Volatile Organic Compounds Production from Aerobic Biotreatment of Dairy Wastewater by a Sequencing Batch Reactor

Hong, Jihyung

Department of Industrial Machinery Engineering, Sunchon National University, Sunchon 540-742 Korea

연속회분식반응기(SBR)에 의한 낙농폐수의 호기성처리에서 휘발성유기물질 발생

홍 지 형

순천대학교 산업기계공학과

Summary

Aerobic sequencing batch reactor (SBR) was used to treat screened dairy wastewaters. The study examined the production of volatile organic compounds (VOCs) and volatile fatty acids (VFAs) in the aerobic SBR and raw manure effluent storage over 35 days. The reduction of total VFAs in the aerobic SBR was over 59% removal than that of the raw manure. Acetic acid production in the aerobic SBR and the raw manure effluent storage were kept 138 and 286 mg/L. The propionic acid in the aerobic SBR was 1.9 mg/L, while the raw manure effluent storage was 68 mg/L, respectively. The concentrations of VOCs in the aerobic SBR reactor and effluent fell down remarkably than the raw manure storage. The results confirmed that the aerobic biological treatment is an essential requirement for minimizing odor problems.

(**Key words** : Aerobic sequencing batch reactor, Aerobic biotreatment, Animal manure management, Volatile fatty acids, Volatile organic compounds, Dairywastewater)

INTRODUCTION

Most objectionable odors from livestock operations are the result of volatile compounds generated during the decomposition of manure. Commonly reported odorous compounds associated with manure and waste water are those containing sulfur, nitrogen, volatile fatty acids (VFAs), and phenols and alcohols. VFAs under anaerobic conditions has high odor potential

Corresponding Author : Prof. Jihyung Hong, Dept. of Industrial Machinery Enging., Sunchon National University, Sunchon, 540-742, Korea, Email:davis46@sunchon.ac.kr, Phone:+82-61-750-3263.

while low odor potential under aerobic conditions. VFAs and phenolic cause strong odor (Pfost et al., 1998).

Aerobic biological treatment is the process of microbial degradation and oxidation of animal manure in the presence of oxygen. The odors from the aerobic treatment process are mainly associated with ammonia that is in the wastewater in the absence of nitrification. The fate of the nitrogen in an aerobic process is of particular importance. These results agreed with the findings reported by Elwell et al. (2004) and Wiles et al. (2000). Both these researchers stated that the aerobic manure composting achieved high performance levels within a few days after the start of the study.

Aerobic sequencing batch reactor (SBR) is used for biological removal of nitrogen from the organic wastes. Intermittent aeration is used for achieving the nitrogen removal through nitrification and denitrification. Sequencing of aeration and no-aeration periods in a treatment reactor create alternative aerobic and anoxic environments (Zhang et al., 2000; Fernanades et al., 1991).

Aerobic SBR treatment can effectively control the nature and quantity of nitrogen in the manure. If designed and operated properly, aerobic SBR may become a promising alternative for treating animal wastewater to control odors and reduce solids and nutrient contents (Zhang et al., 2000).

The aerobic SBR treats wastewater in small batches and fits well with most animal wastewater collection systems (Zhang et al., 1999). Fernandes et al.(1991) studied the aerobic SBR for treating highly concentrated swine manure with about 4% TS. The influent COD, NH3-N and TKN were as high as 31,175 mg/L, 1,265 mg/L and 2,580 mg/L, respectively. Their results indicated that above 97% COD, 99% NH3-N and 93% TKN removal efficiencies were achieved in the liquid effluent at HRTs of 6-9 days and SRT of over 20 days.

Several studies (Li and Zhang, 2004; Bicudo et al., 1999) have shown that aerobic SBRs can be used for animal liquid manure. Studies on the gaseous emissions from wastewater treatment to achieve removal of nitrogen, and the aerobic SBR for treating liquid animal manure are still a lack of information regarding general design concepts in the literature. Several studies conducted by Fernandes et al. (1991) and Bicudo et al. (1999) have shown that the SBR can be effectively used for animal wastewater treatment to achieve high organic matter and nitrogen removal. Williams (2001) reported that the SBR system significantly improved odor emission variables associated with liquid swine manure and the biosolids generated by the SBR system involving aeration have higher odor emissions than the treated effluent in this system. The variation in the rate of production of each VOCs concentrations are similar to those reported by Williams (2001), Bicudo et al. (1999), and Fernandes et al. (1991).

The objectives of this study were to quantify the effects of aerobic biological treatment technology on the VOCs production in dairy wastewater treatment using the aerobic sequencing batch reactor, and to determine the reduction of these volatile compounds by the biological treatment technologies.

MATERIALS AND METHODS

Experimental Design and Manure Preparation

Laboratory studies were conducted on an aerobic SBR for the volatile compounds reduction from the aerobic treatment of screened liquid dairy manure. The aerobic SBR was operated on the basis of a 24 hours cycle at 5 days hydraulic retention time and 20 days solids biological retention. The total solids (TS) and volatile solids (VS) concentration of dairy liquid waste was ranged from 3 to 5% and from 1 to 3%, respectively. The organic loading rate (OLR) was 2 g VS/L/day.

Dairy manure was collected from the Dairy Research Farm of the University of California, Davis. The manure was slurried with the addition of tap water and then screened twice with two sieves with openings of 4 × 4 mm and 2 × 2 mm, respectively, to remove large particles. The screened manure was transported immediately to the laboratory and then stored in a freezer at −20°C until use. The TS and chemical oxygen demand (COD) of the screened manure were 30,000 to 40,000 mg/L and 35,000 to 50,000 mg/L, respectively. When needed, the stored manure was thawed and then diluted with tap water to obtain a desired COD concentration.

Due to relatively lower content of ammonia nitrogen of the raw manure as compared to typical levels in the manure collected on dairy farms, urea was added to increase the NH3-N in the prepared manure from 100-125 mg/L to 500-550 mg/L. The prepared manure was then put into a 50-L feeding tank housed in a refrigerator at 4°C for daily use. The feeding tank had an agitator to mix the wastewater during the feeding of the reactors.

Experimental Set-up and Operation

The original, laboratory-scale aerobic SBR system has been described in detail elsewhere (Zhang et al., 2000; Fernandes et al., 1991). The experimental set-up consisted of laboratory scale aerobic sequencing batch reactor systems (Fig. 1). The reactors, with an inner diameter of 114 mm and the height of 600 mm, were fabricated using acrylic plastic cylinders and the provisions were made for service connections.

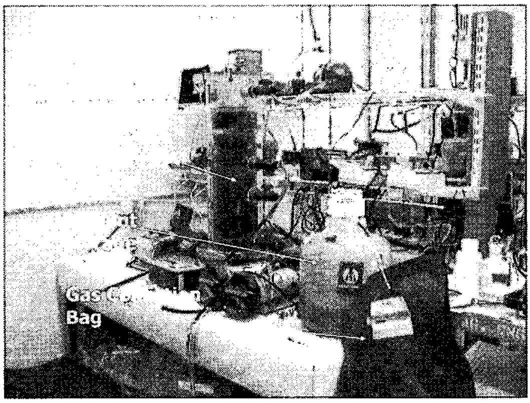

Fig. 1. Experimental photo of aerobic SBR system.

Fig. 2 shows the relevant features of the experimental set-up. A feeding tank (15 liter) with a mixer (Model 50002-30, Cole-Parmer Instrument Co., Vernon Hills, IL, USA), reactor, and gas bag were made of plastic cylinder to facilitate visual observation of

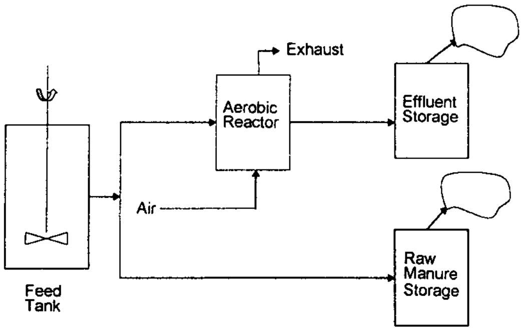

Fig. 2. Diagram of the aerobic SBR and raw manure storage system.

slurry or wastewater behavior in the reactor.

The reactor was connected to two liquid pumps (Model 77200-62, Easy-Load II, Cole-Parmer Instrument Co., Vernon Hills, IL, USA) used for feeding and decanting and to a 10-L Tedlar gas collection bag (Fisher Scientific Pittsburgh, PA., USA), and a wet gas meter (Durant@counter Watertown WI., and Rebel Point Wet Tip Gas Meter Co., Nashville, TN., USA).

The airflow rate into the reactors was about 1.7 L/min per liter of mixed liquor controlled by airflow-meter (Model S400, Dwyer Instrument Inc., WI, USA), which allowed the dissolved oxygen concentration with a dissolved oxygen-meter (YSI, Model 58) to be maintained above 2.5 mg/L and also contributed to the mixing of the liquid content.

The operating volume of the reactor was 4 liters. The reactor was heated to a relatively constant temperature of 25±1℃ using a heated-water jacket (Model 2000, Poly Science, USA).

Initially, the reactor was seeded with 500 mL of dairy wastewater. The reactor was operated on a 24 hr sequencing batch mode according to the sequential phasing shown follow as Mode (time). Fill (3.0 hr), React (19.0 hr), Settle (1.0 hr), Draw (0.5 hr) and Idle (0.5 hr).

Sampling and Analytical Methods

Gas samples were taken twice a week from the sampling port on the gas collection line of reactor and analyzed for volatile compounds using a gas chromatograph (GC) / mass spectrometry (MS) (HP 5890A, Hewlett Packard, Avondale, PA., USA) equipped with a thermal conductivity detector (TCD) and flame ionization detector (FID).

The liquid samples were taken from reactor three times a week and then measured for pH using an Accumet pH meter to monitor the reactor stability. The pH meter was manufactured by Fisher Scientific (Pittsburgh, PA, USA). For each batch digestion, the samples of slurry, before and after digestion were taken and analyzed for TS and VS using standards methods (APHA, 1998).

The reduction of TS and VS in the slurry after digestion were calculated based on mass balances. The VOCs and VFAs production in different storage during the 35-day period were used to evaluate the reduction of volatile compounds in the raw manure storage, reactor and effluent storage.

The chemical analysis was conducted at the analytical laboratory of the Division of Agriculture and Natural Resources at the University of California, Davis. Three replicated determinations were made for each elemental analysis.

RESULTS AND DISCUSSION

VFAs Concentrations

The initial screened dairy wastewater had the pH values of 6.9 ± 0.1. Initial TS and VS were 3 % and 2 %, respectively. The TS and VS reduction of the aerobic SBR were 15.8 % and 29.5 %, respectively.

The VFAs concentrations for the start-up (35 days) period are shown in Table 1. Acetic acid was found major component of the VFA concentration. The highest volumetric acetic concentration reached was 138 mg/L in aerobic SBR effluent and 286 mg/L in raw manure storage (control) until the 35 day.

Table 1. VFAs concentrations in digested effluent and raw manure storage

VFAs(mg/L)	Aerobic reactor effluent	Raw manure storage
Acetic acid	138	286
Propionic acid	1.9	68
Butyric acid	0	22
Isobutyric acid	0	26
Valeric acid	1.4	9.5
Isovaleric acid	0.5	19
Caproic acid	0.7	2.3
Isocaproic acid	0.3	0.8
Heptanoic acid	2.3	2.3
Total VFAs	1446	3502

In the effluent in the aerobic SBR, the propionic, butyric, isobutyric, valeric and isovaleric acids concentration remained fairly lower than that of the raw manure storage (reference). The concentration of the acetic acid in the SBR effluent during the 35 days operation was higher than the others. The butyric and isobutyric acids were not detectable in the effluents after the 35 days. The total VFAs production was measured as 1446 mg/L in aerobic SBR effluent storage and 3,502 mg/L in the raw manure storage during 35 days, respectively.

Based on the VFAs production, the effluent quantity data and the steady state performance were achieved in less odorous than the raw manure storage condition.

VOCs Concentrations

Most objectionable odors from livestock operations are the result of volatile compounds generated during the decompostion of manure. Commonly reported odorous compounds associated with manure and wastewater are those containing sulfur as hydrogen sulfide and mercaptans, those containing nitrogen asd volatile fatty acids etc (Pfost et al., 1998).

VOCs concentrations in gas and liquid phase are shown in Tables 2 and 3, respectively. The highest volumetric acetone, 2-butanone, and benzene production reached in the gas and liquid phase and the acetone, 2-butanone, benzene were formed the major components of the VOC concentration. Under the gas and liquid phase conditions, the acetone removed was 15 times higher compared to the raw manure storage as shown in these two tables. Evidently, most of the VOC was digested in the aerobic reactor. The effluent acetone concentrations decreased 17 to 12 mg/L in the gas phase, and ranged from 24 to 18 μg/L in

Table 2. VOCs concentrations in the gas phase by aerobic SBR and raw manure

VOCs (mg/L)	Raw manure storage	Aerobic reactor	Reactor effluent
Acetone	260	17	12
Carbon disulfide	230	4.4	650
Methylene chloride	0	0	0
2-butanone	180	3.2	0
Benzene	5,500	1.5	16
Tetrahydrofuran	0	2.7	5.9
Cumene	0	1.4	0
Toluene	45	0	3.7
Hexane	ND*	0	0
Cyclohexane	44	0	43
Heptane	500	0	0

* ND : Not detected.

Table 3. VOCs concentrations in the liquid phase by aerobic SBR and raw manure

VOCs (μg/L)	Raw manure storage	Aerobic reactor	Reactor effluent
Acetone	365.34	24.16	17.68
Carbon disulfide	0.00	0.00	0.00
Methylene chloride	0.00	0.00	0.00
2-butanone	283.98	5.05	0.00
Benzene	73.61	0.02	0.21
Tetrahydrofuran	0.00	2.77	6.23
Cumene	0.00	0.03	0.00
Toluene	0.58	0.00	0.05
Hexane	0.00	0.00	0.00
Cyclohexane	0.02	0.00	0.02
Heptane	0.03	0.00	0.00

the liquid phase by aerobic biological SBR system. The concentrations of methylene chloride, cumene, and hexane were very low or undetectable in the aerobic reactor and reactor effluent during the experiment of this study.

CONCLUSION

The production of VOCs emitted during aerobic biological treatment of dairy wastewater was studied at a laboratory-scale SBR. Under the aerobic conditions, the malodorous VFAs and VOCs were significantly declined than that of the raw manure conditions. The concentrations of total VFAs in the aerobic SBR effluent was kept below.

The study also confirms that the aerobic biological SBR is an effective technology for odor control associated with animal wastewater management. It is concluded that the aerobic biological treatment using the SBR system could be used for the odor control treatment of separated liquid animal manure.

적 요

본 연구는 호기성 연속회분식반응기(SBR)에서 낙농폐수의 생물학적처리 과정에서 발생되는 휘발성 유기물질 발생량을 분석한 것이다. 호기성처리 상태에서 악취성분인 휘발성 지방산(VFAs) 및 휘발성 유기물질(VOCs)은 원래 상태보다도 크게 감소하였다. 호기성 연속회분식반응기에서 휘발성지방산은 1,450 mg/L 이하를 나타내고 있었다.

축산폐수처리과정에서 악취처리는 호기성 연속회분식반응기(SBR) 처리 기술이 효과적인 방법이라고 확인되었다. 호기성 연속회분식반응기 시스템은 고액분리된 액상물의 악취물질 제거에 사용될 수 있었다.

(핵심단어 : 호기성연속회분식반응기, 호기성 생물학적처리, 가축배설물관리, 휘발성지방산, 휘발성유기물질, 낙농폐수)

ACKNOWLEDGEMENTS

This work was supported partly by grant from the Professor Exchange Program of the Sunchon National University. The author would like to acknowledge the assistance of my colleagues in laboratories.

REFERENCES

1. APHA. 1998. Standard Methods for the Examination of Water and Wastewater. 18th ed. Washington D.C. : American Public Health Association.
2. Bicudo, J. R., Classen, J. J., Goldsmith, C. D. and Smith, T. 1999. Effects of aeration cycles and hydraulic retention time on the sequencing batch treatment of flushed swine manure. Advances in Environ. Research 3(1):58-73.
3. Elwell, D. L., Borger, D. C., Blaho, D. V., Fahrni, J. K., Keener, H. M. and Willett, L. B. 2004. Changes in concentrations of malodorous compounds during controlled aeration composting. Compost Science and Utilization 12(2):102-107.
4. Fernandes, L., Mckyes, E., Warith, M. and Barrington, S. 1991. Treatment of liquid swine manure in the sequencing batch reactor under aerobic and anoxic conditions. Canadian Agric. Eng. 33(2):373-379.
5. Li, X. and Zhang, R. H. 2004. Integrated anaerobic and aerobic treatment of dairy wastewater with sequencing batch reactors. Transactions of the ASAE 47(1):235-241.
6. Pfost, D. L., Fulhage, C. D. and Hoeme, J. A. 1998. Odors from livestock operations: causes and possible cures. Extension Publication No. G1884.

7. US EPA. Undated, Test Methods for Evaluating Solid Wastes. Ch. 5, Miscellaneous test methods GC/MS, TO-15 & 8260B:VOCs.
8. Wiles, M. C., Elwell, D. L., Willett, L. B., Borger, D. C. and Keener, H. M. 2000. Production of odorous, volatile compounds during composting of hog manure amended with sawdust. Proc. 2nd International Conf. on Air Pollution from Agric. Operations, pp 67-74.
9. Williams, C. M. 2001. Technologies to address air quality issues impacting animal agriculture. Water Science and Technology 44(9): 233-236.
10. Zhang, R. H., Li, X., Collar, C. A. and Fry, R. A. 2000. Aerobic treatment of dairy wastewater with sequencing batch reactor. In: proceedings of the 8th International Symposium on Animal, Agricultural and Food Processing Wastes. October, Des Moines, Iowa, USA. pp. 547-554.
11. Zhang, R. H., Li, X. and Tao, J. 1999. Treatment of dairy wastewater with sequencing batch reactor systems. Presented at the 1999 ASAE Annual International Meeting. ASAE Paper No.994069. St. Joseph, Mich.: ASAE.