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Process Water Management with Regeneration and Recycle

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Abstract

Process water management can be divided into two distinct activities: minimization of freshwater requirement and optimal treatment of wastewater generated. Applying the concept of regeneration and recycling of wastewater in the process, freshwater requirement can be reduced significantly while satisfying environmental regulations. Graphical representation as well as analytical algorithm is proposed to address integrated process water management issues involving regeneration and recycle.

Keywords: water pinch, source composite curve, regeneration and recycle.

1. Introduction

Due to environmental regulations, water management has become an important issue for process engineers. The cost of treating wastewater streams is increasing steadily as environmental regulations are becoming more and more stringent. Process water management can be divided into two distinct activities. One activity deals with optimum allocation of reusable water to different processes to minimize freshwater requirement. Different methods [1-4] have been suggested in the literature to target minimum freshwater requirement in a process. The other activity aims at optimal treatment of wastewater generated in different processes to meet environmental regulations. Different methods [5-6] have been developed to design distributed effluent treatment system. Overall water management in a process industry is usually performed sequentially. The designs of water-using processes are addressed first and subsequently, based on the designed water reuse network the distributed effluent treatment system is designed. This sequential procedure may lead to sub-optimal solution for the distributed effluent treatment system. Therefore, it is essential to target effluent treatment simultaneously with the freshwater targeting [7-9]. Primary objective of this paper is to address these two issues of process water management simultaneously through regeneration and recycle.

Wastewater can be regenerated to remove contaminants which have built up and then the water recycled. In this case water can re-enter processes in which it has previously been used. A treatment unit can simultaneously acts as a regeneration unit. Applying the concept of regeneration and recycling of wastewater in the process, freshwater requirement can be reduced significantly while satisfying environmental regulations. Using the concept of regeneration and recycling, it is even possible to design processes with zero discharge of wastewater. There exist two extreme limits. In the limiting case of zero discharge of wastewater, significant amount of wastewater has to be recycled after regenerating in a treatment unit. The operating cost is typically high for such a case due high cost of effluent treatment. For the other limiting case of no effluent treatment, maximum freshwater may be required in the process such that no treatment is necessary. The operating cost, in such a case, is high due to high cost of freshwater. Based on the relative costs of freshwater and effluent treatment, there exists an optimum operating cost of the overall process. A methodology has been proposed in this paper to target the minimum flow rate of effluent water to be treated in a treatment unit to simultaneously satisfy environmental regulations and a given freshwater supply for a plant consisting several water-using processes. Graphical representations as well as analytical algorithms are proposed to address integrated process water management issues involving regeneration and recycle. The conceptual approach presented in this paper is restricted to single contaminant.

2. Targeting Procedure

Bandyopadhyay et al. [9] have proposed a novel limiting composite curve, called source composite curve, to target simultaneously the minimum freshwater requirement, maximum water reuse, minimum wastewater generation, and minimum effluent to be treated to meet environmental norms. The source composite curve is plotted on concentration (C) vs. contaminant load (m) diagram. However, the proposed methodology does not consider regeneration and recycle. In the following section, a methodology is presented to target minimum effluent to be treated in the treatment unit to meet environmental norms, for a given fresh water supply.

2.1. Targeting Minimum Effluent Treatment Flow rate

Every fixed contaminant load problem may be converted to a fixed flow rate problem at the targeting stage with the limiting water flow rate being the specified flow rate for each process. Therefore, a water allocation problem may be modeled with outlet streams leaving at a specified concentration and flow rate (sources of wastewater), while the inlet streams have a maximum allowable concentration and a specified flow rate. Outlet of any process may be viewed as a source of wastewater, while inlet to any process represents the scope of reusing wastewater or demands of wastewater. The source composite curve represents the maximum contaminant load at different contaminant concentrations. Physically, the source composite curve is equivalent to the grand composite curve in heat exchanger network synthesis and invariant rectifying and stripping curves in distillation. An algebraic procedure for generation of source composite curve and targeting minimum effluent flow rate is given below.

Step 1: For the given problem with given freshwater supply, determine wastewater generation using overall mass balance and consider extended problem with freshwater as a source and wastewater as a demand.

Step 2: Arrange all the distinct concentrations (of freshwater, demands and sources together) in descending order in the first column. Without loss of generality, the entries of the first column are $C_1 > C_2 > C_3 > \ldots > C_n$. Last entry of this column should be zero ($C_n = 0$).

Step 3: For each concentration C_i (in the first column), put the corresponding net flow F_i in the second column. The net flow F_i is calculated by taking the algebraic sum of flow rates corresponding to a concentration C_i. We adopt the convention of positive flow rates for sources and negative flow rates for demands.

Step 4: The corresponding entries in the third column are cumulative flow rates given by the formula $Q_i = \Sigma_{k \le i} F_k$. Last entry of this column should again be zero ($Q_n = 0$) as wastewater flow rate has been determined based on the overall mass balance of the entire problem.

Step 5: Calculates the entries of the fourth column by the formula: $P_i = Q_{i-1} (C_{i-1} - C_i)$. Note that Q_0 is assumed to be zero.

Step 6: Fifth column contains the cumulative contaminant mass load $m_i = \Sigma_{k \le i} P_k$. Now fifth column (cumulative mass load) may be plotted against the first column (concentration) to obtain the source composite curve. Last entry (m_n) in the fifth column signifies the total mass load of the entire process. For regeneration the same has to be thrown out of the system.

Step 7: Draw a vertical line on the mass load vs. concentration diagram at m_n and determine the concentration at which it cuts the source composite curve.

Step 8: Construct a table of concentration and cumulative mass load up to the intersection point.

Step 9: Determine the input mass load to the treatment unit using the formula: $m_T = m_n / r$, where r is the removal ratio of the treatment unit.

Step 10: Calculate corresponding effluent treatment flow rate by the formula: $f_{Ti} = (m_T - m_i)/C_i$. Maximum entry in this column defines the minimum effluent flow rate to be treated for the given problem and establishes the target (f_T). For targeted value of effluent flow rate to be treated the equation $m = m_T - f_T\,C$, represents the effluent treatment line. The point it touches the source composite curve may be defined as the treatment pinch point.

Now the same algorithm may be repeated for different freshwater flow rate and the optimum operating cost may be determined.

3. Illustrative Example

To demonstrate the applicability of the methodology developed in this paper, illustrative example has been solved in this section. The limiting process data for an example, consisting four water-using processes, are given in Table 1 [9]. If freshwater is used to satisfy the demand for each of the individual processes, the freshwater consumption may be estimated to be 300 t/h. However, reusing water from other processes, the minimum freshwater requirement can be calculated to be 70 t/h with a corresponding effluent flow rate of 50 t/h and the minimum effluent treatment flow rate is targeted to be 35.96 t/h [9]. Considering regeneration and recycle, fresh water requirement can be reduced further. In the limiting case of zero discharge of wastewater, fresh water requirement is 20 t/h.

Proposed algorithm may be applied to determine the minimum effluent treatment flow rate for the limiting case of zero discharge. First six steps of the proposed algorithm generate the source composite curve for example with a supply of 20 t/h of fresh water and the numerical values are tabulated in Table 2. As the overall water balance satisfies, the last entry of the third column is zero. Last entry of the fifth column suggests that that 10 kg/h of contaminant has to be removed from the process (m_n = 10). The source composite curve is shown in Fig. 1a. A vertical line at m_n = 10 intersects the source composite curve at 33.33 ppm. Table 3 represents contaminant concentration and cumulative mass load up to the intersection point. Since the removal ratio of the treatment unit is 0.95, the input mass load to the treatment unit may be calculated to be 10.53 kg/h. Last column in Table 3 represents the effluent flow rate to be treated. The minimum effluent flow rate to be treated in the treatment unit is calculated to be 53.51 t/h corresponds to a treatment pinch of 150 ppm. Treatment line and the treatment pinch point are also shown in Fig. 1a.

The same algorithm may be repeated for different freshwater flow rate and corresponding minimum treatment flow may be determined. Variations of the minimum treatment flow rate for different fresh water supply are shown in Fig. 1b. Based on the relative costs of freshwater and effluent treatment, the optimum operating cost of the overall process may be determined.

Table 1. Limiting process data for the four-process example.

Processes	Inlet/Demand		Outlet/Source	
	Concentration (ppm)	Flow rate (t/h)	Concentration (ppm)	Flow rate (t/h)
P1	20	50	50	50
P2	50	100	100	100
P3	100	80	150	70
P4	200	70	250	60

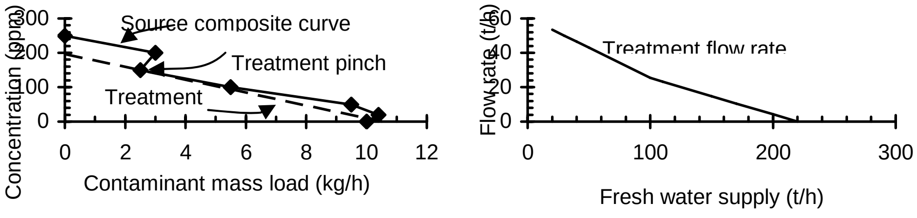
Concentration of contaminant in freshwater, C_{fw} = 0 ppm
Environmental limit for discharge concentration, C_e = 50 ppm
Removal ratio of the treatment unit, r = 0.95

Table 2. Generation of source composite curve for the four-process example.

Concentration (ppm)	Flow (t/h)	Cum. flow (t/h)	Mass load (kg/h)	Cum. load (kg/h)
250	60	60	0	0
200	-70	-10	3	3
150	70	60	-0.5	2.5
100	20	80	3	5.5
50	-50	30	4	9.5
20	-50	-20	0.9	10.4
0	20	0	-0.4	10

Table 3. Targeting minimum effluent treatment flow rate.

Concentration (ppm)	Cumulative mass load (kg/h)	Treatment flow rate (t/h)
250	0	42.11
200	3	37.63
150	2.5	53.51
100	5.5	50.26
50	9.5	20.53
33.33	10	15.79



(a) (b)

Fig. 1. (a) Source composite curve. (b) Variations of minimum treatment flow rate.

4. Conclusions

Water management in a process industry consists of optimal allocation of reusable water to reduce freshwater requirement and optimal design of effluent treatment units to honor environmental norms. Applying the concept of regeneration and recycling of wastewater in the process, freshwater requirement can be reduced significantly while satisfying environmental regulations. In this paper, a graphical representation and an analytical algorithm have been proposed to address integrated process water management issues involving regeneration and recycle. The proposed methodology is demonstrated through an example.

5. References

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