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Full Paper

Using a Chemically Hydrolyzed Biosolids for Co-digestion

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Abstract

Manhattan College performed an independent study on the use of a chemically hydrolyzed biosolids product for co-digestion studies. The biosolids material is produced by Lystek, Cambridge, Ontario Canada. The objective of this study was to determine if the hydrolyzed Lystek product (Lystek) could be used in anaerobic digestion (AD) to potentially increase gas yields and methane content. The AD study was divided into two phases; Phase 1, an initial study using a bioassay procedure to determine the amount of Lystek to add in the anaerobic digestion process for optimal gas yield and methane concentration and Phase 2, a more in-depth study of Lystek using bench scale anaerobic digesters. The results of the bioassay indicated that gas yields increase within a Lystek feed volume range of 15-25% with 20% to 25% yielding optimal results. This information was then use in the bench scale anaerobic digesters. The digesters were operated at an SRT of 15 days. Primary sludge was used in both the control and experimental reactor. The results indicated that the addition of Lystek increased biogas production as well as increased methane content of biogas. In addition, there appears to be little or no hydrogen sulfide in the biogas when using Lystek. There was an increase in ammonia and orthophosphate concentration possibly due to the higher volatile solids reduction in the Lystek reactor. Further research will include evaluating higher percentages of Lystek, dewaterability of the digestate, confirmation of reduced hydrogen sulfide concentration, and evaluation of increased ammonia and phosphate concentrations.

KEYWORDS: Co-digestion, Lystek, Hydrolyzed Product, Improved Digestibility, Biogas

Introduction

The goal of water resource recovery facilities (WRRFs) is to recover resources embedded in wastewater. Anaerobic digestion is a process that allows for recovering of energy in the form of methane. The purpose of this independent study was to determine if the addition of biosolids produced by the Lystek process (Lystek) when added to an anaerobic digester would enhance biogas production. The study was performed in two phases, with the first phase being a bioassay to determine the optimal percentage of Lystek to add to digesters, and the second phase being a bench scale study. The goal was to determine if the addition of Lystek would increase methane concentration and biogas production.

Anaerobic Digestion

Anaerobic digestion is a well-established and understood process used for the stabilization of raw primary and waste activated sludge (Parkin 1986). Essentially, it is a series of processes where microbes break down and digest biodegradable material in the absence of oxygen. The process converts the organic solids in to biogas that can be used as an energy source for heat, or electricity. There are 4 steps in anaerobic digestion: Step 1: hydrolysis; Step 2: acidogenesis; Step 3: acetogenesis; and Step 4: methanogenesis. There are two beneficial by-products of the anaerobic digestion process: biogas and digestate.

Digestion biogas is typically composed of methane (~60-65%) and carbon dioxide (~35-40%) (Abdeshahian et al. 2016). The production rate of biogas varies between 0.7-1.12 m3/kg (12 to 18 ft3/lb) of volatile solids (VS) destroyed and has an energy content of 22 kJ/m3 (~600 BTU/ft3) HHV. The biogas yield is dependent on the digestibility of organic matter in the system, as well as, temperature, pH, kinetics, and solids retention time. Chemical Oxygen Demand (COD) is generally used to quantify substrate energy content and therefore predict biogas production. Biogas production can also be estimated from the percent reduction of volatile solids. The amount and biodegradability of volatile solids introduced to a system can vary causing the gas production to fluctuate. The effectiveness and success of anaerobic digestion is measured by the amount of biogas produced and percent VS or COD reduction.

One objective of modern WRRFs is to optimize and enhance anaerobic digestion to increase biogas production to recover energy embedded in waste, thus reducing their energy footprint. In many cases this enhancement is accomplished through co-digestion. Co-digestion is anaerobic digestion of two or more substrates and is a modification of conventional anaerobic digestion of a single substrate (Mata-Alvarez 2014). The theory behind co-digestion is to add a secondary substrate (waste product) to the anaerobic digester to reduce VS and increase biogas quality and quantity. Currently, common co-substrates include fats, oils, and grease (FOG), food waste, and high COD industrial wastes. The hypothesis for this study is that the addition of Lystek to the digester will enhance biogas production and methane concentration.

Lystek – Thermochemical Hydrolysis

The Lystek process (Figure 1) is an innovative, energy efficient and economical low temperature thermal-chemical sludge hydrolysis technology which uses a proprietary combination of heat to 70-75o C (158 – 167o F), pH 9.5-10.0 using alkali (KOH), and high shear mixing to convert biosolids into a high solids (15% -17%), homogeneous, pathogen-free, and nutrient rich Class A EQ liquid product. The process is applicable to undigested and digested sludges. Process conditions make the residual recalcitrant organics in the digested biosolids more biodegradable. Compared to conventional thermal hydrolysis technologies that operate at high temperatures and pressures, Lystek technology uses milder processing conditions to liquefy sludge biomass. Liquefaction causes disintegration of cells and hydrolysis of complex organic molecules into simpler, more biodegradable compounds.

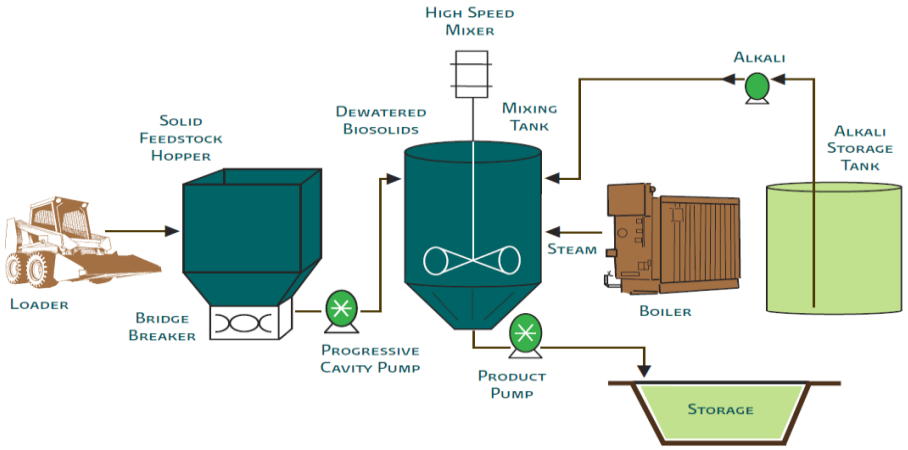

Figure 1. Schematic of Lystek Process

Project Description

The goal of this project was to determine if the addition of the Lystek product to an anaerobic digester would enhance biogas production, to what extent, and at what feed rate. The study was divided into two phases. Phase 1 was a bioassay to quickly determine optimal feed rates and the Phase 2 used bench scale reactors over long SRTs. The sludge used for both the bioassay and the anaerobic digestion study was obtained from Middletown, New York. The following are the characteristics of the sludge:

- Type: Primary
- Total Solids: 2-4%
- Volatile Solids: 76%,
- Chemical Oxygen Demand: 60,000 - 80,000 mg/L
- Soluble Chemical Oxygen Demand: 2000 – 4000 mg/L
- Ammonia: 100-350 mg/L
- Phosphorus: 20-50 mg/L.

Phase 1-Anaerobic Bioassay Study

The anaerobic Bioassay (ABA) was used to determine the optimal feed rate for Lystek addition to anaerobic digesters when mixed with primary sludge on a volume percent basis. The procedure for the anaerobic bioassay was taken from a toxicity assay method developed from “Bioassay for Monitoring Biochemical Methane Potential and Anaerobic Toxicity” by Owen et al. (Owen, 1978). By using this test, the optimal dosage can be quickly determined and then used in the anaerobic reactors. Since the anaerobic reactors are operated at a 15 day SRT, ABA reduces the time required to determine optimal feed rates to one day.

ABA’s were performed in 150 ml glass serum bottles sealed with butyl rubber caps under mesophilic anaerobic conditions. For Assay 1 (Table 1), all serum bottles were dosed with 50-ml digested sludge (Middletown, NY) at the same VS concentration, varying amounts of acetate-propionate solution, and varying amounts of Lystek. For Assay 2 (Table 2), all serum bottles were dosed with 50-ml digested sludge (Middletown, NY) at the same VS concentration, varying amounts of primary sludge, and varying amounts of Lystek. The initial mass of volatile

solids for all ABAs was the same so gas production and relative biodegradability between the different individual assays could be compared. Biogas volumes are given total volume produced (ml) (Figures 2-9). The bottles were prepared at ambient air temperature and then sealed and placed in an incubator at 35°C. Gas flow readings were measured after 1 day with an Agilent Technologies ADM1000 Universal Gas Flow meter with a range of 0 to 1000 mL/min.

The acetate-propionate solution was prepared with 37.5 g/L sodium-acetate and 13.25 g/L sodium-propionate acting as substrate for the anaerobic biomass. Primary sludge served as a secondary substrate to mimic real-life feed conditions. The feed protocol for each substrate is shown in Tables 1 and 2. Two Lystek products were used; one recently obtained using a Canadian Lystek facility (< 6 months) and one prepared from sludge from Hunt's Point WWTP (older product, > 6 months). All ABAs were performed in triplicate for each Lystek product.

Table 1. Acetate-Propionate Feed Protocol

Acetate-Propionate Feed		
Sample Volume (mL)	**Sample Type**	**Percent Lystek**
50	Acetate-Propionate	0% (Control 2)
50	Digestate	
0	Lystek	
42.5	Acetate-Propionate	15%
50	Digestate	
7.5	Lystek	
40	Acetate-Propionate	20%
50	Digestate	
10	Lystek	
37.5	Acetate-Propionate	25%
50	Digestate	
12.5	Lystek	

Table 2. Primary Sludge Feed

Primary Sludge Feed		
Sample Volume (mL)	**Sample Type**	**Percent Lystek**
30	Primary	0% (Control 1)
50	Digestate	
0	Lystek	
25.5	Primary	15%
50	Digestate	
4.5	Lystek	
24	Primary	20%
50	Digestate	
6	Lystek	
22.5	Primary	25%
50	Digestate	
7.5	Lystek	

Phase 1-Results and Discussion

Hunt's Point Lystek

The results using Lystek from Hunt's Point are shown in Figures 2 and 3. The ABA using acetate-propionate plus Lystek showed poor results from Lystek addition, almost as if the acetate-propionate were inhibiting the methanogens as concentration increased (Figure 3). The serum bottle with 0% Lystek feed showed the highest gas production with a decline of about 9% at 15% Lystek feed. There was an increase of about 1% at 20% Lystek as compared to 15% and then a sharp decrease of about 6 % at 25% Lystek. However, the ABA using primary sludge showed encouraging results (Figure 3) with about a 5% increase in gas production from no Lystek to about a 20% Lystek feed rate.

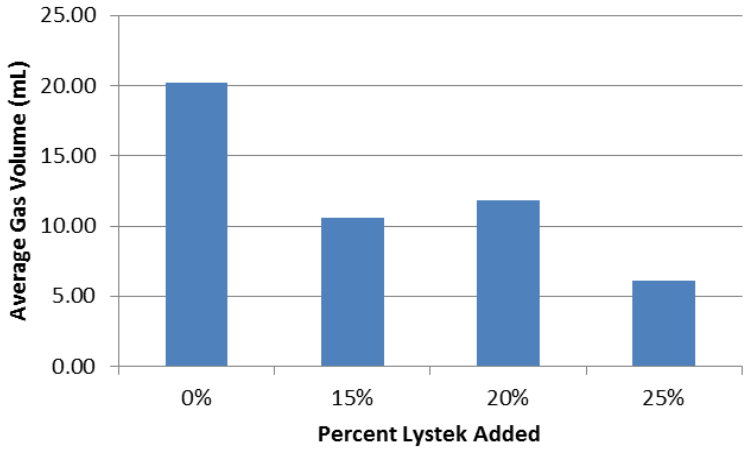

Figure 2. Gas volume produced from various concentrations of Hunt's Point Lystek with Acetate-Propionate

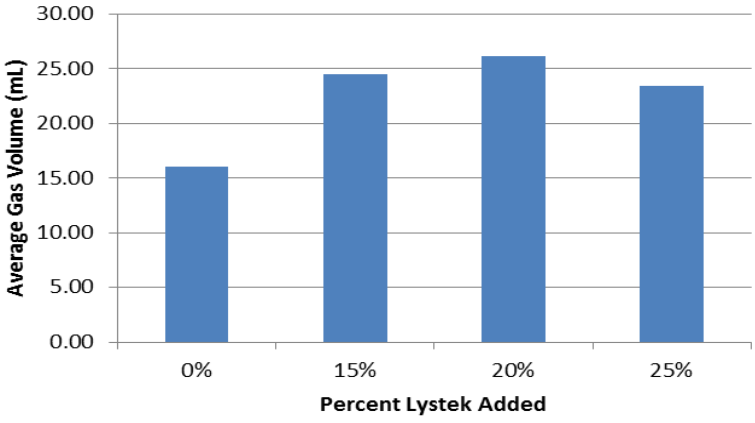

Figure 3. Gas volume produced from various concentrations of Hunt's Point Lystek with primary sludge.

Canadian Lystek

The results using Lystek from Canada are shown in Figures 4 and 5. The optimal dosage once again appears to be 20% Lystek feed and shows a similar pattern to Experiment 1. The Acetate-Propionate results with the Canadian Lystek were different than that from Hunt's Point. In this case, 20% Lystek feed had the same gas production as the 0% Lystek serum bottle, but the volume was lower for the 0% Canadian Lystek as compared to the Hunt's Point Lystek. However, for the primary sludge ABA, there was a much larger increase from no Lystek to 20% Lystek feed and much less of a decline at 25%. Overall in the tests using the Canadian Lystek, there was a significant increase in gas production for all concentrations as compared to Hunt's Point Lystek. This may be due to the Hunt's Point Lystek being more than 6 months old and may have undergone some degradation while in storage. The results from the Acetate-Propionate bottles are relatively consistent for both Lystek products but are hard to understand and need to be analyzed further. Figure 6 shows a side by side comparison of the performance of the two Lystek products.

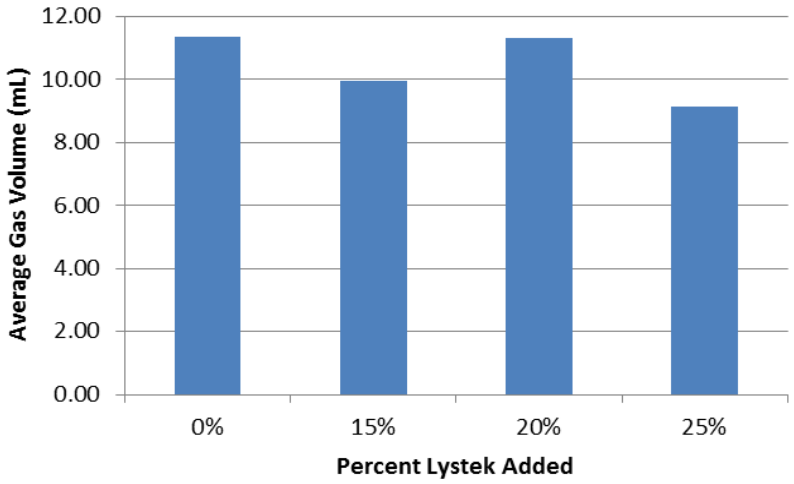

Figure 4. Gas volume produced from various concentrations of Hunt's Point Lystek with Acetate-Propionate

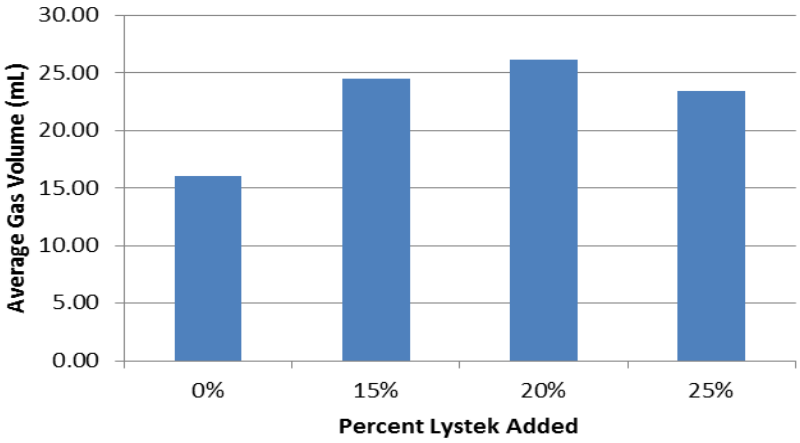

Figure 5. Gas volume produced from various concentraitons of Canadian Lystek with Primary Sludge

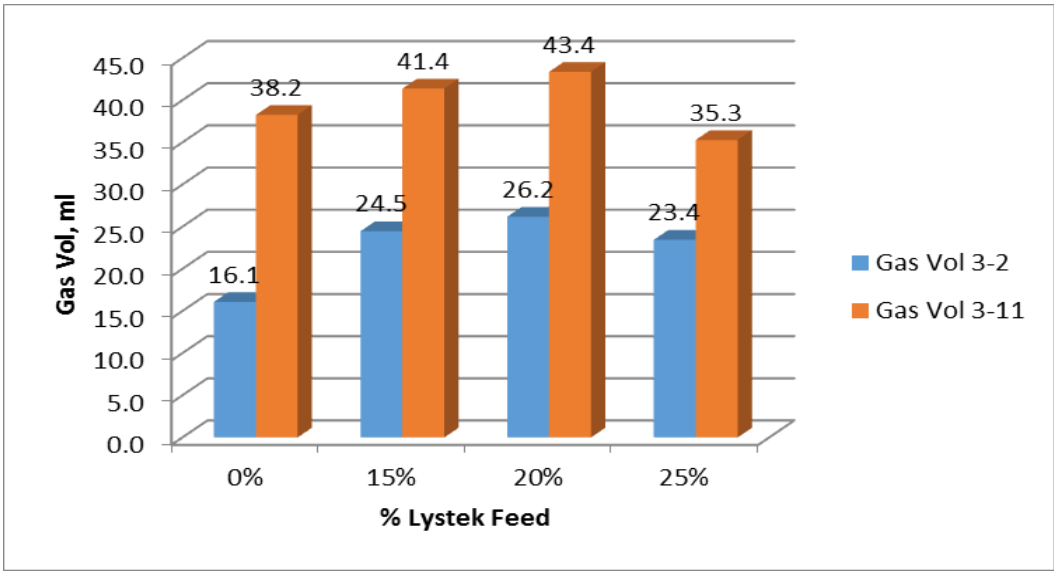

Figure 6. Gas volume produced from various concentrations of Hunt's Point Lystek with Acetate-Propionate

Phase 2-Anaerobic Digester Study

Bench Scale Reactors

Bench scale reactors were used to simulate performance of full-scale anaerobic digestion using a 15-day SRT. The goal was to determine if Lystek would enhance biogas production under the typical conditions used at New York City WRRFs. Two 5-liter batch reactor systems were constructed for this phase of the experiment. The 5-liter custom reactors were wrapped with digitally controlled heating tape and bubble wrap to maintain a temperature of 35°C. To maintain anaerobic conditions, the reactors were sealed using rubber stoppers. Biogas exited from the reactors through a one-way flow valve. Gas volume was continuously measured using HOBOware data loggers attached to wet-tip gas meters (Wet Tip Gas Meter Co., Nashville, TN), which measured gas production by volumetric displacement of water. Biogas composition was determined using a Landtec 5000 biogas meter. The meter was calibrated before each reading using a standard gas mixture of methane, CO_2, and H_2S. The biogas unit measures the percentage of methane (CH_4), carbon dioxide (CO_2), and oxygen (O_2) in the biogas and then subtracts those values from 100%. If the sum does not equal 100%, the difference is typically assumed to be nitrogen. The meter was also used to measure hydrogen sulfide (H_2S) concentration.

The control reactor (Reactor A) was fed primary sludge and (Reactor B) was fed the same primary sludge plus varying amounts of Lystek on a volume-volume ratio with a 15 day SRT. Primary sludge collected from the Middletown, NY, Wastewater Treatment Plant was characterized after collection and before being fed to the reactors. TS and VS analyses were performed using the standard pan method. Hach kits were used to determine the COD (Hach,

TNT 822), NH4-N (Hach, TNT 832), Volatile Acids (Hach, TNT 872), Total Phosphorous (Hach, TNT 840), Ortho Phosphorous (Hach TNT 845), Alkalinity (Hach, TNT 870). This same characterization process was used to determine the characteristics of the reactors as well on every feed day.

From the beginning of the test, there was difficulty in creating anaerobic conditions in the reactors originally thought to be due to air leakage. Although a major effort was made to completely seal the reactors and appurtenant equipment, it was impossible to establish steady state anaerobic digestion determined by low biogas production, low methane concentration, and poor volatile solids destruction. Because of these problems, this system was shut down and a literature search performed which resulted in the development of a new system. (Note: We later determined the problem with the reactors was due to too large a head space entrapping too much air.) This new system was a smaller scale version of the previous reactors and uses 3.5-liter vacuum filter flasks with a working volume of 3 liters and headspace of 0.5 L. Other than the change in physical reactors, the same materials and methods

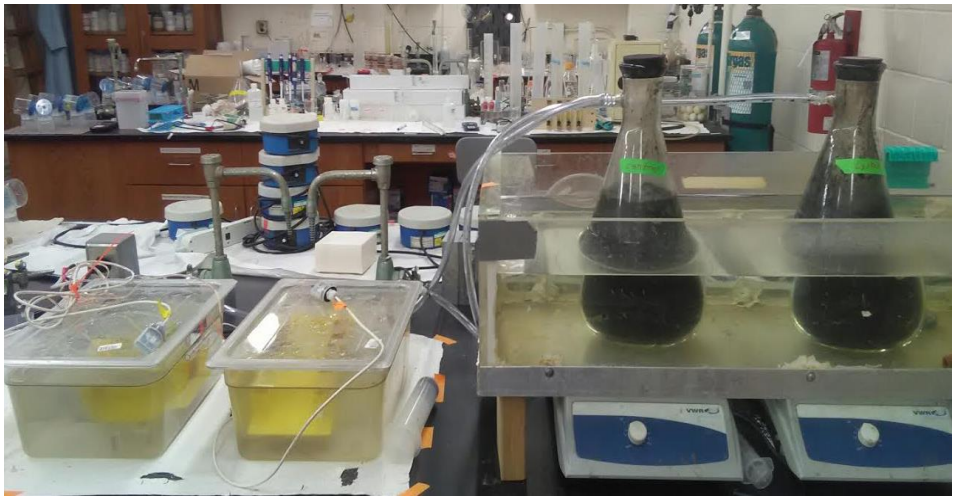

Figure 7. Experimental Setup using 3.5-L Filter Flasks

explained earlier were used with this arrangement as well. Figure 7 is an image of the bench-scale reactors.

The flasks were placed in a water bath set at 35°C and were attached to tipping buckets that recorded gas production. The same gas reading method as previously explained was used. Reactor feeding was performed every Monday and Thursday with feed volumes of 600 mL and 800mL respectively. The working SRT was 15 days. Primary sludge was characterized in the same manner as for the first reactor setup. Initially both reactors were fed primary sludge to establish identical, steady-state conditions before adding Lystek to the experimental reactor. Once steady-state was achieved, primary sludge alone continued to be fed to the control reactor (Reactor A) and primary sludge plus varying amounts of Lystek was fed to the experimental reactor (Reactor B) on a volume-volume ratio. The amount of Lystek was increased over time starting at 15% and ending at 25%. Primary sludge feed solids concentration was maintained between 2-4% solids.

Phase 2-Results and Discussion

The following results and discussion are based on the reactor performance from March 31 through June 16. The Control Digester was fed 100% primary sludge throughout the entire test period. The feed cycle to the Lystek reactor was:

- 03/31/16 - 04/21/16: Baseline Phase, 0% Lystek, 100% primary Sludge (by Volume)
- 04/21/16 - 05/05/16: 15% Lystek, 85% Primary Sludge
- 05/05/16 - 06/06/16: 20% Lystek, 80% Primary Sludge
- 06/06/16 - 06/23/16: 25% Lystek, 75% Primary Sludge

Volatile Solids Reduction

For the first SRT, the volatile solids reduction in both reactors was lower than expected, but started increasing through the second SRT. The Lystek reactor had a greater volatile solids reduction than the control reactor except for the first SRT of the 20% feed period (Figure 8). The Lystek reactor did reach the typical volatile solids reduction expected from anaerobic digestion towards the end of the 20% feed period and continuing throughout the 25% feed period. At a 15-d SRT in a full-scale mesophilic digester, the typical volatile solids reduction would be about 45%. The higher volatile solids reduction in the Lystek reactor correlates fairly well with the biogas yield at the same feed rate.

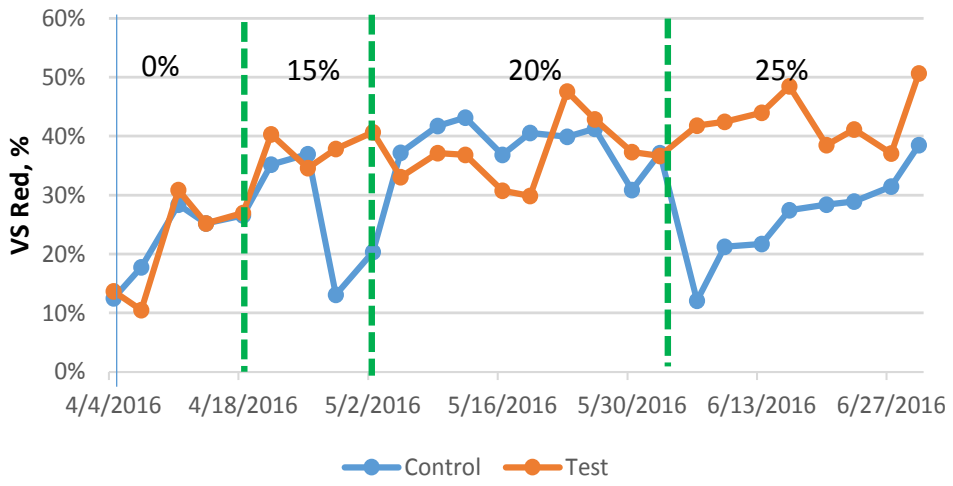

Figure 8. Volatile Solids Reduction

Biogas Yield

Throughout the entire testing period biogas yield was higher in the Lystek reactor than in the control reactor except for a brief period at the beginning of the 15% Lystek feed (Figure 9), likely due to acclimatizing of the microorganisms to Lystek.

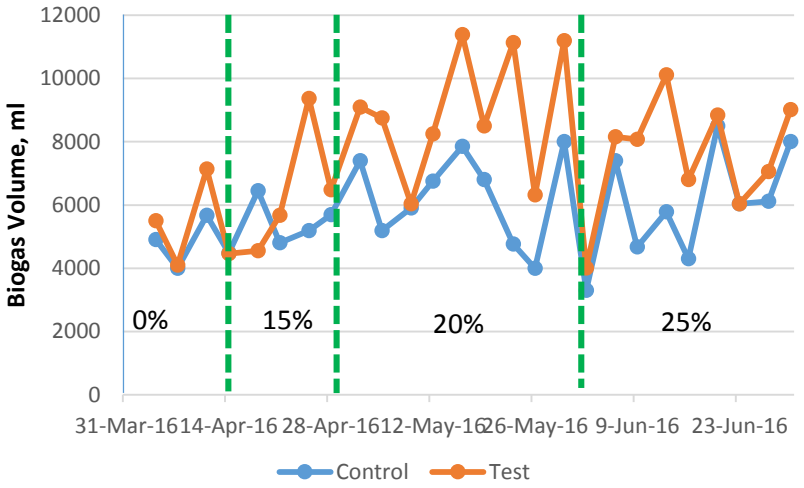

Figure 9. Biogas Yield

Biogas Composition

Methane, carbon dioxide, oxygen, and hydrogen sulfide were measured in the gas twice per week. At 0% to 15% Lystek feed, the methane concentration in both reactors was very similar and ranged from 62% to 72% (Figure 10). For the first few days of the 20% Lystek feed, both reactors produced similar concentrations of methane; however, after about 10 days, the biogas from the Lystek reactor has a much higher methane concentration that did the control reactor. Towards the end of the 20% feed period, there was a significant drop in methane concentration in the Lystek reactor which cannot be explained. When 25% Lystek was fed, the methane concentration significantly increased while the control reactor remained relatively constant. With additional time, the methane concentration in the Lystek reactor decreased but was still higher than the control reactor. The decline at the end was due to no longer feeding the digester in preparation for shutdown. It should be noted that the methane concentration of biogas can range from 55 to 70%, but is typically considered to be between 65 and 70% for wastewater sludge (Metcalf and Eddy, 5th ed). Both reactors had concentrations significantly higher than typical at certain times during the project. To ensure accuracy, the meter was calibrated each day measurements were made, so there is confidence in the results. Moreover, there is certainly a difference in the methane concentration from control to Lystek on a relative basis. In addition to methane, carbon dioxide and hydrogen sulfide concentrations were measured. Carbon dioxide concentrations average about 29% and O_2 remained at less than one percent (~0.3%). Hydrogen sulfide concentrations (Figure 11) increased in the control reactor but decreased to almost zero in the Lystek reactor. The reasons for this are not known at this time. However, there is certainty that these results were not due to an instrument malfunction or calibration error since the measurements for both reactors were done within minutes of one another. One possibility may be a reaction with metal ions which form a sulfide salt instead of hydrogen sulfide. It is important to understand this and requires further study since if there is little to no H_2S in the biogas, there would be a significant reduction in the cost for gas cleaning equipment.

Since digester supernatant or filtrate/centrate from dewatering anaerobically digested sludge is returned to the head of the plant, it is important to quantify the concentration of nitrogen and phosphorous entering the plant through these sidestreams.

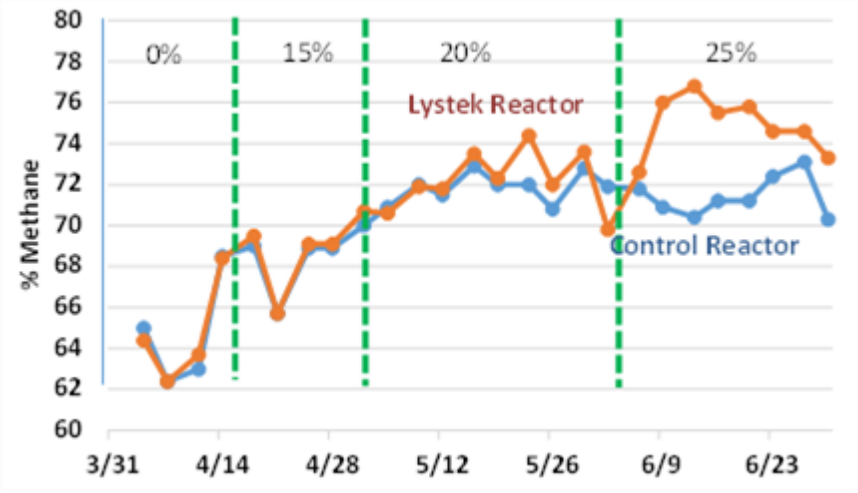

Figure 10. Methane concentration in biogas

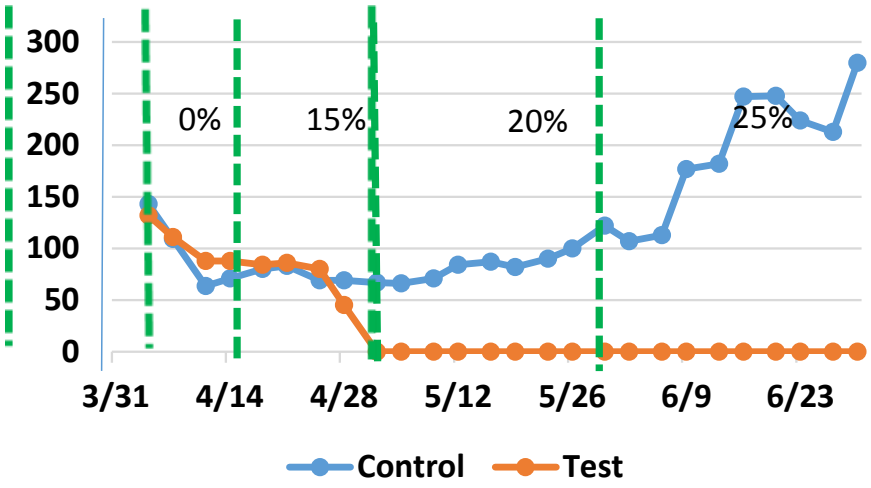

Figure 11. Hydrogen Sulfide concentration in biogas

Ammonia

Ammonia is a concern since it adds to the influent nitrogen concentration and impact facilities that have a nitrogen permit limit. Ammonia is produced in the anaerobic digestion process and the concentration is a function of SRT; the lower the SRT, the lower the concentration. The typical concentration at a 15-d SRT is between 1200 and 1400 mg/L. The ammonia concentration from the Lystek reactor fell within those averages (Figure 12); however the control reactor had a considerably lower concentration. The reason for this is most likely due to the concentration of ammonia in Lystek product coupled with the increased volatile solids reduction within the Lystek reactor. Further studies are needed to confirm and better understand these results

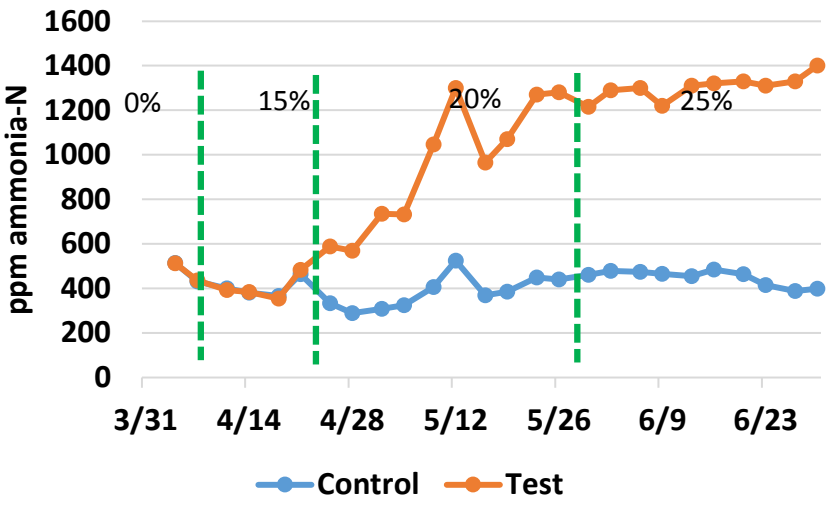

Figure 12. Ammonia Concentration in Digestate

Phosphorous

Phosphorous is released under anaerobic conditions which exist in the digester which can then be returned in plant sidestreams adding to the influent concentration. This is a concern for facilities that have a permit limit for phosphorus. For this project, reactive orthophosphate was measured. Figure 13 shows the concentration of orthophosphate at various concentrations of Lystek feed relative to the control. There appears to be a greater release of orthophosphate in the Lystek reactor which increases at higher concentrations of Lystek feed. This may be due to the increase in volatile solids reduction or the initial concentration of phosphorus in Lystek, but needs further study to understand the reasons for this higher concentration.

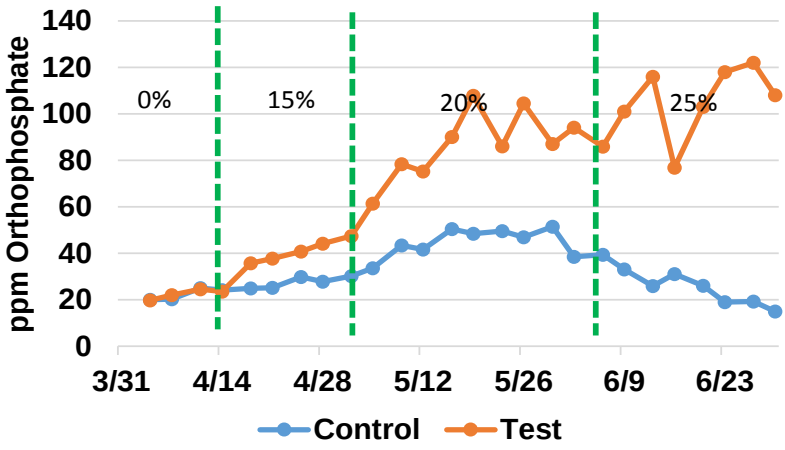

Figure 13. Supernatant ortho-phosphate concentration

Conclusion

The results of this project indicate that adding Lystek to an anaerobic digestion process appears to increase both methane production as well as gas yield as compared to a digestion process with only primary sludge. Hydrogen sulfide production in the digester gas appears to be very low with Lystek as compared to primary sludge. If this can be replicated, this is a significant advantage since it reduces the need for gas clean-up/conditioning prior to use as an energy source. Ammonia production is in the normal range so there is no negative impact by adding Lystek. Volatile solids reduction is also higher than the control. However, there is an increase in ammonia and orthophosphate in the Lystek reactor. The next steps for this research are to use a mixture of primary and waste activated sludge (WAS) to determine if the presence of WAS changes biogas production, H_2S production, etc.; increase the concentration of Lystek to determine optimal concentration, confirm and understand the reasons for little to no H_2S in the biogas, evaluate the reasons for the increase in ammonia and orthophosphate concentrations, and to determine the effects of Lystek addition on dewaterability.

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