ISSN 1001-0742
CN 11-2629/X

JES

JOURNAL OF ENVIRONMENTAL SCIENCES

April 1, 2015 Volume 30
www.jesc.ac.cn

MBR in Wastewater Reclamation

ELSEVIER
Science Press

Sponsored by
Research Center for Eco-Environmental Sciences
Chinese Academy of Sciences

Journal of Environmental Sciences Volume 30 2015

www.jesc.ac.cn

Highlight articles

Review articles

Regular articles

CONTENTS

Available online at www.sciencedirect.com

ScienceDirect

www.journals.elsevier.com/journal-of-environmental-sciences

JOURNAL OF ENVIRONMENTAL SCIENCES

www.jesc.ac.cn

Achieving nitritation at low temperatures using free ammonia inhibition on *Nitrobacter* and real-time control in an SBR treating landfill leachate

Hongwei Sun[1,2], *Yongzhen Peng*[1,*], *Shuying Wang*[1], *Juan Ma*[1,2]

1. *Key Laboratory of Beijing Water Quality Science and Water Environment Recovery Engineering, Beijing University of Technology, Beijing 100124, China. E–mail: shw@emails.bjut.edu.cn*

2. *School of Environmental and Municipal Engineering, Lanzhou Jiaotong University, Lanzhou 730070, China*

ARTICLE INFO

Article history:
Received 10 June 2014
Revised 28 September 2014
Accepted 29 September 2014
Available online 28 January 2015

Keywords:
Landfill leachate
Nitritation
Low temperature
Free ammonia
Inhibition
AOB and NOB

ABSTRACT

Free ammonia (FA) inhibition on nitrite-oxidized bacteria (NOB) and real-time control are used to achieve nitrogen removal from landfill leachate *via* nitrite pathway at low temperatures in sequencing batch reactor. The inhibition of FA on NOB activity during the aerobic period was prolonged using real-time control. The degree of nitrite accumulation was monitored along with variations of the ammonia-oxidizing bacteria and NOB population using fluorescence *in situ* hybridization techniques. It is demonstrated that the end-point of ammonia oxidization is detected from the on-line measured dissolved oxygen, oxidization–reduction potential, and pH signals, which could avoid the loss the FA inhibition on NOB caused by excess aeration. At low temperature (13.0–17.6°C), the level of nitrite pathway rapidly increased from 19.8% to 90%, suggesting that nitritation was successfully started up at low temperature by applying syntrophic association of the FA inhibition and real-time control, and then this high level of nitrite pathway was stably maintained for as long as 233 days. Mechanism analysis shows that the establishment of nitritation was primarily the result of predominant ammonia-oxidizing bacteria developed in the nitrifying bacteria population compared to NOB. This was mainly due to a gradual reduction of nitrite amount that is available to provide energy for the growth of NOB, eventually leading to the elimination of NOB from the bacterial clusters in sequencing batch reactor sludge system.

Introduction

From an environmental and economic point of view, the biological nitrogen removal (BNR) could be an interesting methodology for treating ammonium-rich landfill leachate (Tchobanoglous et al., 2003; Renou et al., 2008). Compared to the chemical methods, BNR reduces chemical consumption and cost, reduces the production of waste solids, and has lower energy requirement (Zhou et al., 2011). The BNR process includes two steps: oxidization of ammonia to nitrate or nitrification and reduction of nitrate to nitrogen gas or denitrification. Nitrification is a two-step reaction. Firstly, ammonia is oxidized to nitrite by ammonia oxidizing bacteria (AOB), which is called nitritation. Secondly, nitrite is oxidized to nitrate by nitrite oxidizing bacteria (NOB), which is called nitratation (Torà et al., 2010).

Typically, AOB and NOB co-exist within bacteria clusters in the BNR systems with a synergetic interaction to accomplish nitrification. AOB oxidizes ammonia to nitrite, which serves as energy

* *Corresponding author*. E-mail: pyz@bjut.edu.cn (Yongzhen. Peng).

http://dx.doi.org/10.1016/j.jes.2014.09.029

source for NOB, and NOB oxidizes nitrite (Lemaire et al., 2008). However, the achievement of nitritation process requires the decoupling of AOB and NOB activities so that nitrogen is removed *via* nitrite, bringing about significant reductions in both oxygen and COD demand (Turk and Mavinic, 1986; Vadivelu et al., 2006; Wang et al., 2013).

Temperature, dissolved oxygen (DO), free ammonia (FA), and free nitrous acid are useful to start-up nitritation in many studies. It has been widely reported that a high concentration of FA can promote nitritation by selectively inhibiting the activity of NOB over AOB (Zhang et al., 2012; Peng et al., 2008; Kim et al., 2006; Park et al., 2010). Moreover, it is believed that high temperature (30–35°C) is an optimal condition for achieving nitritation (Hellinga et al., 1998). Furthermore, nitritation at mild temperatures (20–25°C) has been proved (Guo et al., 2010; Qiao et al., 2010). Nitritation in a pilot-scale sequencing batch reactor (SBR) was achieved at mild water temperatures (26°C) and then at low water temperatures (11.8°C) in a long-term operation by Yang et al. (2007). To the best of our knowledge, however, only Gu et al. (2012) successfully started up nitritation at low temperatures (11–16°C) with a real-time control strategy based on blower frequency and pH in an SBR treating municipal wastewater.

In this study, a lab-scale SBR, operated an alternating aerobic/anoxic strategy, was employed to eliminate nitrogen *via* nitrite from upflow anaerobic sludge bed (UASB)-treated landfill leachate. We investigate the possibility of establishing a nitritation process at low temperatures by integrating FA inhibition on NOB activity with a real-time control. The mechanism responsible for the start-up of the nitritation is explained using fluorescence *in situ* hybridization (FISH) analysis.

1. Materials and methods

1.1. Reactor and operation

A lab-scale SBR with a working volume of 8 L was used. The SBR cycle operation consisted of 2 min feeding; aerobic reaction, anoxic reaction, 30 min settling, 15 min decanting, and idling. The durations of aerobic and anoxic reactions were controlled by using a real-time control.

In each cycle, 4 L of landfill leachate was pumped into the reactor during the filling period. Each filling period was followed by an aerobic period. During aerobic period, enough oxygen was provided by an air blower to keep the DO level between 0.5 and 2.0 mg/L. The DO, pH, and oxidization–reduction potential (ORP) signals were used to indicate the completion of ammonia oxidization. During the followed anoxic period, an additional quantity of 0.3 mL of methanol was added into the reactor as an external carbon source for denitritation. At the same time, the SBR was mixed with an overhead mixer to ensure complete mixing. The pH and ORP signals were also recorded to give indication of the denitritation finish. Sludge settlement and supernatant discharge then followed.

1.2. Wastewater and inoculated sludge

The raw leachate was collected from a municipal landfill site (located at Beijing, China) and the leachate characteristics are as following (range, average): COD (460–850, 665 mg/L), TN (172–225, 199 mg/L), NH_4^+-N (131–180, 155 mg/L), NO_3^--N (0.02–2.3, 0.56 mg/L), NO_2^--N (0.01–0.66, 0.04 mg/L), pH (7.5–8.8, 8.5) and alkalinity (5000–8500, 6500 mg $CaCO_3$/L).

The seed sludge was taken from the municipal wastewater treatment plant in Beijing, China. The seeding sludge was a mixture of heterotrophic and autotrophic microorganism. The average levels of mixed liquor suspended solids (MLSS) and volatile MLSS (MLVSS) in the SBR were 1500–2500 and 1200–2100 mg/L, respectively.

1.3. Analytical methods

The chemical oxygen demand (COD), ammonia nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^--N), nitrite nitrogen (NO_2^--N), MLSS, and MLVSS were analyzed according to the standard methods (APHA, 1998). The total nitrogen (TN) was analyzed using a total organic carbon analyzer (Multi N/C 3000, Analytik Jena AG, Jena, Germany). DO, pH and ORP were continuously detected using a pH/oxi 340 analyzer (WTW Company, Munich, Germany).

FISH was performed as specified in Amann (1995). Specific oligonucleotide probes used in this study were EUBmix (Daims et al., 2001) for the detection of all bacteria, Nso1225 for ammonia-oxidizing β-proteobacteria (Mobarry et al., 1996), NIT3 for *Nitrobacter* and Ntspa662 for *Nitrospira*. FISH images were captured using an OLYMPUS-BX52 fluorescence microscope (Olumpus Corporation, Tokyo, Japan). Fish quantitatification was performed, where the relative abundance of the each group was determined in triplicate as mean percentage of all bacteria.

1.4. Calculations

The FA concentration (mg/L) was calculated as a function of pH, temperature (T), and total ammonium as nitrogen (TAN); the calculation was modified from Anthonisen et al. (1976):

$$FA(mg/L) = \frac{17}{14}\frac{TAN \times 10^{pH}}{\exp\left(\frac{6334}{273+T}\right) + 10^{pH}}. \quad (1)$$

The nitrite accumulation ratio (NAR, %) was calculated using Eq. (2):

$$NAR = \frac{NO_2^- \text{-N}}{NO_2^- \text{-N} + NO_3^- \text{-N}} \times 100\%. \quad (2)$$

2. Result and discussion

2.1. FA inhibition and real-time control to promote nitrite pathway

2.1.1. NOB inhibition by FA to optimize nitrifying bacteria population

The inhibitory effects of FA on AOB and NOB have been widely reported, NOB has been described to be much more sensitive to FA than AOB. The difference in the inhibitory effects of FA on the metabolisms of AOB and NOB indeed have been suggested as a major factor leading to elimination of NOB, which is critical for achieving nitritation.

Fig. 1 presents typical profiles of the FA, nitrogen, DO, pH, and ORP during each SBR cycle. FA levels were plotted during the nitritation process, which clearly show that the FA level gradually decreased from 18.8 mg/L at the beginning of nitritation to 0.21 mg/L at the end of nitritation because both the ammonium concentration and the pH decreased (there were only slight changes in ambient temperature, which was of 26.5 ± 0.7°C) throughout the SBR cycle. This decreasing FA concentration implies that the inhibitory effect that FA placed on NOB activity gradually weakened as nitritation proceeded.

If the aeration is continued after complete oxidation of ammonia, the extremely low level of FA would lose its inhibition on NOB activity, resulting in the conversion of nitrite to nitrate by NOB in the system. Therefore, how to avoid the loss of NOB inhibition by FA is critical for achieving nitritation in a nitrogen removal system.

2.1.2. Implementation of NOB inhibition by FA with real-time control

As shown in Fig. 1b, because nitritation produces acid, at the beginning of nitritation, pH decreased gradually. When ammonia was depleted, pH began to increase. Meanwhile, DO and OPR increased sharply as nitritation only required 25% as much of the oxygen as that of nitrification, ammonium valley, DO break point, and ORP break point appeared on the pH, DO and ORP profiles, respectively. During anoxic period, pH increased due to the production of strong base during denitritation and ORP decreased. At the end of denitritation, ORP decreased sharply whereas pH began to decrease. Nitrite apex on the pH profile and nitrite knee on the ORP profile indicated the completion of denitritation.

Thus, these key points correlated well with the conversion of nitrogen during biological nitrogen removal. Ammonia valley and DO break point and ORP break point not only represented the end of nitritation exactly, but also maintained the nitrite accumulation rate by avoiding excessive aeration.

Gao et al. (2009) found that excess aeration (aeration is still on after ammonia oxidization) could promote the conversion of nitritation to nitrification. In other words, if the aeration is stopped as soon as nitritation finishes, the activity of the NOB population would be continuously inhibited by FA in the nitritation, which ensures that nitrite is no longer available for NOB. However, real-time control is available to prevent the occurrence of excess aeration, as indicated by these key points on DO, pH and ORP curves, respectively. In our study we were able to prolong favorable FA inhibition using real-time control to achieve the nitrite pathway in the SBR.

2.2. Start-up nitritation at low temperatures by means of FA inhibition and real-time control

The SBR was operated for approximately 10 months. FA inhibition on NOB activity and real-time control for achieving nitrogen *via* nitrite was applied throughout the experimental period. As Fig. 2 shows, the SBR operation consisted of two periods: start-up period (0–77 days) and maintenance period (78–310 days). The operational temperature in the SBR was 13.0–17.6°C and the NAR gradually increased from 0.3% to 91.7% during the start-up period. It is clear that at these low temperatures, nitritation was successfully started up in the SBR but operational temperatures increased slowly during this period. It is worth noting that at low temperatures nitritation was achieved but waste temperature increased slowly due to seasonal transition. On day 154, the water

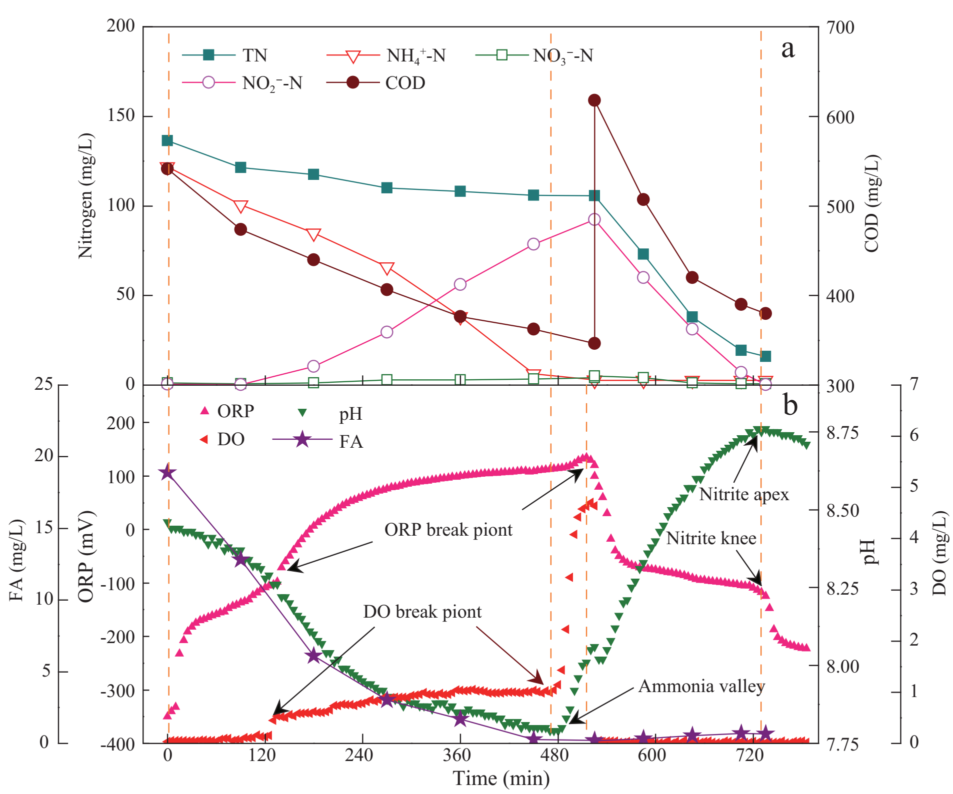

Fig. 1 – Mechanism of achieving nitritation in the SBR by FA inhibition and real-time control.

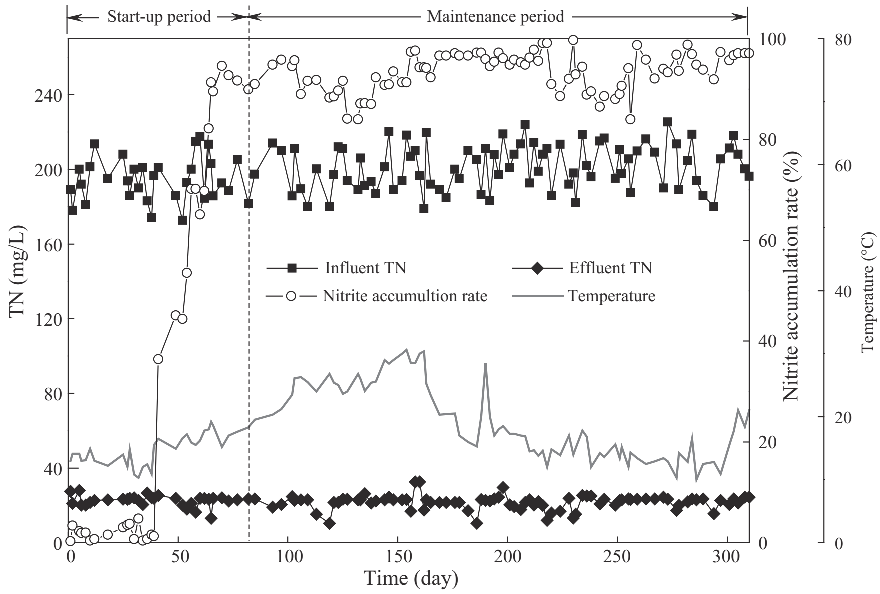

Fig. 2 – Dynamics of influent TN, effluent TN, nitrite accumulation rate and temperature during the whole operation.

temperature increased to 30.6°C, and then water temperature gradually decreased.

During the following maintenance period, the average NAR was steady at approximately 93.4% for 234 days until the end of this period, when the operational temperature in the SBR varied widely (10.0–30.6°C). It is worth mentioning that, from day 154 to 286, the nitrite accumulation did not deteriorate, even though the operational temperature gradually decreased to 10.0°C (the lowest level in our study) on day 286. The nitritation process in the SBR was well maintained by applying FA inhibition and real-time control. At the same time, the average effluent TN was below 21.8 mg/L, which indicates that advanced nitrogen removal was obtained in the system.

2.3. Optimization of nitrifying population in the sludge at low temperature

Optimization of nitrifying bacterial population is crucial for achieving nitritation in the SBR system. The nitritation process can be rapidly achieved when AOB is dominant nitrifying bacteria and NOB is eliminated from the system, even under these low temperatures (13.0–17.6°C). As noted previously, nitritation was maintained at low temperatures because the nitrifying bacteria population was optimized (Yang et al., 2007; Guo et al., 2010). Meanwhile, higher temperatures (>20°C) in the SBR should be kept in order to start up the nitritation process.

However, it was interesting to find, in our study, that it was possible to start up the nitritation at low temperatures and to optimize the nitrifying bacteria community. Fig. 3 shows that the microbial population composition was analyzed by FISH techniques. FISH quantification showed that the approximate sizes of AOB and NOB were 2.5%–3.0% and 1.5%–2.0% in the inoculated sludge, respectively. After applying FA inhibition on NOB and real-time control strategy for 77 days, the AOB fraction increased to 4.0%–6.5% and the NOB fraction was almost negligible. Therefore, only AOB was present in the system.

As shown in Fig. 4, ammonia oxidation worked well during the experimental period. At the end of aeration period, the nitrite concentration increased gradually from 0.7 to 109.8 mg/L and the nitrate concentration decreased from 88.3 to 4.9 mg/L. The energy and growth of AOB were stronger than that of NOB due to synergetic interaction of FA inhibition on NOB and robust real-time aeration control. In this case, we could have inferred that the NOB, which did not have sufficient growth potential and opportunities, were gradually eliminated due to the inhibition of their growth kinetics. Therefore, a stable nitritation process was successfully started up at this low temperatures range (13.0–17.6°C) in this system.

2.4. Mechanism of start-up nitritation at low temperatures

As shown in Table 1, previous publications have discussed the roles of FA and real-time control in achieving nitritation. FA was suggested as a contributing factor towards nitritation because the growth of NOB was inhibited by higher FA concentration while the growth of AOB was less inhibited or was not influenced. In such cases, AOB might be selected as the dominant nitrifying bacteria, while the NOB might still exist in the activated sludge system.

Real-time control was an effective method for achieving nitritation, especially in the SBR process, because that it would exert a negative effect on the NOB activity without having any harmful effects on the AOB. In such systems, AOB was optimized by real-time control, while NOB was washed out from the system.

Compared with literatures summarized in Table 1, it is noted that stable nitritation was successfully started up and maintained at low temperatures as long as 233 days in this study. Thus, the combination of FA inhibition and real-time

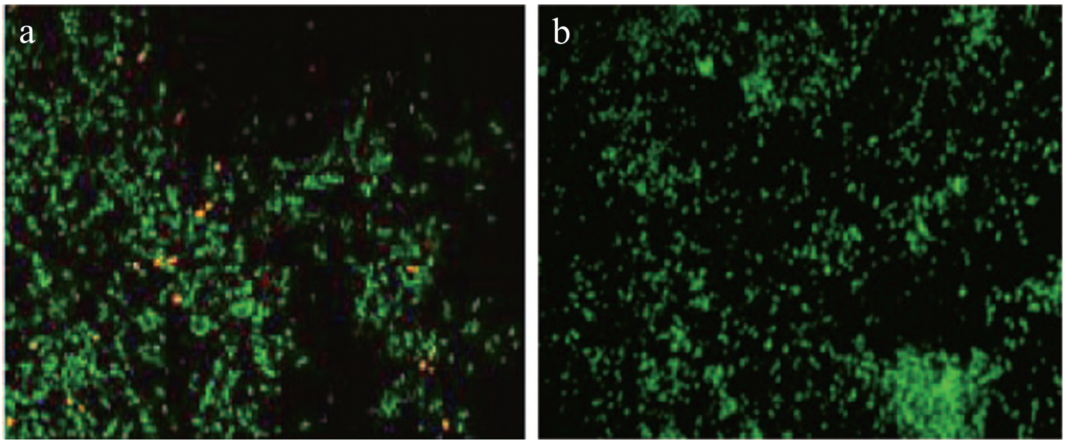

Fig. 3 – Fluorescence *in situ* hybridization (FISH) results for AOB and NOB: (a) NSO1225 target for AOB; (b) NIT3 target for *Nitrobacter*, Ntspa662 target for *Nitrospira* (red color signifies AOB in panel a, green color signifies all bacteria in panels a and b, NOB was not detected in panel b).

control is reliable and simple for achieving nitrogen removal *via* nitrite pathway from leachate.

Usually, nitritation was achieved at mild and high temperatures due to the specific growth rate of AOB (μ_{AOB}) being higher than that of NOB (μ_{NOB}). But why did, in our SBR system, nitritation started up at such low temperatures? Low temperatures (<20°C) would exert a negative impact on the activities of AOB and NOB, and μ_{AOB} was lower than μ_{NOB}. This means that AOB was unlikely able to out-compete NOB at temperature range of 13.0–17.6°C in this study.

However, AOB has been described to be much more tolerant to FA than NOB, so FA played a critical role in selectively inhibiting or limiting the growth of NOB. Moreover, when real-time control was applied in the SBR, the aeration was stopped immediately as soon as nitritation finished, as indicated by these key points on the DO, ORP, and pH profiles during each aeration period. As a result, nitrite, the energy source for NOB, was reduced to nitrogen gas in the denitritation process, further limiting the growth of NOB to some extent. Therefore, in such system, NOB growth gradually weakened due to the FA inhibition and the reduction of their energy source. We conclude that through FA inhibition on NOB and robust real-time control, AOB gradually became the dominant nitrifying bacteria in the activated sludge and nitritation was started up at low temperatures. This implies that it is feasible to start up nitritation at an SBR wastewater

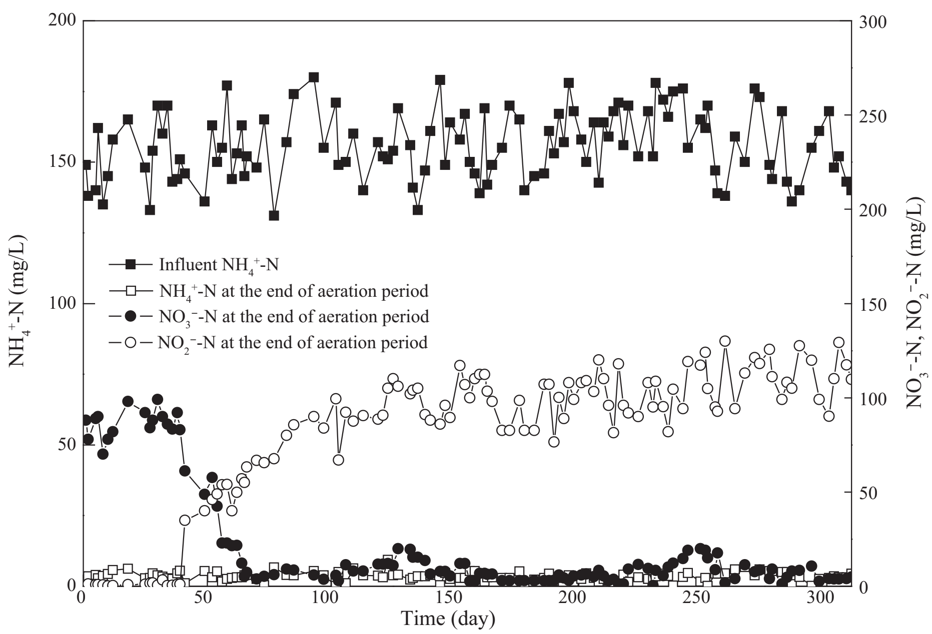

Fig. 4 – Variations of NH_4^+-N, NO_3^--N and NO_2^--N at the start and end of aeration period during the whole operation process.

Table 1 – Summary of main literature findings on the achievement of nitritation under normal/low temperatures.

The operational process and wastewater	Temperature (°C)		Days		Approach of achieving nitritation	Mechanism for achieving nitritation	Reference
	Start up nitritation	Maintain nitritation	Start up nitritation	Maintain nitritation			
A lab-scale two-stage UASB-A/O system treating landfill leachate	17–25	25–30	35	120	The NOB inhibition by FA aeration time control based on pH	The FA inhibited NOB growth, but almost had no impact on AOB	Peng et al. (2008)
A 10.8 L lab-scale swim-bed reactor treating synthetic wastewater containing high ammonium	20–30	10–30	60	240	The synergetic inhibition of FA and FNA on NOB	The NOB activity was inhibited by FA and FNA, AOB was confirmed to be the dominant nitrifying bacteria	Qiao et al. (2010)
Two 2.5 L lab-scale A/O SBR with and without step-feed treating synthetic wastewater	28	28	44	85	The combination of FA inhibition on NOB, step-feed strategy and nitrifying granules	The NOB activity was inhibited by FA, step-feed and granules was favorable for nitrite accumulation	Wang et al. (2012)
A 7.0 m^3 pilot-scale SBR treating campus wastewater	11–16	17–26	40	140	Real-time control strategy (based on blower frequency and pH) coupled with SND activity	Nitrifying bacteria community was optimized: AOB was domain and NOB was washed out	Gu et al. (2012)
A 54 m^3 pilot-scale SBR treating real municipal wastewater	17.3–25	11.9–26.5	120	177	A real-time control (based on DO, pH and ORP) coupled with step-feed pattern	Nitrifying bacteria community was optimized: AOB was dominant and NOB was washed out	Yang et al. (2007)
A 7 L lab-scale SBR treating abattoir wastewater	18–22	18–22	50	90	Aeration phase length control and step-feed operational pattern	The NOB were eliminated from the sludge system due to the gradual reduction of their energy source of nitrite	Lemaire et al. (2008)
An 8.0 L lab-scale SBR treating real landfill leachate	13.0–17.6	10.0–30.6	77	233	The NOB inhibition by FA and process control (based on DO, pH and ORP)	NOB activity was completely suppressed by FA inhibition and the reduction of available energy source of nitrite for NOB growth	This study

Upflow anaerobic sludge bed (UASB), anoxic/oxic (A/O), nitrite-oxidized bacteria (NOB), ammonia-oxidizing bacteria (AOB),free ammonia (FA), free nitrous acid (FNA), sequencing batch reactor (SBR), simultaneous nitrification and denitrification (SND), dissolved oxygen (DO), and oxidization–reduction potential (ORP).

treatment plants in winter, and nitrite pathway could be established without assuming that NOB have poorer growth kinetics than AOB.

3. Conclusions

Nitritation process can be achieved rapidly at low temperatures (13.0–17.6°C) in 77 days and was maintained stably for as long as 233 days by applying FA inhibition on NOB coupled with a real-time control. In such systems, AOB became dominant nitrifying bacterial population, but NOB was eliminated due to the inhibition of their growth kinetics. The reduction of the NOB growth kinetics would help to achieve nitrite pathway. The end-point of ammonium oxidation can be reliably detected from the on-line DO, pH and ORP signals. Therefore, the real-time control could implement NOB inhibition by FA to speed-up the onset and establishment of the nitrite pathway.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (Nos. 51168028, 51168027) and the Science and Technique Foundation Project for Youth of Gansu Province (No. 1107RJYA279).

REFERENCES

Amann, R.I., 1995. In situ identification of microorganisms by whole cellhybridization with rRNA-targeted nucleic acid probes. In: Akkermans, A.D.L, van Elsas, J.D, de Bruijn, F.J (Eds.), Molecular Microbial Ecology Manual. Holland, Kluwer Academic Publications, Dordrecht, pp. 1–15.

Anthonisen, A.C., Loehr, R.C., Prakasam, T.B.S., Srinath, E.G., 1976. Inhibition of nitrification by ammonia and nitrous acid. J. Water Pollut. Control Fed. 48 (5), 835–852.

APHA, 1998. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, DC.

Daims, H., Ramsing, N.B., Schleifer, K.H., Wagner, M., 2001. Cultivation-independent, semiautomatic determination of absolute bacterial cell numbers in environmental samples by fluorescence in situ hybridization. Appl. Environ. Microbiol. 67 (12), 5810–5818.

Gao, D.W., Peng, Y.Z., Li, B.K., Liang, H., 2009. Shortcut nitrification–denitrification by real-time control strategies. Bioresour. Technol. 100 (7), 2298–2300.

Gu, S.B., Wang, S.Y., Yang, Q., Yang, P., Peng, Y.Z., 2012. Start up partial nitrification at low temperature with a real-time control strategy based on blower. Bioresour. Technol. 112 (5), 34–41.

Guo, J.H., Peng, Y.Z., Huang, H.J., Wang, S.Y., Ge, S.J., Zhang, J.R., Wang, Z.W., 2010. Short- and long-term effects of temperature on partial nitrification in a sequencing batch reactor treating domestic wastewater. J. Hazard. Mater. 179 (1–3), 471–479.

Hellinga, C., Schellen, A.A.J.C., Mulder, J.W., van Loosdrecht, M.C.M., Heijnen, J.J., 1998. The SHARON process, an innovative method for nitrogen removal from ammonium-rich waste water. Water Sci. Technol. 37 (9), 135–142.

Kim, D.J., Lee, D.I., Keller, J., 2006. Effect of temperature and free ammonia on nitrification and nitrite accumulation in landfill leachate and analysis of its nitrifying bacterial community by FISH. Bioresour. Technol. 97 (3), 459–468.

Lemaire, R., Marcelino, M., Yuan, Z.G., 2008. Achieving the nitrite pathway using aeration phase length control and step-feed in an SBR removing nutrients from abattoir wastewater. Biotechnol. Bioeng. 100 (6), 1228–1236.

Mobarry, B.K., Wagner, M., Urbain, V., Rittmann, B.E., Stahl, D.A., 1996. Phylogenetic probes for analyzing abundance and spatial organization of nitrifying bacteria. Appl. Environ. Microbiol. 62 (6), 2156–2162.

Park, S., Bae, W., Rittmann, B.E., 2010. Operational boundaries for nitrite accumulation in nitrification based on minimum/maximum substrate concentrations that include effects of oxygen limitation, pH, and free ammonia and free nitrous acid inhibition. Environ. Sci. Technol. 44 (1), 335–342.

Peng, Y.Z., Zhang, S.J., Zeng, W., Zheng, S.W., Mino, T.K., Satoh, H., 2008. Organic removal by denitrification and methanogenesis and nitrogen removal by nitrification from landfill leachate. Water Res. 42 (4/5), 883–892.

Qiao, S., Matsumoto, N., Shinohara, T., Nishiyama, T., Fujii, T., Bhatti, Z., Furukawa, K., 2010. High-rate partial nitrification performance of high ammonium containing wastewater under low temperatures. Bioresour. Technol. 101 (1), 111–117.

Renou, S., Givaudan, J.G., Poulain, S., Dirassouyan, F., Moulin, P., 2008. Landfill leachate treatment: review and opportunity. J. Hazard. Mater. 150 (3), 468–493.

Tchobanoglous, G., Burton, F.L., Stensel, H.D., 2003. Wastewater Engineering: Treatment and Reuse, fourth ed. Metcalf & Eddy Inc., McGraw-Hill Science Engineering, New York, USA.

Torà, J.A., Lafuente, J., Baeza, J.A., Carrera, J., 2010. Combined effect of inorganic carbon limitation and inhibition by free ammonia and free nitrous acid on ammonia oxidizing bacteria. Bioresour. Technol. 101 (15), 6051–6058.

Turk, O., Mavinic, D.S., 1986. Preliminary assessment of a shortcut in nitrogen removal from wastewater. Can. J. Civ. Eng. 13 (6), 600–605.

Vadivelu, V.M., Keller, J., Yuan, Z.G., 2006. Effect of free ammonia and free nitrous acid concentration inhibition on the anabolic and catabolic process of an enriched *Nitrosomonas* culture. Biotechnol. Bioeng. 95 (5), 830–839.

Wang, X.H., Jiang, L.X., Shi, Y.J., Gao, M.M., Yang, S., Wang, S.G., 2012. Effects of step-feed on granulation processes and nitrogen removal performances of partial nitrifying granules. Bioresour. Technol. 123, 375–381.

Wang, K., Wang, S.Y., Zhu, R.L., Miao, L., Peng, Y.Z., 2013. Advanced nitrogen removal from landfill leachate without addition of external carbon using a novel system coupling ASBR and modified SBR. Bioresour. Technol. 134, 212–218.

Yang, Q., Peng, Y.Z., Liu, X.H., Zeng, W., Mino, T., Satoh, H., 2007. Nitrogen removal via nitrite from municipal wastewater at low temperatures using real-time control to optimize nitrifying communities. Environ. Sci. Technol. 41 (23), 8159–8164.

Zhang, L., Zhang, S.J., Han, X.Y., Gan, Y.P., Wu, C.C., Peng, Y.Z., 2012. Evaluating the effects of nitrogen loading rate and substrate inhibitions on partial nitrification with FISH analysis. Water Sci. Technol. 65 (3), 513–518.

Zhou, Y., Oehmen, A., Lim, Melvin, Vadivelu, V., Ng, W.J., 2011. The role of nitrite and free nitrous acid (FNA) in wastewater. Water Res. 45 (15), 4672–4682.

JOURNAL OF ENVIRONMENTAL SCIENCES

环境科学学报(英文版)

www.jesc.ac.cn

Aims and scope

Journal of Environmental Sciences is an international academic journal supervised by Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. The journal publishes original, peer-reviewed innovative research and valuable findings in environmental sciences. The types of articles published are research article, critical review, rapid communications, and special issues.

The scope of the journal embraces the treatment processes for natural groundwater, municipal, agricultural and industrial water and wastewaters; physical and chemical methods for limitation of pollutants emission into the atmospheric environment; chemical and biological and phytoremediation of contaminated soil; fate and transport of pollutants in environments; toxicological effects of terrorist chemical release on the natural environment and human health; development of environmental catalysts and materials.

For subscription to electronic edition

Elsevier is responsible for subscription of the journal. Please subscribe to the journal via http://www.elsevier.com/locate/jes.

For subscription to print edition

China: Please contact the customer service, Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China. Tel: +86-10-64017032; E-mail: journal@mail.sciencep.com, or the local post office throughout China (domestic postcode: 2-580).

Outside China: Please order the journal from the Elsevier Customer Service Department at the Regional Sales Office nearest you.

Submission declaration

Submission of the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The publication should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

Editorial

Authors should submit manuscript online at http://www.jesc.ac.cn. In case of queries, please contact editorial office, Tel: +86-10-62920553, E-mail: jesc@rcees.ac.cn. Instruction to authors is available at http://www.jesc.ac.cn.

Journal of Environmental Sciences (Established in 1989)
Volume 30 2015

Supervised by	Chinese Academy of Sciences	**Published by**	Science Press, Beijing, China
Sponsored by	Research Center for Eco-Environmental		Elsevier Limited, The Netherlands
	Sciences, Chinese Academy of Sciences	**Distributed by**	
Edited by	Editorial Office of Journal of	Domestic	Science Press, 16 Donghuangchenggen
	Environmental Sciences		North Street, Beijing 100717, China
	P. O. Box 2871, Beijing 100085, China		Local Post Offices through China
	Tel: 86-10-62920553; http://www.jesc.ac.cn	Foreign	Elsevier Limited
	E-mail: jesc@rcees.ac.cn		http://www.elsevier.com/locate/jes
Editor-in-chief	X. Chris Le	**Printed by**	Beijing Beilin Printing House, 100083, China

CN 11-2629/X **Domestic postcode: 2-580** **Domestic price per issue RMB ¥ 110.00**

ISSN 1001-0742

9 771001 074154 04