Management and Operation of a Full-Scale Poultry Waste Digester

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ABSTRACT A full-scale (587 m³) poultry anaerobic digester was monitored for 3 years. The digester processes the manure from 70,000 caged layers and is operated on a 22-day retention time at 35 C. Resulting biogas is used to fuel an 80 kW engine-generator set; the electricity is sold to the local utility. Biogas production averaged 0.39 m³/kg volatile solids added. Mean methane content of the biogas was 58.3%. Electrical cogeneration over the study period averaged 833 kWh/day. System improvements have reduced the parasitic electrical demand for the facility to 16%. Management of the influent solids content was found to be the single most important factor in continued consistent biogas production and digester stability. Management of grit in the influent was found to be critical because this material tends to settle in the digester. A technique was developed to settle grit from the manure prior to entering the digester.  
(Key words: anaerobic digestion, methane, manure, co-generation)

INTRODUCTION

Anaerobic digestion of animal manures has been a topic of considerable research in the last few years. The benefits of this process include the production of a readily useable byproduct—biogas—and the reduction of odor potential from manure. Ashworth et al. (1984) indicated that between 85 and 100 digesters either have been constructed or are planned to be constructed on US farms. Of this number only four were located on poultry operations and some of these were no longer in operation. Converse et al. (1981) reported on one poultry digester that was operated for at least five years. Recently, Safley et al. (1985) reported on a poultry anaerobic digester constructed in 1983. This digester processes the manure from 70,000 caged layers in a 587 m³ digester operated at 35 C with a 22-day hydraulic retention time (HRT). The resulting effluent is discharged into an anaerobic lagoon. This paper will report on the management and operation of the earlier-mentioned digester for the period August 1983 through May 1986.

SYSTEM OPERATION

Influent Management. The anaerobic digester was constructed in 1983. The system is completely described in an earlier report by Safley et al. (1985). The insulated, completely stirred digester is operated on a 22-day HRT. Management of the digester begins with the initial processing of the manure as it comes from the layer houses. The manure is augered into a pit where sufficient water is added to reduce the
total solids (TS) concentration from 25 to 6%. Determination of the TS concentration of the manure in the pit is made using a hydrometer (Tunney, 1981). This method has been found to be reasonably accurate and offers the advantage of being done frequently and on site. Safley and Owens (unpublished data) have found that at 6% TS the bulk of the large grit particles in the manure will settle by gravity and accumulate in the processing pits, which can be periodically cleaned. Elimination of grit at this point helps to minimize its accumulation in the digester, which is considerably more difficult and costly to clean. Cleaning the digester will be discussed later. Also, reduction of the raw manure to 6% TS reduces the ammonia concentration which can become inhibitory to digester performance.

The manure in the pit is agitated for several minutes followed by 20 min with no agitation to permit grit to settle. Next, the manure is pumped into a second pit used to hold the processed slurry until it is automatically fed into the digester once every three hours. The manure after dilution and grit removal is 6% TS. Periodic addition of manure aids in uniform gas production and helps to prevent dense layers of scum from forming on the surface of the digester liquid.

Liquid used to dilute the raw manure comes from two sources: fresh water from a well and lagoon liquid. Both liquids are used in approximately equal proportions. During periods of low rainfall the use of undiluted lagoon liquid leads to reduced biogas production - possibly from elevated salt concentrations. The lagoon receives effluent from the digester and is highly loaded. The use of fresh groundwater exclusively is precluded because ground water is relatively scarce and its use leads to too rapid filling of the lagoon and the subsequent increase in amount of liquid must be managed.

**Digester Mixing.** The digester contents are periodically hydraulically mixed using one of three methods. A centrifugal pump (Gorman Rupp, Mansfield, OH) is used to recirculate the liquid. The suction line for this pump takes liquid at a point approximately 2 m above the digester floor. The discharge line from the pump is connected to a manifold that permits the liquid to be channeled in one of three directions: up through a shell-and-tube heat exchanger located in the center of the digester, over the surface of the liquid to assist in breaking up any floating scum, or through a rotatable floor nozzle used to resuspend settled sludge. Each of these alternatives is used frequently. However, the digester is typically agitated by pumping through the heat exchanger for 3 to 5 min every 3 hr during digester loading. Additional agitation is done as needed.

**Biogas Processing.** Biogas removed from the headspace of the digester first passes through a scrubber that consists of a metal tank packed with wood chips impregnated with iron fillings. The scrubber packing material (approximately 4.2 m³) must be replaced at intervals of 9 to 12 months. The scrubber packing material is constantly regenerated using a small air compressor operating at an air flow of approximately 0.7 m³/hr. The daily biogas production passing through the scrubber has ranged from 481 to 708 m³. The hydrogen sulfide (HS) concentration of the biogas entering the scrubber ranges from 4,000 to 6,000 ppm. The scrubbed biogas has an H₂S concentration typically below 1 ppm. The H₂S determinations are made using calibrated gas tubes (National Draeger, Inc., Pittsburgh, PA).

The scrubbed biogas is used directly in the engine/generator (Katolight, Inc., Mankato, MN) set during the time it is in operation. When the engine is not being operated during off-peak hours as set by the utility purchasing the electricity-the biogas is compressed and stored in an ASME 1,724-kPa-rated tank. This gas is used to supplement the biogas flow from the digester while the engine is operating.

In addition to the monitoring of H₂S in the biogas, C0₂ is also monitored closely. The C0₂ measurements are made on-site using a Bacharach gas tester. Over time it has been found that CO₂ readings are a good indication of digester stability. For this particular digester CO₂ readings under 42% typically
indicate acceptable performance. Readings over 42% warn of excessive loading rates and possible digester failure. The Bacharach gas tester (Bacharach Instruments, Pittsburgh, PA) typically indicated CO$_2$ gas levels 2 to 5% lower than those determined by subtracting the methane contents (determined by gas chromatography) from 100%.

**Monitoring Digester Health.** Periodic samples of digester effluent are taken and analyzed at the Water Quality and Waste Management Laboratory of the North Carolina State University Biological and Agricultural Engineering Department. Various parameters including pH, alkalinity, conductivity, and total organic acids (TOA) have been studied in an effort to correlate the parameters to digester performance. The TOA values were relatively high. However, Converse *et al.* (1981) reported volatile fatty acid values in poultry digester influent to average 15,040 ppm as acetic acid. In this study the poultry manure was allowed to preferment in the processing pits for 1 to 2 days prior to entering the digester. This prefermentation allowed time for acid production. Laboratory procedures for these analyses are described by Safley *et al.* (1985). Although these parameters aid in predicting digester performance none of them has been found to accurately warn of potential problems.

**TABLE 1. Digester performance**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean$^1$</th>
<th>n</th>
<th>SD$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatile solids (VS) destroyed, %</td>
<td>53.1</td>
<td>113</td>
<td>22.2</td>
</tr>
<tr>
<td>CH$_4$%</td>
<td>58.3</td>
<td>87</td>
<td>5.6</td>
</tr>
<tr>
<td>Biogas production (daily) m$^3$/m$^3$ Digester</td>
<td>.83</td>
<td>91</td>
<td>.23</td>
</tr>
<tr>
<td>m$^3$/kg VS added</td>
<td>.39</td>
<td>44</td>
<td>.11</td>
</tr>
<tr>
<td>m$^3$/kg VS destroyed</td>
<td>.60</td>
<td>44</td>
<td>.19</td>
</tr>
<tr>
<td>m$^3$/bird</td>
<td>.007</td>
<td>91</td>
<td>.002</td>
</tr>
<tr>
<td>Feeding rate, kg VS/m$^3$ per day</td>
<td>1.66</td>
<td>113</td>
<td>.71</td>
</tr>
<tr>
<td>BA:TA$^3$ (digester effluent)</td>
<td>.79</td>
<td>12</td>
<td>.04</td>
</tr>
</tbody>
</table>

1 August 1983 to May 1986 (digester was operational for 136.5 weeks of this 147-week period).
2 Standard deviation.
3 December 1985 to May 1986 ratio of bicarbonate alkalinity (BA) to total alkalinity (TA).

Recently a simple test was recommended by Pos *et al.* (1985) that compares the ratio of the concentration of bicarbonate alkalinity (BA) to total alkalinity (TA). This ratio (BA:TA) has been found to be useful in predicting acceptable loading rates, especially during digester startup. The BA:TA ratio of the digester influent is typically below .5; this indicates inhibition. However, the BA:TA ratio of the digester effluent ranges from .75 to .85, which is in the healthy range according to Pos *et al.* Tables 1 and 2 provide information regarding the biological efficiency and gas production of the digester as well as information on typical parameter concentrations of digester influent and effluent.

**Digester Startup.** Startup of a poultry digester has been found to be an exceptionally critical time. This digester has always been filled initially with lagoon liquid for startup because of the proximity of the lagoon. The digester is brought to operating temperature (35°C) over a 7 to 14-day period depending on the ambient temperature. A shell-in-tube heat exchanger (A. O. Smith Harvestore, Barrington, IL) is used to maintain digester temperature. Heat for the digester is taken from the engine. During this time little processed manure is added until the CO$_2$ concentration in the biogas goes below 45%.
TABLE 2. Mean values for digester influent and effluent

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influent</th>
<th>Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Total Kjeldahl nitrogen, ppm</td>
<td>5,508</td>
<td>1,490</td>
</tr>
<tr>
<td>NH₃-N, ppm</td>
<td>3,955</td>
<td>1,197</td>
</tr>
<tr>
<td>pH</td>
<td>7.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Total organic acids, ppm as acetic acid</td>
<td>8,447</td>
<td>2,868</td>
</tr>
<tr>
<td>Alkalinity, ppm as CaCO₃</td>
<td>19,111</td>
<td>5,808</td>
</tr>
<tr>
<td>Total solids (TS)³ % wet basis</td>
<td>5.88</td>
<td>1.93</td>
</tr>
<tr>
<td>Volatile solids, % TS</td>
<td>67.24</td>
<td>6.65</td>
</tr>
<tr>
<td>Conductivity, microsiemens/cm</td>
<td>22,802</td>
<td>6,288</td>
</tr>
</tbody>
</table>

1 August 1983 to May 1986; mean 121 observations.
2 Standard deviation.
3 After initial grit removal.

Once this occurs the loading rate is gradually increased as long as the CO₂ level does not increase. The BA:TA ratio in the poultry manure digester during startup ranges from .60 to .70. Typically 2 to 4 weeks after the digester reaches operating temperature full feeding can be resumed (22-day HRT). If the CO₂ level begins to increase during startup the loading rate will not be increased until the CO₂ concentration lowers. If possible, seed material from the digester is saved in the processing pits for reinoculating the refilled digester. This has been found to expedite the startup of the digester.

**Digester Cleaning.** One of the major problems encountered in managing the digester is grit in the manure which accumulates in the digester and forces periodic (9 to 12-month interval) cleanouts. Managing the influent to allow for grit settling in the processing pits will greatly decrease the digester cleanout frequency. Cleanout is a costly operation as gas production is significantly reduced for 2 to 4 weeks. However, the actual cleanout process can generally be accomplished in 1 to 2 days.

Grit that has settled in a digester presents a special materials handling problem. Once the digester is emptied of its readily drainable contents the remaining grit has been found to be most easily removed hydraulically, using high pressure hoses. At this site a large pump is typically located near the lagoon and lagoon liquid is pumped into the digester. One or two workers using hoses wash the grit from the digester. A pit is dug outside the digester and the grit-laden liquid is directed here, where the grit settles. The liquid from this pit flows back into the lagoon. If insufficient pressure is used to fluidize the grit and transport it rapidly from the digester, it will resettle in the digester prior to removal. Once the grit has settled in the pit it is removed using a backhoe and transported to a disposal site. Because of the cost and inconvenience of the cleanout process for the digester, managing the influent to allow for grit settling in the processing pits is recommended. Without grit removal in the influent, grit and undigested solids accumulation in the digester has been found to vary from .0012 to .0018 m³/bird per year.

**Gas Compressor.** The greatest difficulty encountered in operating the gas handling system has been the maintenance of the biogas compressor (Gardner-Denver, Denver, CO). The relatively inexpensive unit requires periodic overhaul, approximately semiannually. However, since the utility purchasing the power pays a premium price for "on-peak" electricity, it is necessary to compress and store gas during "offpeak" hours. Systems not requiring gas storage are definitely advantageous.
Daily Monitoring and Management. The farm owner typically spends between 30 min and 1 hr daily in managing the digester. During this time he maintains records regarding the amount of electricity generated, the amount of gas produced, and the quality of the biogas (CO\textsubscript{2}). The operator also notes any mechanical irregularities andempties all condensate drains. In addition the manure pits are observed and agitated if needed. Additional time is scheduled for routine maintenance and repair and the amount of this time is highly variable.

IMPROVEMENTS MADE

Numerous improvements have been made to the system since it was put into operation. One modification that has had positive impact on the management of the system is the addition of a dedicated mix pump (Flygt, Norwalk, CT) in the second manure storage pit. This pump automatically mixes the pit contents several minutes prior to feeding the digester. This mixing resuspends the settled solids and allows a more uniform digester influent. Without this pump manure solids accumulate in the storage pit.

Another improvement is the installation of a low-pressure gas system which allows direct use of biogas while the engine is operating and reduces compressor operation. Not only is the electrical consumption of the compressor reduced but also the demand charge from operating a large motor during peak hours is reduced. Prior to installing the low-pressure system the compressor required an average 111.7 kWh/day (range 59.4 to 141.4). After installing this system electrical usage decreased by nearly 40% to 67.6 kWh/day (range 59.4 to 83.9).

Yet another modification was a diversion valve on the engine exhaust line that can bypass the exhaust heat recovery unit. By diverting the exhaust heat when not needed the electrical consumption of the radiator fan motor decreased more than 25% from 58.4 kWh/day (range 42.7 to 70.0) to 43.0 kWh/day (range 33.1 to 52.1).

The combined impact of the last two mentioned modifications was to reduce the electricity required to operate the digester systems by 30%. The mean daily electrical requirement is 136 kWh (range 78 to 220) while the mean daily electricity generated is 833 kWh (range 451 to 1240). Therefore, the electricity required to operate the system is approximately 16% of the daily electricity generated.

ADDITIONAL MODIFICATIONS NEEDED

The largest problem that yet affects the overall performance of the digester system is the need to periodically (every 9 to 12 months) empty the digester and remove grit. Because of this requirement the effective time of operation is limited to approximately eleven months per year. A method is needed that would either remove the grit from the influent or remove this material from the digester without having to empty the entire contents.

CONCLUSIONS

Anaerobic digestion of poultry manure can be effectively accomplished on the farm. Reasonable gas production (.39 m\textsuperscript{3}/kg volatile solids added) and subsequent electrical cogeneration (833 kWh/day) have been demonstrated. Maintaining a consistent TS level in the influent is important in getting consistent gas production. The removal of grit from the influent would have the single greatest impact on overall performance by reducing the digester down time. Competent management and personal attention is needed in certain areas of operation, namely, processing of digester influent, maintenance of equipment, and observation of system performance.
REFERENCES


