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An Effective Method for Targeting Water-using Networks of Single Contaminant Involving Regeneration Reuse/Recycling

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Targeting of water-using networks involving regeneration reuse/recycling is often more difficult than that of the ones involving reuse only, especially for the regeneration unit with fixed removed ratio (RR) model. An effective method is presented in this article for targeting single contaminant water-using networks with fixed RR-model regeneration unit. The targeting procedure is based on the analysis of the features of the networks, and a few relationships developed from flow rate and mass load balances. The results of one literature example show that the target of a water-using network of single contaminant involving regeneration reuse/recycling can be obtained easily with the proposed method. From the targeting procedure proposed, it can be seen that the deeper we understand the features of water-using networks with regeneration unit, the simpler the targeting procedure.

1. Introduction

Recently, it has been an urgent problem to utilize water resource efficiently and reasonably with the aggravation of water scarcity and water pollution. Water system integration, one of important techniques for minimizing wastewater, has attracted more and more attention. The introduction of regeneration unit in a water-using network can significantly reduce freshwater consumption and wastewater discharge. However, targeting and design of the water-using networks involving regeneration reuse/recycling is often more difficult than that of the ones involving reuse only.

Although many methods have been proposed for targeting single contaminant water-using networks involving regeneration reuse/recycling, most of them are relatively complicated. Wang and Smith (1994) proposed a graphical method for targeting and design of water-using networks involving regeneration reuse. In the work of Kuo and Smith (1998), the target of water-using network involving regeneration was obtained by migrating streams, which were classified into two groups, based on two mechanisms and seven criteria. Feng et al. (2007) investigated the optimal water supply line for single contaminant networks involving regeneration recycling to determine the minimum freshwater consumption, minimum regenerated water flow rate and optimal regeneration concentration. Bandyopadhyay and Cormos (2008) presented a graphical representation named source composite curve to target the regeneration flow rate. In the method of Pan et al. (2011), it required several iterations, in which detailed calculations of all the allocations from sources to demands should be carried out, to obtain the final results.

In this article, we will present a simple and effective method for targeting water-using networks of single contaminant involving regeneration reuse/recycling. By analyzing the features of water-using processes and regeneration unit, a few relationships among the contaminant mass load discharged into wastewater, the contaminant mass load in the streams of the network and the contaminant mass load removed by the regeneration unit can be obtained. Then, the regeneration target can be calculated easily based on these relationships. In the targeting procedure, only one step of detailed calculation is required.

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2. Analysis on features of water-using network with regeneration unit

The models of regeneration units can be classified into fixed regenerated concentration type and fixed removal ratio (*RR*) type (Wang and Smith, 1994) and in (Kuo and smith, 1998).
In the *RR*-model: $RR = (F_{in}C_{in} - F_{reg}C_{reg})/(F_{in}C_{in})$. Assuming that there is no water loss in regeneration operation, the above equation can be simplified into Eq(1):

$$C_{reg} = C_{in}(1 - RR) \tag{1}$$

For a water-using network with *RR*-model regeneration unit, the flow rate and concentration of the regenerated stream are unknown before detailed design. Therefore, it is more difficult to design the water-using networks with *RR*-model regeneration unit than that with fixed regenerated concentration model. We will focus the discussion on the water-using networks with *RR*-model regeneration unit. The single contaminant water-using networks with regeneration unit will be analyzed as follows.

2.1 Contaminant mass load balance for a water-using network with regeneration unit

The contaminant mass load balance for a water-using network with regeneration unit is shown in Figure 1.

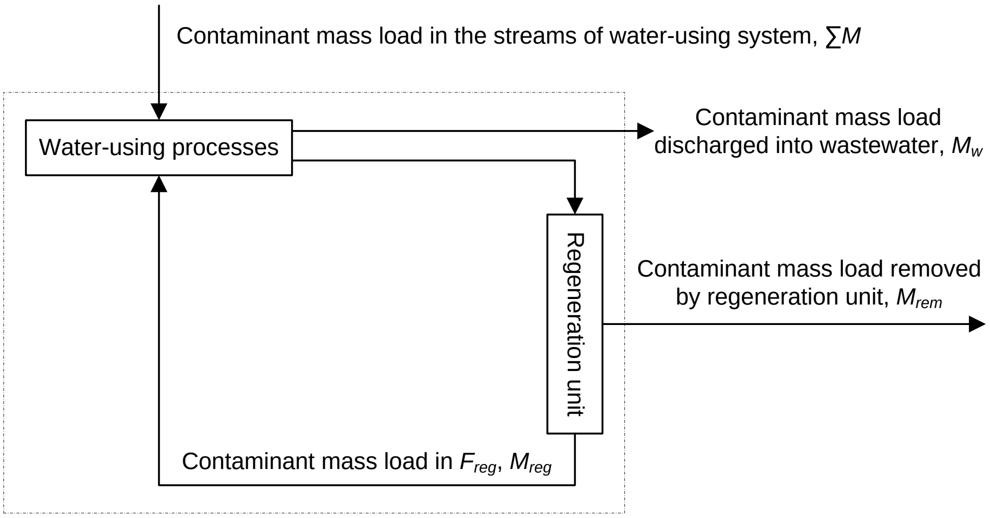

Figure 1: Contaminant mass load balance for a water-using network with regeneration unit

The contaminant mass load in the streams of water-using system is:

$$\sum M = M_w + M_{rem} \tag{2}$$

where M_w is the contaminant mass load discharged into wastewater, and M_{rem} is the contaminant mass load removed by the regeneration unit.

2.2 Flow rate balance for a water-using network with regeneration unit

A water-using network without water loss is shown in Figure 2.

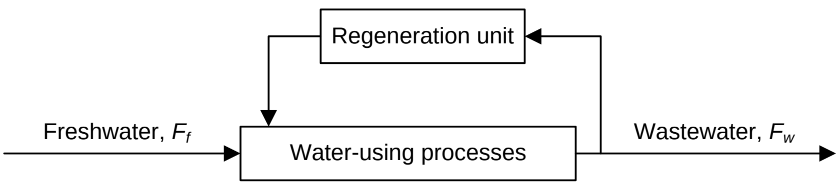

Figure 2: Flow rate balance for a water-using network with regeneration unit

The flow rate balance for the network is:

$$F_f = F_w \tag{3}$$

where F_f is the flow rate of freshwater, and F_w is the flow rate of wastewater.

From Eq(3), the flow rate of wastewater stream can be obtained. The contaminant mass load discharged into wastewater, which is expressed as $M_w = F_w C_w$, can thus be obtained. Then, the contaminant mass load removed by regeneration unit, M_{rem}, can be calculated with Eq. (2), because $\sum M$ can be obtained easily.
The *RR* value can be expressed as:

$$M_{rem} / (M_{reg}+M_{rem}) = RR \tag{4}$$

From Eq(4), the contaminant mass load in regenerated stream, M_{reg}, can be obtained:

$$M_{reg} = M_{rem} (1/RR - 1) \tag{5}$$

Meanwhile, M_{reg} can be represented with Eq(6):

$$M_{reg} = F_{reg} C_{reg} \tag{6}$$

2.3 Obtaining regeneration target values

Since M_{reg} can be calculated from Eq(5), if we can develop some other equations which delineate the relationships between the regeneration targets F_{reg} and C_{reg}, their values can be obtained by solving Eq(6) and these equations simultaneously. The relationships obtained by Xu et al. (2013) can assist the targeting procedure. Let us describe them briefly as follows.
For a water-using network of single contaminant involving regeneration, the source and demand streams can be arranged in ascending order of the contaminant concentrations from bottom to top, respectively, as shown in Figure 3. Eqs(7-8) show the relationships of flow rate and contaminant load balances between the demand and source streams below the regeneration pinch:

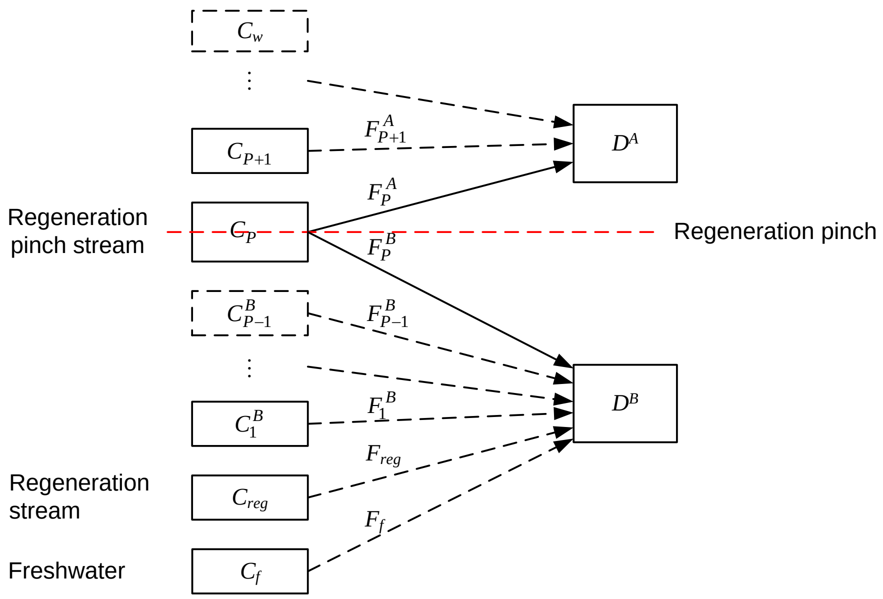

Figure 3: Sources to satisfy the demands below the regeneration pinch

$$MD^B = F_f\, C_f + F_{reg}\, C_{reg} + \sum_{i=1}^{P-1} F_i^B\, C_i^B + F_P^B\, C_P \tag{7}$$

$$FD^B = F_f + F_{reg} + \sum_{i=1}^{P-1} F_i^B + F_P^B \tag{8}$$

where MD^B and FD^B are the cumulative contaminant mass load and cumulative flow rate of demand streams below the regeneration pinch, F_f and C_f are the flow rate and concentration of freshwater, F_{reg} and C_{reg} are the flow rate and concentration of the regenerated stream, F_i^B and C_i^B are the flow rate and concentration of source stream S_i, F_P^B is the flow rate of pinch-source stream allocating to demand stream below the regeneration pinch, and C_P is the concentration of the pinch-source stream.

From Figure 3 and Eqs(7-8), it can be seen that if the regeneration pinch is known, the parameters, MD^B, FD^B, F_f, C_f, $\sum_{i=1}^{P-1} F_i^B C_i^B$, $\sum_{i=1}^{P-1} F_i^B$ and C_P, are known. Therefore, the regeneration target values, F_{reg}, C_{reg} and F_P^B, can be obtained by solving Eqs(6-8) simultaneously.

3. The targeting procedure

Based on the above analysis, we can obtain the target of regenerated stream consumption for the water-using networks with *RR*-model regeneration unit by using the procedure shown in Figure 4, which will be discussed in detail as follows:

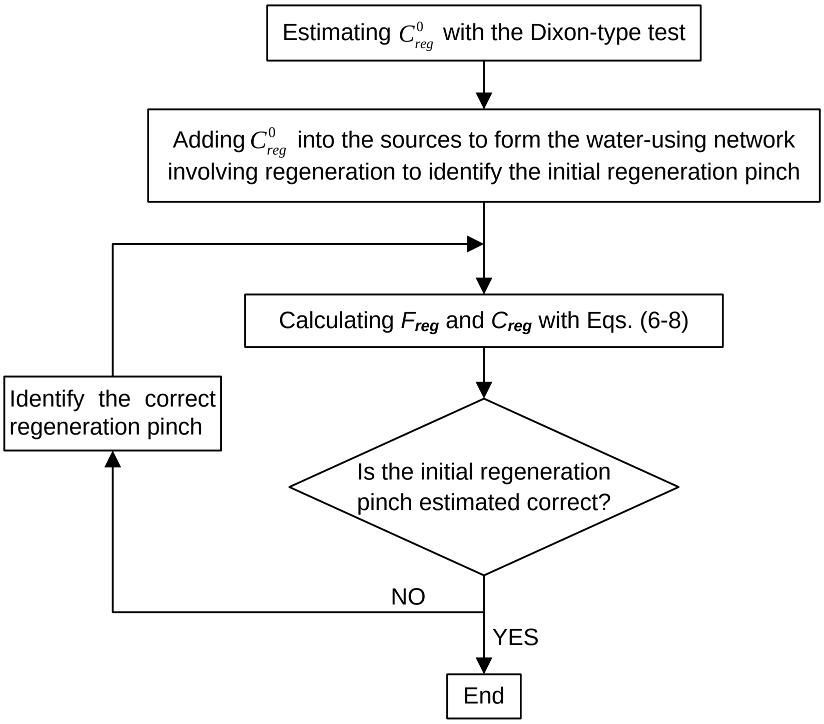

Figure 4 :The targeting procedure proposed

3.1 Estimating the initial regenerated concentration

The regeneration stream is formed by internal source(s). The initial regenerated concentration can be estimated based on the usage of the internal sources. Generally speaking, allocations of the internal sources are as follows: those with very low concentrations would be reused by other processes, those with very high concentrations would be discharged, and those with medium concentrations might form the regeneration stream. In this paper, the Dixon-type test will be employed to identify the internal sources to be regenerated. The sources, which pass the Dixon-type test will form the initial regeneration stream. The readers are referred to Barnett and Lewis (1985) for more information about the Dixon-type test. The initial regenerated concentration can be obtained with Eq(1).

3.2 Identifying the initial regeneration pinch

By adding the initial regenerated stream into the sources of the original network, the network involving regeneration can be formed (Liu et al. 2009a). Then, the initial regeneration pinch can be identified with the method presented by Liu et al. (2009b).

3.3 Obtaining the regeneration target value

The regenerated concentration C_{reg} and the flow rate of the regenerated stream F_{reg} can be obtained from Eqs(6-8).

There are two situations in calculating F_{reg} and C_{reg}: (a) if the initial regeneration pinch is estimated correctly, F_{reg} and C_{reg} can be obtained from Eqs(6-8); (b) if the initial regeneration pinch is not estimated correctly, the correct pinch point can be determined based on the results of the first step calculation, return to Section 3.3 to obtain the target of water-using network, based on the new regeneration pinch.

4. Case study

This example is taken from Kuo and Smith (1998), with limiting data shown in Table 1. The removal ratio value is 95 %. The data of demand and source streams generated from Table 1 are shown in Table 2.

Table 1: Limiting data for Example

Process	C_{in}^{max} (ppm)	C_{out}^{max} (ppm)	F^{lim} (t h^{-1})	M (g h^{-1})
1	0	200	40	8,000
2	100	200	50	5,000
3	100	400	30	9,000
4	300	400	60	6,000
5	400	600	40	8,000

Table 2: Generated data of demand and source streams for Example

Demand			Source		
C_{in}^{max} (ppm)	F_D (t h^{-1})	M_D (g h^{-1})	C_{out}^{max} (ppm)	F_S (t h^{-1})	M_S (g h^{-1})
0	40	0	200	90	18,000
100	80	8,000	400	90	36,000
300	60	18,000	600	40	24,000
400	40	16,000			

There is no outlier for the concentrations of the sources by using the Dixon-type test. All the internal sources will be used to calculate the initial regenerated concentration, C_{reg}^{0}, with Eq(1):

$$C_{reg}^{0} = C_{in}(1-RR) = [(18000+36000+24000)/(90+90+40)]\times(1-0.95) = 17.73 \text{ ppm}$$

Include the initial regenerated stream into the sources of the original network to form the network involving regeneration. By using the method of Liu et al. (2009b), it is obtained that the initial regeneration pinch is 200 ppm, the concentration of discharged wastewater is 600 ppm, and the flow rate of discharged wastewater is 40 t h^{-1}.

The contaminant mass load in the streams of water-using system, $\sum M$, is 36,000 g h^{-1}, and the contaminant mass load discharged into wastewater, M_W, is 40 × 600 = 24,000g h^{-1}. Therefore, the contaminant mass load removed by regeneration unit, M_{reg}, is obtained as 36,000 - 24,000 = 12,000 g h^{-1} from Eq(2). The contaminant mass load in regenerated stream is 12,000 × (1 / 0.95 - 1) = 631.58 g h^{-1} from Eq(5).

From Eqs(6-8), we have:

$$\begin{cases} M_{reg} = F_{reg}C_{reg} \\ 100\times 80 = F_{reg}C_{reg} + 200F_P^B \\ F_P^B + F_{reg} = 80 \end{cases} \tag{9}$$

Solving Eqs(9), we can obtain: $F_P^B = 36.84$ t h^{-1}, $F_{reg} = 43.16$ t h^{-1} and $C_{reg} = 14.63$ ppm.

According to Xu et al. (2013), when the regenerated concentration is 14.63 ppm, the regeneration pinch is 200 ppm, the initial regeneration pinch is estimated correctly. Therefore, 14.63 ppm and 43.16 t h^{-1} are the targets of the regenerated concentration and the regenerated stream flow rate for this network, respectively.

The results obtained in this paper and those in the literature are listed in Table 3. It can be seen from Table 3 that the targets for freshwater and regenerated water consumption, the regenerated concentration and the wastewater flow rate are the same as those of Pan et al. (2011). However, the method of Pan et al. (2011) requires three iterations, in which detailed calculations of all the allocations from sources to demands should be carried out, to obtain the final results. Compared to the method of Pan et al. (2011), the method proposed only need one step simple calculation. Therefore, the method proposed is much simpler.

Table 3: Comparison of the results obtained in this paper and those in the literature

Literature	F_f (t h^{-1})	F_{reg} (t h^{-1})	C_{reg} (ppm)	F_w (t h^{-1})
This paper	40	43.16	14.63	40
Kuo and Smith (1998)	44	40	14.50	44
Pan et al. (2011)	40	43.16	14.63	40

5. Conclusions

A simple and effective method is proposed for targeting the single contaminant water-using networks with fixed RR-model regeneration unit. The targeting procedure is based on the analysis of the features of the networks, and a few relationships developed from flow rate and mass load balances. In the targeting procedure, the initial regenerated concentration is first estimated according to the features of water-using processes and regeneration unit. The regeneration pinch at the initial regenerated concentration is then identified. Finally, the regeneration target is obtained based on a few relationships developed in this article. The results of one literature example show that the targeting calculation effort can be reduced with the proposed method. From the targeting procedure proposed, it can be seen that the deeper we understand the features of water-using networks involving regeneration, the simpler the targeting procedure.

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