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Design of water-using networks of multiple contaminants with two internal water mains

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ABSTRACT

This paper presents a new method for design of water-using networks with two internal water mains. A conventional water-using network without internal water mains is obtained first by using the concentration potential method. The processes are divided into three parts to form an initial structure of the water-using network with two internal water mains, based on the features of the conventional water-using network obtained. The final design can be obtained in a few iterations by adjusting the amounts of the internal water mains. The results of a few literature examples show that the designs obtained in this work are comparable to that obtained in the literature. The significance of the work presented is that all the design steps, including the formation and adjustment of the internal water mains, are orientated with clear engineering meanings, which are expressed by the values of concentration potentials.

1. Introduction

Water scarcity and stricter environmental regulations have pushed forward the researches on wastewater minimization. Being an effective technology for saving freshwater and reducing wastewater, water system integration has become one of the research focuses recently.

Many methods have been proposed in water system integration. Wang and Smith (1994) proposed water pinch method to target the minimum freshwater consumption and wastewater discharge with the limiting composite curves. Kuo and Smith (1998) applied pinch analysis method to design water-using network involving regeneration. Castro et al. (1999) extended the regeneration-reuse approach to take into consideration the problem of multiple pinches. Gomes et al. (2007) proposed water source diagram to synthesize water mass-exchange networks for water/wastewater minimization. Tan et al. (2007) developed a systematic procedure based on water pinch analysis for the retrofit of water network with regeneration, which further minimized freshwater consumption and wastewater generation in an existing water network. Chen and Lee (2010) presented a series of graphical analysis to exploit all water reuse opportunities. Parand et al. (2013) proposed a new design method for water network synthesis without waste discharge.

Mathematical programming methods are also widely used to design and target water networks of multiple contaminants. Takama et al. (1980) investigated the water allocation problems by using superstructure coupled with mathematical programming method. Majozi (2005) presented a superstructure that included all possible recycle and reuse possibilities for freshwater and wastewater minimization. Statyukha et al. (2008) developed a non-linear programming (NLP) model for targeting the minimum freshwater consumption and wastewater discharge, in which global optimal solutions were not guaranteed. Teles et al. (2009) presented two mixed-integer linear programming (MILP) based procedures to solve the difficulty of obtaining global optimal solutions of the NLP. Handani et al. (2010) developed an MILP model to minimize freshwater consumption and wastewater generation for systems involving regeneration units. Poplewski et al. (2011) proposed an adaptive random search method for design of water network with regeneration processes. Sotelo-Pichardo et al. (2011) presented a general mathematical programming model for the optimal retrofit of water networks involving recycle, reuse and regeneration. Tokos et al. (2013) proposed a bi-objective optimization method for evaluating the economic and environmental impacts for total water network retrofitting. McClymont et al. (2013) presented a novel hyper-heuristic approach which was specialized for a bi-objective formulation of water network design problem.

In the work discussed above, the processes are connected with pipes directly. If the entire plant involves only a few processes, the networks are fairly simple. However, the piping

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network with many process units will be very complicated and it is difficult to operate and control for a large petrochemical or chemical complex. Moreover, the change of water flowrate or water quality of some processes might influence the others significantly.

To solve the difficulties mentioned above, Feng and Seider (2001) proposed a structure with one or more internal water mains for water-using networks. The water-using networks with internal water mains can overcome the above mentioned limitations to some extent. Wang et al. (2003) introduced a concept of “water-saving factor” to design the water-using networks of multiple contaminants with single internal water main. Wang et al. (2005) proposed a method for design of the water-using networks with internal water mains. The method of Wang et al. (2005) emphasized the significance of determining the location of the first internal water main, and discussed how to allocate water streams of the internal water mains to subsequent processes. Zheng et al. (2006) used a superstructure and a mixed-integer nonlinear programming (MINLP) approach to design the water-using networks of multiple contaminants with internal water mains. Ma et al. (2007) presented an optimization method for design of the water-using networks with internal water mains based on empirical rules. They designed an initial water-using network by using mathematical programming methods first. The structure of the water-using network with internal water mains was determined based on the initial network obtained. He et al. (2010) proposed a simple method based on the concentration potential concepts (Liu et al., 2009a) to design the water-using networks with internal water mains. In their method, a conventional water network was obtained with the concentration potential concepts (Liu et al., 2009a), and then an initial structure of the water-using network with internal water mains was developed based on the conventional network. The final design was obtained with a trial-and-error approach. Su et al. (2012) proposed a new method to design the water-using network with single internal water main by using the concentration potential concepts (Liu et al., 2009a) as well.

In this paper, we propose a new method to design the water-using networks with two internal water mains based on the methodology concepts of concentration potentials proposed by Liu et al. (2009a). An initial structure of the water-using networks with two internal water mains can be determined based on the conventional water-using network which is obtained by using the concentration potential method (Liu et al., 2009a). The final design can be obtained by adjusting the amounts of the internal water mains in a few iterations. It is shown that the proposed method is simple, and the results obtained are comparable to that obtained in the literature.

2. Basic concepts

Determination of the concentration order of streams is often important in design and targeting of water-using networks. For a water-using network of single contaminant, it is easy to determine the concentration order of streams. However, it is often difficult to determine the concentration order of streams for the water-using network of multiple contaminants. In order to solve the problem, Liu et al. (2009a) introduced new methodology concepts of Concentration Potentials of the Demand (CPD) and Concentration Potentials of the Source (CPS) for the water-using networks of multiple contaminants. The concepts of concentration potentials have been successfully applied in design of water network involving reuse only (Liu et al., 2009a), regeneration reuse (Liu et al., 2009b) and regeneration recycling (Pan et al., 2012). Wang et al. (2012) combined the concentration potential concepts with an LP approach to design the water-using networks of multiple contaminants. Fan et al. (2012) presented a new design method for the water-using networks involving both fixed flowrate operations and fixed contaminant load ones. Zhao et al. (2013) proposed a new method for design of regeneration recycling water networks involving internal water mains based on the concentration potential concepts.

The CPD value of a demand stream is a measure of the overall possibility of the demand to reuse the source streams, as shown in Eq. (1):

$$\mathrm{CPD}(D_j) = \sum_{l=1}^{\mathrm{NS}} \min_{k=1,2,\cdots,\mathrm{NC}} \left(\frac{C_{D_j,k}^{\lim}}{C_{S_l,k}} \right) \tag{1}$$

where $C_{D_j,k}^{\lim}$ is the limiting concentration of contaminant k in demand D_j, $C_{S_l,k}$ is the concentration of contaminant k in source S_l, NC is the number of contaminants, and NS is the number of source streams.

The lower the CPD (D_j) value of a demand stream, the lower the conventional concentrations of the demand stream, as has been proved by Liu et al. (2009a).

The CPS value of a source stream is a measure of overall possibility of the source to be reused by the demand streams, as shown in Eq. (2):

$$\mathrm{CPS}(S_l) = \frac{1}{\sum_{j=1}^{\mathrm{ND}} \min_{k=1,2,\cdots,\mathrm{NC}} \left[\frac{C_{D_j,k}^{\lim}}{C_{S_l,k}} \right]} \tag{2}$$

where ND is the number of demand streams.

The lower the CPS(S_l) value of a source stream, the higher the overall possibility for the source to be reused by the demands.

3. Design procedure

A few heuristic rules are proposed in this paper for design of the water-using networks with two internal water mains. The design procedure is shown in Fig. 1 and will be discussed in the following sections.

3.1. Developing a conventional water-using network

A conventional water-using network without internal water mains is obtained by using the concentration potential method (Liu et al., 2009a) first. The brief design procedure is as follows:

a. Arrange the processes in ascending order of the CPD values obtained based on the limiting concentrations;
b. The processes with the lowest CPD values will be performed first, and they often use freshwater;
c. If a source stream is used up, it will not be considered in the following steps;
d. The CPD values of the processes to be performed will be calculated based on the current available sources, which are freshwater and the outlet streams of the performed processes;
e. Satisfy the demand streams by the current available sources. The outlet concentrations of the performed processes can be obtained based on mass balance;
f. Return to step c, till all processes are performed.

The readers can refer to Liu et al. (2009a) for detailed design procedure.