On-Farm Co-Digestion of Food Waste with Dairy Manure

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INTRODUCTION

Sustainable management of biowastes is currently a major concern in the United States. As of 2007, the United States had over 1 million livestock and poultry operations, 6.6% of which were dairy facilities - 69,890 dairy farms (US NASS, 2009). A variety of methods are used to collect, store, and treat manure. As concerns over water quality and other environmental factors increase, improved methods for manure treatment, including anaerobic digestion, are being utilized.

Anaerobic digestion is a biological technology for the treatment of organic wastes and the production of biogas, which can be used as a fuel for heating or co-generation of electricity and heat. In addition to renewable energy production, the utilization of anaerobic digestion technology results in other benefits: (1) improved water quality, (2) decreased odor, (3) reduced greenhouse gas emissions, and (4) increased income from non-market benefits (tipping fees, digested fiber, and carbon trading) (Archer and Kirsop, 1990; Powers et al., 1999; USEPA, 2004; Clemens et al., 2006; Klavon, 2011).

Anaerobic digestion of animal manure has been extensively researched and demonstrated. However, based on investment returns from energy production, the economics of dairy digesters are not always favorable due partly to the relatively low biogas yield of dairy manure, as compared to many other types of organic wastes such as food waste. One approach for improving the economics of dairy digesters is to increase their biogas production rate by co-digesting the manure with more degradable wastes, provided that there are appropriate off-farm wastes available in the vicinity of dairy farms and the farm land is capable of incorporating additional nutrients and salts in the off-farm wastes (El Mashad and Zhang, 2010). Nevertheless, the type and ratio of food waste used in the co-digestion process needs to be carefully considered in order to prevent an adverse reduction in biogas production. The purpose of this research was to study the methane production potential of different food waste as a co-digestion substrate with dairy manure.

Study Site

Food waste samples were taken from a dairy farm in Rising Sun, MD that accepts food waste in a covered lagoon digester. The digester input consists of 98% of cow manure and the remaining 2% is a mixture of wastes from cranberry, ice cream, turkey and meatball production processing. The chicken fat and ice-cream wastes are introduced into the digester once a week and the cranberry and meatball fat wastes are adding on alternate weeks.

METHOD

Sample Characterization

The samples were collected in October 2011 and transported to the laboratory on ice. Once reaching the laboratory, the samples were characterized for pH, total solids (TS), volatile solids (VS), and chemical oxygen demand (COD), according to Standard Methods (APHA, 1998).

Specific Methanogenic Activity Test (SMA)

Specific methanogenic activity tests (SMA) were used to characterize available inoculum sources, prior to incubation, as developed by Zeeuw (1984). In this study, the SMA was conducted based on the methods of Sorensen (1993) and used to determinate if the inoculum of the effluent of Kilby farm (co-digestion system) was a better inoculum source for the laboratory testing compared to a inoculum source from a digestion system that does not utilize food waste co-digestion. Effluent and Influent from Kilby digester and the effluent from a dairy manure-only digester at the USDA Beltsville Agricultural Research Center (BARC), located in Beltsville-Maryland, were analyzed.

The SMA test determines accumulated methane in serum bottles (70ml) spiked with acetate over a 48-hour test period. The bottles were filled with 50 ml of the respective test inoculum source and 2 ml of acetate (30 g/l), purged with O_2-free gas (N_2/CO_2 at 70/30), sealed with butyl rubber stoppers and aluminum crimps and placed on a shaker in an environmental chamber at 35°C (Table 1). Gas sampling began three hours after incubation and was determined every three hours for the first 24 hours, and three times per day for the remainder of the 48-hour test period. Bottles without acetate substrate were included as controls and prepared and tested in the manner described above.

Table 1: SMA test design

	Inoculum source (ml)	**Acetate (ml)**	**DI water (ml)**	**# Bottles**
Manure Control	50	-	2	3
Manure Acetate	50	2	-	3
Kilby Effluent Control	50	-	2	3
Kilby Effluent Acetate	50	2	-	3
BARC Control	50	-	2	3
BARC Acetate	50	2	-	3

Triplicate samples from each substrate were taken to determinate the TS and VS content of the biomass prior to incubation. To estimate the pH change of the biomass due to gassing and/or addition of substrates, the pH was measure after the addition of each substrate and after purging with the N_2/CO_2 mixture. Additionally, the pH in the bottles at the end of the experiments was measured to check if any significant changes had occurred.

Anaerobic Toxicity Assay (ATA)

Through Anaerobic Toxicity Assays (ATAs), the four industrial food wastes were analyzed in order to determine their potential toxicity as possible co-digestion substrate. Anaerobic inoculum and the standard feedstock were assayed without food waste as controls and in combination with varying percentages of four potential toxicants, as shown in Table 2. The feedstock was prepared based on feedstock requirement reported by Moody (2011).

Table 2: Assay Volume for potential toxicant (2-30% inclusion)

Toxicant	2%	5%	15%	30%	0% - control	0% - Glucose Control
Pot. Toxicant (mL)	0.6	1.6	4.8	9.6	0.0	0.0
DI water (mL)	31.4	30.4	27.2	22.4	34.0	32.0
Inoculum (mL)	32.0	32.0	32.0	32.0	32.0	32.0
Feedstock (mL)	2.0	2.0	2.0	2.0	0.0	2.0
Total Vol.	66	66	66	66	66	66
Total Gas space	94	94	94	94	94	94
# of Bottles	3	3	3	3	3	3

The inoculum for the ATA was the effluent of Kilby farm digester, as identified in the SMA results. The headspace in each bottle was purged with a mix of 30% CO_2 and 70% N_2 to establish anaerobic conditions after the substrates were added to the bottles. The bottles were incubated under mesophilic conditions (35°C) for four days. All assays, including the feedstock and inoculum control, were performed in triplicate. Biogas production and biogas methane content were measured daily. The results were used to calculate the percent inhibition of methane production for each substrate inclusion rate. Biogas production was measured via volume displacement using a 50-mL wetted glass, gas tight graduated syringe with two mL gradations. The methane content of the biogas was determined using an FID Gas Chromatography.

RESULTS

The initial characterizations of the substrate (TS, VS, pH) are provided in Table 3.

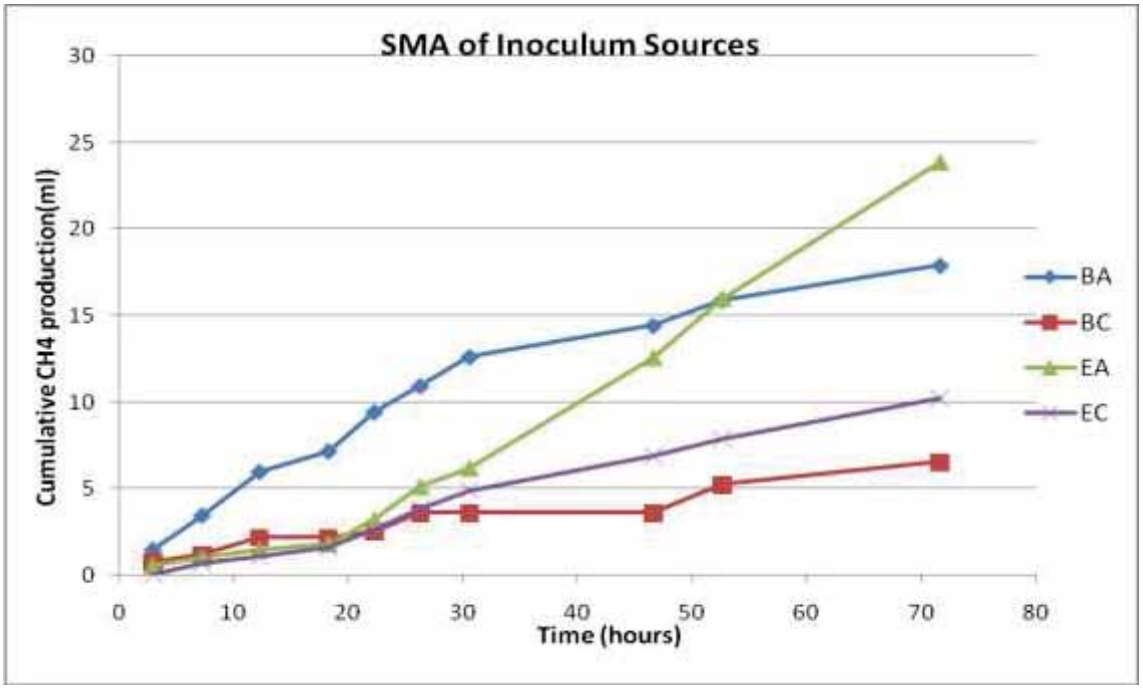
Table 3: Characterization of the waste substrates. TS=Total Solids, VS=volatile solids.

Substrate	TS (mg/g)	VS (mg/g)	pH
Meatball	127	119	4.42
Chicken	283	271	5.79
Cranberry	227	227	2.85
Ice-Cream	5.7	11.6	4.39
Kilby's Effluent	7.2	6.3	6.88
BARC Inoculum	15.8	7.9	7.66

SMA Results

The SMA test results showed that the difference between methane production using the Kilby Farm effluent inoculum source and the BARC manure-only digester inoculum source were not significantly different (Figure 1), with the Kilby Farm effluent having a slightly higher methane production compared to the BARC manure-only digester inoculum source, and therefore in the remainder of this study, Kilby's effluent was chosen as the inoculum source.

Figure 1: Methane production comparing the digester BARC (B) and Kilby's effluent (E) as inoculum sources with acetate (A) and without acetate (C).



ATA Results

The cumulative daily methane productions for the ATA experiments are shown in Figure 2. After graphing the cumulative production, the linear segment of the resulting curve was selected (between Days 2 and 3) and percent inhibition (I) was calculated for each potential toxicant's inclusion rate using Equation 1, a modification from the one proposed in Moody et al. (2011).

Equation 1:

$I=1-[(VolCH_4test)-(VolCH_4Con)/(VolCH_4FeedCon)-(VolCH_4Con)]*100$

Where *$VolCH_4test$* is the methane volume produced per milliliter of toxicant added at the selected time (48 hours) for each potential toxicant percentage inclusion, *$VolCH_4Con$* is the volume of methane produced at the selected time for the inoculum control, and *$VolCH_4FeedCon$* is the volume of methane produced at the selected time for the feedstock control. A negative value for percent inhibition indicates there was no inhibition; a positive value indicates the percentage inhibition related to the potential toxicant.

For all the four substrates tested, the ATA results showed effects of toxicity (Table 4). For cranberry waste and meatball fat, the methane production for each inclusion rate was lower than the feed control (only containing standard feedstock and inoculum) (Figure 2a & 2b). For chicken fat and ice cream wastes, the methane production was lower than the feed control for all the inclusion rates, except the 2% where the methane production was greater (Figure 2c & 2d).

Table 4: Inhibition percentage for each substrate analyzed with four different inclusion rate (2, 5, 15 & 30%). (A negative value indicates no inhibition; a positive value indicates the percentage inhibition related to the potential toxicant)

Substrate	**Percent Inhibition (I) based on each Inclusion rate**			
	2%	**5%**	**15%**	**30%**
Cranberry	11.2	21.5	23.7	25.4
Chicken	-5.79	19.5	23.1	25.0
Meatball	-22.4	12.5	25.4	26.2
Ice-cream	-66.1	7.03	21.9	24.7

The percent inhibition for cranberry waste ranged from 11 to 25%, for meatball fat inhibition ranged from -5 to 25%, while the chicken and ice cream waste had inhibition values ranging between -22 to 26%.

DISCUSSION

Literature has shown that the inclusion of food waste as a co-digestion substrate can greatly increase methane production (Lansing et al., 2008; El Mashad and Zhang, 2010; Rongping et al., 2010). However, in the case of the four substrate analyzed in this study, the inclusion percentage above the 5% begin to exhibit signs of toxicity. Toxicity in co-digestion of pig manure and grease and fats wastes were also shown in Lansing et al. (2010) when the percentage was 5%, with no toxic effects at 2.5%. These findings show the importance of performance ATAs before possible co-digestion food products are introduced into anaerobic digestion environments.

Figure 2a: Anaerobic toxicity assay result analysis for the cranberry waste (CR), cumulative methane production for each inclusion rate (2, 5, 15 & 30%) in comparison to the feedstock control (Feed_Con) and inoculum control (In_CON).

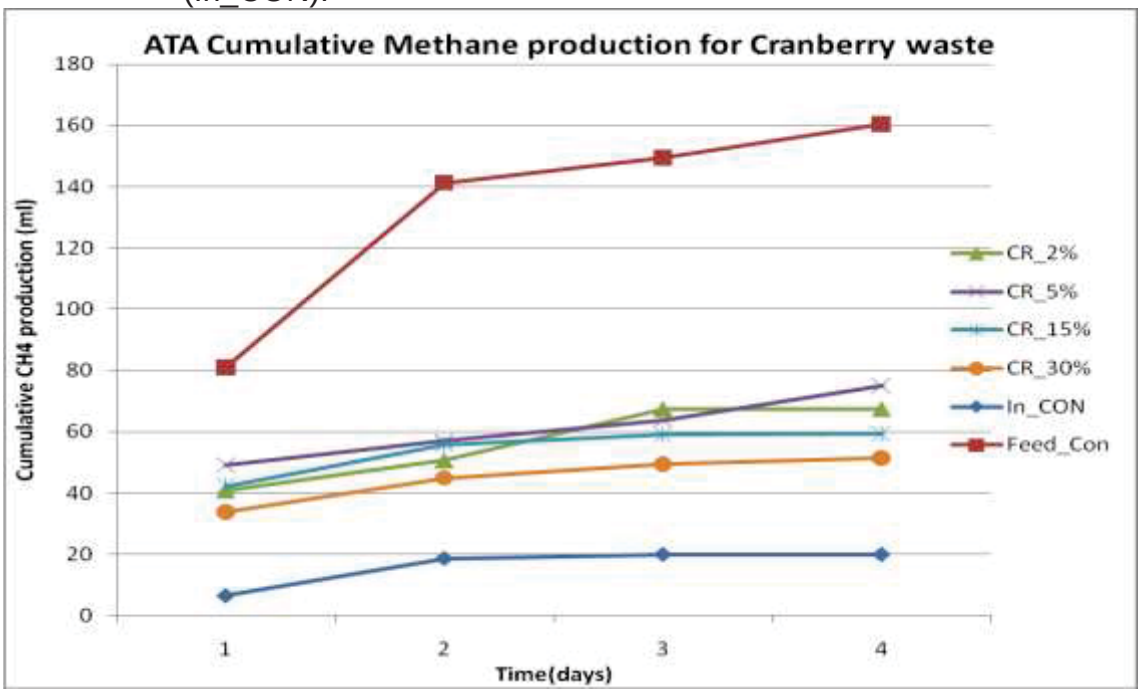


Figure 2b: Anaerobic toxicity assay result analysis for the Meatball fat (MB), cumulative methane production for each inclusion rate (2, 5, 15 & 30%) in comparison to the feedstock control (Feed_Con) and inoculum control (In_CON)

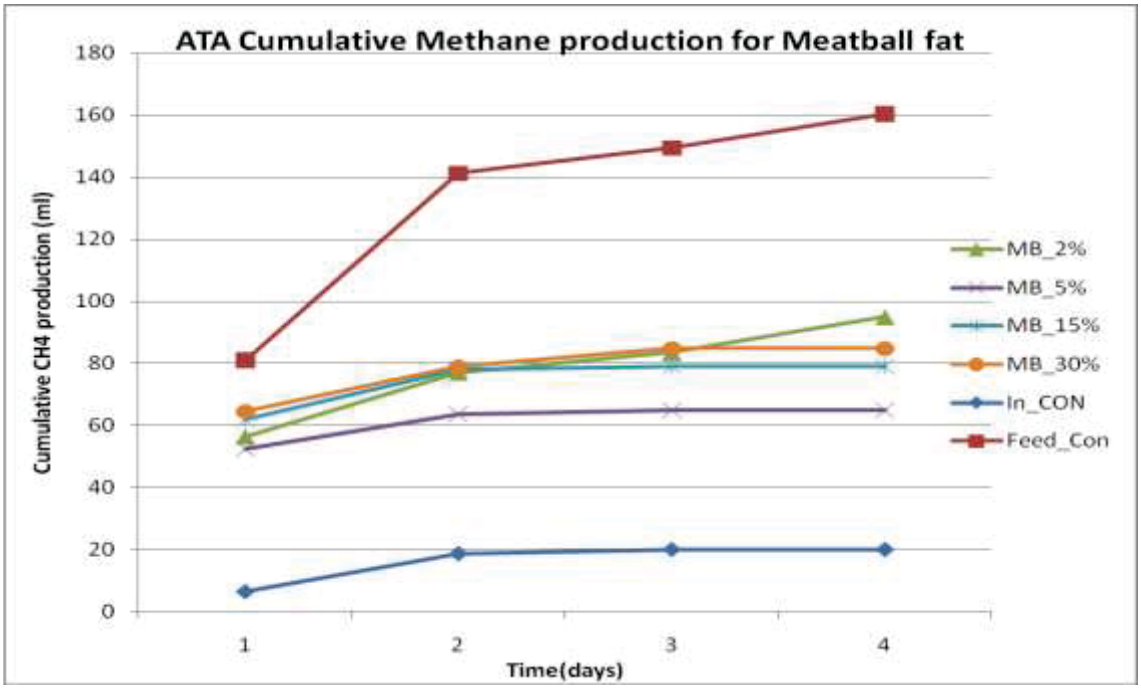


Figure 2c: Anaerobic toxicity assay result analysis for the Chicken fat (CK), cumulative methane production for each inclusion rate (2, 5, 15 & 30%) in comparison to the feedstock control (Feed_Con) and inoculum control (In_CON)

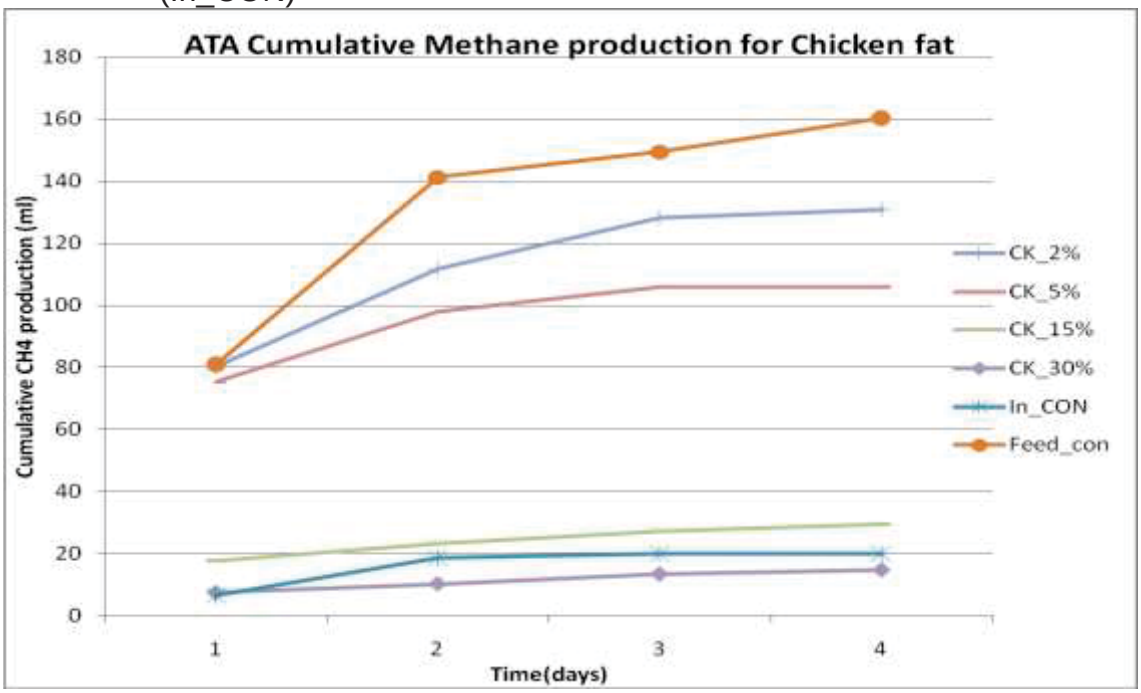


Figure 2d: Anaerobic toxicity assay result analysis for the Ice-Cream (IC), cumulative methane production for each inclusion rate (2, 5, 15 & 30%) in comparison to the feedstock control (Feed_Con) and inoculum control (In_CON)

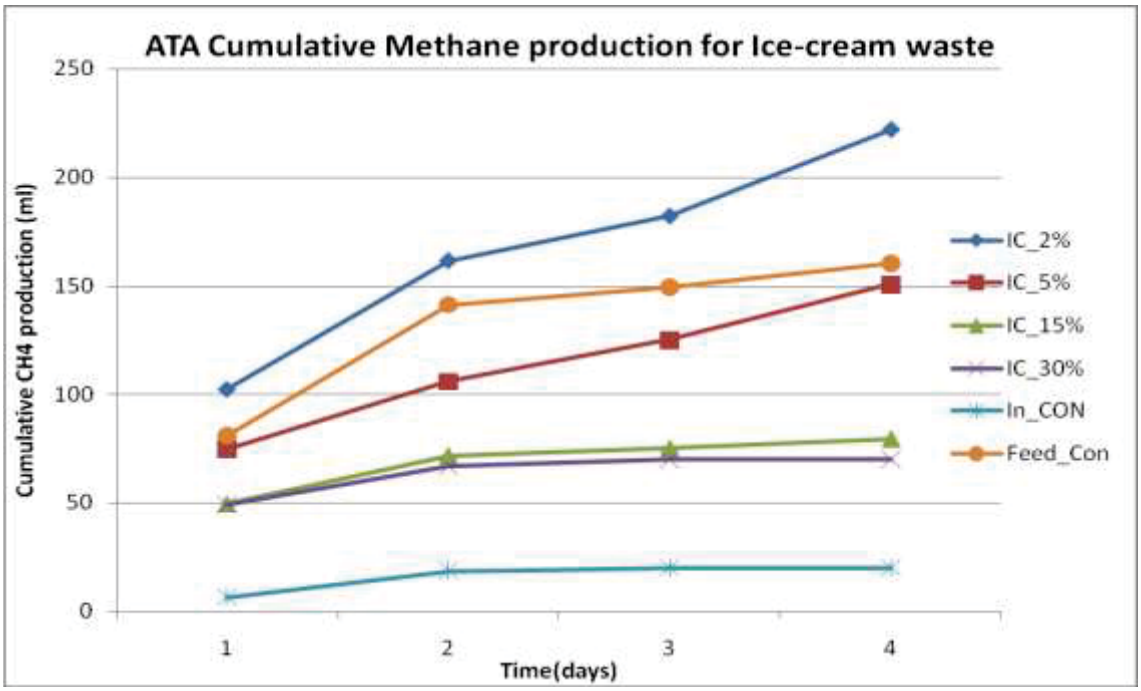
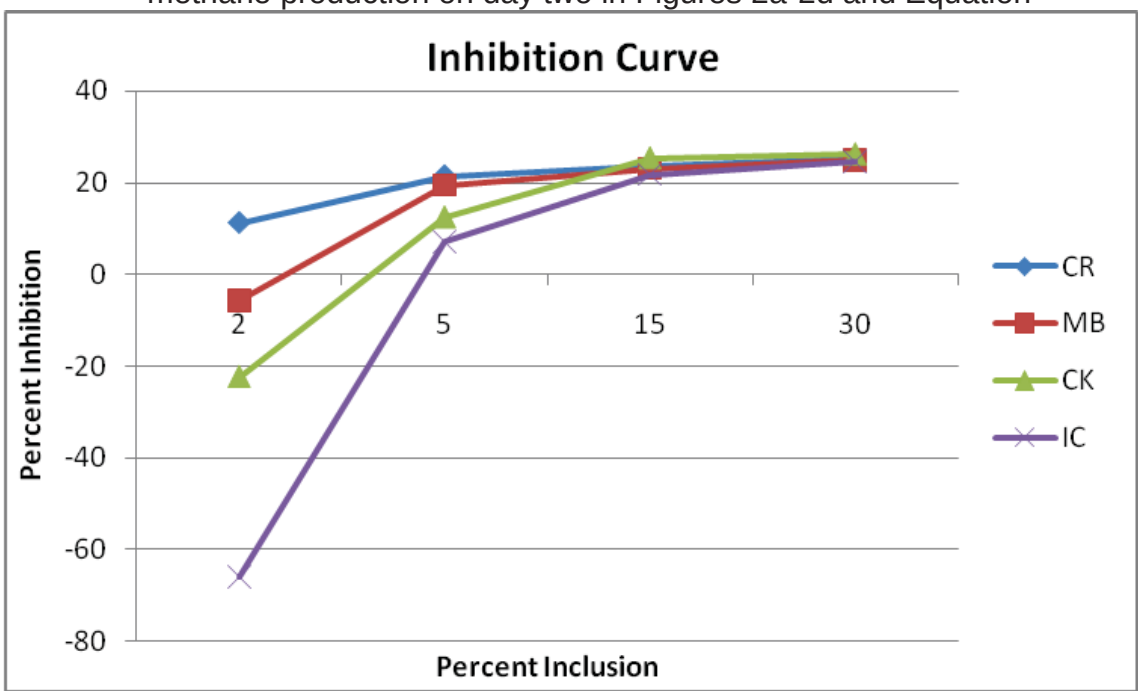


Figure 3: Anaerobic toxicity assay result analysis. Percent inhibition (I) calculated using methane production on day two in Figures 2a-2d and Equation



CONCLUSION

These findings show the importance of performance ATAs before possible co-digestion food products are introduced into anaerobic digestion environments. This study is being complemented with an on-going 60-day biochemical methane potential assay (BMP) to analyze the potential biogas production when both substrates (cow manure and industrial food waste, in this case) are digested together.

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