Initial Feasibility Study of an Anaerobic Digestion System for Robert Morris University

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Abstract

Organic wastes produced by colleges and universities, specifically food wastes from campus dining facilities, are rich in both nutrient content and in potential biogas production. These facilities can take advantage of these natural resources by processing them through an anaerobic digestion system that yields biogas that can be used to displace need for natural gas or can be turned into onsite electricity. Waste that would have otherwise ended up in a landfill can be recycled to capture energy that would have been lost to the environment and convert it into a usable form for campus use.

Introduction

According to an EPA study titled "Municipal Solid Waste Generation, Recycling, and Disposal in the United States" over 36 million tons of food waste and 33 million tons of yard trimmings were produced in the United States in 2012. Most of this waste was sent to landfills, with only 4.8% of the food waste and 57.7% of the yard trimmings being recycled, mostly through the use of compost. If even a small portion of these waste streams could be redirected for use in biodigesters, a substantial amount of energy could be created.

Colleges and universities with on-campus dining facilities produce sizable quantities of organic food waste from both pre- and post-consumer sources. Pre-consumer waste includes scraps remaining from meal preparation, and post-consumer waste consists of leftover organic material that was or could not be eaten. One way to take advantage of the natural biological byproducts of the decomposition process is through anaerobic decomposition. The organic waste can be added to a biodigestion system located on campus. During the decomposition process in the biodigester, bacteria break down the organic material and produce biogas (methane, or CH_4). If these scraps are sent to landfills, this gas is lost to the atmosphere. If it were harvested in the biodigestion system, the methane could be utilized as energy to provide heat or power to the campus, thereby reducing the need for natural gas. A useful byproduct from the biodigestion process is very high grade compost that could then be used in landscaping on-campus, effectively reducing landscaping costs.

Anaerobic Digestion Process

Input materials are one of the most important aspects when considering the final design of any digestion/composting process. Biochemical methane potential of organic waste is in large part a result of the material's amount of lignin and lignocellulose content; higher levels limit the amount of biogas production due to the resistance of the lignin to biodegradation. Thus, the input of more herbaceous materials such as grass and leafy greens will yield more methane (Triolo, Pedersen, Qu, & Sommer, 2012). In addition, chemicals present in grass (i.e. glycine-betaine) can help to reduce toxic sodium levels that can occur in the digestate during the anaerobic process (Suwannoppadal, Ho, & Cord-Ruwisch, 2012). Greens are a major component of campus food wastes and, due to the maintenance of the large lawns at most university campuses, grass clippings are in abundance. With the addition of food waste from local cafes or restaurants near these campuses, a greater biogas yield would be expected (Brown & Li, 2013) (Yazdani, Barlaz, Augenstein, Kayhanian, & Tchobanoglous, 2012). However, constant monitoring is recommended if food waste is added in order to maintain optimal pH levels of around 7 in the digester to prevent it from becoming too acidic or basic (Chen, Romano, & Zhang, 2010). The largest amount of biogas production occurs within the first ten days of digestion and tapers off considerably until the anaerobic process is completed at 35 days (Muršec & Vindiš, 2009).

Chemicals can be added which increase the biodegradability of lignin-containing waste, but such treatments result in an increase in the cost of the process (Monnet, 2003).

Another benefit of the anaerobic digestion process is the elimination of noxious odors that result from the aerobic composting process. The use of the resulting nutrient material, whether the raw digestate or a further composted product, reduces the need for synthetic fertilizers, making the entire process both economical and ecologically sound (Wilkie, 2005). Furthermore, small-scale digesters, such as what would be appropriate for colleges and universities, are relatively low-maintenance systems; however, they do have high start-up costs (Rajendran, Aslanzadeh, & Taherzadeh, 2012) which could discourage their use, especially in small or privately funded schools. The investment made in the system could be quickly recovered if the digester is utilized for both its biogas potential and fertilizer production. With the implementation of a two-stage anaerobic digestion system, colleges and universities could recover the initial investment costs more quickly, as these systems have been shown to be more efficient in their energy production (Bouallagui, Touhami, Ben Cheikh, & Hamdi, 2005).

In order to use the biogas produced during this process for powering a gas engine for energy generation, it is necessary to remove the high level of siloxanes from the gas. An inexpensive component containing vermiculite can be added to the system to filter out the unwanted siloxanes (Khandaker & Seto, 2010). In addition, the presence of hydrogen sulfur in the gas results in an objectionable smell that can be removed through filters containing specially treated iron filings (Cepero, Savran, Blanco, Piñón, Suárez, & Palacios, 2012).

In addition to the production of biogas providing an alternative fuel source to the RMU campus, another reason for studying the implementation of an anaerobic digestion system is that many states will be outlawing food waste being sent to landfills as early as 2017.

Many colleges and universities have constructed biodigesters both on and off campus, including Morrisville State College, Vermont Tech, Michigan State University, and Oklahoma

State University. Ohio State University's Wooster campus, in partnership with a private energy company, installed a biodigester in 2009 that currently is capable of providing 4 megawatt-hours of electricity each year to the campus (Espinoza, 2013). Each of these existing digesters uses not only campus food and landscape waste but also farm waste as input material. In the three Pennsylvania counties surrounding the RMU campus, there are over 300 working farms (75 in Beaver County, 17 in Allegheny County, and 219 in Butler County) (Environmental Working Group, n.d.). It is possible that future collaborations between RMU and any number of these farms could facilitate greater energy production by combining both campus and farm waste sources.

The digester at RMU could possibly allow for surrounding communities to contribute food and other organic waste. This way RMU could produce energy from the waste, while the community could receive a portion of the compost, providing both a great channel for collaboration and good visibility for the project throughout the community.

Materials and Methods

To assess whether an anaerobic digestion system would be feasible on the RMU campus, three small scale digesters were constructed from 5-gallon plastic buckets with lids. Plastic flexible hose was connected to each lid on one end and a 5-gallon polyethylene collapsible water container on the other end. Valves were placed on two sections of the hose to control and close off portions of the digester system during the gas production process. All connections and joints were sealed to ensure that they were airtight to prevent loss of biogas or other byproducts of the anaerobic digestion process and to inhibit the entering of oxygen into the system.

Figure 1: Small-scale Digester Models

To provide a comparison of biogas yield, three different mixtures of organic materials were chosen for the study. A representative sample of food waste produced by RMU Dining Services was placed into one of the digesters. The sample consisted of pre-consumer vegetable and meat scraps, including watermelon, pineapple, and beef pieces as well as portions of mushrooms. All of the material was collected over the course of one week by the dining services staff and had been stored in a sealed plastic bucket at temperatures under 0°C until being processed for the digester.

The second digester contained a combination of two different types of fruit: cantaloupes and apples. Apples were chosen because they contain high amounts of fructose, a natural sugar that is highly fermentable into biogas (Mahawara, Singh & Jalgaonkar, 2012). Cantaloupes do not contain the same levels of natural sugars as do apples, but the fruit has also been shown to produce sizable quantities of biogas upon digestion (Hills & Roberts, 1984). Apples have an average pH of 3.5, while cantaloupes have an average pH level of 6.5. Both of these ingredients have more acidic pH levels than is recommended for Mesophilic anaerobic digestion of 7.0; however, both of these materials have carbon to nitrogen (C/N) ratios of 35:1, which is similar to the ideal anaerobic digestion C/N ratio of 30:1 (Zeshan, Karthikeyan, & Visvanathan, 2012).

In the third digester, a mixture of spinach and celery were added to represent leafy greens. These ingredients have high cellulose content, which has been shown to produce high levels of methane from Mesophilic anaerobic digestion (Fang Lou, Nair, & Ho, 2012).

All of the material was shredded into fine pieces using a blender, and equal parts of organic material and water were added to each digester. The total volume of each digester equaled 2.5 gallons (9.46 liters). A sample of 16 ounces (0.473 liters) of horse manure was added to one gallon of water to create a manure slurry, which was then added in equal portions to each digester. The slurry was used as a seed to provide a starting culture of bacteria since digested solids from an existing digestion system were unavailable. The lids were then placed on the buckets and sealed to prevent airflow from entering or leaving the system. All three digesters were then placed under a fume hood in case methane or other flammable gases were to leak from the system. A thermometer was placed under the hood as well to provide a way to monitor the ambient temperature around the digesters.

After 14 days, gas samples of 4 μL were taken from each digester for analysis using a mass spectrometer/gas chromatograph. This process was repeated over the following 5 weeks at weekly intervals (with one extended 2-week lapse).

The ambient temperature under the fume hood fluctuated daily, with an average value of 18°C and an overall range from 5°C to 24°C. All samples were taken when the ambient temperature was 20°C.

Results

Samples were taken periodically from each digester by means of a small hole drilled into each lid. Each hole was covered with tape, which acted as an impermeable membrane preventing gases from entering or leaving the system. A syringe was used to penetrate through the tape and into the hole, and to then extract 4 μL of gas, with the end of the syringe needle being capped after each sample to prevent collected gas from escaping. The holes in the digester lids were then immediately resealed with tape and the samples placed in a Shimadzu gas chromatograph/mass spectrometer (GCMS) for analysis. After each sample was analyzed, the syringe was then purged of any existing gases and then reused for the next sample.

As a baseline or point of reference, a sample of the air present in the room containing the GCMS was taken and analyzed to compare to the gas samples taken from each digester.

The data from the results of the analyses of each sample are shown in Tables 1-4.

Table 1: Input Material – RMU Cafe

	m/z	Absolute Intensity	Relative Intensity	Likely Element or Compound	CH_4 Increase / Decrease
3-11-14	44.00	1435220	100.00	CO_2	
	27.95	933841	65.07	N_2	
	31.95	112273	7.82	O_2	
	15.95	24049	1.68	CH_4	
	39.95	16889	1.18	Ar	
3-20-14	44.00	1669027	100.00	CO_2	
	28.00	1577266	94.50	N_2	
	31.95	127467	7.64	O_2	
	15.95	33053	1.98	CH_4	↑
	39.95	20543	1.23	Ar	
3-27-14	27.95	1767091	100.00	N_2	
	43.95	1039855	58.85	CO_2	
	31.95	123245	6.97	O_2	
	39.90	30040	1.70	Ar	
	15.90	17848	1.01	CH_4	↓

Table 1: Input Material – RMU Cafe

	m/z	**Absolute Intensity**	**Relative Intensity**	**Likely Element or Compound**	**CH_4 Increase / Decrease**
4-10-14	28.00	1682093	100.00	N_2	
	44.00	956284	56.85	CO_2	
	31.95	111134	6.61	O_2	
	39.95	35053	2.08	Ar	
	15.95	15500	0.92	CH_4	↓

Table 2: Input Material – Fruit

	m/z	**Absolute Intensity**	**Relative Intensity**	**Likely Element or Compound**	**CH_4 Increase / Decrease**
3-11-14	44.00	1575677	100.00	CO_2	
	27.95	1186149	75.28	N_2	
	31.95	127976	8.12	O_2	
	15.95	26119	1.66	CH_4	
	39.95	23223	1.47	Ar	
3-20-14	27.95	1285672	100.00	N_2	
	44.00	1088030	84.63	CO_2	
	31.95	98921	7.69	O_2	
	15.90	19069	1.48	CH_4	↓
	39.95	17923	1.39	Ar	
3-27-14	27.95	1953400	100.00	N_2	
	43.95	1150430	58.89	CO_2	
	31.95	184973	9.47	O_2	
	39.90	33998	1.74	Ar	
	15.90	20481	1.05	CH_4	↑
4-10-14	28.00	1588346	100.00	N_2	
	44.00	904237	56.93	CO_2	
	31.95	115318	7.26	O_2	
	39.95	33517	2.11	Ar	
	15.95	15175	0.96	CH_4	↓

Table 3: Input Material – Greens					
	m/z	**Absolute Intensity**	**Relative Intensity**	**Likely Element or Compound**	**CH_4 Increase / Decrease**
3-11-14	28.00	1933190	100.00	N_2	
	44.00	713997	36.93	CO_2	
	31.95	184117	9.52	O_2	
	39.95	38728	2.00	Ar	
	15.95	14426	0.75	CH_4	
3-20-14	27.95	2443456	100.00	N_2	
	43.95	704740	28.84	CO_2	
	31.95	152451	6.24	O_2	
	39.95	34957	1.43	Ar	
	28.95	17802	0.73	Unknown	
	15.90	14019	0.57	CH_4	↓
3-27-14	27.95	2199768	100.00	N_2	
	43.95	723668	32.90	CO_2	
	31.95	136142	6.19	O_2	
	39.90	39007	1.77	Ar	
	28.95	15952	0.73	Unknown	
	15.90	12925	0.59	CH_4	↓
4-10-14	28.00	1522502	100.00	N_2	
	44.00	903494	59.34	CO_2	
	31.95	120245	7.90	O_2	
	39.95	32203	2.12	Ar	
	15.95	15195	1.00	CH_4	↑

Table 4: Air					
	m/z	**Absolute Intensity**	**Relative Intensity**	**Likely Element or Compound**	**CH_4 Increase / Decrease**
4-10-14	28.00	1682289	100.00	N_2	
	31.95	377805	22.46	O_2	
	39.95	36951	2.20	Ar	
	28.95	12249	0.73	Unknown	
	15.95	8919	0.53	CH_4	

In the preceding charts, the mass-to-charge ratio, (m/z), is the ratio of the mass number to the charge number of ions. The charge number of ions, z, represents the number of electrons removed from the gas molecules under analysis and is usually considered to be equal to one in gas chromatography/mass spectrometry (GCMS); therefore the m/z value can be compared to the mass of the molecule or element present (Shimadzu Corporation, n.d.). Absolute Intensity can be defined as the total number of ions detected by the GCMS, and Relative Intensity sets the ion with the greatest intensity to a value of 100.00 and bases the percentages of the Absolute Intensities of the remaining detectable ions according to the same scale (GC Image GCxGC Edition Users' Guide, n.d.). The Likely Element or Compound column is the determination of the most probable ion based on the detected m/z value. In the last column, CH_4 Increase/Decrease, an arrow indicates whether the Absolute Intensity of CH_4, when compared to the previous sample, has increased (up arrow, ↑) or decreased (down arrow, ↓) in value.

None of the three model digesters were able to produce any significant amounts of methane. The samples of fruit and those taken from the RMU café both showed decreasing amounts of methane production over the 30 day trial, with only the high cellulose greens (celery and spinach) showing any increase in methane production over the time span. The results of each sample are shown on the following graph of sample date vs Absolute Intensity of CH_4.

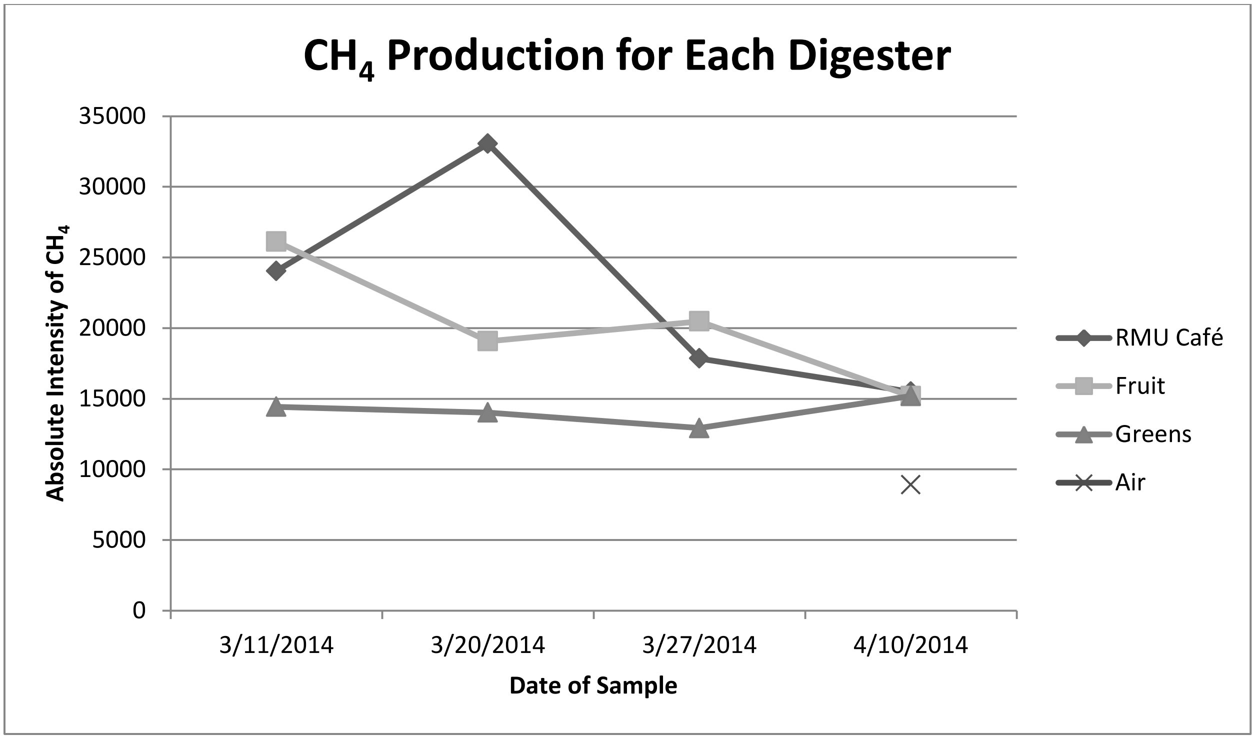

Figure 2: CH_4 Production Chart

Discussion

The results obtained from the digesters indicate that, although some small amounts of methane were produced, there was not a significant volume of biogas created. After each sampling of gas, the 5-gallon collapsible water container, which served as a gas collection vessel, was removed, emptied of as much gas as possible, and reattached. At no time over the course of the experiment did the collection containers fill with any substantial amount of gas. For the last two sample dates, no measurable amount of gas could be observed and the containers remained in a collapsed state. There are several possible reasons for the failure of production of biogas:

Temperature

The ambient temperature under the fume hood reached a maximum of 24°C, and for the majority of the experiment was far below this temperature, at times reaching as low as 5°C.

There are three conditions under which anaerobic digestion can take place, with temperature ranges as shown in Table 5 (Peces, Astals, & Mata-Alvarez, 2013).

Table 5: Ideal Anaerobic Digestion Temperatures by Type

Digestion Type (Bacteria Present)	Temperature Range
Psychrophilic	4°C - 15°C
Mesophilic	25°C - 40°C
Thermophilic	45°C - 70°C

Since the target of this experiment was the Mesophilic range, attempts were made to raise the ambient temperature under the fume hood. An electric heating mat was added underneath the digesters to provide a constant source of heat to the bottom of the containers; however, the heat mat was only able to raise the temperature to a maximum of 24°C. Additionally, two incandescent lamps were placed under the hood, but the additional heat given off by the bulbs was insignificant.

For future experiments, a small electric space heater or other source of continual heat should be considered, along with an accurate monitoring system and thermostat to maintain the temperature within the ideal Mesophilic range. Although these options were considered for this experiment, space under the fume hood was limited and would not allow for the introduction of heating sources other than those actually used.

Location

Due to possible leakage concerns, all three digesters were placed under a fume hood in a campus laboratory. The area under the hood measured 36 inches deep and 60 inches wide, and the three digesters fit into the space with very little extra room. The top of the hood was vented to the outside air to allow any gases that might escape from the digesters to safely exit to the atmosphere; however, the vent also allowed for outside air to enter the hood. This experiment was conducted between February and April of 2014, and the outside temperatures over this time span dropped as low as -16°C (Accuweather.com, n.d.). Although the temperature under the hood never reached below 5°C, the average temperature maintained was not in the Mesophilic range. If the experiment had been conducted during warmer summer months, the ambient temperature would have been considerably higher since any incoming air from the outside would have been much warmer.

For future experiments, a different location on campus should be considered. If the experiment were to be done during warmer months, the digesters could be placed outdoors in a covered structure that would allow for both safety and better temperature control. If the experiment must be conducted during cooler months, alternate heating sources should be considered that would raise the temperature to the Mesophilic range.

Vessels

In addition to temperature, another possible source of failure for this experiment was the pH level of the digestate. If pH levels become too acidic or basic, the bacteria necessary for anaerobic digestion are unable to reproduce or possibly even survive. The ideal pH level for methane production in an anaerobic digester is between 6.8 and 7.2, with the optimum level around 7.0 (Ward, Hobbs, Holliman & Jones, 2008). Since the digesters were sealed, it was not possible to monitor the pH level during the course of the experiment. Levels above or below the ideal range could have been a factor in the lack of methane production in the digestion system.

For future experiments, it is recommended to redesign the digesters to allow for continual pH monitoring during the digestion process. An improvement to the design could include removable lids that provide a seal to prevent gas from entering or escaping the system but also allow material to be added to adjust pH levels, if necessary. In lieu of this design change, a probe could be added to the sealed system that would permit pH monitoring; however, the pH level would not be able to be adjusted, and this option, although better than the current experimental model, would still not be ideal.

Input materials

The thesis of this experiment was to determine the feasibility of an anaerobic digestion system on the campus of Robert Morris University, where the largest sources of organic input materials would consist of food waste from the campus dining facilities and possibly landscaping waste (mainly grass clippings and leaves) from the large lawns and landscaped areas. For this reason, a sample of food waste from the RMU cafeteria that included both vegetable and meat scraps was added to one of the digesters. To imitate leafy green organic waste, spinach and celery were added to another digester. An improvement that could be made to this experiment to better simulate campus input material would be to also include grass clippings and leaves along with the food waste. These additions may help to control the pH level and increase the production of methane created during the digestion process.

Another possible reason for the lack of methane production could be the presence of meat scraps in the input material for one of the model digesters. Meat is a nutrient-rich input material that, when not carefully monitored, can cause the digestate to become too acidic. For future experiments, if a redesign of the digester allows for better pH monitoring, the addition of meat can result in a greater methane yield (Xiguang, Romano, & Ruihong, 2010). However, for this experiment, it may have led to a higher (more acidic) than ideal pH level and inhibited the digestion process from producing methane.

One improvement to the experiment that could possibly have the most impact on its success in producing methane is the addition of mesophilic anaerobic inoculum from an existing digester. For this experiment, horse manure slurry was added to simulate the inoculum. This was not ideal, however, as cultures obtained from a working mesophilic digester would provide a better starting condition than bacteria present in manure, which may or may not contain organisms suited for mesophilic digestion.

Conclusions

This research began as a feasibility study for an on-campus digester, but transitioned into a study of parameters that influence methane production. To accomplish this study, three biodigesters were fabricated and used to test three different input streams, each having differing chemical qualities. Although the study did not lead to significant methane production, there were many lessons learned that will guide future RMU researchers in analyzing the methane production potential on campus.

Any further research conducted into this matter should be done in an environment more conducive to Mesophilic anaerobic digestion. The temperatures of the digesters, their contents, and their location should be able to not only be controlled but closely monitored as well. In addition, the digester models themselves should be constructed to allow access to the contents to facilitate pH monitoring and adjustment, as necessary. Future digestion systems should also contain a starter culture of bacteria from an existing Mesophilic digester to stimulate decomposition and the resulting production of methane.

There are many factors to consider when designing an anaerobic digestion system for a college or university. In addition to the research previously suggested, further research is needed to determine the economic feasibility of constructing and maintaining an anaerobic digestion system on the RMU campus. It is important to optimize the system to produce the maximum amount of biogas at the lowest possible cost and in the most efficient way compatible with the input materials available both on site and in relatively close proximity to the site.

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