A Dozen Successful Swine Waste Digesters

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ABSTRACT

Swine waste can be successfully stabilized in farm scale anaerobic digesters. Four examples each of ambient temperature covered lagoon digesters, heated mixed tank digesters and heated mixed lagoons are included. All systems meet Natural Resources Conservation Service draft standards. Gas use in boilers, engine generators and flares is discussed. Summary tables are presented to allow comparisons of costs, savings and gas use between the projects. Biogas recovery and use in boilers or engine generators is discussed. A detailed case study of a single cell heated covered lagoon for odor control from 120,000 pigs is presented. The system cost $1,200,000. The system started up readily and is producing an average 530,000 ft^3 of biogas per day. The system benefits and methane reductions are described.

Keywords: Hogs, swine, pigs, biogas, methane, odor, anaerobic digestion, digester, covered lagoon, complete mix digester, nutrient management, pathogens

Introduction

Anaerobic digestion is more extensively used outside of the US where treatment of animal waste has been a concern for a longer time. An anaerobic digester is a vessel designed to retain decomposing manure for sufficient time at the designed operating temperature to allow the growth of methanogenic bacteria in a “steady-state”. Methanogenic bacteria produce methane as a metabolic biproduct. Electricity and heat production from methane combustion are direct benefits of anaerobic digestion. The effluent of a digester has an earthy smell with some ammonia present. The first dairy digester systems in the US were installed principally to produce energy during the energy crisis. The first pig manure digester systems in the US were installed principally to control manure odors. Today, farmer motivation for building and operating anaerobic digesters has expanded from direct energy benefits to include key non-energy benefits such as: odor control, improved manure handling, mineralization of organic nitrogen, weed seed destruction, pathogen reduction and byproduct production such as digested dairy solids.

Ambient Temperature Covered Lagoon Digesters

Ambient temperature covered lagoon digesters are most successful in warmer climates south of the Mason-Dixon line. A properly sized lagoon receives dilute manure with less than 2% total solids. The manure is either flush or pull plug collected and decomposes in the lagoon resulting in year round biogas production. Gas production varies seasonally and is useable for electricity production or is flared for odor control.

Barham Hog Farm, Zebulon, NC - 4000 sow farrow to wean

Barham Hog Farm has 5 buildings with pit recharge. The farm was built with a single cell treatment and storage lagoon. The project installed a separate covered lagoon prior to the existing lagoon. AgSTAR provided design, installation and troubleshooting support and worked with NRCS to design the lagoon. Lagoon construction began in July 1996. The lagoon cover, 400,000 Btu boiler and a 120 kW generator were installed in December 1996. Biogas use for heating water began in January 1997. Lagoon cover manufacturing problems limited biogas recovery and the production of electricity, however the boiler has operated almost continuously, providing hot water for pig mats under farrowed pigs. The owner was refunded his money and has purchased a new 40 mil HDPE cover. The 18 month average for biogas recovery is 632 m3/d (22,300 ft3/d) of biogas. Much of the year the generator is operated 12 hr/d at up to 90 kW during the daytime and during nighttime 12 hours, a boiler is operated to produce hot water for keeping baby pigs warm . Odor is virtually non-existent. Cheng (1999) found that 30% of the total Kjeldahl nitrogen (TKN), 75% of the P and 20% of the K was retained in the covered cell. Cheng (1999) found pathogen reduction to be 2 to 3 orders of magnitude.

The farm has been limited to offsetting about $18,000 per year in electricity and about $12,000 per year in propane purchases. The local utility is not in favor of farm cogeneration. However, odor control benefit is very important to the owner because large subdivisions are being built within one mile of the farm. Also, the improved biological stabilization and nutrient mineralization in the digester resulted in the effluent from the storage lagoon containing 60% less nutrients than before. Consequently, the farm manure treatment and nutrient application complies with the 1997 manure management regulations without additional investment.

Martin Family Farm, South Boston, VA - 600 sow farrow to feeder pig

Martin Family Farm covered the first cell of a two cell lagoon receiving flushed manure in 1993 and began engine-generator operations in spring 1994 with a matching grant from the Southeast Regional Biomass Energy Program (SERBEP). The first cover slowly sank and collected less gas each year. In 1997, Engineered Textile Products of Mobile, AL and Seamens Corporation contributed a demonstration XR-5 modular cover system to replace the original failed cover design. Martin Farms installed the new cover and replaced the corroded lagoon heat loop with radiators. Methane recovery has been continuous throughout the project, though gas use has not been. The farm has produced up to 397 m3/d (14,000 ft3/d) of biogas and 600 kWh/d during the summer. Winter gas production drops off to less than 170 m3 (6,000 ft3/d) and use has been problematic. The farm has planned and purchased a hot water boiler for pig mats under farrowed pigs. A boiler will more closely match the farm labor skill and availability. Odor is virtually non-existent, the effluent is stable and nutrient content of the second lagoon has been reduced substantially.

The major benefit to the farm has been odor control and elimination of objections by neighbors. The farm has produced several thousand dollars worth of electricity. A secondary benefit from the two cell approach has been nutrient reduction in the second lagoon and ease of effluent management in sprinklers on fields that are closer to the neighbors than the farm is.

Corneche, Chile - 102,000 finish hogs and La Ramirana, Chile – 20,000 Sows + 40,000 wean – finish.

Both of these facilities chose to install an anaerobic digester system in order to reduce the odor emanating from their waste storage lagoons. Their manure collection systems are pull plug and flush systems. The lagoons are earthen basins and were fully covered with HDPE liner with the edges buried around the lagoon banks. The Corneche installation was producing biogas by July 2002 and no problems were experienced during start up. The La Ramirana digester will be under going start up in late 2003. The primary benefit to both farms is the reduction of odor. Both farms will be flaring the biogas for odor control. No electricity will be generated with the biogas.

Farm	Start	Pigs	Type	Cost	Savings	Gas use *
Martin	1993	600	sows	$ 120,000	odor	E, F
		2,000	grower			
Barham	1996	4,000	sows	$ 289,500	$ 29,000	E, H, F
Corneche	2002	102,000	finisher	$ 700,000	odor	F
La Ramirana	2003	20,000	sows	$ 800,000	odor	no
		40,000	wean-fin			
* - E = electricity, H = hot water, F = flare						

Tank Complete Mix Digesters

Tank Complete mix digesters are used to treat waste with 3 to 10% total solids. This concentration contains adequate volatile solids to produce enough biogas (60% methane, 40% carbon dioxide) to maintain digester temperature. These units are usually heated with hot water from an engine to 100 degrees and mixed to maintain a high level of bacterial activity. The hydraulic retention time is greater than 12 days. Complete mix digesters produce a steady gas output that can be used for cogeneration or in a boiler.

These units can represent a cost savings over using an ambient temperature lagoon designed to Natural Resources Conservation Service (NRCS) or American Society of Agricultural Engineers (ASAE) standards to perform the same level of treatment for odor control. Ambient temperature lagoons would be 10-20 times larger than these digesters to perform the same function.

Colorado Pork, Lamar, Colorado and Bell Farms, Thayer, IA - 5,000-sows farrow-to-wean each

The farms are very similar in size and operation. Colorado Pork has about 600 more pigs growing as replacement gilts. However, the farm buildings and equipment are different. Both facilities were built in 1997-8 on sites that had been range or pasture. Environmental concerns of neighbors and state authorities prompted both owners to weigh waste management alternatives. Both chose complete mix digesters with separate storage to: 1. biologically stabilize manure, eliminate odor and optimize methane recovery for electricity production. 2. reduce their investment in waste management and 3. avoid problems with regulators by installing an environmentally beneficial system.

Periodically, plugs are pulled and manure is drained to a concrete collection tank and then pumped to the 2,100-2,200 m3 concrete tank digesters. The digesters are heated, mixed and covered by two biogas inflated plastic gas collection domes. Effluent at Colorado Pork flows into a nearby basin to be evaporated, while Bell Farms effluent is stored in 2 concrete tanks for annual application to cropland. Biogas fuels one Caterpillar 3306 engine attached to an 80 kW generator at each farm. All electricity produced is used on the farms. Heat, recovered as hot water from the engine and exhaust, is used to maintain the appropriate temperature in the digester. Biogas is automatically flared when not being used by the engine (for example during maintenance). The farms produce up to 60% of their own electricity needs. The farms are not expected to have surplus electricity to sell to the utility and do not have sales metering. The farms chose not to sell electricity rather than submit to uneconomical requirements and controls of the utility company. Future plans include using excess heat in the farrowing barns.

The Colorado Pork digester heating began August 6, 1999 using natural gas to fuel the generator. System operations on biogas began late September 1999. The digester has been problem-free. The engine has had typical startup mechanical problems, however, the unit has been operating continuously. In the first 5 months, the generator operated over 90% of the time, burning 48,160 m3 (1,700,000 ft3) of biogas and producing 140,000 kWh at an average load of 50 kW. The system output increased to 67 kW after 2 bad sensors were found and fixed. From early 2002 to Fall 2002 the farm was closed while sow stock was changed. The farm and the digester returned to operation in late 2002.

The Bell Farms digester was filled and heated over a 90-day period and started biogas production in August 1999, after delays due to additional construction on the digester tank. Full biogas yield was reached in September 1999. The digester has been virtually trouble free. The generator has operated 77% of the time during the first 6 months yielding 64,250 m3 (2,268,000 ft3) of biogas with an electricity output average of 67 kW. Typical startup issues of bad sensors cropped up. The engine was rebuilt under warranty after a breakdown due to loss of coolant. The system had a manure spill reach a ditch through a drain added by contractors. The local utility and the larger transmission and distribution utility were inconsistent on requirements for interting the farm to the utility grid. The methane recovery system at both Colorado Pork and Bell Farms has diminished farm costs of production by reducing the quantity of electricity purchased, while greatly improving site odors from manure storages which were objectionable to all who experienced them and contributing to the farm's environmentally sound manure management strategy. At Bell Farms, the digester is annually producing about $46,600 worth of electricity at $0.09/kWh. The annual value of electricity produced at Colorado Pork is estimated to be $34,800 based on $0.07/kWh.

DJ Acres, 7 Valleys Pennsylvania, 15,000 farrow to finish

The anaerobic digestion facility at DJ Acres as with many of these facilities was designed to reduce the odor coming from their waste storage ponds. The digester was started-up in 1986. Start up had been slow due to low winter temperatures. The manure at the farm was scraped producing a slushy mixture that lended itself to treatment in a complete mix digester. The digester consisted of one concrete tank that were heated and mixed and covered with inflatable tops. The biogas was used to produce heat and electricity. The heat was recovered from the engine by doing jacket and exhaust heat recovery. The generator produced 90% of the heat required by the farms. The electricity generated was used onsite with the surplus sold to the local utility. The hog farm was closed nine years later in 1995 resulting in the end of the digester operation as well.

Gypsy Hill Farm, Lancaster PA – 4000 Pigs and Whey.

The Gypsy Hill complete mix digester was originally designed by a company called Energy Cycle in 1983. The system has been in operation since that time producing biogas and 120 kW of electricity. The system was redesigned and rebuilt, increasing its capacity, by RCM Digesters in 2000. All the electricity produced is sold to the utility. The heat recovered from the engine is used to heat the digester, and any additional heat is used to meet the farms thermal needs. Excess biogas is flared for odor control.

Manure collection at the farm is accomplished by mechanical scrapers. The manure is then sent to a collection tank before mixing with cheese whey and introduction into the digester. Effluent from the digester is stored in a metal tank and an earthen basin prior to field application.

Tohoku Farm, Aomori, Japan – 30,000 Pigs farrow to finish and
Kazuno Farm, Hachinohe, Japan – 21,000 Pigs farrow to finish

These two facilities are similar in size and operation. Both chose to install anaerobic digestion equipment primarily for odor reduction. Manure collection at the facilities employs mechanical scrapers. The manure flows to a mixing tank before it is sent to the digester. At both sites the digester consists of 2 separate concrete tanks each covered by an inflatable cover. In Tohoku the effluent from the digester flows to an HDPE lined basin prior to land application. At Kazuno, effluent is further treated by extended aeration to meet local requirements. The primary benefit experienced at both farms is waste treatment and electricity generation. The electricity generated is used on farm in both cases to power aeration treatment. Neither site has experienced any start-up or operational problems since beginning operation in October 1989 at Kazuno and January 1989 at Tohoku.

Farm	Start	Pigs	Type	Cost	Savings	Gas use
DJ Acres	1986	17,000	farrow to	$ 250,000	$72,000	E, H, F
			finish			
Gypsy Hill	1983	4,000	finish	$ 289,500	$ 29,000	E, H, F
		12,000 g	whey			
Tohoku	1989	21,000	farrow to	unknown	unknown	E, H, F
			finish			
Kazuno	1989	30,000	farrow to	unknown	unkknown	E, H, F
			finish			
Swine USA	1999	5,000	sow	$ 525,000	$ 36,000	E, F
Colorado Pork	1999	5,000	sow	$ 374,000	$ 44,800	E, F
* - E = electricity, H = hot water, F = flare						

Heated Mixed Covered Lagoon

Heated mixed covered lagoon digesters are used to treat waste with 3-6% total solids with adequate volatile solids to produce enough biogas (60% methane, 40% carbon dioxide) to maintain digester temperature. These units are heated to maintain a high rate of bacterial growth. Mechanical mixing or stirring is used to improve the contact between substrate and microorganisms thereby promoting decomposition of the substrate.

A heated digester should represent a cost savings over using an ambient temperature lagoon designed to Natural Resources Conservation Service (NRCS) or American Society of Agricultural Engineers (ASAE) standards to perform the same level of treatment for odor control. Heated mixed covered lagoons are 1/3 the volume or less of ambient temperature lagoons to perform the same function. The design and operation goal of the subject digester is consistent biological stabilization of waste and odor control rather than optimization of biogas production and use while stabilizing the waste.

Apex Pork - 8,600 Head Pig Finishing Facility, Rio, IL
Apex Pork has 8,600 hogs in 9 buildings with pull plug manure collection. Three years of seasonal odor episodes from the manure storage pond were not acceptable to downwind neighbors. The farm chose Resource Conservation Management, Inc. to design an innovative, low cost, heated, mixed covered earthen lagoon digester. A bank-buried insulated floating cover is installed on the 36.3 x 48.5 x 5 meter (120 x 160 x 16.5 ft) lagoon which can hold roughly 20 days worth of manure. The digester produces enough methane to fuel a boiler to heat the digester and flares unused methane. Stabilized digester effluent flows to the storage pond. The pond no longer emits odorous gases. The primary benefits to the owners are odor reduction of stored and field applied manure. There have been no odor complaints since the digester was installed. Compliance investigations by state regulators has stopped. The digester is able to accommodate the variation in manure loading rate that results from all-in-all-out operation.

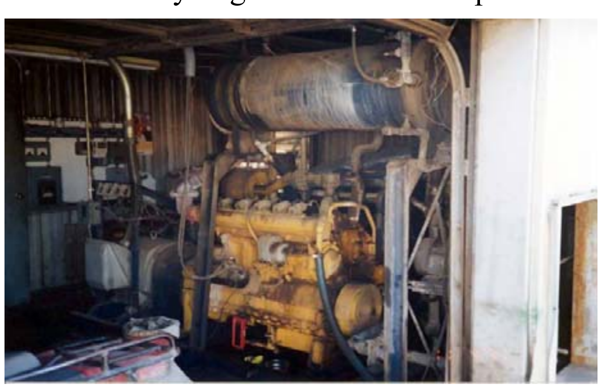
The digester started up in about 30 days switching to biogas from propane in June 1998. By mid summer, 1998 the system was producing 1,020 m3 (36,000 ft3) of biogas per day. The unit was running well when a microburst damaged the gas collection cover and nearby buildings in August 1998. The partial cover was replaced with a bank attached floating cover over the whole lagoon in October 1998. Concurrently the farm was emptied of pigs to allow building renovations and a change of pig production technique. The farm, originally a continuous flow facility, converted to all-in-all-out operations. Digester heating began in December 28, 1998. The boiler system was switched to biogas January 24, 1999 and has run full time with little or no maintenance since. The digester gained temperature during the coldest times of the year. The digester has been through 3 grow-out cycles without problems. The system is simple to operate and the owner only spends about 10 minutes daily to check the system. Several lessons of this project were: 1. A bank-buried complete lagoon cover, though a more expensive first cost, is less expensive to maintain than a floating edge partial cover. 2. Inexpensive cover materials such as 20 mil HDPE coated fabric can present problems in extreme weather. 3. Pig operations can change rapidly and radically and present a completely different waste stream.

Peralillo, Chile – 120,000 Finish Hogs, La Estrella, Chile – 137,000 Finish Hogs and Pocillias, Chile – 238,000 Finish Hogs.
La Estrella and Pocillias were built in 2002 and have been started as of January and February of 2003. Peralillo has been in operation since January 2001. All three facilities have a mixture of pull plug and flush manure collection. The collected manure flows to heated mixed lagoons where it is treated and the effluent sent to an earthen basin for storage and use. The primary benefits at all three sites has been odor reduction and waste treatment. The biogas generated is used to fire boilers at all the sites and the hot water generated meets the thermal needs of the digesters. Peralillo did not experience any start up problems. La Estrella and Pocillias both experienced some plumbing problems at the outset as a result of low winter temperatures.

Farm	Start	Pigs	Type	Cost	Savings	Gas use *
Apex	1993	8,600	finisher	$ 174,000	odor	H, F
Peralillo	2001	120,000	finisher	est $1,100,000	odor	H, F
La Estrella	2003	137,000	finisher	est $1,200,000	odor	H, F
Pocillias	2003	238,000	finisher	est $1,500,000	odor	H, F
* - E = electricity, H = hot water, F = flare						

Biogas recovery and use in engine generators or boilers

Biogas can be used for electricity production in an engine generator set, hot water production in a boiler, or flared for odor control. A Caterpillar 3306 engine (shown below) has been used continuously to generate 45 kW of power for the last 21 years.



The biogas boiler in Pocillias Chile produces 20 Mbtus of thermal energy used to generate hot water for use in the hog farm.

One of the primary benefits of anaerobic digestion is odor control. If the biogas is not being used to generate electricity or hot water then it will be flared to control the odor.

Detailed case study of a single cell heated covered lagoon

Perallillo, Chile - 120,000 Head Pig Finishing Facility, South America

Background

The farm has 120,000 hog capacity in 120 buildings. The site is operated as an all-in-all-out grow-finish facility. Approximately 90 buildings were built with flushed manure systems and 30 were constructed with pull plug manure collection. All wastes were originally drained to a storage facility which was the dammed upper portion of a small watershed drainage. The storage facility has almost 88 acres of surface area but is predominantly shallow, less than 10 feet average depth. Quite a bit of shallow sloped land was included in the storage. The facility was sized for about 6 months of volumetric storage. Odor from the manure storage pond was not acceptable to the owners, workers, neighbors, or government officials. In addition, seasonal pumping of manure exposed large areas of perimeter beaches that served as breeding grounds for copious quantities of flies.

The owners committed to resolution of the problem, conducting a world-wide solicitation for designers with demonstrated cost effective technology. The farm owner chose Resource Conservation Management, Inc. to design an innovative, low cost, heated, mixed covered earthen lagoon digester based on similar success of the approach that was demonstrated at Apex Pork in Rio, IL on an 8,900 head finisher facility.

Manure Collection and Transfer
All flush buildings are flushed daily with fresh water. The flush manure flows to collection tanks. Collection tanks are pumped daily to the digester. Pull plug buildings are pulled on a rotating schedule where 2 to 3 buildings are drained to a transfer tank on a daily basis and then pumped to the digester. The daily flow to the digester varies between 900 m3 and 1800 m3.

Digester
A bank-buried insulated floating cover is installed on the 105 x 105 x 9 meter (346 x 346 x 29.7 ft) lagoon which can hold roughly 20 days worth of manure (32,000 m3 approximately 8,000,000 gallons).

Digester Heating
The digester is operated at 35 degrees C and can vary up to 4 degrees C. Digester is heated with an external exchanger.

Digester Mixing
The digester is mechanically mixed. Pump mixing is continuous.

Gas Production
The digester produces enough methane to fuel a boiler to heat the digester and flares unused methane. Gas production has varied between10,200 m3 to 15,500 m3 (360,000 to 550,000 ft3/d) since the digester startup. After 2 hydraulic retention times with the farm fully populated, the digester output averaged 530,000 ft3/d over a 2 month period. Gas production fluctuations are expected due to fluctuations in farm pig population.

Digester Effluent
Stabilized digester effluent flows to the storage pond.

Digester Operations
The digester was started up over a 4 month period in ending in November 2000. Flare operation began in late December with flaring of 150,000 ft3 of biogas. By late January

2001 the system was producing 5,600 m3 (200,000 ft3) of biogas per day. The unit was running well when the pig population was brought up to farm capacity.

The digester maintained temperature during the coldest times of the year. The digester has been through 3 grow-out cycles without problems. The system is simple to operate and a single operator is charged with operating the system. The main work is checking the system operations readings.

Construction Costs

The costs for construction are shown in the appended table. Most equipment was imported and these costs are included in the cost estimate. In-country construction costs are remarkably similar to US construction costs as virtually all construction materials and equipment are imported, thereby offsetting labor cost savings. The capital cost is approximately $10.06/pig of capacity. The system life should be 15 years. Assuming no interest charges and 2.5 turns per year the cost per pig produced would be $0.27.

Operation Costs

Operations are routine at this time. Approximately 1.5 men are working at the digester, though their main work is pumping manure from buildings to the digester and from the digester to storage. Assuming this facility has 2.5 turns per year, the cost per pig shipped is approximately $0.25.

Results

After 2.5 years of operation the digester is healthy and operating well. It is maintaining its heat level and the storage no longer emits malodorous gases. The primary benefits to the owners are odor reduction of stored and field applied manure. There have been no odor complaints since 4 months after the digester was started up. Compliance observations by regulators continue, but the government participated in an open house 6 months after startup to demonstrate their support of the odor control solution. The digester is able to accommodate the variation in manure loading rate that results from all-in-all-out operation. The attached figures present operational information including influent flow, biogas flow and CO2 variations.

Lessons Learned

Several lessons of this project were: 1) Low cost, in-ground, heated, mixed, floating cover digesters can meet farm environmental needs; 2) Large single tank, anaerobic reactors are possible on farms; 3) Finishing farms with flush manure collection have the options of heated anaerobic digesters.

Future Options

The owner would like to generate electricity for his operations. There is the possibility to install about 1.5 megawatts of electric capacity. Equipment costs and benefits have been developed. Equipment specifications have been developed. Negotiations with the power company have begun.

The success of the project in meeting its environmental goals led the owner to begin another project to retrofit other farms with RCM design anaerobic digesters.

A Low-Cost Digester to Control Odors at a 120,000 Head Hog Farm

Paper Number 012298 Session 128 Poster #142

Construction Costs

Earthwork, soil testing	$ 94,000
Influent piping	$ 37,000
Digester liner, cover, stirrer, heat exchanger, gas collection	$ 470,000
Effluent pump station	$ 67,000
Energy building	$ 72,000
Gas handling - meter, pump, flare, controls, piping and wiring	$ 144,000
Boiler with shipping and duties	$ 175,000
Engineering	$ 142,000
Startup	$ 7,000
Total Cost	$ 1,208,000

Approximate U.S. Capital Cost - $10.06/head capacity for reliable odor control

Estimated U.S. Operating Costs - $ 0.25/head sold (1.5 employees plus repairs)

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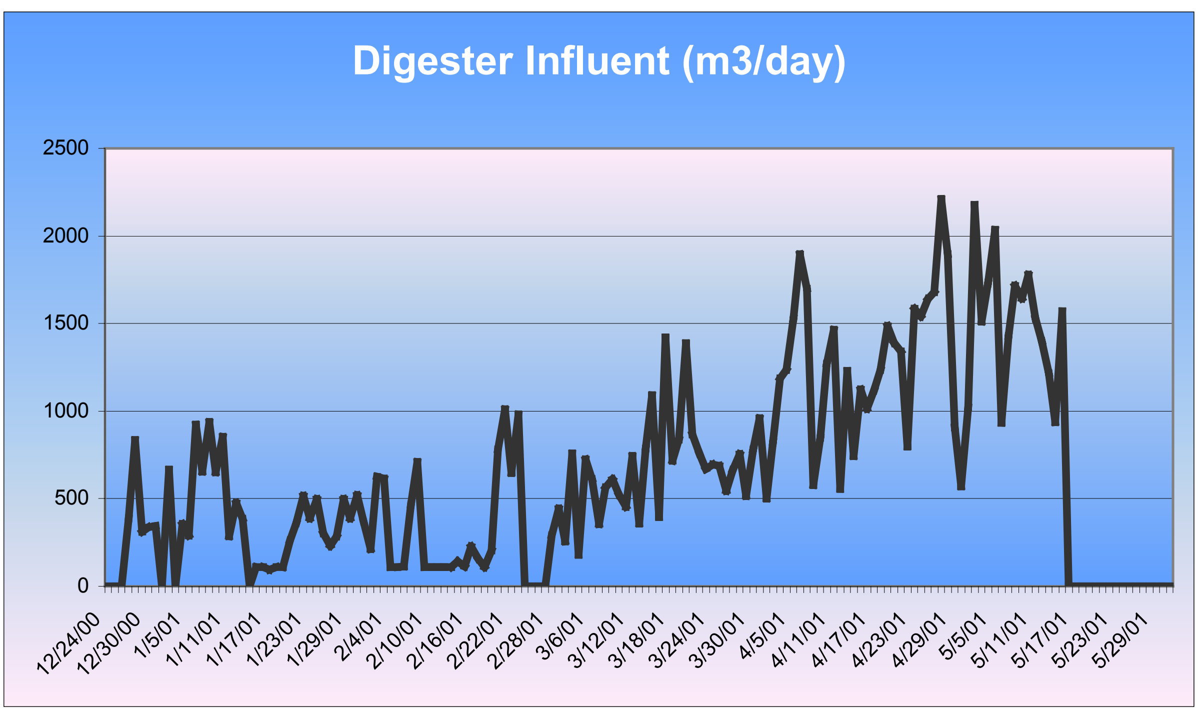

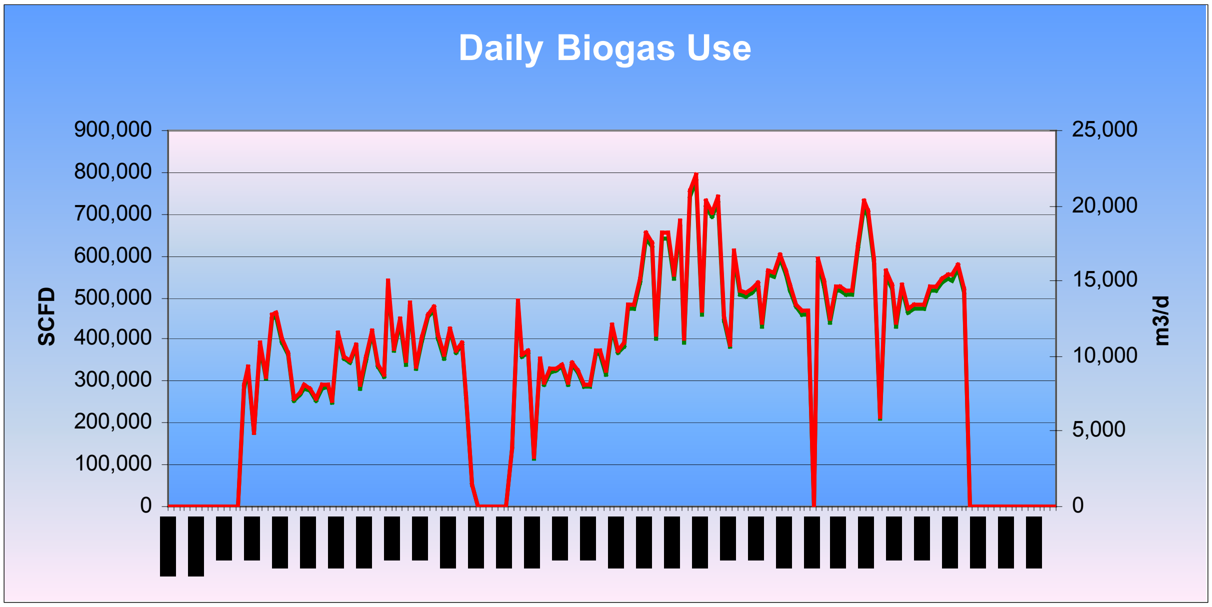
Daily Biogas Use
SCFD
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800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
m3/d
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20,000
15,000
10,000
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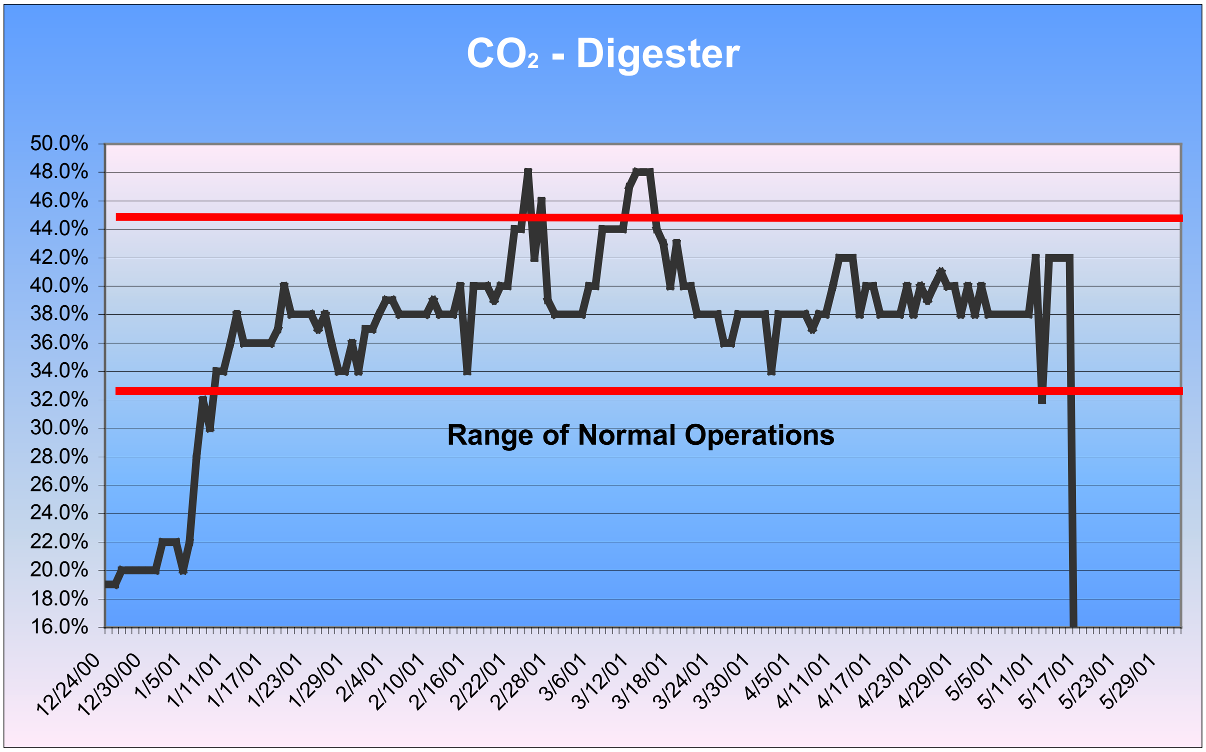
CO2 - Digester
50.0%
48.0%
46.0%
44.0%
42.0%
40.0%
38.0%
36.0%
34.0%
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30.0%
28.0%
26.0%
24.0%
22.0%
20.0%
18.0%
16.0%
Range of Normal Operations
12/24/00
12/30/00
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1/23/01
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