Treatment of strong nitrogen swine wastewater in a full-scale sequencing batch reactor

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Abstract Treatment of swine wastewater containing strong nitrogen was attempted in a full-scale SBR. The strongest swine wastewater was discharged from a slurry-type barn and called swine-slurry wastewater (SSW). Slightly weaker wastewater was produced from a scraper-type barn and called swine-urine wastewater (SUW). TCOD, NH_4^+-N and TSS in raw SSW were 23,000–72,000 mg/L, 3,500–6,000 mg/L and 17,000–50,000 mg/L, respectively. A whole cycle of SBR consists of 4 sub-cycles with anoxic period of 1 hr and aerobic period of 3 hr. The maximum loading rates of both digested-SSW and SUW were similar to 0.22 kg NH_4^+-N/m^3/day whereas the maximum loading rates of raw SSW was up to 0.35 TN/m^3/day on keeping the effluent quality of 60 TN mg/l. The VFAs portion of SCOD in raw SSW was about more than 60%. The VFAs in SUW and digested-SSW were about 22% and 15%, respectively. NH_4^+-N and PO_4^{3-}-P in SSW were removed efficiently compared to those in digested-SSW and DUW because SSW had high a C/N ratio and readily biodegradable organic. High concentration of organic was useful to enhance denitrification and P uptake. Also the amount of external carbon for denitrification was reduced to 5% and 10% of those for digested-SSW and SUW.

Keywords Biological nutrient removal; full-scale SBR; swine wastewater; slurry-type wastewater

Introduction

Swine wastewater has very strong organic, nutrients, fiber and minerals compared to domestic sewage. For instance, the ranges of TCOD, SCOD, NH_4^+-N and PO_4^{3-}-P in the swine wastewater from Kimhae City, Korea were 23,000–72,000 mg/l, 15,000–60,000 mg/l, 3,500–6,000 mg/l and 40–160 mg/l, respectively. The swine wastewater was composed of feces and urine, and BOD of feces would be about 10–80 times higher than that of urine. Therefore, their compositions and concentrations were highly influenced by performance of separation between feces and urine. There were two different types of barns in Korea such as slurry-type and scrapper-type whether feces were separated from urine or not. The swine-slurry wastewater (SSW) was mixture of whole feces and urine discharged from the slurry-type barn. The swine-urine wastewater (SUW) was mixture of partial feces and whole urine from the scrapper-type barn. The ranges of C/N and SS in SSW were 10–20 and up to 100,000 mg/l, respectively. However, those in SUW were varied with content of feces influenced by separation degree. Generally the content of feces, C/N, and SS in SUW were 20%, 4 and 5,000 mg/l, respectively. The survey results for types of barns presented in Yangsan City that the slurry-type and scrapper-type barn were 40% and 30%, respectively, and others were from miscellaneous types (Lee, 2003). Due to the strong concentrations of organic and SS in SSW, SSW is often prohibited from public swine treatment plants in Korea. Currently, 90% of SSW in Korea is dumped in the ocean; however, once the ocean-dumping is banned within a few years, tremendous problems will arise.

Anaerobic digestion is one of the well-known methods for biological treatment handling of concentrated organic matter such as swine wastewater, especially SSW. The anaerobic digestion can reduce organic loading but also hydrolyze non-biodegradable organic matters that result in increase of readily biodegradable organic matter. The feces from the scrapper-type barn are usually collected to make compost and the urine is discarded with SSW by ocean-dumping or treated by biological methods. The lagoon, aerobic digestion, anaerobic digestion, SBR, A^2/O, and UCT have been applied for treating swine wastewater. A research group in Australia (Edgerton *et al*., 2000) has reported that SBR was economical process in space and expense as well as flexible against shock loading in biological nutrient removal. So SBR has been gradually increased at small- and medium-size of sewage and swine wastewater treatment plants.

In this research, a full-scale SBR was attempted to treat the SSW and SUW. Promising methodology for SBR operation was demonstrated for treating nitrogen and phosphorous in SSW.

Materials and methods

Operation of full-scale SBR

The full-scale SBR with effective volume of 20 m^3 and digester of 30 m^3 for swine wastewater treatment were installed in Kimhae City. The full-scale SBR was rectangular shape with W 3 m × L 5.5 m × H 2.5 m. A ring blower supplied 3.64 m^3 air/min through 30 units of disk type diffusers on the bottom of reactor. An impeller type mixer was installed and operated during the anoxic stage for proper mixing. As shown in Figure 1, one whole-cycle of SBR was 24 hr and consisted of 4 sub-cycles with 1 hr anoxic period and 3 hr aerobic period. Other periods for 3 hr settling, 20 mins decanting, 20 mins sludge wasting and 20 mins idling were followed. The influent wastewater was fed at the beginning of each anoxic period except the final anoxic period. Each feed volume was 0.2–0.5 m^3 with the feeding rate of 20 ml/min for 10–20 mins depending on the strength of the wastewater. Therefore, overall hydraulic retention time (HRT) was 10–25 days. During the final anoxic period, the methanol was fed for completing denitrification. Three kinds of swine wastewater including raw SSW, digested-SSW and SUW were tested for their treatability in SBR. The initial normal nitrogen-loading rate was 0.22 kg NH_4^+-N/m^3/day as suggested by Kim *et al.* (2000), and the volume of feed was gradually increased to evaluate the maximum removal capacity on maintaining the effluent quality of 60 TN mg/l.

Classification of influent swine wastewater and analytical methods

SSW was individually collected from each slurry-type barn. Prior to feeding to SBR, the hairs, sand and other matter were removed using a solid-liquid separator (vibrating type,

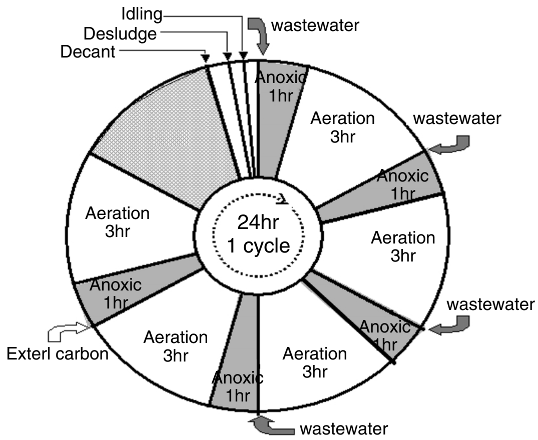

Figure 1 Schematic diagram of overall SBR operating cycle

Hwaju, Korea). For the comparison purpose, after the anaerobic digester was operated for a short period, its effluent was fed to the SBR. The effluent from the digester was considered as digested-SSW. The digester was operated with HRT of 7–20 days at 35 °C. SUW was simply taken from the influent line of the Kimhae city's public swine wastewater treatment plant. SUW was also treated with the solid-liquid separator prior to treating by SBR. The ratio of TCOD/NH_4^+-N in SSW varied from 6 to 9 depending on various slurry-type barns while the ratio of TCOD/ NH_4^+-N in SUW was not exceeded in 3.5. $TCOD_{cr}$, TSS, VSS and alkalinity were analyzed according to Standard Methods (AWWA, 1998), and $SCOD_{cr}$, NH_4^+-N and PO_4^{3}-P were analyzed with Auto Analyzer 3 (Bran+Luebbe, France) after filtering with 0.45 mm filter (Watman, USA). The respiration rate was measured with a continuous type of respirometer (EnvironSoft, Korea). Triplicate volatile fatty acid (VFA) samples were injected into GC (HP 5890 series 2, USA) equipped with a capillary column (HP-INNOW ax, 30 m × 0.32 cm × 0.5 mm). The temperature of the GC oven was increased from 60 to 250 °C with a rate of 10 °C /min. The temperature of the FID detector and injector were maintained at 275 °C and 250 °C. Acetic acid, propionic acid and butyric acid were used as standards for VFAs.

Results and discussion

Characterization of swine wastewater

Due to extremely strong concentration, it was difficult for the swine wastewater to be successfully treated in the biological process. Most researchers tried to reduce the concentration of swine wastewater to an appropriate concentration by following some methods such as dilution, settling and centrifuging prior to studying the feasibility of the biological processes (Ra *et al*., 2000; Bernet *et al*., 2000). However, this research has attempted to treat SSW directly without any pre-treatment. The characteristics of two different types of SSW and SUW are shown in Table 1. The treatability of that wastewater was studied at the full-scale SBR. The ranges of TCOD, NH_4^+-N and TSS of raw SSW were 23,000–72,000 mg/L, 3,500–6,000 mg/L and 17,000–50,000 mg/L, respectively. Dramatic variations of those components were caused by various storage periods of SSW at a storage tank in the barn before collection. The settling and fermentation processes at the storage tank could reduce organic and nutrient concentrations. The range of TCOD/ NH_4^+-N ratio of SSW was 6–9. Those values were higher than the theoretical one required for completing denitrification at anoxic period. COD of SUW was about one-third of SSW whereas NH_4^+-N was just slightly lower than SSW. Therefore, the TCOD/NH_4^+-N ratio of SUW resulted in 2.4–3.2.

Evaluation of readily biodegradable organic in swine wastewater

The readily biodegradable organic in the raw wastewater was evaluated by VFAs and

Table 1 Characteristic of swine wastewater discharged from Kimhae area, Korea

(Unit : mg/L except pH)

Components	SSW		SUW
	raw SSW	digested-SSW	
$TCOD_{cr}$	23,000–72,000	13,500–23,000	9,000–13,000
$SCOD_{cr}$	15,000–60,000	12,000–20,000	8,000–11,000
NH_4^+-N	3,500–6,000	3,500–4,900	3,100–4,300
PO_4^{3}-P	40–160	50–140	20–40
TSS	17,000–50,000	10,000–25,000	1,900–2,300
VSS	10,000–37,000	7,000–17,000	1,500–1,800
Alkalinity	15,000–22,000	20,000–23,000	12,000–13,000
pH	8.5–9	8–8.5	8.5–9

SSW (swine-slurry wastewater); whole mixture of feces and urine discharged from slurry-type barn
SUW (swine-urine wastewater); mixture of partial feces and whole urine from scraper-type barn

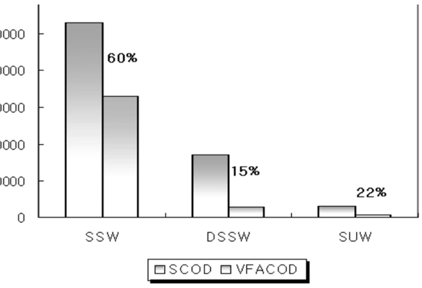

Figure 2 Concentrations and contents of VFA in swine wastewaters

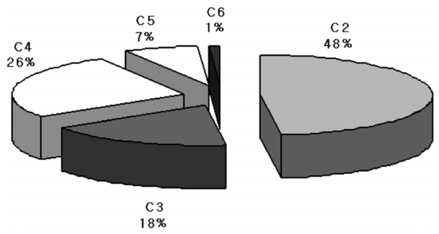

Figure 3 Characteristics of VFAs in swine-slurry wastewater (SSW)

respiration rates. Figure 2 shows the results of SCOD, VFAs in terms of COD unit and the percentile of VFAs (COD) to SCOD. The VFAs portion of SCOD in raw SSW was about more than 60%. VFAs in SSW were analyzed further and are summarized in Figure 3. Acetic acid represented by C_2 was more than 48% and the portion including formic acid and propionic acid represented by C_2–C_4 was 70%. VFAs in SUW and digested-SSW were about 22% and 15%, respectively. This meant that SUW lost its readily biodegradable organic by losing the feces in the scraper-type barn and the digested-SSW lost it by digestion in the anaerobic reactor. Since the swine wastewater contained very high content of short chain organic, it might be degraded very rapidly. Also because it contained high alkalinity and maintained relatively high pH, the acid production didn't inhibit the methane fermentation. Therefore, the digestion brought rapid reduction of valuable VFAs, resulting in insufficient denitrification and phosphorous uptake (Kang *et al.*, 2002).

The respirometery was used to estimate the readily biodegradable organic portions in the SSW and SUW by measuring the oxygen uptake rate (OUR). As shown in Figure 4, the initial peak periods of OUR such as about 3 hr in SSW and 1hr in SUW represented the readily biodegradable organic and the rest of the tails indicated the slowly biodegradable organic (Ko *et al.*, 2001). The areas under initial peak period to the whole areas were 63%

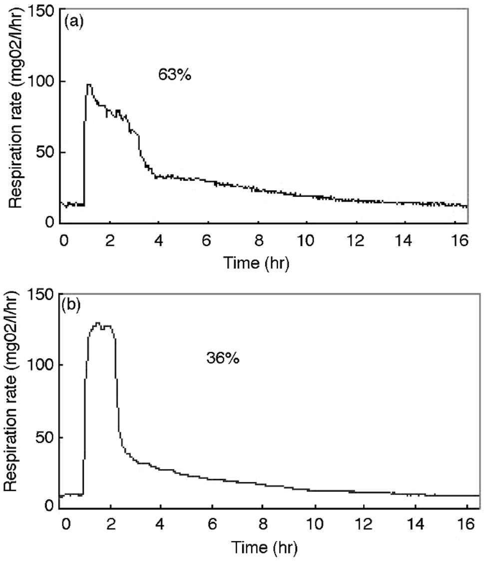

Figure 4 Respirometry for estimating the content of readily biodegradable substrate: (a) in SSW and (b) in SUW

and 37% in SSW and SUW, respectively, which were similar to those ratios of VFAs to SCOD.

Operating characteristic of intermittent feeding in SBR

The operating characteristic of intermittent feeding with SSW and SUW were evaluated based on temporal profiles of NH_4^+-N, NO_x-N and PO_4^{3-}-P during 24 hr of one whole-cycle operation. Figure 5(a) represents the experimental results of SSW at the TCOD/NH_4^+-N ratio of 9. Figure 5(b) represents those of the SUW at the ratio of 3.5. The nitrogen loading rates were 0.25 kg NH_4^+-N /m^3/d in both cases and the external carbon was added to cause enough denitrification of NO_x-N 50 mg/l. In both cases nitrification occurred completely in each aerobic sub-cycle. Denitrification with SSW was completed in each anoxic sub-cycle. NO_x-N produced at the final aerobic stage was removed completely by addition of methanol. However, in SUW case NO_x-N was accumulated from the third sub-cycle and the fixed amount of external carbon was not enough to remove 85 mg/l of NO_x-N. Even though the concentration of NH_4^+-N was high enough to cause the substrate inhibition against nitrification, the inhibition could be avoided by increasing dilution rate using intermittent feeding of wastewater during the sub-cycle operation (Kim *et al.*, 2000).

Initially it was expected that the dynamic phosphorus release and uptake during the sub-cycles might occur because SSW contained relatively high concentration of VFAs, however, this did not occur. Only at the final aeration period PO_4^{-3}-P was taken more than that in influent so that the effluent PO_4^{-3}-P was very low. Since this operation was cycled, when SSW was fed, PO_4^{-3}-P in the last sub-cycle remained relatively low. Feeding SUW case,

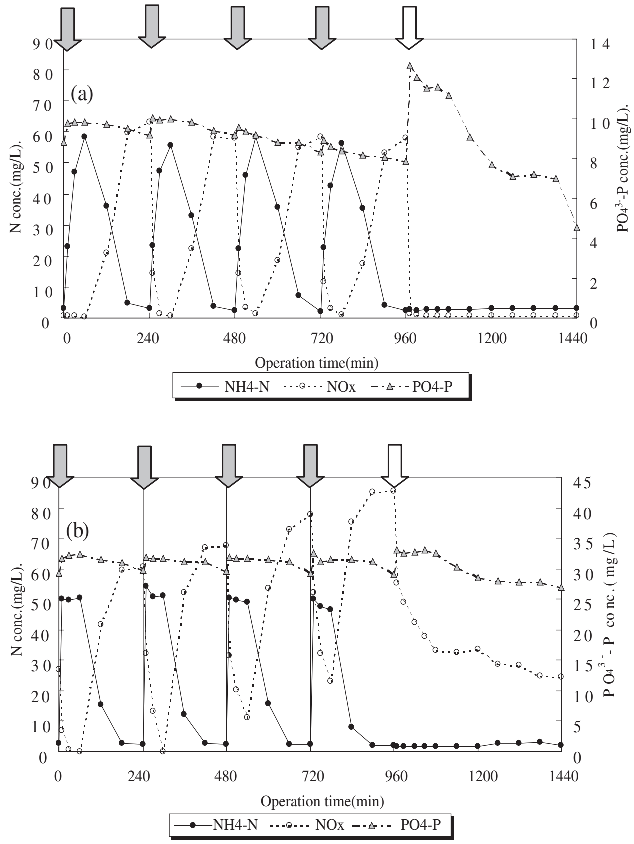

Figure 5. Temporal variation of NH_4^+-N, NO_x-N and PO_4^{3-}-P during one full cycle: (a) SSW; (b) SUW (⇩; wastewater feeding, ⇩; external carbon feeding)

the dynamic phosphorus release and uptake did not occur even at the final aeration period. The results indicated that when SSW was treated in SBR the intermittent feeding method was recommended for removal of nitrogen and phosphorus. However, this technique was not satisfactory for SUW for nitrogen and phosphorus removal due to its low readily biodegradable organic.

Effect of wastewater characteristics during long period operation of SBR

SUW with 2.4–3.2 of TCOD/ NH_4^+-N ratios was fed directly into the SBR for 200 days with varied loading rates from 0.1 to 0.45 kg NH_4^+-N/m^3-day. The result is shown in Figure 6. NH_4^+-N in influent was about 3,000–4,300 mg/l and the desirable T-N concentration in effluent was below 60 mg/l. This was achieved during most of the operation periods except occasional effluent T-N upset over 200 mgN/l. This kind of problem could be overcome with an automatic control operation based on ORP or DO profile (Poo *et al.,* 2002). The residual NO_x-N at the last step of the sub-cycle was not so high and could be removed completely with the addition of a small amount of methanol. Phosphorus concentration in SUW was about 20 mg/l but a large amount of P was released and accumulated in the SBR. It violated the effluent quality guideline of 8 mg T-P/l in Korea. Obviously this was due to limited substrate for both denitrification and phosphorous uptake/release. Therefore, additional chemical treatment might be recommended for proper removal of phosphorus in SUW.

For comparison purpose, the anaerobic digester has been operated as a pretreatment of SSW for a short period. The anaerobic digester effluent (digested-SSW) was fed to the SBR with loading rate of 0.15–0.25 NH_4^+-N/m^3-day and TCOD/ NH_4^+-N ratios of 2–3.2. The results are shown in Figure 7. Only 30 days operations for digested-SSW were performed due to occurrence of uncontrollable foam that had not appeared during SSW treatment. The SCOD range of digested-SSW was 8,000–15,000 mg/l because a large amount of biodegradable organic was removed in the anaerobic digester. As expected, NO_x-N was accumulated up to 200 mg/l due to lack of organic. At the beginning of operation, NH_4^+-N in effluent was appeared to over 20 mg/l. Once nitrifying bacteria were stabilized, active

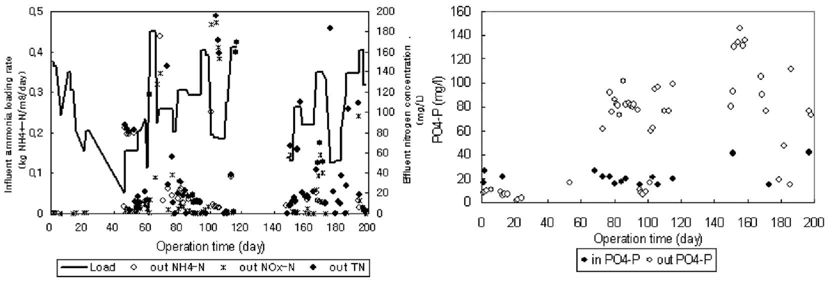

Figure 6 200 days operation of SBR for treating SUW

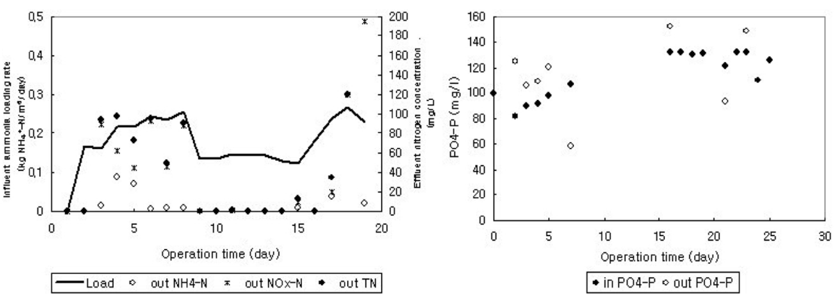

Figure 7 Temporal profiles of nitrogen and phosphorus concentrations in SBR for treating digested-SSW

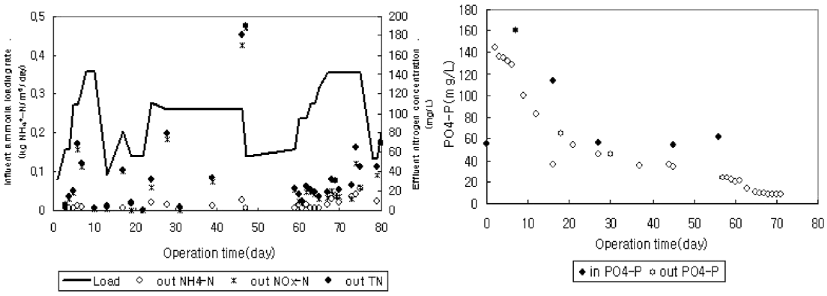

Figure 8 Temporal profiles of nitrogen and phosphorus concentrations in SBR for treating SSW

nitrification provided over 90% of the removal efficiency of NH_4^+-N regardless of various NH_4^+-N loading rates. However, the anaerobic digester could be converted to a fermenter that can produce organic acids, if the hydraulic retention time is reduced below about 24 hr (Kang *et al.*, 2002). PO_4^{3-}-P of 60–150 mg/l in effluent was even higher than USW influent due to the phosphorus release in the SBR.

Finally the treatment of SSW was attempted and the effluent profiles of NH_4^+-N and PO_4^{3-}-P were shown in Figure 8. Compared to USW, SSW had higher C/N ratio of 6 and presented very stable effluent quality below 20 mg T-N/l over whole operating periods of 80 days. Even SCOD of SSW was fluctuated from 20,000 to 70,000 mg/l, SCOD of effluent was maintained around 1,000 mg/l. Without the addition of methanol, the T-N concentration did not exceed 70 mg/l regardless of the large variation in NH_4^+-N loading rates. It meant that a large portion of biodegradable organic in SSW enhanced proper denitrification. Nitrification inhibition during aerobic periods could generally be expected in the case of swine wastewater treatment, however, the accumulation of NH_4^+-N was not observed during the aerobic period. Since SUW experiments were performed prior to SSW experiments, residual PO_4^{3-}-P from previous SUW experiments resulted in relatively high initial PO_4^{3-}-P in SBR. However, the initial PO_4^{3-}-P of 170 mg/l was dramatically decreased up to 8 mg/l during 65 days thereby becoming very stable. High organic concentration of SSW could induce PO_4^{3-}-P uptake. In spite of the above benefits of SSW, it usually contains high TSS and organic that may lead to possible problems such as pipe clogging, reactor upset and etc. Thus the SSW is still refused at swine waste treatment plants in Korea. However, strong organic of SSW could be evaluated as a critical material for further nutrient removal. Amount of COD required for 1 g denitrification was calculated based on accumulated NO_x-N at the final aerobic stage. The external carbon required for denitrification of SSW, digested-SSW, and SUW was 0.1 g COD/g NH_4^+-N, 2.14 g COD/g NH_4^+-N and 1.06 g COD/g NH_4^+-N, respectively.

Evaluation of the maximum nitrogen loading rate in SBR

Figure 9 shows the effluent T-N concentration of digested-SSW, SUW and SSW at various nitrogen-loading rates. To satisfy 60 mg T-N/l of effluent quality in Korea, the loading rates of digested-SSW and SUW should be managed around 0.22–0.25 kg T-N/m^3/day. However, the loading rate of SSW was able to increase up to 0.35 TN/m^3/day. Largest portion of T-N in the effluent was form of NO_x-N. Even addition of sufficient methanol during the anoxic period was expected to reduce T-N in effluent, this caused reverse effect of organic loading shock to SBR. The maximum organic loading rate of SSW was about 3 kg COD/m^3/day, which was 2.5 times higher than 1.2 kg COD/m^3/day of SUW. However, treated SSW volume was only around 87% of SUW. Finally, these results have proved that extremely strong swine wastewater could be well treated using intermittent feeding method in full-scale SBR without any dilution or pretreatment.

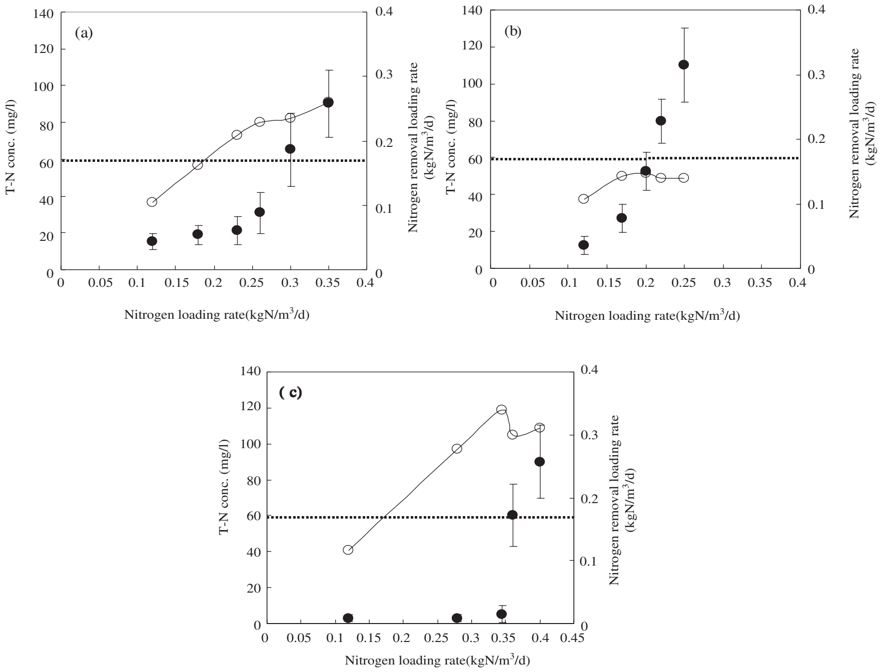

Figure 9 Comparison of maximum nitrogen loading rates at each wastewater; (a) digested-SSW (b) SUW (c) SSW (●: T-N concentration as mg/l, ○: nitrogen removal loading rate as kg N/m^3/day)

Conclusions

SSW has been considered to be a notorious wastewater for biological treatment process due to extremely high organic, T-N and TSS. In this work, the full-scale SBR with intermittent feeding method was demonstrated to remove NH_4^+-N and PO_4^{3-}-P from SSW very efficiently due to high C/N ratio and readily biodegradable organic. However, digested-SSW and SUW were not treated well due to lack of readily biodegradable organic. Also amounts of external carbon for denitrification were economically saved up to about 1/20 of that for digested-SSW and 1/10 of that for SUW. The anaerobic digester possibly gave the reverse effect on the following removal of nutrients and formation of thick foam in SBR. Also low C/N ratio of digested-SSW and SUW can be replenished with addition of SSW to enhance their treatability.

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