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Comparative study of two biological nitrogen removal processes: A/O process and step-feeding process

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Abstract: Two biological nitrogen removal processes are compared in the aspect of nitrogen removal, process operation and energy saving. Results show that when the returned sludge ratio is 50% of the inflow rate, the step-feeding process achieves over 80% total nitrogen (TN) removal efficiency, but the TN removal efficiency of the A/O process is only 40%. Moreover, filamentous sludge bulking can be well restrained in the step-feeding process. Given the conditions of a returned sludge ratio of 100% and a nitrifying liquor recycle ratio of 200%, the TN removal efficiency is 78.32% in the A/O process, but the sludge volume index (SVI) value increases to 143 mL/g. In the step-feeding process, the SVI is only 94.4 mL/g when the TN removal efficiency reaches 81.1%. The step-feeding process has distinct advantages over the A/O process in the aspects of practicability, nitrogen removal and operating stability.

Key words: activated sludge; biological nitrogen removal; A/O process; step-feeding process; efficiency

The nitrogen and phosphorus removal technology aimed at eutrophication control has been the focus in the field of biological wastewater treatment. Phosphorus in the wastewater can be removed by conventional biological phosphorus removal processes combined with chemical sedimentation, while nitrogen can only be removed effectively and economically with biological methods[1]. Nowadays, in most countries, especially in China, about 70 percent of the wastewater treatment plants use an A/O process for biological nitrogen removal[2]. In the A/O process, the influent first enters an anoxic denitrification zone to denitrify, improving the nitrogen removal efficiency. Moreover, most organic carbon in the influent is biodegraded by denitrification bacteria, which can shorten the aerobic duration time. But because of construction of the A/O process, the NO_X-N concentration in the effluent equals that in nitrifying liquor recycling, which explains that the total nitrogen (TN) removal efficiency of the A/O process cannot be high.

A step-feeding activated sludge process was developed as a means of circumventing some of the problems of the plug-flow reactor. It is a fact that in the step-feeding process some stages of denitrification-nitrification reactors operate in series. This modification has the following advantages: 1) Regarding process operation, it eliminates the internal nitrifying liquor recycle. Nitrifying liquor in every aerobic zone directly enters the next anoxic zone; 2) Regarding treatment efficiency, it improves the TN removal efficiency. If the nitrification and denitrification perform completely at each stage, the TN concentration is only determined by the nitrate concentration produced in the previous stage; 3) Regarding reaction rate, the organic substances distribute along the reactors, which lessens the differences between the oxygen supply rates and oxygen consumption rates; 4) Regarding activated sludge loading, the primary effluent is introduced by step-feed and the returned sludge enters the head of the reactor, which gives rise to a suspended solids gradient along the reactor and improves the treatment capacity of the system. Several wastewater treatment plants in America and Japan have been extended, renewed or retrofitted as step-feeding processes so as to enhance nitrogen removal. However, most studies have concentrated on theoretical analysis and computer simulation[3-4]. Some practical experiences are drawn from operations of an extended, renewed or retrofitted conventional activated sludge process[5-7]. But seldom has the literature reported about extending, renewing and retrofitting. There is no research about the comparison between the A/O process and the step-feeding process.

1 Material and Methods

1.1 Pilot plant

The process studied is a biological wastewater treatment plant based on an A/O and a step-feeding process, as shown in Fig. 1. The two-channel cuboid reactor has a dimension of 800 mm × 220 mm × 500 mm made of plexiglass. The type of final clarifier is upright with a working volume of 30 L. The flow rates of influent, internal cycle and retuned sludge are controlled by peristaltic pumps (Lange Z2515-300M), respectively. For the purpose of maintaining plug-flow and concentration gradient, the aerobic and anoxic zones in each stage are separated by clapboards as different joint compartments. The volume ratio of the anoxic zones and aerobic zones can be adjusted by these flashboards. By adjusting the feeding location, the reactor can be operated as an A/O or a step-feeding process. A mechanical mixer is used in each anoxic zone to provide well mixed liquid. A number of outlets

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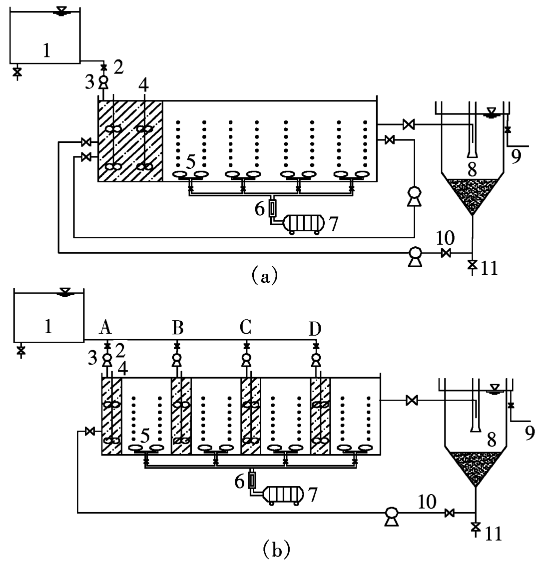
for sample analysis are emplaced at a 200 mm distance from the reactor bottom in each anoxic and aerobic compartment. An air compressor is used for aeration. Air flow meters are used for controlling the airflow rate and the DO concentration in reactor. The solid retention time (SRT) is controlled at 18 d using a hydraulic control approach[8]. The temperature of the reactor is kept at (20 ± 1) ℃ by a temperature controller.



1—influent tank; 2—check valve; 3—peristaltic pump; 4—mechanical mixer; 5—diffuser; 6—air flow meter; 7—air compressor; 8—upright clarifier; 9—effluent; 10—return sludge; 11—waste sludge

Fig. 1 Schematic diagram of biological nitrogen removal process. (a) A/O process; (b) step-feeding process

1.2 Sludge and wastewater

The inoculation sludge for the biological process was obtained from the secondary clarifier of Wenchang Wastewater Treatment Plant (A/O process, $2 \times 10^5 m^3/d$), Harbin, China. The feed was mixed with brewery wastewater and tap water. Nitrogen and phosphorus were adjusted by adding NH_4Cl and KH_2PO_4 to the feed water. Sodium bicarbonate or sodium hydroxide was also added to adjust the alkalinity. Other elements such as $MgSO_4$, $CaCl_2$, and $ZnSO_4$ were also added. The composition of synthetic wastewater is shown in Tab. 1.

Tab. 1 Composition of synthetic wastewater

Compound	Concentration/($mg \cdot L^{-1}$)
Brewery wastewater	9 500 to 10 500
Glucose	500 to 650
Starch	200 to 250
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

The start-up of the biological process was initiated with cesspool wastewater. While the reactor was operated for 3.5 d in a batch mode to provide the initial colonization and accumulation of microorganisms, the reactor was then operated gradually in a continuous flow mode with synthetic wastewater. Steady state was reached after 48 d of operation. Once the steady-state was realized, various experiments were conducted with different influent COD and ammonia concentrations.

1.3 Analytical methods

The DO and temperature are measured continuously using a YSI 5730 oxygen probe. COD_{Cr}, NH_4^+-N, TKN (kjeldahl nitrogen), NO_2^--N, NO_3^--N, MLSS, TN, PO_4^{3-}-P, and alkalinity are measured according to standard methods[9].

2 Results

2.1 A/O process

In the aerobic zone, ammonia is nitrified and the nitrate thus produced is recycled with the mixed liquor into the anoxic zone, wherein denitrification takes place. The returned sludge from the settler is recycled into the anoxic zone, where the influent and sludge are mixed under anoxic conditions. By adjusting the returned sludge ratio and nitrifying liquor recycle ratio, four different experiments are conducted in order to investigate nitrogen removal and the performance of the A/O process. The experimental design is shown in Tab. 2. During these experiments, the characteristics of the influent are kept at the same level, TKN of 38 mg/L, TN of 40 mg/L, COD of 360 mg/L. The volume ratio of anoxic to aerobic zones is 1∶3.5.

Tab. 2 Experimental design %

Experiment	Returned sludge ratio	Nitrifying liquor recycle ratio
a	50	0
b	100	0
c	100	100
d	100	200

Fig. 2 shows the track analysis data and Fig. 3 shows the TN removal efficiency and sludge volume index (SVI). In Fig. 2, the alphabetic number A means the anoxic zone, O means the aerobic zone, and the Arabic numerals represent the compartments. In experiment a, the TN removal rate is 40%, and the SVI is 123 mL/g; in experiment b, the TN removal rate is 47.92%, and the SVI is 127 mL/g; in experiment c, along with the increase in the cycle rate, the TN removal rate and the SVI are 66% and 133 mL/g, respectively; in experiment d, the TN removal rate and the SVI are 78.32% and 143 mL/g, respectively. Under the conditions of the HRT of 8 h and an influent C/N (COD/TKN) ratio of 9.0, both complete nitrification and denitrification are achieved. The concentration of TN in the effluent is only determined by the nitrate produced in the aerobic zone. But nitrate in returned sludge and recycled nitrifying liquor are equal to the nitrate in the effluent, so it is difficult for the A/O process to achieve a high nitrogen removal efficiency. When the returned sludge ratio is 100% and the nitrifying liquor recycle ratio is 200%, the A/O process can only achieve a TN removal efficiency of 78.5%. The SVI is also investigated under different operating conditions. Along with the increase in the returned sludge ratio and the nitrifying liquid cycle ratio, the SVI also increases. In experiment d, the A/O process is nearly operated as a complete-mixing process, which is one of the reasons for filamentous sludge bulking[10]. It should be noted that the degradation of COD proceeds thoroughly before nitrification, so it is not shown in the figures[11-12].

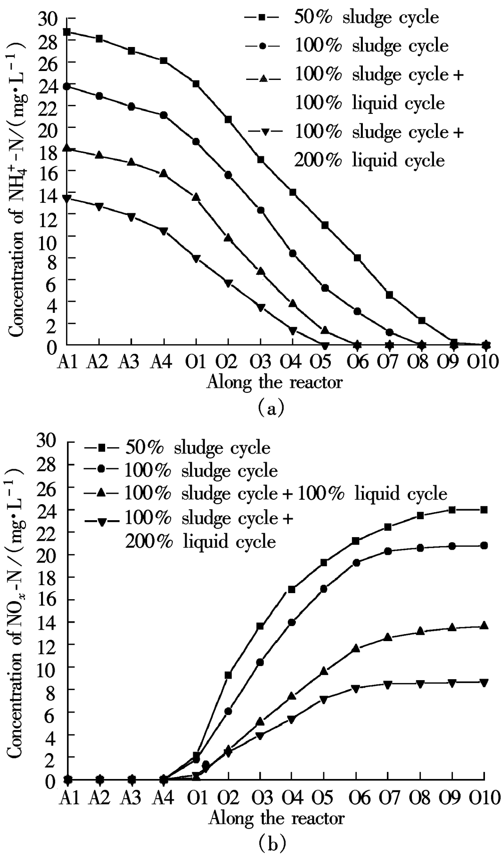


Fig. 2 Variations of NH_4^+-N and NO_x-N concentrations along the reactor in different experiments

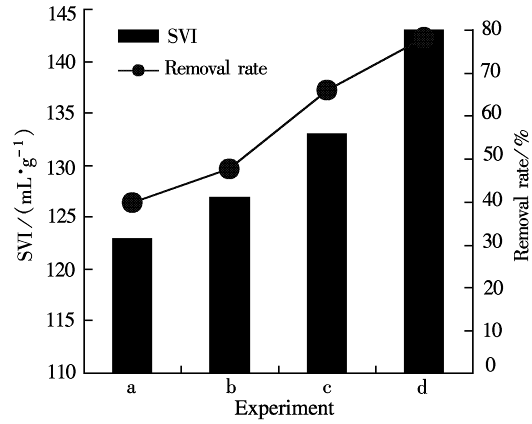


Fig. 3 The variations of TN removal efficiency and sludge volume index

2.2 step-feeding process

To compare the step-feeding process with the A/O process, both processes are operated at the same SRT, temperatures and HRT. In this study, a four-stage operating mode of step-feeding process is adopted with the influent flow distributed equally in the four stages. The volume ratio of the four-stage and the anoxic to the aerobic zone in each stage is 1∶1 and 1∶3.5, respectively. The returned sludge ratio is constant at 50%. Experiments are performed at a C/N ratio of 6, 8.25, 10.5 (influent COD concentration is constant at 330 mg/L). The concentrations of NH_4^+-N, NO_x-N, effluent TN, COD in different stages and nitrogen removal efficiency under different C/N ratios are shown in Tab. 3. The experimental results indicate that when the influent C/N ratio is 6, 8.25, and 10.5, the experimental nitrogen removal efficiency is 80.78%, 81.09%, and 80.48%, respectively, which is in accord with the theoretical value of 83.3%[13]. The average SVI in the step-feeding process is only 94.8 mL/g.

Tab. 3 Variation of biological nitrogen removal efficiency under low and middle C/N ratios with equal influent flow distribution

C/N ratio	Stage	NH_4^+-N/(mg·L^{-1})		NO_2^--N/(mg·L^{-1})		NO_3^--N/(mg·L^{-1})		COD/(mg·L^{-1})	Effluent TN/(mg·L^{-1})	Removal efficiency/%	SVI/(mL·g^{-1})
		Start	End	Anoxic zone	End of aerobic zone	Anoxic zone	End of aerobic zone	Anoxic zone			
6	A	12.80	1.45	0	0.28	0	15.09	82	10.569	80.78	95.6
	B	7.15	1.49	0	0.42	0	11.14	74			
	C	5.90	1.30	0.10	0.63	0	9.29	62			
	D	5.30	1.10	0.26	1.18	0	8.39	42			
8.25	A	10.60	1.70	0	0	0	10.32	80	7.658	81.09	94.4
	B	8.50	1.65	0	0	0	8.67	72			
	C	4.10	1.40	0	0	0	7.14	64			
	D	3.54	0.85	0	0.17	0	6.68	45			
10.5	A	2.85	1.00	0	0	0	6.74	72	5.876	80.48	94.6
	B	2.05	0.75	0	0	0	6.71	68			
	C	1.35	0.50	0	0	0	6.60	60			
	D	1.00	0	0	0	0	5.86	56			

3 Discussions and Comparisons

3.1 Total nitrogen removal efficiency

Compared with the A/O process, the step-feeding process has distinct advantage in terms of nitrogen removal efficiency. When the returned sludge ratio is 50%, the step-feeding process achieves over 80% TN removal efficiency, but the TN removal efficiency of the A/O process is only 40%. To attain an 80% TN removal efficiency in the A/O process, a 350% nitrifying liquor recycle ratio is required[12]. The step-feeding process has advantages of high nitrogen removal efficiency.

3.2 Sludge bulking

The operation stabilities, especially in sludge bulking, of both the processes are also investigated. Because the activated sludge micro-organisms undergo aerobic and anoxic environments sequentially and frequently, filamentous sludge bulking can be well controlled in the step-feeding process[10]. While the experimental results obtained from the A/O process show that SVI are 123, 127, 133 and 143 mL/g from experiments a to d, respectively, averaging 131.5 mL/g, which is close to the threshold value of filamentous bulking sludge[11]. Under conditions of C/N ratios of 6, 8.5 and 10.5, the SVI in the step-feeding process are

95.6, 94.4 and 94.6 mL/g, respectively. It is unnecessary to worry about the sludge bulking problem.

3.3 Energy saving

To attain a high TN removal efficiency, a high nitrifying liquid cycle ratio (200% to 300%) is usually needed in the A/O process. Absolutely large amounts of power consumption is wasted. Compared with the A/O process, the step-feeding process consists of two or more stages of denitrification-nitrification reactors in series. So the energy for internal recycle is unnecessary. The only additional cost is the investment for inflow pumps. Compared with the nitrifying liquid cycling consumption, this investment is almost negligible in a biological nitrogen removal wastewater treatment plant. It is obvious that the advantages of the step-feeding process are energy saving.

4 Conclusion

It is verified in this paper that the step-feeding process has distinct advantages over the A/O process with regards to practicability, nitrogen removal, energy saving and operating stability. Experimental results show that when the returned sludge ratio is 50% of the inflow rate, the step-feeding process achieves over 80% TN removal efficiency, but TN removal efficiency of the A/O process is only 40%. To attain a 78.5% TN removal efficiency in the A/O process, a 200% nitrifying liquor recycle ratio is required as well as a 100% returned sludge ratio. Moreover, filamentous sludge bulking can be well restrained in the step-feeding process. Compared with the A/O process of 131.5 mL/g, the average SVI in the step-feeding process is only 94.8 mL/g during course of the experiment. In order to improve the development and the application of the step-feeding process in the field of enhanced nitrogen removal, the performance characteristics, nitrogen removal characteristics and influence factors of the step-feeding process are urgently needed to be investigated.

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A/O 工艺与分段进水两种生物脱氮工艺的比较研究

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摘要:从脱氮率、工艺运行以及节能角度对 A/O 工艺与分段进水 2 种生物脱氮工艺进行比较. 结果表明,当污泥回流比为 50% 的条件下,分段进水工艺能达到高于 80% 的总氮去除率,但是 A/O 工艺只能达到 40%. 在污泥回流比为 100%、硝化液回流比为 200% 的条件下,A/O 工艺能够达到 78.32% 的总氮去除率,但是 SVI 值将达到 143 mL/g. 而达到同样甚至更高的总氮去除率(81.1%),分段进水工艺的 SVI 值只有 94.4 mL/g. 分段进水工艺中污泥膨胀得到很好的控制. 分段进水工艺在适用性、脱氮率、运行稳定性方面优于 A/O 工艺.

关键词:活性污泥;生物脱氮;A/O 工艺;分段进水工艺;效率

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