Thai Environmental Engineering Journal Vol. 34 No. 1 (2020) : 27-34
www.eeat.or.th

Reduction of Methane and Nitrous Oxide from High Strength Municipal Solid Waste Leachate by Sequencing Batch Reactor with *Alcaligenes faecalis* No.4

Nararatchporn Nuansawan[1,2*], Chayanid Witthayaphirom[3] and Makoto Shoda[4]
[1]Department of Civil and Environmental Engineering Technology, Industrial Technology College,
King Mongkut's University of Technology North Bangkok, Thailand
[2]Green Building Research Group, King Mongkut's University of Technology North Bangkok, Thailand
[3]Department of Environmental Engineering, Faculty of Engineering,
Kasetsart University, Bangkok, Thailand
[4]Chemical Resources Laboratory, Tokyo Institute of Technology, Yokohama, Japan
[*]E-mail : Nararatchporn.n@cit.kmutnb.ac.th

Abstract

This research investigated the performance and greenhouse gas emission from high strength municipal solid waste (MSW) leachate by sequencing batch reactor(SBR) with *Alcaligenes faecalis* No.4 (*A. faecalis* No.4). The SBR was carried out by anaerobic reactor followed by aerobic reactor. The system was operated at hydraulic retention times (HRT) of 2 days during 130 operating days (Run 1) and 45 days with *A. faecalis* No.4 (Run 2). At steady state, the organic removal efficiencies were found to be 62.7% for (Run 1) and 86.7% for (Run 2). The organic carbon and nitrogen were mainly removed in aerobic reactor. The surface emission rates of methane and Nitrous oxide in aerobic reactor were reduced 35% and 14%, respectively with *A. faecalis* No.4.

Keywords : *Alcaligenes faecalis* No.4; Municipal Solid Waste Leachate; Greenhouse gas emission; Sequencing batch reactor

Introduction

Leachate pollution from solid waste disposal is receiving more attention as the increase in the amount of solid waste collected from urban areas is dumped into landfills or open dumpsites, especially in developing countries. More stringent regulations on leachate control have been put forward for a better management of solid waste disposal sites. Municipal solid waste leachate contains other compounds, including organic substances and toxic substances.

Sequencing batch reactor (SBR), which is widely used for biological nutrient removal (BNR) in municipal and industrial wastewaters [1]. Sequencing batch reactor (SBR) has become a global researcher's focus to optimize operational flexibility, space saving, and operating costs [2, 3].

This study aims to develop a two-step SBR process. However, greenhouse gases (GHGs) can be produced significantly from biological activity during treatment because methane (CH_4) can be produced under anaerobic conditions in the initial stages of treatment [4]. Significant CH_4 emissions can occur at non-oxygenated areas of the leachate system under high loading [5]. In addition, the appearance of high levels of nitrogen in the leachate can cause the emission of N_2O significantly soon after the raw leachate is aerated [6]. N_2O is released during nitrogen removal since N_2O is produced by autotrophic nitrifying bacteria, most of which are ammonia oxidation bacteria [7] during the nitrification, but most of them would be produced during denitrification [8].

In order to overcome limitation of indigenous nitrifying microorganisms, microorganisms that have heterotrophic nitrification and aerobic denitrification abilities such as *Paracoccus denitrificans*, *Pseudomonas stutzeri* and *Alcaligenes feacalis* have been introduced as potential microorganisms that may be used to overcome problems inherent in the conventional method [9]. Among them, *Alcaligenes faecalis* No.4 (*A. faecalis* No.4), has several advantages over other microorganisms such as (1) procedural simplicity, where nitrification and denitrification can take place simultaneously, (2) shorter acclimatization period, (3) lesser buffer quantity needed because alkalinity generated during denitrification can partly compensate for the alkalinity consumption in nitrification. *A. faecalis* No.4, was used to treat concentrated organic and nitrogenous wastewater such as anaerobic digester, coking wastewater, cattle wastewater (12,000 mgCOD/L) as well as high strength ammonium wastewater (5,000 mgN/L) from chemical companies [10]. In greenhouse gas emission perspective, *A. faecalis* No.4 were found to contribute to reduce methane production whereas this specific microorganism can remove 40-50% of ammonium through denitrification and 90% of denitrified products was in the form of N_2 [11, 12]. The rest of removed ammonium was convert to intracellular nitrogen thus producing less N_2O during its process.

To explore the possibility in enhancing of treatment performance of two-stage SBR through bio-augmentation of *A. faecalis* No.4, an experimental study was carried out to investigate the organic and nitrogen removals and greenhouse gas (CH_4 and N_2O) emission from the two-stage SBR system. Specific objective of this study was to determine appropriate operating condition of two-stage SBR to achieve high treatment efficiencies while producing low greenhouse gas emission.

Methodology

Lab-scale SBR unit with capacity of 5 l/d was used in this study. The schematic diagram of the experimental system is shown in Figure 1. The system consisted of two treatment steps. The anaerobic and aerobic reactor, each has 0.010 m^3 working volume. The aeration was continuously supplied to the aerobic reactor which maintained DO level of 3-4 mg/l (Controlled by aeration pump).

Hydraulic retention time (HRT) in both tanks was kept at 2 days. The study was conducted in two experimental systems. Run 1 (without *A. faecalis* No.4, 130 days) and 2 (with *A. faecalis* No.4 in aerobic tank, 45 days), are operated continuously from anaerobic (Stage I) to aerobic reactors (Stage II). The two run have been used to provide stable conditions in terms of water quality and emissions.

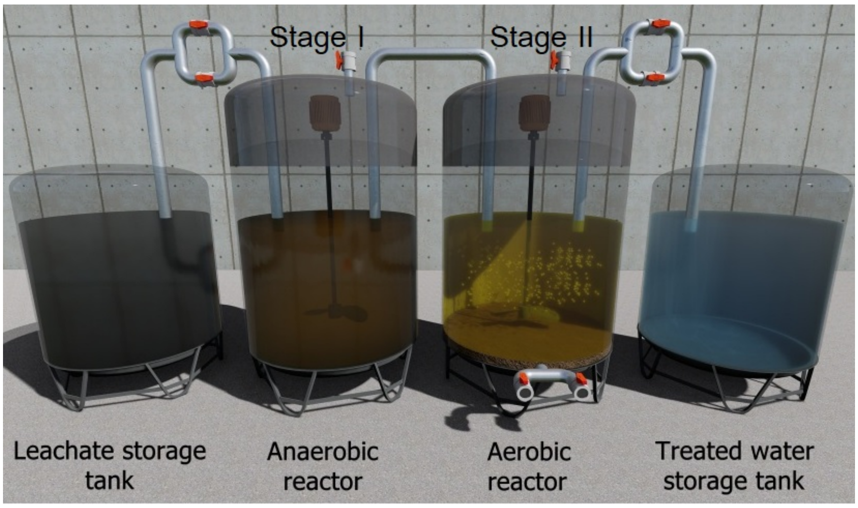

Figure 1 Schematic of two-stage SBR system

Leachate preparation and water quality analyses

Raw leachate was obtained from solid waste collection trucks into waste disposal area**,** collected at the station every week. Wastewater samples were kept in a glass container and stored at 4°C. All leachate analysis was performed according to the standards for water and wastewater [13]. The water parameters used in the analysis include pH, DO, BOD, COD, TOC, SS, NH_3, TKN, NO_2 and NO_3. In the reactor, MLSS concentrations were monitored. Total viable cell numbers in aerobic tank (expressed as cell per ml.) was counted on L agar plates [14], while greenhouse gases include CH_4 and N_2O. Chemical characteristics of leachate are shown in Table 1. The leachate used exhibited high organic concentrations in terms of BOD, COD and TOC and was acidic in nature. SBR was prepared by mixing fresh leachate and tap water at a ratio of 1: 3 v/v to maintain a constant COD concentration in leachate feed. The average concentration was 8,050 mg COD/L and was to be consistent in feed water.

Table 1 Chemical characteristics of raw and feed leachate

Parameters	Raw leachate		Diluted leachate used in the experiment	
	Range	Average(SD)	Range (System I & II)	Average (System I & II)
pH	3.2-5.1	4.25(0.82)	4.8-5.9	5.24(0.73)
BOD(mg/l)	58,520-70,500	62,050(5,210)	5,150-5,530	5,240(210)
COD(mg/l)	72,400-84,200	74,320(5,260)	7,500-8,560	7,840(340)
TOC(mg/l)	16,550-23,540	19,870(2,210)	2,580-3,380	2,890(310)
SS(mg/l)	410-1,420	680(32)	82-550	235(120)
NH^{+}_{3}-N(mg/l)	2,480-3,350	2,800(290)	730-850	770(51)
TKN(mg/l)	2,620-3,530	3,220(310)	820-1,130	905(80)
NO^{-}_{2}-N(mg/l)	0.4-0.9	0.6(0.40)	0.3-0.6	0.4(0.05)
NO^{-}_{3}-N(mg/l)	0.9-2.8	2.0(0.60)	0.3-2.3	1.7(0.8)

Note: The numbers show avg. (SD) values

Determination of greenhouse gas emission

During the operation, a closed-flux chamber was occasionally placed on top of anaerobic and aerobic reactors to determine greenhouse gas emission from the system. Close flux chamber is a chamber made of plastic plate with 150-mm in diameter and 100-mm in height. During the measurement, special care was taken to make sure that there were not any gas leakages. The reactor surface area which covered the chamber was 0.018 m^2. In order to determine the emission rate, gas samples from the closed-flux chamber were collected into a 9-ml vial by a gas-tight syringe at different time intervals (e.g. every 30 minutes) up to 120 minutes. Then, gas composition in a vial was analyzed by using a gas chromatograph (GC) for CH_4 and N_2O analysis. Closed flux chamber operated by allowing upward diffusive gas to accumulate in the chamber. As the area of flux chamber and reactor was equal, the increasing rate of gas in the chamber was used to determine the mass of emitting gas as follows.

$$F_{AN} = \frac{V\Delta C(298)}{A\Delta t(273+T)} \quad (1)$$

Where F_{AN} = Mass of gas emitted from anaerobic ($g/m^2.d$) at 25°C ; V =volume of chamber (m^3); $\Delta C/\Delta t$ = gas concentration gradient ($g/m^3.d$); T = temperature measured in degree: Celsius (°C). The gas emission was measured from anaerobic reactor at different times during the operation period. For the determination of gas emission from aerobic reactor, gas samples were collected from the cover chamber equipped with gas outlet port. The size of cover chamber was identical to that used in anaerobic reactor. The gas emission was determined from supplied air flow rate and measured outflow gas concentration using the following equation.

$$F_{AE} = Q_{air}\, C/A \quad (2)$$

Where F_{AE} = Flux of gas emitted from aerobic reactor ($g/m^2.d$), Q_{air}= supplied air flow rate (m^3/d), C = outflow gas concentration (g/m^3) and A= area of the cover chamber (m^2).

Results and Discussion

Treatment performance of SBR

During the 1st run (W/O *A. faecalis* No.4), the BOD and COD efficiencies in the SBR system were 64.5% and 51.3%, respectively. NH_3 and TKN removals were also higher than 50% as shown in Table 2. Most of nitrified nitrogen was denitrified resulting in low concentrations of oxidized nitrogen. In the 2nd run (With *A. faecalis* No.4), slightly higher BOD COD and TKN removal efficiencies of 80.1% 67.8% and 75.1%, respectively were obtained but changed to indicating. At with *A. faecalis* No.4 conditions, much higher biodegradable organic (BOD) concentrations were detected in the effluent of aerobic reactor even though the effluents from first stage anaerobic reactor were only moderately elevated.

Figure 2 shows the variation of biomass (MLSS) concentrations in anaerobic and aerobic reactors as well as *A. faecalis* No.4 population. In Run 1, MLSS in aerobic reactor gradually increased from 7.1 to 9.2 gl^{-1} at an increasing rate 0.017 $gl^{-1}d^{-1}$ while MLSS in the anaerobic reactor were kept relatively constant at about 4.2 gl^{-1}. When *A. faecalis* No.4 was introduced in the aerobic reactor in Run 2, MLSS was continuously increased to 13.3 gl^{-1} having higher biomass increasing rate of 0.095 $gl^{-1}d^{-1}$. This significant increase in biomass concentration in the aerobic reactor was possibly associated with the growth of *A. faecalis* No.4. The results indicate that the *A. faecalis* No.4 could utilize carbon and nitrogen compounds presented in the leachate efficiently for their growth under aerobic condition. Their cell concentrations were increasing from $6.5x10^8$ to $5.3x10^9$ cells ml^{-1} during that period. Naturally, the growth of *A. faecalis* No.4 were also found associated with elevated pH condition as the pH was found increase from 8-9 on day 132 and up to more than 10 during initial period (day 141-145) of Run 2 during which a decrease in *A. faecalis* No.4 population was observed. Subsequent operation with pH control (day 146-175) between 8 and 9 led to more stable operation and steadily growth of *A. faecalis* No.4. Extremely high pH condition, e.g. more than 11, was also reported to inhibit the growth of *A. faecalis* No.4 in previous study [14]. These results suggested that with *A. faecalis* No.4 had insignificant effect on the SBR performance on organic and nitrogen removals.

Table 2 Effluent qualities from SBR during steady operation

Parameters	Without *A. faecalis* No.4			With *A. faecalis* No.4		
	Eff. (An-SBR)	Eff. (Ae-SBR)	% Removal	Eff. (An-SBR)	Eff. (Ae-SBR)	% Removal
pH	6.4(0.3)	7.3(0.2)	-	6.5(0.2)	9.5(0.6)	-
DO	0.0(0.02)	4.1(0.5)	-	0.2(0.1)	2.1(0.3)	-
BOD	3,915(137)	1,860(138)	64.5	4,035(154)	803.0(206)	80.1
COD	6,482(94)	3,157(151)	51.3	6,540(101)	2,106(345)	67.8
TOC	2,006(140)	750(91)	62.7	2,098(140)	279(432)	86.7
NH^+_3-N	615(42)	300(30)	50.2	624(33)	619(126)	77.9
TKN	642(32)	285(14)	55.5	701(26)	175(62)	75.1
NO^-_2-N	0.16(0.06)	0.08(0.07)	48.3	0.21(0.11)	0.05(0.12)	72.5
NO^-_3-N	0.64(0.16)	0.3(0.09)	55.4	0.88(0.3)	0.2(0.13)	77.3

Note: The numbers show avg. (SD) values

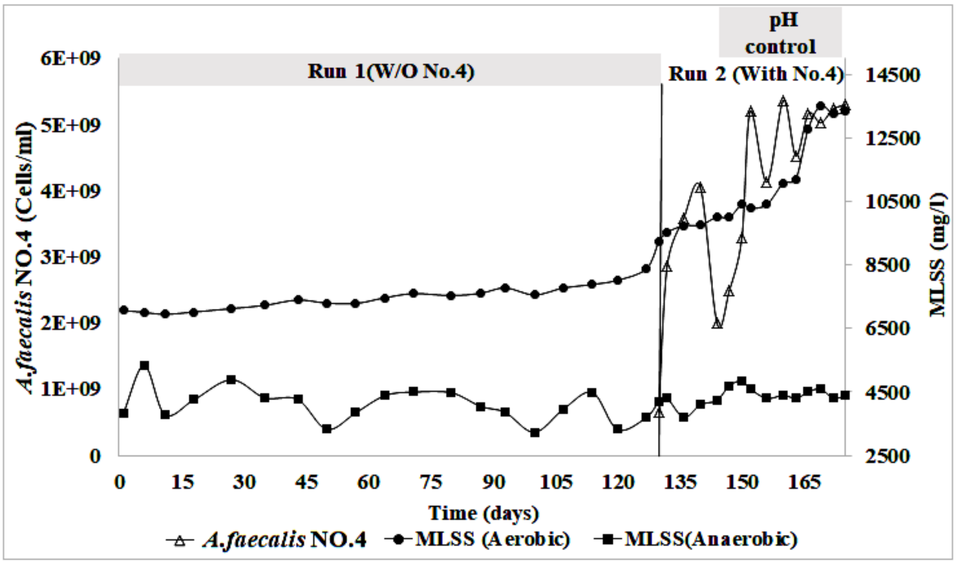

Figure 2 Characteristic of *A. faecalis* No.4 and biomass concentration

Measurements of greenhouse gas emissions from SBR

Table 3 presents surface emission rates of CH_4 and N_2O from anaerobic and aerobic reactors during leachate treatment. During the 1st run (W/O *A. faecalis* No.4), average CH_4 emission rate from anaerobic and aerobic reactors was 0.195 and 0.013 $g/m^2.d$. This is equivalent to CH_4 mass of 0.0035 and 0.0003 g/d. Meanwhile, N_2O emission rate was 0.0217 and 0.0022 $g/m^2.d$. These results show that both greenhouse gases were mainly emitted from the anaerobic reactor. When put *A. faecalis* No.4 operated in the 2nd run, CH_4 and N_2O emission rates were found decreasing in aerobic reactors. These results show that both GHG were mainly emitted from the anaerobic reactor. Similar observation on the CH_4 emission trend during the treatment process was reported in [1]. The major source of CH_4 emission came from the first reactor which was favorable for methanogens. Meanwhile, Anaerobic reactor N_2O production could take place where DO was maintained at about 0.5 mg/l. In previous research, it was reported that high N_2O production was observed under a DO level less than 2 mg/l [5, 7] as N_2O was produced from denitrification instead of N_2 in low oxygen condition [15].

Table 3 CH_4 and N_2O emission from anaerobic and aerobic reactors of SBR system

Conditions	GHGs	Anaerobic($g/m^2.d$)		Aerobic($g/m^2.d$)	
		Range	Avg	Range	Avg
W/O *A. faecalis* No.4	CH_4	0.127-0.297	0.195	0.012-0.018	0.0132
	N_2O	0.004-0.024	0.022	0.0020-0.0028	0.0022
With *A. faecalis* No.4	CH_4	0.142-0.267	0.209	0.007-0.012	0.0086
	N_2O	0.006-0.037	0.023	0.0017-0.0022	0.0019

Conclusion

An experimental study on greenhouse gas emission from two-stage SBR treating highly concentrated leachate suggested CH_4 gas were mainly emitted from first anaerobic stage at an average rate of 0.195 and 0.209 $g/m^2.d$ at Run I and Run II. Meanwhile, the emissions from second aerobic reactor were 0.0132 and 0.0086 $g/m^2.d$, respectively. Decreases in Run II in aerobic reactor, decreased CH_4 emission by 35%. Based on this conclusion, it is recommended to run the system at a very high storage capacity, which will improve the efficiency of wastewater treatment and reduce greenhouse gas emissions. *A. faecalis* No.4 with heterotrophic nitrification and aerobic denitrification abilities was bio-augmented in two-stage SBR yielding improved organic carbon and nitrogen removals. High organic carbon (86.7%) and nitrogen (75%) removals were achieved even the system was operated with *A. faecalis* No.4.

References

[1] Wang, X., M. Jia, X. Chen, Y. Xu, X. Lin, C.M. Kao and S. Chen. 2014. Greenhouse gas emissions from landfill leachate treatment plants: A comparison of young and aged landfill. Waste Manage. 34: 1156-1164.

[2] Chamchoi, N. and S. Nitisoravut. 2007. Anammox enrichment from different conventional sludges. Chemosphere. 66: 2225-2232.

[3] Jaramillo, F., M. Orchard, C. Munoz, M. Zamorano and C. Antileo. 2018. Advanced strategies to improve nitrification process in sequencing batch reactors - A review. J. Environ. Manage. 218: 154-164.

[4] Yan, X., L. Li, and J. Liu. 2014. Characteristics of greenhouse gas emission in three full-scale wastewater treatment processes. J. Environ. Sci. 26: 256-263.

[5] Nuansawan, N., J. Boonnorat, W. Chiemchaisri, and C. Chiemchaisri. 2016. Effect of hydraulic retention time and sludge recirculation on greenhouse gas emission and related microbial communities in two-stage membrane bioreactor treating solid waste leachate. Bioresour. Technol. 210: 35-42.

[6] Lin, L., Lan, C.Y., Huang, L.N. and Chan, G.Y.S. 2008. Anthropogenic N_2O production from landfill leachate treatment. J. Environ. Manage. 87: 341-349.

[7] Kampschreur, M.J., N.C.G. Tan, R. Kleerebezem, C. Picioreanu, M.S.M. Jetten, and M.C.M. van Loosdrecht. 2008. Effect of dynamic process conditions on nitrogen oxides emission from a nitrifying culture. Environ. Sci. Technol. 42: 429-435.

[8] Aboobakar, A., E. Cartmell, T. Stephenson, M. Jones, P. Vale, and G. Dotro. 2013. Nitrous oxide emissions and dissolved oxygen profiling in a full-scale nitrifying activated sludge treatment plant. Water Res. 47: 524-534.

[9] Gupta, S.K. and M. Kshirsagar. 2000. Quantitative estimation of Thiosphaera pantotropha from aerobic mixed culture. Water Res. 34: 3765-3768.

[10] Shoda, M. and Y. Ishikawa. 2015. Heterotrophic nitrification and aerobic denitrification of a Wastewater from a Chemical Company by *Alcaligenes faecalis* No.4. Int. J. Water and Wastewater Treatment. 1.2: 1-5

[11] Joo, H.S., M. Hirai and M. Shoda. 2005. Characteristics of ammonium removal by

hetetropic nitrification- aerobic denitrification by *Alcalisgenes faecalis* no.4. J. Biosci. Bioeng. 100: 184-191.

[12] Shoda, M. and Y. Ishikawa. 2014. Heterotrophic nitrification and aerobic denitrification of high-strength ammonium in anaerobically digested sludge by *Alcaligenes faecalis* strain No.4. J. Biosci. Bio. Eng. 117(6): 737-741.

[13] APHA. 2005. Standard Methods for the Examination of Water and Wastewater. 21st Edn, American Public Health Association/ American Water Works Association/ Water Environment Federation. Washington, D.C.

[14] Joo, H.S., M. Hirai and M. Shoda. 2006. Piggery wastewater treatment using *Alcalisgenes faecalis* strain no.4 with heterotrophic nitrification and aerobic denitrification. Water Res. 40: 3029-3036.

[15] Itokawa, H., K. Hanaki and T. Matsuo. 2001. Nitrous oxide production in high-loading biological nitrogen removal process under low COD/N ratio condition. Water Res. 35: 657-664.