

# THE IMPACT OF DAIRY HOUSING AND MANURE MANAGEMENT ON ANAEROBIC DIGESTION

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- Differences in manure characteristics and biogas potential from different housing systems
- How these characteristics affect digester technology selection

The Impact of Dairy Housing and Manure Management on Anaerobic Digestion

## ABSTRACT

When considering the development of an anaerobic digester system, it is important to understand how differences in dairy housing and manure management impact manure characteristics and biogas potential. Two common dairy housing practices suitable for anaerobic digestion are freestall barns and open or dry lot. Manure collection and conveyance practices with these housing systems range from daily to weekly collection using scrape, scrape-flush or flush. Bedding type and usage as well as climactic conditions are factors that should also be taken into account during planning. Differences in these systems influence the availability and digestibility of the dairy manure as well as the appropriateness of various digester technologies.

Utilizing a pool of data from dairy manure samples submitted to the Michigan State University Anaerobic Digestion Research and Education Center (ADREC) over the past several years, manure solids characteristics from the various systems will be presented. Measured biogas and methane production data from biogas assays conducted at the ADREC will also be evaluated. Based on the characterization and biogas potential information, the discussion will focus on the challenges of digesting manure from various dairy housing systems and the appropriateness of different digester technologies.

**Keywords:** anaerobic digestion; dairy housing; biogas potential, manure characteristics

## INTRODUCTION

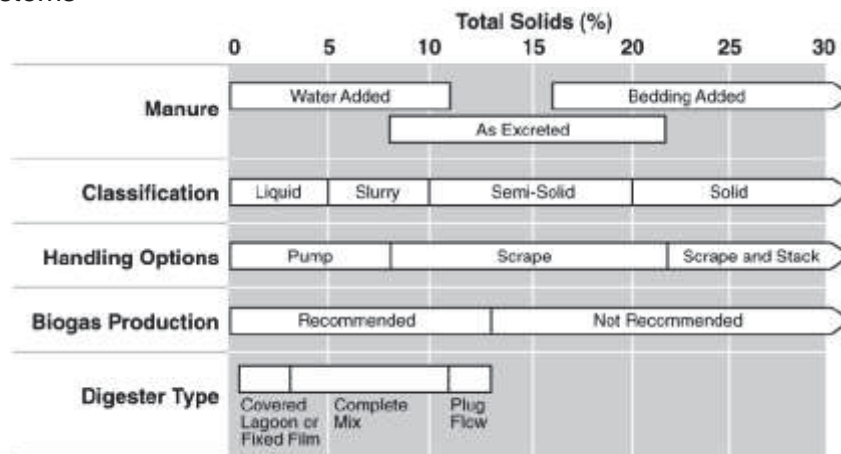
The solids content of dairy manure varies from farm to farm based on the type of housing, manure collection practice, bedding usage and environmental conditions. The American Society of Agricultural and Biological Engineers (ASABE) and Midwest Plan Service (MWPS) have published “as excreted” or fresh manure characteristic data which provides a starting point for conceptual design and business plan development for an anaerobic digester project<sup>1,2</sup>. Table 1 summarizes the basic manure solids data from ASABE in terms of total solids (TS), volatile solids (VS), fixed solids (FS) for a lactating dairy cow.

Table 1. ASABE manure characteristics<sup>1</sup>

| Description           | TS   | VS   | FS  | VS : TS |
|-----------------------|------|------|-----|---------|
|                       | (%)  | (%)  | (%) | (%)     |
| Dairy - lactating cow | 13.3 | 11.3 | 2.0 | 85.0    |

Manure is a mix of water, undigested solids, gut microflora and their metabolic byproducts<sup>3</sup>. The characteristics of “as excreted” manure are useful for initial planning, however it does not describe the site-specific nature of the manure needed for full design of an anaerobic digestion system. During the collection, manure from barn floor or lot is mixed with other material including urine, bedding, feed and water from drinkers or precipitation, resulting in a feedstock with different solids characteristics compared to “as excreted” manure. The composition of the manure as collected is critical in determining the appropriate handling options and digester technology as shown in Figure 1.

Figure 1: Manure Handling Practices Affect the Feasibility and Choice of Biogas Digester Systems<sup>4</sup>



<sup>1</sup> ASABE. 2005. Manure Production and Characteristics. ASAE D384.2 MAR2005

<sup>2</sup> MidWest Plan Service (MWPS). 2000. Manure Characteristics. MWPS-18, Section 1.

<sup>3</sup> Wilkie, A.C. 2005. Anaerobic Digestion of Dairy Manure: Design and Process Considerations. NRAES 176: 301-312.

<sup>4</sup> EPA AgSTAR. 2004. Market Opportunities for Biogas Recovery Systems; A Guide to Identifying Candidates for On-Farm and Centralized Systems

Figure 1 provides general guidance for a few digester technologies based on the TS concentration of the feedstock. The TS concentration of manure is a key selection factor for appropriate digester technology because it impacts both the material handling and ability to mix the manure<sup>5</sup>. In Table 2, the acceptable ranges for organic loading rate (OLR), hydraulic retention time (HRT) and TS are shown for several common digester systems used with dairy manure feedstock. Organic loading rate is a design feeding range for organic matter, measured as VS or chemical oxygen demand (COD), intended to maintain biological health and maximize biogas production. Hydraulic retention time is the theoretical time which the fluid or slurry remains in the anaerobic digester.

Table 2: Design Parameters for Common Anaerobic Digestion Technologies<sup>6</sup>

| AD System                 | OLR                        | HRT  | TS range |
|---------------------------|----------------------------|------|----------|
|                           | (kg COD/m <sup>3</sup> /d) | (d)  | (%)      |
| Covered lagoon            | < 0.20                     | > 40 | 0.5 - 3  |
| Plug-flow                 | 1 - 6                      | > 15 | 11 - 13  |
| Complete mix              | 1 - 10                     | > 15 | 3 - 10   |
| Fixed-film                | 5 - 10                     | < 5  | 1 - 5    |
| Induced blanket reactor   | 5 - 10                     | < 5  | 6 - 12   |
| Up-flow sludge blanket    | 5 - 10                     | < 5  | < 3      |
| Sequencing batch reactors |                            | < 5  | 2.5 - 8  |

Manure moisture content and bedding usage are two critical factors affected by dairy housing, which influence the design parameters in Table 2 as well as the system volume, heating requirements, flow characteristics and material handling<sup>7</sup>. In addition, the type and quantity of bedding may also contribute to a loss of usable volume and biogas production due to sludge accumulation or the formation of a floating blanket. Obtaining site-specific manure characteristics is critical during the design of an on-farm anaerobic digester to ensure a long term, successful system.

## DAIRY HOUSING AND BEDDING

### Dairy Housing Systems

The most common dairy housing systems in the United States are the freestall barn and the open or dry lots. Freestall housing, which combines the resting and feed areas under roof can be found throughout the country but are most common in the cooler regions or areas with high precipitation. By maintaining the herd under roof, manure is not exposed to direct sunlight and precipitation is excluded. During the collection of

<sup>5</sup> EPA AgSTAR. 2004. A Manual For Developing Biogas Systems at Commercial Farms in the United States. Second Addition.

<sup>6</sup> EPA AgSTAR. 2011. Recovering Value from Waste Anaerobic Digester System Basics

<sup>7</sup> EPA AgSTAR. 2011. Recovering Value from Waste Anaerobic Digester System Basics.

manure, the solids characteristics will change when the “as excreted” manure is mixed with urine, bedding, feed and additional water from drinkers, sprinklers or precipitation<sup>8</sup>. Generally, 100% of the manure is collected from freestall barns daily and available as feedstock.

Open and dry lot housing uses separate areas for cattle feeding, rest and exercise. The open lot typically consists of a large, uncovered dirt or concrete corral, a shaded loafing area and a feed area. Providing a shaded area gives cattle relief from precipitation and heat. While open lot housing is found throughout the country, it is the predominate system used in the dry, southwest. Manure is typically collected and removed from the feed alley and shaded resting area of the lot daily. Similar to freestall housing, manure collected from these areas will be mixed with bedding, feed, urine and water. Collection of manure from the open area will vary from daily to annually depending on environmental conditions and management preferences. Availability of manure for anaerobic digestion will depend on the amount of manure deposited on the concrete alley and the site-specific collection practices. In addition, manure collected from the open lot area may contain large amounts of grit depending on what material is used to construct the lot. Environmental conditions will have a significant impact on the moisture and solids content of the manure from open lot dairies.

While less common, tie-stall and manure pack systems are used on many smaller or older dairy farms. Similar to the freestall barn, the cattle are housed under roof and the manure is not exposed to precipitation or direct sunlight. Less frequent cleaning and greater usage of bedding may result in manure from these systems having a higher TS concentration compared to “as excreted” manure. The higher solids concentration could easily exceed the TS ranges for conventional technologies shown in Table 2 and will require special consideration during planning. Another consideration with manure packs is the potential loss of biogas production potential due to biological activity while the material is stored in place. This natural loss of biogas potential should not be overlooked when planning digestion systems. Similar to freestall housing, 100% of the manure from tie-stall or manure packs should be available for anaerobic digestion once the material is removed from the barn.

## Bedding

Bedding is used in most dairy housing systems to provide a clean, dry and comfortable resting area. Materials used for bedding are divided into two categories; inorganic and organic.

Sand is the most common inorganic bedding material used for dairy bedding. While sand is an ideal bedding for cow comfort, it does contribute a significant mass of FS to the manure stream and does not improve biogas production. Mechanical issues associated with inorganic bedding include premature equipment wear, clogging pipes and loss of digester capacity due to grit or sludge accumulation. Sand manure

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<sup>8</sup> Van Horn, H.H., A.C. Wilke, W.J. Powers, and R.A Nordstedt. 1994. Components of Dairy Manure Management Systems. *Journal of Dairy Science*. 77:2008-030.

separation systems can remove adequate quantities of sand and reduce the mean particle size to residual sand to allow for successful anaerobic digestion. Drawbacks to sand separation include the addition of dilution water which increase volume and the potential loss VS during the sand removal. Generally, the minimum dilution needed to achieve meaningful separation is one part dilution water to one part sand-laden dairy manure (SLDM)<sup>9</sup>. Based on research conducted at a Michigan dairy farm, the VS loss due to sand separation ranged from 10% to 40% depending on the system complexity and management<sup>10</sup>.

Organic bedding options vary depending on regional availability. Common organic bedding materials include wood shavings, sawdust, newspaper, straw or composted/digested/dried manure solids. For digestion, organic bedding poses fewer mechanical challenges and may contribute to biogas production. While there are significantly less FS compared to sand, grit accumulation can be an issue with organic bedding as it does contain some FS.

## MANURE COLLECTION AND CONVEYANCE

### Collection & Conveyance

Traditionally, manure collection and conveyance systems have been classified as scrape (mechanical), flush or a scrape-flush combination. Manure collection is the process of removing manure from the alley, gutter or lot. Conveyance is the movement of manure from the point of collection to the treatment system or storage. Housing practices and environmental conditions are two factors which drive the selection of manure collection and conveyance practices. Scrape collection is common in northern and eastern regions, where cold temperatures and wet conditions are prevalent. Conveyance of scrape manure can be scrape or flush. Flush, or hydraulic, manure collection is common in the warm, dry climates of the south and west, where irrigation is common. With flush systems, typically collection and conveyance are combined into a single process. Both scrape and flush system can be used in either freestall or open lot housing and with both inorganic and organic bedding.

Scrape or mechanical collection involves the physical removal of the manure from the freestall alley using either a blade or tire mounted to a tractor, an automatic scrape driven by a pulley system or a vacuum tank. Scraping manure from alleys results in well-mixed slurry containing anything deposited in the alley (manure, urine, bedding, feed, water from drinkers and other debris). Incorporating the other material deposited on the alley or surface with manure will result in minor changes in the solids make up. A drawback to scrape systems is manure conveyance. Unless the manure storage or treatment system is located adjacent to the manure source, a secondary system will be needed to convey the manure to its final destination. Many variations of conveyance systems exist including tractor scrape, mechanical conveyors (gutter cleaners, augers,

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<sup>9</sup> Wedel, A.W. and W.G. Bickert. 1996. Separating Sand from Sand-Laden Manure: Factors Affecting the Process. Paper No.: 19964016. ASAE, St. Joseph, MI.

<sup>10</sup> Kirk, D.M. 2009. Impact of Sand Manure Separation on Anaerobic Digestion. Ph.D. dissertation.

cable scrapers) or flush flume. Traditional scrape collection and conveyance generally do not result in a loss of VS or a large increase in water content, with the exception of scrape-flush which relies on water to convey manure from the barn.

Flush systems utilize water, recycled or fresh, to scour and collect manure from the freestall alley and convey it to the point of treatment or storage<sup>11</sup>. Similar to scrape systems, any material deposited in the alley or on the barn floor will be incorporated into the manure stream with flush collection. For anaerobic digestion, the addition of water during flush collection is drawback. Flush manure collection systems can use as little as 3,500 gpm for organic bedding to over 10,000 gpm for sand bedded farms to adequately clean the floor<sup>12,13</sup>. The addition of water due to flush collection conveyance can be as high as 220 to 620 gallons per cow per day<sup>9</sup>. This large addition of water may require additional digester volume and heating capacity for successful digestion.

### Manure Characteristics and Biogas Potential

Manure characteristics will vary depending on the type of dairy housing facility, the use of bedding and the manure collection system. Table 3 summarizes manure characteristics data from several different combinations of dairy housing and manure collection. The data provide was collected from raw samples evaluated at the Michigan State University Anaerobic Digestion Research and Education Center (MSU ADREC) between 2006 and 2011.

As shown in Table 3, the “as excreted” manure from both the dry lot and freestall facilities had a slightly higher TS compared to the ASABE values in Table 1. This is due to the fact that sample collection from the freestall barn and dry lot excluded urine (only feces was collected).

Dry lot manure samples in Table 3 were collected from several New Mexico facilities during the late summer and early fall. The increase in TS from the “as excreted” sample to the daily scrape to the weekly scrape is largely due to the addition of bedding and the evaporation of moisture. Daily scrape manure samples were collected from the feed alleys. At the time of collection the dry lot daily scrape samples were mixed with urine, feed, additional water and bedding which was tracked in the alley. Daily scrape samples were collected approximately 6 to 24 hours after the manure was collected from the freestall alley.

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<sup>11</sup> Elder, J.D. and R. Petty. 2003. Flush Systems and Sand. ASAE Publication No. 701P0203. Fifth International Dairy Housing Proceedings. Fort Worth, TX.

<sup>12</sup> Barbari, M., E. Bresci, P. Ferrari and A. Giacomini. 2007. Hydraulic Approach to Flush Systems for Dairy Manure Removal. ASABE Publication Number 701P0507e. Sixth International Dairy Housing Conference Proceeding. Minneapolis, MN.

<sup>13</sup> Harner, J.P., J.P. Murphy, J.F. Smith, M. Brouk, and T.D. Strahm. 2003. Experiences with Handling Sand Laden Dairy Manure Using Gravity. ASAE Publication No. 701P0203. Fifth International Dairy Housing Proceedings. Fort Worth, TX.



Table 3. Average dairy manure solids characteristics for different housing systems<sup>1</sup>

| Dairy Housing System | Bedding             | Manure Collection/Type  | TS   | VS   | FS   | VS : TS |
|----------------------|---------------------|-------------------------|------|------|------|---------|
|                      |                     |                         | (%)  | (%)  | (%)  | (%)     |
| Dry lot              | Dried manure solids | As excreted             | 14.3 | 11.5 | 2.8  | 80.7    |
| Dry lot              | Dried manure solids | Daily scrape            | 21.9 | 15.1 | 6.7  | 69.3    |
| Dry lot              | Dried manure solids | Weekly scrape           | 58.8 | 22.6 | 36.2 | 39.1    |
| Freestall            | Sand                | As excreted             | 15.0 | 12.8 | 2.6  | 85.3    |
| Freestall            | Sand                | Sand laden              | 23.7 | 7.3  | 16.4 | 30.8    |
| Freestall            | Sand                | Sand separator effluent | 5.4  | 3.2  | 4.5  | 59.4    |
| Tiestall             | Wood shavings       | Daily scrape            | 16.3 | 14.3 | 2.1  | 87.3    |

<sup>1</sup>Data from testing completed at the MSU Anaerobic Digestion Research & Education Center

Weekly scrape manure from the dry lot dairies were collected from manure piles that were scraped from the shaded loafing area into the open to facilitate drying. This material was typically allowed to dry for a period of days to weeks before being returned to the shaded area for bedding, resulting in the large increase in TS. During the collection process, the weekly scrape manure was mixed with gravel and other inorganic debris used to create the base of the dry lot increasing the concentration of FS. Aerobic decomposition may also contribute to a loss of VS in the weekly scrape samples, resulting in an increase in the FS concentration<sup>14</sup>.

Numerous samples were collected from sand bedded freestall dairies in the upper Midwest and Northwest. Sand for bedding has a density over 1.5 times greater than manure<sup>15</sup>. The density coupled with the quantity of sand used for bedding, 35 lb of sand for every 1,000 lb of body weight, explain the large increase in TS and FS in the SLDM samples. Due to the mechanical and settling issues associated with SLDM, to date all digesters on sand bedded dairy farms separate sand prior to entering the anaerobic digester. The sand separator effluent samples were collected from mechanical sand separation systems which used recycled liquid manure for dilution.

The tie-stall manure sample was collected from the MSU Dairy Teaching and Research Center. Tie-stall manure at the dairy was mixed with urine, wood shavings bedding and water spilled from drinkers.

In all instances presented in Table 3, the TS increased compared to the baseline “as excreted” manure due to a loss of moisture or the inclusion of bedding. In addition to the consideration of the specific TS, VS and FS concentrations during the planning of a digester it is also important to consider the VS to TS ratio (VS:TS). The VS:TS ratio is an indicator of site specific changes in the manure solids characteristics which will impact the system design and performance. For example, if a systems is designed for a specific OLR, a declining VS:TS ratio suggests that additional feedstock will be needed

<sup>14</sup> Burke, D.A. 2001. Dairy Waste Anaerobic Digestion Handbook. Environmental Energy Company. Olympia, WA.

<sup>15</sup> MidWest Plan Service (MWPS). 2000. Manure Characteristics. MWPS-18, Section 1.

to maintain the design OLR. A VS:TS ratio significantly different than what was used in the design process will impact the OLR, biogas production, hydraulic retention time and many other physical and biological processes.

Biogas potential of manure is based largely on the organic matter (VS) which can be degraded anaerobically. Table 4 contains biogas potential data from the dairy manure of three different dairy housing systems. The biogas potential data based on the initial or feedstock VS, was generated under ideal laboratory conditions using Biochemical Methane Potential (BMP) assay procedures<sup>16</sup>. While “as excreted” and daily scrape manure had similar biogas potentials, the weekly scrape and sand separator effluent generated significantly less biogas per pound of VS.

Table 4. Biogas potential of dairy manure from different housing systems<sup>1</sup>

| Dairy Housing System | Bedding             | Manure Type               | VS                                       |  |
|----------------------|---------------------|---------------------------|--|--|
|                      |                     |                           | Ave.                                     | St. Dev.                                 |
|                      |                     |                           | (ft <sup>3</sup> of biogas/<br>lb of VS) | (ft <sup>3</sup> of biogas/<br>lb of VS) |
| Dry lot              | Dried manure solids | As excreted               | 8.8                                      | 2.5                                      |
| Dry lot              | Dried manure solids | Daily scrape <sup>2</sup> | 8.2                                      | 1.8                                      |
| Dry lot              | Dried manure solids | Weekly scrape             | 5.4                                      | 1.2                                      |
| Freestall            | Sand                | Sand separator effluent   | 6.4                                      | 2.2                                      |
| Tiestall             | Wood shavings       | Daily scrape              | 8.5                                      |  |

<sup>1</sup>Data from testing completed at the MSU Anaerobic Digestion Research & Education Center

<sup>2</sup>For the biogas assay, daily scrape manure was blended with green water

This is an indication that the mixtures of VS contained in those samples are not as readily digestible as fresh manure with minimal handling. It is important to remember that VS are a mixture of organic compounds ranging from simple organic compounds (acids, sugars, cell matter) to large particles of undigested feedstuffs. Several factors could contribute to the differences in biogas potential for sand separator effluent or weekly scrape manure. Losses of smaller, more readily degradable VS during sand separation or due to aerobic decomposition resulting from the weekly scrape could contribute to the differences in biogas potential.

<sup>16</sup> Faivor, L.L. and D.M. Kirk. 2011. Statistical Analysis of a Biochemical Methane Potential Test Using Dry Lot Dairy Manure as a Case Study. 2011 ASABE Annual International Meeting, paper number 1110918.



## CONCLUSIONS

Dairy manure from most housing system can be an ideal feedstock for anaerobic digestion. Key to developing a successful project is understanding during the planning phase, how site-specific conditions influence the solids characteristics and the biogas potential of the manure. The moisture content of manure is influenced by the housing system, environmental conditions and type of bedding. Reductions in the TS concentration and increases in the volume of manure are attributed to the addition of water from cattle drinkers, cooling systems and hydraulic manure collection and conveyance. Bedding generally increases the TS concentration. However, the addition of VS or FS will depend on the type and quantity of the bedding. Sand bedding will add significantly to the TS and FS in the manure and will require removal prior to introduction into the digester. Organic bedding will add to the TS, FS, and VS in the manure and will require planning to avoid sludge accumulation or the development of a floating layer.

To avoid technological problems during the operation of a digester, it is important to consider how the housing and manure collection practices influence the manure characteristics. Reviewing the manure collection and conveyance practices as well as the annual application records will provide site-specific data on the manure volume. In addition, testing the manure intended for anaerobic digestion and reviewing historical manure analysis records will provide important information regarding the solids characteristics. If there are significant changes in the volume or solids concentrations compared to published data, it may warrant further investigation to determine the cause and impact on anaerobic digestion. While success is never guaranteed, a little extra effort during planning will significantly increase the likelihood of creating a long term, robust project.

## ACKNOWLEDGMENTS

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