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Comparison of chloride effect between A^2O and SBR processes treating domestic wastewater

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ABSTRACT

The synthetic wastewater as influent containing different chloride concentrations (150, 500, 1,000, 1,500, 2,500, and 5,000 mg/L) was fed to sequencing batch reactor (SBR) and anaerobic/anoxic/oxic (A^2O) reactor to investigate the effect of influent chloride concentration on organics and nutrients removal. With the chloride concentration increasing from 150 to 5,000 mg/L, the chemical oxygen demand (COD) removal efficiency decreased linearly from 96.4 and 94.8% to 48.4 and 63.0% for SBR and A^2O process, respectively. No significant effect of influent chloride concentration on nitrification process was observed in A^2O reactor, while a sharp increase of effluent NH_3-N concentration to 2.4 mg/L was detected in SBR process when the influent chloride concentration increased to 5,000 mg/L. In terms of phosphorus removal, the removal efficiency for total phosphorus (TP) started to decrease when 1,500 mg/L chloride was fed into the influent for both processes. However, more severe effect was observed in A^2O reactor, without any phosphorus removal at 2,500 and 5,000 mg/L chloride concentrations. When the chloride concentration increased from 1,500 to 5,000 mg/L in SBR, the TP removal efficiency gradually decreased from 86.0 to 57.5%.

Keywords: Anaerobic/anoxic/oxic reactor; Biological nutrients removal; Chloride effect; Organics removal; Sequencing batch reactor; Wastewater treatment

1. Introduction

Due to seawater intrusion phenomenon in many coastal countries, high levels of soluble salts are often detected in daily water when the seawater back flows into the river water. For this reason, wastewater also contains high levels of salinity. Besides, more and more industries like seawater food industries and chemical industries also can generate saline wastewater [1]. It was reported that high salinity concentration, mainly presented as the form of chloride, has negative effects on organic matter, nitrogen, and phosphorus removal during the wastewater treatment [2]. Wastewater with high concentration of saline is often difficult to treat using biological wastewater treatment [3]. Previous research has reported that high concentration of chloride can cause plasmolysis and loss of cell activity, which has significant effect on the biological wastewater treatment [4–6]. Although biological treatment is influenced by high levels of salt, biological nutrient removal (BNR) systems proved efficient to use [7,8]. Among these BNR technologies, anaerobic/anoxic/oxic (A^2O) and sequencing batch reactor (SBR) processes are

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attracting many interests. The A^2O process is the most commonly used BNR process, utilizing a continuous flow pattern. It is a single-sludge suspended growth system incorporating anaerobic, anoxic, and aerobic stages in sequence [9]. The SBR process utilizes a semi-continuous flow and possesses such advantages as compact structure and cost-effectiveness, compared with other BNR processes [10].

Many researchers investigated the effect of chloride on each process. Ng et al. [11] investigated the effects of sodium chloride (NaCl) on the performance of SBRs using a microbial culture developed from a domestic sewage treatment plant. Panswad and Anan [12] reported that the performance of A^2O process was inhibited by the inoculation of chloride acclimated seeds when treating high chloride wastewater. However, very few studies have compared the performance of A^2O and SBR processes treating saline wastewater simultaneously, fed with the same seed culture and influent wastewater.

In this study, both A^2O and SBR processes were employed to treat saline wastewater at various chloride concentrations (150–5,000 mg/L), considering the maximum chloride concentration observed in wastewater during the seasonal salinity period in Macau SAR (Special Administrative Region), China, close to 5,000 mg/L, and the reactor performance was compared in terms of the chloride effect on biological organics and nutrients removal.

2. Materials and methods

2.1. Experimental setup

Schematics of SBR and A^2O reactor are shown in Fig. 1. Both reactors were composed of acrylic plastic with a working volume of 15 L. Air compressors were used for aeration and mechanical stirrers were used to provide liquid mixing. Dissolved oxygen (DO) concentration was maintained at 3–4 mg/L and below 0.1 mg/L in aerobic and anaerobic/anoxic tanks, respectively, and the pH ranged from 6.5 to 7.5 for both processes.

Using the SBR, 26 L of wastewater was treated each day. At the start of each cycle, wastewater was fed to the SBR, such that the volumetric exchange ratio in the reactor was 43%. Approximately, 1,000 mL of activated sludge was wasted daily to maintain the solids retention time (SRT) at 15 days. The stirring rate was constant at 40 rpm during fill and react steps. The concentration of mixed liquor suspended solids (MLSS) was 2,875 ± 234 mg/L for the SBR.

Same as for the SBR, about 1,000 mL of activated sludge was wasted per day in the A^2O reactor to maintain the SRT at 15 days. The MLSS concentration in the A^2O reactor was 2,785 ± 135 mg/L, similar to the SBR. The total hydraulic retention time (HRT) for the A^2O process was 12 h, with anaerobic, anoxic, and oxic phases operated at 2.4, 3.6, and 6 h HRT, respectively. All the experiments were conducted at ambient temperature (22–25℃). Both reactors were operated for 30 days to evaluate the effect of influent chloride concentration on the reactor performance.

2.2. Synthetic wastewater

The composition of synthetic wastewater was as follows (in mg/L): glucose, 375 (400 as COD); NH_4Cl, 119 (31 as N); KH_2PO_4, 22 (5 as P); $NaHCO_3$, 110; $CaCl_2$, 2.8; $MgCl_2{\cdot}6H_2O$, 40.8; and 0.5 mL/L of a trace mineral solution. The trace mineral solution consisted of (in mg/L): $CuSO_4{\cdot}5H_2O$, 0.02; $MnSO_4{\cdot}H_2O$, 0.06; $ZnSO_4{\cdot}7H_2O$, 0.09; and $FeCl_3{\cdot}6H_2O$, 0.97 [13]. For the effect of chloride, different concentrations of NaCl was added to the synthetic wastewater, at 86, 662, 1,486, 2,310, 3,958, and 8,078 mg/L, corresponding to the chloride concentrations of 150, 500, 1,000, 1,500, 2,500, and 5,000 mg/L.

The seeding activated sludge for both processes was obtained from the aeration tank at the regional wastewater treatment plant that employs the SBR-based UniTANK system. The sludge was acclimated in both reactors for three months before the experiments started.

2.3. Analytical methods

Suspended solids (SS) and volatile suspended solids were measured following the Standard Methods [14]. The concentrations of COD, total nitrogen (TN), total phosphorus (TP), and ammonia/nitrogen were measured by the HACH method using spectrophotometer (HACH DR/2800, Hach Company, Loveland, Colorado). The concentrations of NO_2^--N NO_3^--N, and PO_4^{3-}-P were measured by ion chromatography (Dionex ICS 2500). The DO concentration was measured using a DO meter (HACH HQ20), and pH was measured using a pH meter (HACH ONE Laboratory pH Meter).

3. Results and discussion

3.1. Effect of chloride on SBR process

Chloride or salinity significantly affected organics and nutrients removal in the SBR, resulting in the effluent COD concentration increased with the increase in chloride concentration. As shown in Fig. 2,

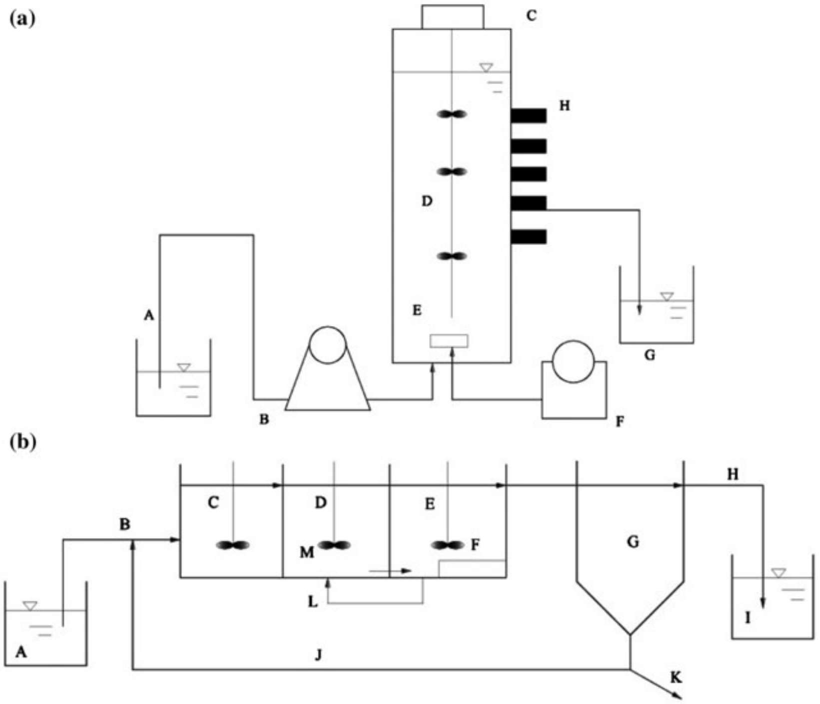

Fig. 1. Schematic diagram of (a) SBR (A. influent tank; B. pump; C. agitator; D. blade; E. air diffuser; F. aerator; G. effluent tank; H. sampling ports); and (b) A^2O reactor (A. influent tank; B. influent; C. anaerobic tank; D. anoxic tank; E. aerobic tank; F. air diffuser; G. clarifier; H. effluent; I. effluent tank; J. recycled activated sludge; K. wasted activated sludge; L. internal recycle; M. mixer).

the COD removal efficiency decreased linearly from 96.4 to 48.4% with the increase in chloride concentration from 95 to 5,000 mg/L. It was reported that the high levels of salt content could produce the high osmotic pressure on bacterial cells, causing plasmolysis, dehydration, and disintegration of bacterial cell and loss of cell activity, thereby resulting in low organic removal efficiencies [11]. Plasmolysis could also cause the release of non-dissolved cellular components, leading to the increase in effluent SS (also refer to Table 1).

Nitrogen removal was not negatively affected until the chloride concentration increased up to 5,000 mg/L. Effluent NH_3-N and TN concentrations increased sharply to 2.4 and 4.3 mg/L, respectively, with the chloride concentration at 5,000 mg/L. However, the obvious accumulation of nitrite and nitrate in the effluent was not observed throughout the experiments, mainly due to nitrifiers more sensitive to chloride/salinity than denitrifiers. The effects were less severe for TN than for COD, implying that the autotrophic nitrifiers could adapt to a high ionic strength environment better than the heterotrophs. In addition, the denitrifiers possessed a better salt tolerance capability than the nitrifiers.

Phosphorus removal, on the other hand, was not affected until the chloride concentration increased to 1,500 mg/L. The TP removal efficiency almost dropped linearly from 84.6 to 52.5% with the increase in chloride concentration from 1,000 to 5,000 mg/L (Table 1). The phosphorus release process was very sensitive to the high chloride/salinity concentration. The PO_4^{3-}-P concentration at the end of anaerobic phase was only 4.1 mg/L in the mixed liquor when 5,000 mg/L of chloride was introduced into the influent wastewater, while it was 8.9 mg/L when no NaCl was added. The insufficient phosphorus release subsequently led to the low phosphorus removal under the high salinity situation.

3.2. *Effect of chloride on A^2O process*

As shown in Table 2, the performance of A^2O process at different influent chloride concentrations was similar to the SBR process, showing the adverse effect of high chloride concentrations on COD removal. The effluent COD concentration increased from 19 to 159 mg/L when the chloride concentration increased from 150 to 5,000 mg/L. However, the nitrification process was not obviously affected with the chloride

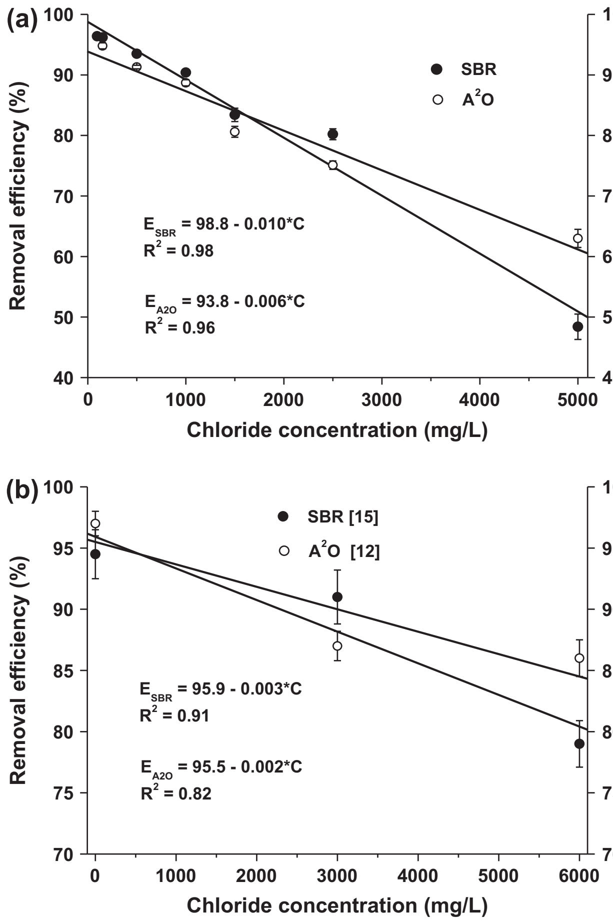

Fig. 2. Effect of chloride concentrations on COD removal efficiencies in SBR and A^{2}O processes; (a) current study and (b) other studies.

concentration up to 5,000 mg/L. The effluent NH_3-N concentration lower than 1 mg/L was always achieved throughout the experiments. The phosphorus removal process was also negatively affected by high chloride concentrations. An increase in effluent TP concentration was observed after 1,500 mg/L or higher chloride was introduced into the influent wastewater. When the influent chloride concentration was increased to or higher than 2,500 mg/L, the effluent TP concentrations were even same as the influent. The effluent SS values increased from 14 to 24 mg/L with the increase of chloride concentration from 150 to 5,000 mg/L.

3.3. Comparison of chloride effect between SBR and A^{2}O processes

For the organics removal, the adverse effects on COD removal were observed in both processes (Fig. 2). Data presented in Fig. 2 were correlated with a linear equation in the following form:

$$\text{SBR process}: E_{\text{SBR}} = 98.8 - 0.010 \times C,\ R^2 = 0.98$$

$$\text{A}^2\text{O process}: E_{\text{A}^2\text{O}} = 93.8 - 0.006 \times C,\ R^2 = 0.96$$

where E is the percentage of COD removal and C is the chloride concentration in mg/L. When the chloride concentration was ≤ 2,500 mg/L, the COD removal efficiencies for SBR process were higher than those for A^{2}O process. However, A^{2}O process showed higher percentage of COD removal than SBR process when the chloride concentration increased to 5,000 mg/L. This would imply that the heterotrophic bacteria responsible for COD removal in SBR might have obtained a better salt tolerance capability than those in A^{2}O reactor at chloride concentrations up to 2,500 mg/L, while it was the opposite when the chloride concentration further increased to 5,000 mg/L. Similar trends were also found [12,15], as shown in Fig. 2(b). Better COD removal was achieved in SBR process when the chloride concentration was 3,000 mg/L, while A^{2}O process showed higher percentage of COD removal when the chloride concentration increased to 6,000 mg/L.

Table 1
Performance of SBR process at different chloride concentrations

Parameters		COD	NH_3-N	TN	TP	SS
Influent (mg/L)		384 ± 5	27.8 ± 1.4	30.6 ± 0.4	5.1 ± 0.2	N.A.
Effluent (mg/L)	150	15 ± 2	0.05 ± 0.01	2.5 ± 0.2	0.8 ± 0.0	5 ± 1
	500	25 ± 1	0.08 ± 0.03	2.5 ± 0.2	0.8 ± 0.1	7 ± 1
	1,000	37 ± 1	0.10 ± 0.05	2.4 ± 0.1	0.8 ± 0.0	14 ± 2
	1,500	64 ± 5	0.13 ± 0.03	2.5 ± 0.2	0.9 ± 0.0	20 ± 1
	2,500	76 ± 4	0.10 ± 0.05	2.4 ± 0.2	1.6 ± 0.1	24 ± 2
	5,000	198 ± 6	2.38 ± 0.16	4.3 ± 0.3	2.4 ± 0.1	32 ± 2

Note: N.A.: Not applicable.

Table 2
Performance of A^2O process at different chloride concentrations

Parameters		COD	NH_3-N	TN	TP	SS
Influent (mg/L)		356 ± 18	27.5 ± 0.9	29.7 ± 0.3	5.0 ± 0.2	N.A.
Effluent (mg/L)	150	19 ± 12	0.6 ± 0.1	2.7 ± 0.2	0.7 ± 0.2	14 ± 6
	500	30 ± 2	0.4 ± 0.1	3.5 ± 0.2	0.7 ± 0.1	12 ± 0
	1,000	39 ± 4	0.3 ± 0.2	3.9 ± 0.1	0.7 ± 0.1	15 ± 2
	1,500	69 ± 8	0.9 ± 0.4	3.4 ± 0.2	1.2 ± 0.1	20 ± 0
	2,500	96 ± 2	0.6 ± 0.1	2.8 ± 0.2	4.9 ± 0.1	24 ± 0
	5,000	159 ± 9	0.6 ± 0.4	3.3 ± 0.3	4.9 ± 0.0	24 ± 0

Note: N.A.: Not applicable.

The effects of chloride on nitrogen removal in SBR and A^2O processes were a little different (Fig. 3). Relatively lower effluent concentration of ammonia was achieved in SBR when the chloride concentrations were ≤ 2,500 mg/L. In comparison, when 5,000 mg/L chloride was introduced into the influent wastewater, a sharp increase in effluent ammonia concentration was observed in SBR, while the nitrification process in A^2O reactor was not obviously affected, implying nitrifiers in A^2O process obtained a better tolerance capacity against high salinity. This phenomenon may be due to different nitrifiers present in two reactors. The effluent nitrate concentration for both reactors did not change much throughout the experiments, indicating that denitrifiers were more tolerant to high salinity. This observation also agrees with the result from Panswad and Anan [12], which indicated that the impact of the chloride shock on nitrifiers was more obvious than on denitrifiers.

The adverse effects of high chloride/salinity on phosphorus removal were observed in both processes. As shown in Fig. 4, as high as 90% of PO_4^{3-}-P was removed when the chloride concentration was ≤1,000 mg/L. However, a sharp decrease in phosphorus removal in A^2O process was observed when the chloride concentration further increased. The phosphorus removal even totally failed when 2,500 or 5,000 mg/L chloride was introduced into the influent wastewater. The adverse effects of high salinity on phosphorus removal were not that severe in SBR as in A^2O reactor. The phosphorus removal efficiency decreased almost linearly from 86.0 to 57.5% when the chloride concentration increased from 1,500 to 5,000 mg/L. Therefore, the phosphate accumulating organisms seemed to possess a better tolerance capacity to high chloride concentrations in SBR. This might have been caused by the presence of different microorganisms for phosphorus removal in two reactors. For the high chloride level, the excess phosphorus uptake would subsequently be negatively affected, resulting in poor phosphorus removal. This observation also agrees with the result from Uygur and Kargi [15], which

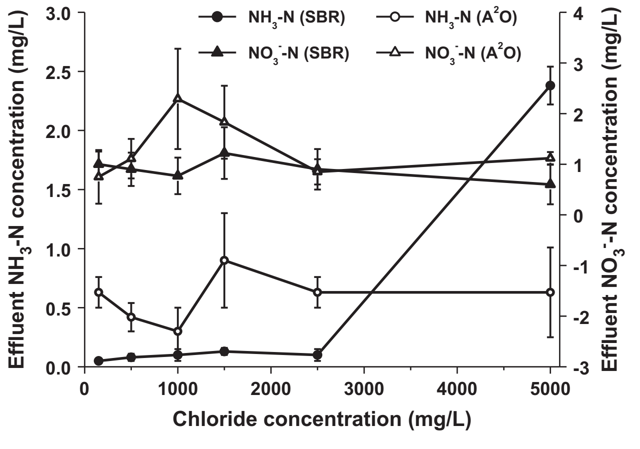

Fig. 3. Variation of effluent NH_3-N and NO_3^--N concentrations at different chloride concentrations in SBR and A^2O processes.

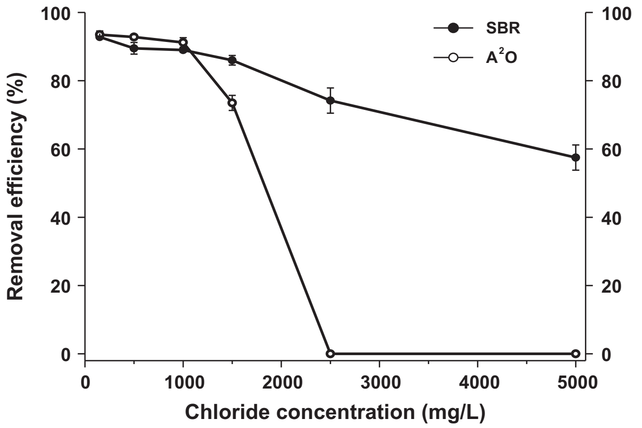

Fig. 4. Variation of PO_4^{3-}-P removal efficiencies at different chloride concentrations in SBR and A^2O processes.

reported that the percentage of PO_4^{3-}-P removal decreased from 96 to 47% when the chloride concentration increased from 0 to 6,000 mg/L.

4. Conclusion

Different concentrations of chloride (150, 500, 1,000, 1,500, 2,500, and 5,000 mg/L) were introduced into the influent for SBR and A^2O reactor to investigate the effect of influent chloride concentration on both organics and nutrients removal. When the chloride concentration increased from 95 to 5,000 mg/L, the COD removal efficiency decreased linearly from 96.4 and 94.8 to 48.4 and 63.0% for SBR and A^2O reactor, respectively. The obvious effect of influent chloride concentrations on nitrification process was not observed in A^2O reactor, while a sharp increase in effluent NH_3-N concentration to 2.4 mg/L was detected in SBR process when the influent chloride concentration increased to 5,000 mg/L. However, the denitrification process was not significantly affected for both processes throughout, with the effluent NO_3^--N concentration at 0.6–1.2 and 0.8–2.2 mg/L for SBR and A^2O reactor, respectively. For the phosphorus removal, the effluent TP concentration started to increase when 1,500 mg/L chloride was fed into the influent for both processes. However, more severe effect was observed in A^2O reactor, without any phosphorus removal at 2,500 and 5,000 mg/L chloride. When the chloride concentration increased from 1,500 to 5,000 mg/L, the TP removal efficiency gradually decreased from 86.0 to 57.5% in SBR.

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