CHEMICAL ENGINEERING TRANSACTIONS Volume 18, 2009
Editor Jiří Klemeš
 ISBN 978-88-95608-04-4 ISSN 1974-9791
DOI: 10.3303/CET0918142

A mass-load-based procedure for minimizing total flowrate of the water systems with single contaminant

Zhi-Yong Liu*, Ying Zhang, Yi Yang

School of Chemical Engineering, Hebei University of Technology,
Tianjin 300130, China

The research on the water-using networks of single contaminant can provide insights for research on the water-using networks with multiple contaminants. In this paper, a mass-load-based design procedure is proposed for the water-using networks of single contaminant to minimize the total flowrate, because larger flowrate might cause larger equipment and higher operating cost. An example is solved to show the procedures.

1. Introduction

Water is one of the most important natural resources. Many techniques have been developed to improve the analysis and design of water-using systems (for example, Wang and Smith 1994, Doyle and Smith 1997, Zheng et al. 2006, and Liu et al. 2009).
Savelski and Bagajewicz (2001) realized that higher total flowrate through the processes may lead to larger equipment. Prakash and Shenoy (2005) addressed that to minimize the total flowrate for fixed contaminant load problems, the below-pinch units, of which both the inlet and outlet concentrations are below the pinch point, should be satisfied by freshwater, and the above-pinch units, of which both the inlet and outlet concentrations are above the pinch point, should be satisfied by the cleanest available streams.
In this paper, we will investigate the design of water-using network of single contaminant to minimize the total flowrate of the system. For a water-using system, the total flowrate through the process units provides a measure of the capital cost. Therefore, development of a method for design of a water-using network with minimum total flowrate is valuable.

* Corresponding author. Phone and Fax: +86-22-6020-2047, email: liuzhiyong@hebut.edu.cn

Please cite this article as: Liu Z.Y., Zhang Y. and Yang Y., (2009), A mass-load-based procedure for minimizing total flowrate of the water systems with single contaminant, Chemical Engineering Transactions, 18, 869-874 DOI: 10.3303/CET0918142

2. Minimization of the total flowrate of water-using network

In order to reduce total flowrate of a water-using network, it is often to use freshwater for some processes even though the limiting inlet concentrations of these processes are not zero (Prakash and Shenoy, 2005). However, we should analyze which process can use freshwater without increasing freshwater consumption first. Let us consider Example 1 with the data shown in Table 1, which are taken from Savelski and Bagajewicz (2001). Figure 1 shows the shifted composite curves for this example. The pinch point for this network is the source of 300 ppm. The minimum freshwater requirement target for the network is 166.27 t/h.

Table 1. Data of example 1

Process number	m (kg/h)	C_{in}^{max} (ppm)	C_{out}^{max} (ppm)	F_{max} (t/h)	F_{min} (t/h)	$\frac{F_{max}}{F_{min}}$
1	2	25	80	36.36	25	1.45
2	2.88	25	90	44.31	32	1.38
3	4	25	200	22.86	20	1.14
4	3	50	100	60	30	2
5	30	50	800	40	37.5	1.07
6	5	400	800	12.5	6.25	2
7	2	200	600	5	3.33	1.5
8	1	0	100	10	10	1
9	20	50	300	80	66.67	1.2
10	6.5	150	300	43.33	21.67	2

The below-pinch group includes processes P_1, P_2, P_3, P_4 and P_8; the across-pinch group, in which the inlet concentration of a process is below the pinch concentration and the outlet concentration is above the pinch concentration, includes P_5, P_7, P_9 and P_{10}; and the above-pinch group includes P_6. When all the below-pinch units are satisfied by freshwater, the inlet concentrations of the below-pinch processes will be zero. We call the network, in which the limiting inlet concentrations of some processes will be taken as zero, as zero-inlet-equivalent network. By using the targeting procedure proposed by Liu et al. (2007), it is found that that the freshwater target for the zero-inlet-equivalent network of Example 1, in which all the inlet concentrations of the below pinch processes are taken as zero, is 168.8 t/h.

From the above discussion it can be seen that sometimes, if all the below-pinch units use freshwater, the freshwater target of some water-using systems might increase. Therefore, if we want to use freshwater for the below-pinch units to reduce the total flowrate of the system, we should analyze the corresponding zero-inlet-equivalent network, and identify whether the freshwater target increases or not. Now, let us determine the priority order of the processes which can use freshwater. When using freshwater solely and assuming the concentration of the freshwater is zero, the minimum flowrate will be:

$$F_{\min,i} = \frac{m_i}{C_{out,i}^{\max}} \tag{1}$$

where m is the mass load, F is flowrate, and C is concentration.

The maximum flowrate of a process will be:

$$F_{\max,i} = \frac{m_i}{C_{out,i}^{\max} - C_{in,i}^{\max}} \tag{2}$$

From Eqs (1) and (2), the ratio of $F_{\max,i} / F_{\min,i}$ is:

$$\frac{F_{\max,i}}{F_{\min i,}} = \frac{C_{out,i}^{\max}}{C_{out,i}^{\max} - C_{in,i}^{\max}} = \frac{1}{1 - \frac{C_{in,i}^{\max}}{C_{out,i}^{\max}}} \tag{3}$$

From Eq. (3) it can be seen that the larger the value of $C_{in,i}^{\max} / C_{out,i}^{\max}$, the larger the value of $F_{\max,i} / F_{\min,i}$, the larger the effect of reducing the flowrate of a process by decreasing the inlet concentration. Therefore, for the processes with the same inlet concentration, the process with the largest value of $C_{in,i}^{\max} / C_{out,i}^{\max}$ should be performed first to decrease the total flowrate of the network.

3. Design of network with minimum total flowrate

The design procedure for the networks with minimum total flowrate is as follows:

(1) Determine the pinch and freshwater target, first;

(2) Divide the processes into three groups, according to the inlet and outlet concentrations of the processes:

- Group 1 including below-pinch processes only;
- Group 2 including across-pinch processes only;
- Group 3 including above-pinch processes only;

In each group, the process with the lowest concentration will be performed first. The current available cleanest source stream can be reused for the process with larger value of $C_{in,i}^{\max} / C_{out,i}^{\max}$ in preferential way;

(3) The below-pinch processes should be performed first, because their outlet streams might be reused by the other processes. Pinch analysis for the zero-inlet-equivalent network can be carried out to identify which process(es) in group 1 can use freshwater without increasing the freshwater target;

(4) Then, the processes in Group 2 and Group 3 will be performed in turn.

We will show the design procedure for the water-using network with minimum total flowrate in case study.

4. Case study

Now, let us revisit Example 1. As discussed earlier, the below-pinch group includes processes P_1, P_2, P_3, P_4 and $P_{8;}$ the across-pinch group includes P_5, P_7, P_9 and $P_{10;}$ and the above-pinch group includes P_6.

For the below-pinch group, P_8 should be performed first because its inlet concentration is zero. The value of $C_{in}^{\max} / C_{out}^{\max}$ for P_1, P_2, P_3 and P_4 are 0.31, 0.28, 0.13 and 0.5, respectively. Therefore, the performing order of these processes is P_4, P_1, P_2 and P_3. However, as discussed earlier, if all the below-pinch units of this example use freshwater, the freshwater target will change. The processes with larger value of $C_{in}^{\max} / C_{out}^{\max}$ should use freshwater first. If we choose P_8, P_4, P_1, and P_2 as the freshwater-using processes, by carrying out pinch analysis for the zero-inlet-equivalent, it is found that the pinch point and freshwater target of the zero-inlet-equivalent system, in which P_8, P_4, P_1, and P_2 use freshwater, will be the same as that of the original one. Therefore, P_8, P_4, P_1, and P_2 can use freshwater without changing the freshwater target.

For the across-pinch group of P_5, P_7, P_9 and P_{10}, the inlet concentrations are 50, 200, 50 and 150 ppm, respectively. The inlet concentrations of P_5 and P_9 are the lowest, and they should be performed before the other processes. Because the outlet concentration of P_9 (300 ppm) is lower than that of P_5 (800 ppm), P_9 should be performed first. The performing order of the across-pinch group is P_9, P_5, P_{10} and P_7. The above-pinch process P_6 should be performed last.

The detailed design is discussed as follows. For the below-pinch group, D_1, D_2, D_4 and D_8, the inlet streams of P_1, P_2, P_4 and P_8, will use freshwater, and the amounts are 20, 32, 30, and 10 t/h, respectively. For D_3, the mass load is 0.571 kg/h, which is equivalent to

7.14 t/h of S_1, the outlet stream of P_1. Freshwater consumption for P_3 is 15.72 t/h. The remainder of S_1, whose mass load is $2-0.571=1.429$ kg/h, can be used for the next process. The other processes can be designed similarly.

The design obtained in this work is shown in Figure 2. Freshwater consumption is 166.27 t/h, which is the same as that of Savelski and Bagajewicz (2001). The total flowrate for all the processes is 296.7 t/h, which is 85.5% of 347.2 t/h, obtained by Savelski and Bagajewicz (2001). The reuse piping number is 11, and freshwater piping number is 8, which are better than the results (reuse piping number is 15, and freshwater piping number is 7) obtained by Savelski and Bagajewicz (2001).

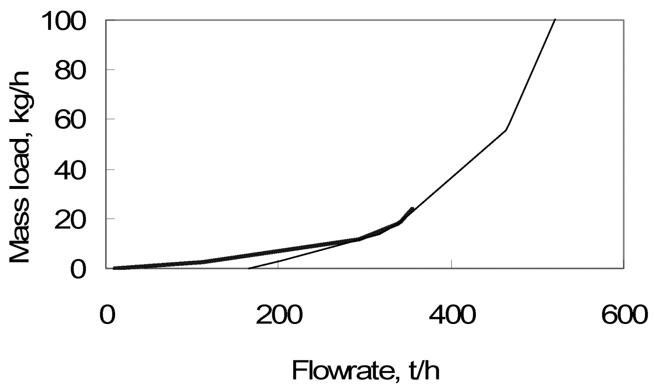
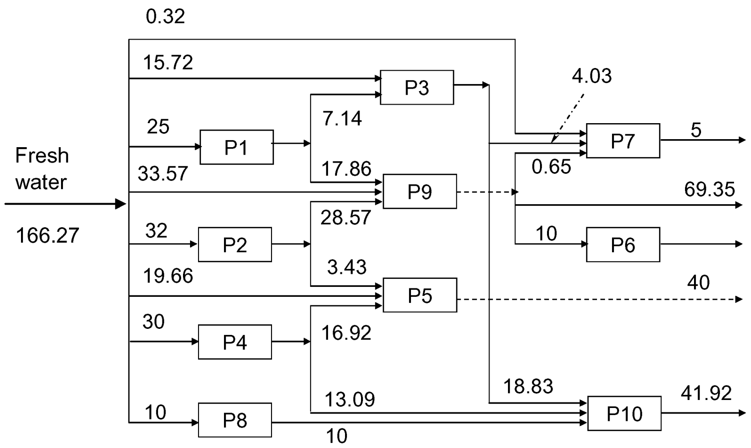


Figure 1. Shifted composite curves for Example 1



Note: The numbers are flowrates in t/h.

Figure 2. Design obtained for Example 1.

5. Conclusions

In this paper, a mass-load-based design procedure is proposed for the fixed-mass-load water-using networks of single contaminant to minimize the total flowrate. The results of the illustrated example show that the design obtained in this work is better than that obtained in the literature.

Acknowledgements

This work is financially supported by the National Natural Science Foundation of China under grant number 20776036, the Research Foundation for Returned Scholars from Overseas of Human Resources Department of Hebei Province, China, and the Natural Scientific Research Foundation of Hebei Province, China.

References

Doyle S, Smith R. Targeting water reuse with multiple contaminants. *Transaction of Institution of Chemical Engineers*. 1997; Part B, 75: 181-189.

Liu Z-Y, Yang Y, Wan L-Z, Wang X, Hou K-H. A heuristic design procedure for water-using networks with multiple contaminants. 2009; 55: 374-382.

Liu Z-Y, Yang Y-Z, Zhang Y. Determining the pinch point qualitatively and calculating the targets of fresh water and wastewater numerically. *Chemical Engineering Research & Design*. 2007; 85: 1485-1490.

Prakash R, Shenoy UV. Targeting and design of water networks for fixed flowrate and fixed contaminant load operations. *Chemical Engineering Science*. 2005; 60: 255-268.

Savelski M, Bagajewicz M. Algorithmic procedure to design water utilization systems featuring a single contaminant in process plants. *Chemical Engineering Science* 2001; 56: 1897–1911.

Wang YP, Smith R. Wastewater minimisation. *Chemical Engineering Science*. 1994; 49: 981-1006.

Zheng X, Feng X, Shen R, Seider W. Design of optimal water-using networks with internal water mains. *Industrial and Engineering Chemistry Research*. 2006; 45: 8413-8420.