Anaerobic co-digestion of municipal sludge with FOG enhances the destruction of sludge solids

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Abstract
The objective of this study was to investigate the benefits of co-digestion of a sludge-mix of primary sludge (PS)/thickened waste activated sludge (TWAS) with concentrated fat-oil-grease (FOG) over a wide range of FOG/sludge-mix volumetric feed ratios. The biodegradability (i.e., COD to methane conversion) of PS, TWAS, sludge-mix, and FOG was 43.0, 38.6, 41.8, and 97.7%, respectively, with a pseudo first-order rate of 0.13, 0.12, 0.13, and 0.18 d^{-1}, respectively. Batch co-digestion of sludge-mix and FOG at COD ratios ranging from 93.2:6.8 to 27.3:72.7% resulted in methane production linearly correlated to both the total waste blend and FOG COD loading and an enhanced degradation of the sludge-mix COD to as much as 10.9% (increased from 42.2 to 53.1%) when the feed FOG COD was 18.5% of the total waste COD loading. Overall, co-digestion of mixed municipal sludge with FOG is feasible and recommended to meet target biogas/methane levels at municipal wastewater treatment facilities taking into account the trade-off between energy production and solids destruction to fit their particular needs.

Keywords
Co-digestion; biogas; FOG; methanogenesis; VS destruction; ultimate digestibility

INTRODUCTION

Anaerobic co-digestion of two or more waste streams has been tested for municipal sewage sludge co-digested with a range of high strength waste streams such as fat-oil-grease (FOG), food, agricultural, animal, and industrial wastes (Mata-Alvarez et al., 2011; Tezel et al., 2011). Co-substrate selection depends on its properties, such as digestibility, complementary nutrient richness, and toxicity; its cost, availability, as well as transportation, handling, and storing considerations also determine the economic feasibility of municipal sludge co-digestion. The benefits of anaerobic co-digestion of organic wastes have recently been reviewed (Esposito et al., 2012). Analysis of ultimate digestibility data from co-digestion tests conducted with mixtures of waste streams has traditionally assumed that each waste stream is degraded and utilized independently (i.e., there is no interaction). However, based on previous anaerobic digestibility tests conducted in our laboratory with municipal sludge co-digested with high-strength, highly degradable waste streams, an increase of sludge ultimate digestibility was observed in the case of co-digestion, over that measured when sludge was digested alone (Kabouris et al., 2008; Tandukar and Pavlostathis, 2011). Although we have attributed such results to an enhancement of sludge digestibility brought about by the relatively higher microbial activity supported by the highly degradable, high-strength waste streams, quantitative confirmation of such a beneficial effect has not been documented. It should be noted that in addition to an increased ultimate sludge digestibility during co-digestion, which leads to higher methane yield, a higher extent of solids destruction is equally as important a benefit of sludge co-digestion in terms of sludge management and final disposal. Additional benefits from potential increased kinetics may also result in the case of sludge co-digestion, which could have a significant, positive impact on the digester residence time. The objective of the present study was to delineate the benefits of municipal sludge co-digestion with concentrated FOG over a wide range of FOG/sludge volumetric feed ratios.

MATERIALS & METHODS

Waste samples

Primary sludge (PS), thickened waste activated sludge (TWAS), and digested sludge samples were collected at the F. Wayne Hill Water Resource Center, Gwinnet County, GA, USA. Concentrated FOG was provided by a commercial FOG management company. A sludge-mix was prepared by mixing PS and TWAS at a ratio of 40:60% on a TS basis just before the test was conducted. The following analyses were performed for all samples: pH, total and volatile solids (TS, VS), total and soluble chemical oxygen demand (COD), volatile fatty acids (VFAs), ammonia, total Kjeldahl nitrogen (TKN), protein, lipids, and carbohydrates.

Ultimate Digestibility Test

Ten 1-L glass reactors (R1-R10), sealed with rubber stoppers and flushed with helium gas, were set up as previously described (Kabouris et al., 2008). R1 contained seed (pre-incubated digester contents obtained from a municipal mesophilic anaerobic digester) and media (seed control). Three reactors (R2, R3, and R4) were set up with seed, media, and PS, TWAS, or sludge-mix, respectively (sludge controls). R5 contained seed, media, and FOG only (FOG control). Five reactors (R6 through R10) were set up with seed, media, sludge-mix and FOG at increasing FOG/sludge-mix volumetric feed ratios from 2.1 to 44.1% (v/v), with a feed total COD loading ranging from 5.3 to 10.3 g/L; the FOG-COD contribution ranged from 6.8 to 72.7% of the total initial feed COD. The seed concentration in all ten reactors was 2 g VS/L. Incubation was carried out in the dark at 35^{o}C and the reactors contents were mixed once a day using magnetic stirrers. During incubation, the following analyses were conducted: gas production and composition, pH, soluble and total COD, VFAs, ammonia, TS, VS, TKN, total and dissolved sulfides, protein, lipids, and carbohydrates.

Analytical methods

TS, VS, pH, COD, VFAs, TKN, and ammonia measurements were conducted according to *Standard Methods* (APHA, 2012). Total gas production was measured via a pressure/vacuum transducer. VFAs, gas composition (CH_4, CO_2, and H_2S), total, and dissolved sulfides were measured as previously reported (Tugtas and Pavlostathis, 2007). Crude protein was estimated based on organic nitrogen measurements. Total carbohydrates and lipids were measured using the anthrone method (Gaudy, 1962) and a modified chloroform-methanol extraction procedure (Loehr and Rohlich, 1962), respectively.

RESULTS & DISCUSSION

Gas production

Seed-corrected methane production from each reactor over the 84-d incubation, normalized to the initial total substrate COD, is shown in Figure 1. Methane production lag was observed in the FOG-amended reactors, reaching 12 days in R10, which had the highest initial FOG concentration. All reactors achieved more than 80% of their ultimate methane production between 18 and 20 days past the lag phase. CO_2 production was higher and had a smaller lag than methane production, indicating that, compared to methanogenesis, fermentation was not delayed in the FOG-amended reactors. Based on pH, COD, VFAs, and ammonia data, it was concluded that the lag in methane production in the FOG-amended reactors was not the result of excessive VFAs build-up and acidification, but rather acclimation of the digested sludge seed to the relatively high FOG levels used in these reactors. The biodegradability (i.e., COD to methane conversion) of PS, TWAS, sludge-mix, and FOG was 43.0, 38.6, 41.8, and 97.7%, respectively, with a pseudo first-order rate of 0.13, 0.12, 0.13, and 0.18 d^{-1}, respectively.

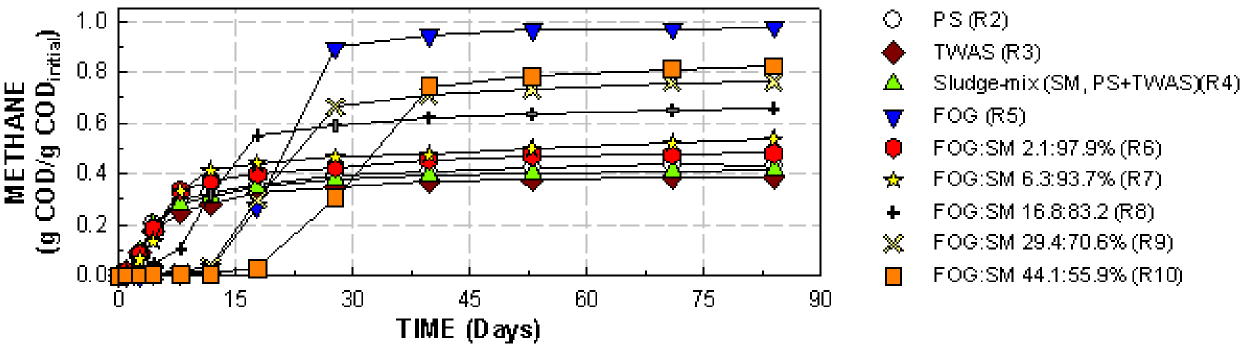

Figure 1. Seed-corrected, cumulative methane production normalized to the initial total substrate COD.

Extent of biodegradation

The VS destruction was 42% in the sludge-amended reactors and increased to about 97% in R5 (FOG control) as the initial FOG level increased. The total COD destruction increased from 42.2% in the sludge-mix amended reactor to as high as 92.1% in R5. The methane content ranged between 62.8 and 71.2%. The net methane production ranged from 515 to 769 mL at 35^{o}C for the reactors amended with sludge only (R2, R3, and R4), and increased by increasing the FOG fraction, reaching the highest value of 2,499 mL at 35^{o}C in R10. The highest methane yield normalized to the initial total substrate COD (97.7%) was achieved by R5 (FOG control). The methane production in reactors R6 to R10 increased proportionally to the sludge-mix and FOG COD loading level (Figure 2A). The sludge-mix derived methane was calculated assuming that the observed FOG ultimate digestibility (97.7%) applied also in the case of R6 to R10 during co-digestion with the sludge-mix. Methane production was linearly correlated with the initial COD level of the waste blend (sludge-mix+FOG), the FOG, and the sludge-mix. Linearity implies that none of the reactors was organically overloaded. In the case of sludge-mix and FOG co-digestion in R6 to R10, the methane production as a function of total initial waste blend COD is as follows:
$M = [(0.977)\ f_{FOG}) + (0.439)\ f_{SM}]\ tCOD$ where, M is methane production (mg COD/L reactor); f_{FOG} and f_{SM} is the FOG and sludge-mix fraction of the total initial waste blend COD, respectively; and *tCOD* is the total initial waste blend COD (mg/L). The extent of destruction of carbohydrates, protein, and lipids, as well as kinetic analysis of COD destruction and conversion to methane were evaluated (data not shown).

Enhancement of sludge solids destruction

The expected COD/VS destruction of the FOG/sludge-mix blend in R6-R10 was calculated as the weighted value based on the ultimate degradability of the sludge-mix and FOG in the control reactors (R4 and R5, respectively) and the fraction of each waste component in the five reactors (R6-R10). Assuming that the seed biodegradability was the same in the seed control as well as in all test reactors, all data were seed corrected. Then, any additional COD/VS destruction was calculated by subtracting the estimated values from the observed ones. Because the FOG-COD conversion to methane, as well as the COD and VS destruction were very high in the FOG control (R5)(97.7, 92.1, and 96.9 %, respectively), any calculated additional COD/VS destruction was assigned to the sludge-mix component of the feed. The sludge-mix degradation based on COD and VS destruction ranged from 42.4 to 53.1 and from 43.1 to 54.6, respectively, while the extent of the sludge-mix COD and VS destruction in R4 (sludge-mix control) was 42.2 and 42.8%, respectively. Thus, the extent of both COD and VS destruction of the sludge-mix in reactors R6 to R10 was higher than that observed in the control reactor (R4), but the enhancement diminished as the FOG loading increased from reactor R6 to R10, which had the highest FOG/sludge-mix COD and VS ratio, and thus the lowest sludge-mix level. As a result of co-digestion of sludge-mix with FOG, the sludge-

mix degradation was enhanced by 0.2 to 10.9% based on COD data (Figure 2B), and by 0.3 to 11.8% based on VS data (Figure 2C). For the conditions of this study, although relatively high FOG levels can be co-digested with municipal sludge resulting in high methane yields, it appears that F
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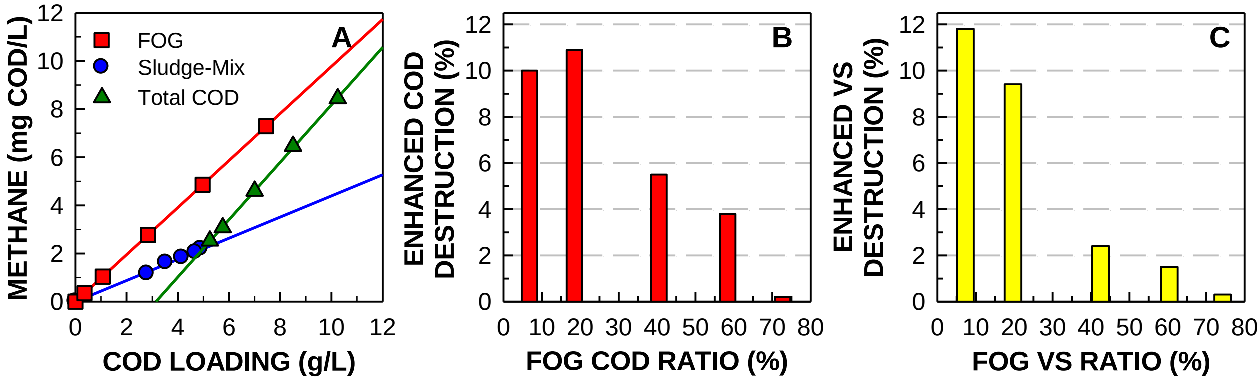

Figure 2. Methane production normalized to reactor liquid volume as a function of initial total waste blend, sludge-mix, and FOG COD level (A) and enhanced sludge-mix COD (B) and VS destruction (C) as a function of initial FOG COD and VS ratio in batch reactors amended with sludge-mix and FOG (Reactors R6 to R10).

CONCLUSIONS

Co-digestion of municipal sludge with FOG increased methane production and enhanced the destruction of sludge COD and VS as compared to digestion of municipal sludge alone. However, the enhanced methane production, COD and VS destruction of the sludge-mix decreased when the waste blend FOG:sludge-mix COD ratio was above 20:80%, which corresponds to a total waste loading of 5.8 g COD/L. High methane production can be achieved with an increased high-strength waste loading as long as the digester retention time, as well as the COD and VS destruction do not drop below acceptable lower values. Such decisions should be based on optimization taking into account the overall digestion system performance along with other, plant-wide materials and permit constraints in order to benefit from the trade-off between energy production and solids destruction to meet the needs of a wastewater treatment facility.

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