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 50-kW engine/generator set. A boiler is used to heat the digester during the startup phase of the system and anytime the engine is not running. The methane digester system is sized to treat manure from around 400 milking cows. When operational, the system generated an annual average of 324,629 kW.hr of electricity between 28 Feb. 2007 and 15 July 2013. However, the system was also down for three extended periods (about 23 months in total) primarily due to leakages in the heat exchangers within the digester.

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 who helped secure additional funds from the United States Department of Energy's Office in Golden, Colorado. 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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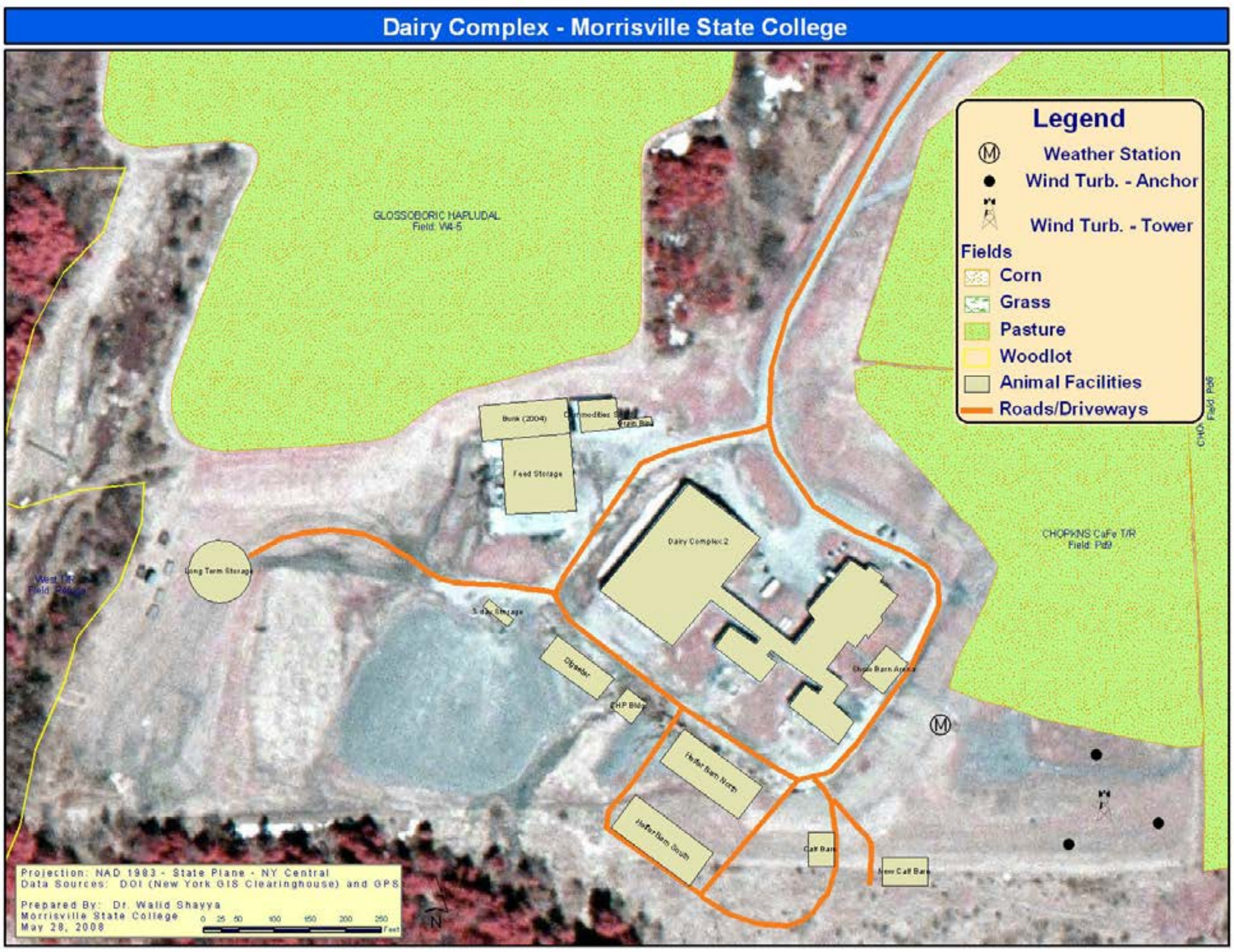
1. Anaerobic Digestion Overview

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's 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, a dry cow and bred heifer barn, two calf barns, a dairy show barn, a mobile classroom, 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). It was also intended to treat 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.

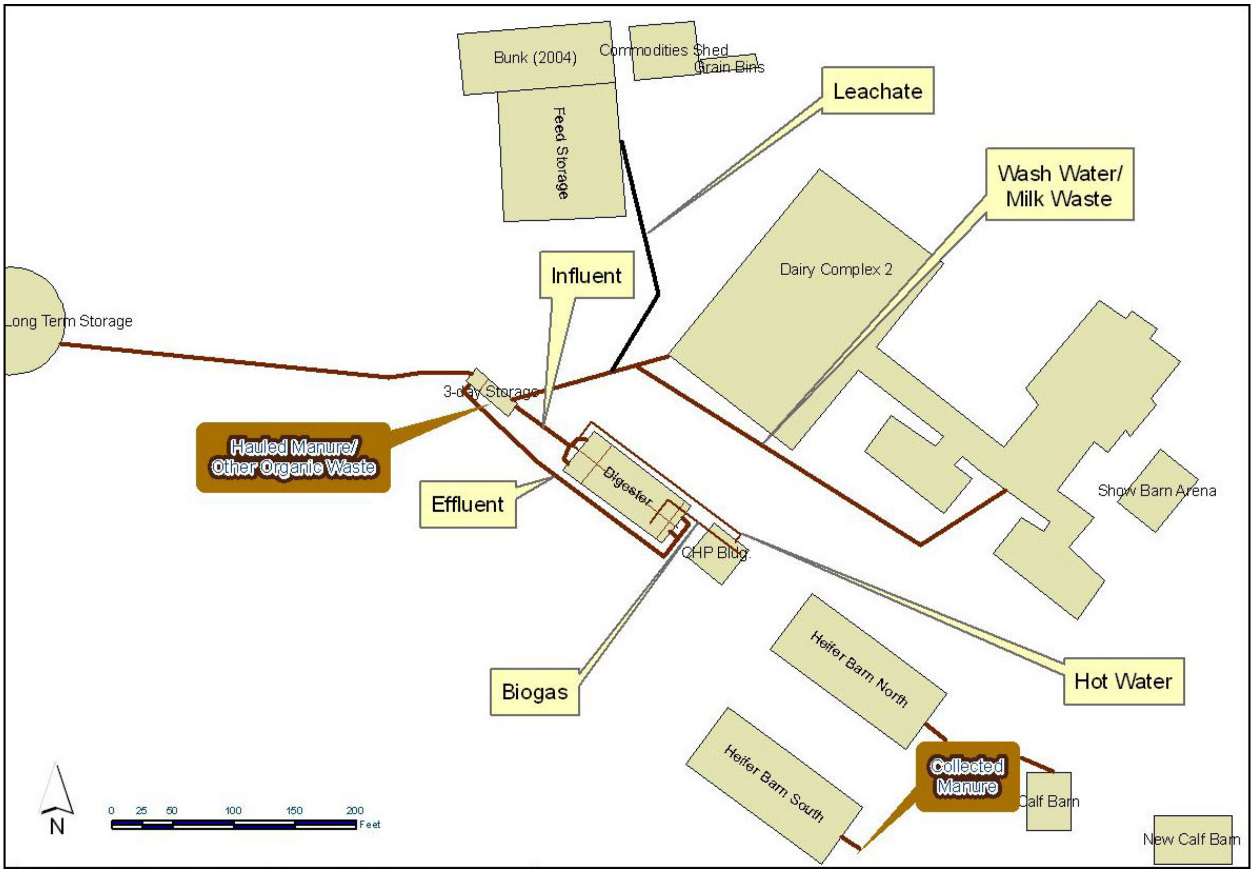
Environmental concerns were also an issue since manure was spread daily on fields. Long-term storage was not a viable option without the digester since it could have exasperated odor issues, present even when manure was hauled on a daily basis (especially during the summer months). Following a feasibility 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 extremely important. In addition, focus was also placed on a system that allows for conducting applied research while addressing environmental issues and providing both energy savings and economic benefits.

In summary, 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

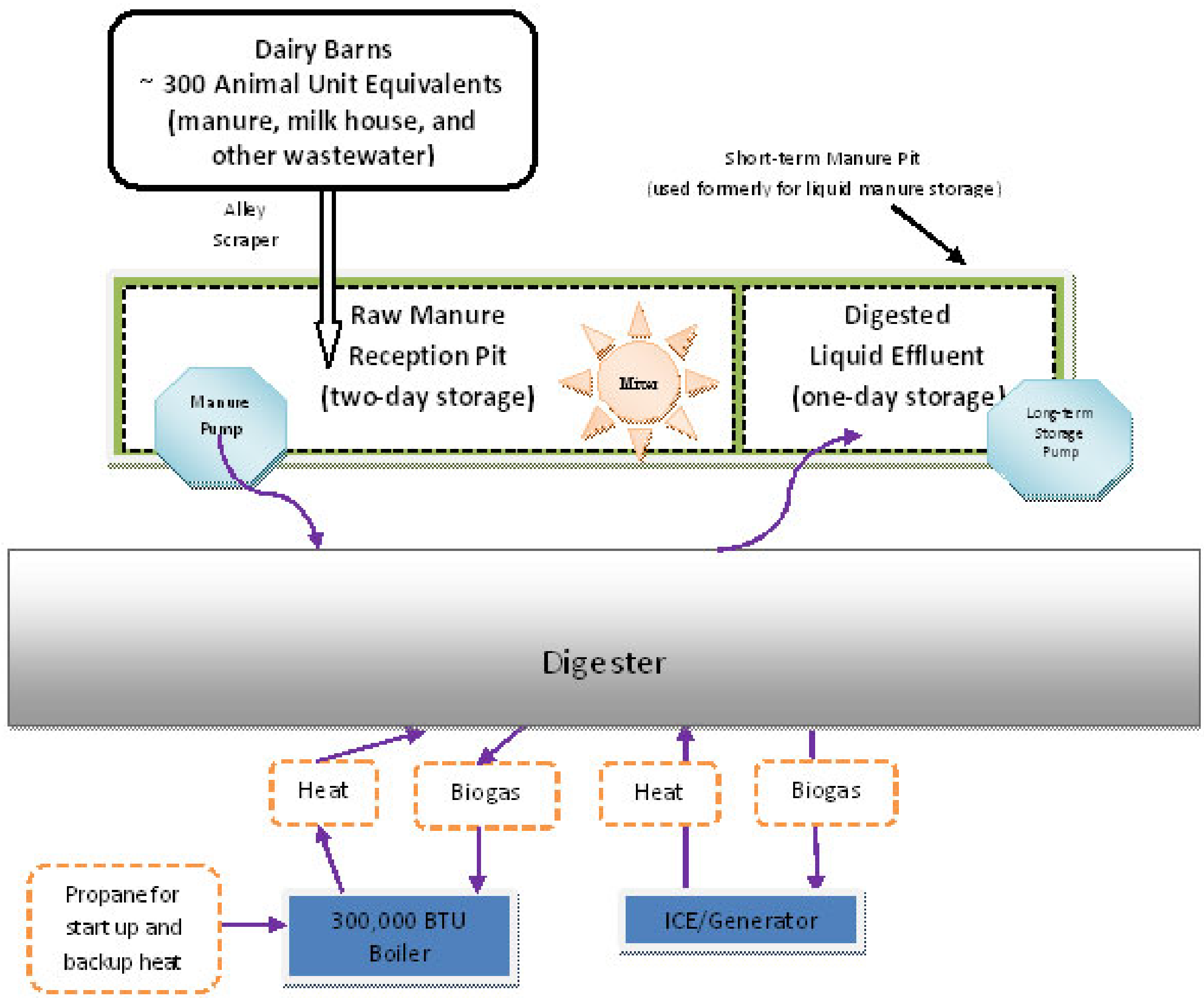
The process for the development of an anaerobic digester at Morrisville State College's free-stall Dairy Complex was initiated in 2002 after a feasibility study funded by the NYS Department of Agriculture and Markets was completed in 2001. However, it was not until August 2005 when the award for constructing the system was made. The methane digester project was designed by David Palmer at Cow Power Company of Syracuse, NY, in conjunction with Tiry Engineering of Chippewa Falls, WI. 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 (north and south) 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^{0}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 tank. 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 feeding to the internal combustion engine.

Manure is scraped from the main barn to a central channel, where it flows to a collection pit located west 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 pumped to the digester on hourly basis).

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 long-term storage or loaded onto a tanker for spreading on agricultural fields.

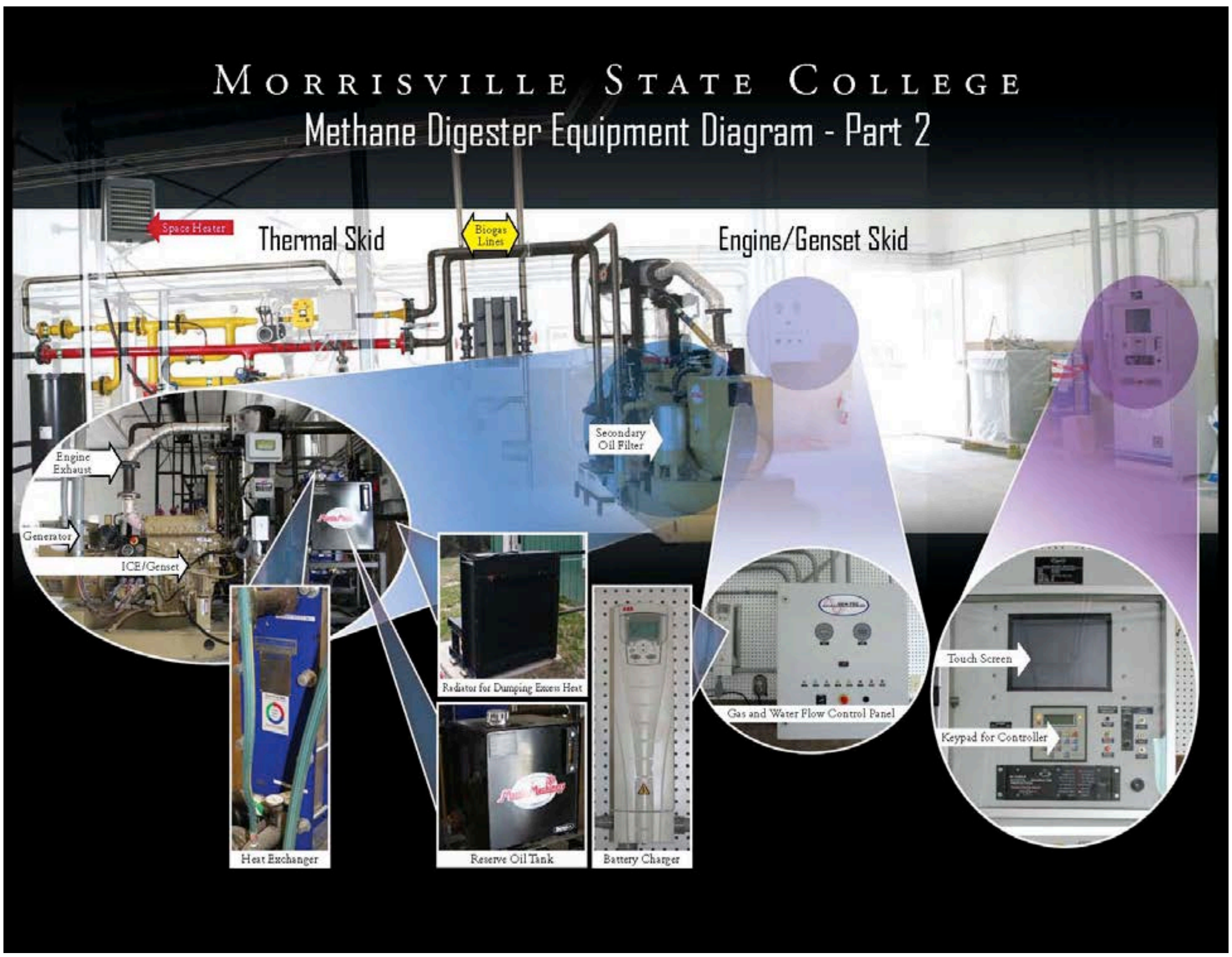


5. Biogas Utilization

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 not only used to maintain the digester temperature but also heat 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 installed within the CHP to be used to heat the digester during the startup phase

or when the ICE is down. The boiler was acquired from Performance Engineering Group of Livonia, MI, as a research donation. Stainless steel biogas lines connect the gas chambers within the two sides of the digester to the CHP building. Finally, a flare system is 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 23,287 ft^3/day (about 81 ft^3/lactating cow equivalent/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 40.3 kW which corresponds to an annual electricity production of 341,885 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 south side of digester reached a level that is a few inches below the baffle on the effluent side. The heating of the digester started on October 11, 2006, following both 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 slightly, the pH of the samples remained 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 on the south 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 9th of November, 2006, following the increase of temperature in the digester to an average of 108^{o}F. The high temperature occurred because of failed attempts to find the correct setting on the boiler to yield the optimum temperature of 98^{o}F in the digester. Within a few 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 and adding the 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 following months and the readings were comparable. H_2S concentrations were also measured using the Dräger tubes and were approximately 1,500 ppm.

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

The process of flaring the biogas continued until the interconnect with the power grid was approved by NYSEG (our electric power provider) and the combined heat and power generation system was authorized to start on February 27, 2007. The system was in operation from 28 February 2007 to 1 December 2008 (when a leak in the main heat exchanger of the grit chamber of the south side of the digester was discovered). The leak was fixed and the system was operational again on June 12, 2009. A second leak in the main heat exchanger on the digester's north side prompted another shut-down of the system between 26 September 2011 and 9 January 2012. A third leak in the maintenance heat loop of the main chamber on the north side of the digester forced the digester to be shut down for a third extended period of time from 9 March 2012 to 30 April 2013.

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 28 February 2007 (except for a combined total of about 22 months when the system was down). The operation of the digester is overseen by the farm manager (operational data are collected in the morning of each day by a trained member of the staff). Over the seventy-three months of digester operation, a daily average of 22,457 ft^3 of the generated biogas from the digester was used for electric power generation (more biogas is being produced since the 22,457 ft^3/day represent the volume metered to the ICE). During the period, the ICE/generator set ran an average of 22.9 hours/day and an average electrical output of 889 kW.hr/day was measured. Details of system operation are available online as explained in the last section of this document. A summary of system operation during the 73-month period of digester operation is provided in Table 1. Monthly and annual summaries of digester operation are provided in Tables 2 and 3.

Table 1. Summary parameters of MSC digester operation during the period of 28 February 2007 to 15 July 2013.

	Averages					
	Daily During the Period	Annual During the Period	Daily per Lactating Cow Eq.	Weekly per Lactating Cow Equiv.	Projected Monthly per Lactating Cow	Projected Annual per Lact. Cow
Number of Lactating Cow Equiv.	291					
Electrical Output (kW)	38.6		0.13			
Volume of Flared Biogas (ft^3)	3,906	1,425,528				
Utilized Biogas from North Side (ft^3)	11,054	4,034,733				
Utilized Biogas from South Side (ft^3)	11,403	4,161,989				
Total Utilized Biogas (ft^3)	22,457	8,196,722	77.2	540.2	2,315	28,168
Energy Value in Biogas (Therms)	115.8	42,255	0.4	2.8	11.9	145
Generated Electricity (kW.hr)	889	324,629	3.1	21.4	91.7	1,116
Biogas Volume Utilized for Each kW.hr Generated (ft^3/kW.hr)	31.1					
Generator Runtime (hr)	22.9	8,340				
Efficiency of Chemical to Electrical Energy Conversion (%)	25.9					

Table 2. Monthly summaries of MSC digester operation during the period of 28 February 2007 to 15 July 2013.

Month	Average Number of Lactating Cow Equivalents	Monthly Generated Electricity (kW.hr)	Monthly Generator Run Time (hr)	Average Electrical Power (kW)	Monthly Average of Utilized Biogas (ft^3)	Daily Average of Utilized Biogas (ft^3)	Average Daily Generated Electricity (kW.hr)	Average Biogas Volume Utilized for Each kW.hr Generated	Average Eff. of Chemical to Electrical Energy Conversion (%)	Average Daily Generator Run Time (hr)
Mar., 2007	228	29,695	650	46.6	670,700	21,008	935	22	28.3	20.2
April, 2007	226	27,189	679	39.9	661,800	22,060	906	25	28.4	22.6
May, 2007	215	26,363	720	36.6	708,400	22,852	850	27	27.4	23.2
June, 2007	214	18,606	686	27.0	568,600	18,953	620	31	26.2	22.9
July, 2007	209	22,325	717	31.2	658,500	21,242	720	30	25.4	23.1
Aug., 2007	278	25,508	702	36.1	705,900	22,771	823	28	24.9	22.6
Sep., 2007	289	26,868	657	40.9	688,600	22,953	896	26	24.9	21.9
Oct., 2007	283	29,815	692	43.0	729,800	23,542	962	25	25.1	22.3
Nov., 2007	298	31,402	690	45.4	727,300	24,243	1,047	23	25.5	23.0
Dec., 2007	324	32,478	737	44.1	769,100	24,810	1,048	24	25.8	23.8
Jan., 2008	316	30,482	739	41.3	751,300	24,235	983	25	26.0	23.8
Feb., 2008	319	29,172	688	42.4	721,600	24,883	1,006	25	26.1	23.7
Mar., 2008	311	30,799	735	41.9	763,700	24,635	994	25	26.1	23.7
April, 2008	313	29,224	659	42.7	703,300	23,443	974	24	26.2	22.0
May, 2008	288	30,916	729	42.4	766,300	24,719	997	25	26.3	23.5
June, 2008	283	27,947	715	39.1	730,600	24,353	932	26	26.2	23.8
July, 2008	273	29,946	728	41.1	773,100	24,939	966	26	26.2	23.5
Aug., 2008	265	28,105	735	38.2	780,700	25,184	907	28	26.1	23.7
Sep., 2008	265	25,989	707	36.8	728,100	24,270	866	29	26.0	23.6
Oct., 2008	262	25,307	733	34.5	715,100	23,068	816	28	25.8	23.6
Nov., 2008	289	22,289	714	31.2	630,000	21,000	743	33	25.7	23.8
Dec., 2008										
*June, 2009	320	13,922	380	36.6	360,700	23,163	870	27	25.5	23.8
July, 2009	306	31,706	730	43.3	769,700	24,829	1,023	25	25.6	23.5
Aug., 2009	317	32,579	736	44.3	796,500	25,694	1,051	24	25.7	23.7
Sep., 2009	303	27,892	654	42.8	680,800	22,693	930	25	25.7	21.8
Oct., 2009	304	31,571	712	44.3	747,500	24,113	1,018	24	25.8	23.0
Nov., 2009	301	27,327	709	38.4	671,700	22,390	911	25	25.9	23.6
Dec., 2009	299	31,864	731	43.5	724,500	23,371	1,028	23	25.9	23.6
Jan., 2010	300	30,720	739	41.5	719,000	23,194	991	24	26.0	23.8
Feb., 2010	300	26,510	660	39.9	627,900	22,425	947	30	26.1	23.6
Mar., 2010	300	26,152	740	35.3	648,200	20,910	844	25	26.1	23.9
Apr., 2010	303	28,264	715	39.6	718,600	23,953	942	29	26.1	23.8
May, 2010	299	31,280	735	42.6	791,100	25,519	1,009	25	26.1	23.7
June, 2010	293	29,344	696	42.1	740,500	24,683	978	25	26.1	23.2
July, 2010	279	30,676	733	41.8	794,700	25,635	990	26	26.1	23.6
Aug., 2010	273	29,402	709	41.4	760,100	24,519	948	26	26.1	22.9
Sep., 2010	277	30,080	703	42.8	758,000	25,267	1,003	25	26.1	23.4
Oct., 2010	282	30,546	733	41.7	747,200	24,103	985	28	26.1	23.6
Nov., 2010	291	29,408	681	42.5	685,500	22,850	980	23	26.2	22.7
Dec., 2010	304	22,443	554	40.3	531,300	20,767	859	24	26.2	21.0
Jan., 2011	312	29,176	742	39.3	694,500	22,403	941	24	26.3	23.9
Feb., 2011	318	26,408	669	39.5	615,400	21,979	943	23	26.3	23.9
Mar., 2011	324	24,203	737	32.7	590,800	19,058	781	25	26.3	23.8
Apr., 2011	324	29,744	707	42.1	642,100	21,403	991	22	26.4	23.6
May, 2011	315	33,875	719	47.1	740,867	24,696	1,129	22	26.5	24.0
June, 2011	302	33,752	724	46.6	774,733	24,991	1,089	23	26.5	23.4
July, 2011	306	26,984	667	40.4	654,533	21,114	870	25	26.6	21.5
Aug., 2011	299	21,089	631	33.9	553,567	17,857	680	31	26.6	20.3
*Sep., 2011	302	18,947	584	32.3	507,600	19,523	729	29	26.5	22.5
Oct., 2011										
*Jan., 2012	308	1,825	453	4.0	179,787	8,172	83	103	26.4	20.6
Feb., 2012	311	1,443	525	3.3	206,913	7,135	50	192	26.3	18.1
*Mar., 2012	311	266	111	7.5	41,200	4,578	30	197	26.2	12.3
Apr., 2012										
*May, 2013	314	14,586	400	36.7	381,100	19,055	729	31	26.2	20.0
June, 2013	311	25,860	647	40.3	692,800	23,093	862	27	26.2	21.6
*July, 2013	314	9,296	279	31.0	307,000	20,467	620	41	26.1	18.6

** Digester not operational throughout the month (except for the last month when the data was only avilable until 15 July 2013).*

Other than for a short period (around March 17, 2007) when the system was shutting down several times a day and times when the system was down for repairs (on three separate occasions for a total of 22 months), the original ICE that was first started on 28 February 2007 operated mostly non-stop except for 41 oil changes that took place on average every 680 hours. The engine was eventually replaced by a new engine in December 2010. The original ICE was in operation until December 7, 2010 when it was shut down for replacement with the new unit. The original engine was in operation for 27,858 hours. The engine was evaluated after it was removed from operation and will be overhauled and set aside as a stand-by unit. The unit's condition was documented in a separate case study (available online from the digester's page).

The new ICE was installed by a technician from Martin Machinery. Swapping the engines took two days and the new unit was started on Friday - December 10, 2010. Eleven oil changes on the new engine have already been performed to date, on average every 800 hours.

Table 3. Annual summaries of MSC digester operation during the period of 28 February 2007 to 15 July 2013.

Year	Average Number of Lactating Cow Equivalents	Annual Generated Electricity (kW.hr)	Annual Generator Run Time (hr)	Average Electrical Power (kW)	Annual Average of Utilized Biogas (ft^3)	Daily Average of Utilized Biogas (ft^3)	Average Daily Energy Value in Produced Biogas (Therms)	Average Daily Generated Electricity (kW.hr)	Average Biogas Volume Utilized for Each kW.hr Generated	Average Efficiency of Chemical to Electrical Energy Conversion (%)	Average Daily Generator Run Time (hr)
2007	257	270,249	6,932	38.9	6,901,600	22,477	116	880	26	26.1	22.6
2008*	289	310,176	7,882	39.2	8,063,800	24,071	124	926	27	26.1	23.5
2009**	307	198,377	5,007	42.3	4,887,200	23,807	123	984	24	25.7	23.3
2010	292	344,825	8,398	41.0	8,522,100	23,713	122	958	26	26.1	23.3
2011^	311	244,236	6,180	39.4	5,772,600	21,459	111	908	25	26.4	23.0
2012#	310	3,534	1,089	4.2	427,900	7,132	37	59	160	26.3	18.2
2013˜	313	49,741	1,326	37.0	1,380,900	21,245	110	765	32	26.2	20.4

* 2007 data are only for measurements that pertain to the period after the system was started on 28 February 2007 (i.e., 299 out of 365 days)
** 2008 data are only for measurements of the system when it was operational until November 30, 2008 (I.e., 335 out of 365 days)¥
*** 2009 data are only for measurements of the system starting from June 14, 2009 (i.e., 201 out of 365 days)¥
^2011 data represent recorded measurements of the system until 26 September 2011 (i.e., 269 out of 365 days)¥
#2012 data represent recorded measurements when the system was operational between 9 January and 9 March 2012 (i.e., 61 out of 366 days)¥
#2013 data represent recorded measurements between 11 May and 15 July 2013 (i.e., 66 out of 365 days)¥
¥ System was shut down for repairs and generated no power for extended periods on three occasions since it was first started in 2007

8. Economic Information

Detailed economic analysis on the system is yet to be developed. This would 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 budgetary 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 need to be analyzed.

Existing economic information on the system include the initial capital costs (Table 4) and the potential savings in electric energy costs due to the installation of the system. Grid electric energy costs at the Dairy Complex along with the "demand" power requirements for the period of January 2006 to July 2013 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 ($1,243/month from March 2007 to November 2008, July 2009 to September 2011, and May 2013 to June 2013) to the average of electric costs of the 39 months that did not include the generation of electric power through the utilization of biogas in the ICE ($3,228/month). If this approach is followed, an average saving of $1,985 is realized each month due to electric power generation by the system through the utilization of biogas generated from the digester. These could result in about $24,000 in annual savings of electrical energy.

Table 4. Initial capital costs on the anaerobic digester system.

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 Total	**$935,987**

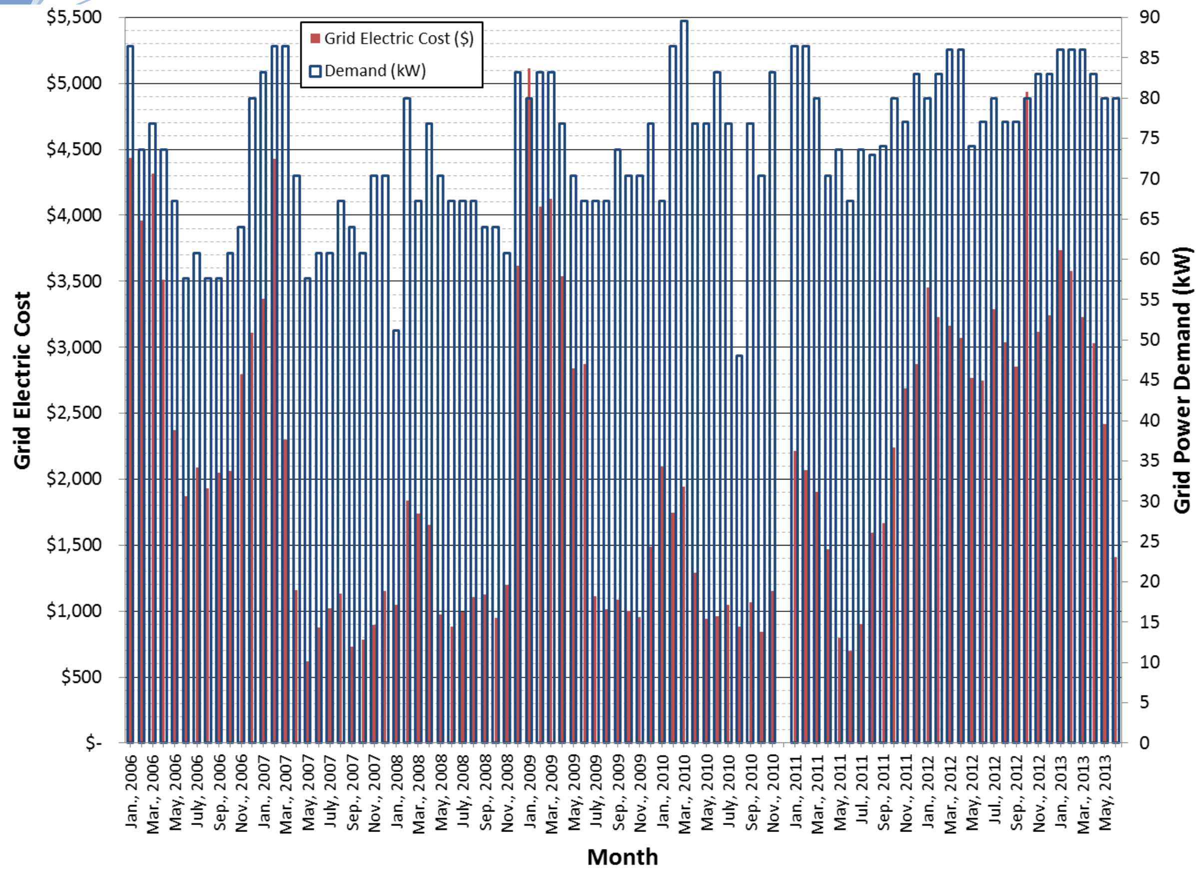


Figure 1. Grid electric energy costs at the Dairy Complex along with demand power requirements for the period of January 2006 to June 2013 (grid power usage data missing for December 2010).

An alternative method to assess the value of the generated electrical power (Figure 2) is to base the calculations on the average monthly generated electricity (27,050 kW.h/month) after assigning a “dollar value” to each kW.h generated (a value of $0.10/kW.h is selected, a figure less than the $0.12/kW.h average cost observed for the electric bills from the 39-month period that did not include the production of electricity from the generated biogas). This should be acceptable given that the generated electricity does not completely meet electrical power demand at the facility. In this case, an average monthly benefit of $2,705 (about $32,460/year) may be attributed to the operation of the digester.

Regardless of the method employed in estimating electrical energy savings due to the operation of the digester, there needs to be an assessment of additional costs incurred due to the operation of the digester (e.g., the propane utilized to heat-up the digester during startup). Any additional benefits (e.g., hot water being used to heat up the adjacent greenhouse) must also be factored in the analysis.

Finally, while the digester has provided a notable economic advantage to Morrisville State College as detailed above, several unforeseen costs pertaining to digester maintenance have been noted. These costs primarily center upon the heat exchange system in the digester. Since operation of the digester began on February 27, 2007 three distinct instances of leakage in the system have been detected, resulting in relatively extensive periods during which the digester was inoperable. A leak in the main heat exchanger, located in the grit chamber on the digester's south side, resulted in the digester being shut down from December 17, 2008 to June 13, 2009. A second leak in the main heat exchanger, located in the grit chamber on the digester's north side, prompted shut-down between September 26, 2011 and January 9, 2012. Finally, a leak was discovered in the maintenance heat loop located in the main chamber on the north side of the digester, which again forced the digester to be shut down from March 9, 2012 to April 30, 2013.

In each of these cases, maintenance periods were prolonged due to relatively inaccessible leak locations, the build-up of solids in the digester (which necessitated tank cleaning prior to maintenance), and the requirement that maintenance be performed by individuals with confined-space qualifications. Thus, in addition to the monetary cost of remediation, each maintenance issue preceded a substantial period where the digester became inoperable resulting in additional expenditures on outside electricity. Considering these economic ramifications, design of a similar system might afford a superior product by utilizing stainless steel piping in the heat exchange system, rather than the schedule 40 piping used in the MSC digester. Stainless steel piping would markedly reduce the potential for the leaks, and thus eliminate the negative economic ramifications expressed here.

9. Testing Results

Samples from the influent and effluent sides of the digester were collected each month by the farm manager from October 2007 to November 2008. The samples were sent the same day to the BioEnergy Laboratory at Cornell University. Upon arrival, the samples were refrigerated at a temperature of approximately 4^{o}C until the samples were tested. During the stated period, fourteen influent/effluent sample sets were tested and analyzed. The analysis of the individual parameters measured from the first eight sets of samples 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). Pertinent excerpts from the report follow:

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 sampling and testing protocol (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."

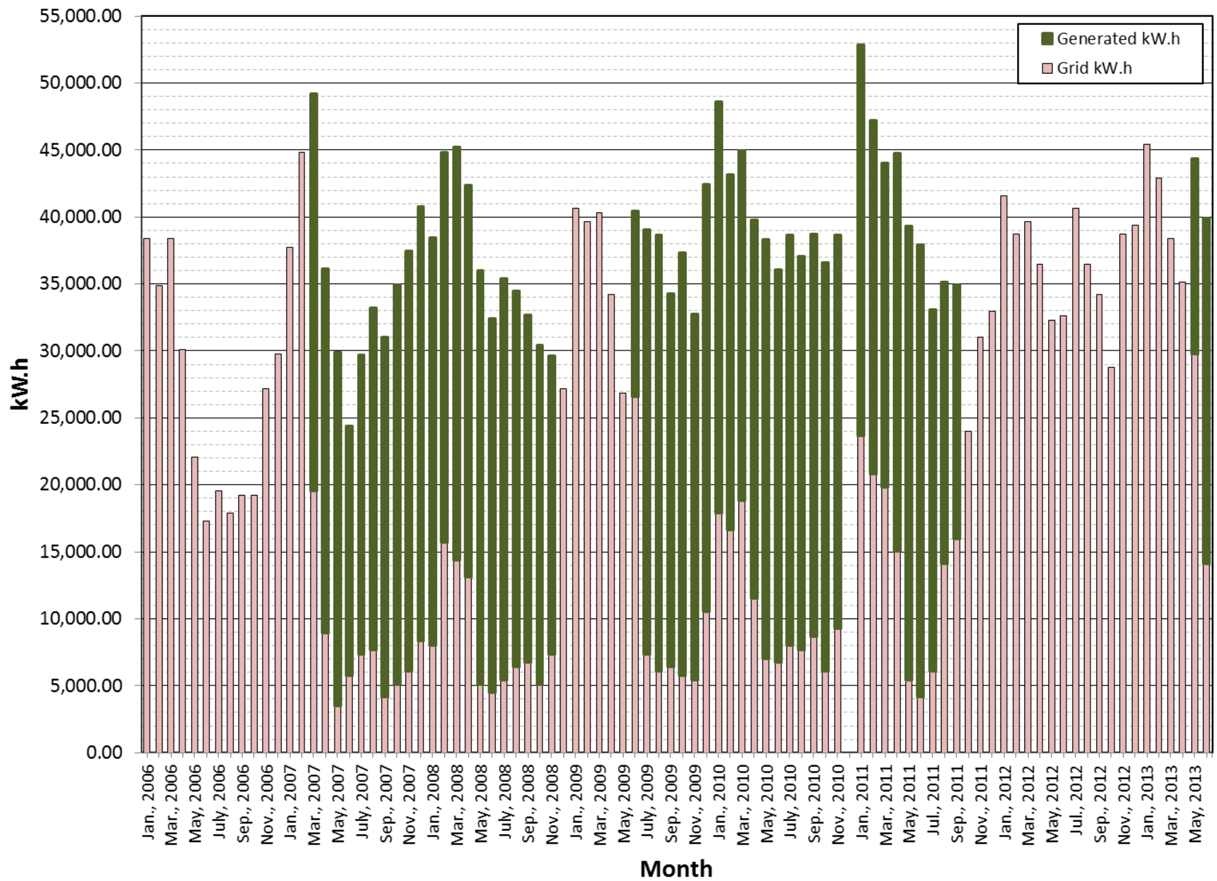


Figure 2. Utilized and generated electric power at MSC's Dairy Complex for the period of January 2006 to June 2013.

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 or 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 system performance. The percent of VS removed during digestion varied approximately between 20 and 50%. However, six out of the first 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)

"Like 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^{o}C) 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^{o}C. 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 corresponds 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, or 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 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. The test 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 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 concrete for 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. The applications allowed for the eventual resolution of the problem. Pressure testing before filling the digester with manure is time-consuming and expensive but was needed in this case.

10.2. Solid-liquid Separation

It is very evident after operating the system for the past several years 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. Crusting and Solid Deposition 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 to maintain optimal operation of the system. Dairy manure as produced should 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. Some solids will also get deposited in the tank for the same reason, as discovered after the system was shut down to repair leaking heat exchanger in both sides of the digester. The lower solid content could have been due to the initial startup of the system when a few feet of water were retained in the south side of the digester following the pressure-testing of the tank for leaks. The reason for making this decision was primarily due to the difficulty in removing all of the used water as well as the interest in filling the tank as quickly as possible. One cannot help but wonder about the impact of this decision on the operation of the system. Of course, this problem must have been exasperated by the excess use of water on daily basis while cleaning the milking parlor (refer to Figure 3).

To address the issue of crusting during the period when the digester was operational, different approaches were attempted in addition to attempting the use of the least amount of water. These included adding some waste frying oil whenever possible (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 of sawdust) had positive results. Overall, the changes listed above seemed to alleviate some of the problems of crusting. However, the issue of crusting was never completely resolved, while the collection of solids in the digester was observed to be much more severe than expected as observed when both the south and north sides of the tank had to be emptied to repair the heat exchangers.

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 contributed to the “crusting” and “solid deposition” issues discussed earlier. After the process of mixing the influent and pumping the manure into the digester was automated, it became possible to “feed” the digester on hourly basis making it less labor-intensive and, hopefully, positively impacting some of the issues associated with crusting and solid deposition.

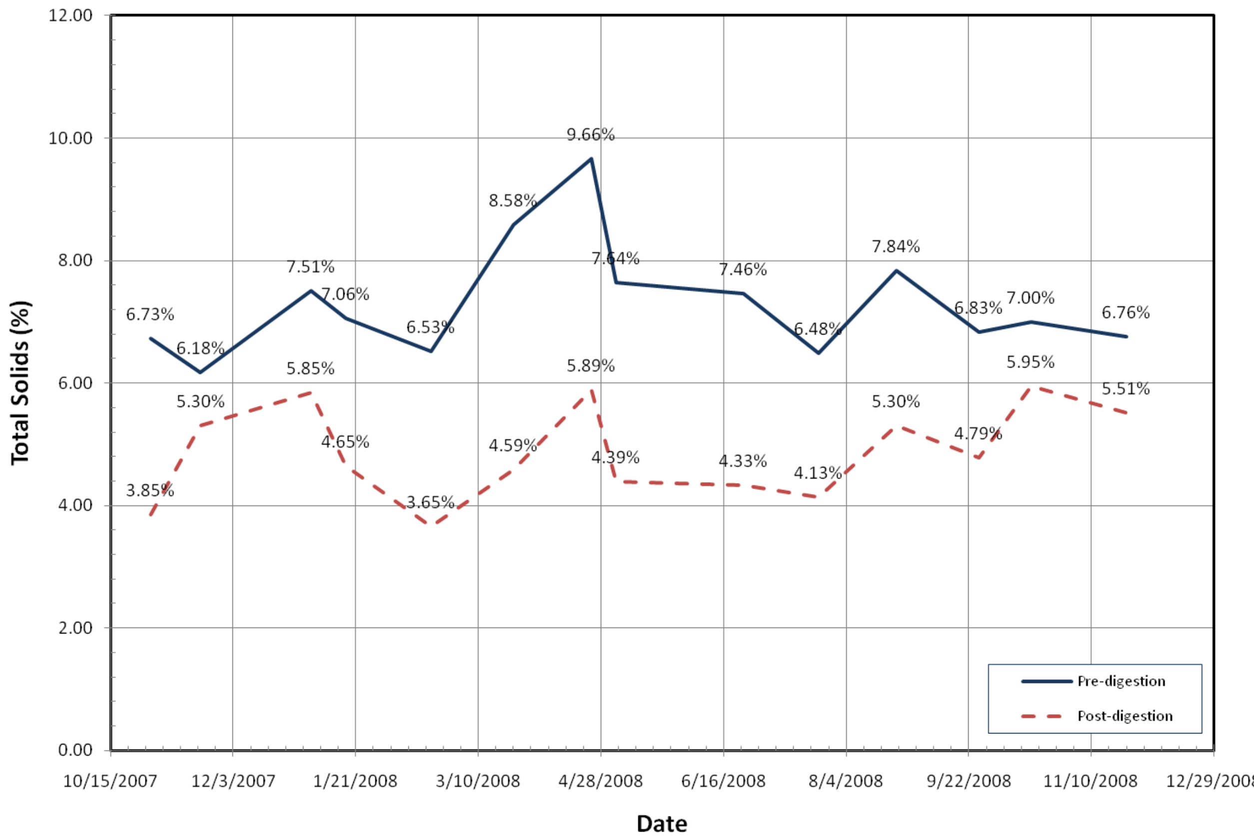


Figure 3. Plot of influent/effluent solid contents in MSC's digester.

10.5. Mechanical/Electrical Systems

Complete engine 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 prior assembly of compatible equipment and controls, so that on-farm hassles are reduced. On the other hand, it is advisable that manufactured skids include off-the-shelf components to facilitate replacement of skid components which may be otherwise difficult to locate. For example, we recently encountered an extensive delay when a specialty component (the engine controller) failed. The manufacturer did not have a replacement in stock and was thus forced to produce a replacement. Needless to say, this proved to be very costly in both the price of the component and the delay in returning the system to operation (about 2 months in this instance). Such an issue could have been quickly remedied had critical skid components been readily available, either locally or from a national supply chain.

10.6. Digester Design

The dual-chamber digester construction is meant to avoid an excessively long digester and to provide reasonable spans for the concrete top. As such, it provides an attractive and a viable design approach. This enables the shutting-down and the start-up of each side independently as well as 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. In addition, the design and installation of the heat exchangers within the digester were somewhat flawed. To date (i.e., July 15, 2013), the system was down for extended periods of time due to leakages in the heat exchangers within the digester. In each instance, maintenance periods were prolonged by months due to relatively inaccessible leak locations, the build-up of solids in the digester (which necessitated tank cleaning prior to maintenance), and the requirement that maintenance be performed by individuals with confined-space qualifications. In addition to the monetary cost of remediation, each maintenance issue preceded a substantial period where the digester became inoperable resulting in additional MSC expenditures on power from the grid. Considering the economic ramifications, design of a similar system might afford stainless-steel piping in the heat exchange system, rather than the schedule 40 black piping used in the MSC digester. Stainless-steel piping would markedly reduce the potential for the leaks, and thus eliminate the negative economic ramifications expressed previously.

10.7. Noise and Corrosion Control

Burying the exhaust pipe from the ICE in the equipment building, using steel lines for vital exhaust pipe sections in the equipment building, and conveying the exhaust some distance from the building ought to reduce the potential for corroding vital components of the system. However, corrosion of the exhaust components outside of the CHP building (including the non-steel metallic pipes and muffler) due to the presence of sour gas in the exhaust gas was an issue. In addition, internal combustion engines are still very loud, necessitating additional sound control measures in most applications (this could not be implemented in our system due to 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 both to heat the influent and maintain the desired temperature. In such instances, added external energy will be needed to maintain the digester's temperature.

10.9. Sensor Calibration

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

10.10. Insulation of Gas Lines

Insulation 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 tape was used to prevent the gas lines to the flare from freezing. In addition, some modification to the gas lines was attempted while the digester was down for repair in order to avoid frozen gas lines. While the modifications to the gas lines were done, an additional gas meter was installed to gauge the volume of biogas being flared. In November 2009, a small building was erected over the installed gas meter assembly and valves to prevent the gas line to the flare from freezing (although a heat tape still had to be used during the winter months to prevent the gas lines from freezing).

10.11. Digester Design and Economic Considerations

The process of designing and building an anaerobic digester is usually very involved and somewhat lengthy. This process was even more involved and extremely protracted for our digester given the multiple number of design re-runs pursued in an attempt to scale back on the scope of the project to meet budgetary constraints, regulations for a state project, and prevailing work force conditions. Along the way, some important design elements were eliminated resulting in a system that runs very well but is somewhat compromised when dealing with maintenance issues (e.g., eliminating the access manhole in the center of the top of the main compartment of each side of the digester – meant to access the tank if/when it needs to be serviced). Given some of the issues encountered when the system had to be serviced after the heat exchanger started leaking, it would have been useful if some of the alterations to the design were not implemented. Of course, a hard-top digester will always present difficulties when maintenance of an internal digester component is required compared to a soft-top system when the top could easily be removed.

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 accessible from the "Technology" tab which may be accessed from the home page of the college's website at www.morrisville.edu. The main page on "Alternative Energy Projects" can also be accessed directly using the following address: www.morrisville.edu/alternativeenergy/default.aspx. In addition, two slideshows were developed to present overviews of digester construction and operation. Finally, an "adobe Flash" show was developed to conceptually highlight the process of anaerobic digestion. These links may be accessed online at www.morrisville.edu/alternativeenergy/methanedigester.aspx.

For additional questions, please contact any of these individuals:

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