여러 가지 오염물질을 포함한 폐수처리 시스템의 새로운 최적화 방법

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Modified Approach of Wastewater Minimization in Multiple-Contaminant Systems

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Introduction

Environmental issues are raised according as a lot of products are produced by most part of industries. Governments reinforce the limitation of environmental index as a policy of air pollution, water pollution and so on since industries take a focus on the 'Development' letter than the 'Protection of Environment'. Especially water, which is inevitable for human beings, is becoming more interesting. Europeans have devoted to water minimization since early ages where water is rare. These days, we also take focus on water since we are a water-defect country.

Heat pinch technology, which is applied to heat exchange network as a tool of energy optimization, was developed in 80's. Wang and Smith[1,2] developed water pinch technology which is based on mass transfer while heat pinch technology was based on heat transfer. At first, the theory was applied to just one-contaminant transportation through water. Then multi-contaminant system is applied by the theory since there are generally several contaminants in the processes. It is same as one-contaminant except that *proportional mass-transfer assumption* is applied. In this paper, it is assumed not that proportion of mass transfer of all contaminant is equal but that mass-transfer is dependent on other contaminant as a linear function. Although its basis is similar, interactions between contaminants are considered to apply real processes of industry.

Problem definition and assumption

We consider a simple process which consists of two operations. There are two kinds of contaminants in the effluent flow of the operations which are limited by inlet/outlet concentration as shown in **Table 1**. The minimum freshwater flowrate can be obtained by *Concentration-Interval Diagram(CID)* and *Concentration-Composite Curve*[3]. The minimum flowrate is 50.0te/hr considering only contaminant A while it is 60.0te/hr considering contaminant B only. It is the question what is the optimum value considering contaminant both A and B. Would it be the smaller value or larger one? Otherwise, another value?

In order to solve this problem, Wang and Smith[1] and Mann and Liu[3] used *proportional mass-transfer assumption* i.e., the ratio of mass load of each contaminant is equal to the ratio of maximum limited mass load. So the following equation is possible.

$$\frac{C_{iA,n}-C_{iA,in}}{C_{iA,out}-C_{iA,in}}=\frac{C_{iB,n}-C_{iB,in}}{C_{iB,out}-C_{iB,in}} \tag{1}$$

For example, if concentration of A in the operation 1(i=1), concentration interval 2(n=2) i.e., $C_{1A,2}$ is 50ppm then $C_{1B,2}$ is 40ppm. Under this assumption, the minimum flowrate is 60te/hr by water pinch technology through inlet-concentration shift and outlet-concentration shift[3].

Modified Proportional mass-transfer assumption

Solubility of solids are different from solids. In the mixing of liquids, water could absorb solute, i.e., contaminant, by its selection according to the process condition. So the equation (1) is able to modified as follow.

$$(mass \quad load \quad of \quad B)=\alpha\cdot(mass \quad load \quad of \quad A)$$
$$\left(C_{iB,n}-C_{iB,in}\right)f_i=\alpha_i\cdot\left(C_{iA,n}-C_{iA,in}\right)f_i$$
$$\left(C_{iB,n}-C_{iB,in}\right)=\alpha_i\cdot\left(C_{iA,n}-C_{iA,in}\right) \tag{2}$$

Although the value of α_i could be obtained experimentally according to the conditions of operations, in this paper let α_1=0.9 and α_2=1.2 constant. This difference results from the different operating conditions of operation

1 and 2. Under this assumption, the concentration limit of the limiting process data could be changed by interactions of the two contaminants. There is modified limiting process data in **Table 2** and **Figure 1**.

Here, water of point *a* in Figure 1 is not able to be reused in operation 2 since the concentration of contaminant B is not permitted. Therefore, inlet-concentration shift is necessary by feasibility analysis. The result of inlet-concentration shift is illustrated in **Figure 2** and **3**. There illustrates the following concentration composite curve in **Figure 4** and **Table 3**. The minimum flowrate is 60.0te/hr.

Outlet-concentration shift is applied to reuse of outlet of operation 1 to operation 2 while the outlet is not over the concentration of the operation 2. We convert concentration scale of operation 2 to contaminant A^* in order that concentration of operation 2 at n=3 is not lower than that of operation 1.

$$\frac{C_{iA^*,n} - C_{iA^*,in}}{C_{iA^*,out} - C_{iA^*,in}} = \frac{C_{iB,n} - C_{iB,in}}{C_{iB,out} - C_{iB,in}} \tag{3}$$

Figure 5 represents the result of the outlet-concentration shift. Figure 6 illustrates concentration-composite curve. **Table 4** illustrates CID. Water supply line is minimum value of 60.0te/hr as the final result. In this point, inlet/outlet-concentration shift does not imply the variation of real concentration. The scale of concentration on the graphs is converted to gain the minimum flowrate. The result is same under the proportional mass-transfer assumption. However it does not imply that there is no difference between them. The minimum flowrate depends on the position of the pinch point. And the assumption does not affect the position of pinch. **Figure 7** illustrates a simple water-using network design of the example.

Conclusions

It is remarkable that this research focuses on the water pinch technology of multi-contaminant system and modifying the previous approach in order to enable this method to apply real industry. The difference of mass-transfer appetence of different contaminants is due to their interaction. It seems not reasonable that the difference is determined by the characteristics of the very operations or limiting process data which is affected by environmental policy. So it is powerful that the function representing the mass-transfer interaction of contaminants can be used in this point. In this paper, the function is assumed as linear while it is more reasonable than previous approach that considered only limiting process data. For a further application, it must be based on the theory of mass-transfer to consider the interactions circumspectly.

Acknowledgment

This work was supported by the Brain Korea 21 Project.

References

[1] Wang, Y. P. and R. Smith: "Wastewater Minimisation" *Chemical Engineering Science*, **49(7)**, 981-1006, 1994a.
[2] Wang, Y. P. and R. Smith: "Design of Distributed Effluent Treatment Systems" *Chemical Engineering Science*, **49(18)**, 3127-3145, 1994b.
[3] Mann, J. G. and Y. A. Lin: "Industrial Water Reuse and Wastewater Minimization", *McGraw-Hill*, Virginia, 1999.

Table 1. Limiting Process Data

Operation *I*	Contaminant *J*	$\Delta m_{ij,tot}$ (kg/hr)	$C_{ij,in}$ (ppm)	$C_{ij,out}$ (ppm)	f_i^{lim} (te/hr)
1	A	3	0	100	30
	B	2.4	0	80	
2	A	4	50	150	40
	B	5.6	20	160	

Table 2. Modified Limiting Process Data

Operation *I*	Contaminant *J*	$\Delta m_{ij,tot}$ (kg/hr)	$C_{ij,in}$ (ppm)	$C_{ij,out}$ (ppm)	f_i^{lim} (te/hr)

1 (α=0.9)	A B	2.67 2.4	0 0	88.9 80	30
2 (α=1.2)	A B	4 4.8	50 20	150 140	40

Table 3. CID Considering Both Contaminant A and B

Concentration A(ppm)	Operation 1 (30te/hr)	Operation 2 (40te/hr)	Mass load A(kg/hr)	Cumulative Mass load A	Flowrate (te/hr)
0	▲			0.00	0.00
	│		0.67		
22.2	│	▲		0.67	30.18
	│	│	4.67		
88.9	│	│		5.33	**60.00**
		│	1.33		
122.2		│		6.67	54.55

Table 4. CID for Contaminant A, Based on the Shifted Concentration Scale(A^*), Following an Outlet-Concentration Shift on Operation 2

Concentration A^* (ppm)	Operation 1 (30te/hr)	Operation 2 (40te/hr)	Mass load A^* (kg/hr)	Cumulative Mass load A^*	Flowrate (te/hr)
0	▲			0.00	0.00
	│		0.67		
22.2	│	▲		0.67	30.00
	│	│	4.67		
88.9	│	│		5.33	**60.00**
		│	2.67		
155.6		│		8	51.43

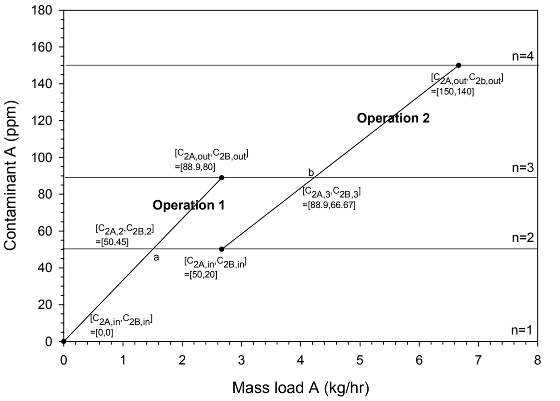

Figure 1. Limiting water profiles for contaminant A

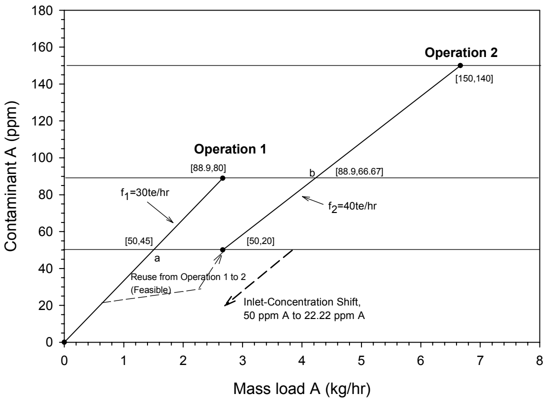

Figure 2. Limiting water profiles for contaminant A prior to an inlet-concentration shift on operation 2

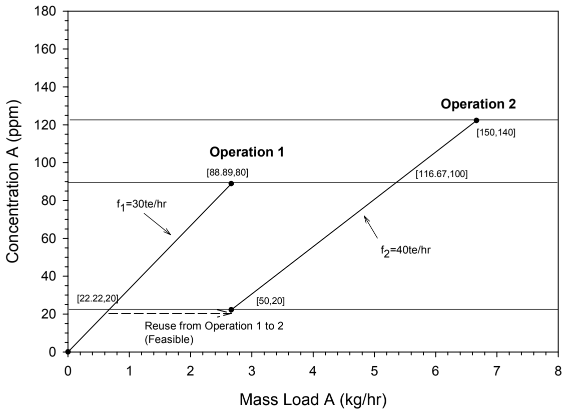

Figure 3. Limiting water profiles for contaminant A following an inlet-concentration shift on operation 2

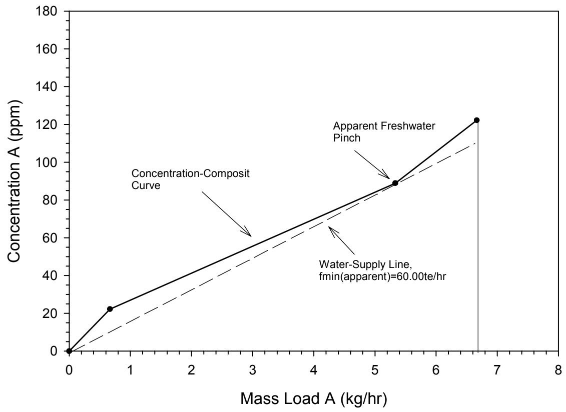

Figure 4. Concentration-composite curve and water-supply line for contaminant A following an inlet-concentration shift on operation 2

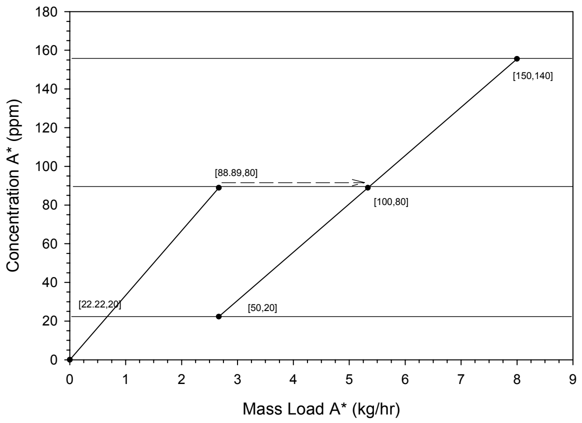

Figure 5. Limiting water profiles for contaminant A based on the sifted concentration scale(A^*) following an outlet-concentration shift on operation 2

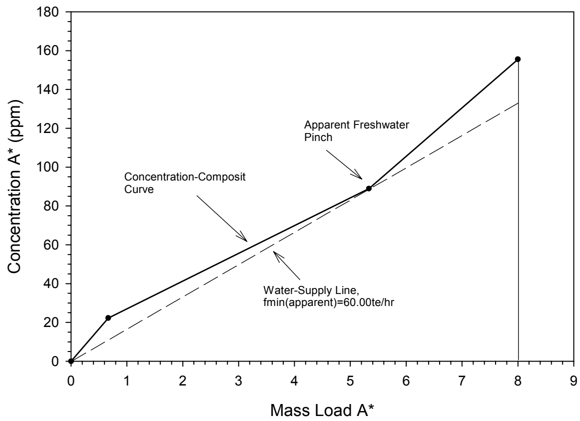

Figure 6. Concentration-composite curve and water-supply line for contaminant A based on the sifted concentration scale(A*) following an outlet-concentration shift on operation 2

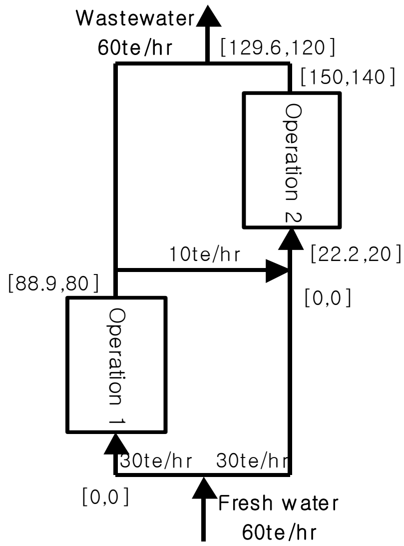

Figure 7. Block diagram of simplified water-using network