ULTIMATE FLOWRATE TARGETING WITH REGENERATION PLACEMENT

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Abstract: Water regeneration has been widely accepted as an effective mean to further reduce flowrate targets in a water network, and is often employed after the opportunity for flowrate reduction via water reuse/recycle have been exhausted. In this work, a new numerical targeting procedure is proposed to locate the minimum regeneration flowrate that achieves the ultimate fresh water and wastewater targets for both fixed flowrate and fixed load problems. Literature examples are solved to illustrate the applicability of the developed technique.

Keywords: process integration; pinch analysis; water minimization; targeting; water regeneration.

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DOI: 10.1205/cherd07025

0263–8762/07/
$30.00 + 0.00

Chemical Engineering Research and Design

Trans IChemE,
Part A, September 2007

INTRODUCTION

The exhaustion of natural resources will soon become the major problem for the world. The fact that the world faces a water crisis recently has become increasingly clear. For instance, water withdrawal for most uses (domestic, industrial, and livestock) is projected to increase by at least 50% by the year 2025 (Rosegrant *et al.*, 2002). Challenges remain widespread and reflect severe problems in the management of water resources in many parts of the world. These problems will intensify unless effective and concerted actions are taken, as was made in the World Water Vision (Cosgrove and Rijsberman, 2000).

Apart from that, the increase of public awareness about environmental issues and stringent emission legislations have forced the process industries to look into cost effective measures in reducing production and treatment costs to ensure business competitiveness. One of the active areas for cost reduction activities has been that of resource conservation. Via in-plant material reuse/recycle, both raw material consumption (and its associated treatment) as well as the quantity of its generated waste are reduced significantly. In the context of resource conservation, *reuse* means that the effluent from one unit is used in another unit and does not re-enter the unit where it has been previously used. On the other hand, *recycle* allows the effluent to re-enter the unit where it has been previously used [Figure 1(a)]; (Wang and Smith, 1994). Significant work has been performed to systematically address in-plant water reuse/recycle and regeneration/treatment in the past decade. These works are reviewed in the following sections.

Targeting for Water Reuse/Recycle

The seminal work of graphical technique for water network synthesis was done by Wang and Smith (1994), who proposed a two-step pinch analysis approach in synthesising a water network, based on the more generalized work of mass exchange network synthesis (El-Halwagi and Manousiouthakis, 1989). The limiting water profile was used in the first step to locate the minimum water flowrates, i.e., fresh water consumption and wastewater generation, prior to detailed network design in the second step. Although this is a groundbreaking work that leads to the in-depth understanding of water network synthesis, the method can only be applied to mass transfer processes that utilise water as mass separating agent in removing a fixed amount of impurity load from the process streams (also known as *fixed load problem*).

Realizing the limitation of the fixed load model, Dhole *et al.* (1996) and Polley and Polley (2000) later proposed to use the

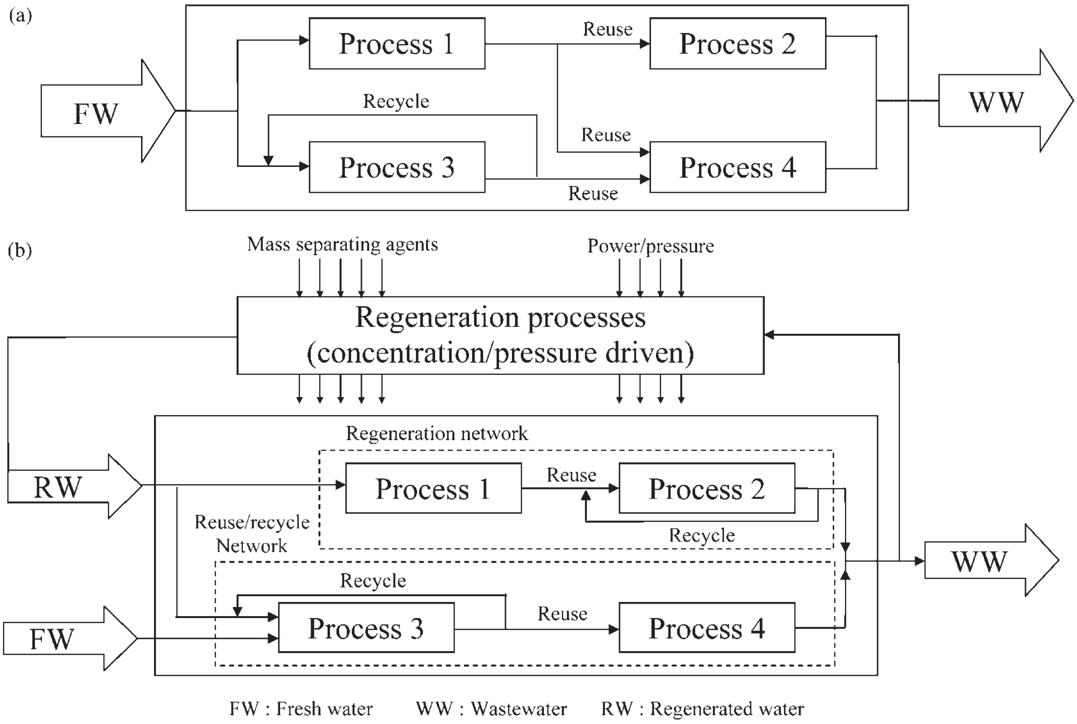

Figure 1. (a) Water reuse/recycle network; (b) smaller fresh water and wastewater flowrates for water network with regeneration.

water source and demand composite curves where impurity concentration is plotted versus water flowrate for the non-mass transfer-based processes. These composite curves cater for processes where water flowrate is of concern during water reuse/recycle (fixed flowrate problem). The approach was then extended into its algebraic form known as the evolutionary table by Sorin and Bédard (1999). However, later works showed that these approaches do not guarantee absolute minimum water flowrate targets (Hallale, 2002; El-Halwagi *et al.*, 2003; Manan *et al.*, 2004; Prakash and Shenoy, 2005).

In the work of Hallale (2002), water surplus diagram is used to determine the water targets. However, the iterative procedure for plotting the water surplus diagram makes the approach cumbersome and tedious. Manan *et al.* (2004) overcomes this by introducing a non-iterative algebraic method called the water cascade analysis (WCA) technique based on the concept of water surplus diagram (Hallale, 2002).

Another non-iterative graphical tool known as the material recovery pinch diagram that locates the minimum water targets was individually developed by El-Halwagi *et al.* (2003) as well as Prakash and Shenoy (2005). The numerical tool equivalent to the material recovery pinch diagram has also been developed (Almutlaq *et al.*, 2005; Almutlaq and El-Halwagi, 2006). The last four graphical and numerical tools are by far the most promising techniques in locating the minimum water targets in a water network. While graphical targeting tools provide the conceptual insights for network synthesis, numerical tools are preferred when rapid and accurate answers, or when repeated calculation is needed. Once the water targets are established, the water network will be designed to achieve the minimum targets using the available design tools (e.g., El-Halwagi, 1997; Kuo and Smith, 1998; Feng and Seider, 2001; Prakash and Shenoy, 2005; Aly *et al.*, 2005; Gomes *et al.*, 2007).

Targeting for Water Regeneration

Water regeneration involves partial or total upgrading of water purity using purification technique(s). In general, these purification techniques can be categorized as pressure-driven (e.g., filtration, membrane separation) and concentration-driven (e.g., adsorption, ion exchange, steam stripping) separation processes. By intercepting a process stream to match the process constraint (e.g., limiting concentration of water sink), the level of contaminant in the water sources are reduced and the regenerated water can either be reused in other water-using processes or recycled to the same process. This leads to further reduction of water flowrates in the network.

Flowrate targeting for water regeneration was first proposed by Wang and Smith (1994). The authors extended the use of the limiting water profile which was developed for flowrate targeting in a reuse/recycle network to set the flowrate targets for regeneration placement (Wang and Smith, 1994). In this early work of regeneration targeting, inlet to a regeneration unit will draw from water streams that reach the pinch concentration after they have been reused/recycled in the water-using processes. More recently, Agrawal and Shenoy (2006) extended the same targeting approach for the fixed flowrate problems. However, as pointed out by Kuo and Smith (1998), the approach of drawing water sources at pinch concentration for regeneration may fail to locate the minimum water targets in cases where pinch is reallocated to a new concentration after regeneration took place in the water network.