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Effective Treatment of Night Soil Using Anaerobic Sequencing Batch Reactor (ASBR)

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Abstract−Laboratory experiments were conducted to investigate the performance of the anaerobic sequencing batch reactor (ASBR) process for night soil treatment. The reactors were evaluated at an equivalent hydraulic retention time (HRT) of 10 days with an equivalent loading rate of 2.6 kgVS $m^{-3}day^{-1}$ (3.1 kgCOD $m^{-3}day^{-1}$) at 35 °C. Digestion of night soil was possible using the ASBR at an HRT of 10 days in spite of high concentration of ammonia nitrogen and settleable solids. Solids were accumulated rapidly in the ASBRs, and their concentrations were 2.3-2.4 times higher than that in a completely mixed control reactor. Increases in gas production were observed in the ASBRs compared with the control reactor. Average increases in equivalent daily gas production from the ASBRs were 205-220% compared with that from the control run. The ASBR with reaction period/thickening period (R/T) ratio of 1 showed a little higher gas production and organic removal efficiency than that with R/T ratio of 3. Volatile solids removal based on supernatant of the ASBRs was 12-14% higher than that of control reactor. Thus, the ASBR was a stable and effective process for the treatment of night soil having high concentration of settleable organics and ammonia nitrogen.

Key words: Anaerobic Sequencing Batch Reactor, Night Soil, Digestion, Solid-Liquid Separation, Ammonia Toxicity

INTRODUCTION

Night soil, which is a residual product of human life, includes not only high strength organic matter and ammonia nitrogen but also pathogenic bacteria. Problems of public health and water pollution caused by uncontrolled disposal of night soil have been a pending issue throughout Asia. Various night soil treatment processes including conventional anaerobic digestion have been applied for rural and un-sewered areas in Korea. The anaerobic process has been widely used as an ideal process for the treatment of high strength organic wastes, since it can be operated with low maintenance cost, and produces valuable biogas. As development of new energy sources has been a prominent focus throughout the world, high-rate anaerobic processes enhancing valuable biogas production from wastes attract environmental scientists and engineer's attention.

Considerable work on high-rate anaerobic processes, which have the ability to hold biomass within the reactor, has been done, focusing mainly on decreasing hydraulic retention time (HRT) and increasing biomass. The initial work on a high-rate anaerobic process called "anaerobic contact process" was developed in the 1950s by Fullen [1953]. Most of the other high-rate anaerobic processes, which include the anaerobic filter, two-phase digestion, and the upflow anaerobic sludge blanket process, have been also designed mainly in order to decrease HRT and increase solids retention time (SRT). The anaerobic sequencing batch reactor (ASBR) process, which repeats a cycle including feeding, reaction, thickening, and withdrawal steps in a single reactor, is one of the novel and promising high-rate anaerobic processes. While most high-rate anaerobic processes require an external clarifier or solids recycle facility, the ASBR process can maintain a high concentration of methanogenic bacteria in the system without additional facility or serious operational difficulties. Recently, several investigators have carried out studies on the ASBR process. Kennedy et al. [1991] and Suthaker et al. [1991] indicated that feeding/reaction period ratio was a critical design parameter on the ASBR process. Sung and Dague [1992] studied the effect of reactor shape and mixing type on the performance of the ASBR process. Herum and Dague [1993] investigated the effect of vacuum application to the ASBR prior to the thickening step, and pointed out that vacuum application resulted in improved sludge thickenability. Chang et al. [1994] investigated the performance of the ASBR for the digestion of municipal wastewater sludge in order to develop an improved anaerobic process for high-solid-content waste, and Hur et al. [1998] also investigated the solid-liquid separation characteristics of digested sludge in the ASBR. The objectives of this research were to investigate the performance of the anaerobic sequencing batch reactor for digestion of a night soil under inhibitory condition caused by high ammonia nitrogen in the feed night soil, and to assess the effect of reaction/thickening period ratio on the digestion efficiency.

MATERIALS AND METHODS

1. Experimental System

Three laboratory scale anaerobic digestion systems were used for the experimental study. Fig. 1 shows the schematic diagram of the ASBR system used in this study. Each digestion system consisted of a conventional high-rate type anaerobic reactor and a floating type gas collector equipped with a counterweight, and was maintained at the temperature of 35±1 °C. Each reactor made of Plexiglas was 40 cm high, and had a working volume of 5 liters. Three reactors, two for the ASBR run and the other for a control run, were

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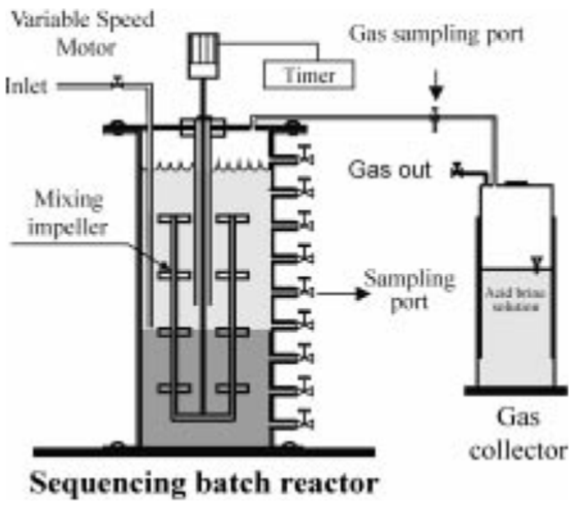

Fig. 1. Schematic diagram of the ASBR system.

identical except for mode of operation. Two reactors for the ASBR run were operated with different reaction period/thickening period (R/T) ratios. All reactors had six fill and draw ports, which were placed at every 5-cm interval from the top of the reactor.

2. Characteristics of Night Soil

Feed night soil was collected periodically from a flow equalization chamber in a night soil treatment plant located in Andong, Korea. Collected night soil was screened with a standard sieve #20, and kept at temperature below 4 °C. The feed night soil was heated to approximately 35 °C just before feeding to avoid a temperature shock. The feed night soil had high ammonia nitrogen content, and the average volatile fraction of total solids was 69%. Average C/N (COD/ammonia nitrogen) ratio of the feed was 6.9. Table 1 shows the characteristics of the feed.

3. Operation Methods

The operating conditions of the ASBRs and completely mixed control reactor are summarized in Table 2. A cycle of the ASBR including feeding, reaction, thickening, and withdrawal step was sequenced continuously. Feed night soil was supplied and discharged manually for about 30 minutes. Mechanical mixing was provided during feeding and reaction period. During 1-day thickening period, digested sludge in the ASBR was thickened under hydraulically ideal quiescent conditions. Since efficiency and stability of the ASBR system relies on internal solid-liquid separation, thickening period determination of high-solids-content night soil was important. A thickening period of one day was determined through preliminary thickening test of feed night soil. ASBR systems were operated with two R/T ratios of 1 and 3 under the same thickening period of 1-day. The reactors for ASBR runs were operated with completely mixed daily-fed mode under the same operating conditions as their corresponding control reactors until they showed the same performance as observed for the control runs. A completely mixed daily-fed reactor (CSTR) without thickening step was simultaneously operated as a control run to compare its baseline performance with that of the ASBR.

When the night soil is treated, inorganic or non-biodegradable solids contained in the influent will end up accumulating in the reactor and take some of the reactor space [Chang et al., 1994; Hur et al., 1998], and then accumulated solids contained in the clarified effluent because of thickened sludge volume exceeding predetermined level should be carried away during decant step of the ASBR. A phenomenon called the "crowding out" effect or cycle mutual effect between thickened sludge volume and gas production demonstrates the consequence of the solids accumulation [Hur et al., 1998]. The crowding out effect will occur in the ASBR fed with night soil; however, no attempt was made t to intentionally control solids retention time (SRT) since performance of the ASBR could be regarded as a stabilized pseudo-steady state [Hur et al., 1998].

4. Analytical Methods

Analyses were performed for the feed night soil and clarified effluent after thickening on pH, alkalinity, volatile acids (VA), total solids (TS), volatile solids (VS), and COD. All analyses were conducted as per procedures in the APHA Standard Methods [APHA,

Table 1. Characteristics of the feed night soil

Parameter	Range	Average	Standard deviation
pH	6.9-8.4	7.6	0.36
Alkalinity (mgCaCO$_3$ l^{-1})	10,270-20,830	14,390	2,470
Volatile acids (mgHAc^{-1})	1,840-14,820	9,340	4,900
COD (mgl^{-1})	22,330-38,750	32,140	3,870
Total solids (mgl^{-1})	26,810-46,800	36,690	3,520
Volatile solids (mgl^{-1})	15,060-36,400	25,350	3,270
Suspended solids (mgl^{-1})	24,700-30,800	27,300	2,750
Volatile suspended solids (mgl^{-1})	10,600-25,300	22,600	2,410
Total Kjeldahl nitrogen (mgl^{-1})	7,120-8,850	7,760	710
Ammonia nitrogen (mgl^{-1})	2,240-7,500	4,650	1,190
Un-ionized ammonia nitrogen (mgl^{-1})	16-570	103	-
Thickened volume (VV^{-1}%)^b	22-89	42	15
Centrifuged volume (VV^{-1}%)^c	13-22	17	3

^{a}Calculated values at given pH.
^{b}Sludge volume after 1-day thickening in a 1 liter graduated cylinder.
^{c}Sludge volume after centrifugation at 3,000 rpm for 5 minutes.

Table 2. Operating conditions

Parameter	Control reactor	ASBR (R/T ratio : 1)	ASBR (R/T ratio : 3)
Temperature (°C)	35	35	35
Equivalent HRT (days)	10	10	10
Working volume (L)	5	5	5
Withdrawal volume ($Lcycle^{-1}$)	0.5	1.0	2.0
Organic loading rate			
One cycle basis ($kgVSm^{3-1}d^{-1}$)	2.6	2.6	2.6
($kgCODm^{3-1}d^{-1}$)	3.1	3.1	3.1
Feeding period basis ($kgVSm^{3-1}d^{-1}$)	2.6	5.1	10.3
($kgCODm^{3-1}d^{-1}$)	3.1	6.1	12.3
Operation period (days)[a]	290	290	290
Cycle time (days)	1	2	4
Feeding & withdrawal period (hours)	0.5	0.5	0.5
Reaction period (days)	1	1	3
Thickening period (days)	-	1	1

[a]Operating period after change in 10-day HRT.

1992]. Gas production and pH changes were recorded daily and other analysis items were tested twice a week for alkalinity, VA, TS, VS, and COD. Dynamic changes in organics concentration and gas production in the system during 1-cycle were also determined hourly to identify digestion dynamics in the ASBR system. Composition of digester gas was determined by gas chromatography using a thermal conductivity detector and Porapak Q as a packing material. Interface height of the digested sludge in the ASBR was measured directly in the reactor during thickening period, while those of the sludge in the control reactor and feed night soil were measured in a 1-L graduated cylinder.

RESULTS AND DISCUSSIONS

1. Behaviors During Acclimation Period

All reactors were operated as a CSTR mode at 30-day HRT during the initial period for acclimation to night soil. The HRT of 30 days, which was chosen as the HRT during acclimation period, was found to exhibit stable digestion of night soil generally accepted in the literature. As shown in Table 1, feed night soil has high ammonia concentration of 4,650 mgl^{-1}. Average un-ionized ammonia nitrogen concentration, which was calculated from measured ammonia nitrogen concentration and pH, was 103 mgl^{-1}. Previous research by McCarty [1964] reported that ammonia nitrogen was an essential nutrient for anaerobic bacteria, and those concentrations between 50 and 200 mgl^{-1} were beneficial, while those in excess of 3,000 mgl^{-1} were toxic to methanogens regardless of pH. On the other hand, other investigators [Parkin and Miller, 1982] reported that under optimal conditions, methanogens were able to acclimate to the near 10,000 mgl^{-1} of ammonia nitrogen without any decrease in process performance. Bhattacharya and Parkin [1989] indicated that with continuous addition of ammonia nitrogen, high-SRT systems can tolerate higher concentrations than low-SRT systems, and the toxic level of un-ionized ammonia nitrogen is a strong function of SRT. During the initial acclimation period of this study, some problems occurred in all reactors by ammonia toxicity. Behaviors of digestion during acclimation period under high ammonia concentration are given in Fig. 2. It takes about five months to reach a

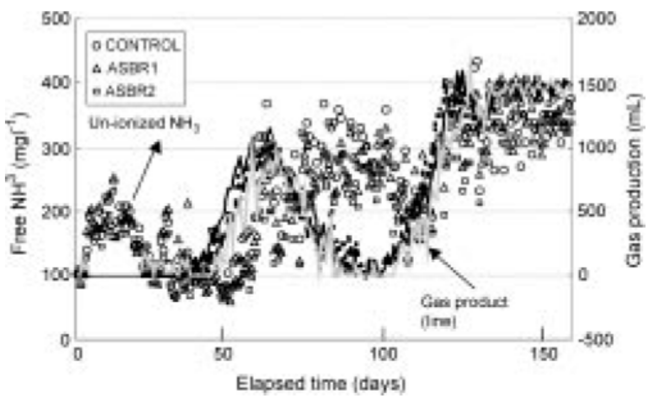

Fig. 2. Acclimation behaviors during initial period under high un-ionized ammonia concentration with CSTR mode operation at 30-day HRT.

steady state in all reactors.

2. Start-up Behaviors of the ASBR

The reactor for the ASBR run had been operated with a completely mixed mode at the operating conditions of the control run for six months until it showed the same performance in terms of pH, VA, and gas production as that of the control run.

Two reactors for the ASBR run were converted to sequencing batch mode, while the other reactor for the control run was operated in CSTR mode. After start-up at 30-day HRT, a change in HRT was carried out gradually for minimizing shock loading. The mixed liquor total solids accumulation profiles during the HRT conversion are shown in Fig. 3. At the beginning of the HRT conversion period, solids accumulated rapidly in the ASBRs. Fig. 3 shows a fairly linear increase in solids concentrations in the ASBRs from 30-day HRT to the middle phase of 20-day HRT regardless of the R/T ratios. During the latter half of 20-day HRT, solids concentrations in the ASBRs had a little margin according to R/T ratio. The solids concentrations in the ASBRs were 2.3-2.4 times higher than that in the control reactor at 10-day HRT after start-up period.

3. Characteristics of Solid-Liquid Separation

Difficulties associated with solid-liquid separation are often

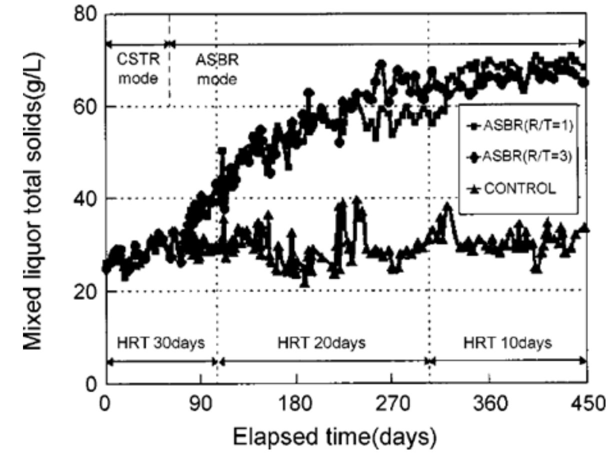

Fig. 3. Solid accumulation profiles during the period of HRT change.

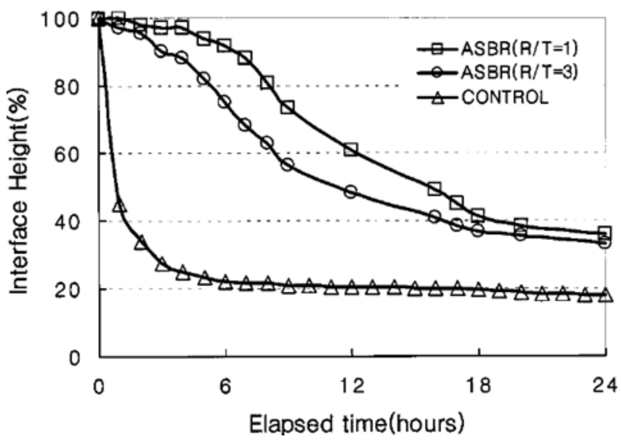

Fig. 4. Characteristics of the solid-liquid separation of sludges.

encountered in anaerobic processes. Good solid-liquid separation is especially important to the design and operation of the ASBR process, since internal solids concentrations in the ASBRs were significantly higher than in the control run as shown in Fig. 3. Characteristics of the solid-liquid separation of the digested sludge in the ASBRs were different from that of the control run, as shown in Fig. 4. Poor solid-liquid separation was expected undoubtedly for the digested sludge in the ASBR, since thickened volume of the feed having an average of 42% ranged from 22% to 89% after 1-day thickening period. The thickened volume in the ASBRs ranged from 36% to 37%, while the digested sludge from a control reactor had thickened volume of 17% after 1-day thickening period. Thickening velocities of the sludge in the ASBRs were lower than in the control run.

Sludge thickenability in the ASBR could be evaluated as a ratio of concentration or mass of solids in the thickened sludge to that in the effluent. Sludge thickenability in the ASBR with shorter reaction time (R/T=1) was lower than that with longer reaction time (R/T=3). One of the reasons for the poor thickenability at shorter reaction time was the instability of the organics due to lower reaction time. Shorter reaction caused lower degradation of organics leading to continuous gas evolution during the thickening step regardless of the thickened sludge volume. Therefore, we believed that sludge thickenability is closely related to the solids concentration and internal gas evolution. Because the ASBR with low R/T ratio had shorter reaction period than that with high R/T ratio, the amount of night soil solids left when thickening begsn in the ASBR with low R/T ratio was larger than that in the ASBR with high R/T ratio. It should be noted that the ASBR with high R/T ratio had faster thickening velocity than that with low R/T ratio. Solids accumulation in the ASBR was governed by the effluent withdrawal volume prescribed by a designed HRT and cycle period rather than influent solids concentration after sufficient build-up of sludge bed. This is because solids accumulating above a predetermined level for effluent withdrawal should be carried away during the draw step. Average SRTs based on the effluent total solids of the ASBRs under various operating conditions were 1.3 to 4 times longer than those of the control runs.

Identification of solid-liquid interface was impossible for the initial 5 hours in the ASBR with R/T ratio of 1 during the thickening period. This was caused by active interface gassing between solids and liquid as reported by Yim and Kwon [1997]. Therefore, we believed that electric force or vacuum application would be challengeable in the ASBR at the initial period of thickening period as noted by Yi and Iwata [1995]. Time required to obtain a thickened volume of 50% was 12 hours in the ASBR with R/T ratio of 3, while that in the ASBR with R/T ratio of 1 was 16 hours. Solids concentration profiles in the thickened sludge bed were also examined at the end of the thickening period of the ASBRs, as shown in Fig. 5. The profiles clearly demonstrate remarkable accumulation of solids in the ASBRs.

4. Steady-state Performance

Steady-state performance of the ASBRs could be regarded as a pseudo-steady state, since artificial control of SRT was not employed.

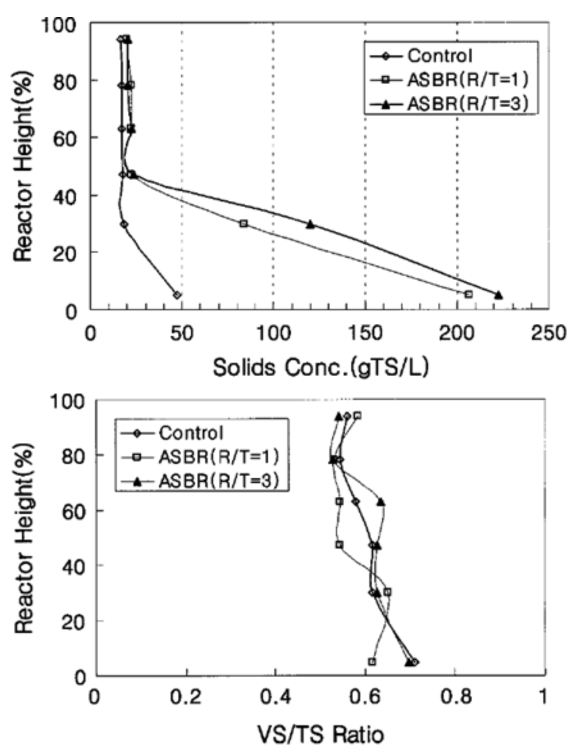

Fig. 5. Solids profiles at the end of thickening step.

Table 3. Steady-state performances (Averages±standard deviation)

Parameter	Control reactor	ASBR (R/T ratio : 1)	ASBR (R/T ratio : 3)
Digested sludge[a]			
pH	8.04±0.11	8.14±0.11	8.13±0.11
Volatile acids (mgHAcl^{-1})	5,660±1,460	2,230±800	2,056±690
Alkalinity (mgCaCO$_3$l^{-1})	15,370±1,880	14,990±1,870	15,800±1,700
Solids & COD removals			
TS removal (%)			
Digested sludge basis	28.2±6.2	38.6±4.4	39.8±6.1
Clarified effluent basis[b]	41.3±5.8	49.5±6.2	49.1±5.8
VS removal (%)			
Digested sludge basis	28.3±3.8	45.5±3.7	45.4±5.7
Clarified effluent basis[b]	44.6±5.8	59.3±7.9	57.2±8.4
COD removal (%)			
Digested sludge basis	26±4.9	49.2±4.3	48.4±7.8
Clarified effluent basis[b]	56.3±7.5	67.4±3.9	65.5±5.3
Gas production rate (GPR)			
Equivalent GPR (mLday^{-1})	1,440±120	3,200±250	2,950±260
Specific GPR (LL^{-1}day^{-1})[c]	0.29±0.02	0.64±0.03	0.59±0.03
Gas yield (m^{3}kgVS^{-1} fed)	0.11±0.01	0.25±0.02	0.23±0.02
(m^{3}kgCOD^{-1} fed)	0.09±0.02	0.21±0.02	0.19±0.02
Methane content (%)	69.7±0.2	72.4±0.1	72.1±0.1
Solid-liquid separation			
Centrifuged volume (VV^{-1} %)	10.8±1.5	6.3±0.5	8.6±0.5
Thickened volume (VV^{-1} %)	16.9±5.7	37±11	35.8±10.5

[a]Digested sludge of the ASBR was withdrawn at the end of reaction period.
[b]Supernatant after 1-day thickening in a 100 mL cylinder at 35 °C.
[c]Equivalent gas production per unit reactor volume.

The SRT of the ASBR was controlled only by the loss of solids in withdrawal step. Steady-state performance of the ASBRs with an equivalent HRT of 10 days and their corresponding control run is summarized in Table 3.

4-1. Organics Removal

The COD removal efficiencies based on clarified effluent after 1-day thickening were 66-67% in the ASBRs, while it was 56% in the control reactor. The VS removals of the ASBRs were 57-59%, while that of the control reactor was kept at 45%. On the other hand, organics removal based on digested sludge was remarkably different between ASBR and control. The VS removals based on digested sludge in the ASBRs were 45-46%, whereas that of the control reactor was as low as 28%. The COD removal based on the clarified effluent of the control run was a little lower than that reported in the literature, which was obtained using a conventional completely mixed digester at an HRT of 16 days [Lee, 1982], while those of the ASBRs were higher than that reported in the previous study. It should be noted that an additional thickening facility is required at a conventional completely mixed digester to obtain such organic removal, whereas the ASBR can achieve the same organic removal at shorter HRT without any additional thickener.

4-2. Gas Production

Fig. 6 shows variation of pH and cumulative gas production per one cycle from the ASBRs and their corresponding control run during sequences of batch period after start-up of the ASBR. As shown in Fig. 6, the pH increased to near 8.5 by deamination after 30 days elapsed. Significant change in gas production was observed with

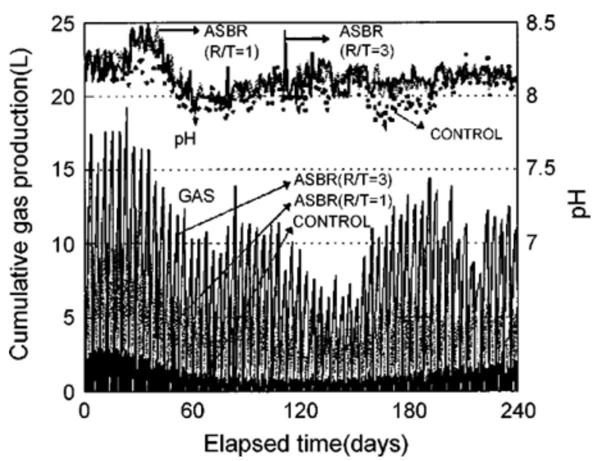

Fig. 6. Cumulative gas production according to the pH variation during sequences of batch period after start-up of the ASBR.

pH change. The gas production decreased in all reactors according to the increment of un-ionized ammonia caused by pH increase. Since the urea in night soil was hydrolyzed to ammonium carbonate by the enzyme urease, the pH of the anaerobic reactor increased and affected the anaerobic microorganisms. From the first affected period by pH to the middle of sequenced batch period, gas production changed susceptibly with pH variation. During the latter half of the sequenced batch period, gas production was stabilized ac-

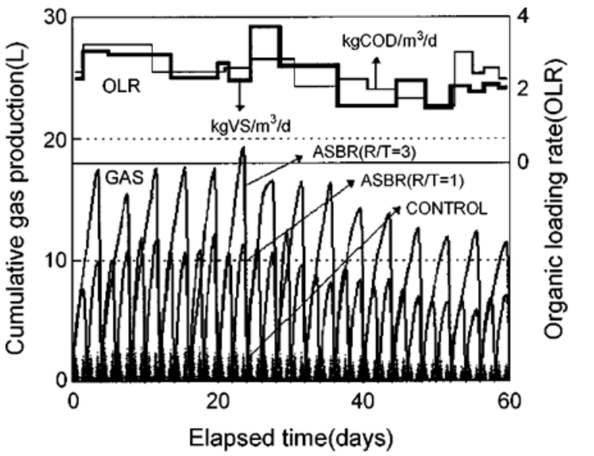

Fig. 7. Equivalent organic loading rate and cumulative gas production during sequences of batch period of the ASBR.

cording as the pH of anaerobic reactor was maintained 8.0 to 8.2. In all cases, remarkable increase in gas production was observed at the ASBRs compared with the control run, as shown in Table 3 and Fig. 6. Average increase in equivalent daily gas production from the ASBRs was 205-220% compared with that from the control run. Maximum gas yields based on VS added ranged from 0.23 to 0.25 $m^3kg^{-1}VS^{-1}$ from the ASBRs, while that from control run was 0.11 $m^3kg^{-1}VS^{-1}$. It was believed that the increase in gas production from the ASBRs was the combined result of accumulation of microorganisms and additional long-term degradation of organics. Fig. 7 shows variation of equivalent daily organic loading rate and cumulative gas production from the ASBRs and their corresponding control run during sequences of batch period after start-up of the ASBR. Gas production decreased in direct proportion to a decrease in organic loading rate.

4-3. Dynamic Changes in Organics and Gas Production During One Cycle

Fig. 8 shows the dynamic changes in organic matter and gas production behavior during one cycle in the system at an equivalent HRT of 10 days. Approximately 72% of total gas production during one cycle of the ASBR with R/T ratio of 1 was generated for 1-day reaction, and 28% of total gas production was generated during the 1-day thickening period, while in case of R/T ratio of 3, 88% of total gas was produced for 3-day reaction, and rest of the total gas was produced during the 1-day thickening period. It was noted that 50% of gas production during 1-day thickening period in the ASBR with R/T ratio of 1 was generated within the initial 10 hours, and internal gassing during the initial thickening period caused sludge solids to re-suspend. The COD removal was higher than VS removal during 1-day thickening period in all cases.

CONCLUSIONS

Digestion of night soil by the anaerobic sequencing batch reactor (ASBR) was investigated to evaluate the performance of the ASBR process. The reactor performance was assessed at an equivalent HRT of 10 days with an average equivalent loading rate of 2.6 kgVS m^{-3} day^{-1} at 35 °C. The main conclusion drawn from this study was as follows:

Digestion of a night soil was possible by using the ASBR at an HRT of 10 days in spite of high concentration of ammonia nitrogen and settleable solids in the night soil. The ASBRs showed higher digestion performance than the completely mixed control reactor. The reaction period/thickening period ratio (R/T ratio) of the ASBR could be considered as a meaningful operational parameter. The ASBR with R/T ratio of 1 showed higher gas production and organic removal efficiency than that with R/T ratio of 3, while the ASBR with R/T ratio of 3 had faster thickening velocity than that with R/T ratio of 1. Increases in equivalent daily gas production from the ASBRs were 205-220% compared with that from control reactor. The remarkable increase in gas production from the ASBRs was believed to be the combined result of accumulation of microorganisms and additional long-term degradation of organics. Solids were accumulated rapidly in the ASBRs, and their concentrations were 2.3-2.4 times higher than that in the control reactor. No adverse effect on solid-liquid separation was observed in the ASBRs in spite of solids accumulation. A conventional anaerobic digester could be easily converted to the ASBR without any stability problems. The VS removals based on the digested sludge of the ASBRs were 45-46%, whereas that of the control reactor was as low as 28%. It should be noted that a completely mixed digester requires an additional thickening facility to obtain similar organics removal to ASBR. The ASBR was a stable and effective process for the treatment of night soil having high concentration of settleable organics

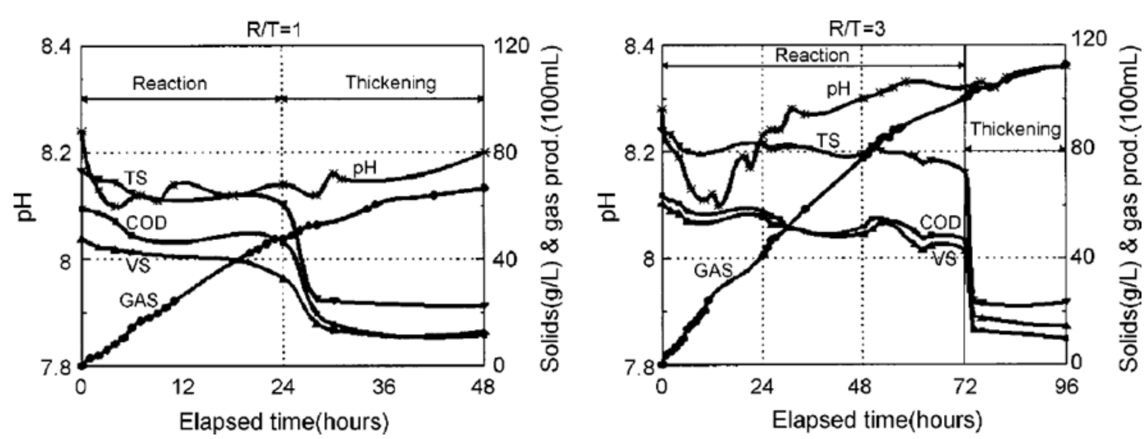

Fig. 8. Dynamic changes in organic matter and gas production in the ASBRs during one cycle.

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