005) have their roots within an optimization framework. The mathematical techniques may be categorised by two subsections, namely, with and without scheduling consideration.

Sun et al. presented a novel two-step sequential methodology for the optimization of cooling-water system (CWS) (Sun et al., 2015). The first step is to use a thermodynamic model to obtain the optimal cooler network. In the second step, the hydraulic model is established to obtain the optimal pump network with auxiliary pumps installed in parallel branch pipes. In series or series-parallel configuration of cooler network, cooling water can be recycled or reused between coolers.

Klemeš (Klemeš, 2012) provided a brief overview of the recent techniques and methodologies in industrial water recycle/reuse. Lee et al (Lee et al., 2013). proposed a mathematical model for the synthesis and design of chilled water networks and explored opportunities of reusing or recycling chilled water. One of the earliest methods to design a cooler network was introduced by Kim and Smith (Kim and Smith, 2001). Their design methodology concentrated mainly on minimising cooling water flow-rate.

This paper explains the use of mixed-integer nonlinear programming (MINLP) (Biegler et al., 1997); by using a coordinate technique for wastewater re-usage distribution. The wastewater re-usage distribution can be solved quickly by using parallel or sequential methods that is a significant advantage for this technique.

2. MINLP coordinates technique

The main objectives of the MINLP coordinate technique are:

- wastewater and condensate, as produced during different industrial processes, could be collected for: utilities for steam-generation and the preparations of raw materials;
- wastewater and condensate could be collected within the main reservoir;
- the distribution from the main reservoir could be used as the parallel or sequentially splitting parts including different alternatives.

MINLP can be used for wastewater re-usage distribution during different alternatives. Economical wastewater re-usage distribution would optimise within industry. Wastewater and condensate, as produced during different chemical processes, could be collected within the main reservoir in regard to generating of different pressure steams and the usages of raw materials.

The main reservoir may include wastewater distribution during the different splitting parts ($P(S)$, and $S=\{S_1,S_2,...,SS\}$) regarding the parallel (Fig. 1) or sequential parts (Fig. 2) including different alternatives. The streams from main reservoir $P(S)$ under the same conditions could be parallelly divided on smaller streams by using different alternatives $YB(S,A)$. The streams from main reservoir $P(S)$ could be sequentially divided on smaller streams by using different sequential alternatives $YB(S,A)$ under the different progressive conditions.

Positive variables $P(S)$ provide the splitting parts of the distribution without binary variables:

$$\sum_S P(S) = 1 \tag{1}$$

$P(S)$ are included deliberately as splitting parts and not as binary variables, thus allowing better wastewater re-usage distribution. It means choosing between values 0 and 1, and therefore it could be easier to assume restrictions regarding the existing capacity.

The total mass flow rate (F_{tot}) is distributed to the individual $F(S)$:

$$\sum_S F(S) = F_{tot} \tag{2}$$

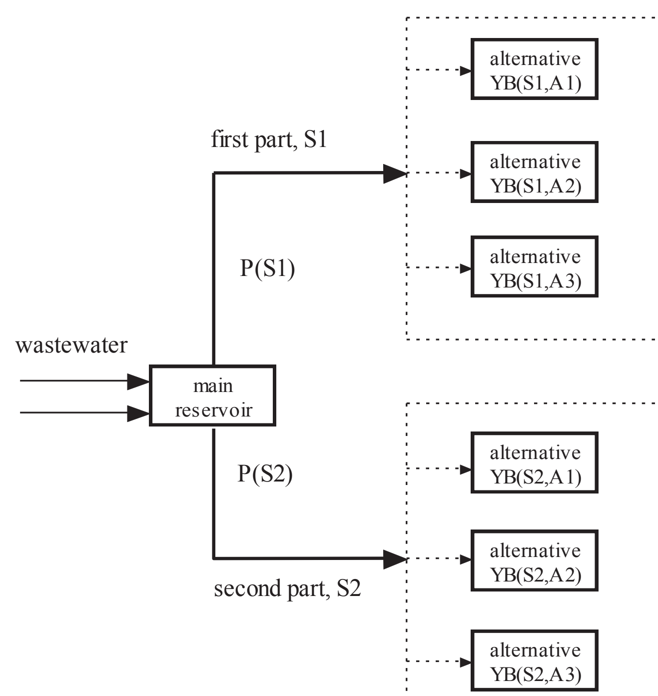

Fig. 1. Diagram of MINLP coordinates technique by using parallel method.