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Hydraulic Method of Controlling Solids Retention Time in Step-Feed Biological Nitrogen Removal Process

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ABSTRACT

Controlling of solids retention time (SRT) in the activated sludge process is critical for ensuring effective wastewater treatment. Because of the disadvantages of conventional control methods, the hydraulic method of controlling SRT was improved in this study and applied into the step-feed biological nitrogen removal process. After the application of the hydraulic control method, conventional SRT changed from 17.67 to 19.08 days and hydraulic SRT was constant at a desired 20 days. Hydraulic control of SRT simplified process control, and produced good effluent quality where the total nitrogen removal efficiency with four stages ascended from 72.6 to 85%. Variations of hydraulic SRT under different influent wastewater strength and flow rates were investigated, and the results showed that a relative constant SRT value could be maintained easily. The feasibilities of applying the hydraulic method of controlling SRT in step-feed biological nitrogen removal process with different operational modes, including different stage numbers processes, different influent flow rate distributions, and volumes in each stage and different volume ratios of the anoxic zone to the aerobic in each stage, were verified and the results were satisfactory. Under constant SRT the total nitrogen removal efficiency of the step-feeding process with three, four, and five stages was 80, 85, and 95%, respectively.

Key words: activated sludge; biological nitrogen removal; hydraulic method; solids retention time; step-feeding process; wastewater treatment

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INTRODUCTION

In recent years, intensive attention has been given to the control of the wastewater treatment process, especially the biological nitrogen removal process, and the control of the whole plant operation (Tong *et al.*, 1980; Ferrer *et al.*, 1998; Bongards, 2001; Zhu *et al.*, 2005). The control objective and parameters ranged from recycle sludge ratio, aeration, effluent suspended solid, external carbon addition, loading rate, and discharge rate of wasting sludge to dissolved oxygen concentration. The recycled activated sludge must provide sufficient concentration of biomass in the reactors to maintain the required treatment efficiency despite of time-varying influent organic loading and flow rate (Pfister *et al.*, 1998). The wasting of the sludge is necessary to keep either a given food to the micro-organism ratio or sludge age and to operate the settler under dynamic stability. The importance of solids retention time (SRT) as a control parameter is that the specific growth rate and thus the physiological state of the micro-organisms in the system as well as the settling characteristics of the sludge can be controlled simultaneously (Takacs *et al.*, 1991). The use of conventional SRT control methods are obviously troublesome, and time-delay, especially in the step-feed biological nitrogen removal (SFBNR) process because the mixed liquid suspended solids (MLSS) concentration in each stage changes along with the influent flow distribution. Hydraulic control of SRT was introduced by Garrett (1958), for direct wasting of mixed liquor solids and did not apply to step-feeding processes because of the difference of MLSS in each stage.

In the last decade many researchers have paid much attention to the SFBNR process because of the high nitrogen removal efficiency. There were many valuable conclusions in the aspects of theoretical analysis (Shigeo, 1996; Larrea *et al.*, 2001; Zhu and Peng, 2006) and practical operation (Kayser *et al.*, 1992; Lesouef, 1992; Schlegel, 1992; Gorgun *et al.*, 1996; John *et al.*, 1996; Zhu *et al.*, 2007). But none is about the SRT control in the step-feeding process. In this study the hydraulic control SRT method is improved and applied into the step-feed biological nitrogen removal process. The result of introducing the hydraulic method of controlling SRT to the step-feed biological nitrogen removal process is evaluated. The effect of hydraulic SRT on biological nitrogen removal in the step-feed process is also examined.

METHODOLOGY

The SRT is defined in the following equation:

$$\mathrm{SRT} = \frac{V \cdot X}{(Q - Q_w) \cdot X_e + Q_w X_R}$$

in which X is the concentration of biomass in the reactor, g/m^3, V is the volume of reactor, m^3, Q is the influent wastewater flow rate, m^3/day, Q_W is the waste sludge flow rate, m^3/day, X_e is the biomass concentration in the effluent, g/m^3, and X_R is the biomass concentration in the waste sludge, g/m^3.

Over the years, the industry has developed various methods to adjust the waste flow and control SRT, including (Tchobanoglous *et al.*, 2003):

1. direct SRT control using measurements of MLSS inventories and waste sludge solids flow rates (total suspended solids [TSS] concentrations and flow rates);
2. F:M control;
3. maintain a constant MLSS level in the aeration tanks.

The three methods mentioned above require TSS and biological oxygen demand (BOD) estimation by laboratory methods, centrifuge spins, or on-line analyzers. Also, the definition of MLSS inventory may or may not include clarifier inventories or solids without aeration, for example, anaerobic zones. The use of a conventional SRT control method is obvious troublesome and time-delay work, especially in the step-feeding process because the MLSS concentration in each stage changes along with the influent flow distribution.

The hydraulic method of controlling SRT may be explained easily by an example. Assume an SFBNR process with an average daily flow of Q m^{3}day^{-1}, an average sludge return flow rate of R m^{3}day^{-1}, aeration tank volume of V_A m^3, and a sedimentation tank volume of V_S m^3. For maintaining SRT at a constant value of X_{SRT}, it is necessary to waste (100/X_{SRT}) percent of the TSS in the system each day. However, (100/X_{SRT}) percent of the return sludge cannot be wasted because the sludge makes several passes through the sludge return line each day and more would be wasted than intended. If it were known how many passes through the sludge were made each day, however, it would be possible to calculate the percentage of the return sludge that should be wasted on a continuous basis; that percentage would be (100/X_{SRT}) divided by the number of passes made each day. In this part, discussion about the suspended solids (SS) concentration in the effluent is not considered in the hydraulic SRT calculation. This cannot be neglected when settling problems exist. But in China, the effluent solids concentrations are always less than 15 mg/L in many wastewater treatment plants (WWTP). Some information of SS concentrations of influent and effluent in some WWTP in Beijing is shown at the Web site (http://www.chinasewage.com/). Moreover, in the step-feeding process, the influent is distributed to each anoxic zone along the reactor and the recycled sludge is just returned to the first stage. There must be a gradient solids concentration along the reactor. The MLSS of the first stage is even higher than 6,000–7,000 mg/L. So the SS of the effluent could be ignored compared to this.

The number of passes the sludge making each day may be calculated for any plant (Garrett, 1958). The total number of passes per day for a step-feeding process is equal to 1 divided by the TSS detention time in the system. The TSS retention time is equal to the sum of the solids detention time in each stage and in the sedimentation tanks.

An important issue should be illuminated. The essence of plug-flow reactor emphasizes that the retention time of any hydroelements (wastewater and activated sludge) is equal (Tchobanoglous *et al.*, 2003). In the step-feeding process, wastewater and sludge in the reactor are well mixed in one stage and plug flow in integration, which indicates the solids retention time of one stage is equal to the hydraulic retention time. Once the number of passes per day has been calculated, it is a simple matter to determine the continuous wasting rate for each SRT. Thus, for the SFBNR process, the continuous wasting rate, calculated as the percentage of the gross return sludge ($R + W$), and may be calculated as:

$$W = \frac{100}{X_{\mathrm{SRT}}} \cdot \left(\frac{V_{\mathrm{A1}}}{Q_1 + R} + \frac{V_{\mathrm{A2}}}{Q_1 + Q_2 + R} + \cdots + \frac{V_{A(n-1)}}{Q_1 + Q_2 + \cdots Q_{n-1)} + R} + \frac{V_{\mathrm{An}}}{Q + R} + \frac{V_S}{Q + R} \right) \quad (1)$$

in which W is the waste sludge discharge ratio, counted as the percentage of the gross return sludge, X_{SRT} is the aimed SRT value (day), Q is the influent flow rate in stage, m^3/day, V_A is the aeration tank volume in stage, m^3, V_S is the sedimention tank volume, m^3, R is the sludge return rate, m^3/day, and n is the the number of stage.

For a given plant with a specific number of aeration and sedimentation tanks in service, V_A and V_S are fixed. Therefore, for any given SRT, the only variables that affect the wasting rate are Q and R. Thus, the wasting rate becomes solely dependent on the hydraulic flow through the process.

MATERIALS AND METHODS

Reactor system

The experimental setup used for the continuous-flow biological nitrogen removal experiment was a laboratory pilot-scale reproduction of the step-feed process (Fig. 1). The continuous flow reactor was made of Plexiglas with a working volume of 80 L with a dimension of 800 × 220 × 500 (L × W × H) mm. Each stage consisted of an anoxic and an aerobic zone. The ratio of anoxic reactor volume to aerobic reactor volume was adjusted by a number of flashboards. For the purpose of maintaining plug-flow and concentration gradient, the aerobic zones in each stage are separated by clapboards as three joint compartments. The reactor could also be operated as a three- or five-stage process by adjusting clapboards and influent feeding location. A mechanical mixer is used in the anoxic zone to provide complete mixed liquid. A number of outlets for samples analysis are emplaced with the distance of 200 mm from the reactor bottom in each anoxic and aerobic zone. An air compressor was used for aeration. An air flow meter was used to control the airflow rate and dissolved oxygen (DO) concentration in reactor. The type of final clarifiers was an upright clarifier with a working volume of 30 L.

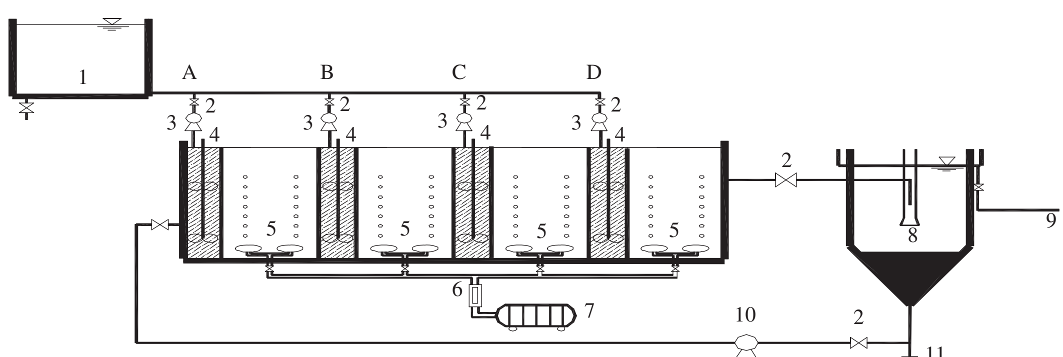

Figure 1. Schematic diagram of step feed biological nitrogen removal process. 1. influent tank; 2. check valve; 3. feed pump; 4. mechanical mixer; 5. diffuser; 6. air flow meter; 7. air compressor; 8. secondary clarifier; 9. effluent; 10. return sludge pump; 11. waste sludge.

Table 1. Composition of synthetic wastewater.

Compound	*Concentration (mg/L)*
$CH_3COONa \cdot 3H_2O$	454.5
Glucose	500–650
Starch	200–250
Amylum	200–250
Maltose	127.0
NH_4Cl	114.6
$NaHCO_3$	900.0
$MgSO_4 \cdot 7H_2O$	150.0
NaCl	110.0
$CaCl_2$	85.5
$ZnSO_4$	90.0

Wastewater composition

The reactor feed consists of synthetic wastewater with characteristics similar to those of domestic wastewater (Watanabe *et al.*, 1995). It was prepared by using tap water, dechlorinated by the use of sodium thiosulfate, and the addition of dosages of chemicals as indicated in Table 1. A few of glucose and amylum that are not very easily biodegradable organic materials were also added to supplement chemical oxygen demand (COD). In addition, some other organic materials such as glucose and maltose also exist in the synthetic wastewater. Nitrogen and phosphorus were adjusted by adding NH_4Cl and KH_2PO_4 to the feed water. Sodium bicarbonate was also added to adjust alkalinity. The characteristics of influent wastewater are shown in Table 2.

Experimental operating procedures

The start-up of the SFBNR process was initiated by seeding the synthetic wastewater with the sludge collected from the secondary clarifier of Harbin Wenchang wastewater treatment plant (A/O process, 100,000 m^3/day^{-1}). The reactor was operated for 12 days in a batch mode to provide the initial colonization and accumulation of micro-organisms. The reactor was then operated in a continuous-flow mode by gradually increasing the flow rate to promote bacterial growth. Steady state was reached after 28 days of operation. After the cultivation of the activated sludge, the experiments lasted for 10 months. The temperature of the reactor was kept at $20 \pm 1°C$ by a temperature controller during the experiment period. The dissolved oxygen was above 2.0 mgL^{-1} in the aerobic zone of each stage. The wastewater was continuously fed into the reactor and the flow rates were controlled by four peristaltic pumps.

Samples and analytical procedures

The main parameters measured were MLSS in each stage and concentration of return sludge. Other parameters including COD, NH_4^+-N, TKN (Kjeldahl nitrogen), NO_2^--N, NO_3^--N, TN, and alkalinities were also measured. Samples were prepared by filtering with 0.45-μm Whatman filter papers. Wastewater pH, temperature, and DO were monitored daily. The measurement of DO was conducted using YSI Model 58 DO meter, pH, and temperature were measured using a Cole Parmer pH/mV/°C Meter Model 59002-00. All analyses were performed in accordance with the Standard Methods (APHA, 1995).

RESULTS AND DISCUSSIONS

Mathematical relationship

The mathematical relationship between the influent flow rates, the sludge waste rate and sludge recycle rate to maintain a constant SRT for a given number of aeration tanks and sedimentation tank in service is shown graphically in Fig. 2. In this case, the operator would en-

Table 2. Influent wastewater characteristics.

Wastewater characteristic	*Value*	*Average*
BOD	150–250 (mg/L)	200 (mg/L)
COD	290–450 (mg/L)	350 (mg/L)
TKN	30–50 (mg/L)	45 (mg/L)
Ammonia	28–45 (mg N/L)	38 (mg N/L)
Nitrite and nitrate	0–0.5 (mg N/L)	0.36 (mg N/L)
Alkalinity (as $CaCO_3$)	180–250 (mg/L)	200 (mg/L)
Phosphate	4–8 (mg P/L)	5 (mg P/L)
pH	6.8–8.0	7.7

BOD, biological oxygen demand; COD, chemical oxygen demand; TKN, total Kjeldohl nitrogen.

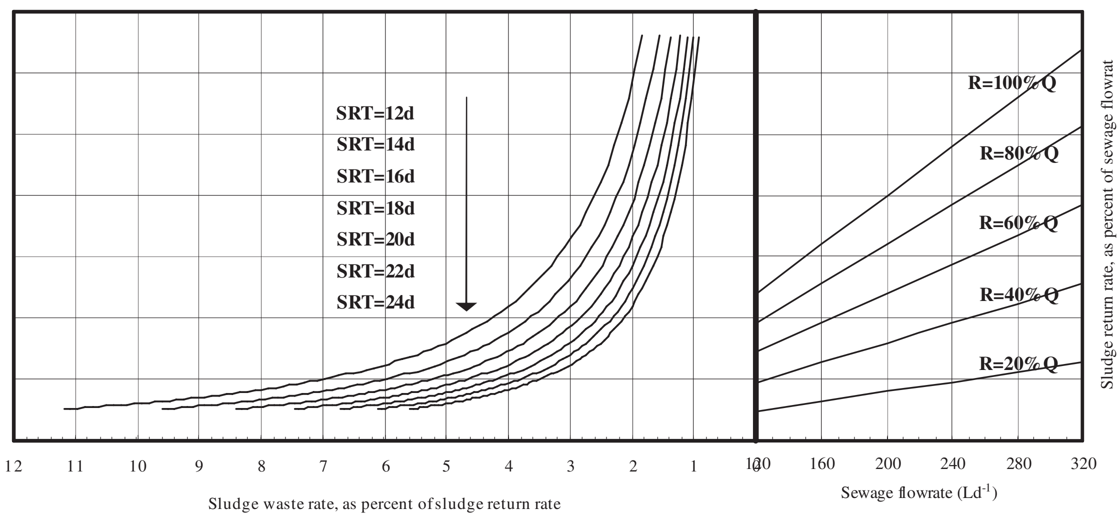

Figure 2. Mathematical relationship of sludge recycle ratio, waste sludge rate, SRT, and influent flow rate. In this case, the operator would enter the lower right–hand corner of the figure for a given wastewater flow, go up the line until it intersected the particular sludge return flow ratio, and go to the left to intersect the desired SRT; then it would go down the graph to determine the continuous wasting rate as the percentage of the return sludge.

ter the lower right–hand corner of the figure for a given wastewater flow, go up the line until it intersected the particular sludge return flow ratio, and go to the left to intersect the desired SRT; then it would go down the graph to determine the continuous wasting rate as the percentage of the return sludge. These equations can be programmed into a computer spreadsheet, providing a real-time target waste sludge flow based on current clarifier recycle ratios, influent flow rates, aeration tanks, and sedimentation tank in service. Figure 2 and its underlying equations provide the operator/engineer a simple way to change the SRT in the pilot plant tested by changing the waste sludge flow or to maintain a constant SRT when there are changes in sludge recycle ratio.

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For example, if it were desired to change the current operational target from 20 days to 16 days SRT, the waste flow rate would change from 2.38 L/day^{-1} to 2.98 L/day^{-1} at a constant 40% recycle ratio and influent flow rate 240 L/day^{-1} (influent flow distribution is 1:4:3:2 in four stages, respectively). Alternatively, the recycle ratio may be changed in response to pending clarification or thickening failures. In this case, it is necessary to change waste sludge flow rate to maintain a constant SRT. Using Fig. 2, a waste flow rate changing from 1.8 L/day^{-1} to 2.65 L/day^{-1} would maintain an 18-day SRT if the recycle ratio was reduced from 80 to 40% as a potential response to a pending clarification failure. Estimates of such waste sludge flow rate changes are more straightforward than using conventional control methods.

Hydraulic control of solids retention time

Steady state was reached after 28 days of operation. The criteria for reaching the steady state was a constant

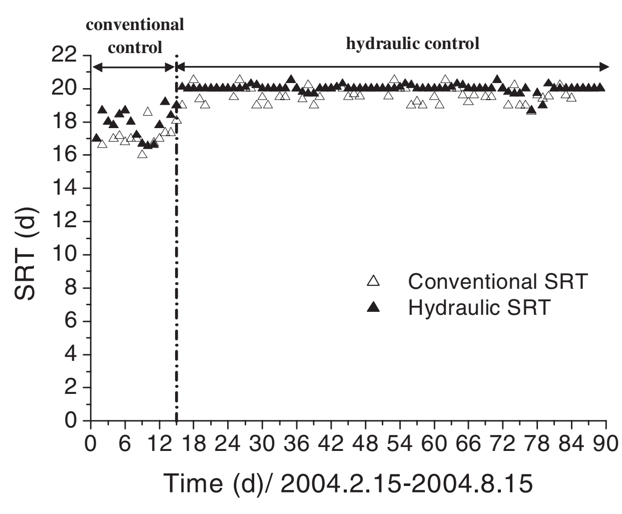

Figure 3. Variations of conventional SRT and hydraulic SRT before and after application of hydraulic control method.

biomass concentration in the reactor for more than 30 days, and the dynamic pattern in DO and pH did not vary from cycle to cycle under same influent loading rate. Moreover, the step-feeding process was operated with conventional SRT control method for two sludge ages (38 days). Then the conventional SRT control method was used during the February 1, 2004 to February 15, 2004 period. The hydraulic SRT control method has been used since February 15, 2004. Hydraulic SRT is a calculate result of combining influent flow rate, sludge recycle rate, and waste sludge rate in Eqs 1. In the period of 1st day February 2004 to 15th February 2004 by substituting some operational parameters, such as influent flow rate, sludge recycle rate and waste sludge rate in Equation (1), we can get the value of hydraulic SRT. So we can discharge the waste sludge rate by the calculated numerical value. Hydraulic and conventional SRT value can be measured by the discharge rate of waste sludge. Each day, the conventional and hydraulic SRT were compared, along with a review of all aeration process data and effluent quality data, to ensure that the aeration process would not be out of control. Variations of conventional SRT and hydraulic SRT were shown in Fig. 3.

There was a constant consistent relationship between the conventional and hydraulic SRT. From Fig. 3 we can see that after application of the hydraulic SRT control method the SRT is constant at a target, which is the main objective of this study. The average value of conventional SRT changed from 17.67 to 19.08 days after the application of the hydraulic control method. Hydraulic control of SRT was maintained at the desired 20 days. The scatter of the conventional SRT compared to the hydraulic SRT, after February when the hydraulic SRT was kept constant, is readily apparent. In this instance, the scatter of the conventional SRT is due to natural variations in sampling and analytical measurements. In practice, more significant variations in conventional SRT levels were introduced for the reason of overadjustments based on highly variable, time-delayed measurements.

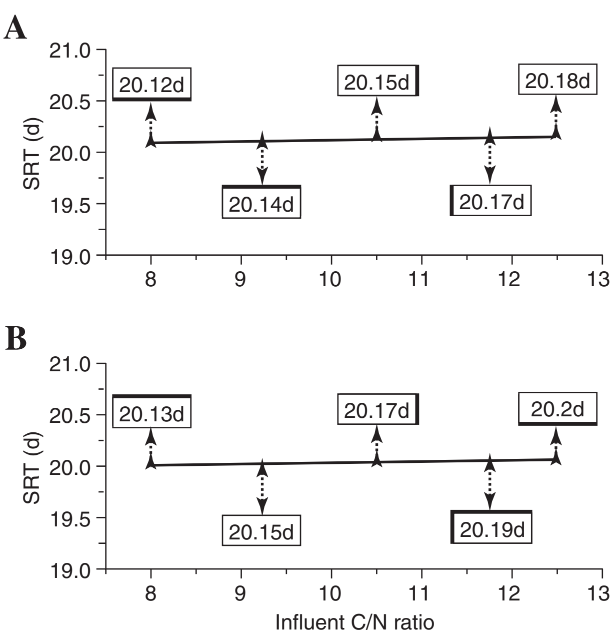

Figure 4. Variations of hydraulic SRT under different influent COD and ammonia concentration. In **A**, the concentration of influent TKN was constant at 44 mg/L, whereas COD was variable. In **B**, the concentraiton of influent COD was constant at 330 mg/L, whereas TKN was variable.

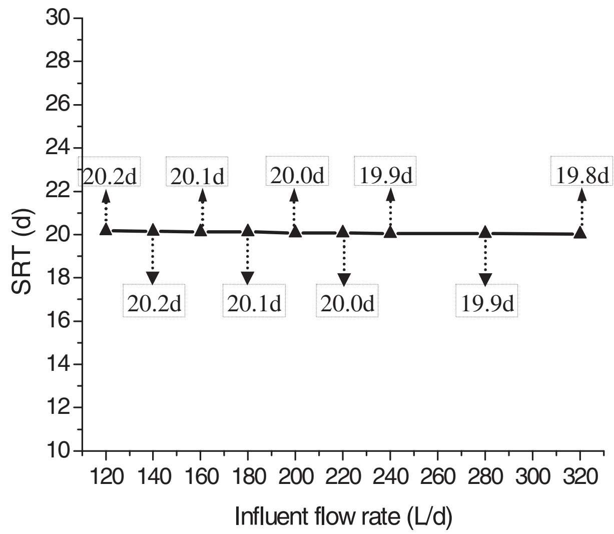

Figure 5. Variations of hydraulic SRT under different influent flow rate.

The variations of hydraulic SRT under different influent wastewater strength were investigated and the results are shown in Fig. 4. In Fig. 4A, the concentration of influent TKN was constant at 44 mg/L, whereas COD was variable. In Fig. 4B, the concentration of influent COD was constant at 330 mg/L, whereas TKN was variable. The results revealed that a relatively constant SRT, 20 ± 0.2 days, was maintained under different influent COD and TKN concentrations.

When the SRT is controlled hydraulically, the solids level automatically adjusts to the influent COD. If the influent COD increases, the solids level also increases. Thus, more solids are wasted even though the percentage of the wasted return sludge is constant. Likewise, if the COD in the influent wastewater drops, fewer solids grows and solids level in the process drops. Thus, fewer solids are wasted even though the percentage of sludge that is wasted remains the same. This is one of the major advantages of hydraulic control method over other

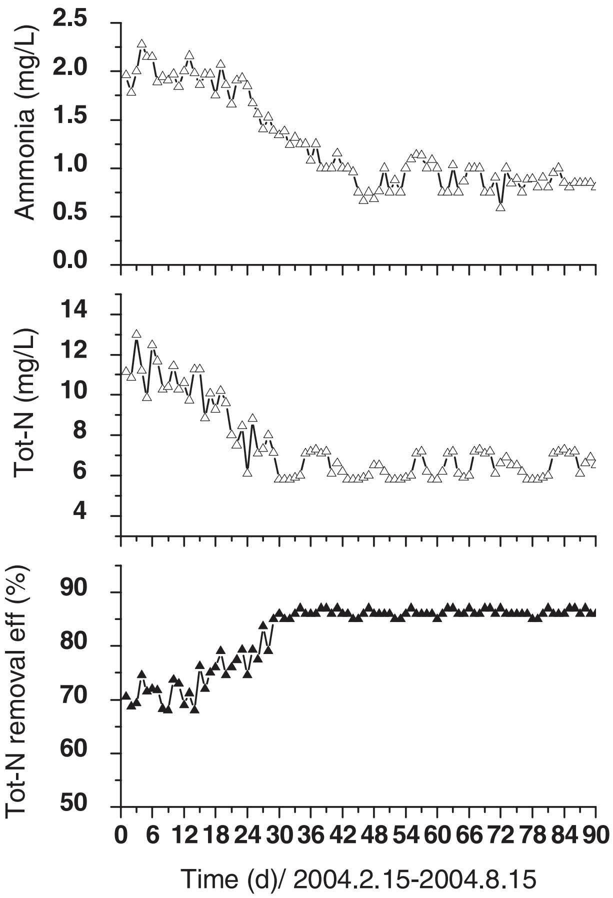

Figure 6. Variations of effluent ammonia, total nitrogen concentration, and total nitrogen removal efficiency before and after application of hydraulic control method.

control methods discussed previously. With other control methods, the operator is always trying to catch up with the COD loading. With the fixed solids method of control, as the solids level changes the operator adjusts the wasting rate the next day. If an operator is controlling the plant to a fixed food-to-micro-organism ratio, about 1 day is required to make the solids adjustment. If the operator uses BOD to determine the food-to-micro-organism ratio, it may take 5 days or a week to adjust the solids level. By the time these adjustments are made, the food load might have changed in other directions. With the hydraulic method of control, the solids level is adjusted automatically as the COD changes. The solids level is always moving in the direction that it should move to maintain a fixed food-to-micro-organism ratio.

It is interesting to note that, at longer SRT, the influent forward wastewater flow has a minimal affect on the SRT determination. The hydraulically determined SRT changes only from 20.18 days to 19.83 days when the flow increases from a typical low flow rate (120 L/day^{-1}) to a typical high flow rate (320 L/day^{-1}), assuming that other variables are kept constant (Fig. 5). In the experiments the sludge recycle ratio was constant at 40% of total influent flow rate. The experimental results indicate that a constant hydraulic controlled SRT is easily obtained by keeping the clarifier return ratio and the waste flow constant.

Biological nitrogen removal

A relative higher SRT would promote the stability of a biological nitrogen removal system, especially for the

Table 3. Array of operational conditions of SFBNR process.

Run	*Stage*	*Influent flow rate*[a]	*Volume*[b]	*Volume ratio of anoxic to aerobic zone in each stage*
A	1	25%	35%	1 : 5
	2	45%	40%	1 : 4
	3	30%	25%	1 : 3
B	1	15%	10%	1 : 6
	2	45%	40%	1 : 2.5
	3	25%	30%	1 : 3.5
	4	15%	20%	1 : 3
C	1	15%	8%	1 : 7
	2	40%	35%	1 : 5
	3	25%	25%	1 : 4
	4	12%	18%	1 : 3.5
	5	8%	14%	1 : 3

[a]Expressed as the ratio to total influent flow rate; [b]Expressed as the ratio to total reactor volume.

nitrification reaction (Leeuw and Jong, 1993; Rothman, 1998). The effect of hydraulic SRT on effluent ammonia concentration was obvious in this study. After the application of hydraulic method of controlling SRT into the SFBNR process, the SRT was constant at 20 ± 0.15 days, which provided the advantages for nitrifiers' growth in terms of the long age. The average concentration of ammonia in four stages process declined from 2.05 mgL^{-1} to 0.71 mgL^{-1}, as shown in Fig. 6. The concentration of total nitrogen in the effluent can be determined by the nitrate or nitrite in the aerobic zone of the last stage, only if in each stage complete denitrification in anoxic zone are carried out. In the last stage, where there is no nitrate accumulation and the inflow is at the minimum ratio, total nitrogen concentration in the effluent can maintain the lowest level (Zhu *et al.*, 2007). Along with high nitrification efficiency, average concentration of effluent total nitrogen declined from 10.5 mgL^{-1} to 6.75 mgL^{-1}. Accordingly, the average total nitrogen removal efficiency ascended from 72.6 to 85%.

The applications of hydraulic method of controlling SRT into the step-feeding process with different operational modes were also investigated. The experimental array of operational conditions of the SFBNR process is shown in Table 3. The operational results of the step feeding process about biological nitrogen removal with different operational modes, including different stages number processes, different influent flow rate distributions, and volumes in each stage and different volume ratios of anoxic zone to aerobic in each stage, are shown in Fig. 7. From the figure, high-average total nitrogen removal efficiency, higher than 80, 85, and 95%, could be achieved in the step-feeding process with three, four, and five stages, respectively. The removal efficiencies under

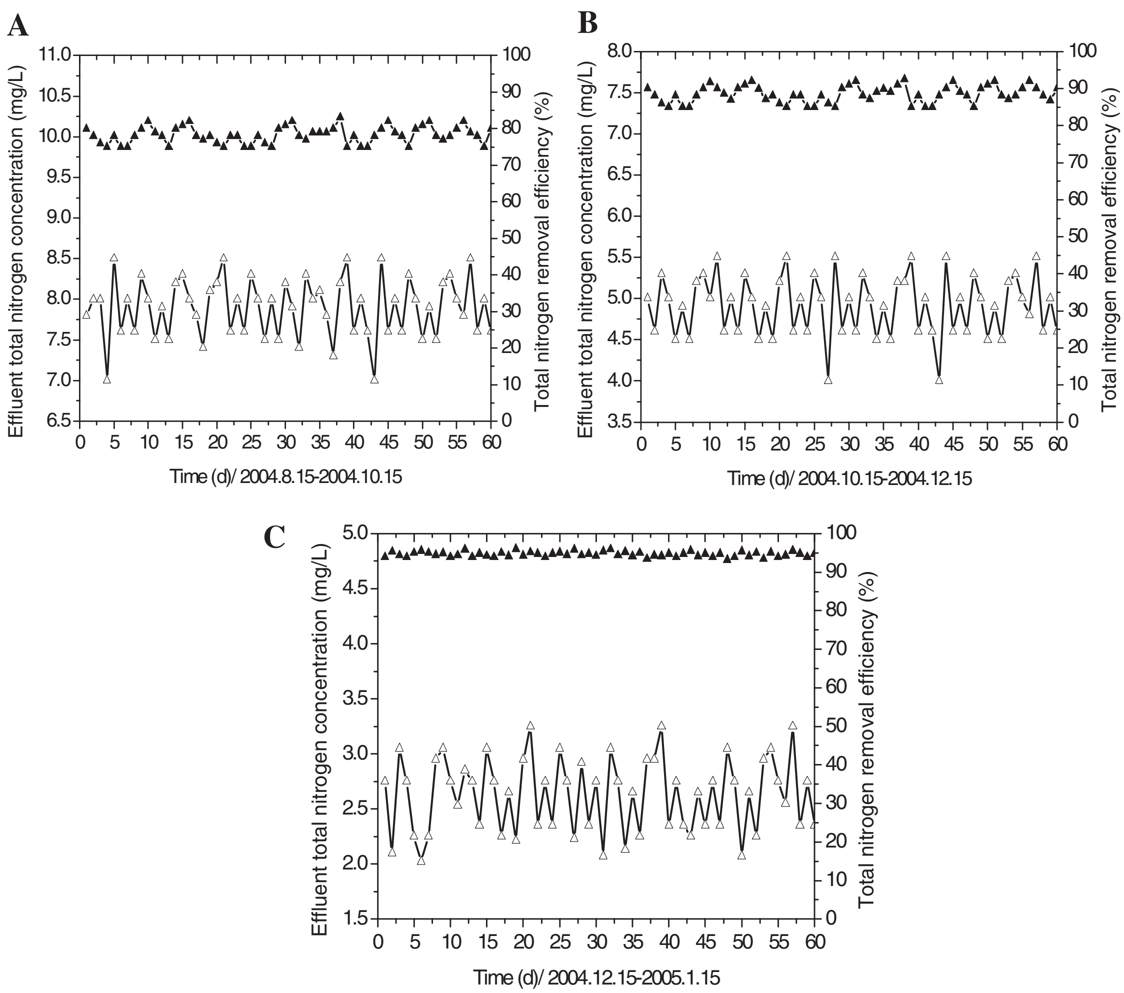

Figure 7. Variations of effluent total nitrogen concentration and total nitrogen removal efficiency after application of hydraulic control method. (**A**) Three-stage process, (**B**) four-stage process, (**C**) five-stage process. (▲) Total nitrogen removal efficiency; (□) effluent total nitrogen concentraiton.

different operational modes were all close to the theoretical values and kept stable (Zhu and Peng, 2006). The feasibilities of applying the hydraulic method of controlling SRT in the step-feed biological nitrogen removal process were verified under different operational modes and the results were satisfactory.

Comparisons between conventional SRT controlling methods and hydraulic method

It is very necessary to compare the conventional SRT controlling methods with the hydraulic method in technological, operational, and economical aspects. It is important to demonstrate the realistic sense of the new method.

The uses of hydraulic control of SRT provides an operator or engineer a simple, cheap, real-time means to calculate the waste and return flow rates and to achieve a desired SRT. It only requires a simple spreadsheet or overlay graphs for the calculation of return and waste sludge flow rates to achieve a target SRT. A readily apparent advantage of using hydraulic SRT is the elimination or reduction of conducting lab analysis of MLSS and return sludge total solids and the associated measurement variations and time lags. If the operator uses BOD to determine the food-to-micro-organism ratio, it may take 5 days or a week to adjust the solids level. By the time these adjustments have been made, the food/load ratio might have changed in other directions.

Further, more hydraulic control of SRT can improve the measurement and control process. More accurate and reliable liquid flow meters (Q, R, and W) replace the noisy TSS measurements involving sampling and analytical errors. In practice, more significant worth of the hydraulic method would be exhibited because of the characteristics of overadjustments and time delayed in the conventional method.

CONCLUSIONS

In this paper, the hydraulic method of controlling SRT was developed and applied into the step-feeding biological nitrogen removal process. In order to verify the feasibility, 12 months of experiments were performed. The effects of introducing the hydraulic method of controlling SRT were evaluated, and these conclusions were drawn:

1. The hydraulic method of controlling SRT is an effective and simple method of solids control. During 12 months of constant hydraulic control of SRT, the SFBNR process achieved a very stable operation. Hydraulic control of SRT at a constant level produced good clarification and excellent effluent quality. The average water quality of the treated effluence of four stages SFBNR was 0.71 mgL^{-1} of ammonia, 6. 75 mgL^{-1} of total nitrogen, and 85% total nitrogen removal efficiency.
2. The operational results of the step-feeding process with different operational modes, including different stages number processes, different influent flow rate distributions, and volumes in each stage and different volume ratios of anoxic zone to aerobic in each stage, also showed a stable operation. The SRT value was constant at 20 ± 0.15 days. The total nitrogen removal efficiencies were higher than 80, 85, and 95% with three, four, and five stages, respectively. The experiments verified the feasibility of the application of the hydraulic method of controlling SRT.
3. The comparisons between conventional SRT controlling methods and the hydraulic method were investigated in the technological, operational, and economical aspects. The results showed the advantage of hydraulic method over the conventional method.
4. In this paper the hydraulic method of controlling SRT in the SFBNR process, which is a specific activated sludge process from the point of process construction, was investigated. This method can also be applied into other conventional activated sludge processes such as SBR, A/O, and A^2/O processes.

RECOMMENDATIONS

1. SRT curves should be prepared for all possible flow patterns and for various numbers of tanks in use;
2. an analysis should be made of plant records to determine the average flow for each day of a week during each month;
3. it is preferable that the wasting rate be adjusted daily in the anticipation of the expected flow and return rate. It is possible, however, to get good treatments without ever adjusting the wasting rate, providing average flows that does not vary considerably from day to day;
4. the feasibility of the hydraulic method of controlling SRT in the step-feeding process needed to be investigated under poor sludge settleability.

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