MANURE PROCESSING
for Farm Sustainability

Biological Systems Engineering
COLLEGE OF AGRICULTURAL & LIFE SCIENCES
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Manure Processing Fact Sheet Series

Anaerobic Digestion from Animal Manure

Introduction

Anaerobic digestion (AD) is the process in which microorganisms degrade organic feedstocks to produce biogas and digestate in the absence of oxygen. Biogas is valued for its energy content in the form of methane, the main component of biogas (**Figure 1**). Digestate, the degraded organic material remaining after the digestion process, contains nutrients and reduced odor, pathogens and antibiotic content as a result of the high temperatures in the digester. Optimal temperatures occur between 50-60°F (thermophilic) or 30-38°C (mesophilic). Feedstocks (in this case manure) contains volatile solids, many of which are destroyed during digestion, and nitrogen, that is mineralized from organic nitrogen to ammoniacal nitrogen in the digestion process. Reduced volatile solids in the digestate can reduce greenhouse (GHG) emissions in the form of methane from downstream manure storage. However, the increased ammoniacal nitrogen can increase downstream ammonia emissions during storage and land application if mitigation measures (e.g., storage covers, injection) are not implemented.

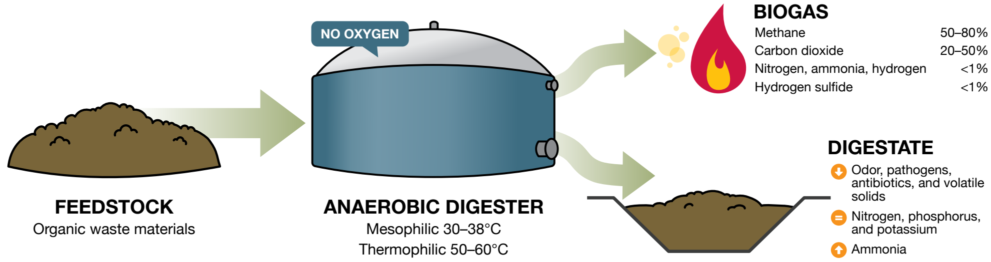

Figure 1. Characteristics of the anaerobic digestion process, outputs.

Manure is among the lowest methane yielding feedstocks in digesters (**Figure 2**), but it is widely used in agricultural AD systems due to its continuous availability in one location, its capacity to resist changes in pH, and its relatively easy integration into existing manure management systems. The AgSTAR program, a cooperative effort among the US Department of Agriculture (USDA) and the US Environmental Protection Agency (EPA), presents comprehensive and detailed information about agricultural AD systems in the US and aspects to consider when planning, building and operating these systems (AgSTAR-EPA 2021).

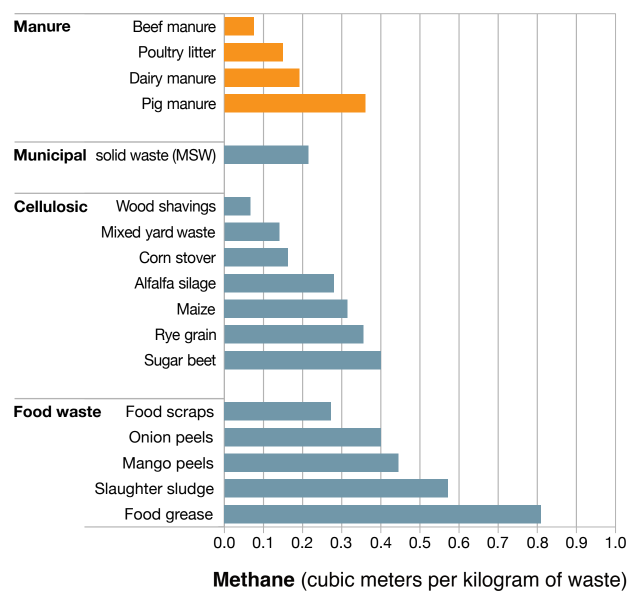

Figure 2. Methane yield per kilogram of dry material of some common organic inputs to produce energy (Adapted from Moody et al. 2011 and Appels et al. 2011).

Technology Basics

A digester, or reactor, is a sealed container that can be flexible in design to adapt and respond to the needs of the farm providing the feedstock. Some of the most popular designs that increase in complexity and cost are covered lagoons, plug-flow, and complete mix digesters (**Figure 3**). Covered anaerobic lagoons use a sealed flexible cover to trap the produced biogas and store the digestate in a single cell or have additional cells to store the digestate. Plug-flow and mixed plug-flow digesters are generally constructed partially or fully below grade to reduce heating needs. These digesters have flexible or rigid covers and are designed so that manure flows through the digester entering in one side and exiting in the opposite side. Plug-flows are popular on dairy farms as they have a defined flow path with increased control over hydraulic retention time that can be important in pathogen destruction. Complete mixed digesters are generally above grade, enclosed heated tanks that use mixing devices to increase the exposure of the feedstock to methane producing bacteria. As a result, these systems work best with liquid and slurry manures.

The AD process starts with the daily collection and transport of manure, along with some organic bedding if used on the farm, to the digester where it typically resides for 5 to 28 days (also known as hydraulic retention time). Sand separation is recommended when sand is used as bedding to prevent buildup and costly maintenance in the digester. It is recommended that manure is transported to the digester from the collection site as often as possible to minimize the holding period, but at a minimum once per day. Given that manure immediately begins to break down after excretion, any delay will reduce the biogas production in the digester. The hydraulic retention time is much shorter for digesters operating at thermophilic temperatures than those operating at mesophilic temperatures. A shorter hydraulic retention time translates to a smaller digester, and lower investment costs. However, digesters operating at thermophilic temperatures require more energy to maintain these high temperatures and can require more management (due to the lower range of thermophilic microorganisms that can reduce stability) resulting in increased operation and maintenance costs. In the US, the majority of the anaerobic digesters operate in the mesophilic range (AgSTAR-EPA 2021).

Figure 3. Types of anaerobic digesters: a) Covered lagoon, b) plug-flow, and c) complete mixed.

Performance

Methane production from manure is highly variable based on multiple factors such as digester type, operating temperatures, manure characteristics, etc. On average, methane production can range from 0.08 m^3/kg dry beef manure to 0.39 m^3/kg dry pig manure (**Figure 2**). To increase biogas production, manure can be supplemented with other organic feedstocks available on-farm (spoiled milk or silage) or transported off-farm (food waste, fats, etc.). This practice of mixing feedstocks is known as co-digestion.

Products

Biogas is produced continuously during the digestion process and either immediately converted to energy or stored for later conversion. Biogas can be directly burned to produce heat for use on-farm, fed to a generator (with a previous cleaning of hydrogen sulfide) to produce electricity exported to the grid, cleaned and injected into the natural gas grid, or cleaned and compressed to be used as a transportation fuel. Most of the existing agricultural AD systems in the US generate electricity for the grid, but new projects are almost entirely targeting renewable natural gas (RNG) production. This trend is driven mostly by the economic incentives from both the Renewable Fuel Standard (RFS) and the California Low Carbon Fuel Standard (projects in other states can qualify for this credit if they are connected to the same gas grid as CA), which can range from 40 to 70$/MMBtu.

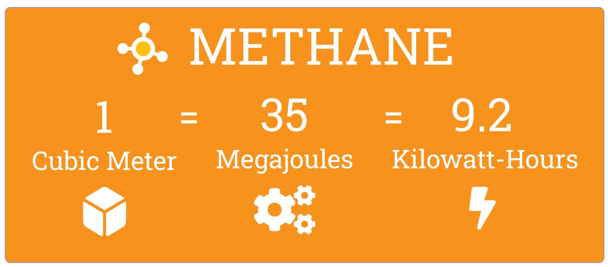

Figure 4. Energy values of methane.

Digestate, the effluent from the digester, is most commonly separated through a mechanical separation system to add value and flexibility while managing digestate. The AD process increases conversion of nitrogen from organic to its inorganic forms, which are more available for crop uptake and the reason why separated liquid digestate is generally land applied as a fertilizer. The liquid fraction can be transported more efficiently and economically through pumps due to reduced solids and nutrient content. With less moisture and a higher nutrient concentration the solid fraction can be land-applied on-farm, transported for use on other farms, or used as bedding for cows due to the reduction of pathogens during the digestion process (Burch et al. 2018).

Cost

Capital costs required to install an AD system can vary significantly based on the digester design, size, and additional technologies used for management of products (e.g. generator, solid-liquid separator). Average capital costs for complete plug-flow and complete mix AD systems can range from $1,000 to $2,000 per cow with real dairy cow systems reporting cost going from $1.2 million for a 700-cow farm to $2.7 million for a 2,800-cow farm with costs to maintain an electricity generator alone representing $0.015 to $0.02 per kWh (Lazarus 2019).

More recently, Cowley et al. (2019) reported capital investments of $2.1 million ($400 per hog) and variable costs of $60,000 for 5,250-head hog operations using anaerobic digesters with electricity production compared to capital investments of $1 million ($200 per hog) and variable costs of $55,000 for 5,000-head hog operations with covered lagoons also producing electricity. Total operation and maintenance costs can range from 2 to 7% of these costs (USDA-NRCS 2007). Economies of scale limit the feasibility of these systems to downscale. Covered lagoons are cheaper, averaging $0.05 to $0.11 per kWh + $3.82 per MWh for O&M costs (USDA-NRCS 2007), but their methane production is also lower.

Environmental Benefits and Trade-Offs

Methane is a valuable fuel (**Figure 4**), but also a GHG that is 28 times more potent than carbon dioxide (Myhre et al. 2013). AD can reduce the impact to climate change by promoting and capturing methane produced from manure, compared to methane losses to the atmosphere from simply storage. After digestion, biogas combustion produces biogenic carbon dioxide, which is part of the carbon cycle. This reduction comes from the destruction of most of the degradable volatile solids in manure, which are responsible for methane emissions during storage. The destruction of volatile solids in real life AD systems can range from 16%–31% in farms only processing manure to 59% in farms with co-digestion (Aguirre-Villegas, Larson, and Sharara 2019). GHG emissions from manure storage, handling, and processing can be reduced by more than 50% when integrating an AD system (Aguirre-Villegas, Larson, and Reinemann 2014). Moreover, if renewable energy from biogas replaces the production and combustion of fossil fuels, the credits from the avoided fossil-based emissions can make the farm a net sink of GHG emissions depending on the AD system size (Aguirre-Villegas and Larson 2017). However, the AD process converts some of the organic nitrogen to its inorganic form, which more easily volatilized as ammonia. Total ammoniacal nitrogen is increased by 6% in digesters only processing manure and up to 150% in co-digestion systems (Aguirre-Villegas, Larson, and Sharara 2019). A cover during manure storage and injection or rapid incorporation of manure are effective strategies to reduce ammonia volatilization. Other benefits from AD including reducing odor, pathogens, and antibiotics.

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