Optimal Water Network with Zero Wastewater Discharge in an Alumina Plant

CHUN DENG, XIAO FENG
Department of Chemical Engineering
Xi'an Jiaotong University
No.28, Xianning West Road, Xi'an, Shaanxi, 710049
CHINA
xfeng@mail.xjtu.edu.cn http://gr.xjtu.edu.cn:8080/web/xfeng

Abstract: Zero wastewater discharge has been the ultimate goal of green water utilization in process industries. To make the water network with zero wastewater discharge economically beneficial, the system should be optimized. Alumina industry is a heavy water consumption industry, hence studying water re-use and zero wastewater discharge (ZWD) for water system in alumina plants is very important. This paper analyzes a practical water system of an aluminum plant on the basis of graphical method for ZWD water system. The water system of aluminum plant features great amount of water loss and consists of several operation with fixed flowrate constraints. On the concentration-mass load diagram, the optimal water supply line considering water loss for the water system with ZWD is constructed. The optimal regeneration water flow rate and optimal regeneration concentration are targeted. Base on these targets and local recycling scheme, the optimal water using network with ZWD considering fixed flowrate constraints is obtained. The alumina plant accomplishes the goal of zero wastewater discharge and the freshwater saving rate achieves 62.7%.

Key-Words: integration, wastewater minimization, zero discharge, water system, alumina plant, fixed flowrate, fixed mass load

1 Introduction

To achieve sustainable development of ecosystem [1], the problems for freshwater scarcity and water environment pollution [2, 3] need to be dealt with. To reduce freshwater usage and wastewater discharge has become one of the main targets of design and optimization of process systems. Zero wastewater discharge (ZWD), as the ultimate goal of wastewater minimization, is also the research focus of many investigators. The alumina industry is a heavy water consumption industry and its corresponding wastewater discharge is also in large amount.

Water system integration treats the water utilization processes in an enterprise as an organic whole, and considers how to allocate the water quantity and quality to each water-using unit, so that water reuse is maximized within the system and simultaneously the wastewater is minimized [4-6]. To achieve the sustainable development target, advanced treatment technologies are applied to achieve the material close circuit to the largest extent and the zero wastewater discharge.

Water using operations essentially are classified into two categories: fixed contaminant load (FC) operations (e.g., washing, scrubbing, and extraction), and fixed flowrate (FF) operations (e.g., boilers, cooling towers, reactors). FC operations are based on the mass-transfer-model. FF operations do not involve any mass transfer and the main concern is the flowrate, not the amount of contaminant picked up.

For FC problems, Wang and Smith [5] proposed a graphical method based on water pinch technology. The method to target and design water systems with regeneration recycle was developed in their work and the optimal regeneration concentration was assumed to be pinch concentration [5]. Feng et al. [7] proposed the conceptual approach for targeting the water system with regeneration recycle and their work showed that the optimal regeneration concentration is not necessarily the pinch concentration. Both of the papers above only deal with the water system with fixed contaminant load operations without considering water loss.

For fixed flowrate water systems, Wang and Smith [8] pointed out that the water flowrate constraints can be met by local recycling or splitting of water-using operations. Later, many studies have been conducted on discussing Fixed flowrate (FF) problems [9-17]. Ng et al. [9] proposed a new numerical targeting procedure to locate the minimum regeneration flowrate that achieves the ultimate fresh water and wastewater targets for both FC and FF problems. Agrawal and Shenoy [10] extended the limiting composite curve concept from FC problem to FF problem. Targets for water system with regeneration could be obtained through proposed procedure and it could be applied for FC problem without water losses [10]. However, no reported papers have discussed the FC problem considering water loss, which is common in practical process plants. Hence, Deng et al. [18] extended the graphical approach proposed by Agrawal and Shenoy [10] to analyze the fixed contaminant mass loads (FC) water system with water loss.

Zero wastewater discharge (ZLD) is to accomplish closed circuit of water to the maximum extent and eliminate wastewater discharge. Goldblatt et al. [19] pointed out that the pushing powers for zero discharge are as follows: to minimum freshwater consumption, to reduce wastewater generation, to eliminate the contaminants which are prior legal prohibition, and to develop economical and environmental benign strategy. They utilized the hierarchical procedure to illustrate the strategies for ZWD (Fig. 1). Habets and Knelissen [20] provided a possible zero discharge system by integration of chemical and biological treatments for a paper mill's wastewater. Koppol, et al. [21] analyzed the advantages and disadvantages for ZWD, proposed the mathematical programming based method to discuss the possibilities of ZWD for different industries and designed the water network for ZWD in a paper mill. Li et al. [22] explored a hybrid approach to actualize zero liquid discharge. The basic method is wastewater minimization and using the advanced treatment technologies. Foo et al. [12] illustrated the zero liquid discharge network for a paper mill using the Water Cascade Analysis (WCA). Agrawal and Shenoy [10] reported that the zero liquid discharge would be achieved if the regeneration outlet concentration is lower than or equal to the lowest demand concentration. However, the physical insights for zero liquid discharge are lack of analysis. Deng, et al. [18] proposed a graphical method to obtain the necessary conditions for ZWD water system, which is the post-regeneration concentration is not higher than the ZWD maximum post-regeneration concentration. For both the water system with or without considering the water loss, formulas were deduced for calculating the optimal targets (optimal regeneration flow rate and optimal regeneration concentration) for ZWD water system [18].

As reported in several literatures [6, 23, 24], water system integration has been successfully utilized in many refineries and other chemical plants, and water-saving rate is 20-30% in general. However, the case of alumina plant using water system integration to achieve zero wastewater discharge has not been reported. Moreover, the water system of alumina plant consists both of FF and FC operations and is a hybrid problem. Great amount of water loss is another feature of the water system of alumina plant.

This paper applies the graphical method [13] for analyzing the ZWD water system to an alumina water using system. The possibility for achieving the ZWD is discussed and the regeneration water flow rate and regeneration concentration are optimized. Finally, the optimal water network for ZWD is constructed.

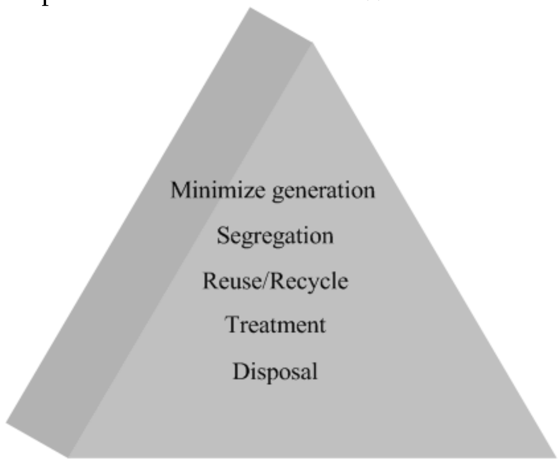

Figure 1 the hierarchical procedure for ZWD

2 Conceptual approach for targeting the optimal ZWD system

As a matter of fact, a water system with zero wastewater discharge is a specific case of regeneration recycle systems without wastewater outlet [18].

The targets of an optimal ZWD system include the minimum freshwater consumption, the optimal regenerated water flowrate, and the optimal regeneration concentration [7].

When considering water loss, from water balance of a water-using system, the freshwater consumption of the ZWD system is $F_{ws} = F_{loss}$, that is, the whole freshwater supply is utilized to compensate the water loss.

For a certain water system, there is a maximum post-regeneration concentration $C_o^{\max}$. If the post-regeneration concentration C_o is higher than $C_o^{\max}$, the water system with C_o cannot accomplish zero liquid discharge. Only when $C_o \le C_o^{\max}$, the zero liquid discharge is feasible [18]. $C_o^{\max}$ is specified by water loss quantity and limiting composite curve of the system. Generally, the concentration of the crosspoint of the limiting composite curve of the system and the freshwater supply line is the maximum post-regeneration concentration $C_o^{\max}$. The limiting composite curve of a water-using system can be constructed by using the method proposed by Agrawal and Shenoy [10]. The freshwater supply line is a straight line with a starting point at the contaminant concentration of the freshwater and a slope whose reciprocal is equal to the freshwater flowrate ($F_{ws} = F_{loss}$).

If the regenerated water flowrate is determined, a regenerated water line can be got, which starts from the post-regeneration concentration C_o , and the reverse of whose slope is equal to the regenerated water flowrate. By combining the freshwater supply line and the regenerated water line, a water composite supply curve can be constructed [5].

According to the geometrical relationships between the limiting composite curve and the optimal water composite supply curve of the system, it can be found that there are a limiting regenerated water point and a limiting regeneration load point [7]. The limiting regenerated water point restricts the regenerated water flowrate, and the limiting regeneration load point restricts the optimal regeneration concentration. Hence, the general formulas for the optimal regenerated water flowrate and the optimal regeneration concentration are deduced in the work of Feng et al. [7].

To explore the limiting regenerated water point and the limiting regeneration load point, either graphical method or problem table method can be used. When the concentration - mass load diagram is used, an iterative process should be used by eliminating the surplus driving force. When the problem table is used, the exploring process is more straightforward. In this paper, the problem table approach or Composite Table Algorithm (CTA) [10] is introduced firstly. Once the limiting composite curve is constructed via the calculated data, the graphical approach is applied to analyze the water system. Then the general formulas proposed by Feng et al. [7] are implemented to determine the optimal targets. All the procedures are illustrated via the synthesis of the water system of an alumina plant.

3 The present water-using system of the alumina plant

At present, the alumina plant consumes 710t/h freshwater, discharges 445t/h wastewater and loses 265t/h water during the process. According to the analysis and evaluation of the water using operations of the alumina plant, the operations which possess the possibility for water saving are set as researching objects. Referring to the rules proposed by Foo, et al. [11] and Zheng, et al. [20] to determine contaminants and limiting concentrations, the alkalinity can be set as the key contaminant. Then the inlet and outlet limiting concentrations for each operation (as it is shown in Table 1) can be obtained by assumption, analysis and comparison.

Noticeably, this water system is a hybrid water system, that is, the system contains both FC processes and FF processes. As shown in Table 1, P2 (Purge for outlet of lime burner) and P4 (Red mud washing) are washing process and can be modeled as FC operations. However, P1 (Cooling for raw material pump), P3 (Cooling for sintering equipment), P5 (Cooling for vacuum pump of evaporator) and P6 (Cooling for calcinations equipment) are cooling process and P7 (Re-circulating water system) is to compensate the water loss of cooling system. All of them can be modeled as FF operations and the flowrate constraints have to and will be considered in the network design step.

The inlet limiting flow rate is defined by Eq.(1):

$$F_{i,IN}^{\lim} = \frac{M_i}{C_{i,OUT}^{\max} - C_{i,IN}^{\max}} \qquad (1)$$

Assuming each operation has its own fixed water loss $F_i^{loss}, \forall i \in P$ and each water loss totally happens at the outlet of each operation. So the outlet limiting flow rate is defined by Eq.(2):

$$F_{i,OUT}^{\lim} = F_{i,IN}^{\lim} - F_i^{loss} \qquad (2)$$

The total water loss is

$$F_{loss} = \sum_{i=1}^{P} F_i^{loss} = \sum_{i=1}^{P} (F_{i,IN}^{\lim} - F_{i,OUT}^{\lim}) \qquad (3)$$

According to Eq.(3), the total water loss of this water system is found to be 265t/h.

In general, mass balance over the total water system gives,

$$F_{ws} = F_{ww} + F_{loss} \qquad (4)$$

where F denotes the flow rate, and subscripts ws, ww and loss denote freshwater supply, wastewater and water loss, respectively.

Considering the water loss has $F_{loss} \neq 0$. Zero wastewater discharge means $F_{ww} = 0$. According to Eq.(4), $F_{ws} = F_{loss} = 265\text{t/h}$, that is, the whole freshwater supply is utilized to compensate the water loss.

The present water using network is shown in Fig.2. It can be seen that the present water system does not consider water re-use.

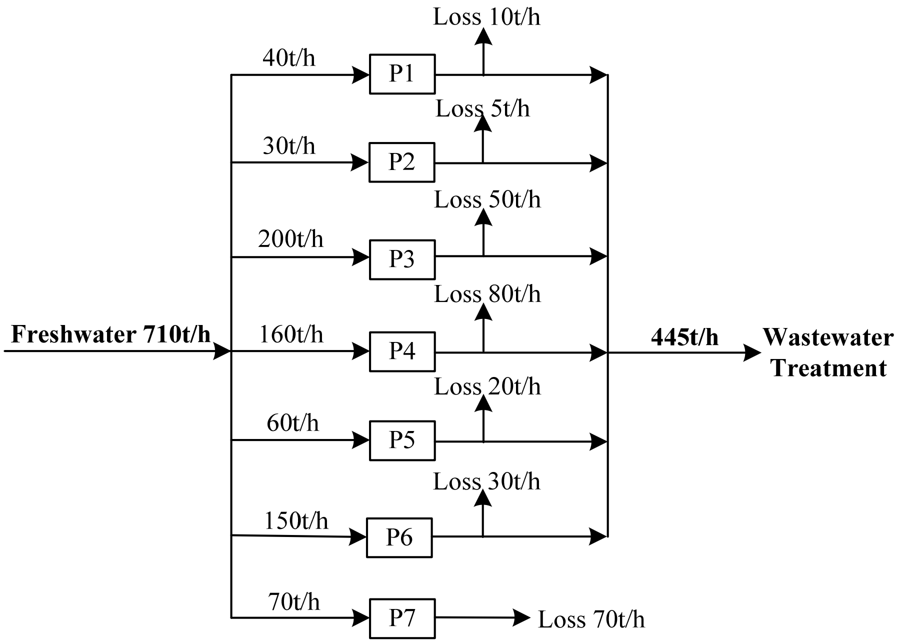

Figure 2 the present water using network for the alumina plant

4 Determining the optimal parameters for ZWD water system

The inlet streams are considered as demands, while the outlet streams are considered as sources. The fixed contaminant mass load problem in Table 1 is thus converted to an equivalent fixed flow rate problem in Table 2.

Then the Composite Table Algorithm (CTA) is implemented and the steps are given below. All the calculations are summarized in Table 3.

(1)Tabulate all concentrations (of all internal sources, demands and external resources) in increasing order in the first column. Do not repeat a concentration value if the same concentration occurs more than once. Add one more arbitrary concentration (in parentheses) at the bottom of the column such that it is the largest value. Because the maximum concentration of demands and sources is 200ppm, the terminal concentration can be assumed to be $C_{out}^{\lim} = 250\text{ppm}$ as shown in the last row of the first column. Without loss of generality, the concentration for the kth row is denoted as C_k such that

$$C_1 < C_2 < \cdots < C_k < \cdots < C_N \quad (5)$$

(2)Tabulate the net flow rates (F_{k+1}) in the second column. The sum of the flow rates of the sources is subtracted from the sum of the flow rates of the demands present in each concentration interval.

(3)Tabulate the net mass loads (ΔM_{k+1}) in the third column. Multiply the net flow rate by the concentration difference of the corresponding interval to obtain the net mass load (as shown in Eq.(6)).

$$\Delta M_{k+1} = F_{k+1}(C_{k+1} - C_k) \quad (6)$$

(4)Tabulate the cumulative mass load (ΔM_k^{cum}) in the fourth column via Eq.(7). The limiting composite curve (curve BCPDE in Fig. 3) can be constructed via plotting the concentration column against the cumulative mass load column.

$$\Delta m_{k=1} = 0$$
$$\Delta m_k^{cum} = \sum_{k=1}^{k} \Delta m_k \quad (7)$$

(5)Tabulate the freshwater supply flow rates for direct reuse in the fifth column via Eq.(8). The maximum value in the fifth column reveals that the minimum freshwater target for direct reuse is 327.5t/h.

$$F_{ws} = \frac{\Delta m_k^{cum}}{C_k - C_{ws}} \quad (8)$$

Once the limiting composite curve is constructed, the ZWD maximum post-regeneration concentration ($C_o^{\max}$) is determine in the next step. Here, the freshwater supply line AF (the reciprocal of its slope is 265t/h) cross the limiting composite curve BCPDE at point C (Fig. 3). The concentration corresponding to the point defines the ZWD maximum post-regeneration concentration $C_o^{\max} = 48\text{ppm}$. The outlet concentration for the wastewater treatment equipment of the alumina plant is known as $C_o = 20\text{ppm}$, that is $C_o \le C_o^{\max}$. So the ZWD condition is satisfied. The optimal water supply line for ZWD at $C_o = 20\text{ppm}$ is denoted as AVPGM (in Fig. 4).

Table 1 Limiting data for the operations [a]

Process	*Water using process*	M_i *(g/h)*	$C_{i,IN}^{\max}$ *(ppm)*	$C_{i,OUT}^{\max}$ *(ppm)*	$F_{i,IN}^{\lim}$ *(t/h)*	F_i^{loss} *(t/h)*	$F_{i,OUT}^{\lim}$ *(t/h)*
P1	Cooling for raw material pump	1600	20	60	40	10	30
P2	Purge for outlet of lime burner	1200	60	100	30	5	25
P3	Cooling for sintering equipment	12000	20	80	200	50	150
P4	Red mud washing	16000	100	200	160	80	80
P5	Cooling for vacuum pump of evaporator	2400	20	60	60	20	40
P6	Cooling for calcinations equipment	9000	20	80	150	30	120
P7	Re-circulating water system	8400	80	200	70	70	0

[a] P7- Re-circulating water system uses 70t/h freshwater to compensate the water loss of re-circulating water of the water system.

Table 2 Limiting data for demands and sources

	$C_i^{\max}$ */(ppm)*	$F_i^{\lim}$ */(t/h)*		$C_i^{\max}$ */(ppm)*	$F_i^{\lim}$ */(t/h)*
Demands			Sources		
$P1_{in}$	20	40	$P1_{out}$	60	30
$P2_{in}$	60	30	$P2_{out}$	100	25
$P3_{in}$	20	200	$P3_{out}$	80	150
$P4_{in}$	100	160	$P4_{out}$	200	80
$P5_{in}$	20	60	$P5_{out}$	60	40
$P6_{in}$	20	150	$P6_{out}$	80	120
$P7_{in}$	80	70	$P7_{out}$	200	0

Table 3 the Composite Table Algorithm (CTA)

$C_i^{\max}$ (ppm)	F_{net} *(t/h)*	M_{net} *(kg/h)*	M_{cum} *(kg/h)*	$\frac{M_{cum}}{C - C_{ws}}$ *(t/h)*
20			0	0
60	450	18	18	300
80	410	8.2	26.2	**327.5**
100	210	4.2	30.4	304
200	345	34.5	64.9	324.5
(250)	265	(13.25)	(78.15)	(312.6)

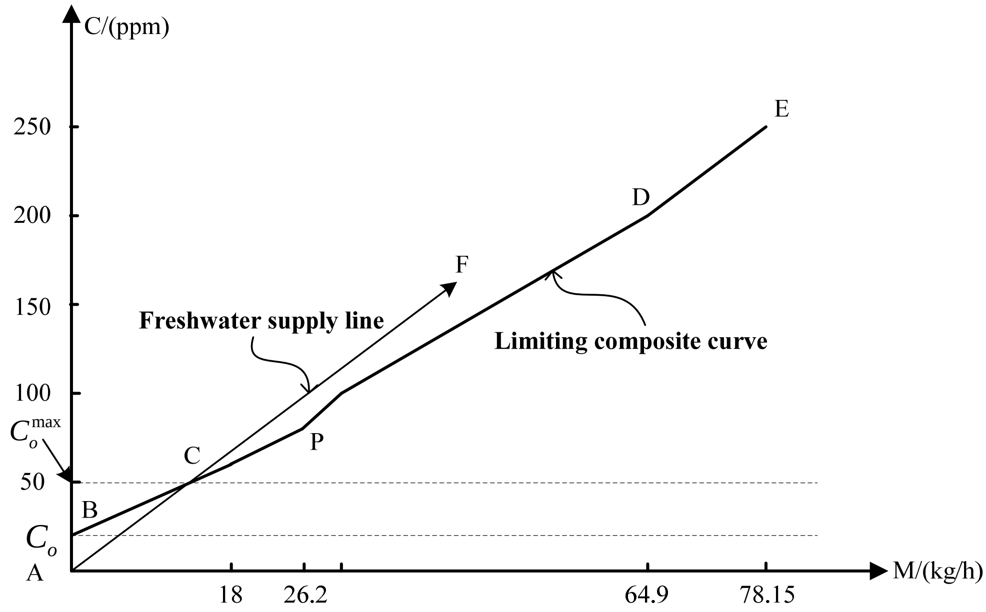

Figure 3 determine the maximum ZWD post-regeneration concentration

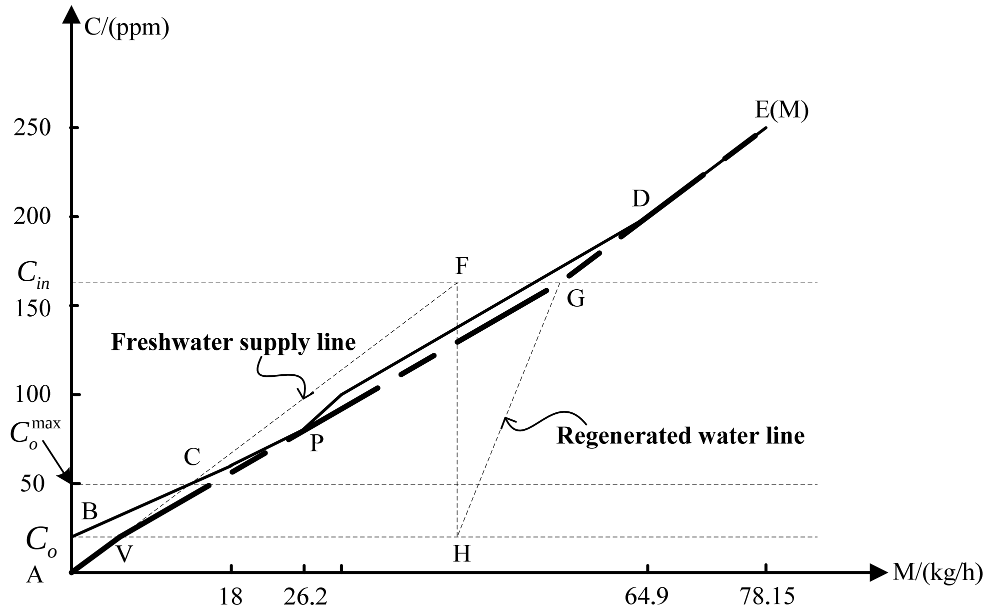

Figure 4 the optimal water supply line for ZWD for the alumina plant

From Fig. 4, it can be read, that the mass load at point P is $M_p = 26.2\text{kg/h}$, the concentration at point P is $C_p = 80\text{ppm}$, that the mass load at point D is $M_D = 64.9\text{kg/h}$, and the concentration at point D is $C_D = 200\text{ppm}$.

The optimal regenerated water flow rate can be calculated by Eq.(9),

$$F_{reg} = \frac{M_P - F_{ws}C_P}{C_P - C_o} \tag{9}$$

where m and C denote the contaminant mass load and contaminant concentration, respectively,, and subscripts reg and P denote regeneration and point P in Fig. 4, respectively. Noticeably, line HG in Fig.4 denotes the optimal regenerated water line.

The optimal regeneration concentration can be calculated by Eq.(10),

$$C_{in} = \frac{M_D - F_{ws}C_D}{F_{reg}} + C_o \tag{10}$$

where subscript D denotes the point D in Fig.4.

From Eqs.(9) and (10) with $M_p = 26.2\text{kg/h}$, $C_p = 80\text{ppm}$, $M_D = 64.9\text{kg/h}$, $C_D = 200\text{ppm}$,

$F_{ws} = 265\text{t/h}$, $C_o = 20\text{ppm}$, gives $F_{reg} = 83.33\text{t/h}$ and $C_{in} = 162.8\text{ppm}$, which are the optimal regenerated water flow rate and optimal regeneration concentration, respectively.

5 Design for the optimal ZWD water network

To design the water network for fixed contaminant problem, Prakash and Shenoy [8] proposed three design rules:

Rule 1: All units must have their outlet concentrations equal to the maximum allowable values.

Rule 2: If a unit crosses the pinch (the pinch concentration is between the inlet and outlet limiting concentration of the unit), the inlet concentration must be forced to its maximum allowable value. This rule may be simply implemented through the near neighbor algorithm (NNA) proposed by Prakash and Shenoy [8].

Rule 3: If a unit totally below or above the pinch, the cleanest source available is utilized to the maximum amount. The cleanest source below the pinch is usually freshwater.

Utilizing the above three design rules, based on the optimal targets for ZWD, the design starts with the process having the minimum inlet concentration and proceeds in increasing order of inlet concentrations.

The optimal targets of this water system for ZWD are as follows: $F_{ww} = 265\text{t/h}$, $F_{reg} = 83.33\text{t/h}$, $C_{in} = 162.8\text{ppm}$, $C_o^{max} = 48\text{ppm}$, given $C_o = 20\text{ppm}$, and pinch concentration $C_p = 80\text{ppm}$.

Process 1, 3, 5 and 6 are below-pinch units. In accordance with Rule 3, the cleanest available source is freshwater. Apart from that, the 20ppm regenerated water is also need to be taken into consideration. According to Rule 1, all the outlet concentration should be achieve the maximum value. Take process 1 for example, its outlet concentration is 60ppm. Its freshwater requirement is calculated as $1600/(60-0) = 26.67\text{t/h}$, 10t/h water loss at the outlet and the wastewater discharge of process 1 is 16.67t/h at 60ppm. Process 3 consumes 150t/h freshwater and discharges 100t/h wastewater at 80ppm with the loss 50t/h. Process 5 consumes 40t/h freshwater and discharges 20t/h wastewater at 60ppm with the loss 20t/h. The residual freshwater 48.33t/h is fed into process 6, which can not satisfy its water requirement. The 83.33t/h regenerated water and 6.67t/h outlet stream form process 5 are supplied to process 6. Its actual inlet concentration is 14.94ppm and its outlet stream is 108.33t/h at 80ppm. There is 30t/h water loss in it.

Process 2 is an across-pinch unit with maximum allowable inlet concentration below the pinch concentration (60<80ppm) and outlet concentration above the pinch concentration (100>80ppm). The inlet concentration should equal 60ppm in accordance with Rule 2. At this time, the available sources are 16.67 t/h of the outlet stream (60ppm) from process 1, 100 t/h of the outlet stream (80ppm) from process 3, and 13.33t/h of the outlet stream (60ppm) from process 5. According to the NNA, the outlet streams from process 1 and process 5 should be utilized firstly because their concentration is equal to the concentration of the inlet concentration of process 2. The outlet streams from process 1 and process 5 satisfy process 2 to the moment. Then process 2 discharges 25t/h wastewater at 100ppm with the loss 5t/h.

Process 4 and 7 are above-pinch units. According to Rule 3, the cleanest sources (the output streams of process 3 and process 6 at 100ppm) are used. Process 7 consumes 70t/h of the outlet stream from process 6 and the entire water is used to compensate the water loss. Process 4 consumes 100t/h of the outlet stream from process 3 and 33.33t/h wastewater from process 6. There is 80t/h water loss in process 4, which discharges 53.33t/h wastewater at 200ppm.

The wastewater streams entering into the regeneration process are as follows: 25t/h outlet stream of Process 2(100ppm), 5t/h residual outlet stream of Process 6(80ppm) and 53.33t/h outlet stream of Process 4(200ppm). The result shows that the regenerated flow rate is 83.33t/h and the regeneration concentration is 162.8ppm, which is coincidence with the optimal targets.

Without considering flowrate constraints, the optimal water network with zero waste discharge is shown Fig.5.

In Fig.5, it can be found that the inlet flowrates of P1, P3, P5 and P6 are less than their limiting inlet flowrates. However, those processes have fixed flowrate constraints and here the local recycling [8] is applied to meet fixed flowrate requirements. The recycling flowrate of process i ($F_{i,\text{recycle}}$) can be obtained through subtracting the present flowrate ($F_{i,IN}$) from the inlet limiting flowrate ($F_{i,IN}^{\lim}$), as shown in Eq. (11)[8],

$$F_{\text{recycle}} = F_{i,IN}^{\lim} - F_{i,IN} \quad (11)$$

The recycling flowrates of P1, P3, P5 and P6 are calculated by using Eq.(11) and they are marked in final ZWD water network considering fixed flowrate constraints (Fig. 6).

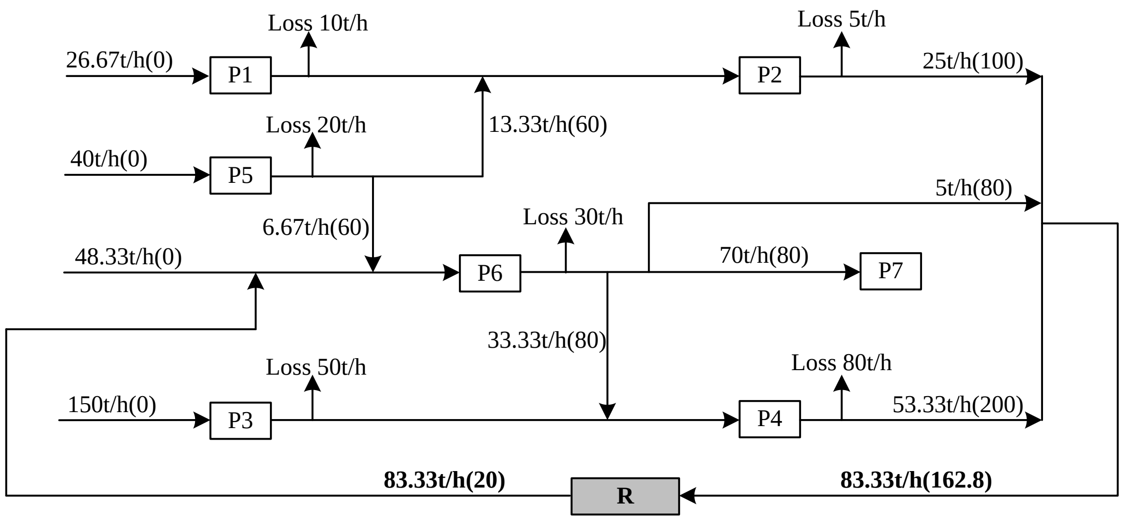

Figure 5 the optimal ZWD water network for the alumina plant (unit in parenthesis: ppm)

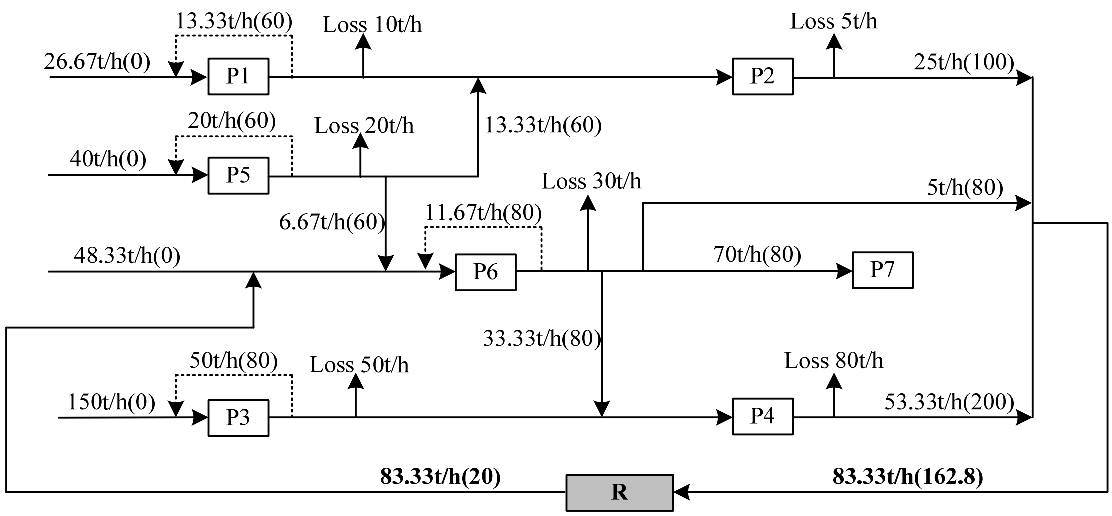

Figure 6 final ZWD water network considering fixed flowrate constraints (unit in parenthesis: ppm)

6 Results

Before the retrofit, the water using system for the alumina plant consumes 710t/h freshwater and discharges wastewater about 445t/h. The discharged contaminant mass load (M_d) can be used to describe the burden to the environment. As shown in Eq. (8), the discharged contaminant mass load (M_d) equals discharged flow rate form process *i* ($F_{i,d}$) multiplied with its outlet concentration ($C_{i,OUT}$). Because all the outlet streams from processes of this water system before retrofit are discharged into the environment and the discharged flow rate form process *i* ($F_{i,d}$) can be replaced by the outlet flowrate of process *i* ($F_{i,OUT}$)

$$M_d = \sum_{i \in P} F_{i,d} \times C_{i,OUT} = \sum_{i \in P} F_{i,OUT} \times C_{i,OUT} \tag{8}$$

According to the limiting data (Table 1), the discharged contaminant mass load of the present water system (M_d) can be calculated as 44300g/h. After applying the ZWD theory to retrofit the water system, the freshwater consumption is reduced to be 265t/h, which is used to compensate the water loss. The freshwater flowrate reduction is about 445t/h and the freshwater saving rate is 62.7%. Zero wastewater discharge is accomplished. Then the discharged contaminant mass load (M_d) can be zero and the environment burden is almost totally removed.

A heuristic retrofit procedure is summarized and it can be applied to water systems of other plants, as shown in Fig. 7

Moreover, the retrofit for the water system is cost-effective. The local freshwater price is RMB ￥2.7 per ton and the wastewater discharge fee is RMB￥0.6 per ton. It can reduce the 445t/h of freshwater and 445t/h of wastewater. Hence it can save RMB￥1.17×10^7 per year (annual operation hour is 8000h). The capital cost for equipments (i.e. regeneration equipment, pipes and pumps) is RMB ￥2×10^7. Then the payback period is 1.7 years.

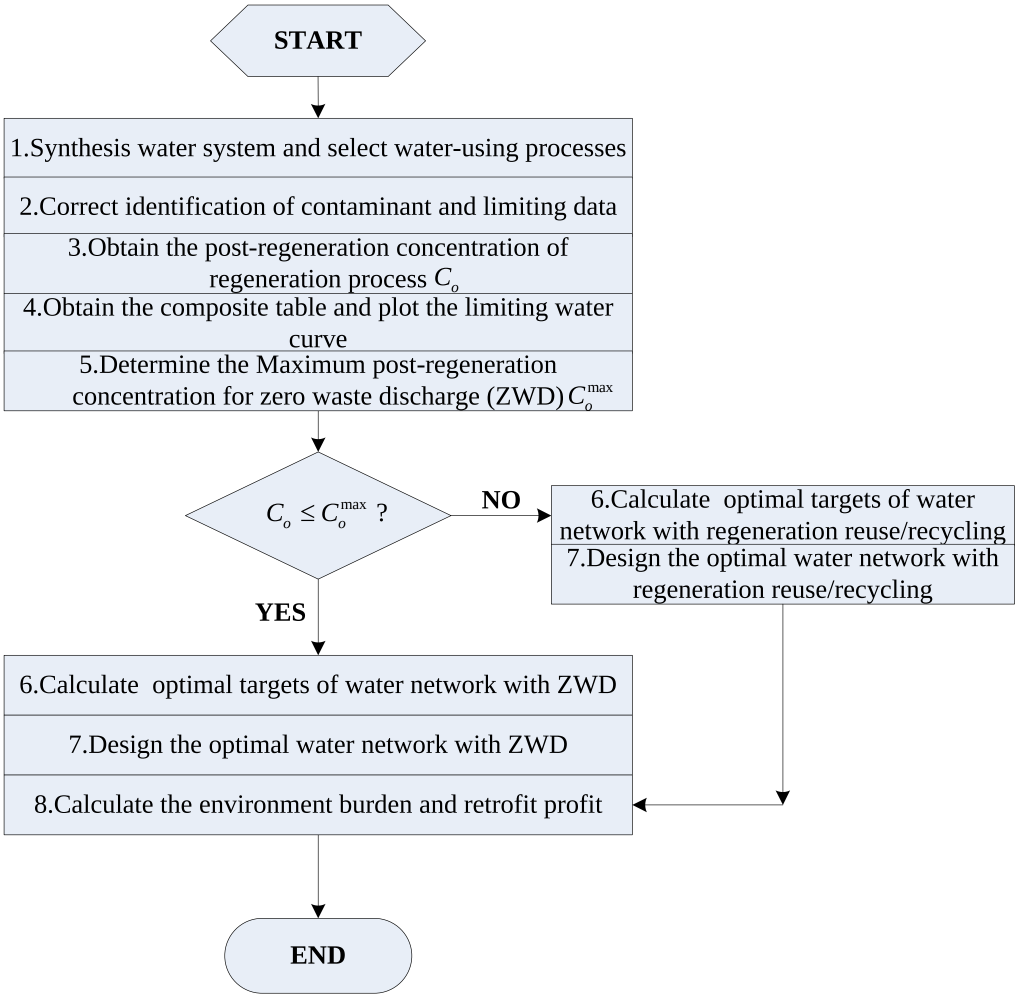

Figure 7 the heuristic retrofit procedures for water system

7 Conclusions

Based on the graphical method for ZWD water system proposed by Deng, et al.[13], this paper proposed a retrofit strategy for an alumina plant water system to accomplish zero wastewater discharge. The approach can deal with the hybrid problem containing both FF and FC operations without ignoring water loss in the alumina plant.

Firstly, the water system of the alumina plant is analyzed to obtain the limiting data of main water-using operations. Then, the limiting data and water loss amount for each water using process are converted into sources and sinks data to apply the Composite table algorithm (CTA) proposed by Agrawal and Shenoy [10]. The limiting composite curve can be drawn on the concentration-mass load diagram. The ZWD maximum post-regeneration concentration can be obtained from the limiting composite curve, and then justify the possibility for accomplishing ZWD. The optimal ZWD water supply line is constructed and the corresponding optimal targets (the optimal ZWD regenerated water flow rate and regeneration concentration) are calculated. Finally, the optimal ZWD water network is synthesized according to the design rules proposed by Prakash and Shenoy [13], and local recycling is used tomeet the fixed flowrate constraint of some processes.

The alumina plant water system accomplished zero wastewater discharge and the freshwater saving rate is 62.7%.

Nomenclature

C	Contaminant concentration, ppm;
CTA	Composite table algorithm;
F	Water flow rate, t/h;
FC	Fixed contaminant mass load;
FF	Fixed flowrate;
M	Mass load, kg/h;
NNA	Nearest neighbors algorithm;
P	Set of processes of the water system;

Superscripts:

lim	Limiting data;
loss	Water loss;
max	Maximum value;

Subscripts:

D	Point D;
i	Index for operation i;
in	Inlet (concentration before regeneration)
IN	Inlet;
o	Outlet (concentration after regeneration)
loss	Water loss;
OUT	Outlet;
P	Point P;
recycle	Local recycle;
reg	Regeneration;
ws	Freshwater supply;
ww	Wastewater.

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