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ANAEROBIC DIGESTION OF FLUSHED DAIRY MANURE

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1. Introduction

In Florida, dairies use water extensively for barn flushing and waste collection, because it is sanitary and less labor-intensive. However, the practice of hydraulic flushing results in greatly increased volumes of dilute wastewater. In addition, many dairies have incorporated fan and sprinkler cooling systems for cow comfort in the warm Florida climate, which contributes even more water to the waste stream. The use of large volumes of flushwater for dairy manure collection, however, means that conventional anaerobic digestion using complete-mix or plug-flow technologies is neither practical nor economical, since the dilute manure streams (typically less than 1% TS) would require excessively large digester volumes and higher heat inputs in order to achieve the hydraulic residence times and operating temperatures required for stable digestion (HRT > 15 days at 35^{o}C).

Figure 1: Hydraulically flushed alley.

Many dairies also use sand for freestall bedding, since sand provides a clean and comfortable inorganic bedding material. A sand trap may be used to recover some of the sand for reuse. However, the presence of sand in the waste stream presents additional problems for conventional digester designs.

Primary treatment (mechanical screening or sedimentation, or both) of flushed dairy manure is widely practiced in the dairy industry since it is helps to prevent clogging in wastewater irrigation systems. Solids removed by screening and sedimentation can be land applied to serve as a soil amendment, or exported off-farm to dispose of excess nutrients. Even after physical separation of suspended-phase solids, the liquid fraction of flushed dairy manure still poses a significant environmental challenge. However, the bulk of the methane potential remains in the wastewater fraction.

In Florida, the most common manure management system utilizes short-term holding ponds for flushed manure wastewater storage, with subsequent pumping to sprayfields to supply fertilizer nutrients and irrigation water for production of forage crops. Although effective for nutrient recycling, these systems tend to be odor intensive. Odorants in livestock manure result primarily from the partial decomposition of organic matter by anaerobic microorganisms. With short-term storage, just as the odorous intermediate products accumulate, the wastewater is sprayed onto cropland through pivot irrigation, thereby volatilizing the odorous compounds and creating a high odor nuisance potential.

2. Fixed-Film Digestion

The optimal manure management system should provide a sustainable approach designed to minimize environmental impacts and maximize resource recovery. Anaerobic digestion under controlled conditions offers a holistic manure treatment solution that not only stabilizes the wastewater but also produces a significant amount of energy in the form of biogas, controls odors, reduces pathogens, minimizes environmental impact from waste emissions, and maximizes fertilizer nutrient and water recovery for reuse. In anaerobic digestion, organic matter in the wastewater is microbiologically converted in the absence of oxygen to biogas, a mixture of mostly methane and carbon dioxide. The biogas produced can be collected and used on-farm, either as a direct energy source (e.g. for heating water) or converted to electricity. The choice of which digester design to use at a given livestock operation is driven by the existing, or planned, manure handling system.

Flushed dairy manure wastewater – defined as the liquid fraction of flushed dairy manure after particulate solids are removed – is usually too dilute for conventional anaerobic digestion systems. One practical alternative is to apply high-rate anaerobic digestion technology, such as fixed-film digestion, to recover energy and treat the flushed dairy manure wastewater at much shorter residence times (≤ three days) than allowed by conventional technologies. A fixed-film anaerobic digester – designed specifically for such dilute wastewaters – has recently been developed at the University of Florida. This unique anaerobic digester design allows biogas recovery and biological stabilization (permanent odor reduction) of the liquid portion of flushed dairy manure at ambient temperature conditions.

The basic fixed-film digester design consists of a tank packed with inert media on which a consortia of bacteria attach and grow as a biofilm – hence the term "fixed-film" digester. As the wastewater passes through the media-filled reactor, the anaerobic biomass converts the organic matter in the wastewater to biogas. Immobilization of the bacteria as a biofilm prevents washout of slower growing cells and provides biomass retention independent of hydraulic retention time. Fixed-film digesters, therefore, are ideally suited for treating large volumes of dilute wastewater because large numbers of bacteria can be concentrated inside smaller digesters operating at shorter hydraulic retention times than would be needed to achieve the same degree of treatment with conventional suspended-growth anaerobic reactors. Generally, the fixed-film design is suitable for any livestock waste that is subject to dilution with water for transport or processing, or the liquid fractions from physical separation processes. Also, fixed-film digesters have a smaller footprint than conventional designs – an important factor where land availability is limited.

Being a contained system, the fixed-film anaerobic digester controls gaseous emissions that contribute to the greenhouse effect. Methane is a potent greenhouse gas with a global warming potential 21 times that of carbon dioxide. Using the biogas as an alternative fuel reduces methane emissions from livestock wastes and conserves fossil fuel resources, thereby also decreasing overall emissions of carbon dioxide into the atmosphere. Being a completely closed system, a fixed-film digester also allows more complete anaerobic digestion of the odorous organic intermediates found in stored manure to less offensive compounds, producing an effluent with significantly reduced odor potential.

Although the volatile solids (VS) content of livestock manure is an indicator of potential methane production, the specific methane yield on a VS basis is not a constant. This is due to variations in the VS composition, which consists of both readily degradable organic compounds including lipids, proteins and carbohydrates, as well as more refractory organics which may include lignocellulosic materials, complex lipopolysaccharides, structural proteins (keratin), *inter alia*. In other words, "all volatile solids are not equal" and, therefore, exhibit different rates and extents of biodegradation during anaerobic digestion. Research has shown that fibrous solids have a low biogas potential because of the low biodegradation rates and refractory nature of lignocellulosic materials to microbial attack. Just as these fibers are not digested in the rumen they will also not degrade, in the short term, during anaerobic treatment. Since solids separation tends to remove a VS fraction that is high in fibrous solids, it also tends to remove the non-degradable portion of the VS, leaving the more degradable fraction in the flushed dairy manure wastewater. Therefore, fixed-film digesters achieve the highest treatment efficiency with diluted wastewater, or low concentrations of suspended solids.

Table 1: Wastewater Characterization

- Temperature
- pH
- Conductivity
- Alkalinity
- Total COD
- Soluble COD
- Total solids
- Volatile solids
- Total suspended solids
- Volatile suspended solids
- Total Kjeldahl nitrogen
- Ammonia
- Total phosphorus
- Soluble reactive phosphorus
- Sulfate

A primary benefit of separation of fibrous solids from flushed manure is the production of two fractions that are inherently more manageable than the original slurry. Minimizing waste stream solids avoids clogging problems and/or impaired biofilm activity in the digester. The benefits in terms of ease of materials handling, production of a high-fiber by-product, and reduction in digester volume requirements are substantial. The fibrous solids have potential use for bedding, refeeding and horticultural applications.

While many dairies utilize hydraulic flushing for manure management, the parameters of any waste management system are site-specific and may vary significantly from one dairy operation to the next. The bioenergy potential of the feedstock is an important parameter in sizing a fixed-film digester and calculating cost-benefit ratios.

Chemical oxygen demand (COD) reduction is linked to methane production – for every kilogram of COD converted, 0.35 m^3 of CH_4 is produced, which is equivalent to 12,000 BTU. For a given dairy farm, the COD concentration of the separated flushed dairy manure is a function of site-specific factors such as the number of cows and the flushwater volume contributing to the waste stream. Therefore, it is important to characterize the wastewater and compile baseline data with regard to number of animals, degree of confinement and type of bedding, feed ration/dry matter intake, volume of flushwater usage, extent of solids separation, and other relevant parameters, in order to design an appropriate fixed-film anaerobic digester for a given farm situation. Typical wastewater characterization parameters are listed in Table 1. A thorough characterization of flushed dairy manure wastewater, which examines fluctuations in soluble and particulate fractions under field-scale conditions, can aid the design and operation of fixed-film digestion by matching the appropriate reactor volume with the proper organic loading rate and hydraulic retention time. Higher organic loading rates serve to optimize volumetric methane productivity, while lower organic loading rates maximize treatment efficiency. Future plans for herd expansion should also be considered in sizing a digester so that adequate digester capacity is available.

3. University of Florida Digester

A demonstration-scale fixed-film digester has been built and is in operation at the University of Florida's Dairy Research Unit (DRU), located in Hague, Florida. The digester is an integral part of the overall waste management system at the 500-milking cow DRU and serves as a model for the dairy industry.

The milking herd at the DRU is confined to freestall barns, which are hydraulically flushed to a wastewater collection channel. The cows are bedded on sand. Milking parlor wash-down water, combined with udder-wash water, also flows to the wastewater channel. In summer, misters are used in the freestall barns to keep the cows cool, contributing additional water to the waste stream. The wastewater initially flows down the collection channel to a sand trap, where some of the sand is recovered for reuse. After the sand trap, the wastewater flows to a mechanical separator, which removes large fibrous solids. The wastewater then flows across a settling basin and over a weir into a sump. A portion of the flushed dairy manure wastewater is pumped from the sump to feed the digester, while the remainder flows directly to a primary storage pond.

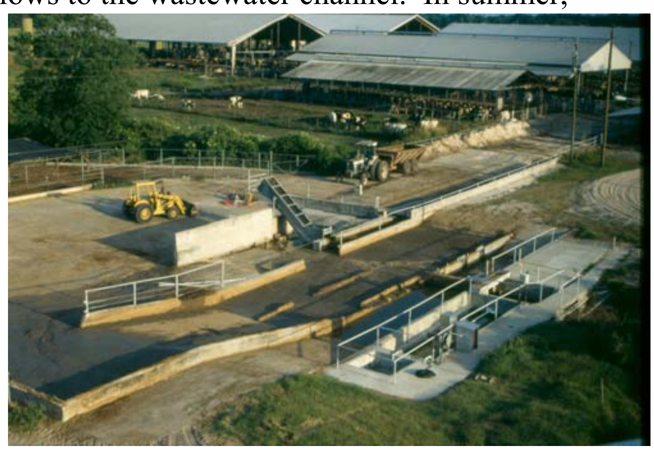

Figure 2: Mechanical separation and sedimentation.

The DRU fixed-film biogas digester demonstrates the application of fixed-film anaerobic digestion for bioenergy production and biological stabilization of flushed dairy manure wastewater at a working Florida dairy, under field conditions. As constructed, the complete digester system consists of a 100,000 gallon, fixed-roof digester tank; a biogas collection and flare system; feed, recycle and desludging pumps; and a mechanical building for housing pump controls and ancillary equipment. The digester is packed with media, which provides a large surface area for bacterial attachment. This enables stable biogas production at low hydraulic retention times (≤ 3 days), even at low ambient temperature conditions (< 20 ^{o}C). About half of the volatile solids in the flushed dairy manure is removed during pretreatment by mechanical separation and sedimentation. This material is not pumped through the fixed-film digester, but best serves as a soil amendment. Also, this fixed-film digester design can tolerate the presence of fine sand in the wastewater without affecting performance.

The separation of fibrous solids increases the COD to VS ratio of the flushed dairy manure wastewater. Fixed-film anaerobic digestion of the resulting wastewater removes 50% of the remaining COD at a 3-day HRT. Biogas (80% methane; 20% carbon dioxide) produced in the digester is flared continuously to reduce odors and methane emissions. A portion of the biogas is also used directly on-site to fuel water heaters, providing hot water for use in the milking parlor. Solids removed by the mechanical separator and from the settling basin are land applied. Currently, a local certified organic farm is also using the separated solids in vegetable production after a suitable curing period.

Figure 3: Fixed-Film Anaerobic Digester.

4. Conclusion

Since many dairies are heavily reliant on hydraulic flushing for manure management, large volumes of wastewater are generated. These dilute wastewaters represent a significant bioenergy resource if processed by anaerobic digestion. However, until now, there has not been an anaerobic digester design available to handle such dilute agricultural waste streams.

Fixed-film anaerobic digestion offers a sustainable alternative to treat the liquid fraction of flushed dairy manure, providing major benefits in terms of energy production, waste stabilization and odor control, and pathogen reduction, while conserving the fertilizer value of the wastewater. The fixed-film anaerobic digester developed at the University of Florida was designed specifically to treat the liquid fraction of flushed dairy manure, with a portion of the digester biogas being utilized to heat water for use in the milking parlor.

Generally, the fixed-film design is suitable for any livestock waste that is subject to dilution with water for transport or processing, such as dairy and swine manure. Effective implementation of fixed-film anaerobic digestion technology demands that the digester be integrated with the existing manure management system. This requires an understanding of this innovative technology and of the impact that site-specific waste management practices can have on both the energy potential of the feedstock and the efficient operation of the digester unit.