Biogas Anaerobic Digester Considerations
for Swine Farms in North Carolina

Collecting biogas from anaerobic digestion of swine manure can benefit the environment by reducing methane emissions (has potential value for equivalent carbon credits or greenhouse gas (GHG) credits), and by providing energy, as biogas is about 60 to 70 percent methane. Methane has an energy value of about 1,000 BTU/SCF[1], so biogas can have an energy value of about 600 BTU/SCF.

Plug-flow or complete-mix anaerobic digesters using metal or concrete vessels have been used on dairy and other animal farms where the dry matter or total solids content in the wastewater is over 5 percent. These types of digesters are discussed in Barker (2001), Fulhage et al. (1993), Balsam (2006), and US EPA AgStar (2008a). However, as manure becomes more diluted, the volume of the vessel increases and this increases costs.

Swine farms in N.C. typically use a flush system, either tank flush (several times daily) or shallow pit-recharge (about once per week), to transport manure from the barns. The resulting flushed wastewater is very dilute, about 98 to 99 percent water and 1 to 2 percent dry matter. The two types of digesters that are best suited for flushed wastes are: (1) In-ground ambient (or heated) covered digesters, and (2) Fixed-film digesters. Existing anaerobic lagoons can also be covered to collect biogas.

Covered Anaerobic Lagoons

Uncovered anaerobic lagoons have been used extensively in North Carolina for swine manure treatment and storage. Biogas can be collected by covering an existing anaerobic lagoon. The biogas is typically 60 to 70 percent methane (CH_4) and 30 to 40 percent carbon dioxide (CO_2). Anaerobic lagoons are designed to treat the manure and keep odor emission at a reasonable level. Loading rate of the lagoon is based on a design permanent treatment volume and is about 1 ft^3 of treatment volume per pound of Live Animal Weight (LAW) for a feeder-to-finish operation, or about 5 to 6 pounds volatile solids (VS)/1,000 ft^3 per day. Single-cell anaerobic lagoons have additional volume for manure and wastewater production for a period of time (usually 3 to 6 months), sludge accumulation (sometimes optional), temporary storage of excess rainfall (rainfall that exceeds evaporation), and runoff (if any), a 25-year, 24-hour storm rainfall and runoff amount, freeboard, and sometimes a "heavy-rainfall" amount. If there is a second cell, the wastewater storage can be subtracted from the first cell and put in the second cell. By allowing overflow to a second cell, a relatively constant volume can be maintained in the first cell.

Collected biogas from a small area (1.5 m x 1.5 m) of three swine lagoons during 1- to 3-month periods in summer indicated biogas yields of 0.10 to 0.33 ft^3 per day per square ft of area, or 0.03 to 0.04 ft^3 per day per cubic ft of lagoon volume (Safley and Westerman, 1988). Biogas production from covered swine lagoons has not been reported for full-scale projects in North Carolina.

Covered Digesters

NRCS has recommended that the design operating volume of an ambient-temperature anaerobic digester be based on either the daily VS loading rate per 1,000 ft^3 or the minimum hydraulic retention time (HRT) adequate for methane production, whichever is greater. NRCS (2003a) has recommended a 40-day minimum HRT with a maximum loading rate of approximately 10 pounds volatile solids per 1,000

[1] SCF is "standard cubic foot," which is defined as quantity of gas in 1 cubic foot of volume at 60ºF and 1 atmosphere pressure. In this paper, gas volumes are generally reported as ft^3 because the references have not stated that volumes were converted to "standard cubic foot." The gas laws are used to convert from one set of temperature and pressure to another. Standard temperature and pressure conditions may be defined differently by various organizations.

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ft^3 per day for eastern North Carolina. The total volume of the digester should equal the minimum treatment volume except where waste storage is included in the design. The digester storage volume does not need to account for rainfall except for partially covered digesters. Design of a covered digester can include higher loading rates than for a typical anaerobic lagoon and a lower hydraulic retention time (HRT), which means the volume of the digester can be lower than for an anaerobic lagoon, and the size of the cover can be smaller. Normally, covered digesters should maintain a constant volume by having an overflow into a storage unit. The storage unit could have a permeable cover or an impermeable cover to reduce ammonia emissions from the storage unit.

Temperature effect: A covered lagoon or digester will operate without added heat at the ambient temperature of the liquid, which typically varies from about 40ºF to 90ºF (about 5ºC to 32ºC). Cooler temperatures reduce biogas production, so the biogas production is seasonal for ambient-temperature covered lagoons or digesters. Safley and Westerman (1994), in lab studies with swine manure loaded at 6.2 pounds VS per 1000 ft^3 per day, reported an increasing biogas production rate from 6.8 ft^3/lb VS added at 50ºF to 8.2 ft^3 per pound VS added at 68ºF.

The temperature variation could be buffered somewhat by adding insulation to the cover, but adding insulation also makes the cover more complex and results in higher costs. If insulation is utilized and heat is added, it is possible to keep the liquid temperature in the mesophilic temperature range (95ºF to 104ºF) (35ºC to 40ºC) and obtain higher biogas production using a lower HRT, perhaps 20 to 30 days. Because the temperature is kept as constant as possible, the biogas production should be essentially constant per unit of organic matter loaded. However, because the weight of the pigs and the manure production rate varies, the organic matter loading will likely vary, and thus the biogas production will vary accordingly to the loading rate.

Volatile solids loading: Actual volatile solids loading may differ from estimated volatile solids production in ASABE (2005) and NRCS (2008) tables. Loss of VS could occur in the barn or in pump stations, either from degradation or from accumulation of solids in corners or areas of low mixing. Data collected for flushed swine manure on one feeder-to-finish farm (Westerman, 2007) indicated that measured VS was approximately 50 percent less than ASABE (2005) table values of VS production. For existing farms, flow rates should be determined and samples of the flushed manure should be taken and analyzed to calculate a VS loading rate. Also, the VS loading will vary with size of pigs. The live weight of pigs will vary on many farms, especially for "all-in, all-out" farms, and this should be considered for changes in loading rate and for calculating an average loading rate.

Case Studies of Covered Digesters

Reports have been released for three covered digesters constructed in N. C. that were designed for flushed swine wastes. One digester was on a 4,000-sow farrow-to-wean farm with pull-plug shallow pits (Cheng et al., 2004) (See Figure 1), and was designed to be deeper than a typical lagoon in an attempt to maintain a higher temperature in the winter and reduce the amount of area covered per unit volume. Another digester was on a 1,000-sow

Figure 1. Ambient-temperature covered digester at 4000 sow farrow-to-wean farm in Johnston County, N.C. Cover was installed in 1998.

Figure 2. Covered lagoon at Black Farms near Lillington, N.C. Cover was installed in 2008. Cover has ports for recycle lines for flush water and irrigation pump intake as well as a pipe system across bottom of lagoon for removing sludge. Two lagoons for 6000 finishing pigs were covered.

Table 1. Covered digesters in North Carolina for flushed swine manure.

Parameter	Units	Barham Farm (Cheng et al., 2004)	Carroll's Farm (Safley et al., 1993)	Vestal Farm (Bull and Worley-Davis, 2005)
Type of Farm	head	4000 sow farrow to wean	1000 sow farrow to finish	9,792 finishers
Live animal weight	lb	1,600,000	1,560,000	1,468,800
Type of flush system		Pull-plug shallow pit	Flush tanks	Flush tanks
Digester volume	ft^3	864,500	935,400	100,800
Digester size	ft	265x265x20	265x265x24	138x138x13.2
Loading rate	lb VS/1000 ft^3/day	4.32 (measured)	9.3 (design)	65 (design)[1]
HRT	days	176	22.4	25 (design)[1]
Type of digester	Temperature range	Ambient temperature	Ambient temperature	Mesophilic (95 ºF ± 3º F)[2]
Biogas production	ft^3/day	33,192 (2003 avg.) Range from <10,000 to > 72,000 (1/1/2003 to 12/31/2003)	28,000 to 30,000 (5/15/1993 to 8/23/1993)	22,000 to 47,000 SCF (8/6/2004 to 8/29/2004)
Biogas production	ft^3/lb VS loaded	8.89	3.5	Insufficient data
Methane content in biogas	percent	63.7 ± 4.7[2]	68 to 80 percent	Not reported

[1]System included a solids-liquid separation tank to concentrate solids so that much of the flushed liquid bypassed the covered digester and went directly to a storage pond. Data was insufficient to determine actual loading rate and HRT.

[2]Mean ±standard deviation.

farrow-to-finish farm with flush tanks; it was also deeper than a typical lagoon (Safley et al., 1993). The third one was on a 9,792-head finishing farm with flush tanks. It featured a heating system and 6-inch Styrofoam insulation to maintain a constant temperature (Bull and Worley-Davis, 2005). Information for the three projects is listed in Table 1.

Only one of the projects reported gas production over an entire year. The ambient-temperature covered digester for a 4,000-sow farrow-to-wean farm showed a biogas production range of < 10,000 ft^3/d to > 70,000 ft^3/d, and averaged 33,000 ft^3/d with 63.7 percent methane over a one-year period (Cheng et al., 2004). The loading rate was about 4.3 lb VS/1000 ft^3/day, which is slightly lower than the recommended loading for the permanent treatment volume in an open anaerobic lagoon, and slightly less than half the maximum loading rate recommended by NRCS (2003a) for covered digesters. However, the loading rate was based on measured flow and influent samples, not on tables for VS production. The average biogas production was 8.9 ft^3/lb VS loaded. HRT time for this covered digester was 176 days, which is about four times longer than the minimum HRT (40 days) recommended by NRCS (2003a). The other two projects reported biogas production for only a limited time in the summer and were in the range of 22,000 to 47,000 ft^3/d. The design HRTs of these two projects was about 25 days. The summer gas production from the covered digester reported by Safley, et al. (1993) was only about 3.5 ft^3/lb VS loaded (based on design VS loading, not measured loading).

Fixed-film Digesters

Fixed-film digesters are also called attached-growth digesters or packed-bed digesters. Because there are less suspended solids in the dilute wastewater to provide surfaces for bacteria to grow and perform their conversions, adding plastic or other media to the digester allows the bacteria to attach to a surface. Research has been conducted at lab scale at Auburn University in Alabama (Hill and Bolte, 2000) and at N.C. State University (Cheng and Liu, 2002) with fixed-film or attached-growth digesters for flushed swine manure, but no full-scale systems have been used for dilute swine manure. Because the flushed manure is dilute, the wastewater flow rate through the digester is high, and the HRT is small. In the N.C. research with a media specific gravity of 0.98 (media slightly less dense than water) and 35ºC temperature, the Chemical Oxygen Demand (COD) and volatile suspended solids reductions were 68 percent and 73 percent, respectively, with HRT of 10 days and were 55 percent and 60 percent, respectively, with HRT of 5 days (Cheng and Liu, 2002). The influent COD concentration was about 2,000 mg/L. Methane yield per pound COD removed in the digester was similar for both HRTs, 3.85 ft^3 CH_4; the biogas was 70 percent methane, so biogas yield was 5.5 ft^3 biogas per pound COD removed. Total volatile solids loading was not reported, so the gas production per unit of VS loading cannot be calculated and compared to data from the covered digesters. However, the Barham farm earthen ambient-temperature digester study (Cheng et al., 2004) reported COD and VS. Biogas yield was 3.92 ft^3 per pound COD loaded. The COD and VS removals in the Barham farm digester averaged 93 percent and 88 percent, respectively, but settling was part of this removal.

The type of flush system and frequency of flush are important factors in the design of fixed-film digesters. They are normally designed with tanks as the digester, so lower HRT keeps the tank smaller and the costs lower. A pit-recharge system may empty 20,000 gallons or more for each "flush," which may typically be one flush per week for each barn. The flush-tank system has more frequent and smaller flushes, perhaps four to eight flushes per barn per day. The volume of flush per week is typically less with the pit-recharge system. Thus, it is important to know the flows and the concentrations when designing a fixed-film digester.

Many types of media have been used in fixed-film digesters. Many shapes made with plastic media will increase surface area per unit volume. The media can also be denser than water or less dense, so that it floats. One main consideration for selecting the media is the potential for pore clogging, which would result in non-uniform biofilm, channeling of flow (uneven flow in a cross-section of the digester), and possibly flow rate reduction if resistance to flow increases.

Considerations for Utilizing Covered Lagoons and Digesters

Odor: Because the digesters are covered or closed and gases are collected for combustion, digester odor emission is prevented. After digestion, there is also less potential for odor production from the effluent or the biosolids compared to the fresh or raw flushed waste. Thus, digesters can have benefits for reducing odor from an operation.

Potential carbon credits for reducing methane emissions: Because the gases are collected and combusted, methane emission into the atmosphere is reduced compared to an open lagoon. Methane is a greenhouse gas that is considered to be about 21 times more effective than CO_2 in trapping heat, so greenhouse gas (GHG) credits or carbon credits for reducing methane emission are possible. Several companies are involved in buying and selling GHG or carbon credits, and this is an evolving business. Many of the companies work with guidelines from the Chicago Climate Exchange (http://www.chicagoclimatex.com/content.jsf?id=103). See AG-708 for more information on carbon credits.

Safety hazards: Biogas consists almost entirely of methane and carbon dioxide (60 to 70 percent methane and 30 to 40 percent carbon dioxide), but it also contains some hydrogen sulfide (H_2S) and other gases. Hydrogen sulfide can corrode engines when it is used to generate electricity, so most of the hydrogen sulfide should be removed with an iron-based absorbent or other type of scrubber. H_2S can also be removed biologically through a microbial filter, where a small amount of air is injected into the biogas to convert H_2S to sulfur. Biogas is flammable and potentially explosive when mixed with air at 5 percent to 15 percent concentrations. Asphyxia can result if the oxygen concentration in air falls below 19.5 percent (air normally contains 21 percent oxygen). Also, hydrogen sulfide can be fatal at concentrations of 700 to 2,000 ppm. As long as there are no leaks of biogas into an enclosed space, the safety hazards of conveying biogas from a digester to an engine generator or boiler for combustion should be minimal.

Ammonia: Ammonia loss from open lagoons is a concern for both airborne aerosol formation and for nitrogen deposition in ecologically sensitive areas. Covering a lagoon or digester will prevent the mass transfer of ammonia from the liquid directly to the atmosphere. During combustion of biogas, the ammonia may be converted to NO_x (nitric oxide—NO—and nitrogen dioxide—NO_2), but more information is needed on the amount of ammonia removed with the biogas and ammonia conversions.

Solids/liquid separation: Biogas production is generally related to the amount of volatile solids (VS) that are destroyed in the digester. For a fixed-film digester, separating some of the coarse solids from the liquid might reduce the potential for media plugging. However, some of the potential for biogas production is removed with the separated solids. Also, increasing the solids content for a covered digester, especially if it is maintained at mesophilic temperature, might be beneficial. If solids separate or thicken and the more dilute liquid is not utilized in the digester, then some of the biogas potential is removed with the liquid.

Biosolids or sludge management: One concern with covered digesters and lagoons is how to remove biosolids or sludge after several years of accumulation. Just as with a lagoon, much of the phosphorus, copper, and zinc, and a portion of the nitrogen, will settle in the digester and accumulate in the sludge. Thus, the sludge will have high phosphorus, copper, zinc and nitrogen content when applied to land-crop systems. Most likely, the cover will need to be removed to dredge or agitate and pump out sludge. However, some swine anaerobic lagoons in North Carolina have been covered with a pipe system installed by Environmental Credit Corp.(www.envcc.com) in the bottom of the lagoon to pump sludge. The success of removing sludge with the pipe system has not yet been tested. Because fixed-film digesters are usually tanks, it should be easier to remove sludge than in a covered digester. A cone bottom or an auger might remove sludge frequently. The sludge could be applied to land-crop systems, or perhaps dried and composted to use as a soil amendment or fertilizer.

Nutrient management: Digesters mainly convert carbon to methane, so transformations of nitrogen and phosphorus are minimal. However, nitrogen and phosphorus can settle in the covered digester, as they do in an open lagoon, and thus cause a partitioning that can result in different N:P ratios than in the raw flushed manure. There may also be some precipitation in the covered digester, such as magnesium ammonium phosphate (MAP), also called struvite. Precipitation is also affected by pH, which is typically between 7.2 and 8.0. Struvite precipitation generally increases as pH increases.

Because ammonia emission from a covered digester is low and is conserved in the liquid, the digester effluent can have relatively high ammonium/ammonia concentrations. The effluent liquid can emit ammonia if precautions are not taken to reduce ammonia emissions during subsequent storage (such as permeable or impermeable cover) and application to land (such as hose-drag system). Overall, the nitrogen contained in effluent that is applied to land may be significantly increased in a covered lagoon or covered digester when ammonia loss is reduced. A limited amount of data indicate that the total nitrogen concentration in the liquid might be about twice as great in a covered lagoon as in an open lagoon, but more data are needed to verify the increased nitrogen retention. Covered lagoons keep rain out, but evaporation also decreases, although the reduction amount remains unknown. If a covered lagoon or covered digester has a second cell for storage, then the nutrient concentration in liquid from the second cell will depend on whether that cell has a cover and whether the cover is impermeable or permeable.

The amount of nutrients for land application also varies, depending upon what other treatment processes are used. Some possible processes for treating covered lagoon or covered digester liquid include: (1) an aerobic biofilter to convert ammonium to nitrate, and the option of then recycling this high-nitrate liquid to the barns for flushing, converting the nitrate to dinitrogen gas and transporting it to the atmosphere (See Cheng et al., 2004); (2) a struvite crystallizer that reduces phosphorus by forming magnesium ammonium phosphate (MAP), which can be easily dried and taken off farm as a slow-release fertilizer (Westerman, et al., 2008); and (3) using aquatic plants such as duckweed to remove nitrogen, then using the duckweed for feed or for biofuel production (research is underway at N.C. State University). Note that using high-nitrate liquid for flushing barns (item 1 above) will result in loss of some of the wastewater's organic carbon via denitrification and thus reduce the methane-producing potential to some degree.

Rain water management: Rainwater must be pumped off of covered lagoons and digesters. Usually, the cover has "folds" of low areas so that rainwater drains to a point where an electric pump sends it to a drainage waterway outside the area of the covered digester. Rainwater collecting on the cover will push out digester effluent, causing some variation of effluent discharge rates.

Covers and liners: Covers are typically made from 40- to 60-millimeter HDPE plastic. However, there are optional materials, and several companies make and install synthetic covers. Similar materials can also be used for the liner at the bottom of the digester, or a clay liner may be allowed if local permits allow. See the EPA AgSTAR Industry Directory for On-Farm Biogas Recovery Systems (US EPA AgSTAR, 2008) for a list of vendors of covers and other equipment associated with recovering and utilizing biogas.

Biogas utilization: Although there is increased public interest in generating green energy, it is still difficult for farms to sell electricity to utilities at rates that cover the costs of the digester and the electrical generator system. Some farms with digesters have used biogas to operate electrical generators mainly for on-farm use. However, the schedule demand for electricity on the farm may not match the generation schedule. Internal-combustion engine generators and microturbines have been used to generate electricity. Capital cost is high, and it can be difficult to generate enough energy, especially for smaller farms. Other options to electrical generation include using the biogas for a boiler and using the hot water. However, the need for hot water on swine farms is limited; providing heat for baby pigs in a farrowing barn is one possible use. A heat exchanger can also be used with the engine generator to obtain hot water. Another option for biogas is to remove CO_2 and gas impurities and put the methane into a pipeline, or compress it for direct use as a fuel. However, the costs of these processes may be prohibitive.

Costs: A study for dairy farms in Florida (Giesy et al., 2005) analyzed costs for covered lagoons and fixed-film digesters. The study determined that covered lagoon technology was economically preferable to fixed-film digesters for the three dairy farms that participated. The three farms were: A- 650 cows, B- 2,100 cows, and C-600 cows. At 100 percent owner's share of capital investment, 8 percent discount rate, and $0.10/kWh retail value of electricity, anaerobic digestion was feasible only for Farm B with a covered lagoon. At $0.12/kWh, anaerobic digestion was also feasible for a fixed-film digester at Farm B and a covered lagoon at Farm A.

Zering et al. (2005) conducted a cost and returns analysis of the covered digester on the Barham farm in North Carolina. Estimated 2004 costs of adding a clay-lined in-ground ambient digester, cover, and flare was $48.30/1,000 pounds SSLW per year. (Note 1,000 pounds SSLW is equal to 2.31 sows in inventory on a farrow-to-wean farm. See Table 2.) The existing lagoon was used to store effluent from the covered digester. Adding an 80 KW generator set, a tie to the grid, and a shed increased costs by an additional $13.35/1,000 pounds SSLW per year after subtracting the value of electricity generated at $0.043 per KwH. Adding an aerobic biofilter for converting some of the ammonia to nitrate added $11.20/1,000 pounds SSLW per year. These cost estimates are based on the actual Barham farm system and invoices, and are lower than the standardized costs developed for a similar-sized farm in the study.

Additional information on costs and other information about anaerobic digesters on U.S. livestock production facilities is available in NRCS Technical Note No. 1 (NRCS, 2007).

Table. 2. Conversion factors used in calculations of Steady-State Live Weight (SSLW)[1].

Type of operation	Pounds per head
Farrow-to-finish	1,417[2]
Farrow-to-feeder	522[2]
Farrow-to-wean	433[2]
Wean-to-feeder	30
Feeder-to-finish	135
Gilt	150
Boar – stud	400

[1]Taken from NRCS Conservation Practice Standard Waste Treatment Lagoon No. Code 359. http://efotg.nrcs.usda.gov/references/public/NC/NC359WTLJul08.pdf

[2]Per sow.

Summary

Information on biogas production from covered anaerobic lagoons and earthen digesters in North Carolina is limited. NRCS has set a Conservation Practice Standard for the ambient-temperature anaerobic digester, but biogas production is not estimated. The only covered digester with a full year of data in N.C. reported, for a 4,000 sow farrow-to-wean farm, a biogas production range of < 10,000 ft^3/d to > 70,000 ft^3/d, and averaged 33,000 ft^3/d with 63.7 percent methane over a one-year period. Data for fixed-film digesters for swine manure is limited to lab data at this point. Request technical assistance to determine the appropriate type of digester and the digester design for a specific site.

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