The Use of Anaerobic Digestion Systems to Mitigate Air Emissions from U.S. Livestock Production Facilities

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Species: Dairy, Swine, Poultry, Beef
Use Area: Manure Treatment
Technology Category: Anaerobic Digestion
Air Mitigated Pollutants: Odor, Methane, Hydrogen Sulfide

Description:

Liquid manure stored in open tanks, pits, ponds or lagoons will generate and release methane, hydrogen sulfide, and odor emissions. Anaerobic digestion (AD) systems reduce these emissions by generating and capturing biogas (which contains methane and hydrogen sulfide) as well as odor and ammonia that would normally be released to the atmosphere form an uncovered manure storage system. The methane, odor and trace amounts of other gases generated from the digested manure are collected as biogas, and the captured biogas can be combusted to produce heat or electrical power. Anaerobic digestion provides multiple environmental benefits including:

- Odor reduction
- Greenhouse gas emission reduction
- Production of a renewable energy source (biogas)

The biogas production efficiency of an anaerobic digestion system varies based upon digester type and design, manure type and amount, bedding material, and dilution water. Theoretical biogas production calculated for dairy, beef, swine and poultry is 1.9, 0.4, 0.2, 0.01m^3 of biogas/animal/day respectively (USDA NRCS, 2007). These values assume a 30% digester efficiency for dairy and beef manures, a 60% conversion efficiency for swine manure and a 70% conversion efficiency for poultry manure. Anaerobic digester system cost is variable dependent upon digester type and farm-specific conditions. Based on an analysis of 38 AD systems in the USDA NRCS Technical Note 1; *An Analysis of Energy Production Costs from Anaerobic Digestion Systems on U.S. Livestock Production Facilities*, published in 2007, one-third (1/3) of the system capital costs are associated electrical generation equipment. This analysis also suggests that it can be difficult for an anaerobic digestion system to provide any rate of return if electrical power is produced and sold back to the grid at wholesale power rates of around 3 cents per kilowatt hour. This same study concluded however that based on an analysis of 38 AD systems in the US, that an AD system appears to be economically feasible without subsidization when the biogas produced can be utilized for on-site heating without excessive gas cleaning costs.

Mitigation Mechanism:

For certain livestock operations, large amounts of stored manure result in odor that can create a nuisance for neighbors and greenhouse gas emissions that contribute to global warming. Odor, as well as methane, a greenhouse gas twenty-one times more effective than carbon dioxide at trapping heat in the atmosphere, forms under anaerobic conditions when manure is stored. Anaerobic digesters collect gases generated by manure during the anaerobic digestion process and route the odor and other trace gases along with the biogas to be combusted. The biogas and other collected gases are either flared or combusted as fuel in either a boiler, reciprocating internal combustion engine or a micro-turbine. Essentially, the system produces bioenergy from manure by generating and capturing methane produced by the digestion process. Manure is fed into the digester either by gravity flow or pumped from a collection sump into the digester. The manure undergoes digestion in a closed chamber for a hydraulic retention time period typically ranging from 20 - 60 days depending on the type of digestion system used. During this time bacteria break long-chain compounds into shorter chain compounds through hydrolysis, and these shorter chain compounds are in turn converted to volatile fatty acids during fermentation and finally the volatile fatty acids are converted to methane by methanogenic bacteria. The biogas collected from the top of the digester is flared or used for power. The digested effluent is discharged and used as a crop nutrient source, since the anaerobic digestion process does not remove manure nutrients. Following anaerobic digestion, the effluent will remain relatively odor free. The use of a manure anaerobic digestion system will reduce odor emissions from both the manure storage and land application process.

Applicability:

Anaerobic digesters have traditionally been utilized with liquid manure slurries. A variety of system types are available that are suited for different manure types and thus different animal species and production systems. Digesters have a better chance of providing an economic return if they combine income from various system outputs including utilization of the biogas, digested solids, effluent, and carbon credits.

The following types of anaerobic digesters have been demonstrated to work with animal manures to date.

Anaerobic sequencing batch reactor (ASBR) – An anaerobic digester configuration that is operated in a four-step batch mode. These steps are: 1) fill, 2) react, 3) settle, and 4) decant.

Continually stirred tank reactor (CSTR) - An anaerobic digester configuration where the system is continuously mixed and the manure in the digester is uniformly distributed. This digester type is also known as a Complete Mix system.

Covered anaerobic lagoon - Earthen structures, that may or may not include heat addition, designed to collect biogas produced from stored animal manures. These systems may use full or partial covers. A partial cover allows for biogas collection from the majority of the lagoon surface area while maintaining a simple system to allow collected rainwater to be drained from the covered area

Fixed-film digester - An anaerobic digester configuration where anaerobic microbes (biomass) are grown on a fixed structure within the digester. This digester configuration has excellent biomass retention and can therefore be operated at low hydraulic retention times. Manure contacts biomass attached to a structural surface in the reactor when it flows through the reactor. These systems are also known as Anaerobic Filters and may be designed to operate in either an upflow or down flow mode.

Induced blanket reactor (IBR) - An anaerobic digester contact process that uses a layer (called a blanket) of anaerobic biomass to digest manure as it moves through the digester.

Mixed digester - An anaerobic digester configuration where mixing occurs, but where the system is not continuously mixed as in a Complete Mix (or CSTR) system.

Plug-flow digester - A manure anaerobic digester configuration that typically uses a concrete horizontal tank with a flexible gas collection cover. Manure is pumped into one end of the digester and is displaced down the digester where it exits at the far end. A high solids manure is required to achieve plug-flow (no mixing) conditions within the digester. Plug-flow systems are commonly used with scrape collected dairy manures.

Upflow anaerobic sludge blanket digesters (UASB) - An anaerobic digester design that passes influent through a granulated sludge bed. This bed is composed of anaerobic micro-organisms (biomass) that digest the substrate as it passes through the bed.

System types that have been successfully integrated on multiple livestock operations to date include covered anaerobic lagoons, plug-flow digesters, and continually stirred tank reactors (mixed digesters).

Limitations:

Anaerobic manure digesters have a high capital cost when compared to tradition manure storage systems. Given the capital cost and the wholesale electricity rate usually received for excess power produced by a manure digester used to generate electrical power, it may not be possible to receive an economic return from an anaerobic digester based on power sales alone.

Methane, a colorless and odorless gas, is flammable. When exposed to air, biogas can be highly explosive depending on the methane concentration of the biogas. The AD system should be checked periodically for leaks. Safety precautions should be taken including the use of adequate flame traps and pressure reducers on biogas delivery lines.

Historically a large percentage of manure digesters installed in the US have not remained operational. In the past, poor system design, improper system installation, and unsatisfactory system management have been identified as reasons for the high percentage of manure digesters that are no longer operational (Lusk, 1998). A farm considering the installation of an anaerobic digestion system should be aware of the substantial capital costs, management and technical expertise needed to operate an AD system, and potential safety issues with handling flammable biogas (Jones, Nye, and Dale 1980). If a farm intends to sell the power generated to a utility provider, an analysis to examine the economic feasibility of such a venture should be undertaken.

Cost:

An economic analysis of 38 manure anaerobic digestion system installations is provided in USDA NRCS, 2007. The analysis is based on cost data available for specific anaerobic digestion systems that had been installed in the US over the last decade. For the 38 systems included in the analysis the capital cost adjusted to 2006 dollars for a covered lagoon anaerobic digestion system ranged from $88,000 to $162,000, and for plug flow anaerobic digestion systems cost ranged from $69,000- $603,000. The majority of the systems included in the analysis (19 of 38) were dairy plug flow anaerobic digestion systems. The average per head cost for the dairy plug flow systems was $543 per cow in 2006 dollars. These costs do not include an estimate for operation and maintenance costs, which was calculated as ranging from approximately 2-7% of the total capitol costs of the digester and generator set. Furthermore, the analysis concludes that approximately 36 percent of the total capital cost is associated with electrical generation equipment. Initial capital costs of electrical generation equipment ranged from $114,000 to $326,000 for the 38 case studies reviewed. The majority of anaerobic digestion system operation and maintenance (O&M) costs are associated with the electrical generation equipment (Kramer 2002). More information concerning electricity and biogas production costs for digester type by species is provided in USDA NRCS, 2007.

Implementation:

The installation of a manure anaerobic digestion system on a U.S. farm typically requires a significant capital expenditure. As of this writing (2008) manure anaerobic systems do not appear to be economically feasible for power production alone. The return from electrical power generated from biogas combustion will typically not provide enough revenue to provide a positive return on the capital investment. When the total benefits of an anaerobic digestion system, such as odor control, carbon credit sales, power and or heat generation, are combined however anaerobic digestion systems can provide a positive return for some farms.

After implementation, data to record and measure the performance of the AD system as instructed in *A Protocol for Quantifying and Reporting the Performance of Anaerobic Digestion Systems for Livestock Manures* (Martin, 2007) will lead to a better understanding of the long-term performance of anaerobic digestion systems.

Technology Summary:

Manure anaerobic digestion systems provide excellent odor control from manure storage and land application areas when manure is digested prior to these activities. In addition to odor control, anaerobic digesters also reduce greenhouse gas emissions when compared to conventional uncovered manure storage. The digestion process produces biogas which contains approximately 65% methane as biogas, and the captured biogas can bee combusted to produce heat or electrical power. Anaerobic digesters do not reduce nutrients however, so the same land requirement for nutrient management planning will remain after the installation of an anaerobic digester.

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Additional Resources:

Jones, D.D., J.C. Nye, and A.C. Dale. 1980. Methane generation from livestock waste. Publication #AE–105. Purdue University Cooperative Extension Service, West Lafayette, IN. 15 p.
http://pasture.ecn.purdue.edu/%7Eepados/swine/pubs/methane.htm

Martin, J.H. 2007. A Protocol for Quantifying and Reporting the Performance of Anaerobic Digestion Systems for Livestock Manures. Hall Associates, Georgetown, DE.
http://www.epa.gov/agstar/resources/protocol.html

Midwest Rural Energy Council (MREC) Anaerobic Digestion and Biogas Website
http://www.mrec.org/anaerobicdigestion.html

U.S. Department of Agriculture. Natural Resources Conservation Service. 2003. Anaerobic Digester, Ambient & Controlled Temperature Practice Standard 365/366. National Handbook of Conservation Practices.
http://www.nrcs.usda.gov/Technical/Standards/nhcp.html

U.S. Department of Agriculture. Natural Resources Conservation Service. 2007. TN210.BIME.1. An Analysis of Energy Production Costs from Anaerobic Digestion Systems on U.S. Livestock Production Facilities.
http://directives.sc.egov.usda.gov/viewDirective.aspx?id=3551

U.S. Department of Energy. A Consumer’s Guide to Energy Efficiency and Renewable Energy
http://www.eere.energy.gov/consumer/your_workplace/farms_ranches/index.cfm/mytopic=30002

References

Jones, D.D., J.C. Nye, and A.C. Dale. 1980. Methane generation from livestock waste. Publication #AE–105. Purdue University Cooperative Extension Service, West Lafayette, IN. 15 p. *http://pasture.ecn.purdue.edu/%7Eepados/swine/pubs/methane.htm*

Kramer, J.M. 2002. Agricultural biogas casebook. Resource Strategies, Inc. Madison, WI.

Lusk, P. 1998. Methane recovery from animal manures: a current opportunities casebook. 3rd Edition. NREL/SR–25145. Golden, CO: National Renewable Energy Laboratory. Work performed by Resource Development Associates, Washington, DC.

Martin, J.H. 2007. A Protocol for Quantifying and Reporting the Performance of Anaerobic Digestion Systems for Livestock Manures. Hall Associates, Georgetown, DE.

U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001. Global Change Program, Office, Office of the Chief Economist, U.S. Department of Agriculture. Technical Bulletin No. 1907. 164 pp. March 2004.

U.S. Department of Agriculture. Natural Resources Conservation Service (NRCS). 2007. TN 210-8 An Analysis of Energy Production Costs from Manure Anaerobic Digestion Systems on U.S. Livestock Production Facilities.

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