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Anaerobic Digestion Case Study: Identifying Viable Feedstock Sources for Small Scale Biogas Production at Auburn University

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Abstract

Anaerobic digestion has been a suggested method for diverting waste products (wood chips, poultry and cow waste, food waste, etc.) from landfills to create second generation products. This includes the production of biogas with high methane concentrations for energy use and nutrient-rich effluent that can be used in future biofuels research or as an organic fertilizer substitute. This benefits local communities by converting a potential pollutant and waste item into carbon neutral energy. Anaerobic digestion occurs when a feedstock and an inoculum full of methanogens (methane producing bacteria) are incubated in an oxygen-free environment. The objective of this research project was to investigate the potential for utilizing campus food waste and local poultry litter as a feedstock for anaerobic digestion. Specifically, overall quantity and quality of biogas produced was assessed through biogas methane potential (BMP) testing which was carried out in 160 ml batch reactors. Biogas was measured through pressure readings and its methane and carbon dioxide content assessed by gas chromatography. Understanding the BMP of local waste streams will benefit campus stakeholders in future decision-making processes as well as assist in scale-up efforts. Initial testing was done to examine the BMP of local poultry litter and food waste separately which is a necessary step prior to testing digestion of these two waste streams in combination. BMP testing revealed biomethane production levels as high as 450 mL/g volatile solids and 360 mL/g volatile solids using poultry litter and food waste, respectively. Given the promising results, efforts to construct a series of larger fed-batch reactors were initiated. Laboratory scale anaerobic digesters and an on-line gas monitoring system were designed and constructed. The campus dining program, Tiger Dining, at Auburn University has expressed enthusiastic interest in this concept and hopes to employ a pilot scale digester whose biogas can heat greenhouses on campus. Future research can investigate uses of the nutrient rich biosolids and a cost-benefit analysis of a pilot scale anaerobic digester, both in conjunction with current campus sustainability initiatives.

Keywords: Anaerobic Digestion, Food Waste, Poultry Litter

1. Introduction

With populations growing exponentially around the world, there is an increased need for the development of new methods to deal with the increasing amount of organic wastes being produced. These wastes contribute greatly to local, regional, and global levels of pollution as well as raise numerous health concerns. Uncontrolled breakdown of organic wastes can lead to nutrient runoff which causes eutrophication and oxygen free "dead-zones" in downstream waterways[1]. Decomposition of organic waste also contributes to greenhouse gases (particularly methane)[2] and bacteria/pathogens from organic wastes can contaminate food and water supplies (i.e. salmonella)[3,4] to name just a few issues.

Anaerobic digestion is a possible treatment method for organic waste that has been utilized around the world. For example, some researchers have investigated how bioreactors that utilize anaerobic digestion in developing countries can help to alleviate the following issues[5]:

- Poor indoor air quality and subsequent chronic health problems
- Unequal exposure to hazards by gender
- The need for cooking fuel
- Deforestation for fuel use
- Lack of treatment of animal wastes
- Expensive inorganic fertilizers
- Mitigation of methane released into the atmosphere

However, these issues are not limited to developing countries and they can also be found in urban/developed countries. Anaerobic digestion is the process of loading organic wastes into an air-tight sealed bioreactor with methane-producing bacteria and archaea (methanogens) that will convert the volatile solids (VS) from the organic wastes into biogas, which is comprised of methane, carbon dioxide, and trace other gases (e.g. hydrogen sulfide). Organic inputs can come from food, crop, and animal waste streams. The biogas can then be collected and numerous second-generation products can be developed from this collected biogas (Figure 1). Some of these include generating electricity, producing heat, or synthesized into biodegradable plastic or a liquid biofuel. In addition, anaerobic digestion has been shown to greatly reduce pathogen populations in manure waste streams[6]. As previously stated, this technology has been implemented in rural and developing countries, but is also popularly used at the residential, municipal, and regional scales within the United States[4].

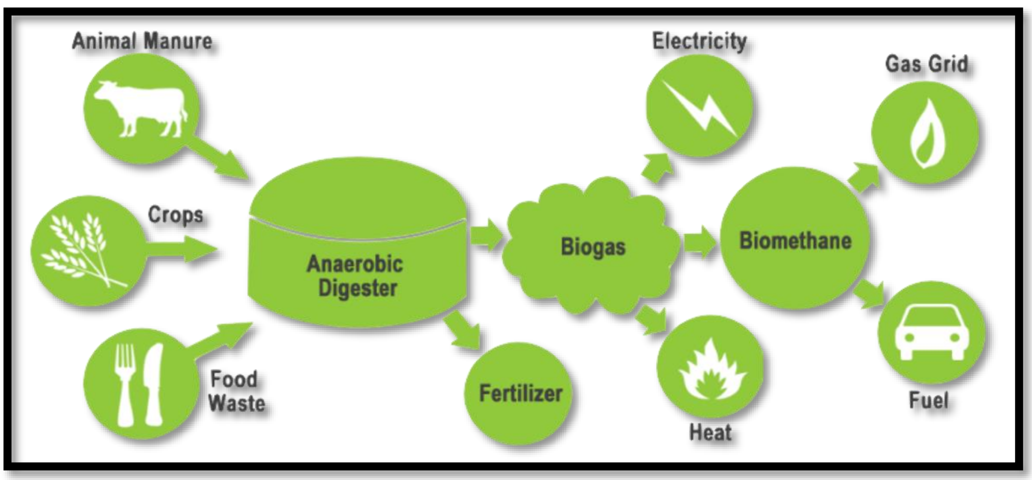

Figure 1: Common inputs and outputs for anaerobic digestion

Auburn University is a land grant institution in Auburn, Alabama with a strong research tradition in agriculture. Auburn, AL has a population of approximately 63,000 people, and a student population of just under 30,000. Auburn and the state of Alabama produce numerous potential inputs that could be used in the anaerobic digestion process to produce second generation products that benefit the university or local community. Two waste sources that this research specifically investigates are poultry litter and food waste (from on-campus dining facilities).

In 2016, the state of Alabama produced just under 6 billion pounds of marketable poultry meat, and is the fourth largest producer of poultry products in the United States[7]. It is commonly estimated that for every pound of marketable poultry produced, approximately 0.5 to 0.7 pounds of poultry litter is also produced[8]. This means that between 1.5 and 2.1 million tons of poultry litter is produced annually in the state of Alabama alone, which exceeds previous estimates of one million tons poultry litter annually. Poultry farming makes up approximately 60% of the agricultural business conducted in Alabama, and according to the Alabama Department of Environmental Management, agricultural operations have directly contributed to the impairment of over 515 miles of streams and waterways[9].

It is estimated that between 30% and 40% of all food produced in the United States is wasted, amounting to approximately 133 billion pounds of food in 2010[10]. It is currently not quantified how much food waste is generated on Auburn University's campus, and there is a lack of research on quantifying food waste produced on university campuses as a whole. However, close to 30,000 pounds of food are recovered each year that is redistributed by the Campus Kitchens Project to food-insecure people in the community. The remaining food that is thrown away is sent to the landfill. Auburn University has multiple buffet and single service dining locations that are utilized by students every day of the year. Food waste puts unnecessary strain on natural and economic resources.

Working closely with local stakeholders including the director of campus dining and local poultry farmers, there is a desire in the community to reduce the effects of these waste streams. With Auburn University being a land grant institution, there is a desire to become more sustainable with regard to agricultural and food wastes. Anaerobic digestion is a possible solution to generating useful energy from waste. For this to happen, the potential waste streams need to be analyzed to determine the bio-methane potential (BMP) or quantity and quality of biogas that can be produced. The objective of this study was to conduct BMP testing on poultry litter and food waste streams and, pending encouraging results, lay the groundwork for process engineering by developing larger-scale batch-fed reactors with on-line biogas monitoring.

2. Methodology

The first focus of this project was to determine the volatile solids (VS) content of local sources of poultry and food waste. Poultry litter was collected from a local broiler operation from three locations within the poultry farm to see if there is a spatial variation in the VS content of poultry litter. Two of the locations were inside of an operating poultry house: the surface litter (top 3 inches) and deep litter (3-6 inches below surface). Litter was also collected from a pile of waste litter located outdoors. Food waste was collected from Village Dining, an on campus buffet style dining venue. Kitchen staff scraped food scraps from the students' plates into a bucket that was later blended into a more homogenous mixture (Figure 2) in a food blender. The food waste mainly contained pizza crusts, fruit cores, rice, and various breads. Inoculum, containing high concentrations of mesophilic methanogens (methane producing bacteria that function best at 35 ºC), was collected from an anaerobic digester at a local waste water treatment plant in Columbus, GA. The total solids content and volatile solids content were calculated using EPA Method 1684[11].

Figure 2: Food waste that was collected and blended into a more homogenous mixture

Once the VS was calculated for the two separate waste streams and the inoculum, 160 mL reactors were loaded with varying ratios of waste (substrate) and inoculum while maintaining a constant volume and concentration of VS.

Different substrate to inoculum (SI) ratios were tested (Table 1) in order to determine which ratios produce the largest quantity of biogas per reactor volume as well as the greatest conversion efficiency of volatile solids to methane (BMP). Each reactor contained 60 mL of liquid (water and inoculum) and 10 g/L of VS (Figure 3). The reactors were placed in a shaker incubator at 150 rpm and 35 ^{O}C for three to four weeks.

Table 1: Substrate to inoculum ratios tested

Ratio (Substrate: Inoculum)	Percentage VS from Substrate	Percentage VS from Inoculum
Inoculum	0%	100%
1:4	20%	80%
2:3	40%	60%
3:2	60%	40%
4:1	80%	20%
Substrate	100%	0%

Figure 3: Loaded bioreactor (left) and shaker incubator (right)

The pressure was read in the reactors every two days using a pressure gauge connected to a needle that pierced the rubber cap. This pressure was then converted into moles using the ideal gas law. Once production slowed, gas samples were taken and injected into a gas chromatographer with a thermal conductivity detector (GC-TCD) to determine the concentrations of various gases in the biogas (methane, CO_2, and other impurities).

Due to Le Chatelier's Principle, the buildup in gas pressure that was measured to determine gas production also inhibits gas production. This is a limitation of BMP testing in batch reactors, however, the results should still accurately represent relative differences in treatment conditions. Efforts to scale up this process will require further testing in fed-batch reactors with continuous removal and measurement of biogas.

3. Data

Table 2 shows the average VS concentrations for the three different types of poultry litter (intake surface, intake deep, and cake waste) and the food waste. The percentages shown are based on total weight (TW) or total solids (TS). Standard deviations are also shown for the food waste. Standard deviations are not shown for the poultry litter samples due to a sample size of two but the values in all replicates were similar.

Table 2: Volatile solids (VS) concentrations of the different poultry litter and food waste samples

Type of Substrate	Percent VS of TW	Percent Water of TW	Percent Ash of TW	Percent VS of TS
Surface Litter (SL)	49.38%	38.78%	11.84%	80.66%
Deep Litter (DL)	34.17%	56.13%	9.70%	77.89%
Waste Litter (WL)	48.70%	35.95%	15.35%	76.03%
Food Waste (FW)	39.19%±0.552%	58.88%±0.566%	01.93%±0.0409%	72.17%±2.481%

Figures 5 and 6 show the cumulative volume of biogas produced for poultry litter and food waste, respectively. The volume was calculated by converting pressure readings to moles and then converting moles to volume assuming atmospheric pressure. Figure 7 shows the gas composition for the different poultry litter samples after 17 days of incubation. Figure 8 shows the same information for the food waste, after incubation of 19 days. The percentage label signifies how much of the VS came from the substrate.

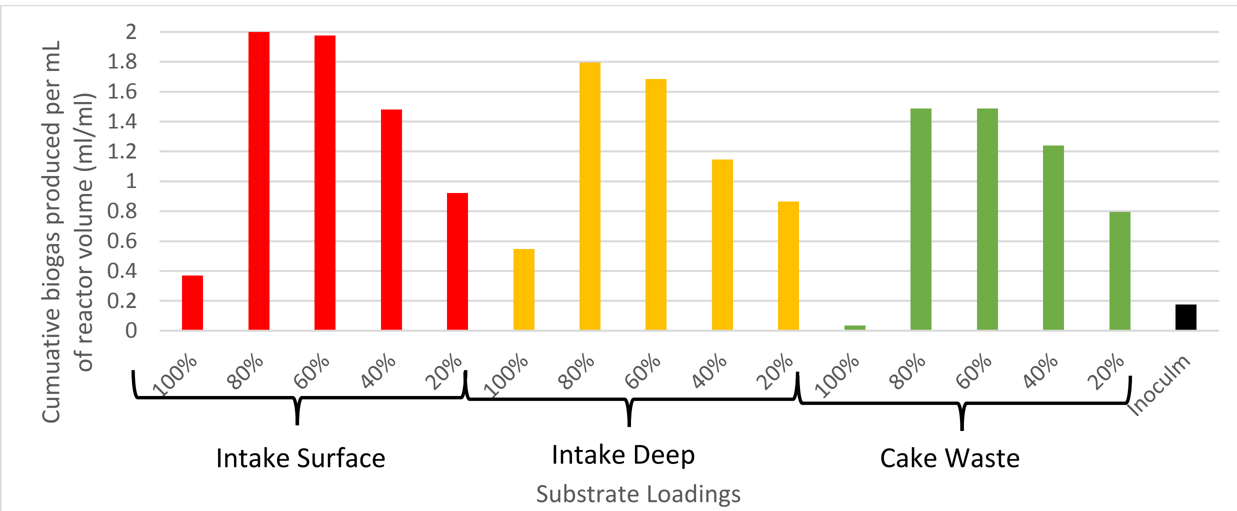

Figure 5: Cumulative volume of biogas produced for poultry litter samples per ml of liquid in the reactor. Percent values on the x-axis are substrate to inoculum ratios

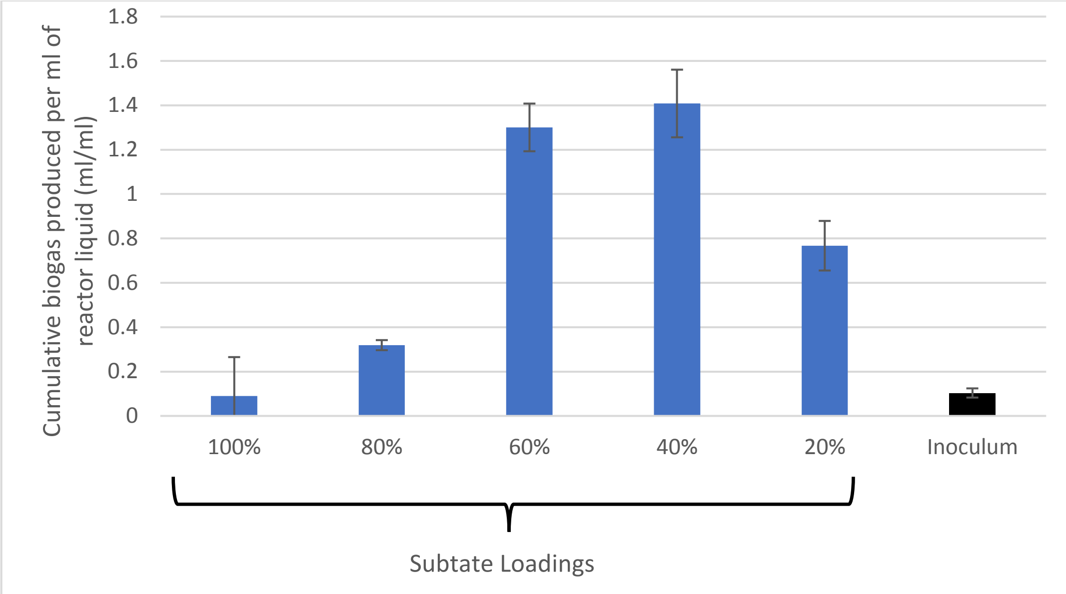

Figure 6: Cumulative volume of biogas produced for the food waste samples per ml of liquid in the reactor. Percent values on the x-axis are substrate to inoculum ratios. Error bars are SD based on n=3.

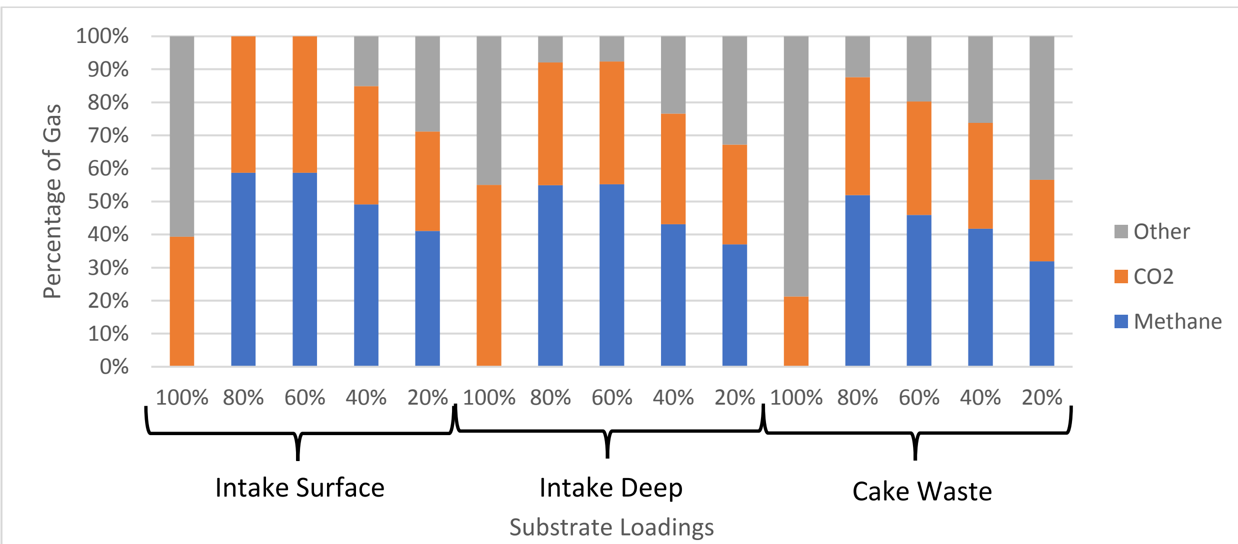

Figure 7: Gas composition of poultry litter. Other gas was predominantly nitrogen gas in the headspace of the reactor. Percent values on the x-axis are substrate to inoculum ratios

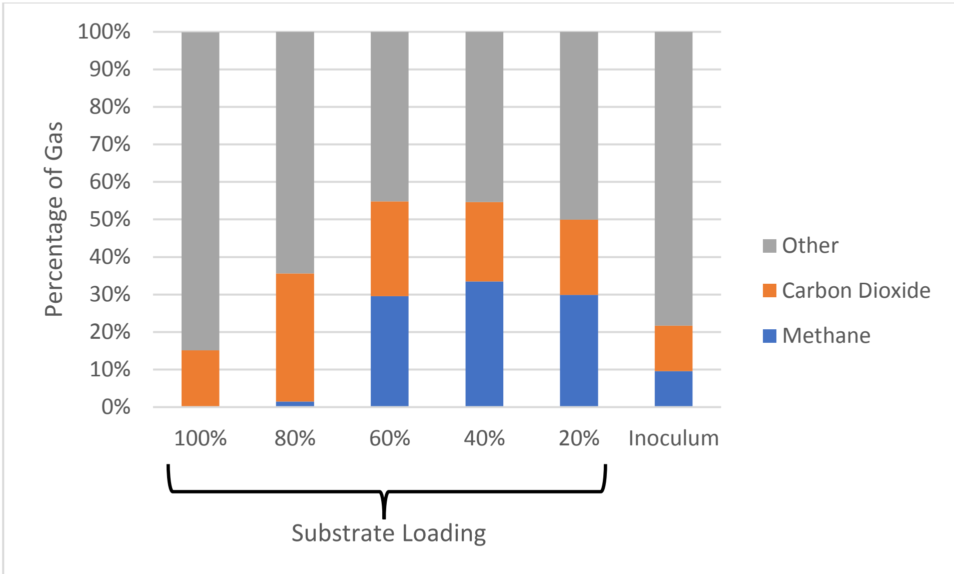

Figure 8: Gas composition of food waste. Percent values on the x-axis are substrate to inoculum ratios

Using the gas chromatography data from figure 7 and 8, along with the total volume of gas produced, the bio-methane potential (BMP) was calculated. This is the milliliters of methane produced per gram of volatile solids in the substrate. Figure 9 and 10 shows the average BMP for different substrate to inoculum ratios.

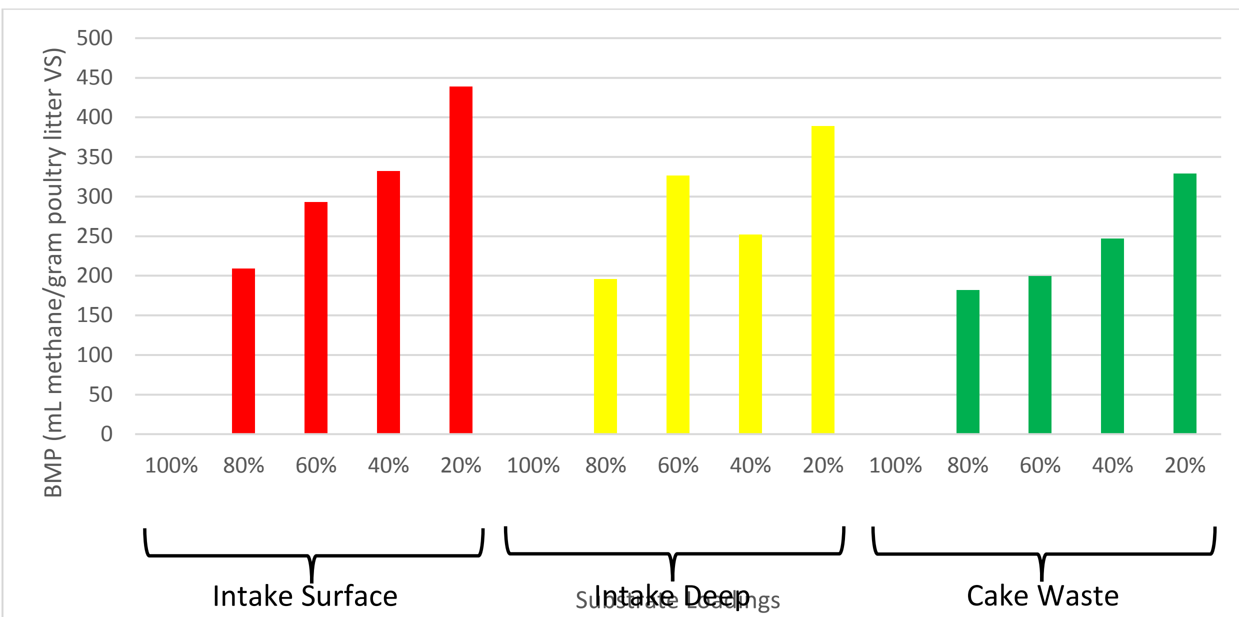

Figure 9: Bio-methane potential of poultry litter (n = 2 biological replicates for each condition). Percent values on the x-axis are substrate to inoculum ratios

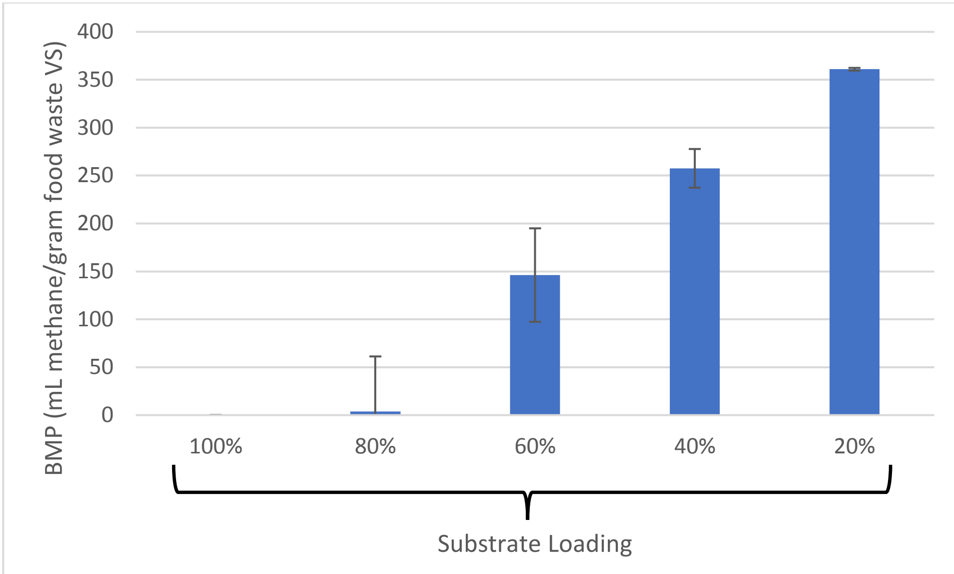

Figure 10: Bio-methane potential of food waste (n = 3 biological replicates for each condition and bars show standard deviation). Percent values on the x-axis are substrate to inoculum ratios.

4. Conclusion

4.1 Biogas Analysis

The source of poultry litter had an apparent effect on its ability to be converted to biogas. The volatile solids in the intake surface poultry litter were more digestible than the solids in the deep litter. The majority of the chicken manure lies in the upper layer compared to the bedding material, such as pine shavings, in the lower levels. Pine shavings are primarily lignocellulosic materials which cannot be easily broken down in anaerobic conditions[12].

The poultry litter and food waste both produced large quantities of biogas containing high concentrations of methane, when digested in the appropriate ratios (Figures 5 and 6). Low SI ratios led to higher BMP, indicating higher efficiency of waste conversion to methane. However, loading the reactor primarily with inoculum also increases the size of the reactor needed to carry out digestion of a given amount of waste. This tradeoff is apparent from the data shown in Figure 5 where a higher substrate to inoculum ratio results in greater biogas production per ml of reactor volume. Research by others has shown that poultry litter can lead to biomethane potentials of 100-270 ml/g VS[12]. Literature has shown that food waste digestion can lead to BMP of 210-590 ml/g VS[13]. In our study, it was interesting that poultry litter had higher BMP than food waste. More detailed investigation is required to understand the underlying reason for this difference but it could be a result of the relatively high protein content of the food used in this study and consequent ammonium build-up in the reactor as the protein is mineralized. Ammonia is a known and potent inhibitor of methanogenesis in anaerobic digesters[12]. Nevertheless, the batch studies demonstrated robust biogas production on both poultry litter and food waste, indicating these are suitable feedstocks for scale-up testing and optimization.

4.2 Future Research

While batch reactors allow for rapid testing of many experimental conditions, they are not ideal for scale-up testing. The current method to determine gas production was based on the build-up of pressure in the reactor, potentially inhibiting methane production. Thus, a reactor that continuously releases biogas can provide better data for process engineering. Consequently, a gas monitoring system was developed as part of this research project. This device will allow for future research in which biogas production will be monitored on a continuous basis, compared to measuring pressure changes every other day. These gas measurement devices work by monitoring water displacement in a ubend. This is accomplished by measuring the change in water level height using a time of flight (TOF) infrared laser ranging sensor.

With the new biogas monitoring devices constructed, future research can calibrate these devices on larger scale 2-L bioreactors. The larger reactors will be run in fed-batch mode with continuous biogas monitoring. A mixture of food waste and poultry litter will be tested at the same time, to analyze the potential for co-digestion. There is also interest from stakeholders on campus to construct a larger 55-gallon digester to be used as a student demonstration model as part of a new dining hall and greenhouse complex on the Auburn campus.

The end goal of anaerobic digestion on Auburn University's campus is to be able to use the collected methane to heat on-campus greenhouses during colder months in order to reduce the need to purchase natural gas for heat. This will help to close the cycle on food production and help the university's operations become more sustainable. There is an increased desire to grow more food for students directly on campus, and if the waste food can help to power the greenhouses, the university can lower its dependence on outside resources.

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