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Effect of Reflux Ratios for Anoxic Digestion of Sewage during A2O Process

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Abstract
Anaerobic/anoxic/oxic (A2O) process has been proven to be effective for wastewater treatment, especially for nutrient removal. In this study, effect of N/S, C/N and hydraulic retention time (HRT) on anoxic digestion during A2O process was evaluated. The study was carried out for a whole year and covered summer, autumn and winter seasons. The results showed that sulfide and threshold odor number (TON) removal was increased with the increase of S/N ratio; however, nitrate removal was decreased. The optimum S/N ratios were 0.6, 1.0 and 1.5 during summer, autumn and winter, respectively. Whereas, with the increase of C/N ratio nitrate removal was increased and sulfide and TON removal was decreased. The optimum C/N ratio was 6.00 for summer, 4.00 for autumn, and 3.50 for winter. During the whole study period, removal rate for all three parameters was increased with the increased of HRTs. The optimum HRTs were 5h, 7.5h and 8.5h for summer, autumn and winter, respectively. The experiment showed that anoxic digestion is influenced by the reflux ratio and it should be optimized to promote complete anoxic digestion during A2O process.
Keywords A2O; sulfate reduction; nutrient removal, anoxic digestion; C/N ratio

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Introduction

Water pollution is one of the main environmental problems, especially from wastewater disposal. Wastewater treatment plays significant role in safeguarding community health and freshwater quality. Satisfactory disposal of wastewater is necessary before its disposal to receiving water bodies to prevent contamination [1]. There is a need for adequate treatment methods to reduce adverse impacts on the environmental components [2]. Recently, numbers of biological nutrient removal processes have been developed. The anaerobic/anoxic/oxic (A2O) system has been proven to be effective for wastewater treatment. Nitrogen compounds discharged by wastewater into the environment can cause eutrophication and deterioration of freshwater bodies [3]. In A2O system, it is possible to achieve nitrification; denitrification and phosphorus removal simultaneously. As compared to conventional methods, the A2O systems have many advantages such as low operational costs with high removal of nitrogen and phosphorus [4].

Biological nitrogen removal is commonly believed to offer the most efficient process of controlling nutrients in domestic wastewater. Under anoxic conditions, heterotrophic bacteria, responsible for denitrification, convert nitrate to molecular nitrogen. In addition to denitrification, heterotrophic bacteria biodegrade organic matter [5]. In the denitrification process, nitrite (NO_2^-), nitric oxide (NO), and nitrous oxide (N_2O) are intermediates. Each step involves a particular reductase enzyme that catalyzes the transfer of electrons to nitrogen. The electron originates from the substrate, that is, the electron donor. Either inorganic (for example, hydrogen or sulfur) or organic waste compounds can serve as a substrate for denitrification. As a result of denitrification, the electron donor is oxidized while nitrate is reduced [6].

Anaerobic wastewater digestion produces odors that can be a nuisance. Odors can affect the surrounding peoples or community around the treatment facility. Anaerobic wastewater treatment generates hydrogen sulfide (H_2S) by the biological breakdown of sulfate, which is most commonly known and dominant odorous gas related to wastewater treatment process. Sulfate present in domestic wastewater primarily from household cleaning detergents. After reducing sulfate to sulfide (S^{2-}), it reacts with hydrogen to form hydrogen sulfide [7].

$$SO^- + \text{organic matter} \longrightarrow S^{2-} + H_2O + CO_2$$

$$S^{2-} + 2H^+ \xrightarrow{\text{Anaerobic bacteria}} H_2S$$

The odor control and abatement is a major issue during wastewater treatment. Appropriate operational conditions, process design, control and careful oversight are required to reduce odors and improve efficiency of the reactor [8]. Several factors have been linked to biological nutrient removal during A2O process, including nitrate concentration [9], organic carbon load and type [10], temperature and hydraulic retention time (HRT) [11]. The ratios, like N/S and C/N are a simple and effective indicator of organic source [12]. This paper aims to investigate the effects of N/S and C/N ratios, and HRT on anoxic digestion during A2O treatment process.

Materials and Methods

Reactor setup

The lab-scale A2O system was consisted of an anaerobic baffled reactor (ABR), anoxic tank and oxic part. The ABR was 1 m × 0.2 m × 0.75 m (length × width × height) in diameter with 100 L effective volume and divided into five compartments by vertical baffles. The anoxic tank was 1 m × 0.2 m × 0.2 m (height × length × width) in diameter with 32 L effective volume. The oxic unit consisted of three aerobic turntable cells; each cell consisted of a rectangular tank (0.2 m × 0.2 m × 0.1 m in diameter), a rotating disc and a bio-wheel rotating disc, working on the watermill principle.

Wastewater characteristics

The raw sewage water for this study was obtained from the Southeast University, Wuxi, China. The raw sewage has pH 7.06, COD (chemical oxygen demand) 258.4 mg/L, total nitrogen (TN) 33.8 mg/L, NH_4^+-N 25.6 mg/L, total phosphorus (TP) 4.3 mg/L and total soluble salts (TSS) 276 mg/L. The wastewater was generated from dormitories, laboratories, and restaurants on the university campus.

Experimental procedure

The experimental reactor was run for one year from the system start-up. The sodium sulfide ($Na_2S \cdot 9H_2O$) and potassium nitrate (KNO_3) in different concentration (mg/l) according to experiments were added as nitrate-nitrogen and sulfide-sulfur in raw wastewater. The air temperature during the operation was 3–35^{o}C in all seasons. During autumn and spring seasons, temperature range was similar, hence considered single season. Anoxic tank was receiving two inflows, one from anaerobic digestion and another inflow was from oxic unit. Therefore, simultaneously two inflows drained into anoxic unit. The flow ratio from the oxic unit to that from the anaerobic reactor is called reflux ratio. Reflux ratio determines the concentration of carbon, nitrate or oxygen in the anoxic tank. The reflex ratio is one of the most important parameters affecting the anoxic digestion of wastewater and can affect denitrification and deodorization processes. Valves, nozzles, and pumps were used to regulate the flow rate of water from one unit to another.

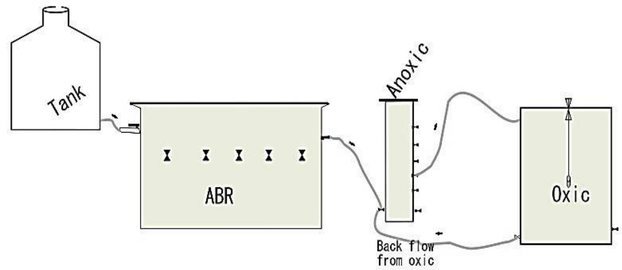

Fig. 1 schematic diagram shows the A2O process and two inflow of anoxic tank. ABR = anaerobic baffled reactor

Analytical methods

Chemical oxygen demand (COD), total Nitrogen (TN), nitrate (NO_3), sulfate and hydrogen sulfide (H_2S) and threshold odor number (TON) were analyzed according to standard methods [13]. Dissolved oxygen (DO) and pH were analyzed by DO200 and PH100 probes (YSI), respectively.

Data analysis

SPSS version-18.0 (SPSS incorporation Chicago, Illinois, USA) and MS-excel programs were used for data analysis and presentation.

Results and Discussion

Effect of different N/S ratios

It has been shown that some bacterial species like *Thiobacillus denitrificans* can oxidize sulfide to elemental sulfur at the same time reducing nitrate to dinitrogen [14]. Therefore, the understanding is clear that the N/S ratio should be a chief factor in the removal of sulfide and nitrate simultaneously. The Fig. 2 and Table 1 shows the impact of the N/S ratio on sulfide, TON and nitrate removal. With the increase of N/S ratio, sulfide and TON removal were increased, whereas nitrate removal was decreased during whole study period. The N/S ratio was 0.4 to 1.2, 0.5 to 0.2 and 1.0 to 2.5, whereas sulfide removal efficiency was 90% to 96%, 83% to 91% and 83% to 89%, TON removal efficiency was 71% to 92%, 69% to 90% and 62% to 87% and nitrate removal efficiency was 81% to 54%, 67% to 29% and 37% to 18% during summer, autumn and winter, respectively. This behavior suggests that sulfide removal was favored by nitrate [15], whereas TON was directly related to sulfide contents that's why TON removal was also improved. However, nitrate removal declined with the increase of S/N ratio, possibly because of dilution of organic matter in the effluent of anoxic tank and the reduction of carbon inhibited heterotrophic denitrification reactions [16]. The findings are also supported by a previous study conducted by Yang et al. [2].

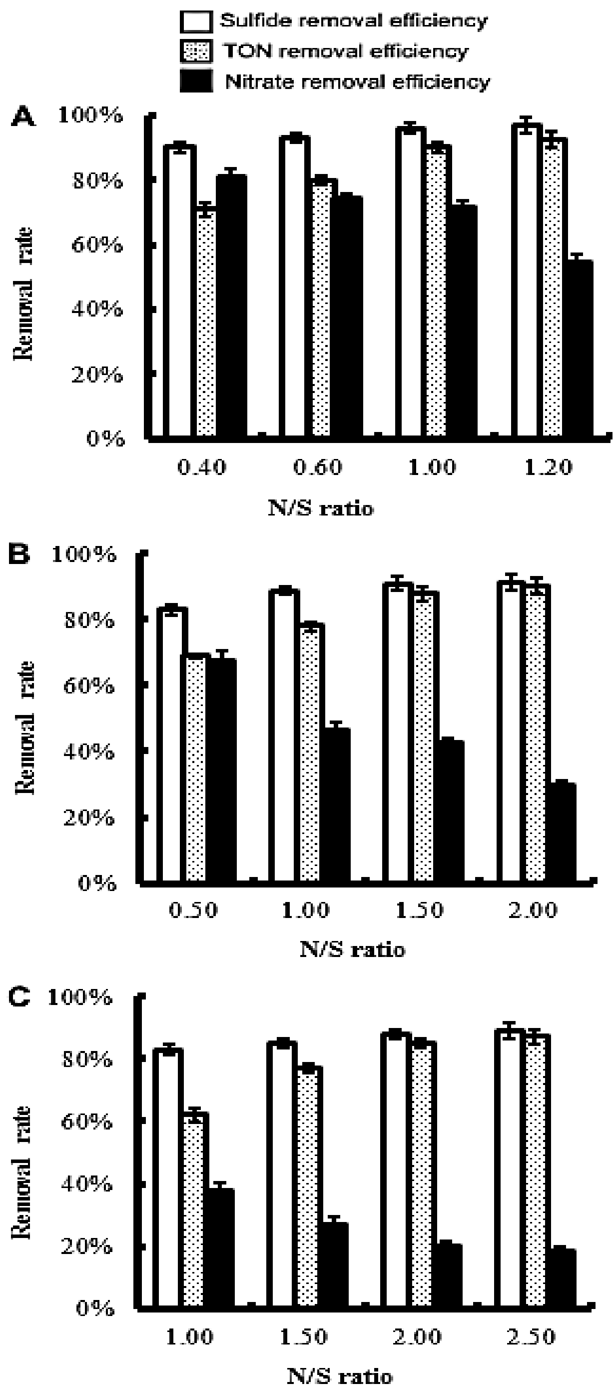

Fig. 2 Removal of sulfide, nitrate and threshold odor number (TON) at different N/S ratios during different study seasons. (A) Summer season; (B) autumn season; (C) winter season. Error bars indicate standard errors of three means.

Table 1 Statistical description of pollutant removal for anoxic digestion during A2O process.

Parameters		N/S	C/N	HRT
TON	Mean	0.808	0.838	0.864
	SE	0.002	0.003	0.003
	lower bound*	0.805	0.831	0.857
	upper bound*	0.812	0.845	0.87
S	Mean	0.895	0.897	0.894
	SE	0.002	0.003	0.002
	lower bound*	0.892	0.892	0.891
	upper bound*	0.899	0.903	0.898
N	Mean	0.473	0.452	0.519
	SE	0.002	0.003	0.003
	lower bound*	0.469	0.446	0.514
	upper bound*	0.477	0.459	0.525

TON = threshold odor number; S = sulfide; N = nitrate; C = carbon; N = nitrogen; SE = standard error; * = 95% confidence level; HRT = hydraulic retention time

Effect of different C/N ratios

Organic carbon present in the sludge is necessary food for microbes, and lower concentration of food decreases the reproduction and survival of microorganisms [17]. Moreover, low amount of microbes leads to a lower rate of nitrogen removal [18]. Domestic wastewater, especially residential water contains low amount of C/N ratio as compare to other nutrients such as nitrogen and phosphorus compounds [18]. The Fig. 3 shows the impact of the C/N ratio on TON, sulfide and nitrate removal. The influent C/N was 4.0 to 10.0, 2.0 to 6.5 and 2.0 to 8.0, whereas sulfide removal was 96% to 90%, 92% to 86% and 89% to 82%, TON removal was 92% to 71%, 91% to 75% and 87% to 77% and nitrate removal was 54% to 76%, 25% to 54% and 18% to 34% during the summer, spring and winter seasons, respectively.

The impact of C/N ratio was quite opposite to that of N/S ratio. In anoxic environment, heterotrophic and autotrophic bacteria coexist and interact with each other. Desulfurization bacteria are autotrophic whereas the heterotrophs are responsible for the organic carbon oxidation and denitrification. Fast growing organisms out compete with the slow growing organism for a common substance and space. Different C/N ratios create a competition environment between autotrophic and heterotrophic organism. As the C/N ratio increased, adequate organic carbon might be used as an electron donor for denitrification, whereas decreasing TON removal was the effect of sulfide contents [19].

Effect of HRT on removal rate

HRT is the average length of the time in which a unit volume of wastewater remains in anoxic tank. It is one of the important parameters that can affect the

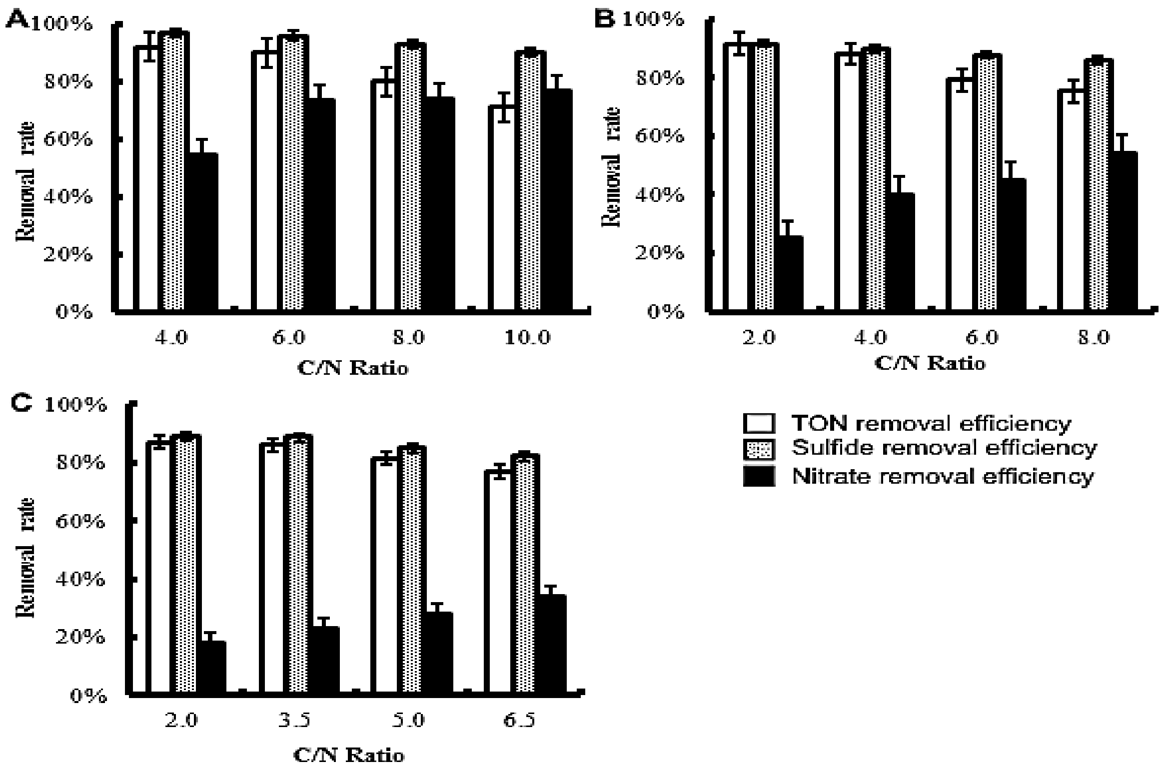

Fig. 3 Removal of sulfide, nitrate and threshold odor number (TON) at different C/N ratios during different study seasons, (A) Summer season; (B) autumn season; (C) winter season. Error bars indicate standard errors of three means.

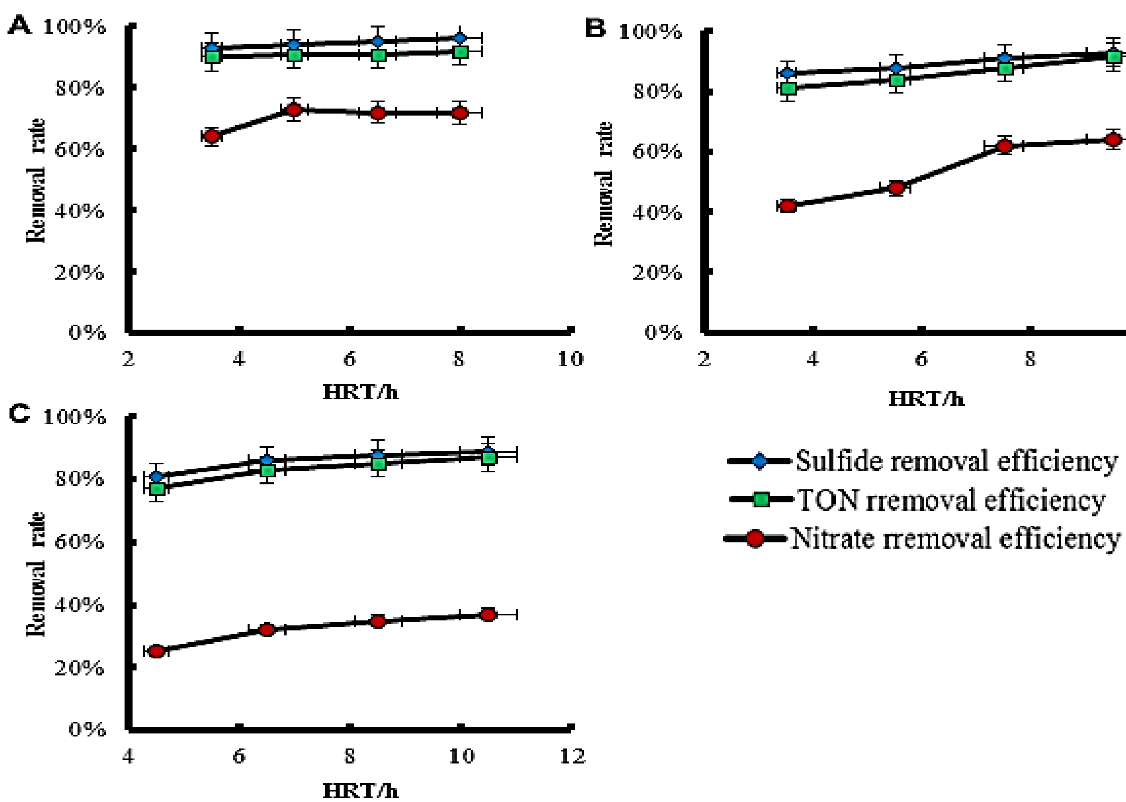

Fig. 4 Effect of HRTs on the removal of sulfide, nitrate and threshold odor number (TON) during different study seasons, (A) Summer season; (B) autumn season; (C) winter season. Error bars indicate standard errors of three means.

anoxic digestion. The Fig. 4 shows the HRT effect on sulfide, TON and nitrate removal. HRTs were adjusted at 3.5 h, 5.0 h, 6.5 h and 8.0 h for summer, at 3.5 h, 5.5 h, 7.5 h and 9.5 h for autumn and at 4.5 h, 6.5 h, 8.5 h and 10.5 h for winter. Overall, during the whole study period the removal rate for all three parameters was increased with the increase of HRTs, except summer season. When HRT was 5h, denitrification reached 73%, sulfide removal reached 94.6% and TON removal was 91.2%. However, when HRTs increased from 5h, no significant pollutant removal was occurred. At higher HRTs, the contact time between sewage and microbes was increased; thereby a significant level of pollutant removal occurred, whereas during summer prolonged HRT caused the poor mass transfer, subsequently no significant increase in removal rate occurred [20].

Conclusions

This study concluded that sulfide and TON removal efficiency was improved with the increase of the N/S ratio, whereas the denitrification rate was decreased during the whole study period. The C/N ratio negatively affected the sulfide and TON removal rates, whereas nitrate removal rate was increased. The prolonged HRTs significantly increased pollutant removal rate. Optimum S/N ratio, C/N ratio and HRTs were, 0.6, 6.0 and 5h for summer, 1.0, 4.0 and 7.5h for autumn, and 1.5, 3.5 and 8.5h for summer, respectively.

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