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Basics of Energy Production through Anaerobic Digestion of Livestock Manure

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Introduction

Bioenergy generated from diversified sources provides local and emerging opportunities to reduce our dependence on foreign oil and petroleum-based fuels. Livestock manure from concentrated livestock operations can be a source of energy production that not only provides an alternative energy source for on-farm use, but mitigates the negative consequences of odor from livestock operations. Biogas generated from manure can be used directly in a gas-fired combustion engine or a microturbine to create electricity. Additional energy in the form of waste heat from turbine operations can be used to provide heat or hot water for on-farm use, as well as maintain the temperature of a digester during a cold winter.

The Anaerobic Digestion Process

Anaerobic Digestion (AD) occurs when organic material decomposes biologically in the absence of oxygen. This process releases biogas while converting an unstable, pathogen-rich, nutrient-rich organic substrate like manure into a more stable and nutrient-rich material with a reduced pathogen load (Fig. 1). Biogas is composed of approximately 65% methane with the remaining content being mostly carbon dioxide and other trace gases (Jones, 1980). The left over, more stable substrate can be a good source of fertilizer, or in some cases, further composted and reused as a bedding material.

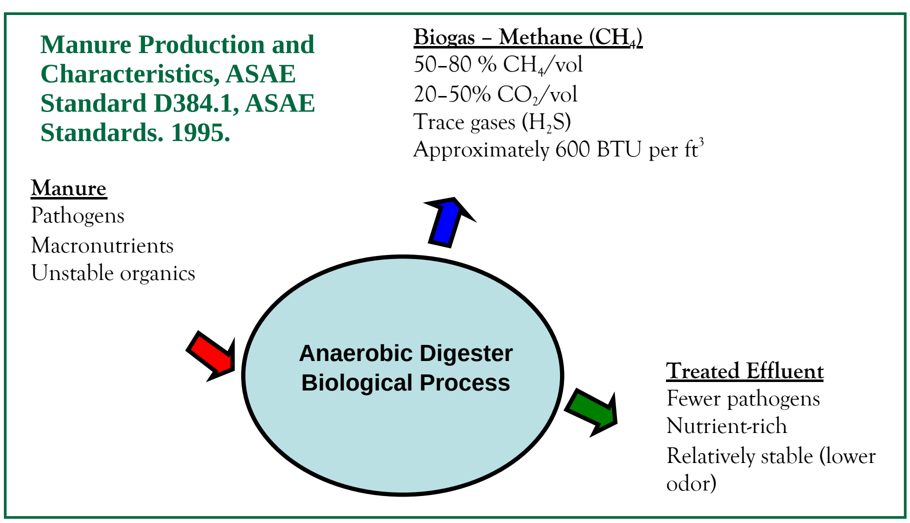

Figure 1. *Schematic of basic process of anaerobic digestion (after Robert T. Burns, Iowa State University)*

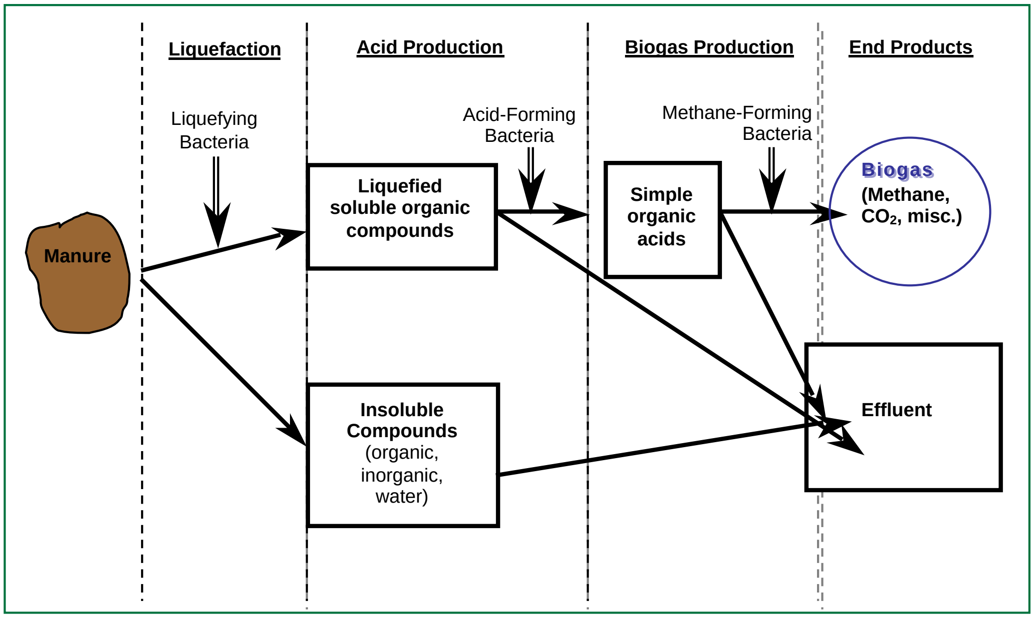

Figure 2. *Schematic of the anaerobic digestion process*

Two anaerobic reactors (foreground) showing flexible covers to collect gas as part of a community AD system in Juehnde in Southern Lower Saxony, Germany. Also shown: housing for an electric generation set and an underground mixing tank.

Piping for transporting digested liquid manure effluent from the AD reactor to an open lagoon on a farm in Oregon.

An anaerobic digester is the unit of operation used to produce methane from manure. Figure 2 is a schematic that shows the anaerobic digestion process. In an anaerobic digester, the organic substrate is first liquefied by bacteria. This is followed by a two-step process involving acid production by acid-forming bacteria (acidogenesis) and methane production from the acids with methane-forming bacteria (methanogenesis). In most cases, after digestion the effluent can be relatively easily separated into solid and liquid fractions. In the case of dairy cows, the solid fraction may be used as recycled bedding, and the rest of the digested material may be land-applied at the agronomic rate to meet the soil and crop needs. The biochemical methane potential (BMP) of manure varies by livestock species and is a measure of the methane production potential of the manure. Production is measured as cubic feet of methane gas per animal unit (AU). An animal unit, as defined by the ASABE Standard, is based on 1000 live weight of the livestock. (*ASABE Standards*, 2005).

Table 1 shows the BMP of some common livestock waste streams. In addition to livestock waste, residue from nearby food processing has been effectively utilized within the anaerobic digester system to boost methane production. This included high-starch or high-fat content materials.

Anaerobic digesters can be categorized based on (1) the operating temperature of the AD unit and (2) the AD unit process design. The latter allows either separate acidogenesis and methanogenesis reaction or mixed acidogenesis and methanogenesis reactions. These temperature ranges

Table 1. *Characteristics and Operational Parameters of the Most Important Agricultural Feedstocks for Anaerobic Digestion*

Feedstock	Total Solids TS (%)	Volatile Solids (% if TS)	C:N Ratio	Biogas Yield [c] (m^3, kg^{-1} VS)	Retention Time (days)	CH_4 Content (%)	Unwanted Substances	Inhibiting Substances	Frequent Problems	References
Pig Slurry	3 – 8 [d]	70 – 80	3 – 10	0.25 – 0.50	20 – 40	70 – 80	Wood shavings, bristles, $H_2$0, sand, cords, straw	Antibiotics, disinfectants	Scum layers, sediments	2, 3, 11, 13
Cow Slurry	5 – 12 [d]	75 – 85	6 – 20 [a]	0.20 – 0.30	20 – 30	55 – 75	Bristles, soil, $H_2$0, NH_4+, straw, wood	Antibiotics, disinfectants	Scum layers, poor biogas yield	2, 3, 11, 13
Chicken Slurry	10 – 30 [d]	70 – 80	3 – 10	0.35 – 0.60	> 30	60 – 80	NH_4+, grit, sand, feathers	Antibiotics, disinfectants	NH_4+-inhibition, scum layers	2, 7
Whey	1 – 5	80 – 95	n.a.	0.80 – 0.95	3 – 10	60 – 80	Transpiration impurities		pH – reduction	2, 11
Fermented Slops	1 – 5	80 – 95	4 – 10	0.35 – 0.55	3 – 10	55 – 75	Undegradable fruit remains		High acid concentration, VFA-inhibition	2, 11
Leaves	80	90	30 – 80	0.10 – 0.30 [b]	8 – 20	n.a.	Soil	Pesticides		2, 11
Wood Shavings	80	95	511	n.a.	n.a.	n.a.	Unwanted material		Mechanical problems	2, 11
Straw	70	90	90	0.35 – 0.45 [e]	10 – 50 [e]	n.a.	Sand, grit		Scum layers, poor digestion	2, 11
Wood Wastes	60 – 70	99.6	723	n.a.	n.a.	n.a.	Unwanted material		Poor anaerobic biodegradation	2, 11
Garden Wastes	60 – 70	90	100 – 150	0.20 – 0.50	8 – 30	n.a.	Soil, cellulosic components	Pesticides	Poor degradation of cellulosic components	2, 11
Grass	20 – 25	90	12 – 25	0.55	10	n.a.	Grit	Pesticides	pH reduction	2, 11
Grass Silage	15 – 25	90	10 – 25	0.56	10	n.a.	Grit		pH reduction	2, 11
Fruit Wastes	15 – 20	75	35	0.25 – 0.50	8 – 20	n.a.	Undegradable fruit remains, grit	Pesticides	pH reduction	2
Food Remains	10	80	n.a.	0.50 – 0.60	10 – 20	70 – 80	Bones, plastic material	Disinfectants	Sediments, mechanical problems	9

[a]Depending on straw addition; [b]depending on drying rate; [c]depending on retention time; [d]depending on dilution; [e]depending on particle size; n.a.= not available

***Table 2.** Summary of the characteristics of digester technologies.*

Characteristics	Covered Lagoon	Complete Mix	Plug Flow	Fixed Film
Digestion Vessel	Deep lagoon	Round/Square in-/ above-ground tank	Rectangular in-ground tank	Above-ground tank
Level of Technology	Low	Medium	Low	Medium
Supplemental Heat	No	Yes	Yes	No
Total Solids	0.5 – 3%	3 – 10%	11 – 13%	3%
Solids Characteristics	Fine	Coarse	Coarse	Very fine
HRT* Days	40 – 60	15+	15+	2 – 3
Farm Type	Dairy, hog	Dairy, hog	Dairy only	Dairy, hog
Optimum Location	Temperate and warm climates	All climates	All climates	Temperate and warm climates

** Hydraulic Retention Time (HRT) is the average number of days a volume of manure remains in the digester.*

U.S. EPA AgSTAR Handbook, 2007

are identified as psychrophilic (68°F, 20°C), mesophilic (95–105°F, 35–41°C) and thermophilic (125–135°F, 52–57°C). The pH levels of the digester environment should be maintained as close to neutral (pH 7.0) as possible (Jones, 1980). There are a number of process designs currently used to digest livestock manure. The technologies listed below range from the very simple (covered lagoon) to more complicated in an upflow anaerobic sludge bed (UASB). However, most on-farm unit digesters use the simpler systems listed below (usually 1, 2 or 4):

1. Covered lagoons
2. Plug-flow digesters
3. Mixed plug-flow digesters
4. Complete-mixed digesters
5. Fixed-film digesters
6. Temperature-phased anaerobic digesters
7. Anaerobic sequencing-batch reactor (ASBR)
8. Upflow anaerobic sludge bed (UASB)

The components of the typical anaerobic digestion system include: manure collection, anaerobic digester, effluent storage, gas handling, and gas use/electricity generating equipment. In some cases, the gases produced are simply flared off into the atmosphere. The advantages of each system are dependent upon several variables within the livestock operation. Table 2 summarizes the characteristics of four common AD technologies used in livestock operations.

Benefits of Anaerobic Digestion

In a study commissioned by the Great Lakes Regional Biomass Energy Program, the following benefits were documented for dairy operations (Kramer, 2004):

- Revenue from annual electricity sales or cost offsets generated $32–$78 per head.*
- Annual bedding costs were reduced by using digested manure instead of other bedding materials.
- After digestion, manure has improved nutrient availability, reduced acidity, and reduced odor. By avoiding fertilizer purchases, producers saved $41–$60 per head (from dairy cattle).
- Odor control is a key benefit in being a better neighbor. It increased quality of life on and off the farm, helped producers avoid complaints and lawsuits, allowed continuation of the operation or the ability to site new facilities, and increased operational flexibility.
- Anaerobic digestion reduced pathogens associated with manure discharges (Mosier, 1998).

**Resale of electricity depends on state and utility policies.*

What Makes an Operation Appropriate for Anaerobic Digestion?

When considering an on-farm anaerobic digestion facility, careful planning must include an understanding of key variables. The following checklist should benefit the initial

Electric generation unit showing piping for recovering heat that is used to heat up the AD reactor.

process of identifying the feasibility of installing this system on-farm (U.S. EPA AgSTAR, 2007):

- Is the operation a confined feeding operation with at least 500 head of dairy/beef cattle or 2,000 sows/feeder pigs?*
- Is 90% of the manure collected regularly?
- Is manure production and collection stable year-round?
- To be compatible with biogas energy production, is manure managed as liquid, slurry, or semi-solid?
- Is manure free of bedding in the form of sand or other materials such as rocks?
- Is there a ready use for energy recovered on-farm (heat, ventilation fans, etc.)?
- Can the operator manage the system with regular attention, repairs and maintenance, and do they have the desire to see that the system runs successfully?
- Can the livestock production system be modified to add relatively fresh manure to the digester, and store the digested manure?
- Safety is always an important concern when selling excess electricity to the utility grid. Specific wiring considerations are necessary to prevent electrocution during times when power lines are down. Biogas should also be handled with extreme caution.

Control panel for biogas monitoring.

** Note: This will be dependent on state and utility policies on purchasing energy produced on-farm. In some states, the rate is at or near the retail value of electricity, while in other states, there is no state-level policy. At the time of this publication, most states (Indiana included) do not have a requirement that utilities purchase farm-generated electricity.*

Conclusion

Anaerobic digestion of livestock manure is an alternative pathway for managing large organic waste loads and its associated problems encountered in large feeding lots and confined animal feeding operations (CAFOs). When planned correctly, AD can result in revenue from energy sales or savings in on-farm energy generation. Even though AD is not a new technology, its practice on U.S. farms is not common and requires careful planning and implementation in order to reap its benefits. Overall, AD technologies can help preserve and integrate livestock production within communities and creates renewable energy resources to serve a growing bioeconomy within rural communities.

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