ISSN: 2458-8989

Natural and Engineering Sciences

NESciences, 2019, 4(3): 299-307

- RESEARCH ARTICLE-

Effect of Intermittent Aeration and Step-Feed on Nitrogen Removal Performance in Anoxic-aerobic Sequencing Batch Reactor

Engin Gürtekin*

Firat University, Faculty of Engineering, Department of Environmental Engineering, Elazığ, TURKEY

Abstract

In this study, it was investigated the effect intermittent aeration and step-feed on nitrogen removal by providing anoxic-aerobic, anoxic-aerobic-anoxic-aerobic and step-feed anoxic-aerobic-anoxic-aerobic working conditions. Chemical oxygen demand (COD) removal efficiency was the same in all three working conditions and was found to be 91%. The NH_4^+-N removal efficiency is almost the same. The NH_4^+-N removal efficiencies in the W1, W2 and W3 are 92%, 93% and 95%, respectively. Total inorganic nitrogen (TIN) removal efficiency increased by 4% when intermittent aeration was applied. Increasing the efficiency of TIN removal by 24% was achieved by applying the step-feed intermittent aeration. Experimental results show that the effect of intermittent aeration on TIN removal was limited and that TIN removal performance with step-feed intermittent aeration was significantly increased.

Keywords:
Sequencing batch reactor, nitrogen removal, intermittent aeration, step-feed.
Article history:
Received 04 March 2019, Accepted 30 October 2019, Available online 30 October 2019

Introduction

Biological nitrogen removal in sequencing batch reactor is realized by providing alternative aerobic and anoxic conditions (Zhong et al., 2013). Under aerobic conditions, ammonium nitrogen is first oxidized to nitrite nitrogen by ammonium oxide bacteria (AOB) and then oxidized to nitrate nitrogen by nitrous oxide bacteria (NOB) (nitrification). Under anoxic conditions, nitrate nitrogen is reduced to nitrite nitrogen, nitrite oxide, nitrous oxide (N_2O) and nitrogen gas by denitrification bacteria, respectively (denitrification) (Sun et al., 2019). However, due to the inadequacy of carbon source in nitrogen removal with nitrification and denitrification processes, the denitrification

* *Corresponding Author: Engin Gürtekin, E-mail: egurtekin@firat.edu.tr*

process is limited and the nitrate concentration in the effluent is high (Xing et al., 2017). In addition, a high amount of energy is consumed due to the aeration under aerobic conditions and therefore the operating cost increases (Sun et al., 2018). Therefore, it is important to develop new nitrogen removal technologies to increase nitrogen removal in the sequencing batch reactor and to reduce energy and carbon use (Sun et al., 2018).

In recent years, the intermittent aeration strategy, in which the aeration and non-aeration phases are alternately repeated in order to create aerobic and anoxic conditions, is used to increase the nitrogen removal from the wastewater (Lim et al., 2012). The main advantages of implementing the intermittent aeration strategy in the treatment of nitrogen-containing wastewater; to achieve high nitrogen removal, reduce operating costs due to reduced supply of oxygen and reduce the amount of carbon resources required for denitrification (Lim et al., 2012). Step-feed strategy is a method that provides more effective and efficient use of carbon source for denitrification in activated sludge system (Zhong et al., 2013). In the step-feed strategy, the influent is fed into the reactor at the beginning of anoxic phases where denitrification takes place by dividing by equal or certain proportions (Chen et al., 2013).

In the sequencing batch reactor, there are many studies in which both the intermittent aeration strategy is applied and the intermittent aeration and the step-feed strategy are applied together. However, it is quite limited the number of runs in which first the effects of intermittent aeration and then intermittent aeration with the step-feed in sequencing batch reactor are compared. The aim of this study is to evaluate the effects of each strategy on the nitrogen removal performance by applying separately the intermittent aeration and together the intermittent aeration with the step feed in the sequencing batch reactor.

Material and Methods

System operation

The experimental study was conducted in a sequencing batch reactor with a working volume of 5 L. The sequencing batch reactor was operated at 8 hour cycle time. Each cycle consists of 15 min filling, 360 min reaction, 75 min settling, 15 min decanting and 15 min idle phases. The study was carried out in 3 stages. In the first stage of the study (W1), the reaction phase consists of 120 min anoxic and 240 min aerobic phase. In the second stage of the study (W2), where intermittent aeration strategy is applied, the reaction phase consists 60 min anoxic, 120 min aerobic, 60 min anoxic, and 120 min aerobic phase. In the third stage of the study (W3), intermittent aeration and step-feed strategies were applied together. The reaction phase consisted of 60 min anoxic, 120 min aerobic, 60 min anoxic, 120 min aerobic phase and successive feeding to each anoxic phase by dividing the inlet water into two equal volumes (1:1) was carried out. The reactor was inoculated with activated sludge from a city wastewater treatment plant. The sludge retention time in the reactor is 15 days. The reactor was mixed with a mechanical stirrer except for the settling, decanting and idle phases. During the aerobic phase, the aeration was made through the air pump and the diffusers placed at the bottom of the reactor. The mean total suspended solids concentration in the reactor during the experimental study was 3000 ± 100 mg/L. The reactor was operated at 25 ^{o}C.

Synthetic wastewater

The synthetic wastewater consisted of 510 mg/L sodium acetate, 90 mg/L $MgSO_4.7H_2O$, 14 mg/L $CaCl_2.2H_2O$, 153 mg/L NH_4Cl, 46 mg/L Na_2HPO_4, 200 mg/L $NaHCO_3$, 10 mg/L yeast extract and 0.4 mL/L trace elements. Synthetic wastewater has approximately contained COD concentration of 400 mg/L, $NH_4{}^+$-N concentration of 40 mg/L and $PO_4{}^{-3}$-P concentration of 10 mg/L (Sun et al., 2018).

Analytical methods

Chemical oxygen demand (COD) and total suspended solids (TSS) analysis were performed according to Standard Methods (APHA, AWWA, WCPF, 1998). The MLSS concentration was determined using Whatman filter paper. Ammonium, nitrite and nitrate analysis were performed using the Standard Kit (Merck Specquorant, Nova 60). Total inorganic nitrogen (TIN) value was obtained from the sum of ammonium, nitrite and nitrate concentrations.

Results and Discussion

COD, TIN and $NH_4{}^+$-N removal efficiencies obtained in the sequencing batch reactor with anoxic-aerobic (W1), intermittent aeration (anoxic-aerobic-anoxic-aerobic (W2)) and step-feed intermittent aeration (step-feed anoxic-aerobic-anoxic-aerobic (W3)) applications are given in Figure 1. In the sequencing batch reactor, the same COD removal efficiencies were obtained with anoxic-aerobic, intermittent aeration and step-feed intermittent aeration applications. COD removal efficiency was 91 % in all three study stages. COD removal was achieved by using the organic material in the wastewater as an electron donor source during the anoxic phase and consumed as a result of oxidation in the aerobic phase. In another study, the efficient use of organic substrates was attributed to use organic matter as an electron donor for respiration and growth of denitrification bacteria in anoxic conditions (de la Vega et al., 2013). The removal efficiency of TIN in W1, W2 and W3 was 60 %, 64 % and 84 %, respectively. With the application of intermittent aeration, increase in TIN removal efficiency is limited and is 4%. This is due to the fact that the organic matter is completely consumed in the first aerobic phase and that there is no organic material in the second anoxic phase to allow the denitrification process to take place. In another study comparing the performance of sequencing batch reactor and intermittent aeration sequencing batch reactor, 11 % more nitrogen removal was achieved in intermittent aeration sequencing batch reactor (Pan et al., 2013). In the third stage of the study, step-feed was performed and accordingly the increase in TIN removal efficiency was 20 % compared to the second stage of the study. Sun et al. (2018) have found that increased by 12.6 % of nitrogen removal in a step-feed multiple anoxic-aerobic sequencing batch reactor compared to multiple anoxic-aerobic sequencing batch reactor. The total mass balance of the nitrogen present at the influence of the wastewater treatment processes is generated in three ways. First, nitrogen is assimilated for cell synthesis. Second, part of the nitrogen is in the form of total kjehdahl or nitrate/nitrite in the effluent. Third, most nitrogen is converted to nitrogen gas under anoxic or aerobic conditions (Barker & Dold, 1995). Anoxic denitrification efficiencies play an important role in total nitrogen removal. The $NH_4{}^+$-N removal efficiency in the W1, W2 and W3 is almost similar, with removal efficiencies of 92 %, 93 % and 95 %, respectively. Similar $NH_4{}^+$-N removal efficiencies were obtained in all three stages of the study and showed that nitrification was almost the same size. Vaiopoulou & Aivasidis (2008) achieved ammonium removal by 95 % and total nitrogen removal efficiency by 83% with step-feed at 60:25:15 inlet wastewater distribution rate in the treatment of low COD/N ratio wastewater. Ge et al. (2010) found that the efficiency of ammonium removal was 99 % and the total nitrogen removal efficiency was 88 % with the step-feed at the inlet rate of 40:30:30 input wastewater. Liang et al. (2010) achieved an ammonium removal efficiency of 96 % with a step-feed in input wastewater distribution ratio of 42:33:25. Zhong et al. (2013) achieved a TIN removal efficiency of 48.1-59.5 % in the case of intermittent aeration in the granular sequencing batch reactor, and a TIN removal efficiency of 89.7-92.4 % in the case of step-feed intermittent aeration. Ammonia and total nitrogen removal efficiencies in the integrated fixed film activated sludge process with intermittent aeration were 97.2 % and 77.8 %, respectively (Singh et al., 2017).

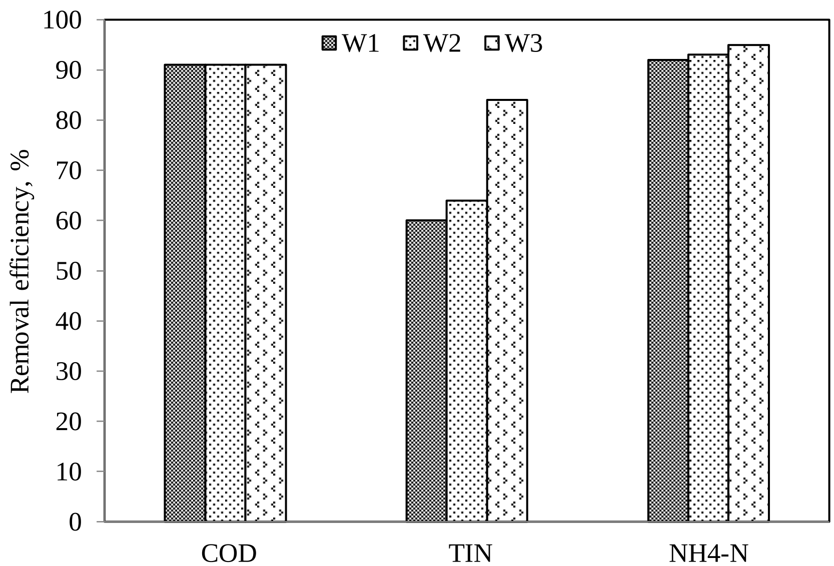

Figure 1. COD, TIN and NH_4^+-N removal efficiencies in W1, W2 and W3.

In conventional biological nitrogen removal, only one sequencing anoxic/aerobic (A/O) is applied to carry out denitrification and nitrification. In the first stage of the study consisting of anoxic-aerobic phases, organic matter decreased due to denitrification process in anoxic phase (Figure 2). In the denitrification process, organic carbon is needed as the electron donor. Theoretically, 2.86 mg COD is required for the removal of 1 mg of nitrate in anoxic conditions with the biodegradable organic substances present in the wastewater. In practice, the organic carbon requirement for complete nitrogen removal is higher than the theoretical value and usually a minimum of 3.5-4.0 mg COD is required (Henze, 1995). Patel et al. (2006) reported that 8.6 mg/L COD was consumed for removal of 1 mg of nitrate. In the aerobic phase, COD concentration decreased rapidly due to oxidation in the presence of oxygen. In the anoxic phase, the limited reduction in ammonium concentration can be due to cell assimilation. The ammonium concentration decreased due to the nitrification process in the aerobic phase. In the anoxic phase, nitrite accumulation is almost absent and in the aerobic phase, there is a small amount of nitrite accumulation. The highest nitrite concentration in the aerobic phase was 1.26 mg/L. Nitrate concentration decreased due to denitrification in anoxic phase and increased due to nitrification in aerobic phase. The decrease in TIN concentration during the cycle is continuous due to denitrification in the anoxic phase and nitrification in the aerobic phase. The denitrification process in the anoxic phase was limited to the nitrate concentration remaining from the previous cycle. The length of the anoxic phase and the amount of organic matter in the wastewater are sufficient for the denitrification process. It is seen that the TIN removal efficiency is limited by the denitrification process in the anoxic phase.

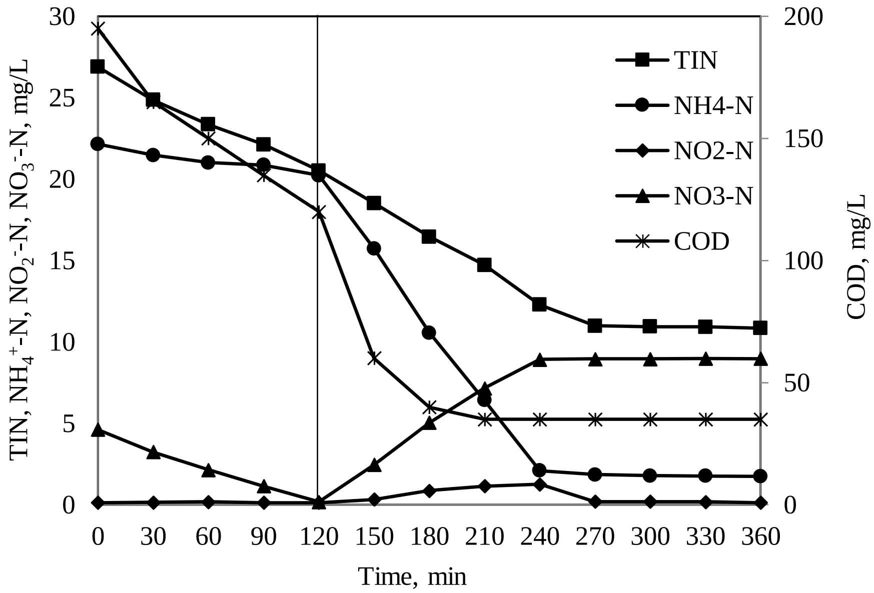

Figure 2. Time profiles of concentrations a) COD, b) TIN, NH_4^+-N, NO_2^--N, NO_3^--N in a typical cycle of W1.

The time variation of COD, TIN, NH_4^+-N, NO_2^--N, NO_3^--N concentrations in the second stage of the study in which intermittent aeration is applied is given in Figure 3. COD concentration decreased due to denitrification in the first anoxic phase. In the first aerobic phase, the COD concentration decreased from 145 mg/L to 35 mg/L as a result of the oxidation in the presence of oxygen. During the second anoxic and second aerobic phase and at the effluent, the COD concentration is the same. The decrease in ammonium concentration in the first anoxic and second anoxic phases can be due to cell assimilation. While the decrease in ammonium concentration in the first anoxic phase was 0.68 mg/L, the decrease in ammonium concentration in the second anoxic phase was found to be 0.15 mg/L. In the first aerobic and second aerobic phases, the ammonium concentration decreased with the nitrification process. Nitrite accumulation in the first and second anoxic phases is so low as to be negligible. In the first and second aerobic phases, a small amount of nitrite accumulation was observed. The highest nitrite concentration in the first aerobic phase was 0.85 mg/L and the highest nitrite concentration in the second aerobic phase was 0.64 mg/L. It is stated that nitrite accumulation in aerobic phase of multiple anoxic-aerobic processes is due to the competition between ammonium oxidizing bacteria and nitrite oxidizing bacteria in low dissolved oxygen conditions (Zeng et al., 2010). Nitrate concentration decreased due to denitrification in the first anoxic phase. However, the denitrification process did not occur due to the lack of sufficient organic matter in the second anoxic phase. Accordingly, the increase in TIN removal efficiency was limited. As a result of the nitrification process that occurred in the first and second aerobic phases, the nitrate concentration increased. The reason for the limited increase in TIN removal efficiency with intermittent aeration is due to the fact that the organic material in the wastewater is oxidized in the first aerobic phase and there is no organic matter required for denitrification in the second anoxic phase.

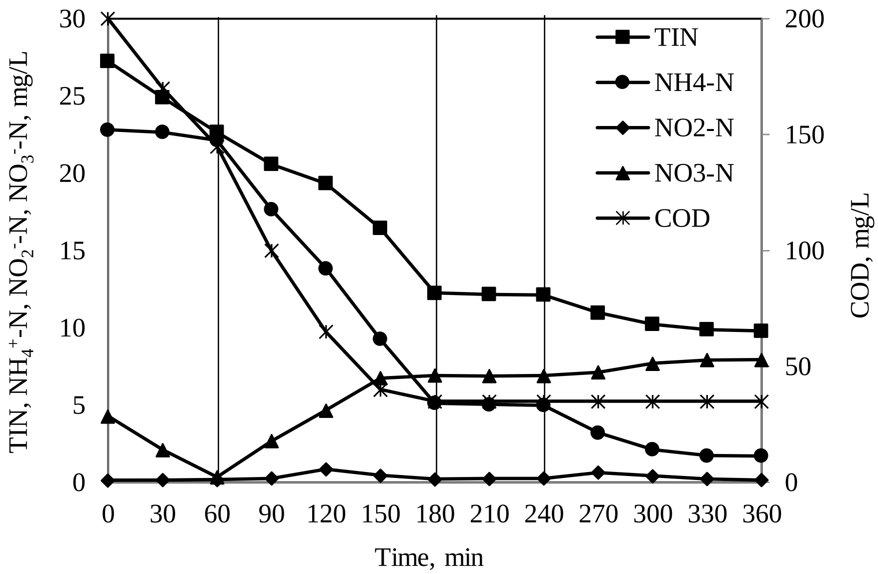

Figure 3. Time profiles of concentrations a) COD, b) TIN, NH_4^+-N, NO_2^--N, NO_3^--N in a typical cycle of W2.

The step-feed strategy in intermittent aeration processes increases the rate of denitrification and improves the total nitrogen removal performance by providing more efficient use of the carbon source at the influent. Also; as the organic load decreases in the aerobic phase, the nitrification rate increases and the required aeration requirement for organic matter oxidation decreases (Chen et al., 2011). In the third stage of the study, in which the intermittent aeration and step-feed were used together, COD concentration decreased due to the denitrification process which occurred by the step-feeding in the first and second anoxic phases (Figure 4). While the COD concentration in the first anoxic phase decreased by 75 mg/L, COD concentration in the second anoxic phase decreased by 50 mg/L. In both aerobic phases, the organic material remaining from the anoxic phases decreased due to oxidation. The limited reduction in ammonium concentration in both anoxic phases is thought to be due to cell assimilation. In the aerobic phases, the ammonium concentration decreased due to the nitrification process. The input of less organic matter into the aerobic phase has been reported to reduce competition for oxygen between heterotrophic bacteria and nitrification bacteria and to improve nitrification (Kim et al., 2009). In the anoxic phases, nitrite accumulation was almost non-existent and limited in aerobic phases. Nitrate concentration decreased due to denitrification in anoxic phases and increased due to nitrification in aerobic phases. The concentration of TIN decreased due to the denitrification and nitrification processes that occurred in both the first anoxic, aerobic and the second anoxic, aerobic phases. The presence of organic carbon in the second anoxic phase due to the step-feed increased the efficiency of TIN removal. It is stated that step-feed in anoxic-aerobic sequencing batch reactor is more efficient both technologically and economically as it increases TN removal by providing more efficient use of carbon source in denitrification process (Yang et., 2007; Zhong et al., 2013).

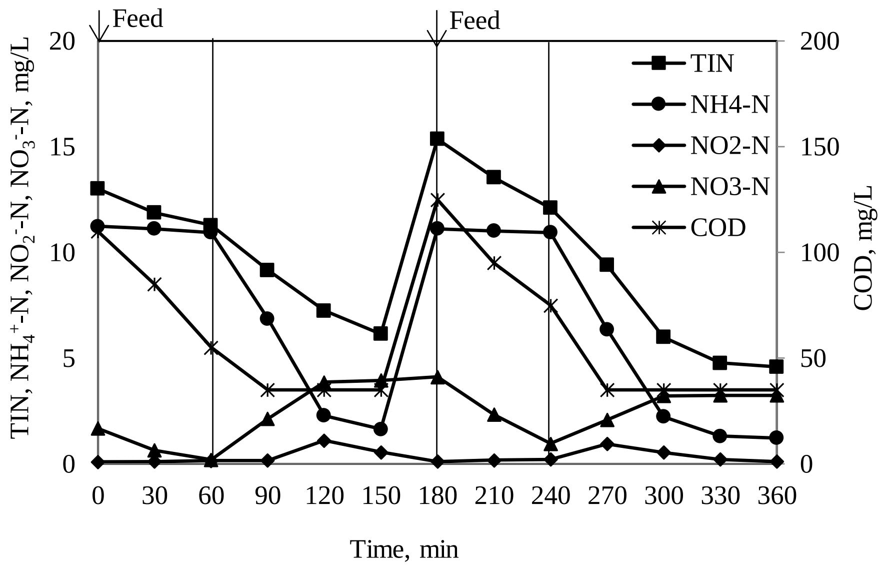

Figure 4. Time profiles of concentrations a) COD, b) TIN, NH_4^+-N, NO_2^--N, NO_3^--N in a typical cycle of W3.

Conclusions

In the sequencing batch reactor, the same COD removal efficiencies have been obtained in anoxic-aerobic, intermittent aeration and step-feed intermittent aeration applications. COD removal efficiency was 91 % in all three study stages. NH_4^+-N removal efficiencies in the W1, W2 and W3 are almost the same, with removal efficiencies of 92 %, 93 % and 95 %, respectively. These results indicate that the nitrification process is substantially complete in all three working conditions. With the use of intermittent aeration, the increase in TIN removal efficiency was limited as the use of the organic carbon source in the denitrification process could not be achieved more effectively. With the application of step-feed intermittent aeration; the organic matter in the wastewater needed for the denitrification process under anoxic conditions was more efficiently used and the TIN removal increased by 24%.

References

APHA, AWWA, WCPF. (1998). *Standard Methods for the Examination of Water and Wastewater***,** 20th Edition, American Public Health Association, Washington, D.C.

Barker, P. S., & Dold, P. L. (1995). COD and nitrogen mass balances in activated sludge systems. *Water Research*, 29(2), 633-643.

Chen, F. Y., Liu, Y. Q., Tay, J. H., & Ning, P. (2011). Operational strategies for nitrogen removal in granular sequencing batch reactor. *Journal of Hazardous Materials*, 189(1-2), 342-348.

Chen, F. Y., Liu, Y. Q., Tay, J. H., & Ning, P. (2013). Alternating anoxic/oxic condition combined with step-feeding mode for nitrogen removal in granular sequencing batch reactors (GSBRs). *Separation and Purification Technology*, 105, 63-68.

de la Vega, P. M., Jaramillo, M. A., & de Salazar, E. M. (2013). Upgrading the biological nutrient removal process in decentralized WWTPs based on the intelligent control of alternating aeration cycles. *Chemical Engineering Journal*, 232, 213-220.

Ge, S., Peng, Y., Wang, S., Guo, J., Ma, B., Zhang, L., & Cao, X. (2010). Enhanced nutrient removal in a modified step feed process treating municipal wastewater with different inflow distribution ratios and nutrient ratios. *Bioresource Technology*, 101(23), 9012-9019.

Henze, M. (1991). Capabilities of biological nitrogen removal processes from wastewater. *Water Science and Technology*, 23(4-6), 669-679.

Kim, D., Kim, K. Y., Ryu, H. D., Min, K. K., & Lee, S. I. (2009). Long term operation of pilot-scale biological nutrient removal process in treating municipal wastewater. *Bioresource Technology*, 100(13), 3180-3184.

Liang, H., Gao, M., Liu, J., Wei, Y., & Guo, X. (2010). A novel integrated step-feed biofilm process for the treatment of decentralized domestic wastewater in rural areas of China. *Journal of Environmental Sciences*, 22(3), 321-327.

Lim, J. W., Lim, P. E., & Seng, C. E. (2012). Enhancement of nitrogen removal in moving bed sequencing batch reactor with intermittent aeration during REACT period. *Chemical Engineering Journal*, 197, 199-203.

Pan, M., Chen, T., Hu, Z., & Zhan, X. (2013). Assessment of nitrogen and phosphorus removal in an intermittently aerated sequencing batch reactor (IASBR) and a sequencing batch reactor (SBR). *Water Science and Technology*, 68(2), 400-405.

Patel, A., Zhu, J., & Nakhla, G. (2006). Simultaneous carbon, nitrogen and phosphorous removal from municipal wastewater in a circulating fluidized bed bioreactor. *Chemosphere*, 65(7), 1103-1112.

Singh, N. K., Bhatia, A., & Kazmi, A. A. (2017). Effect of intermittent aeration strategies on treatment performance and microbial community of an IFAS reactor treating municipal waste water. *Environmental technology*, 38(22), 2866-2876.

Sun, Y., Wang, H., Wu, G., & Guan, Y. (2018). Nitrogen removal and nitrous oxide emission from a step-feeding multiple anoxic and aerobic process. *Environmental Technology*, 39(7), 814-823.

Sun, Y., Xin, L., Wu, G., & Guan, Y. (2019). Nitrogen removal, nitrous oxide emission and microbial community in sequencing batch and continuous-flow intermittent aeration processes. *Environmental Engineering Research*, 24(1), 107-116.

Vaiopoulou, E., & Aivasidis, A. (2008). A modified UCT method for biological nutrient removal: configuration and performance. *Chemosphere*, 72(7), 1062-1068.

Xing, L., Ou, L., Zhang, Y., Zheng, D., & Wu, G. (2017). Nitrogen Removal and N_2O Emission During Low Carbon Wastewater Treatment Using the Multiple A/O Process. *Water, Air & Soil Pollution*, 228(9), 367.

Yang, Q., Peng, Y., Liu, X., 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. *Environmental Science and Technology*, 41, 8159–8164.

Zeng, W., Li, L., Yang, Y., Wang, S., & Peng, Y. (2010). Nitritation and denitritation of domestic wastewater using a continuous anaerobic–anoxic–aerobic (A2O) process at ambient temperatures. *Bioresource Technology*, 101(21), 8074-8082.

Zhong, C., Wang, Y., Wang, Y., Lv, J., Li, Y., & Zhu, J. (2013). High-rate nitrogen removal and its behavior of granular sequence batch reactor under step-feed operational strategy. *Bioresource Technology*, 134, 101-106.