

Approximate Graphical Targeting for Water Network with Two Contaminants

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Water reuse/recycle has become one of the main strategies to reduce fresh water and wastewater flowrates in the process industries. Rigorous pinch analysis techniques have been developed to target for minimise water flowrates for both fixed load and fixed flowrate problems. However, most pinch-based targeting techniques for fixed flowrate problems to date have been focused on single contaminant network. This paper presents a new graphical targeting technique to establish the minimum utility targets for water network with two contaminants. Firstly, a comparison of mass load ratio between water sinks and sources is carried out to determine the leading limiting water sink, source and key contaminant at the pinch concentration. The minimum water targets are next located using a modified material recovery pinch diagram for multiple contaminants. Literature examples are solved to illustrate the applicability of the developed technique.

Keywords: Water minimisation, two contaminants, flowrate targeting, process integration, pinch analysis.

1. Introduction

Water is extensively used in the process industry such as chemical, petrochemical, pulp and paper and textile manufacturing. However, in recently years, stricter environmental regulations, scarcity of quality industrial water and the rising cost of fresh water and wastewater treatment have forced the process plants to reduce water usage. Concurrently, there has been extensive progress in the development of systematic techniques for water reduction, reuse and regeneration within a process plant.

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Over the past decade, the advent of water pinch analysis (WPA) as a synthesis tool for optimal water network has been one of the most significant advances in the area of water minimisation. WPA enables one to locate the minimum utility targets (fresh water consumption and wastewater generation) prior to detailed network design. WPA has been relatively well established for the synthesis of single contaminant water networks for fixed flowrate problems (Hallale, 2002; El-Halwagi *et al.*, 2003; Manan *et al.*, 2004; Prakash and Shenoy, 2005). However, in many cases, it is often necessary to take in account of several contaminants during water network synthesis and the aforementioned approaches single contaminant network may not be applicable.

Takama *et al.* (1980) initiated the synthesis work for multi-contaminants water network based on a non-linear programming (NLP) model for a fixed mass load problem. Nevertheless, this method unable to achieve the global optimum solution. In the seminal work of pinch-based water network synthesis, Wang and Smith (1994) utilised the limiting water profile, an extension of their single contaminant targeting approach to locate the minimum water targets for two contaminants. However, this approach is limited to fixed-load problems involving small number of streams.

In a later work, Doyle and Smith (1997) used linear programming (LP) and NLP approaches to achieve locate flowrate targets for multiple contaminants water network with fixed outlet concentration and fixed mass load models. A methodology that combines insight from WPA and mathematical optimisation approaches was later presented by Alva-Argaez *et al.* (1999). Bagajewicz *et al.* (2000) established a multi-contaminant approach, which combines mathematical programming and optimal criteria to achieve the optimum solution with minimum capital and operating costs. Salveski and Bagajewicz (2003) further extended the necessary conditions of optimality from single contaminant into multi-contaminant water network.

All aforementioned works for multiple contaminants water network synthesis have mainly focused on fixed mass load (mass transfer-based) operations. In many fixed flowrate operations, water flowrate is more important than contaminant load removal (Hallale, 2002; Manan, *et al.*, 2004; Prakash and Shenoy, 2005). Note also that, the fixed flowrate operations can have different inlet and outlet flowrates. This paper extends the source/sink composite curves that was originally developed for single contaminant problem (El-Halwagi *et al.*, 2003; Prakash and Shenoy, 2005) into water network with two key contaminants. Source/sink composite curves enables water flowrate targets to be set prior to detailed network design. Two literature case studies are used to illustrate the methodology.

2. Methodology and Result

2.1 Utility Targeting

The first step in utility targeting is to identify the leading limiting water sink, source and key contaminant at the pinch concentration. First of all, the mass load ratio between sinks and sources, $R_{\Delta m,i,j,c}$ is calculated as follow,

Table 1. Limiting data for Example 1

SK _j	Flowrate, F _j (t/h)	Contaminant, c	Concentration, C _j (ppm)	SR _i	Flowrate, F _i (t/h)	Contaminant, c	Concentration, C _i (ppm)
1	40	A	0	1	40	A	100
		B	25			B	75
2	35	A	80	2	35	A	240
		B	30			B	90

$$R_{\Delta m, i, j, c} = \left(\frac{\Delta m_{SK_j}}{\Delta m_{SR_i}} \right)_c \quad \text{where } i = 1, 2, \dots, N_{SR}, j = 1, 2, \dots, N_{SK} \text{ and } c = A, B, \dots, N_c.$$

$R_{\Delta m, i, j, c}$ indicates the potential of water reuse/recycling from source SR_i to sink SK_j for each contaminant c . In order to maximise reuse/recycle from SR_i to SK_j, the maximum mass load ratio for each contaminant c , $R_{\Delta m, i, j, c}^{\max}$ is selected. Next, the leading limiting water sink, source and key contaminant at the pinch concentration are identified by choosing the minimum value among the selected $R_{\Delta m, i, j, c}^{\max}$, i.e. $(R_{\Delta m, i, j, c}^{\max})^{\min}$.

Table 1 shows the limiting data for Example 1 taken from Wang and Smith (1994), which comprises of two sources and two sinks with contaminants A and B, with the $R_{\Delta m, i, j, c}$ values presented in Table 2. The value in bold represents $R_{\Delta m, i, j, c}^{\max}$ for each contaminant. By comparing these two values, $(R_{\Delta m, i, j, c}^{\max})^{\min}$ is identified as 0.35, which means that contaminant B is the limiting contaminant; while SK₂ and SR₁ are the leading limiting water sink and source at the pinch concentration.

In the second step of utility targeting, a modified source/sink composite curves (El-Halwagi *et al.*, 2003; Prakash and Shenoy, 2005) is used to locate the minimum water flowrate targets. For water network with two contaminants, the source/sink composite curves are created by superimposing the arrows in ascending order by connecting to the lower concentration of contaminant. The arrangement of sources and sinks in the composite curves depends on the information obtained from the first step.

For example 1, Contaminant B is identified as the limiting contaminant; while SK₂ and SR₁ are the leading limiting water sink and source at the pinch concentration. This means that the lines of contaminant B of SK₂ and SR₁ will touch to create a pinch concentration in the source/sink composite curves. Therefore, sink and source composite curves of Example 1 are plotted as SK₁-SK₂ and SR₁-SR₂ respectively (Figure 1). As shown in Figure 1, Example 1 requires 61 t/h of fresh water and wastewater respectively, with 75 ppm identified as the pinch concentration.

Table 2. $R_{\Delta m, i, j, c}$ for Example 1

$R_{\Delta m, i, j, c}$	Contaminant A	Contaminant B
$\Delta m_{SK1} / \Delta m_{SR1}$	0	0.3333
$\Delta m_{SK1} / \Delta m_{SR2}$	0	0.3175
$\Delta m_{SK2} / \Delta m_{SR1}$	0.7	0.35
$\Delta m_{SK2} / \Delta m_{SR2}$	0.3333	0.3333

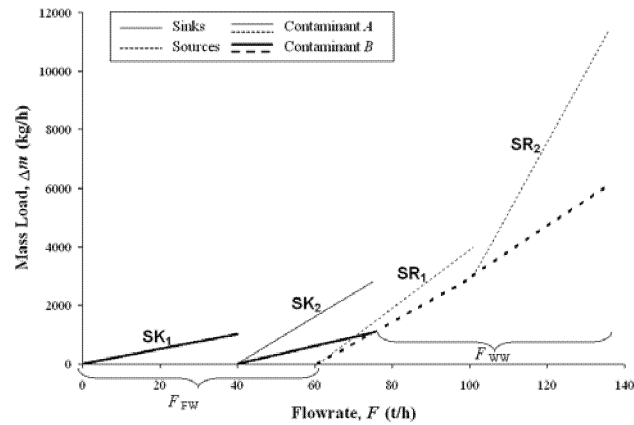


Figure 1. Source/sink composite curves for Example 1.

To show the broad applicability of the targeting method, Example 2 from Wang and Smith (1994) is used for demonstration. Limiting data for Example 2 is shown in Table 3. Figure 2 presents source/sink composite curves for this example. As shown, 114.29 t/h of fresh water and wastewater are required by the water network respectively, with 70 ppm identified as the pinch concentration.

Table 3. Limiting data for Example 2

SK_j	Flowrate, F_j (t/h)	Contaminant, c	Concentration, C_j (ppm)	SR_i	Flowrate, F_i (t/h)	Contaminant, c	Concentration, C_i (ppm)
1	80	A	0	1	80	A	100
		B	20			B	70
2	60	A	80	2	60	A	200
		B	30			B	120

2.2 Network Design

This section briefly discusses network design method for a multiple contaminants network that achieves the established flowrate targets. Network design for a multiple contaminants network utilises the same guidelines of the single contaminant network. Region lower than the pinch concentration (low concentration region) is the most constrained region and hence controls the overall fresh water flowrate of the network. On the other hand, excess of water is found in the region higher than the pinch concentration (high concentration region). Hence, fresh water and water sources in the lower concentration region may not be fed to sinks or mix with water sources in the higher concentration region. The source at the pinch is an exception where it belongs to both regions. Network design procedure for fixed flowrate problems has been established for single contaminant network (El-Halwagi, 1997; Prakash and Shenoy, 2005).

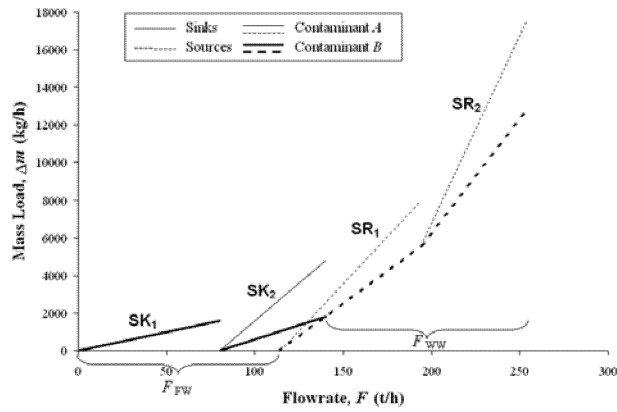


Figure 2. Source/sink composite curves for Example 2.

Network design for Example 1 and 2 are shown in Figure 1 and 2 respectively. As shown, the total fresh water and wastewater flowrates for Example 1 are both amounts to 61 t/h; while network in Example 2 has a minimum flowrates of 114.29 t/h of fresh water and wastewater respectively. These examples prove that the minimum water flowrates for both networks match with the established targets.

3. Conclusion

This paper presents a new targeting approach to locate minimum flowrates in water networks with two contaminants. Source/sink composite curves that was originally developed for targeting a single contaminant network has been extended its use in the two contaminant network. By comparing the mass load ratio between water sinks and sources to determine the leading limiting water sink, source and key contaminant at the pinch concentration, the minimum water targets are located accurately. Two case studies were utilised to demonstrate the applicability of the methodology. This work can be further developed for problems with more than two contaminants.

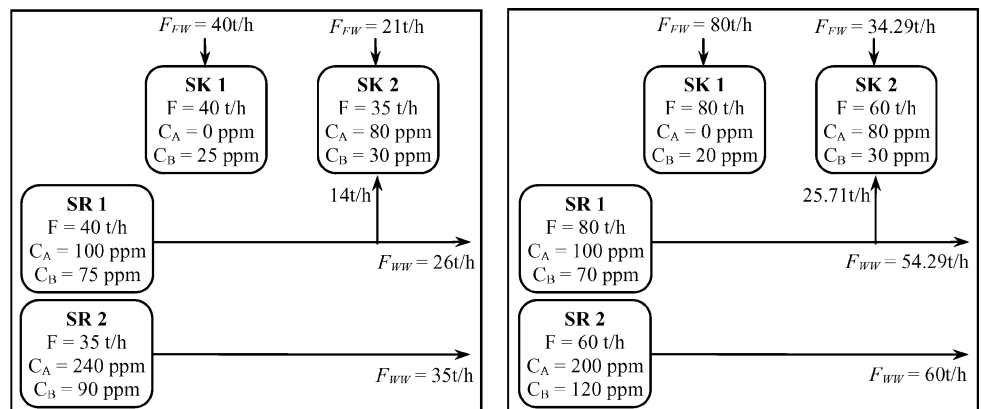


Figure 3. Network design for Example 1 and Example 2

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