The Journal of Undergraduate Research

Volume 9 *Journal of Undergraduate Research, Volume 9: 2011*

Article 4

2011

Long Term, Continuous Temperature Monitoring of a Simple Anaerobic Digester and Open Manure Storage Pond in Eastern South Dakota

J. Darrington
South Dakota State University

E. Cortus
South Dakota State University

Long Term, Continuous Temperature Monitoring of a Simple Anaerobic Digester and Open Manure Storage Pond in Eastern South Dakota

Author: J. Darrington
Faculty Sponsor: Erin Cortus
Department: Agricultural and Biosystems Engineering

ABSTRACT

A two-cell manure storage system with a cover on the first cell was constructed in the late summer of 2009 in Eastern South Dakota. The covered cell acts as a simple anaerobic digester. Continuous temperature monitoring for 8 months shows the winter effluent temperature equilibrated to around 6°C, and that the effluent temperature trend lagged the ambient temperature trend by a month. Manure composition was also analyzed and was found to be relatively steady throughout the system. Volatile solids were the only component that dropped appreciably across the treatment cell, with an observed maximum of 50% reduction.

INTRODUCTION

Anaerobic digestion is a well-known method of utilizing chemical energy from organic wastes, both agricultural and municipal. Anaerobic microbes break down organic material as a part of their metabolism, and certain species produce methane as a waste product. Methane is a greenhouse gas of high regulatory concern with over 20 times the heat capturing capacity as carbon dioxide (EPA, 2011). In a managed anaerobic system, the methane produced can be collected and then burned as a fuel, reducing the total greenhouse gas production of a system. Since digestion is dependent on microbial activity, the environment where the digestion occurs is an important factor in the system's effectiveness. Microbial life occurs in three distinct temperature ranges: thermophilic (50-60°C), mesophilic (25-40°C), and psychrophilic (<20°C). Commonly, anaerobic digesters operate in the mesophilic range. The pH and manure nutrient composition also impact the microbial activity and digestion process.

An unheated manure storage system can be converted to an ambient temperature anaerobic digester (AD) with the addition of a cover and gas collection system (NRCS, 2003). While this type of AD is relatively low-cost and less technical than other types of ADs, gas production is affected by uncontrolled effluent temperature variation. The stored manure moves to an equilibrium temperature based on ambient and soil temperatures, radiation gains and losses, and heat generated during the digestion process.

There have been some studies that have investigated the digestion process under cool conditions. An early study from the Netherlands found no biogas production in dairy effluent

or swine slurry below a temperature of 20°C in any of the studied digesters without addition of previously treated effluent or an inoculum of temperature adapted bacteria (Zeeman et al. 1988). A Russian study in the late 1990's focused on the use of anaerobic digestion in the temperature range of 3 to 9°C. The purpose for their investigation was to determine if psychrophilic anaerobic digestion was a viable alternative for industrial wastewater treatment. They used a two-stage lab-scale system and loaded it with a constant mixture of volatile fatty acids. Under the low temperature conditions they observed a removal rate of over 90% of volatile material after an initial break in period, even when the temperature dropped to a minimum of 3°C for a period of 8 days. In addition to reducing the operational temperature they attempted to decrease the hydraulic retention time to a minimum while maintaining effective removal of volatile matter (Lettinga et al. 1999). This shows that degradation of volatile matter to methane can occur at low temperatures, and can attain high conversion efficiencies. Martin (2008) monitored the performance of a covered lagoon utilizing separated dairy effluent in California. They found no variation in the amount of gas produced by the system during the year of monitoring. The temperature of the effluent varied from 12.4°C (54.4°F) to 28.6°C (83.6°F) and differed from ambient temperature by 9.1°C (15.3°F) in January. As the gas production remained unchanged the temperature of the lagoon never left the optimal range for microbe growth even though the lagoon fell below 20°C. The literature suggests psychrophilic anaerobic digestion has the potential to be effective down to 3°C in an intensely controlled system. Furthermore, effective digestion was shown to continue through a 16.2°C reduction while maintaining gas output. Also, it was found that addition of adapted bacteria to the effluent acted to jump start digestion in cold systems that would otherwise have not produced biogas. The monitored system is not controlled and will not be as effective as a tightly regulated system. However, the simplicity of the construction and maintenance could balance out the loss of performance.

This paper shows preliminary results from a long term, continuous monitoring project of a simple AD system in South Dakota. This temperature data provides baseline measurements for more specific investigations into the overall effectiveness and heat transfer basics of simple AD systems in cooler climates.

MATERIALS AND METHOD

The monitored site was a 1,100-head dairy operation in eastern South Dakota with a flush manure removal system and a two-cell waste storage system. The flushed manure first encountered a solid separation system. The liquid fraction flowed out into the covered cell and the solid portion was used for bedding. The covered cell was connected in series with an open cell that stores the treated liquid that flows from the covered cell. Some of the liquid in the second cell was recycled back through the barn in the flush system.

The cover was a synthetic material, weighted down with concrete tubes to push gas through a gas collection system around the perimeter of the covered cell. The gases produced in the anaerobic conditions of the covered cell were flared off in order to reduce the total greenhouse gas emissions of the system. A total of 12 polyvinyl chloride(PVC) sludgelines were built into the covered cell, parallel to the east wall and along the bottom, approximately

20 cm from the covered cell floor. The purpose of the sludgeline was to allow for agitation and then removal of any sludge accumulation in the covered cell. The sludglines offered a practical access point to inside the covered cell.

Temperature data for the covered cell was collected by threading five temperature loggers (Model UA-001-08, Onset Computer Corp., Bourne, MA) into the sludgelines with cross-linked polyethylene (PEX) tubing. Three loggers were placed at the full depth of the covered cell in sludgelines 3, 7, and 10. Two loggers were placed at approximately half the depth of the covered cell in sludgelines 3 and 10 (Figure 1). The tube and loggers were left in the sludgelines continuously except during monthly data retrieval, from 9/24/2010 to 5/17/2011. Temperature measurements were recorded every 15 minutes.

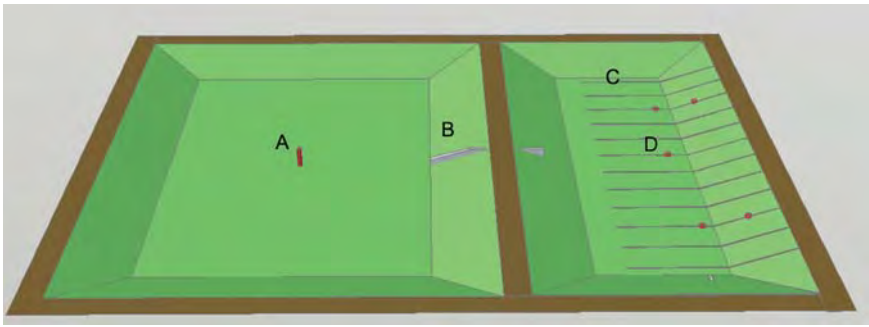

Figure 1. Location of the float (A) and weir (B) in the open cell (left), and the sludgelines (C) and temperature loggers (red circles, D) in the covered cell (right).

Temperature data for the open cell was collected by placing a float in the center of the cell. The float was made of capped PVC pipe and wood. The dataloggers were fastened to a 3-m chain at depths 0.6, 1.8, and 3.0 m from the surface. The float was anchored on the edges of the open cell. The open cell froze over in the winter so the sample rate was set to 1 hour to allow for deployment without retrieval from 11/19/2010 to 4/19/2011.

The ambient temperature 1 m above the south berm of the covered cell was recorded with a logger in a solar shield from 11/19/2010 to 5/17/2011. Prior to 11/19/2010 hourly mean temperature data from Brookings, SD, was used (weatherunderground.com).

The temperature accuracy of the dataloggers was assessed in ice water upon each deployment. The observed logger accuracy was within +/- 0.5°C.

Manure samples were taken every two months starting in December to measure manure composition before and after treatment in the covered cell, as well as on recirculation into the barn (after the open cell). The sample dates were 12/15/2010, 2/8/2011, and 4/19/2011. Effluent was collected prior to treatment just after the solid separation process. Effluent was collected after treatment at the weir that controls flow from the covered to the open cell. Recirculation liquid was collected at the point where it re-entered the barn. Analyses (density, total nitrogen, phosphorus, potassium, ammonium nitrogen, pH, and moisture) were completed by Olson Agricultural Analytical Services Laboratory using standard practices.

The volatile solids were determined by the Water and Environment Engineering Research Center using standard methods.

RESULTS AND DISCUSSION

Temperature in the covered cell in September was around 18°C, with the warmest temperature being 18.6°C on the bottom of sludgeline 10 and the coolest being 17.8°C on the side of sludgeline 10. The temperature steadily declined to a minimum of between 5.5 and 6.5°C throughout the covered cell. The early fall manure temperature of 18°C was cooler than expected and appeared to already be on the decline. The effluent temperature trend in the covered cell lagged the ambient temperature trend by approximately 4 weeks. The temperature trends were defined as periods when the temperature increased, decreased, or stayed the same over a period of time. Figure 2 shows the data collected from both dataloggers in sludgeline 3 as well as the recorded ambient temperature. The temperature in sludgeline 3 stayed essentially constant from 12/17/2010 to 3/25/2011. After 3/25/2011, the manure temperature rose at a gradual rate to a local maximum of 9.9°C for the bottom and 9.6°C for the side loggers. The observed equilibrium temperature reached during the winter was 6-7°C which constitutes psychrophilic conditions.

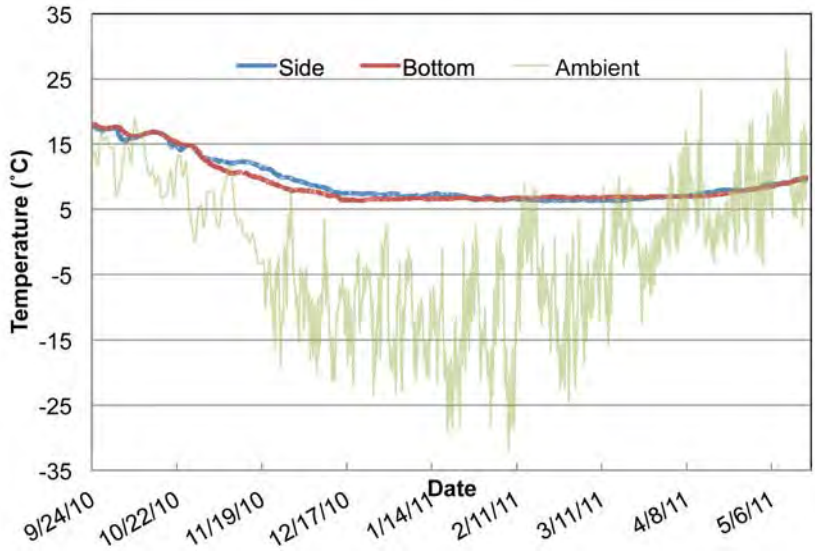

Figure 2. Measured temperature at the side and bottom of sludgeline 3 and ambient temperature.

Temperature in the open cell in November was around 5°C at the 0.6-m (2') depth and around 8°C at the bottom. The 1.8-m (6 ft) and 3-m (10 ft) dataloggers both started on the bottom of the cell as it was recently pumped out in November. As the depth increased the loggers separated and a temperature profile developed as can be seen in figure 3. The response to ambient temperature change was negatively correlated to depth, or the deeper the logger the slower the response to the temperature change. That is most noticeable in mid April when the measured temperature of the 0.6-m (2 ft) datalogger spikes upward in response to higher ambient temperature. The open cell was pumped out again starting on 4/18/2011.

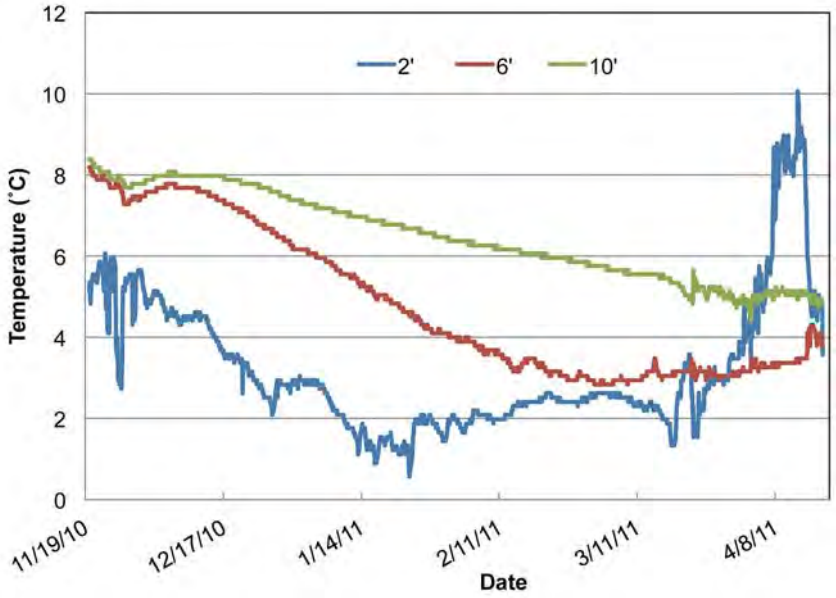

Figure 3. Manure temperatures in the open cell at 0.6 m (2'), 1.8 m (6') and 3 m (10') depths from the surface.

The data for three month-long periods were averaged by hour (Figures 4, 5, and 6). During October of 2010, there is an increase in effluent temperature between noon and 16:00. The average change is small, around 0.15°C, which is less than the accuracy of the sensors, but it is unlikely that the observed increase in temperature at these hours would be due to a consistent error in all of the sensors for the duration of deployment. Figure 5 shows the average temperature over the January 2011 period. The temperature remained constant through this period. Figure 6 shows the data from April-May of 2011. Emerging temperature changes are evident in the morning from 8:00 to noon in all locations. Interestingly, the changes in the spring month (Figure 6) are opposite to what was observed in the fall (Figure 4), and the logger locations of the maximum and minimum temperatures are exactly opposite between fall and spring.

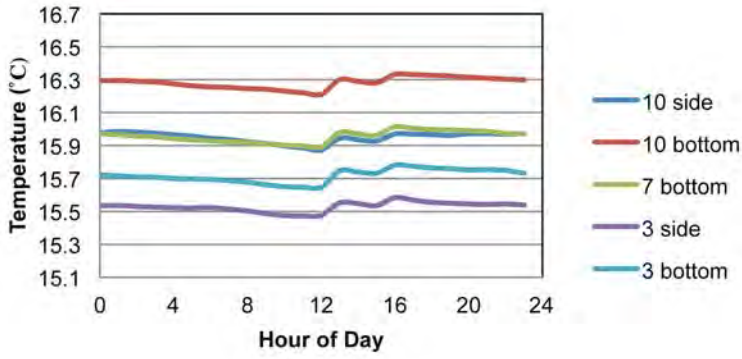

Figure 4. Hourly averages over the 9-24 to 11-4 deployment period.

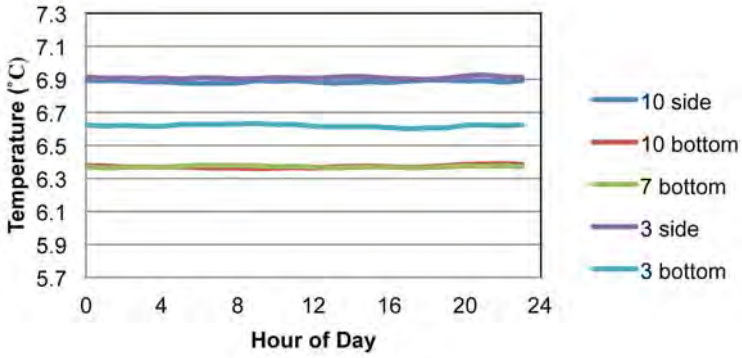

Figure 5. Hourly averages over the 1-12 to 2-8 deployment period.

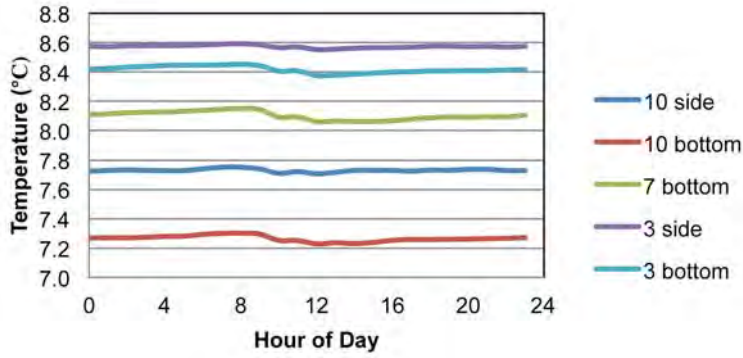

Figure 6. Hourly averages over the 4-19 to 5-17 deployment period.

Based on these measurements, we recommend a temperature sampling frequency of 1 hour to allow for longer deployment durations as the dataloggers are robust enough to handle the environment, as was seen in the open cell. Also, hourly sampling still allows for daily trends to be examined. The recommended location of sampling is multiple depth profiles in the covered manure if possible. If the emergency vents through the cover are located in the full depth of the covered cell, this provides an ideal sampling location for measuring the temperature profile. If temperature profiles through the cover are not an option, sampling in the sludglines works well. It is recommended for future projects to add another sampling location in the sludgeline at a shallower depth so that more of a profile could be seen. Also, it would be interesting to monitor the temperature of the effluent flowing from the closed to the open cell at the weir.

Manure composition results are shown in Table 1. The composition of the effluent at each stage is variable, but does not change appreciably. The solids composition decreases the further through the system the effluent goes, and likewise the density increases towards 1 g/mL, the density of water. The pH of the effluent in all stages was observed highest from the February sampling; this corresponds to a higher ammonia concentration. Ammonia is a base and is less volatile under cool conditions so higher concentrations will lead to higher pH measurements. The manure samples take a snapshot of the effluent compositions at each of the locations. The design hydraulic retention time of the covered cell was 60 days; the total time it took for effluent to be recycled back to the barn in the flush system is not known. Also, only a fraction of the effluent was used as flush water, but it is assumed that the recirculation effluent is representative of the open cell composition.

Table 1 shows that volatile solid composition changed through treatment in the covered cell. Volatile solids are the feed material for the microbial population, and are converted to methane. Thus, volatile solid destruction correlates to the amount of methane produced and is a common method of determining digestion efficiency. On 12/15/2010 the volatile solids were reduced by 50% through the covered cell. The overflow volatile soild composition increased markedly on the following two sample dates. There was an observed 33.5% reduction on 2/8/2011 and an observed 5.6% increase in volatile solids on 4/19/2011. The volatile soilds in the separated effluent on 4/19/2011 were much lower than the previous samples. The sample was taken at a different time of day and likely corresponded with the flushing of washwater used to clean the parlor after the morning milking. Washwater would dilute the effluent which would lower the concentration of observed volatile solids. It is assumed that the volatile solid loading into the covered cell would be relatively constant in the 0.019 to 0.020 g/ml (0.16 to 0.17 lbs/gal) range based on constant diet nutrient composition, homogeneous cattle genetics, and the first two measurements.

Table 1. Manure composition for each sample point and each date.

Sample Location Quality Parameter	12/15/2010	2/8/2011	4/19/2011
After separator, flowing into the closed cell			
Density (g/mL)	0.989	0.9802	0.9684
Total Nitrogen (%)	0.278	0.2366	0.2199
Phosphorus (%)	0.0240	0.0270	0.0220
Potassium (%)	0.152	0.142	0.129
Ammonium (%)	0.112	0.1248	0.1071
pH	7.45	8.14	7.89
Moisture (%)	97.2	97.0	97.8
Total Solids (%)	2.82	3.04	2.20
Volatile Solids (g/mL)	0.019	0.020	0.013
After the closed cell, at the weir, flowing into the open cell			
Density (g/mL)	0.992	0.9967	0.9909
Total Nitrogen (%)	0.184	0.2459	0.2371
Phosphorus (%)	0.0230	0.0210	0.0210
Potassium (%)	0.136	0.135	0.126
Ammonium (%)	0.108	0.1192	0.1131
pH	7.45	8.02	7.69
Moisture (%)	97.8	97.8	97.9
Total Solids (%)	2.25	2.24	2.11
Volatile Solids (g/mL)	0.0096	0.013	0.013
After the open cell, used as recirculation water to flush the barn			
Density (g/mL)	1.01	0.9808	1.001
Total Nitrogen (%)	0.169	0.2233	0.2369
Phosphorus (%)	0.0170	0.0240	0.270
Potassium (%)	0.139	0.138	0.126
Ammonium (%)	0.107	0.1203	0.1131
pH	7.53	7.85	7.72
Moisture (%)	98.1	97.7	97.6
Total Solids (%)	1.87	2.31	2.37

SUMMARY

Data gathered from the monitored site represents baseline data on the seasonal temperature characteristics of a simple anaerobic digester in a climate with harsh winter conditions and extended cold periods. The data show that winter equilibrium temperatures in the covered cell are adequate for digestion processes to occur, although at a reduced rate from the warmer months. An important finding was that the manure temperature stabilized for almost 16 weeks at around 6°C over the winter. Additionally, the hourly averages of manure temperature shows that heat addition in the covered cell follows a cycle that appears to reverse from fall to spring. Future work could include investigation into the effect of the temperature lag of the manure storage system with changes in ambient conditions and ways to reduce or lengthen it.

ACKNOWLEDGEMENTS

The authors acknowledge the help and assistance of the dairy owner; Environmental Capitol Management, LLC; the Griffith Undergraduate Research Program and Scholarship; Scott Cortus; Corey Lanoue; and the Ag Engineering Department.

REFERENCES

EPA. 2011. Methane. United State Environmental Protection Agency. http://www.epa.gov/methane. Accessed May 24, 2011.

NRCS. 2003. Natural Resource Conservation Standard, Conservation Practice Standard: Anaerobic temperature – Ambient temperature. Code No 365. Natural Resource Conservation Service. http://efotg.sc.egov.usda.gov//references/public/ID/365.pdf. Accessed May 24, 2011.

Lettinga, G., S. Rebac, S. Parshina, A. Nozhevnikova, J.B. Vanlier, A.J.M. Stams. 1999. High-rate anaerobic treatment of wastewater at low temperatures. *Applied and Env. Microbiology* 65(4): 1696-1702

Martin, J.H. 2008. An evaluation of a covered anaerobic lagoon for flushed dairy cattle manure stabilization and biogas production. EPA Contract No. GS-10F-0036K

Zeeman, G., K. Sutter, T. Vens, M. Koster, A. Wellinger. 1988. Psychrophilic digestion of dairy cattle and pig manure: Start-up procedures of batch, fed-batch and CSTR-type digesters. *Biological Wastes* 26(1): 15-31