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Biological nitrogen and phosphorus removal using anoxic-anaerobic oxidation ditch under low temperature condition

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Abstract. A pilot-scale anoxic-anaerobic oxidation ditch process was used to investigate the influence of varying temperature on organic substance, nitrogen and phosphorus removal, and the efficiency of these pollutions removal in about 15 ˚C. The results indicated that when the temperature was dropped from about 25 ˚C to about 20 ˚C and about 15 ˚C, the efficiency of TN and NH_4^+-N removal was obviouly affected, although the operational parameters was optimized immediately, while COD and TP was almost not affected. When the temperature was about 15 ˚C, in the steady phase, the DO, MLSS, SRT and RSR were 1.5~2 mg/L, 3722~4085 mg/L, 18 day and 76 %, respectively, the concentration of COD, NH_4^+-N, TN and TP in effluent was 26.2 mg/L, 12.1 mg/L, 3.9 mg/L and 0.34 mg/L, respectively, and the removal rate of these pollutions was 90.7 %, 90.4 %, 73.2 % and 93.2 %, respectively.

Introduction

With the high speed of economic development and swift growth of population in China, about 30~40 billion ton municipal wastewaters are produced every year, and about 80 % of Chinese rivers and lakes have been polluted in varying degrees. In order to relieve and eliminate water systems pollution, the government of China promulgated a more strict effluent standards, which was《Contamination discharge standards of town wastewater treatment plant (WWTP)》 (GB 18918-2002), and the concentration of chemical oxygen demand (COD), ammonia nitrogen (NH_4^+-N), total nitrogen (TN) and total phosphorus (TP) in effluent was 50 mg/L, 5 (8) mg/L, 15 mg/L and 0.5 mg/L, respectively, in the first level A criteria of (GB18918 -2002).

Over the past several decades, biological nutrient removal (BNR) processes have been widely used to treat wastewater containing nitrogen and phosphorus, as well as organic substance to prevent eutrophication [1-3], because the cost is low [4], the processes can remove organic substance, nitrogen and phosphorus simultaneously [5,6], and removal rate of these pollutions was comparatively high. There are many BNR processes used in WWTPs, such as the Sequencing Batch Reactor (SBR), the University of Cape Town (UCT) system, the Bardenpho process, the Anaerobic-Anoxic-Oxic (A^2O) system and Oxidation Ditch (OD) system, et al. Among these processes, the most commonly used processes are A^2O process and OD process in China.

OD system is a widely used BNR process in China, because long hydraulic retention time (HRT) and complete mixing minimize the impact of a shock load, produces less sludge, energy efficient operations result in reduced energy costs [7-8], and so on. A^2O process, which is a single sludge suspended growth system that incorporates sequential anaerobic, anoxic, and aerobic stages [9], can simultaneously remove nitrogen and phosphorus [10]. Anoxic-anaerobic OD process is combined anoxic-anaerobic-oxic (A^2O) process with OD process, and has the both advantages of the processes. In BNR processes, the contaminations in wastewater are mainly removed by microorganisms, so the efficiency of the contaminations removal is affected by many factors, such as the concentration of the contaminations and the pH in influent, influent flow, temperature, and operational parameters. Among them temperature is one of the most important factors, not only because the biological activity of biomass was strongly affected by temperature, but also the temperature in WWTPs is influenced by climate and it is very hard to change the temperature. In the north of China, the temperature is much discrepant in summer and winter, and the temperature changes sharply, when the season varies. Temperature drastically fluctuated result in negatively impact on the steady operation of the WWTPs, such as the removal rate of nitrogen and phosphorus was decreased, ammonia nitrogen nitrification was deteriorated, and sludge bulking or foaming was occurred in the WWTPs [11].

There are many researchers [12~14] investigated organic substance, nitrogen and phosphorus removal in relatively high temperature, while few researchers investigated the contaminations removal in low temperature, and the influence of varying temperature on the contaminations removal, and in simultaneous removal of nitrogen and phosphorus along with organics removal process, the microbial growth condition and characteristics of the related microorganisms are respectively different [15], so the temperature may have different affect on the contaminations removal.

So the aim of the present work was to investigate the influence of varying temperature, which was dropped from about 25 ˚C to about 20 ˚C then to about 15 ˚C, on the contaminations removal, and optimize the operational parameters in low temperature, to achieve high removal efficiency of the contaminations in a pilot-scale anoxic-anaerobic OD process.

Materials and methods

pilot-scale plant. The experiments had been carried out in a pilot-scale anoxic-anaerobic OD process. Configuration process was shown in Fig.1. This process consisted of a water tank (200 L), an anoxic zone (29 L), an anaerobic zone (29 L), an OD reactor (216 L) and a secondary clarifier (53 L). The anoxic and anaerobic zones were made of Plexiglas, and the others were made of stainless steel. The influent rate was 15 L/h, and the HRT of the anoxic zone, anaerobic zone, OD reactor and secondary clarifier were 1.9 h, 1.9 h, 14.4 h and 3.5 h, respectively. 10 % of total influent and all return sludge were pumped to the anoxic zone, and the remaining 90 % influent was pumped to anaerobic zone. Mixers were equipped in both of the anoxic and anaerobic zones, which made the sludge suspend, while three mixers were equipped in the ditches, in order to make the mixed liquids flow in the OD reactor. DO was controlled artificially, and oxidation-reduction potential (ORP) and pH were monitored, but were not controlled. The quantum of aeration was little in the 1, 2 and 3 galleries in the OD system, which only made the sludge suspend, and most of the aeration was in the 4, 5 and 6 galleries.

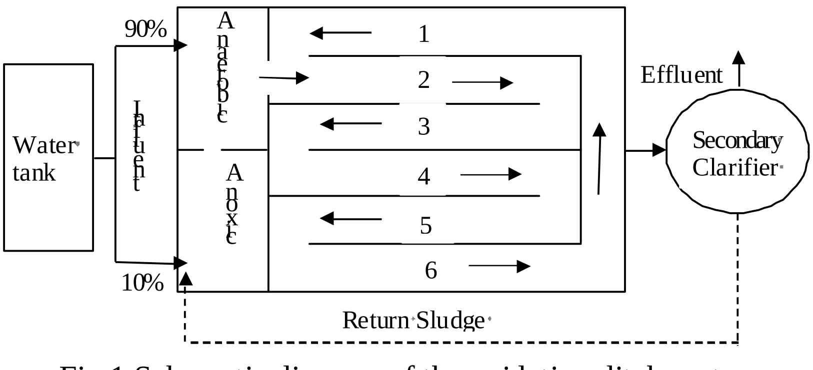

Fig.1 Schematic diagram of the oxidation ditch system

Wastewater and sludge. Municipal wastewater was obtained from residential subdistricts in Xinxiang China. The concentration of TN in the municipal wastewater was very high, but COD and TP were relatively low, so the wastewater was diluted by tap water, and then sugar and $KH_2P_4O_3$

were added to supplement COD and TP. The characteristics of the influent were shown in table 1. The sludge was taken from the A^2O process of Luotuowan WWTP in Xinxiang China.

Tab. 1 Major characteristics of the influent

Parameter		pH	COD (mg/l)	NH_4^+-N (mg/l)	TN (mg/l)	TP(mg/l)
Influent	Range	6.87~7.39	115~449	27.4~60.8	32.5~69.8	2.16~5.37
	Average	7.15	299	45.6	48.2	3.69

Pilot-scale plant start-up and operation. This experiment was carried out in winter. Before this experiment, the anoxic-anaerobic OD system was used to remove organic substance, nitrogen and phosphorus; the mixed liquor in the process was heated, and the temperature was controlled at about 25 ˚C to shorten the start-up period of the pilot-scale system. In order to improve the efficiency of nitrogen and phosphorus removal, the DO in the front of the OD reactor was decreased, an anoxic zone was formed in that place, and the operational mode was changed to anoxic/anaerobic/anoxic/aerobic from anoxic/anaerobic /aerobic. And the DO, RSR, solids retention time (SRT) and mixed liquor suspended solids (MLSS) in this phase were 0.55~0.65 mg/L, 58 %, 12 days and 2416~2636 mg/L, respectively. Then the temperature was decreased to about 20 ˚C (from 10^{th} day), and the DO, RSR, SRT and MLSS were all correspondingly increased to keep high concentration of MLSS in the reactors, and relatively high efficiency of nitrogen and phosphorus removal.

Finally, the temperature was decreased to about 15 ˚C from 31^{st} day, and the operational parameters were optimized immediately, to weaken the adversely effect on organic substance, nitrogen and phosphorus removal. In the steady phase, the DO, RSR, SRT and MLSS were 1.5~2 mg/L, 3722~4085 mg/L, 18 day and 76 %, respectively, and the concentration of COD, NH_4^+-N, TN and TP in effluent was all below the permitted limits in China.

Analysis. The analyses of TN, NH_4^+-N, nitrate (NO_3^--N), nitrite (NO_2^--N), TP and MLSS were performed as described in the Standard Methods of APHA [16]. COD was measured using CR3200-photolab sb (WTW, German), DO, pH, ORP, and temperature were measured continuously using online probes (340i, WTW, German).

Results and discussions

DO concentration in the OD system.DO as the electron acceptor was a very important operational parameter in wastewater treatment process. In this experiment, the concentration of DO in the OD reactor was decided by the concentration of NH_4^+-N and TN in effluent, or the efficiency of nitrification and denitrification. When the temperature was high (about 25 ˚C) and DO was 0.55~0.65 mg/L, the concentration of NH_4^+-N and TN in effluent was relative low, but when the temperature was low (about 15 ˚C), the DO must be increased for the efficiency of nitrification.

The varieties of DO concentration in the steady phase in OD reactor were shown in Fig. 2, and the test samples point of DO was in the mixture flow end of each gallery. The concentration of DO in the OD reactor in different days was fluctuated drastically, but the DO in different gallery in the same day didn't change obviously, especially the DO was high. The aeration flow was almost constant, but the DO was changed obviously between day and night, the reason may be that there was no mechanical sludge scraper in the secondary clarifier, and the concentration of MLSS in return sludge was decreased in the night.

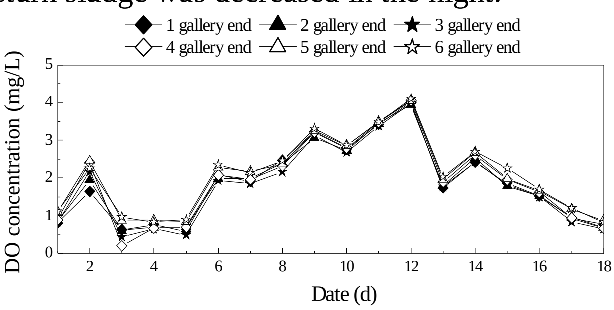

Fig.2 varieties of DO concentration in OD system

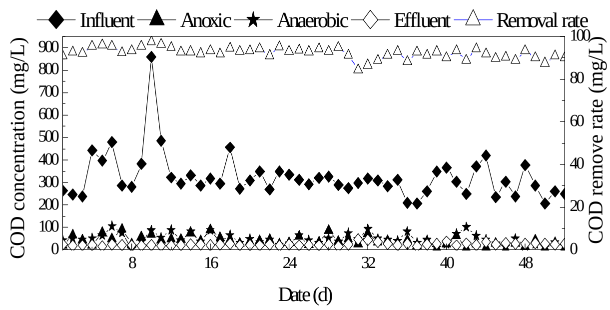

Fig.3 Effect of anoxic-anaerobic OD on COD removal

Organic substance removal. The varieties concentration of COD in the OD system was shown in Fig. 3. The concentration of COD in influent was mostly fluctuated between 200 mg/L and 400 mg/L. COD was decreased distinctly in the anoxic and anaerobic zones, but fluctuated sharply, and the average concentration of COD in the anoxic and anaerobic zones was 39 mg/L and 48 mg/L, respectively. Most of the organic substance was degraded in the anoxic and anaerobic zones, because the organic substance was diluted by return sludge, adsorbed and assimilated by biomass. The COD in the anoxic zone was lower than that in the anaerobic zone, because 10 % of the influent and all the return sludge was pumped to the anoxic zone, while 90% of the influent was pumped to the anaerobic zone.

When the temperature was about 25 ˚C and 20 ˚C, the concentration of COD in effluent was steady and all below 30 mg/L, and the average concentration of COD was 20 mg/L and 21 mg/L, respectively. But when the temperature was decreased to about 15 ˚C, COD was fluctuated obviously and was 47 mg/L in the 31st day, and the average concentration of COD was 27.8 mg/L, which was obviously higher than when the temperature was about 25 ˚C and 20 ˚C. When the temperature was decreased to about 15 ˚C, COD was obviously increased, but it was decreased gradually several days later, the reason was that the bacteria in the process adapted the low temperature, and the concentration of MLSS was increased gradually. The removal rate of COD was all higher than 88%, and average removal rate of COD was 92.2%.

Nitrogen removal. The varieties concentration of NH_4^+-N in the OD system was shown in Fig. 4 (a). The concentration of NH_4^+-N in influent was obviously fluctuated, and the average concentration of NH_4^+-N was 46.6 mg/L. NH_4^+-N in the anoxic and anaerobic zones was 24.2 mg/L and 26.2 mg/L, respectively, because it was diluted by the return sludge. When the temperature was decreased to about 20 ˚C, NH_4^+-N in effluent was increased from 3.7 mg/L to 13.1 mg/L, and was decreased to about 4 mg/L 5 days later; while When the temperature was decreased to about 15 ˚C, NH_4^+-N was increased from 3.8 mg/L to 16.9 mg/L, then to 20.0 mg/L, and was decreased to about 4 mg/L 9 days later, which meant when the temperature was decreased to about 15 ˚C, the activity of *Nitrosomonas* and *Nitrobacter* was affected more seriously, and the bacteria needed more days to adopt the low temperature . The concentration of NH_4^+-N in effluent was less than 5 mg/L since the 41st day, and the removal rate of NH_4^+-N was about 90 % in the steady phase.

The varieties concentration of NO_3^--N in OD system was shown in Fig. 4 (b). The concentration of NO_3^--N in influent was low, and was only about 1 mg/L. NO_3^--N in anoxic and anaerobic zones was 0.59 mg/L and 0.50 mg/L, respectively, in the steady phase (from the 41st day to the end), which was a little higher than when the temperature was about 20 ˚C and 25 ˚C, but had no negative impact on phosphorus release in the anaerobic zone.

The concentration of NO_3^--N in OD effluent and effluent was fluctuated drastically, because the concentration of NO_3^--N was obviously affected by DO and DO was obviously fluctuated. NO_3^--N was higher than 20 mg/L at the beginning of the experiment, then it was decreased gradually, and in the steady phase, NO_3^--N in effluent was slightly lower than in OD effluent, because nitrification was occurred in the secondary clarifier, and NO_3^--N in effluent was approximately 5 mg/L.

The varieties concentration of NO_2^--N in OD system was shown in Fig. 4 (c). The concentration of NO_2^--N in influent, anoxic and anaerobic zones was all low, and the average concentration of NO_2^--N was 0.06 mg/L, 0.11 mg/L and 0.08 mg/L, respectively. NO_2^--N in anaerobic zone was slightly lower than in anoxic zone, because denitrification was occurred in the anaerobic zone. NO_2^--N in effluent was fluctuated drastically in the steady phase, and the average concentration was 2.14 mg/L; although the NO_2^--N was relatively high in the OD reactor, there was not adversely effect on nitrogen and phosphorus removal.

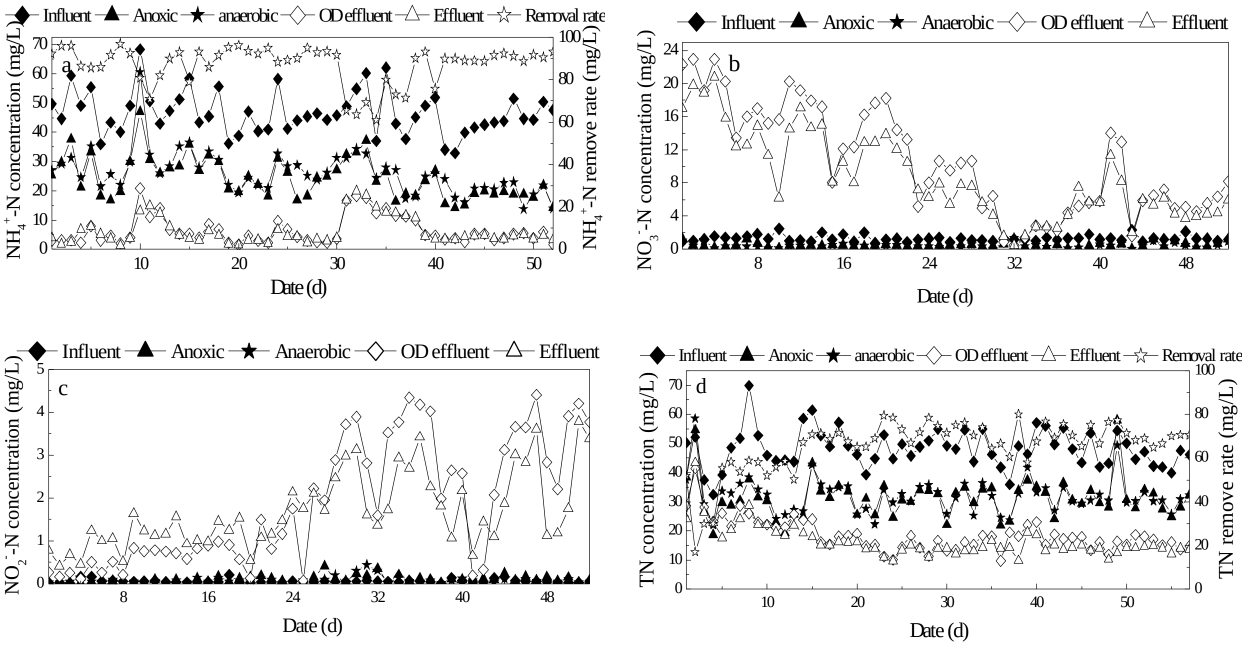

Fig.4 Effect of anoxic-anaerobic OD process on NH_4^+-N (a), NO_3^--N (b), NO_2^--N (c) and TN (d) removal, respectively

The varieties concentration of TN in the OD system was shown in Fig. 4 (d). TN mainly consisted of organic nitrogen, ammonia nitrogen, nitrate nitrogen and nitrite nitrogen, and TN removal is achieved by aerobic nitrification and anoxic denitrification using autotrophic nitrifying and heterotrophic denitrifying bacteria [17, 18]. The concentration of TN in influent was about 50 mg/L, the average concentration of TN was 49.2 mg/L, and the majority of TN in influent was NH_4^+-N in this experiment. Organic nitrogen was converted to ammonia nitrogen, ammonia nitrogen was diluted by return sludge, and the nitrate in return sludge was denitrified to nitrogen gas (N_2) in the anoxic and anaerobic zones, so TN was decreased sharply in these place, and the average concentration of TN was 26.5 mg/L and 27.9 mg/L, respectively. Then the NH_4^+-N was nitrified in the 4, 5 and 6 galleries, and denitrifying bacteria which used the organic substance from the effluent of anaerobic zone denitrified the nitrate and nitrite to nitrogen gas (N_2) in the 2 and 3 galleries. And simultaneous nitrification and denitrification was occured in the OD reactor, because DO was relatively low and there was anoxic micro-environment in the OD reactor.

At the beginning, the concentration of TN in OD effluent was more than 20 mg/L, and then it was gradually decreased to 15.0 mg/L in the 9th day. While when the temperature was dropped to about 20 ˚C, TN was sharply increased to 28.6 mg/L in the 10th day, and then it was decreased gradually. When the temperature was dropped to about 15 ˚C, TN was increased and decreased gradually in the following days, and that phenomenon indicated that when the temperature was dropped, TN removal was obviously affected, and the removal rate of TN was increased, after the nitrifying and denitrifying bacteria were adapted the lower temperature, and the operational parameters was optimized. With the operational parameters such as DO, RSR, MLSS and SRT was optimized, TN in effluent was decreased step by step, and was reduced less than 15 mg/L since the 38th day. The average concentration of TN in effluent was 12.1 mg/L in the steady phase, and the removal rate of TN was about 70 %.

Phosphorus removal. The varieties concentration of TP in OD system was shown in Fig 5. The concentration of TP in influent was drastically fluctuated at the beginning, and it was reached to 12.3 mg/L in the 10th day. The TP was relatively steady in the following days, and the average concentration of TP in influent was 5.38 mg/L.

TP in the anoxic and aerobic zones was much higher than that in influent, although TP was diluted by the return sludge, the reason was that under anaerobic condition, facultative bacteria transformed the organic substance to available biodegradable organic carbon, then phosphorus accumulating organisms (PAOs) preferential transported the production across their cell membranes, hence produced polyhydroxybutyrate (PHB) and released orthophosphate, and the energy used in this reaction was released from the hydrolysis of intracellular polyphosphate and glycogen. Although the effluent of the anoxic zone was diluted by the 90 % of in influent, TP in anaerobic zone was slightly higher than in anoxic zone, because nitrate existed in the anoxic zone, which affected phosphorus release, and phosphorus release was continuously occurred in the anaerobic zone. ORP could indicate the anaerobic condition in phosphorus release process, and when the ORP between -200 mv and -400 mv, phosphorus released well. ORP in the anoxic and anaerobic zones was both lower than -270 mv, and it was a little lower in the anaerobic zone; ORP was about -330 mv in the steady phase in the both zones, which meant anaerobic condition was formed and phosphorus could release well.

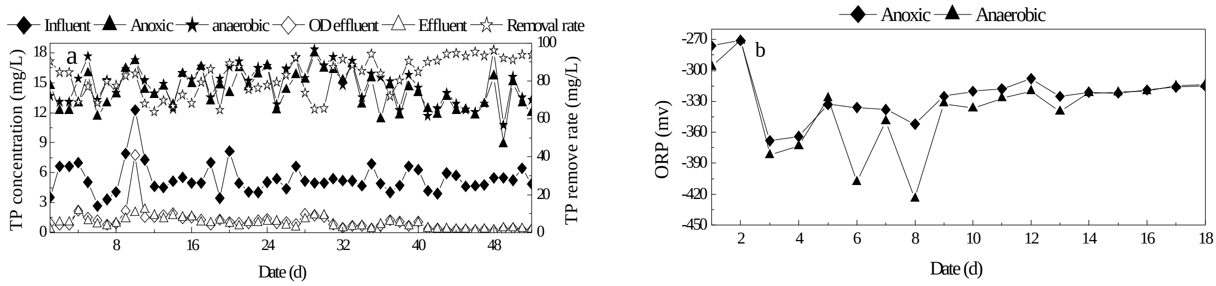

Fig.5 Effect of anoxic-anaerobic OD on TP removal (a), varieties of DO concentration in the steady phase in anoxic and anaerobic zones (b)

Under the aerobic or anoxic condition, PAOs used the energy released from degradation of PHB to absorb the orthophosphate more than needed for growth from the mixture, transformed to intracellular polyphosphate, and formed phosphorus-rich sludge. The more the phosphorus was released in the anaerobic phase, the more it was up-taken in the aerobic phase; finally, phosphorus was discharged as surplus sludge. TP was removed in the OD reactor, and the concentration of TP in OD effluent was relatively low. With the operational parameters such as DO, RSR, MLSS and SRT was optimized, the TP in OD effluent was decreased gradually, and was reduced less than 0.5 mg/L since the 41^{st} day. Phosphorus release and phosphorus release up-take were almost no affected, when the temperature was dropped to about 20 ˚C and 15 ˚C.The average concentration of TP in OD effluent was 0.30 mg/L in the steady, which was lower than that in effluent (0.34 mg/L), because the DO in OD effluent was relatively low, and the HRT of secondary clarifier was relatively long, hence anaerobic micro-environment existed in the secondary clarifier and phosphorus release was occurred. The average removal rate of TP was 93.2 % in the steady phase.

Conclusions

A pilot-scale anoxic-anaerobic OD reactor process was used to removal organic substance, nitrogen and phosphorus under low temperature. The conclusions of this study were as followed:

When the temperature was dropped to about 20 ˚C and about 15 ˚C, the biological activity of biomass was declined obviously; though the operational parameters were optimized, the efficiency of COD, TN and NH_4^+-N removal was obviously affected, while the removal efficiency of TP was almost not affected. And the removal rate of COD, TN and NH_4^+-N was increased in the following days.

After the operational parameters were optimized, the DO, MLSS, SRT and RSR were 1.5~2mg/L, 3722~4085mg/L, 18 day and 76%, respectively, the average concentration of COD, NH_4^+-N, TN and TP in effluent was 26.2 mg/L, 12.1 mg/L, 3.9 mg/L and 0.34 mg/L, respectively, and the average removal rate was 90.7 %, 90.4 %, 73.2 % and 93.2 %, respectively, in the steady phase.

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References

[1]Y Z Peng, X L Wang, B K Li. Anoxic biological phosphorus uptake and the effect of excessive aeration on biological phosphorus removal in the A^2O process. Desalination, 2006,189:155–164.
[2]G Lei, H Q Ren,L L Ding, F F Wang, X S Zhang. A full-scale biological treatment system application in the treated wastewater of pharmaceutical industrial park. Bioresource Technology, 2010,101(15):5852–5861.
[3]J Ma, Y Z Peng, S Y Wang, L Wang, Y Liu, N P Ma. Denitrifying phosphorus removal in a step-feed CAST with alternating anoxic-oxic operational strategy. Journal of Environmental Sciences, 2009, 21:1169–1174.
[4]P Tanwar, T Nandy, R Khan, R Biswas. Intermittent cyclic process for enhanced biological nutrient removal treating combined chemical laboratory wastewater. Bioresource Technology, 2007, 98:2473–2478.
[5]R J Zeng, Z Yuan, J Keller. Improved under-standing of the interactions and complexities of biological nitrogen and phosphorus removal processes, Rev. Environ. Sci. Bio/Technol, 2004,3:265–272.
[6]L M Yuan,C Y Zhang, Y Q Zhang, Y Ding, D L Xi. Biological nutrient removal using an alternating of anoxic and anaerobic membrane bioreactor (AAAM) process. Desalination,2008,221:566–575.
[7]M Tiranuntakul, V Jegatheesana, P A Schneider, H L Fracchia. Performance of an oxidation ditch retrofitted with a membrane bioreactor during the start-up. Desalination, 2005,183:417–424.
[8]X D Hao, H J Doddema, J W van Groenestijn. Conditions and mechanisms affecting simultaneous nitrification and denitrification in a Pasveer oxidation ditch. Bioresource Technology, 1997,59:207–215.
[9]Eun Tae Lim, Gwi Taek Jeong, Sung Hun Bhang, Seok Hwan Park, Don Hee Park Evaluation of pilot-scale modified A^2O processes for the removal of nitrogen compounds from sewage Bioresource Technology, 2009,100: 6149–6154.
[10]Yong Ma, Yongzhen Peng, Xiaolian Wang. Improving nutrient removal of the AAO process by an influent bypass flow by denitrifying phosphorus removal Desalination, 2009,246:534–544.
[11]B Xie, X C Dai, Y T Xu. Cause and pre-alarm control of bulking and foaming by Microthrix parvicella—A case study in triple oxidation ditch at a wastewater treatment plant. Journal of Hazardous Materials, 2007,143:184–191.
[12]Hongjing Li, Yinguang Chen, Guowei Gu. The effect of propionic to acetic acid ratio on anaerobic–aerobic (low dissolved oxygen) biological phosphorus and nitrogen removal Bioresource Technology, 2008,99:4400–4407.
[13]Yongzhen PENG, Hongxun HOU, Shuying WANG, Youwei CUI, Zhiguo Yuan. Nitrogen and phosphorus removal in pilot-scale anaerobic-anoxic oxidation ditch system. Journal of Environmental Sciences, 2008,20:398–403.
[14]Yayi Wang, Yongzhen Peng, Tom Stephenson. Effect of influent nutrient ratios and hydraulic retention time (HRT) on simultaneous phosphorus and nitrogen removal in a two-sludge sequencing batch reactor process. Bioresource Technology,2009,100:3506–3512.
[15]Daekeun Kim, Keum Yong Kim, Hong Duck Ryu, Kyung Kook Min, Sang-Ill Lee. Long term operation of pilot-scale biological nutrient removal process in treating municipal wastewater. Bioresource Technology, 2009,100:3180–3184.
[16]APHA, 1995. Standard Methods for the Examination of Water and Wastewater. 19th ed. Washington DC, USA: American Public Health Association/American Water Works Association/Water Environment Federation.
[17]Pankaj Tanwar, Tapas Nandy, Rehan Khan, Rima Biswas. Intermittent cyclic process for enhanced biological nutrient removal treating combined chemical laboratory wastewater. Bioresource Technology, 2007, 98:2473–2478.
[18]Zhimin Fu, Fenglin Yang, Yingyu An, Yuan Xue. Simultaneous nitrification and denitrification coupled with phosphorus removal in an modified anoxic/oxic-membrane bioreactor (A/O-MBR). Biochemical Engineering Journal, 2009,43:191–196.