Co-Treatment of Municipal Commercial Solid Waste and Cow Manure Using a Two Phase Anaerobic Process

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ABSTRACT

Research was conducted to evaluate the feasibility of producing methane gas from combined segregated municipal and agricultural waste. The combination of the two wastes resulted in sufficient nutrient value and bacterial diversity to improve the biodegradability of cellulose and increase the efficiency of gas production from the combined wastes. The feedstock included municipal solid waste with 70\% paper, 20\% food waste and 10\% lawn clippings. The agricultural waste was feedlot manure. The ratio of municipal waste to agricultural waste was about 10 to 1. The results showed that the combined waste can produce as high as $1.97 \text{m}^3$ of CH\textsubscript{4} per day per $\text{m}^3$ reactor while segregated municipal waste alone produced only $0.46 \text{m}^3$ of CH\textsubscript{4} per day per $\text{m}^3$ of reactor. The average methane content of the produced gas was about 72\%.

KEY WORDS

Agricultural waste, anaerobic digestion, energy, municipal waste, bi-phasic

INTRODUCTION

Millions of tons of municipal solid waste and feedlot manure waste are generated in the United States each year. The significant amount of waste is a major environmental risk, contributing to contamination of air, water and soil. On the other hand, global depletion of fossil fuel and increasing demand for energy is leading into serious energy shortage. There is an urgent need to develop cost-effective technologies from renewable resources such as agricultural and municipal waste. The conventional anaerobic systems which are used to produce methane from organic waste are often inefficient, take a long time and are costly (Ghosh et al, 1975, Ghosh, 1987, Samani et al (1998), Yu et al (2000a). The conventional anaerobic digestion of organic waste is conducted in a single-stage slurry digester that recover only 50-60\% of the feed organic carbon as methane. In a single-phase system, dilute feed slurries with a total solids concentration of about 5-wt\% are used to balance the process of acid production from the solids (acidogenesis), and acid conversion to methane (methanogenesis). With concentrated soluble or high-solid feeds, VFA production proceeds at a much faster rate than the rate of conversion of VFAs to methane, thereby causing acids accumulation, a pH drop, and the consequent inhibition of methanogenesis (Ghosh et al, 1975, Ghosh 1987, Yu et al 2000b). The end result is slower and inefficient conversion of organic material to methane gas as the acid producing bacteria compete with the methane producing. In addition, the large volume of water involved in the slurry process increases the initial volume of the digester, and the initial cost of construction. The two-phase bio-fermentation system avoids the imbalance...
between the processes of acidogenesis and methanogenesis by physically isolating the two major microbial phases in two separate reactors thus resulting in optimum biological environment for bacteria. The end result is a more efficient organic conversion, high gas yield and high methane concentration (Strydom et al 1997, Beccari et al 1998).

METHODS
The two-phase system has a solid phase reactor and a methane production reactor. A schematic of the system is shown in Figure 1. The reactors are shown in Figure 2. The solid phase reactor used in this research was a mild steel waste dumpster approximately 3 meters on a side. The solid phase reactor was insulated using 4 inch insulating foam panels. The methane production reactors are 12-inch diameter PVC insulated with 4 inch fitted foam. Figure 3 shows details of the column insulation as well as gas and liquid sampling ports. The methane production reactors where filled with 1-inch Jaeger Tripac media. The solid phase reactor contains the solid waste that is to be processed. In the solid phase reactor, water is applied from the top of the waste pile using a sprinkler system shown in Figure 2, and is collected at the bottom through a drain line. The water is then re-circulated through the solid waste until a desired level pH is achieved. A pH of 5.0 – 6.0 is indicative of a high volatile fatty acid (VFA) level. The recirculation valving and the pH/ORP probes are shown in Figure 4. The VFA enriched leachate is transferred to the methane reactor where VFAs are converted to methane in a very short time (1-3 days). The water is then returned to the solid phase for re-circulation.

The City of Albuquerque (COA) NM is interested in attempting to implement this technology at a large pilot scale, with expansion to full-scale if the large pilot scale is successful. Albuquerque has identified 83 tons/day of segregated high organic waste in their municipal waste stream. An analysis of this waste stream, as reported by the COA, is shown in Table 1. A surrogate waste stream has been developed at New Mexico State University using paper waste, food waste and grass waste from the university. Because of the small scale of the current pilot unit it is believed that the waste must be homogenized to produce meaningful reliable results. Early attempts were less then successful. Figure 5 shows the type of layering that could not be easily avoided because of the shredded paper component. The left hand picture shows the food and paper, the right hand photo shoes the grass. In this test, a large PVC membrane was used to mix the paper and grass prior to loading in the reactor. The membrane is shown in Figure 6. In this experiment, the system was charged with 180 kg of municipal solid waste which contained 70% paper, 20% food waste and 10% lawn clippings by weight, and 18 kg of fresh feedlot manure. Figures 6 and 7 show the individual components that went into the mixture. Figure 8 shows the cow manure scattered on top of the COA mix. A mass balance approach was used to calculate the field capacity of the waste. This volume of water plus an additional 25% was added to the reactor. The volume of water was checked to insure that there was sufficient liquid to allow recirculation. The leachate was produced by re-circulating water through the solid phase. The enriched leachate was transferred to methane reactor and the rate of methane production and leachate characteristics were measured on a daily basis.
RESULTS AND DISCUSSION

Figure 9 shows the change in chemical oxygen demand (COD) in the effluent from the solid phase reactor as a function of time. The simulated COA separable commercial waste without cow manure peaks at a higher COD value. This is a little misleading. The run with cow manure had additional water in it and was feed more rapidly into the methane production reactors. The really significant information on this figure is the drop in COD around day 85 exhibited by the test without cow-manure added. The COD dropped below 5000 mg/L, VFA dropped to 580 after 118 days, and the pH rose (Figure 11). This combination of information indicated that the carbon available to the consortia of microorganisms present was exhausted. However, with the cow manure present, the COD remained above 5,000 mg/L, and the VFA values remained above 1,500 mg/L out beyond 180 days. There are changes in the concentration of COD in the effluent of the solid phase reactor in the test with cow-manure added. This is caused by a combination of things including: changes in microorganism populations, changes in feeding rates, changes in temperature, and dilution by water addition. Because of the amount of water removed from the system by sampling and by the gas stream, water had to be added back into the system three times. Each of these additions was 20-30 gallons. This issue will be revisited when pH changes are discussed.

Figure 10 shows the change in chemical oxygen demand (COD) between the influent and the effluent of the methane production reactor as a function of time for the Albuquerque separable commercial waste with cow manure added. There is a consistent COD reduction. This is important because the feed rate was continually increased in an effort to cause a failure of the methane reactor. As the feed rate was increased the concentration of COD/VFA in the feed dropped. The increased feed rate also reduced the time available for production of volatile fatty acids. Thus it was not possible to load the methane production column heavily enough to cause it to fail. The effluent of the methane production column has a constant COD concentration of around 2000 mg/L. This is a recirculated system, and there is a fraction of the COD that is not biologically available. It is anticipated that a significant portion of the effluent COD is not available to the methanogens as food. This is supported by the data shown in Figure 12, the effluent VFA’s are consistently in the range of 70-80 mg/L. Since the effluent COD does not increase significantly with time, it is probably available to some degree to the acidifiers and is broken down when recirculated to the solid phase reactor. Notice there are two broad, but distinct, peaks in the influent to the methane production reactor (effluent to the solid phase reactor), it is suspected that this represents shifts in microorganism populations to take advantage of change food sources. As the kitchen waste is diminished the populations shift to take advantage of the grass waste and then the paper waste. Based in COD, VFA, and pH, it does not appear that the microorganism populations where constant through out the treatment process. Unfortunately the microbial work needed to confirm this was not performed. If one could demonstrate that
there where fairly long periods of lower treatment efficiency due to microbial population shifts, one might be in a position to suggest strategies for shortening the treatment time by as much as 50%.

Figure 11 compares the pH in the effluent from the solid phase reactor as a function of time for tests treating simulated City of Albuquerque separable commercial waste with and without cow manure added. A depression in pH is an indication of VFA production. The pH and VFA curves should be well correlated. Without cow-manure added, the pH was rapidly reduced and then just as rapidly climbed back up. It appears that this represents mostly food waste and perhaps a little of the grass waste with very little degradation of the paper. The test with the cow-manure added shows a quick pH depression, followed by a period with an elevated pH. This is followed by a long period with a depressed pH. The first period of low pH is believed to be associated with degradation of the food and grass waste. The period of elevated pH is believed to be an acclamation or growth period for the microorganisms that degrade the paper waste. The extended period of depressed pH appears to represent the destruction of the paper. The pH finally started a steady rise after 180 days which correlates well with the drop in COD below 5,000 mg/L, and the drop in VFA.

Figure 12 shows the volatile fatty acids (VFA) in the effluent to the solid phase reactor (influent to the methane production reactor) and the effluent of the methane production reactor as a function of time for the Albuquerque separable commercial waste with cow manure added. The VFA peak is well correlated with the pH depression, but is not as well correlated with the COD peak. The use of COD alone as a process control parameter is not nearly as useful as pH alone. The combination of COD and pH is useful in controlling the system. The COD is a useful indicator of VFA’s at the end of the treatment process and pH is a good indicator of when VFA concentration is high enough to feed the reactor.

Figure 13 shows the alkalinity in the effluent of the solid phase reactor and the effluent of the methane production reactor as a function of time. This plot is important because it demonstrates that this system did not sour and was not in danger of souring. If the alkalinity drops below 2,000 mg/L, one must consider corrective action. However, this system appears to have consumed most of the available carbon and is still well above 2,000 mg/L.

Figure 14 shows the cumulative gas production from the gas production reactor as a function of time. This comparison of the tests treating Albuquerque separable commercial waste with and without cow manure added shows the gas production rate in liters per day per m³ of reactor volume. The peak gas production rate for combined waste was about 4 times more than that of municipal waste alone. The difference in improved gas production can be attributed to increased nutritional value of combined waste and presence of either the cellulase enzyme in the feedlot manure waste or the production of cellulase by a consortia of organisms seeded into the reactor through the cow manure. The authors have no data to support either possibility, but suspect that there is an consortia of cellulase producing organisms that where seeded in by the cow manure. If
this is the case, the treatment time may be reduced by adding a larger percentage of cow manure. If little manure is available, the organisms may be seeded back by adding a portion of the solid residual from the previous test back into the reactor instead of adding cow manure.

Figure 15 shows the percent methane by volume in the gas produced by the methane production reactor as a function of time. The percent methane is higher in this system then in the single-phase systems because the respiration gases from the acid forming step are not present to dilute the methane. This provides a higher energy per unit volume of gas. Whether or not this is truly an economic or even a practical advantage is yet to be seen.

The gas conversion rate from the COA waste with manure added was about 0.17 m$^3$ of methane per kg of waste during a period of 180 days. The gas conversion rate for municipal waste alone produced 0.046 m$^3$ per kg of waste. From Table 2 it is clear that the gas yield with the cow-manure added is nearly 4x greater than without the manure. The yield is in the same order of magnitude as the yield for the separate constituents in lab scale single-phase reactors. The processing time is significantly reduced for the paper waste. The lab scale single-phase system had a processing time of 550 days for paper waste and the large scale two phase pilot system had a processing time of 180 days. It is believed that this processing time can be significantly reduced by the addition of more fresh cow-manure, or by adding back some of the treated solid residue as seed.

CONCLUSION
There is an excellent opportunity to reduce environmental contamination and alleviate some of the global energy shortage by producing energy from renewable resources such as agricultural and municipal waste. The bi-phasic anaerobic digestion system presented here, has the potential to produce methane gas from organic waste with higher efficiency and better gas quality compared to traditional single phase systems. The gas conversion rate from the COA waste with manure added for the total waste stream of 83 tons/day, would be 13,500 m$^3$ of CH$_4$/day. Currently, the biggest economic obstacle in bio-energy industry is the competition from cheaper fossil fuel. The improved gas conversion rate achieved through the bi-phasic system could be the key factor in cost-effective production of energy from organic waste.

ACKNOWLEDGMENTS
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REFERENCES
Figure 1. Schematic of the two-phase anaerobic treatment system: Phase 1 solid phase volatile fatty acid production reactor, Phase 2 liquid phase methane production reactor.

Figure 2. Left photo is the reactors. The methane production reactor is on the left of this photo. The right photo shows the spray header inside the solid phase reactor.
Figure 3. Photos showing details on the methane reactors. Left photo is the gas separation and recycle piping. The right photo is the mid-point sampling valve and temperature sensor.

Figure 4. These photos show the piping details on the methane production reactors. The left photo is an overview of the piping and valves. The right hand photo shows the pH and ORP probes.
Figure 5. These photos show the feedstock with no cow manure. The left photo is the food and paper waste. The right hand photo shows final mix with grass.

Figure 6. These photos show the feedstock with cow manure. The left photo is 60 mil PVC used for mixing. The right hand photo shows grass used with cow manure.

Figure 7. These photos show the food and shredded paper used for feedstock with cow manure added.
Figure 8. The photo shows the final feed stock mix with the cow manure scattered on top of the mix.

Figure 9. Chemical Oxygen Demand (COD) in the effluent from the solid phase reactor as a function of time. This is a comparison of the Albuquerque separable commercial waste with and without cow manure added.
Figure 10. Chemical Oxygen Demand (COD) in the influent and the effluent of the methane production reactor as a function of time. This is the Albuquerque separable commercial waste with cow manure added.

Figure 11. pH in the effluent from the solid phase reactor as a function of time. This is a comparison of the tests treating Albuquerque separable commercial waste with and without cow manure added.
Figure 12. Volatile Fatty Acids (VFA) in the Effluent to the solid phase reactor and the effluent of the methane production reactor as a function of time. This is the Albuquerque separable commercial waste with cow manure added.

Figure 13. Alkalinity in the Effluent of the solid phase reactor and the effluent of the methane production reactor as a function of time. This is the Albuquerque separable commercial waste with cow manure added.
Figure 14. Cumulative Gas Production from the gas production reactor as a function of time. This is a comparison of the tests treating Albuquerque separable commercial waste with and without cow manure added.

Figure 15. Percent % methane by volume in the gas produced by the methane production reactor as a function of time. This is the Albuquerque separable commercial waste with cow manure added.
Table 1. Albuquerque NM separated commercial solid waste stream and the basis for the proposed recipe for the pilot scale reactor.

<table>
<thead>
<tr>
<th>Category</th>
<th>Total</th>
<th>Paper</th>
<th>Food etc.</th>
<th>Yard Tr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Retail</td>
<td>12,787</td>
<td>10,381</td>
<td>2,249</td>
<td>157</td>
</tr>
<tr>
<td>Educational</td>
<td>10,276</td>
<td>5,388</td>
<td>3,100</td>
<td>1,788</td>
</tr>
<tr>
<td>Govt. Office</td>
<td>2,531</td>
<td>2,282</td>
<td>228</td>
<td>21</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>25,594</td>
<td>18,051</td>
<td>5,577</td>
<td>1,966</td>
</tr>
<tr>
<td><strong>Mass %</strong></td>
<td></td>
<td>71%</td>
<td>21%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Proposed recipe

Table 2. Gas yield and processing time as a function of feed stock and reactor system.

<table>
<thead>
<tr>
<th>Feed Stock</th>
<th>Gas Yield (m$^3$ CH$_4$/dry kg)</th>
<th>Process Time (Days)</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass$^a$</td>
<td>0.127-0.144</td>
<td>135</td>
<td>Single Phase</td>
</tr>
<tr>
<td>Office Paper$^a$</td>
<td>0.217</td>
<td>550</td>
<td>Single Phase</td>
</tr>
<tr>
<td>Food Waste$^a$</td>
<td>0.3</td>
<td>100</td>
<td>Single Phase</td>
</tr>
<tr>
<td>MSW$^a$</td>
<td>0.092</td>
<td>210</td>
<td>Single Phase</td>
</tr>
<tr>
<td>MCSW</td>
<td>0.045</td>
<td>112</td>
<td>Two Phase</td>
</tr>
<tr>
<td>MCSW w/Fresh Cow Manure</td>
<td>0.172</td>
<td>180</td>
<td>Two Phase</td>
</tr>
</tbody>
</table>

$^a$: Barlaz, Morton “Biodegradability of MSW components in Lab-Scale Landfills (1997)
MSW = Municipal Solid Waste
MCSW = Municipal Commercial Solid Waste; 70% paper, 20% food, 10% grass by weight.