Benefits of Food Waste as a Potential Substrate in a Dry Anaerobic Digester

May 2013

Student Investigator: Ryan Bartell
Advisor: Dr. Greg Kleinheinz

University of Wisconsin-Oshkosh
In 2010, organic materials were the largest component of Municipal Solid Waste (MSW) (1). In order to reduce deposition of organic materials into landfills, it is critical that we find alternative methods in which solid and organic waste is recycled or reused. Identifying and characterizing different sources of food waste will help find productive uses for this material while diverting a substantial quantity from landfills. One option to divert food waste from landfills is to bring the waste to an anaerobic digester such as the dry anaerobic digester at the University of Wisconsin-Oshkosh, which would effectively reduce the amount of food waste that is landfilled (33 million tons in U.S in 2010). While studying food waste and its reuse potential is important, it is equally important the study the digestate (end product) of anaerobic digestion as this is a value-added product of the process. Studying the solids generated by a dry anaerobic digester facility helps to characterize one of the major environmental benefits of anaerobic digesters: the mitigation of waste through aerobic composting.

This study tested the chemical characteristics (Total Solids, Volatile Solids, pH, Total Phosphorus, Volatile Fatty Acids), of food waste received from Sanimax, a food waste collection company. The food waste was also tested for biogenic methane potential (BMP) in bench scale fermentation vessels over a period of thirty-two days. Solids analyses showed that the food waste was 14.83% total solids and 91.89% volatile solids, with a fresh matter TS:VS of 1.088 and a pH of 4.7. Although excess acidity of the substrate can be detrimental to methane production, bench scale BMP testing showed that this food waste is an excellent candidate for use as a substrate in a dry anaerobic digester.

Total municipal solid waste (MSW) generated in 2010 was 250 million tons and, organic materials were the largest component of that MSW (1). For MSW, organic materials include yard waste, food waste, food-related paper products, and pet feces. When the food waste is disposed in a landfill, it becomes a substantial source of methane, which is a greenhouse gas.
In the United States, landfills account for about 20 percent of human-related methane emissions and only about half of the total methane generated is captured (1, 2).

In a 2009 study, organic materials in Wisconsin were estimated to make up over 23% of collected solid waste, the largest category of waste (Figure 1). The same study estimated that nearly 1 million tons of organic waste is collected in Wisconsin, and food was the most common category with over 455,000 tons (3). The Wisconsin Governor’s Task Force on Waste Materials Recovery and Disposal recommended that organic diversion should include biofuel and anaerobic digestion energy facilities (3). The groups interested in alternative uses and disposal of organic wastes in Wisconsin face many unknowns, including a lack of understanding of the energy potential (biogas production) of various materials and of the quality of the resulting biosolids. Reducing, recovering, and recycling the food waste will help avert organic materials from landfills and can reduce greenhouse gas emissions into the environment.

![Figure 1](image.png)

**Figure 1.** The abundance of each type of municipal solid waste. Food waste comprises roughly half of all organic solid waste collected.

In the UW-Oshkosh digester, feedstocks are mixed with structural material (hay, grass, etc) and placed inside a fermentation bay (see Figure 2) which is then sealed to create an airtight environment. The structural materials ensure the retention of the feedstock within the fermentation bay as percolate (essentially a liquid microorganism mixture) is sprayed overtop of the feedstock and drains out through a floor drain. Initially, oxygen present within the bay is used by bacteria to
break down hydrocarbons. As oxygen is used up, anaerobic archaea thrive and metabolize carbon
dioxide and/or acetic acid to produce methane.

**Figure 2.** The dry anaerobic digester at University of Wisconsin-Oshkosh. The digester (left)
receives solid organic waste (upper right) from various sources for use in large bays (bottom right)
which create an anaerobic environment for digestion.

**Photo 1.** Ground Sanimax foodwaste.

**Objectives:**

The objectives of this study were to:

1) Determine the chemical and physical characteristics of food waste.

2) Determine the biogenic methane potential of food waste in order to determine its
   potential effectiveness as a substrate in a dry anaerobic digester.
**Methodology:**

Total solids (TS), volatile solids (VS), total phosphorus (TP), pH, biogenic methane potential (BMP), and volatile fatty acid (VFA) content were measured in representative food waste samples.

**Total Solids:** Food waste samples were homogenized in a blender and the mass of each sample was measured and recorded. The samples were then placed in an incubator set to 105°C for a period of at least 24 hours. After 24 hours, the samples were removed from the incubator, weighed, and returned to the incubator. The samples were then weighed again 2 hours later to determine whether or not there was a change in mass. If the mass did not change, then the mass of the sample was recorded (4). This test determines how much of the material is composed of water and how much of the material is solid.

**Volatile Solids:** Samples which were dried in the total solids method were placed in a muffle oven at a temperature of 550°C for at least 4 hours. After cooling in a desiccator, the samples were weighed (5). This test determines how much of the dry matter is composed of volatile organic material. The resulting residue is composed of inorganic material.

**Total Phosphorus:** Samples ashed in the volatile solids method were put through Standard Method 4500 P B5 (6). In this method, the sample is digested using heat, sulfuric acid, and ammonium peroxydisulfate. After digestion, total phosphorus is measured colorimetrically using an ascorbic acid/ammonium molybdate reagent and a spectrophotometer. The resulting absorbance is measured against an established standard curve to determine the final concentration of phosphorus.

**Volatile Fatty Acids:** Food waste samples are diluted with water and centrifuged for 25 minutes. Next, the supernatant is acidified and injected into the gas chromatograph (see Figure 3). Peaks for each of the VFAs (acetic, propanoic, isobutanoic, butanoic, isovaleric, and valeric
acids) are integrated and measured against a standard curve containing known concentrations of each acid (7). VFAs are reported in acetic acid equivalent concentrations.

**pH:** pH was measured using a standard calibrated ion-selective electrode (8).

**Biogenic Methane Potential:** Percolate from the dry anaerobic digester was placed in a jar and connected to a eudiometer (Figure 3, right). The percolate was kept in a water bath at 38°C until it stopped producing gas. At that point, the food waste sample was added to the eudiometer at a loading rate of 3 grams dry weight per liter of percolate (9). Since the biogenic methane potential of the percolate was previously expelled, one can infer that the gas produced was due to the food waste sample. Negative controls (no sample added) and positive controls (microcrystalline cellulose) were also run in each experiment, and the gas produced from the negative controls was subtracted from the treatment groups’ gas totals. Methane, oxygen, carbon dioxide, and hydrogen sulfide measurements were taken daily using a handheld gas meter.

**Figure 3.** Instruments used to measure VFAs and BMP. The gas chromatograph (left) was used to measure the retention time of the VFA’s within the samples, and the eudiometers (right) were used to measure total BMP of the samples.
Results:

Physical and Chemical Characteristics:

Table 1. Results for chemical analyses of food waste.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Matter (% Fresh Matter) (n=10)</td>
<td>14.83%</td>
</tr>
<tr>
<td>Organic Dry Matter (%DM) (n=10)</td>
<td>91.89%</td>
</tr>
<tr>
<td>DM (% Fresh Matter): ODM (% Fresh Matter)</td>
<td>1.088</td>
</tr>
<tr>
<td>Total Phosphorus (n=4)</td>
<td>25.52 mg P/L</td>
</tr>
<tr>
<td>pH (n=10)</td>
<td>4.7</td>
</tr>
<tr>
<td>Volatile Fatty Acids (n=1)</td>
<td>1900 mg/L (acetic acid eq.)</td>
</tr>
</tbody>
</table>

The phosphorus levels are sufficient to encourage microbial growth, and the high VFA content is usually beneficial to methanogenic microbes present in an anaerobic digester.

Biogenic Methane Potential:

Testing shows that the food waste has a BMP of 490 Normal liters per kilogram of dry matter, which is comparable with other feedstocks with have moderate or high BMP values.

Figure 4. Production graph for biogas yield from food waste. The experiment ran for 32 days and yielded 88 Normal liters per kg of fresh material.
Figure 5. Percent CH₄ produced over the duration of the experiment. Methane was measured 7 times throughout the experiment. Methane measurements are taken when enough biogas is produced to zero the instruments.

Table 2. Biogas volumes for dry organic, dry, and fresh matter masses.

<table>
<thead>
<tr>
<th>Biogas Production after 32 days (mean values)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas production from fresh material</td>
<td>88 Ni biogas/kg</td>
</tr>
<tr>
<td>Gas production from dry matter</td>
<td>490 Ni biogas/kg</td>
</tr>
<tr>
<td>Gas production from organic dry matter</td>
<td>94 Ni biogas/kg</td>
</tr>
<tr>
<td>Methane Concentration</td>
<td>73.65</td>
</tr>
<tr>
<td>Carbon Dioxide CO₂</td>
<td>19.6</td>
</tr>
<tr>
<td>Corrected Methane (CH₄)</td>
<td>79</td>
</tr>
<tr>
<td>Corrected Carbon Dioxide (CO₂)</td>
<td>21</td>
</tr>
<tr>
<td>Hydrogen Sulfide H₂S</td>
<td>145</td>
</tr>
</tbody>
</table>

Table 3. Typical BMP values for comparable feedstocks.

<table>
<thead>
<tr>
<th>Substrate for Biogas Production</th>
<th>Biogas Yield (Ni biogas/kg DM)</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal Fat</td>
<td>1000 - 1200</td>
<td>Very High Biogas Yield</td>
</tr>
<tr>
<td>Grass Clippings</td>
<td>700 - 1000</td>
<td>High Biogas Yield</td>
</tr>
<tr>
<td>Spent Fruits</td>
<td>400 - 700</td>
<td>Moderate Biogas Yield</td>
</tr>
<tr>
<td>Straw</td>
<td>250 - 400</td>
<td>Low Biogas Yield</td>
</tr>
</tbody>
</table>
**Conclusions:**

The results of the physical and chemical testing of the food waste show that it is an excellent potential candidate for use in the dry anaerobic digester. The food waste has a TS:VS ratio of greater than 1.0, which is desirable in a feedstock. Although the pH for the food waste is fairly low, the acidity of the food waste can be mitigated by the addition of other, more basic feedstocks. Also, the inside of industrial-scale digesters operate at a pH of about 7.8. Adding slightly less of the food waste to the digester will ensure that the pH remains at a level conducive to methanogenesis. The phosphorus levels are sufficient to encourage microbial growth, and the high VFA content is usually beneficial to methanogenic microbes present in an anaerobic digester.

BMP results reinforce the validity of food waste as a strong candidate for use in anaerobic digestion. A literature comparison of biogas yields from other substrates show that food waste produces a moderate to high biogas yield (Tables 2 and 3).

The data acquired from this experiment helps to elucidate the potential benefits of using food waste as a feedstock in dry anaerobic digestion. Although other studies (10) have analyzed the nutrient content and BMP of food waste for use in a low-solids anaerobic digester, few data have been generated for the potential of food waste in dry anaerobic digestion. This study only begins to characterize the methane potential of food waste in a dry anaerobic digester, and future studies should focus on measuring the BMP of food waste in bench-scale digesters that more closely replicate how the large-scale digester works. A scaled-down version of the large-scale digester would help to show if there are any unforeseen affects to using food waste as a feedstock.

In 2010, the average household in the United States used 11,496 kWh of electricity (11), and one cubic meter of methane can be utilized to produce 2.14 kWh of electricity (12). Based on this study, one dry metric ton of food waste has the potential to produce 1048 kWh of electricity.
electricity (Equation 1). One metric ton of fresh matter has the potential to produce 188.32 kWh of electricity (Equation 2). There are four digestion chambers at the UW-Oshkosh digester, and about 80 tons of food waste is loaded into each chamber for a one month period. Overall, about 320 tons of food waste can be loaded per month, which translates into 60,262 kWh of electricity per month (320 tons x 188.32 kWh) or 723,148 kWh of electricity produced per year (60.262 kWh per month x 12 months). The results from this experiment show that food waste has the potential to produce enough biogas per year to meet the electricity needs of 63 households for a year (723,148 kWh / 11,496 kWh per household).

**Equation 1.** Calculation of electricity produced per metric ton of food waste.

\[
\frac{490 \text{ N liters biogas}}{\text{kg Dry Matter}} \times \frac{1000 \text{ kg}}{1 \text{ metric ton}} \times \frac{1 \text{ Cubic Meter}}{1000 \text{ N liters}} = \frac{2.14 \text{ kWh}}{1 \text{ Cubic meter methane}}
\]

**Equation 2.** Calculation of electricity produced per metric ton of food waste.

\[
\frac{88 \text{ N liters biogas}}{\text{kg Fresh Matter}} \times \frac{1000 \text{ kg}}{1 \text{ metric ton}} \times \frac{1 \text{ Cubic Meter}}{1000 \text{ N liters}} = \frac{2.14 \text{ kWh}}{1 \text{ Cubic meter methane}}
\]
REFERENCES


7. Volatile Fatty Acids Method: Based on: Determination of Volatile Fatty Acids with House Method at Schmack Laboratories in Schwandorf, Germany and method development at the University of Wisconsin Oshkosh.


