# Anaerobic Digestion at Morrisville State College: A Case Study

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Anaerobic digestion can minimize odor, generate biogas, and allow more effective nutrient use by crops. To realize the potential energy, environmental, and cost saving benefits of anaerobic digestion, farmers need information to evaluate the energy, labor, land, and equipment costs. The anaerobic digester project at Morrisville State College involved the design and construction of a heated, hard-top plug-flow anaerobic digester. The digester biologically treats dairy manure and other organic waste generated on campus to produce a stable effluent with improved physical, chemical, and biological characteristics. In the system, biogas (about 60% methane) is produced, captured, and combusted to generate heat and power using a 50kW engine/generator set. A boiler that could run on either biogas or propane is also being used to heat water during the startup phase of the system and anytime the engine generator set is not running. The methane digester system is sized to treat manure from around 400 milking cows. It generated an annual average of 330,000 kW.hr of electricity during the first twenty-one months of operation.

The project was funded by NYSERDA and the New York State Department of Agriculture and Markets, with additional support through U.S. Representative John McHugh, and from the U.S. Department of Energy's Office in Golden, CO. Construction on the project started in August 2005 and was completed in late 2006. The combined heat and power generation system was started on February 28, 2007.

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## Contents:

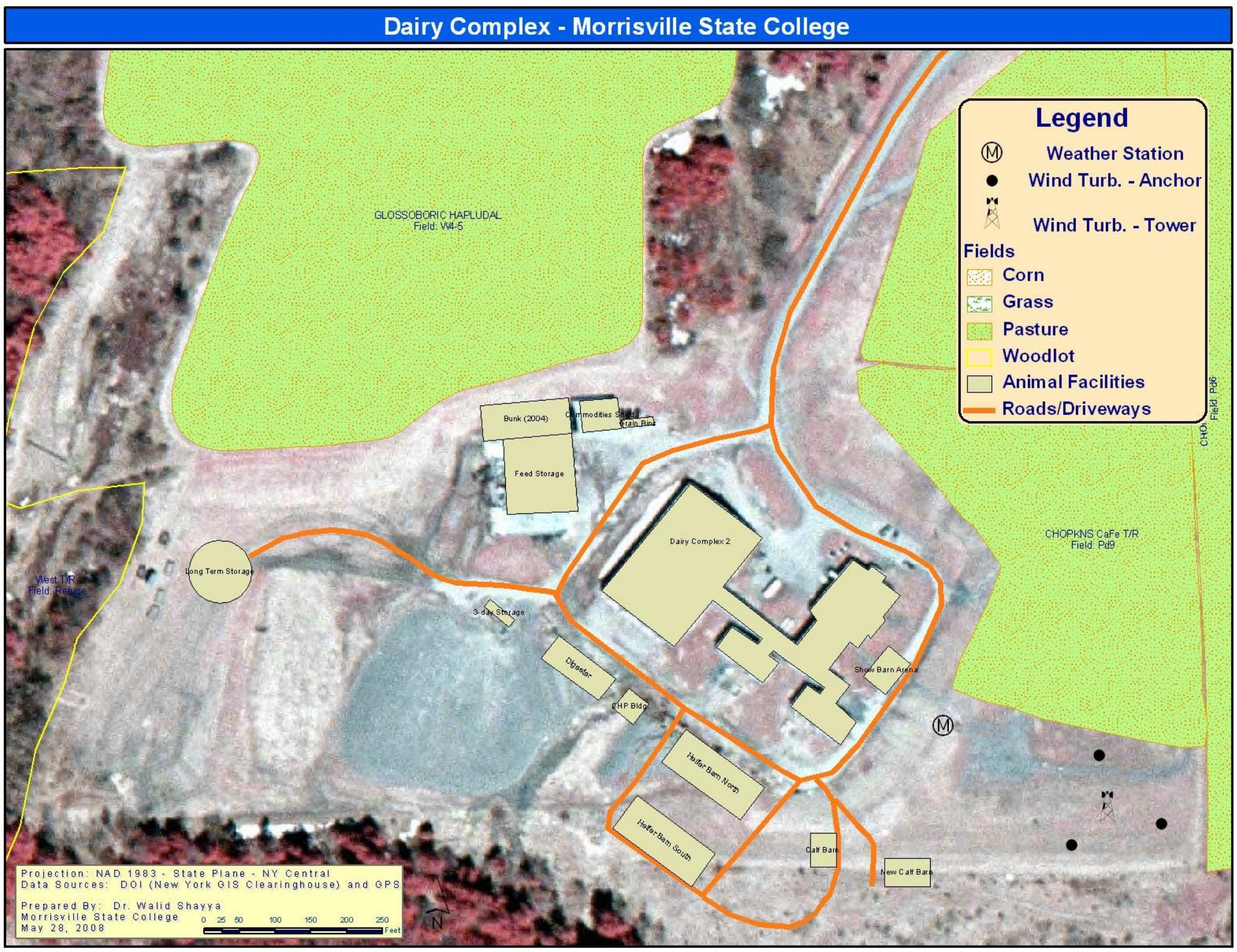


# 1. Anaerobic Digestion Overview

| | |
|---|---|
| **Digester Type:** | Plug-flow |
| **Digester Designer:** | David Palmer, Cow Power |
| **Influent:** | Raw manure |
| **Stall Bedding Material:** | Sawdust |
| **Number of Cows (design):** | 400 milking cows |
| **Tank:** | Two sides, each with two chambers |
| **Tank Dimensions (width, length, height):** | 37'x90'x12' |
| **Cover Material:** | Hard-top |
| **Design Temperature:** | 98°F |
| **Estimated Total Loading Rate:** | 10,000 gallons/day |
| **Treatment Volume:** | 249,000 gallons |
| **Estimated Hydraulic Retention Time:** | 25 days |
| **Solid-liquid Separator:** | None |
| **Biogas Utilization:** | MAN internal combustion engine |
| **Carbon Credits Sold/Accumulated:** | No |
| **Monitoring of Results:** | Ongoing |

# 2. Farm Overview

Morrisville State College dairy farm is a 600-acre free-stall dairy complex housing more than 200 registered Holstein cows. An equal number of replacement dairy cattle are also raised and housed at the facility, bringing the total herd to more than 400 animals. The college's dairy complex consists of a main free stall barn, two heifer barns, dry cow and bred heifer barn, calf greenhouses, dairy show barn, and other auxiliary buildings for storage. The free-stall barn is cleaned with automatic alley scrapers.




The milking parlor is a double-eight herringbone, rapid exit parlor with an automatic cow identification system. Each cow wears a leg band that is scanned as the cow stands in the parlor. The identification system allows accurate monitoring of milk production and cattle activity. The college's cattle are fed on forages grown on the college's farm lands, as well as feed concentrates. In addition to the dairy farm, the college maintains and operates a dairy incubator used in dairy product development for business, manufacturing products for campus use, and educational projects including student research. The incubator is used to produce products such as cheese, ice cream and yogurt.

# 3. Justification for the Digester

Generally speaking, the digester at Morrisville State College (MSC) was intended to treat dairy manure (generated at the free-stall dairy complex) and other organic waste produced on campus and to use the generated biogas to run a combined heat and power generation system. Other objectives included the collection of data on the various components of the system; the analysis of the collected data and the reporting of results; the utilization of the project for demonstration purposes; and the use of the facility within pertinent educational programs offered by MSC.

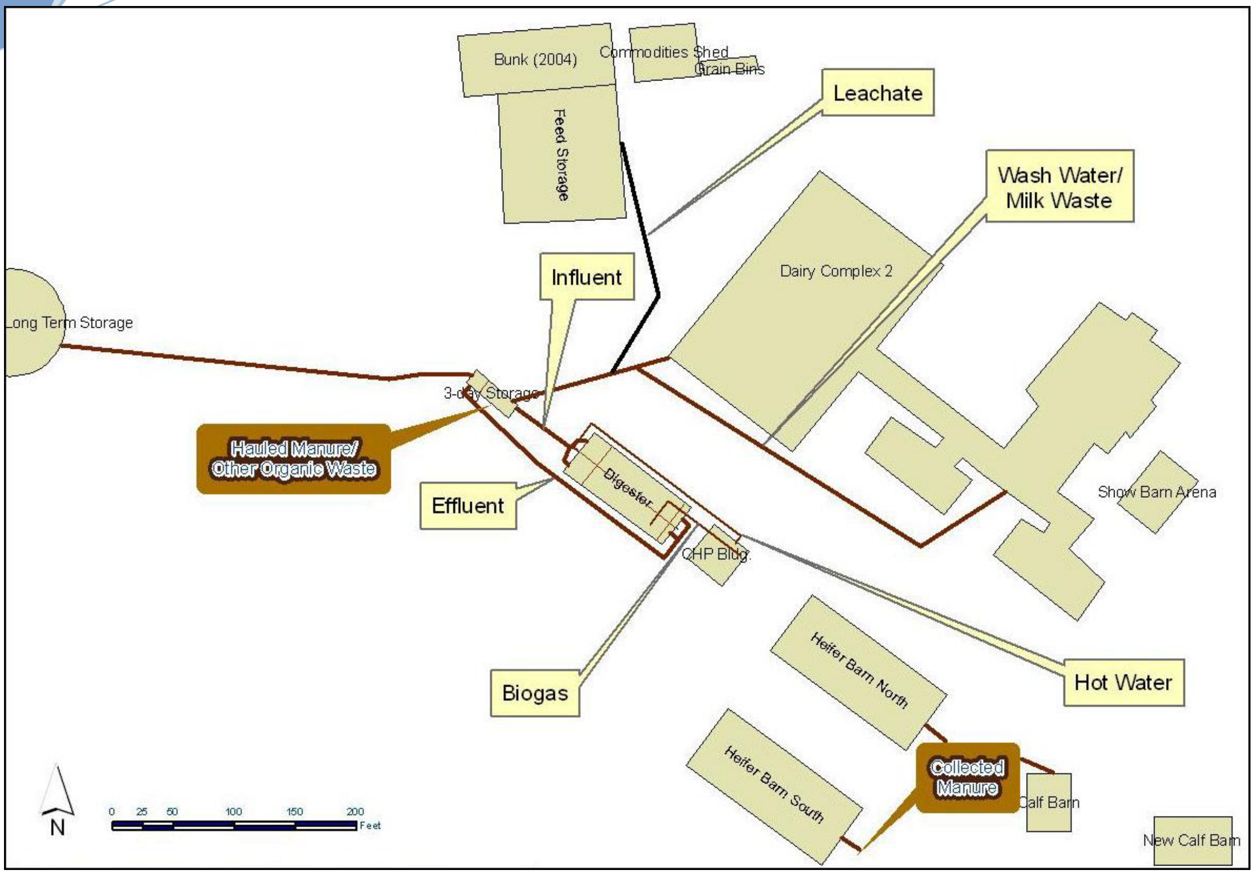
Environmental concerns were also an issue since manure was spread daily on fields. Long-term storage was not a viable option without the digester since it could have exasperated odor issues which were even present when manure was hauled on a daily basis (especially during the summer months). Following a feasibility study that affirmed the utility of installing a digester, a cost-sharing contract supported by both the New York State Energy Research and Development Authority (NYSERDA) and the NYS Department of Agriculture and Markets allowed the project to become a reality. As the digester was designed, the ability to use the system for educational and demonstrational purposes was very important. In addition, focus was also placed on a system that allows for conducting applied research while addressing environmental issues and providing energy savings and economic benefits.

Based on the above, the primary justifications for pursuing the anaerobic digestion system at MSC were to install a system that can demonstrate the following benefits:

- Electricity savings.
- Heating savings (could not be fully implemented due to project-cost overruns).
- Nutrient control.
- Odor reduction.
- Pathogen reduction.
- Reduction in volatile solids introduced into the long-term storage, developed upon the conclusion of the construction phase on the digester.
- Reduction of methane emissions.

# 4. Digester System Description

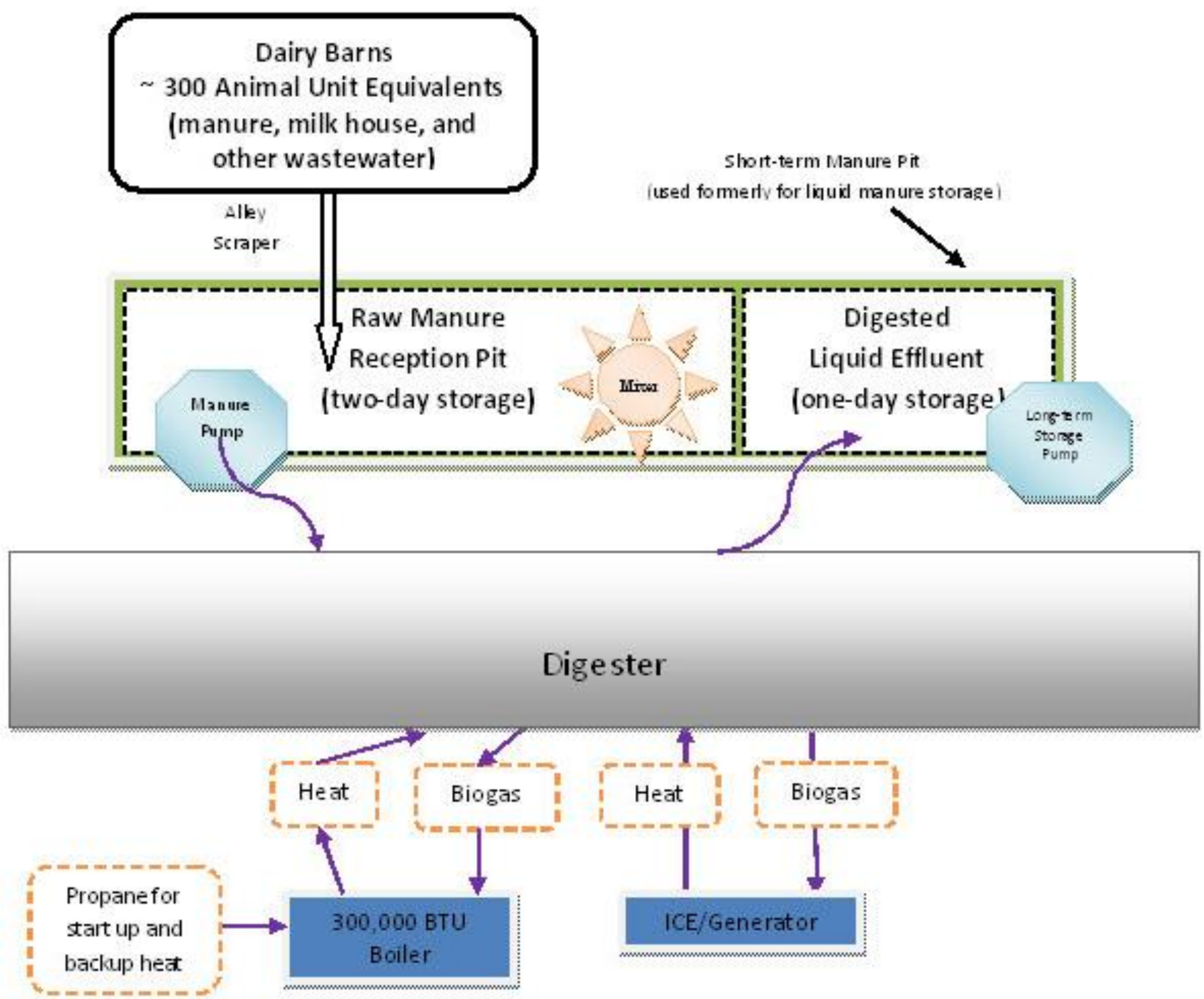
The process for the development of an anaerobic digester at Morrisville State College's free-stall Dairy Complex was initiated in 2002 after a feasibility study funded by the NYS Department of Agriculture and Markets was completed in 2001. However, it was not until August 2005 when the award for constructing the system was made. The methane digester project was designed by David Palmer at Cow Power Company in conjunction with Tiry Engineering. The construction contract was awarded to Paul Yaman Construction in early August, 2005, and the contractor mobilized to the site on August 3, 2005. The design prepared by the consultant and architect included completed drawings and design documents that involved the construction of a two-chamber concrete tank (37'x90'x12') along with the associated below-grade manure transfer piping, tanks, manholes, and valves. It also included the plans for the construction of an equipment building (36'x36') for housing the combined heat and power (CHP) generation system. Complete engine and gas handling skids that meet the specifications of the design were procured from Martin Machinery (GenTec) and factory-installed (the systems were put together with compatible equipment and controls thereby reducing on-farm hassles).


The plug-flow, hard-top digester at MSC is a rectangular, in-ground concrete tank consisting of two sides separated by a concrete wall. Each of the two sides of the digester include another wall that separates the digester tank from a smaller grit chamber where the primary heat exchangers are located for heating the influent waste stream. The bigger chamber on each side of the digester includes a smaller heat exchanger (a heat maintenance loop) to maintain the temperature at an optimum mesophilic condition of about 98$^{o}$F. The hard-top of the digester is constructed of flat pre-cast concrete planks covered with concrete, insulation, and earth. The digester is covered on the inside with a coating of coal tar epoxy, a layer of polyurethane, and a coating of poly-urea (applied to the ceiling of the digester as well as the inside walls of both chambers to a level of about a couple of feet below the liquid line in the tank) in order to provide a biogas-tight digester. It is insulated on the outside with a layer of polyurethane (to maintain temperature) and a coating of poly-urea (to protect the insulation from UV light damage during construction). The design allows for a maximum of 15" of water column pressure to be developed within each of the two sides of the digester. This precludes the need to compress the biogas before being fed to the internal combustion engine.

Manure is scraped from the main barn to a central channel, where it flows to a collection pit located southwest of the main barn. Manure from the two heifer barns is scrapped and hauled to the influent storage tank of the digester (a chamber of the manure reception pit). The manure reception pit was originally used as a short-term storage pit (with a 3-day storage capacity) when the daily-haul method was implemented before the digester was proposed. Once the construction on the digester was initiated, the pit was sub-divided into two compartments (a smaller north-western compartment that stores up to one day of effluent from the digester and a larger south-eastern compartment which could store up to two days of manure and serve as the collection pit where the influent is mixed before being pumped into the digester). The manure from the dairy complex is mixed before being pumped to the influent manifold of the digester where the flow is distributed equally to the two parallel digesters. Initially, the influent was pumped into the digester one to three times each day (during daylight hours). On September 29, 2008, the process of pumping manure to the digester was automated (under the new system, manure is being pumped to the digester every two hours).

As manure is displaced in the two sides of the digester, it flows to the effluent chamber where it gets conveyed to the effluent compartment of the manure reception pit before being pumped to the long-term storage or loaded onto a tanker for spreading on agricultural fields.

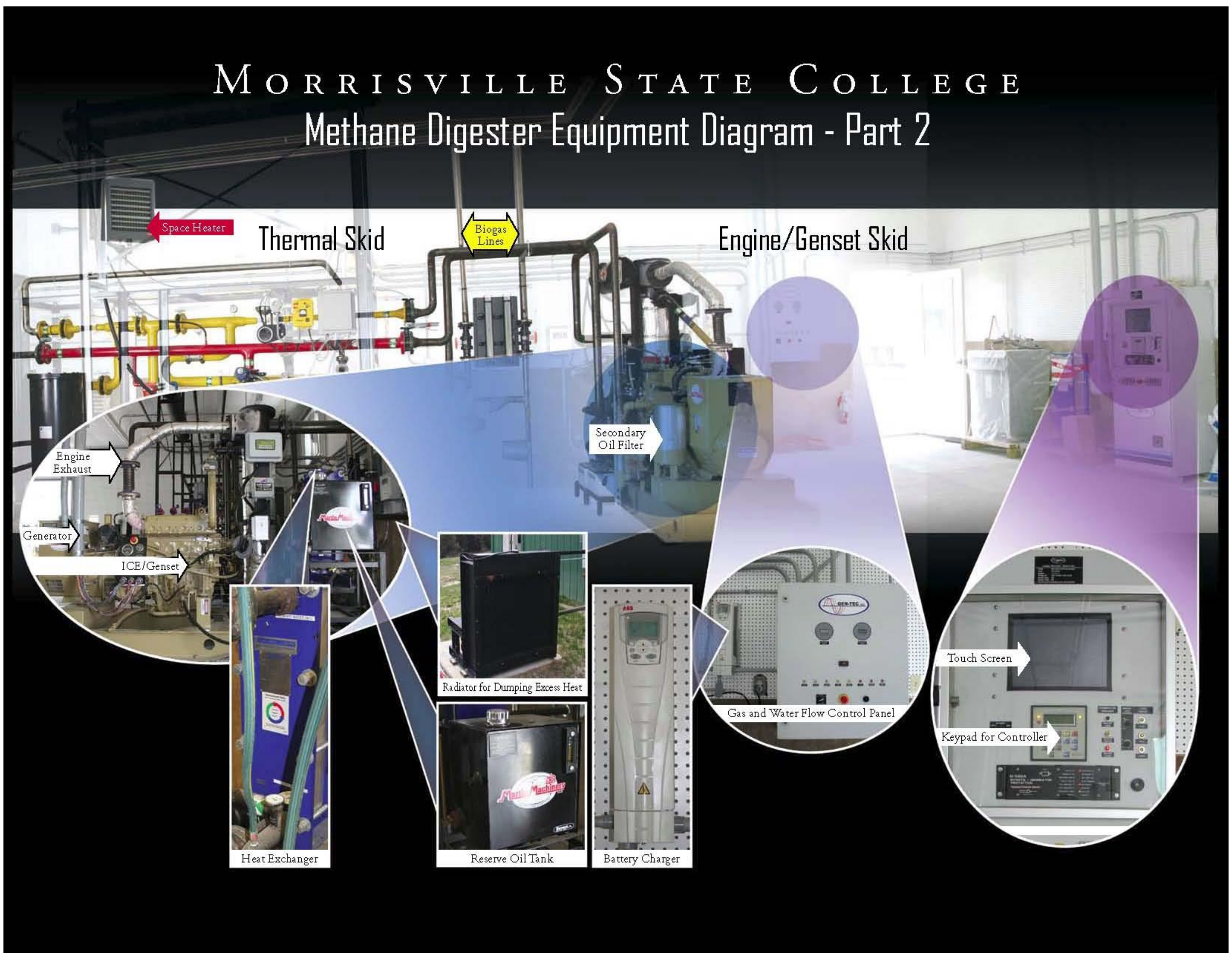


# 5. Biogas Utilization

Biogas is collected from the two sides of the digester and fed to an internal combustion engine (ICE) located in the equipment (or CHP) building. The engine (MAN) is attached to a 50-kW generator. Hot water from the engine is used to maintain the digester temperature and for heating a nearby system that is being used to conduct applied research on growing algae for biodiesel production. A radiator located outside the equipment building is used to release the excess heat. A 300,000-Btu/hr output boiler system is also installed within the CHP to be used to heat the digester during the startup phase as

well as when the ICE is down. The boiler was acquired from Performance Engineering as a research donation. Stainless steel biogas lines connect the gas chambers within the two sides of the digester to the CHP building. A flare system is also installed to burn excess biogas or the generated biogas when the ICE is down (the flare mount and gas line supports are located on the top of the digester's concrete tank).

The ICE utilizes biogas at the rate of 23,320 $ft^3$/day (about 85 $ft^3$/animal unit/day). The biogas consists of methane (about 60%), carbon dioxide (about 40%), a small amount of sulfide compounds (around 1,500 ppm), and other trace gases. On average, the generator electrical output is 39 kW which corresponds to an annual electricity production of 330,000 kW.hr/year.




## 6. Digester Startup

The process of digester startup was initiated on September 21, 2006. By the end of September, the influent that was pumped into the grit chamber of the southwest (SW) side of digester reached up to a level of few inches below the baffle on the effluent side. The heating of the digester started on October

11, 2006, following the connection of the boiler to the thermal skid and the heating of the digester with hot water generated through the burning of propane in the boiler.

During the startup phase of the digester, the acidity and temperature were checked on a daily basis starting from October 17, 2006. Temperature readings were taken at multiple locations along the length of the digester with some being collected from the bottom of the tank through a devised sampler that was put together from a ¾" PVC pipe and fittings. While the temperature readings varied some, the pH of the samples stayed within the range of 7.0 and 7.9.

A total of 100 lb of inoculant (called Propriety Inoculant Material, PIM) was added on November 1, 2006, at four locations within the SW side of the digester. The PIM was obtained from RCAg Industries, Inc., of Rochester, NY, as a research donation to assess the efficacy of the anaerobic microorganisms present in the PIM in starting the anaerobic digestion process. Within six days of the application of PIM, the biogas pressure in the digester developed from about 0.5 inches of water column to 6.6 inches as measured on November 7, 2006.

The gas pressure in the digester dropped to less than 0.5" on the 9$^{th}$ of November, 2006, following the increase of temperature in the digester to an average of 108$^{o}$F. This was the result of attempting to find the right temperature setting on the boiler to provide an optimum temperature of 98$^{o}$F within the digester. Within a couple of days of attempting to address this problem, the temperature in the digester returned to the 96-103$^{o}$F range and the pressure increased again to about 6 inches as measured on November 15, 2006. The correction of the temperature was accomplished by reducing the heat setting on the boiler to 100$^{o}$F as well as the addition of influent.

Using the Dräger tubes, the $CO_2$ concentration of the biogas was measured at 55-60% on November 15, 2006, while the presence of methane was ascertained qualitatively. The measurements were repeated several times in the in the following months and the readings were comparable. $H_2S$ concentrations were also measured using the Dräger tubes and were within the 1,500 ppm range.

The process of filling the northeast (NE) side of the digester was started on November 29, 2006. Half of the collected manure was conveyed to the NE side of the digester with the remaining half being fed to the SW side of the digester that had been producing biogas for about four weeks. Part of the effluent from the SW side of the digester was also pumped into the NE side of the digester to provide the inoculants to startup the anaerobic digestion process as well as fill up the NE side of the digester as quickly as possible. Meanwhile the biogas pressure in the SW side of the digester was measured at 10.5 inches on December 4, 2006.

The installation of monitoring equipment on the system was finalized in early January 2007. The equipment included several thermocouples along with the remaining control wiring to gas meters and thermocouples on the ICE/generator skid.

Production of biogas started soon after the two sides of the digester were filled with the effluent from the dairy complex. Biogas production became consistent starting from December 17, 2006. Flaring the biogas started on December 20, 2006, and went on until the ICE was started briefly on January 9, 2007.

Flaring the biogas continued until the interconnect with the power grid was approved by NYSEG and the combined heat and power generation system was authorized to start on February 27, 2007. The system has been in operation since February 28, 2007, and has generated electrical power consistently since then.

# 7. Digester Operation

As stated earlier, the combined heat and power (CHP) generation system which was installed in the equipment building has been in operation since February 28, 2007. The operation of the digester is overseen by the Farm Manager, Mr. Mark Smith (digester operation data are collected on a daily basis, i.e., each morning, by either Mr. Smith or a trained member of the farm staff). Over the first twenty-one months of its operation (i.e., until November 30, 2008), the digester produced biogas at an average daily rate of 23,320 $ft^3$ (more biogas is actually being produced since the 23,320 $ft^3$/day represent only the volume metered to the ICE). The ICE/genset has been running an average of 23 hours/day. Other than for a short period (around March 17, 2007) when the system was on and off several times, the ICE has been running mostly non-stop except for 28 oil changes that took place on average every 514 hours. During the 16-month time period, an average electrical production of 904 kW.hr/day was generated. Details of system operation are available online as explained in the last section of this document. A summary of system operation during the first 21-month period of digester operation is provided in Table 1. Monthly summaries of digester operation are provided in Table 2.

Table 1. Summary parameters of MSC digester operation during the period of 28 February 2007 to 30 November 2008.

| | Averages | | | | | |
|---|---|---|---|---|---|---|
| | Daily During the Period | Annual During the Period | Daily per Animal Unit | Weekly per Animal Unit | Projected Monthly per Animal Unit | Projected Annual per Animal Unit |
| Number of Animal Units | 274 | | | | | |
| Electrical Output (kW) | 39.1 | | 0.14 | | | |
| Biogas Production–NW side ($ft^3$) | 12,555 | 4,582,446 | | | | |
| Biogas Production–SE Side ($ft^3$) | 10,763 | 3,928,665 | | | | |
| Total Biogas Production ($ft^3$) | 23,318 | 8,511,110 | 85.1 | 695.6 | 2,553 | 31,058 |
| Energy Value in Biogas (Therms) | 120.2 | 43,876 | 0.4 | 3.1 | 13.2 | 160 |
| Generated Electricity (kW.hr) | 904 | 329,997 | 3.3 | 23.1 | 99.0 | 1,204 |
| Biogas Volume Utilized for Each kW.hr Generated ($ft^3$/kW.hr) | 26.7 | | | | | |
| Generator Runtime (hr) | 23.1 | 8,431 | | | | |
| Efficiency of Chemical to Electrical Energy Conversion (%) | 26.2 | | | | | |

Table 2. Monthly summaries of MSC digester operation during the period of 28 February 2007 to 30 November 2008.

| Month | Average Number of Animal Equivalents | Average Monthly Generated Electricity (kW.hr) | Average Monthly Generator Run Time (hr) | Average Electrical Output (kW) | Total Monthly Gas Production ($ft^3$) | Average Daily Generated Electricity (kW.hr) | Average Generator Daily Run Time (hr) |
|---|---|---|---|---|---|---|---|
| Mar., 2007 | 228 | 29,695 | 650 | 46.6 | 670,700 | 935 | 20.2 |
| April, 2007 | 226 | 27,189 | 679 | 39.9 | 661,800 | 906 | 22.6 |
| May, 2007 | 215 | 26,363 | 720 | 36.6 | 708,400 | 850 | 23.2 |
| June, 2007 | 214 | 18,606 | 686 | 27.0 | 568,600 | 620 | 22.9 |
| July, 2007 | 209 | 22,325 | 717 | 31.2 | 658,500 | 720 | 23.1 |
| Aug., 2007 | 278 | 25,508 | 702 | 36.1 | 705,900 | 823 | 22.6 |
| Sep., 2007 | 289 | 26,868 | 657 | 40.9 | 688,600 | 896 | 21.9 |
| Oct., 2007 | 283 | 29,815 | 692 | 43.0 | 729,800 | 962 | 22.3 |
| Nov., 2007 | 298 | 31,402 | 690 | 45.4 | 727,300 | 1,047 | 23.0 |
| Dec., 2007 | 324 | 32,478 | 737 | 44.1 | 769,100 | 1,048 | 23.8 |
| Jan., 2008 | 316 | 30,482 | 739 | 41.3 | 751,300 | 983 | 23.8 |
| Feb., 2008 | 319 | 29,172 | 688 | 42.4 | 721,600 | 1,006 | 23.7 |
| Mar., 2008 | 311 | 30,799 | 735 | 41.9 | 763,700 | 994 | 23.7 |
| April, 2008 | 313 | 29,224 | 659 | 42.7 | 703,300 | 974 | 22.0 |
| May, 2008 | 288 | 30,916 | 729 | 42.4 | 766,300 | 997 | 23.5 |
| June, 2008 | 283 | 27,947 | 715 | 39.1 | 730,600 | 932 | 23.8 |
| July, 2008 | 273 | 29,946 | 728 | 41.1 | 773,100 | 966 | 23.5 |
| Aug., 2008 | 265 | 28,105 | 735 | 38.2 | 780,700 | 907 | 23.7 |
| Sep., 2008 | 265 | 25,989 | 707 | 36.8 | 728,100 | 866 | 23.6 |
| Oct., 2008 | 262 | 25,307 | 733 | 34.5 | 715,100 | 816 | 23.6 |
| Nov., 2008 | 289 | 22,289 | 714 | 31.2 | 630,000 | 743 | 23.8 |

# 8. Economic Information

Detailed economic information on the system is currently being developed. These include an analysis of the initial capital costs to decipher what would have been typical of a comparable system and what was an excessive cost due to design re-runs in order to meet budget constraints, regulations for a state project, and prevailing work force conditions. In addition, economic savings from constructing the digester (including electrical energy savings realized due to the system and the benefits of net metering) as well as benefit/cost analysis and the recovery time on system investment are all issues that are being analyzed.

Existing economic information on the system include the initial capital costs and the potential savings in electric energy costs due to the installation of the system. Initial capital costs on the system (including the long-term effluent storage tank) are as follows:

| Item | Cost |
|---|---|
| **Digester Contractor** | $779,992 |
| General | |
| Site Mobilization ($14,500) | |
| General Requirements ($49,800) | |
| Insurance and Bondings Fee ($21,000) | |
| Site Work | |
| Excavation and Backfill for Building and Utilities ($46,300) | |
| Concrete Work | |
| Poured Concrete Work ($202,357) | |
| Pre-cast Concrete Planks ($46,500) | |
| Metals | |
| Furnish and Install Fabricated Steel ($19,000) | |
| Wood and Plastic | |
| Equipment Building ($38,760) | |
| Thermal and Moisture Protection | |
| Polyurethane Insulation System ($64,310) | |
| Coal Tar Epoxy Coating, etc… ($18,400) | |
| Mechanical | |
| Furnish and Install Mechanical Equipment and Piping ($191,000) | |
| Electrical | |
| Electrical Work ($37,500) | |
| Miscellaneous Change Orders ($30,565) | |
| **Consultant** | $98,446 |
| **Testing of Concrete** | $6,445 |
| **Footbath Bypass** | $6,180 |
| **Tank Sealing** | $19,480 |
| **Confined-space Monitoring** | $9,200 |
| **Platform for Manure Pump** | $7,144 |
| **Separation Wall in the Three-day Manure Reception Pit** | $6,600 |
| **Manure Pump Installation** | $2,500 |
| **Digester Subtotal** | **$935,987** |
| **Slurry Storage** | $246,600 |
| **Total (including the long-term slurry storage)** | **$1,182,587** |

Grid electric energy costs at the Dairy Complex along with the "demand" power requirements for the period of January 2006 to July 2008 are presented in Figure 1. Average savings in electric energy costs due to the installation of the digester may be assessed crudely by comparing the average electric costs of electricity from the grid starting from April 2007 ($3,022) to the average of electric costs of the 13 months that preceded the generation of electric power through the utilization of biogas in the ICE ($1,095). If this approach were to be followed, an average saving of $1,927 is realized each month due to electric power generation that resulted from installing the digester. These could result in more than $23,000 in annual savings of electrical energy.

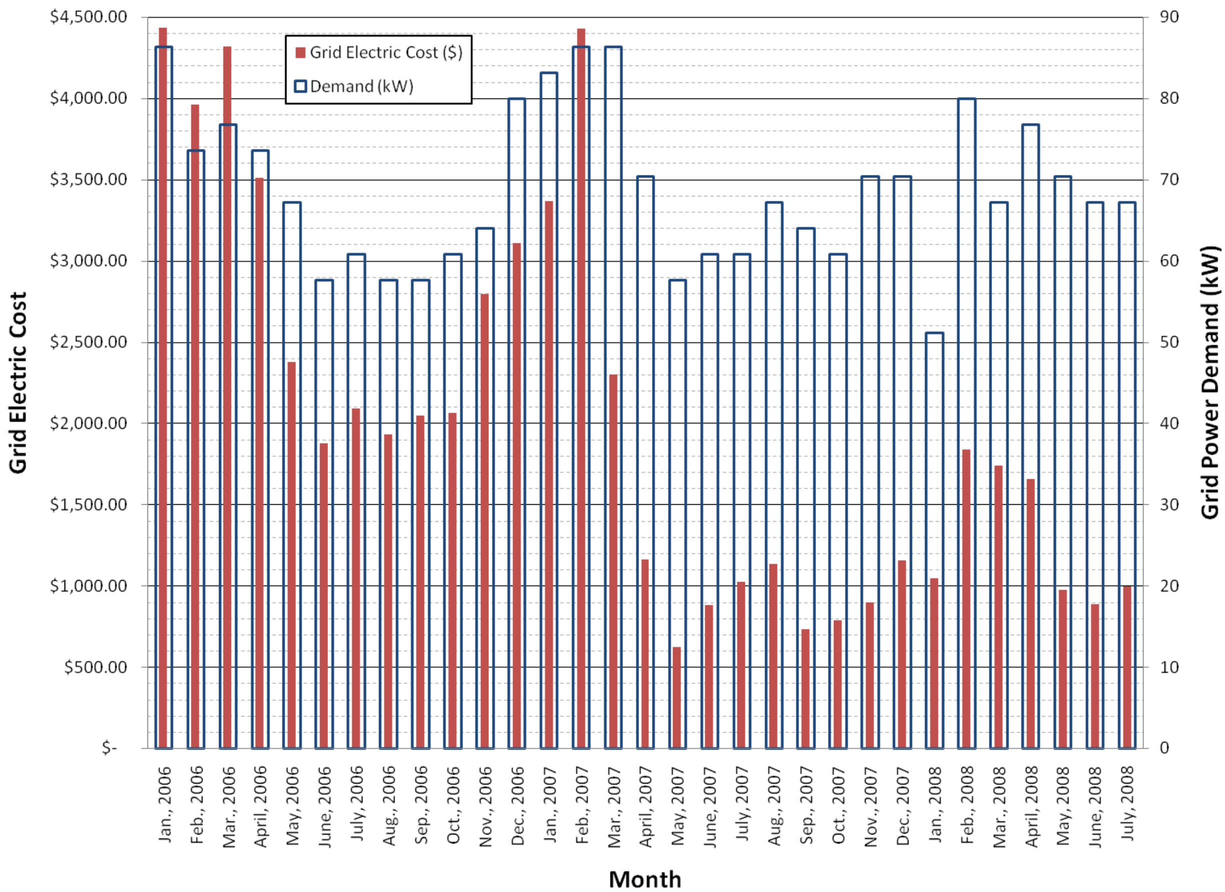



Figure 1. Grid electric energy costs at the Dairy Complex along with demand power requirements for the period of January 2006 to July 2008.

An alternative method to assess the value of the generated electrical power is to base the calculations on the average monthly generated electricity (27,640 kW.h/month) and a "dollar value" being assigned to each kW.h generated ($0.10/kW.h which is less than the $0.11/kW.h average cost observed for the electric bills from the 13-month period that preceded the startup of the digester – could be an acceptable assumption given that the generated electricity does not meet all of the needed electrical power requirements at the Dairy Complex). In this case, an average monthly benefit of $2,760 (about $33,000/year) may be attributed to the operation of the digester. Of course additional costs incurred due to the operation of the digester must be factored in before such any conclusions regarding energy savings are made.

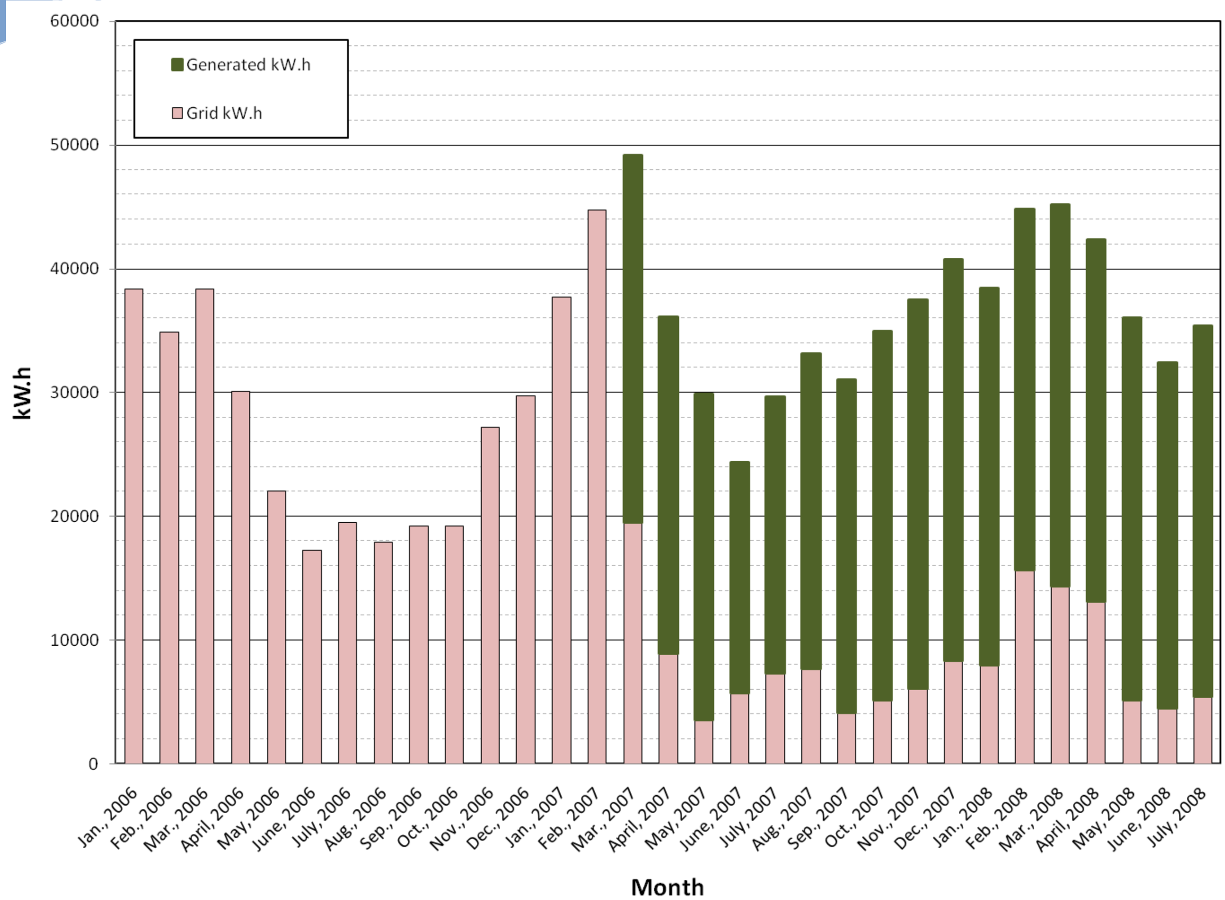



Figure 2. Utilized and generated electric power at the Dairy Complex for the period of January 2006 to July 2008.

# 9. Testing Results

Samples from the influent and effluent sides of the digester are collected each month by the Farm Manager, Mark Smith. The samples are sent the same day to the BioEnergy Laboratory at Cornell University. Upon reception, the samples are refrigerated at a temperature of approximately 4$^{o}$C until the samples are tested. Eight sample influent/effluent sets were tested and analyzed (October 2007 to May 2008). The analysis of the individual parameters measured were reported by Norm Scott and Rodrigo Labatut (Sampling Testing and Evaluation Plan for SUNY Morrisville Digester, Report 6.15.2008, Department of Biological & Environmental Engineering, Cornell University, June 2008). Here are the pertinent excerpts from their report:

## *9.1. pH*

"Results show that the pH of the system is within the optimal values (i.e. neutral) for anaerobic digestion. It can also be observed that the pH increases slightly after digestion, which is expected due to the generation of bicarbonate alkalinity ($HCO_3$-) during the fermentation process – a result of the degradation of nitrogenous organics (mostly proteins) to $NH_3$, and by the reaction of the $NH_3$ with $CO_2$ to form ammonium bicarbonate $NH_4^+ + HCO_3^-$. Alkalinity has an important role in controlling the system pH. It provides buffer capacity for the digestate, which neutralizes volatile acids being produced, and consequently prevents the pH from dropping to critical levels. Even though total alkalinity is not part of the STEP protocol, and therefore it is not measured, results suggest that alkalinity concentration would be sufficient (> 2000 mg/L as $CaCO_3$) to maintain the pH to desirable levels. This is explained because dairy manure contains high concentrations of ammonia-N, which provides plenty of alkalinity, and thus, buffer capacity for the system."

## 9.2. Oxidation Reduction Potential (ORP)

"The ORP is a measure of the capacity of the digestate to be reduced. The more positive the ORP, the more potential the chemical species has to be reduced. During digestion, the substrate being digested gets reduced, which explains why the digestate becomes more negative after the digestion. Thus, the ORP can be used as an indicator of the substrate physico-chemical state, and thus, its feasibility to undergo further reduction towards methane production."

## 9.3. Solid content

"Solids analyses are based on the determination of total solids (TS) and total volatile solids (VS). Total solids indicate the percent of dried matter of the substrate. VS are determined after subjecting the substrate to a temperature of 105°C for at least 12 hrs. Total volatile solids indicate the percent of organic matter contained in the substrate. Volatile solids are determined by subjecting the substrate to a temperature higher or equal to 550°C for an hour, so that all the organic material volatilized (i.e., is burned completely). Ashes remaining are measured and VS are determined by simple difference with TS. Periodic monitoring of solids content before and after digestion is important to evaluate the performance of the anaerobic process."

"Digester performance can be evaluated by measuring the removal efficiency of organic matter. Organic matter can be measured as solids content (TS, VS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), or total organic carbon (TOC). Therefore, the percent of solids destroyed during anaerobic digestion is a measurement of the amount of organic matter being removed by the process, and thus, a measurement of the system performance. The percent of VS removed during digestion varied approximately between 20 and 50%. However, six out of the eight set of samples presented a VS removal efficiency higher than 40%, which is essentially within the expected values. Typical VS removal efficiency values for residence times equal or higher than 30 days are between 45 and 55%. Higher efficiencies under mesophilic conditions (and without pretreatment) are difficult to achieve because of the high lining content of dairy manure. In fact, basically 50% of the VS portion of dairy manure is considered to be refractory."

## 9.4. Chemical oxygen demand (COD)

"Likewise solids content, the COD is a measurement of the organic matter contained in the substrate. The chemical oxygen demand is measured by chemically digesting the organic matter at high temperatures (150$^oC$) with a strong oxidizing agent (i.e. potassium dichromate) under acidic conditions, provided by the addition of sulfuric acid. The COD test measures both the chemical and biological demand of oxygen exerted by the substrate."

"The percent of COD destruction can be also used as an indicator of the digester performance. With the exception of sample sets 2 and 3, the COD removal efficiency varied between 40 and 60%. Differences in COD removal efficiencies are attributed to the same reasons previously explained for solids."

## *9.5. Biochemical oxygen demand (BOD)*

"The BOD test is an assay that determines the amount of organic matter contained in the substrates by measuring the biologically-exerted demand of oxygen under aerobic conditions at 20$^oC$. The BOD corresponds to the mass of oxygen (measured as concentration) required by the microorganisms to completely degrade the "biodegradable portion" of the organic matter. More than 60% of BOD removal was observed in all samples sets."

"Since the COD measures the amount of chemical plus biological oxygen demand, the BOD is contained within the COD concentration, i.e., the BOD concentration is always lower than the COD concentration. Thus, the BOD-to-COD ratio can be used to estimate biodegradability of the substrates. The initial (pre-digestion) BOD-to-COD ratios of all sample sets suggest that dairy manure is about 45 – 50% biodegradable. This aerobic biodegradability changes to about 25% after digestion. This remaining biodegradable substrate may be "aerobically" biodegradable, but not necessarily "anaerobically" biodegradable."

"Similarly, the BOD-to-VS ratio can be used to assess biodegradability based on the total amount of VS contained in the substrate. Based on the initial BOD-to-VS ratio, it is suggested that approximately 50% of the substrate VS is biodegradable."

## *9.6. Total volatile acids (TVA)*

"The most important intermediate products during the anaerobic fermentation are the volatile acids (e.g., acetic acid, butyric acid, propionic acid, and valeric acid). Total volatile acids are measured experimentally using the esterification method and spectrophotometry. TVA's correspond to the sum of the concentrations of all volatile acids, measured as acetic acid. Acetic acid is the most important volatile acid during the methanogenesis, as more than 70% of methane comes from the biological stabilization of this single chemical compound. TVA concentration found in dairy manure is within the typical values reported for this substrate – about 10 g/L. A destruction of about 60% of the TVA's was also observed – thus, roughly 40% of the initial TVA concentration was present in the digester effluent. The fact that nearly 100% of the TVA content is expected to be destroyed during digestion suggests that a) some form of inhibition (e.g. $NH_3$, $H_2$, $H_2S$) could be taking place in the digester, and/or b) the residence time of the digester could be insufficient to complete its digestion."

# 10. Lessons Learned

## *10.1. Sealing the Tank*

A concrete hard-top tank operating under pressure can be difficult to seal (especially when some critical construction details are not followed). The digester had to be tested for air-tightness following construction based on a test delineated in the design manual. It involved the filling of each side of the digester with water and pressure-testing it for leaks. A first test revealed a major leak near the baffle that is located close to the outlet bay on the effluent side of the digester. After re-applying a sealant to where leakages were observed, another leak was observed between the baffle located close to the outlet bay and the walls. Both leaks had to do with an error in pouring the baffle with the top of the digester instead of digester walls and without including a groove to tie the baffle to the walls. Ultimately, an approach was devised to resolve this matter and the baffles were eventually sealed. This, however, did not result in the successful completion of pressure tests as additional tests revealed additional leakages through the top of the digester. This issue was ultimately resolved through the applications of a polyurethane layer and a poly-urea coating to the inside of the digester. The polyurethane-polyurea applications were made to the ceiling of the digester as well as the inside walls of both chambers to a level of about a couple of feet below the liquid line in the tank. These applications allowed for the eventual resolution of the problem. Pressure testing before filling with manure is time consuming and expensive but were needed in this case.

## *10.2. Solid-liquid Separation*

It is very clear after having run the system for more than a year that a solid-liquid separation system after digestion would have been extremely desirable. The use of separated manure solids for bedding could have an economic potential. In addition, the revenue that may be collected from this by-product would be a valuable asset in the economic performance of the digester if a stable and reliable market can be found.

## *10.3. Crust in the Digester*

Crusting in the digester is an issue that has presented several challenges to date. The plug-flow digester relies on the proper solid content of the influent. Dairy manure as produced will not separate into floatable and settleable solids. However, the floatable and settleable solids separate inside the digester when extra water is present resulting in a floating crust. The lower solids content was primarily due to the water used for cleaning in the milking parlor (refer to Figure 3). To address this issue, different approaches were attempted aside from using the least amount of water possible. These included adding some wasted frying oil every now and then (a few gallons every couple of weeks), loading the digester more often (three times a day instead of once a day), and reducing the amount of feed that ended up in the influent stream without going through the animals. In addition, it was observed that avoiding the use of shredded paper (returning to the use sawdust) had positive results. Overall, the changes listed above seemed to alleviate some of the problems of crusting. However, the issue of crusting is yet to be resolved.

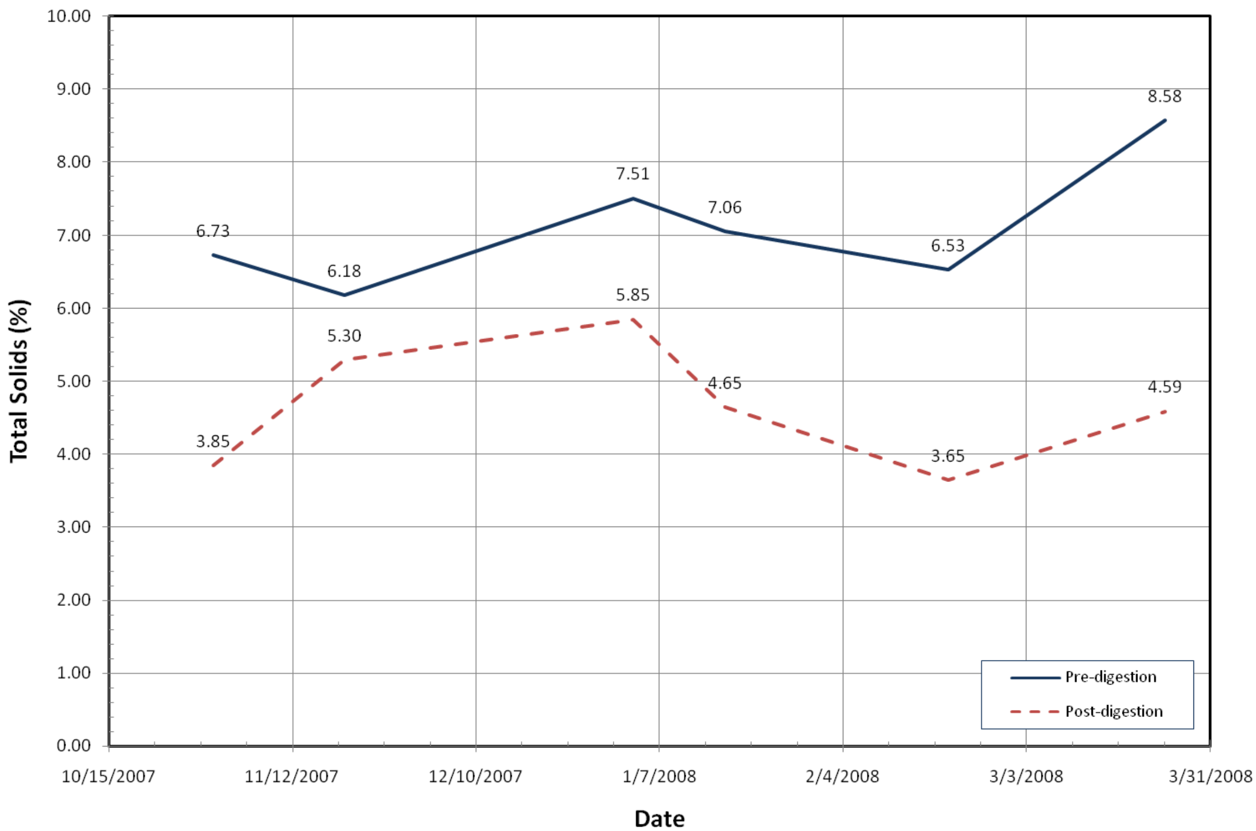



Figure 3. Plot of influent/effluent solid contents, MSC Digester.

## *10.4. Automation of Pumping of Influent Stream*

Until September 29, 2008, manure from the dairy complex was pumped into the digester once to three times each day (during daylight hours) following it being mixed in the influent chamber of the reception tank (one of the two chambers of the original 3-day storage tank). During this period, the mixers/pumps were operated manually. This process may have also contributed to the "crusting" issues discussed earlier. After the process of pumping manure was automated, the influent is now being pumped to the digester every two hours making it less labor-intensive and, hopefully, resolving some of the issues associated with crusting.

## *10.5. Mechanical/Electrical Systems*

Complete engine skids and gas handling skids that have been factory-installed to meet design specifications provide a convenient way to assemble and run the major mechanical and electrical components of the system. Such installations allow for putting together compatible equipment and controls so on-farm hassles are reduced.

### *10.6. Digester Design*

The dual-chamber digester construction was meant to avoid an excessively long digester and to provide reasonable spans for the concrete top. As such, it provided an attractive and a viable design approach. This ought to enable the shutting-down and the starting-up of each side independently and to allow for side-by-side comparisons of system operation under different conditions. However, fully implementing this concept can be somewhat costly and may not be warranted in many standard operations.

### *10.7. Noise and Corrosion Control*

Burying the exhaust pipe from the ICE in the equipment building and conveying it some distance from the building keeps corrosion away from the vital components of the system. However, internal combustion engines are still very loud necessitating additional sound control measures in most applications (could not be implemented in our system due to the need for cost-cutting measures).

### *10.8. Temperature Control*

Maintaining temperature control during the winter is important. Frozen manure and manure that was too wet may have to bypass the digester thereby potentially reducing gas production and the availability of energy to heat the influent and maintain the desired temperature. In such instances, added external energy will be needed to maintain the digester temperature.

### *10.9. Sensor Calibration*

The thermocouples installed on the system seems to require frequent calibrations. Therefore, checking the temperature manually and calibrating the instrumentation should be an important step in system startup and operation.

### *10.10. Insulation of Gas Lines*

Inulatation of exposed gas lines is very critical. This is especially true in an environment where excessive freezing conditions occur during the winter months. For our digester, heat tapes had to be used to prevent the gas lines to the flare from freezing.

## 11. Additional and Contact Information

A website on the methane digester and pertinent renewable energy projects is maintained under Morrisville State College's main page. The website is available under the "Alternative Energy Projects" link which is accessible from the "Technology" tab accessible from the home page of the college's website at http://www.morrisville.edu. The main page on "Alternative Energy Projects " can also be accessed directly using the following url: http://www.morrisville.edu/alternativeenergy/default.aspx. In addition, two slideshows were developed to present overviews of digester construction and operation. These may be accessed online at http://www.morrisville.edu/alternativeenergy/methanedigester.aspx.

For additional questions, please contact any of these individuals:


- Mark Smith, Farm Manager, Morrisville State College. Phone: (315) 684-6087, E-mail: smithm@morrisville.edu
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