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Combined treatment of landfill leachate with fecal supernatant in sequencing batch reactor*

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Abstract: A laboratory-scale sequencing batch reactor (SBR) is used to treat landfill leachate containing high concentration of ammonium nitrogen with municipal fecal supernatant. The SBR system is operated in the following sequential phases: fill period, anoxic period, aeration period, settling period, decant and idle period. The results indicated that the average removal efficiencies of COD, BOD_5, TN, NH_4^+-N were 93.76%, 98.28%, 84.74% and 99.21%, respectively. The average sludge removal loading rates of COD, BOD_5, TN and NH_4^+-N were 0.24 kg/(kg SS·d), 0.08 kg/(kg SS·d), 0.04 kg/(kg SS·d) and 0.036 kg/(kg SS·d), respectively. Highly effective simultaneous nitrification and denitrification was achieved in the SBR system. The ratio of nitrification and denitrification was 99% and 84%, respectively. There was partial NO_2^- denitrification in the system.

Key words: Sequencing batch reactor (SBR), Leachate, Fecal supernatant, Simultaneous nitrification, Denitrification
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INTRODUCTION

Biological nitrification and denitrification is one of the most feasible, effective and economical methods for removing nitrogen from municipal and industrial discharge (Azevedo *et al.*, 1995). Nitrification is the autotrophic oxidation of ammonium (NH_4^+-N), first to nitrite (NO_2^--N), and then to nitrate (NO_3^--N), while denitrification is the heterotrophic, anoxic conversion of nitrate, first to nitrite, and then to gaseous nitrogen compounds (US EPA, 1993). The biological denitrification of nitrate to nitrogen gas needs a lot of organic carbon as electron donors. The equation of denitrification was derived on the basis of McCarty's half reactions theory, and the electronic stoichiometry (Zhou, 2001; 2003). The amount of chemical oxygen demand (COD) required by denitrification of nitrate to nitrogen gas ranged from 2.86 to 16.0 g COD/g NO_3^--N (Zhou, 2001). Therefore, it is difficult for denitrifying bacteria to remove nitrate in wastewater with low COD/NH_4^+-N ratio. For example, ammonium concentration in aged landfill leachate may remain high for years (Stegmann and Ehrig, 1980; Andreottola and Cannas, 1992), and the COD/NH_4^+-N ratio may remain much lower than that from young landfills. Because there was not sufficient COD to support denitrification of nitrate, a supplementary source of organic carbon was required to ensure adequate denitrification. Synthetic chemicals, such as methanol or acetic acid, are effective but quite expensive. It is necessary to find an alternative cost effective source of easily biodegradable carbon.

The use of wastewater as an electron donor for denitrification in a sequencing batch reactor (SBR) was suggested (Pallis and Irvine, 1985). This approach has recently gained popularity, especially the use of domestic wastewater with the organic fraction of municipal solid waste (OFMSW) as a carbon

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source (Beccari *et al*., 1998). However, little research has been done on combined treatment of landfill leachate and fecal supernatant. Combined treatment of landfill leachate and fecal supernatant has many advantages (including organic carbon for denitrification supplied) such as economy, and better control of the influent characteristics, because leachate pollution loads and flow rates have, in general, great variations in time (Hartmann and Hoffmann, 1990).

SBR processes have been extensively applied for treating municipal (Irvine *et al*., 1983) and hazardous wastes (Herzbrum *et al*., 1985) including the biological treatment of landfill leachate (Manoharan *et al*., 1992), SBR has many positive processing characteristics. For example, combining the reactor and the setting tank in the same vessel easily controls performance with respect to reaction time and sludge solids maintenance and also allows flexibility of operation when carrying out different biochemical conversion reactions simultaneously.

This study was aimed at investigating the feasibility of nitrogen removal from ammonia-rich leachate with fecal supernatant by using an SBR system.

MATERIALS AND METHODS

Experimental unit

A schematic diagram of the experimental apparatus is shown in Fig.1. The SBR bioreactor is a plexiglas rectangular (400 mm×400 mm×400 mm) enclosure with working volume of 50 L.

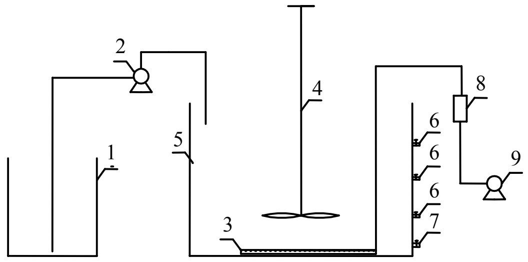


Fig.1 Schematic diagram of the experimental apparatus
1: Feed tank; 2: Electromagnetic metering pump; 3: Aerator; 4: Agitator; 5: SBR bioreactor; 6: Sample port; 7: Mud valve; 8: Gas flow meter; 9: Aicr blast

Analytical methods

Samples were collected once each day. The chemical oxygen demand (COD), biological oxygen demand (BOD_5), total nitrogen (TN), nitrite (NO_2^--N), nitrate (NO_3^--N), and alkalinity were measured according to standard methods (APHA *et al*., 1998). The temperature and dissolved oxygen (DO) were measured with a DO instrument (model: YSI-55, YSI Company, USA). The pH value was measured with a pH meter (model: pHS-25, Jingke Company, China).

Substrate composition

The leachate used in the test was collected from a landfill in Guangdong Province (China), which receives some 450 t/d of municipal solid wastes. The landfill has run for about 7 years. In the recent 6 months, much more meat has been sent to the landfill. Leachate was collected and stored in a regulating reservoir. Raw fecal supernatant taken from the city's influent manure pits was clarified and stored in a septic tank. Leachate and fecal supernatant were mixed in a dosing tank of the landfill SBR system. The influent to the laboratory-scale SBR system was taken from the dosing tank. The characteristics of the leachate, the fecal supernatant and the mixture (influent to the SBR) were summarized in Table 1.

SBR system operational conditions

The SBR system was operated in 24 h batch cycles. Mixed wastewater was fed to the feed tank, and then pumped to the reactor by a metering pump. The pH value was kept at 7.88 to 8.19. Air was supplied to the SBR system through the aerator at the bottom of the reactor. At the beginning of the fill period, 12 L of the mixture in the feed tank was pumped to the system.

The reactor was operated on a cyclic basis: fill period (2 h), anoxic period (2 h), aeration period (18 h), settling period (1 h), decant and idle period (1 h). During the fill and anoxic phases, mechanical mixture was provided by agitation to maintain homogenization. At the end of the aeration period, the agitator was closed and the sludge was allowed to settle. At the end of the settling period, 12 L of the clear supernatant liquid was withdrawn from the reactor from the sample ports. In the aeration period, DO was controlled.

The full-scale SBR system in the landfill site is 1500 m^3. The laboratory-scale SBR system (50 L) was operated at an almost constant temperature of 28

°C seeded with the same activated sludge from the full-scale SBR system with similar influent leachate, which is mixed with some fecal supernatant. Mixed liquid suspended solids (MLSS) were kept to be around 4800 mg/L. SRT (sludge retention time) was kept to about 25 d.

RESULTS AND DISCUSSION

Removal of COD and BOD_5

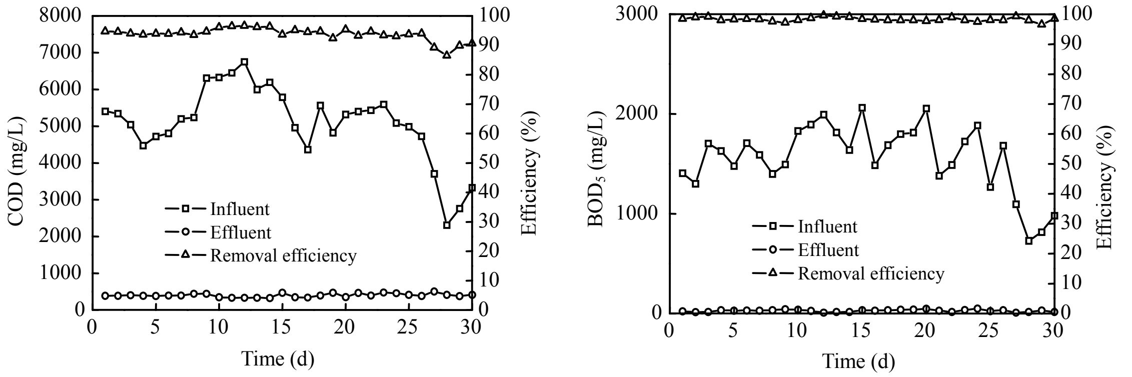
The removal of COD and BOD_5 is shown in Fig.2. High removal efficiencies of COD and BOD_5 have been achieved in the SBR system. The average removal efficiencies of COD and BOD_5 were 93.76% and 98.28%, respectively. The average sludge removal loading rates of COD and BOD_5 were 238.99 g/(kg SS·d) and 76.70 g/(kg SS·d), respectively. BOD_5 in effluent could meet the effluent standard of leachate quality in China. COD in effluent was around 300 mg/L, since the leachate from the aged landfill contained much non-biodegradable COD. Other non-biodegradable organic matter could be removed by applying physicochemical techniques (Diamadopoulos, 1994).

Removal of nitrogen

The variations of NH_4^+-N, NO_3^--N, NO_2^--N and TN are illustrated in Fig.3. High removal efficiencies of NH_4^+-N and TN have been achieved in the SBR system. The average removal efficiencies of NH_4^+-N and TN were 99.21% and 84.74%, respectively. The average sludge removal loading rates of NH_4^+-N and TN were 36.13 g/(kg SS·d) and 39.43 g/(kg SS·d), respectively. The SBR system had visibly rich bacteria including heterotroph and autotroph bacteria in sludge granules, which lead to assimilation and simultaneous nitrification and denitrification. The lost nitrogen had been transformed into gaseous nitrogen compounds escaping from the reactor by

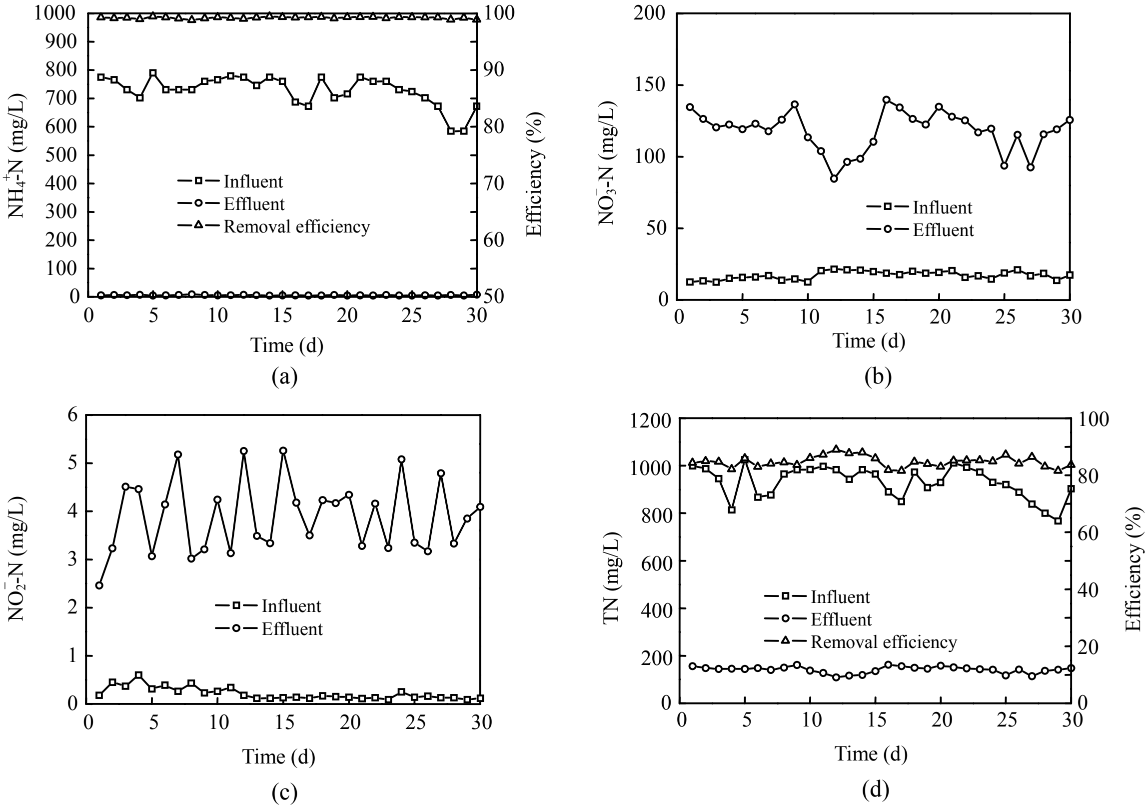
Table 1 Characteristics of landfill leachate, fecal supernatant and influent to the reactor (mg/L)

Parameters	Leachate	Fecal supernatant	Influent	
			Mean	Range
BOD_5	100~1600	800~3800	1560.33	728~2062
COD	1350~6500	2500~8500	5077.00	2305~6747
NH_4^+-N	505~1200	320~709	727.82	584.7~790
NO_3^--N	4~20	2~23	17.14	12.36~21.54
NO_2^--N	0.01~1	0.02~1.2	0.21	0.09~0.60
TN	410~1300	540~1180	929.75	767.5~1024.96
Alkalinity	4000~7000	2500~7500	5485.17	4590~6054



(a) (b)

Fig.2 Removal (a) COD and (b) BOD_5 in the SBR system



(a) (b) (c) (d)

Fig.3 Variations of (a) NH_4^+-N, (b) NO_3^--N, (c) NO_2^--N, and (d) TN in the SBR system

denitrification. It was found that DO concentration of around 0.5 mg/L was suitable for achieving nitrification rate equal to the denitrification rate that would therefore lead to complete simultaneous nitrification and denitrification (SND) (Münch *et al*., 1996). But NO_3^--N and NO_2^--N in effluent were still high because there was insufficient bio-degradable COD in the SBR system to support complete denitrification.

Denitrification via nitrite needs less organic matter than denitrification via nitrate, as Eq.(1) and Eq.(2) show (Zhou, 2001; 2003):

$$\mathrm{COD}/\mathrm{NO_3^-\text{-}N} = 2.86/(1-1.628Y), \qquad (1)$$

$$\mathrm{COD}/\mathrm{NO_2^-\text{-}N} = 1.714/(1-1.628Y), \qquad (2)$$

where Y represents the yield of denitrification microorganisms.

The required COD for complete denitrification via nitrate is about 40% more than that via nitrite. As shown in Fig.4, the practical BOD$_5$/TN ratio in this study changes from 1.52 to 3.68, the average value of BOD$_5$/TN was 2.79, and not enough to support SND via nitrate, it is better to achieve partial denitrification via nitrite in the same system.

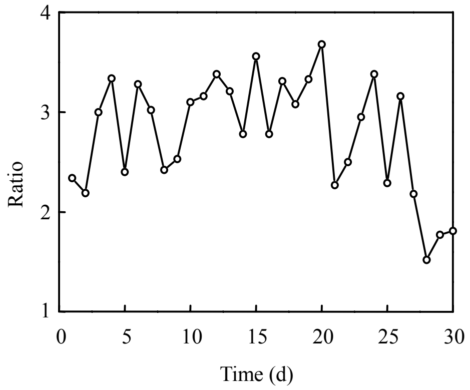


Fig.4 Ratio of BOD$_5$/TN

As shown in Figs.3 and 4, the results showed that high removal efficiency of simultaneous nitrification and denitrification had been achieved. The ratio of nitrification and denitrification in the SBR system are estimated to be 99% and 84%, respectively.

Change of alkalinity in the SBR system

As shown in Fig.5, the average concentrations of alkalinity in influent and effluent were 5485.17 mg/L and 602.73 mg/L, respectively. The effluent alkalinity keeping in quasi-steady state implies that there is stable simultaneous nitrification and denitrification in the system.

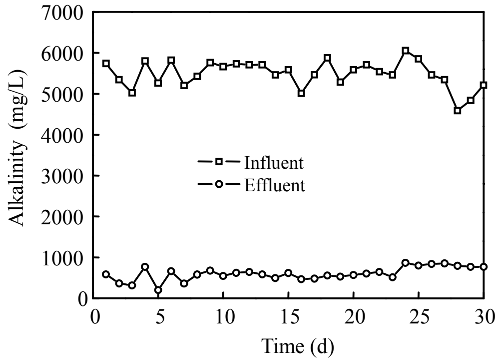


Fig.5 Variation of alkalinity in the SBR system

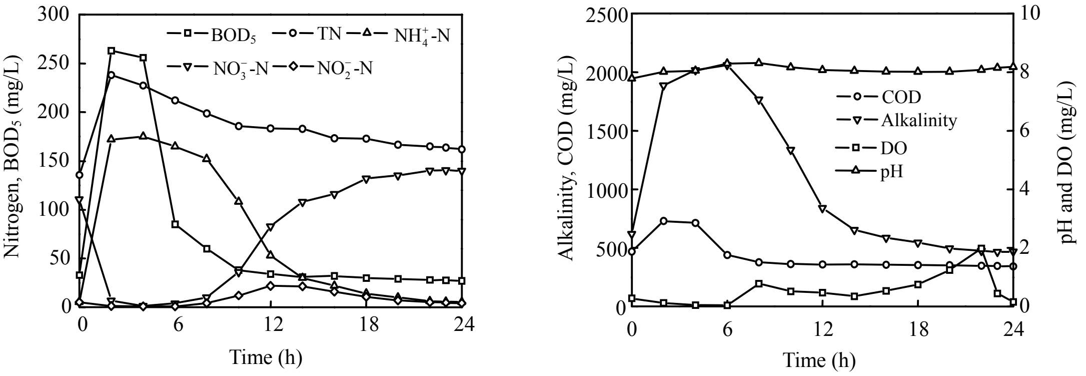
Cyclic study

Track analysis data corresponding to COD, BOD5, nitrogen, DO, pH and alkalinity profile during different phases are shown in Fig.6.

It was shown that the initial concentrations of BOD5, TN, NH_4^+-N, NO_3^--N, NO_2^--N and alkalinity in the reactor were much lower than those of the influent because of the dilution of influent wastewater with the remaining suspension in the system. During the 2 h fill period, the COD, BOD5, TN, NH_4^+-N, NO_3^--N, NO_2^--N and alkalinity increased from 468 mg/L, 33 mg/L, 135.64 mg/L, 5.13 mg/L, 110.45 mg/L, 5.26 mg/L and 619 mg/L to 729.70 mg/L, 263 mg/L, 238 mg/L, 172 mg/L, 6.80 mg/L, 1.34 mg/L and 1886 mg/L, respectively, corresponding to their calculated values of 1546.08 mg/L, 381.45 mg/L, 316.64 mg/L, 168.78 mg/L, 88.43 mg/L, 4.03 mg/L and 1672.84 mg/L due to dilution only. The increased substrate removal during the fill period may account for the physicochemical adsorption of organics on the surface of micro-organism particles or to an intracellular bacteria storage mechanism, assimilation in the biomass and denitrification (Abufayed and Schroeder, 1986; Alleman and Irvine, 1979). Almost complete denitrification occurred during the fill period with the concentrations of NO_3^--N and NO_2^--N decreasing from 110.45 mg/L and 5.26 mg/L to 6.80 mg/L and 1.34 mg/L, respectively. The denitrification efficiency was about 92%.

As shown in Fig.6, subsequent oxidation of organic carbon during the aeration phase results in BOD5 and COD decreasing greatly. In this phase, NH_4^+-N removal is attributed primarily to nitrification, corresponding to an NH_3 loss via air stripping in the reactor considered to be negligible as the pH was around 8. The end product of nitrification process is NO_3^--N with an effluent concentration of 140 mg/L, together with an NO_2^--N concentration of 5.2 mg/L.

Moreover, in Fig.6b, DO concentration decreases rapidly to a low value during the fill and anoxic period, following the introduction of the anaerobic



(a) (b)

Fig.6 Variations of (a) nitrogen, BOD5 and (b) COD, alkalinity, DO and pH during a typical cycle in the SBR system

influent. The DO concentration begins to increase after the oxidation of organic matter and before a great deal of NH_4^+-N is oxidized. The DO concentration increasing at the end of the process implies the end of the nitrification process.

Furthermore, in Fig.6b, the pH value increased in the fill, anoxic and the prophase of aeration period due to denitrification and organic-matter oxidation. pH value decreases because of NH_4^+-N nitrification. The pH value increases again at the end of the aeration period because of CO_2 loss or denitrification. The actual reason needs to be further investigated. Denitrification appears in the fill and anoxic period and alkalinity increases. After nitrification, the alkalinity decreases greatly.

Effluent BOD_5, COD, NH_4^+-N and TN were 27 mg/L, 344 mg/L, 5.25 mg/L and 161.86 mg/L, respectively. The sludge removal loading rates of BOD_5, COD, NH_4^+-N and TN of 73.85 g/(kg SS·d), 250.43 g/(kg SS·d), 34.07 g/(kg SS·d) and 32.25 g/(kg SS·d), respectively, are achieved during the typical operation period. In addition, it was shown that the anoxic phase does not obviously increase removal efficiencies of COD, BOD_5 and nitrogen as the fill phase could be an effective anoxic phase providing high removal efficiencies when effluent nitrate nitrogen is still high. An external fecal supernatant should be supplied in the anaphase of the aeration period. Further research should to be carried out to determine whether or not the removal effect of the SBR could be improved.

Removal effect of the full-scale SBR

Improved removal efficiency of TN has been achieved in the full-scale SBR system after optimal technological process has been adopted based on the results of laboratory-scale SBR system. TN removal and effluent NO_3^--N concentrations in the full-scale SBR system with or without addition of fecal supernatant to the landfill leachate are compared in Figs.7 and 8. Although COD, BOD_5, NH_4^+-N and NO_2^--N concentrations of the effluent varied little in the above-mentioned two cases, the effluent NO_3^--N decreased greatly after the leachate was treated with fecal supernatant. The average TN concentrations in influent leachate with or without fecal supernatant were 893 mg/L and 972 mg/L, respectively, the average TN removal efficiencies were 79.67% and 16.30%, respectively.

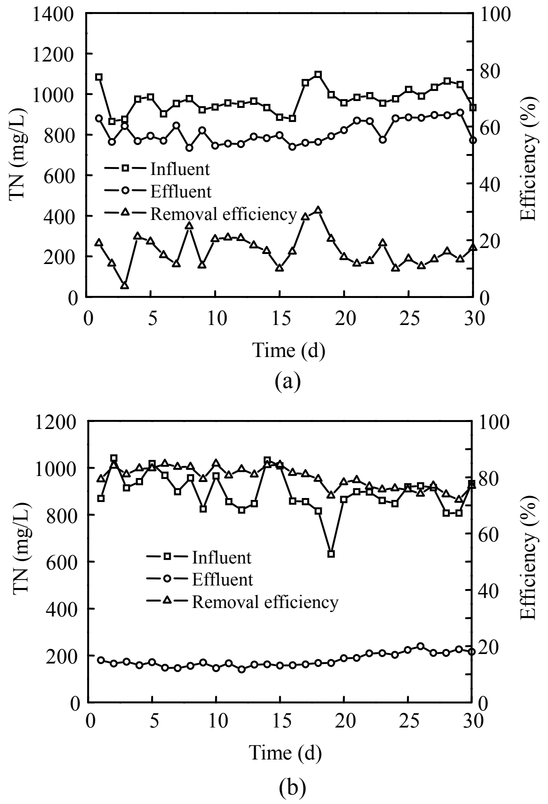


Fig.7 TN removal efficiency after treating leachate (a) without fecal supernatant or (b) with fecal supernatant in the full-scale SBR system

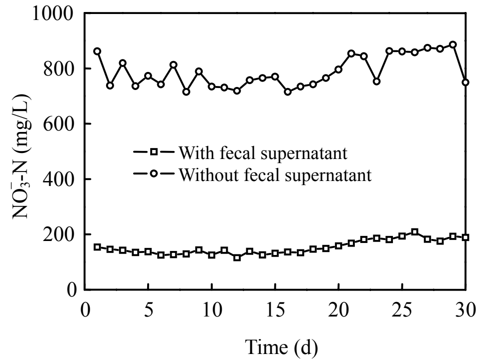


Fig.8 Effluent NO_3^--N concentrations in the full-scale SBR system

CONCLUSION

Mixed wastewater of aged landfill leachate with fecal supernatant was successfully treated in a sequencing batch reactor system. The addition of fecal supernatant successfully increased the COD/NH_4^+-N ratio of landfill leachate.

The average removal efficiencies of COD, BOD_5, TN, NH_4^+-N were 93.76%, 98.28%, 84.74% and 99.21%, respectively. And the average sludge removal loading rates of COD, BOD_5, TN and NH_4^+-N were 238.99 g/(kg SS·d), 76.70 g/(kg SS·d), 39.43 g/(kg SS·d) and 36.13 g/(kg SS·d), respectively. The effluent COD was still close to 300 mg/L because the leachate from the aged landfill had much non-biodegradable COD.

Highly effective simultaneous nitrification and denitrification was achieved in the SBR system. The ratio of nitrification was 99%, the ratio of denitrification was 84%. There was partial nitrogen removal via nitrite.

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