ENVIRONMENTAL SCIENCES 2001 Vol. 10, No. S-1, 35~40
Bulletin of the Korean Environmental Sciences Society

The Effect of Enzyme/Microbial Additive on Anaerobic Digestion of Primary Sludge

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(Manuscript received on December 29, 2000)

Effect of the addition of an enzyme/microbial additive(EMA) to enhance anaerobic digestion of the primary sludge was investigated. Two laboratory scale anaerobic digesters were operated with primary sludge taken from a municipal wastewater treatment plant. The digester receiving EMA with the sludge feed performed better than the control digester, when both were operated at 10-days and 15-days Solid Retention Time(SRT). Addition of EMA to the experimental digester provided 7%(10-days SRT) and 16%(15-days SRT) higher gas production compared to the control digester when both were fed with the same amount of volatile solids. The reduction in volatile solids was 24% better in the experimental digester compared to the control at 10-days SRT, and the improvement was 10% at 15-days SRT. Improvement in COD reduction, and fecal coliform density reduction were also seen in the experimental digester due to EMA addition compared to the control, both at 10-days SRT and 15-days SRT operation. Preliminary cost benefit analysis for a wastewater treatment plant showed that approximately $115/day in gas production improvements can be realized upon addition of EMA to primary sludge anaerobic digesters operating at 10-days SRT. The value of increased gas production was $172/day if the same digesters are operated with EMA addition at 15-days SRT.

Key words : Anaerobic digestion, Microbial additive, Primary sludge, SRT

1. Introduction

Anaerobic digestion is traditionally used to treat concentrated waste streams such as municipal wastewater sludge(both primary and secondary) and agricultural wastes like livestock manure. The advantages of anaerobic digestion include a stable product sludge that is low in pathogens, production of sludge gas containing methane, and reduction in the volatile solids content of the sludge. Anaerobic digestion reduces fecal coliform concentrations in wastewater sludge(both primary and secondary combined) from about 10^8/g total solids to about 10^6/g total solids. The volatile solids reduction levels are in the range of 35~50%, and the gas production rates are in the range of 0.7 ~1.0 m^3/kg volatile solids destroyed during anaerobic digestion[1].

Bioaugmentation of anaerobic digestion process by using microbial additives that enhances the rate of digestion has been suggested. Typically, commercial products have been marketed for enhancing the digestion process, and also for reducing odors of organic nature. Wojnowska and Young[2](1983) obtained moderate success from the application of such commercial microbial products in wastewater treatment units. It was shown that enhanced performance could be achieved in anaerobic digesters in municipal wastewater treatment plant by bioaugmentation[3]. Kim *et al.*[4](1999) showed that addition of microbial products enhanced VS reduction, COD reduction, and gas production rate in anaerobic digestion of swine waste. However, there are no sufficient data to validate the claims of commercial products in enhancing the treatment and reduction of odors during treatment of swine waste by anaerobic digestion. Park[5](1998) made an experiment of sludge dewaterability by adding the mixture of protease and cellulase. It was shown that leaching concentration increased with the amount of addition.

The purpose of this research was to demonstrate the treatment of primary sludge by anaerobic digestion under standard hydraulic conditions, and to investigate the ability of a patented enzyme/microbial additive(EMA) to enhance anaerobic digestion in terms of VS reduction, pathogen destruction, gas production, and odor component reduction.

2. Experiments

2.1. Materials

Laboratory scale anaerobic digesters with the supply of primary sludge from Hammond, Indiana municipal wastewater treatment plant(HWTP) have been used to evaluate the advantages of adding EMA to enhance sludge digestion. Primary sludge was selected because it is the most pathogenous sludge stream in wastewater treatment plants and contains unstabilized organic material that yields methane-containing sludge gas. The average characteristics of the primary sludge feed from HWTP is shown in Table 1.

Table 1. Average characteristics of experimental sludge

Items	Value
Total solids, mg/L	15,000~20,000
Volatile solids, mg/L	11,000~14,500
COD, mg/L	4,500~5,500
pH	6.6~7.0
Alkalinity, mg $CaCO_3$/L	2,800~3,800
Volatile acids concentrations, mg/L	400~550
Fecal coliform density, MPN/g TS	10^7~10^9

The wastewater received by HWTP is predominantly domestic wastewater with less than 25% industrial and commercial wastewater. This type of wastewater is typical for most municipal wastewater treatment plants in the US. Hence, the primary sludge feed used in this study was not expected to have any unusual constituents to affect the results from the experiments. The average primary sludge characteristics shown in Table 1 are typical of those expected in a conventional municipal wastewater treatment plant.

The EMA comprises an enzyme mixture including amylase, lipase, and protease; active facultative and anaerobic bacteria including *Pseudomonas florescence*; and a nutrient source consisting of mushroom compost. The function of EMA is to provide active enzymes that initiate hydrolysis of particulate and a readily available nitrogen source for bacterial growth.

EMA activated in freshwater at 37.8℃ for 24 hours, and acclimated in the feed sludge for another 24 hours was fed to the experimental digester. 1.13g of dry EMA was suspended in 50 mL of tap water(23 g EMA /L water) held at 37.8℃ for a period of 24 hours. An open vessel was filled with 950 mL of primary sludge from HWTP and 50 mL of the activated EMA solution, and held at 37.8℃ for 24-hour period. The resulting feed sludge contained 1130 mg EMA/L. The COD of the EMA solution(1130 mg EMA/L) was found to be 600 mg/L. The contents of the acclimation vessel were inoculated into the experimental digester as the feed, and the entire procedure was repeated every day. The average oxygen uptake rate, and pH of the activated EMA were 22.8 mg O_2/g EMA/hr, and 6.95 respectively.

2.2. Methods

The control digester was fed with the same feed primary sludge from HWTP as the experimental digester, but without EMA addition. The primary sludge feed to the control digester was diluted with tap water(950 mL sludge : 50 mL tap water) to achieve approximately same solids loading rate to both the experimental and the control digesters. The two lab scale(10 L volume) digesters were operated at a sludge retention time(SRT) of 10 days and later at 15 days, with once a day batch feed of the primary sludge and removal of the product sludge(Fig.1). One digester operated

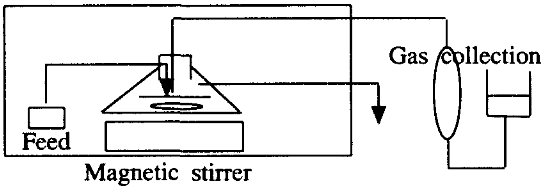

Fig. 1. Digestion apparatus.

without EMA addition served as the control, and the other digester was used as the experimental digester with EMA addition. The digesters were heated and mixed by placing on a heavy duty magnetic stirrer/heaters.

The digesters were operated for a period of 10 weeks with a 10-days initial startup period. Initially, the digesters were operated at 10-days for 6 weeks, and then at 15-days SRT for a period of 3.5 weeks. In order to determine if EMA is more effective at higher sludge retention time in the anaerobic digesters, both the experimental digester and control digester were converted to 15-days retention time from the earlier 10-days retention time. The digesters were operated as before, with the experimental digester receiving the EMA product, and the control digester did not receive any supplement. The performance of both the experimental and the control digesters were assessed by determining the total solids, volatile solids, COD, and fecal coliform density of the feed and the product sludge twice a week. Gas production from each digester was measured by collecting the gas in a plexiglass column using water displacement method. The operation of the digesters was assessed by measuring the pH, alkalinity, and volatile acid concentrations of the digester contents twice a week.

The temperature of the digester contents was maintained at 37℃ by the heater/stirrer to simulate typical anaerobic digester temperature. The pH of the digesters was near neutral (pH=7.0 - 7.2) throughout the experiments. All analytical tests conducted were according to Standard Methods for the Examination of Water and Wastewater[6].

Both, control and experimental digesters were initially seeded with mixed(primary and waste activated) sludge from Hammond Wastewater Treatment Plant(HWTP), and HWTP primary sludge was used as the feed at the rate of 1 L/day. An amount equivalent to the daily feed was wasted from the digester every day to provide capacity for the new feed. Both, feed sludge and product sludge were sampled and analyzed to check the performance and operating parameters of the digesters twice a week.

3. Results and Discussion

3.1. Anaerobic digestion operated at 10-days SRT

The difference in the performance of the two digesters according to each of the parameters measured are presented in Table 2. The results presented in Table 2 are average based on 5 weeks of data after initial startup period of 10 days. Each parameter was measured twice a week.

Based on the results in Table 2, it can be seen that the addition of EMA to anaerobic digester having municipal primary sludge improved the performance of the digester when compared to the control digester performance without EMA addition. The most significant improvement due to EMA addition was seen in the volatile solids destruction and in the chemical oxygen demand (COD) reduction, which are two of the main parameters of organic waste strength. The improvement in fecal coliform reduction, and gas production rates were 9% and 7% respectively,

Table 2. Average treatment efficiency of EMA added digester and the control digester operated at 10-days SRT

Items	Control digester	EMA digester	Difference	% Improvement
Volatile solids reduction,%	33	41	+8%	+ 24%
Total solids reduction, %	29	34	+5%	+ 17%
COD reduction, %	29	34	+5%	+ 17%
Gas production, m^3/Kg VS removed	0.68	0.72	+0.04	+ 7%
Fecal coliform reduction, Log.	2.07	2.24	+0.17	+ 9%

Table 3. Average treatment efficiency of EMA added digester and the control digester operated at 15-days SRT

Items	Control digester	EMA digester	Difference	% Improvement
Volatile solids reduction, %	51	56	+5%	+ 10%
Total solids reduction, %	44	49	+5%	+ 11%
COD reduction, %	38	44	+8%	+ 21%
Gas production, m^3/Kg VS removed	0.76	0.88	+0.12	+ 16%
Fecal coliform reduction, Log.	2.10	2.21	+0.11	+ 5%

indicating that addition of EMA did not significantly enhance those two functions of the anaerobic digestion process.

However, it should be noted that since higher volatile solids are destroyed due to EMA addition, larger volume of gas is produced compared to the control when both are fed with the same amount of sludge. Hence, the combination of greater volatile solids reduction and higher gas production rates result in 31% increase in overall gas production. It was thought that addition of microbial enzymes might increase the solubility of feed sludge to have more gas production[7].

3.2. Anaerobic digestion operated at 15-days SRT

The results presented in Table 3 are a summary of two weeks of operation at 15-days SRT after one SRT of startup period.

It can be seen from results in Table 3 that both the experimental digester and the control digester performed much better at 15-days SRT compared to the 10-days SRT operation in Table 2. The experimental digester with EMA addition showed better performance than the control digester even at 15-days SRT. However, there was only a 10% increase in the volatile solids reduction compared to the 24% increase obtained at 10-days SRT. There was a 16% increase in the gas production rate(m^3 gas/kg VS destroyed) in the EMA added digester compared to the control digester without any supplement. Hence, the combination of higher volatile solids reduction and greater gas production rate in the EMA added experimental digester, resulted in 26% increase in the volume of gas production compared to the control digester without the EMA addition.

3.3. Statistical significance test

The statistical significance of the above results was tested by conducting paired t-Test for significance at 95% confidence interval. The significance of the differences in performance between the experimental digester(with EMA addition) and the control digester(without EMA addition) are shown in Table 4. It can be seen from Table 4 that both at 10-days and 15-days SRT, the performance of the experimental digester was significantly better than that achieved by the control digester for all parameters measured.

Table 4. Paired t-test of performances of experimental digester and the control digester at 95% confidence level

Items	10-days SRT	15-days SRT
Volatile solids reduction	S	S
Total solids reduction	S	S
COD reduction	S	S
Gas production	S	S
Fecal coliform reduction	S	S

S : Significant
NS : Not Significant

3.4. Cost benefit analysis

An hypothetical example of a wastewater treatment plant is illustrated in Table 5 to show the benefit of using EMA for enhancing primary sludge anaerobic digestion.

Basic calculations for 10-days SRT anaerobic digestions are presented in Table 6.

Based on the above calculations, the gain in energy production due to EMA addition is $115/day, which amounts to an yearly benefit of $41,975. This cost benefit does not include the

Table 5. Hypothetical values of a wastewater treatment plant

Items	Value
Flow, m^3/day	18926.3
Influent TSS, mg/L	200
VS, %	80
Primary TSS Removal, %	65
Primary Sludge Production, kg/day	2460
Volatile Solids Production, kg/day	1969

reduction in costs associated with lower residuals disposal to a landfill or landfarm. Similar calculations for the 15-days SRT scenario are shown in Table 7.

Based on the above calculations, the gain in energy production due to EMA addition is \$172/day, which amounts to an yearly benefit of \$62,780. This cost benefit does not include the reduction in costs associated with lower residuals disposal to a landfill or landfarm. The dose of EMA used during these experiments and other work was approximately 0.068 g/g of TS. For this example, the amount of EMA needed is equal to 167 kg EMA/day(0.068 g/g of TS × 2460 kg/day). According to 10-days SRT example, pricing of EMA below \$0.69/kg(\$115 ÷ 167 kg EMA/day) and according to 15-days SRT example, pricing of EMA below \$1.03/kg would make its application economically feasible. However, this hypothetical example calculations are completely theoretical, and the actual figures may be more or less depending on the performance of the EMA for specific applications.

4. Conclusions

Based on the above discussed results, it can be seen that the EMA addition enhanced primary sludge digestion in terms of organic matter destruction, pathogen reduction, and gas production. The most significant improvement is in the combination of volatile solids reduction and gas production rate. This results in less solids residuals to be disposed off or reused, and greater energy production. The overall gas production, due to increased volatile solids destruction and greater gas production rates, increased by 31% and 26% for 10-days SRT and 15-days SRT respectively due to EMA addition to the digester. Based on the cost benefit analysis, it was expected that pricing of EMA below \$1.03/kg would make its application economically feasible.

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Table 6. Hypothetical calculations of EMA added digester and the control digester operated at 10-days SRT

Parameter	Control digester	EMA digester
Volatile solids destroyed, kg/day	1969 × 0.33 = 650	1969 × 0.41 = 807
Gas production, m^3 gas/day	650 × 0.68 = 442	807 × 0.72 = 581
Energy production*, m^3 gas/day	442 × 0.75 = 331.5	581 × 0.75 = 436
Gas value** \$1.10/m^3 gas	331.5 × 1.10 = \$365	436 × 1.10 = \$480

* Digester gas has a heating value of about 75% of natural gas
** Average natural gas price during fiscal year 1996

Table 7. Hypothetical calculations of EMA added digester and the control digester operated at 15-days SRT

Parameter	Control digester	EMA digester
Volatile solids destroyed, kg/day	1969 × 0.51 = 1004	1969 × 0.56 = 1103
Gas production, m^3 gas/day	1004 × 0.76 = 763	1103 × 0.88 = 971
Energy production*, m^3 gas/day	763 × 0.75 = 572	971 × 0.75 = 728
Gas value** \$1.10/m^3 gas	572 × 1.10 = \$629	728 × 1.10 = \$801

* Digester gas has a heating value of about 75% of natural gas
** Average natural gas price during fiscal year 1996

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