Anaerobic Digestion System Selection for Croatian Swine Manures

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Abstract
Interest in the anaerobic digestion (AD) of swine manures and slaughter waste continues to increase due to the potential to produce renewable energy in the form of biogas and due to the expanding market for carbon credits around the world. This paper provides an analysis of the anaerobic digestion types and operational schemes that are best suited to Croatian swine production. In addition, it proposes a methodology to optimize system selection and design by predicting biogas production quantity and quality based on the use of biochemical methane potential (BMP) assays followed by the use of pilot-scale reactors to make final system selections and estimate system hydraulic retention times (HRT) for the selected system design. A review of reactor configurations that are promising for swine manure and slaughter waste digestion suggests that a mesophilic, continuously fed AD system be investigated to digest a mix of Croatian large-scale swine manure and slaughter waste.

Keywords: anaerobic digester, design system selection, swine manure

Introduction

The trend in recent years has been the consolidation of the hog industry in Europe and Croatia as many smaller farms have been incorporated into larger "mega farms". While this greatly increases the economies of scale and reduces the cost of production, it has also brought new challenges. The concentration of animals and the waste produced can put a strain on the local environment. A potential solution could be anaerobic digestion (AD) of hog farm waste (swine manure), mixed and co-digested with slaughter waste where feasible. Anaerobic digestion facilities have been recognized as a useful decentralized source of energy supply since they are less capital intensive than large power plants.

The AD process can be presented as a series of biochemical and microbiological stages in which microorganisms degrade biodegradable material (substrate) in an oxygen free environment resulting in the production of methane (CH4) rich biogas as shown in Figure 1. Anaerobic digestion of two different waste streams (called co-digestion) could be used to address both swine manure and slaughter house waste in Croatia.

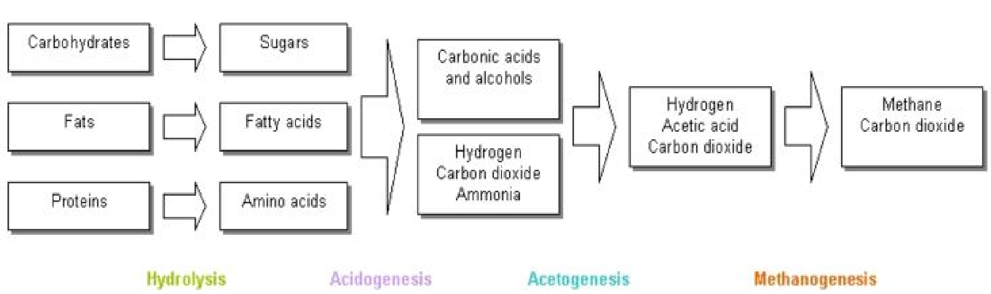

Figure 1. The key process stages of anaerobic digestion (Hydrolysis, Acidogenesis, Acidogenesis, Mathanogenesis), (Ciborowski P. 2004.)

Review of Anaerobic Digester Systems

Substrate composition is a major factor in determining the anaerobic degradability and subsequent methane yield from the digestion process. A range of compositional characteristics including total solids, volatile solids, pH, carbon – nitrogen ratio, COD, and fat contents should be considered as part of the digester selection and design process (Jerger D. et al 2006). A very important consideration is the substrate total solids (TS) content, with lower TS substrates being easier to handle with ordinary pumps and equipment in comparison to more expensive systems required to handle higher TS materials. Total solids content also has a large impact on the selection of digester type and design, since high TS content can result in plugging of some digester configurations.

AD System design and configuration

Before discussing and recommend system types suitable for swine manures and slaughter waste, it is useful to present the general types of AD systems and substrate TS compatibilities. Numerous AD systems with many variations are available, but in general they can be classified into the following categories; Feed type classification: Batch or continuous flow, Temperature classification: Mesophilic or thermophilic, Solid content classification: High solids or low solids and Complexity classification: Single stage or multistage.

Digesters may be **batch loaded or continuously loaded**, (Parsons A.R., et al. 1984). **Batch system** digesters are filled with material (substrate) that remains in the sealed digester until treatment is finished. The degraded substrate is then removed and replaced with a new batch. Batch feeding is a good option when sporadic or limited inputs of substrate will occur. Batch fed AD systems have uneven biogas production which increases slowly after start-up and decreases significantly after a certain period of peak production because the systems become feed limited however. Batch fed systems typically require less daily attention than continuously fed systems. Gas production can be evened out by using an additional batch digester fed at alternating intervals with the primary digester.

Digesters that are fed either continuously, or on a frequent, reoccurring basis (one or more times daily) are typically classified as **continuously loaded**. These systems can be operated as a plug-flow, complete mixed, partially mixed reactor or fixed-film digesters. **Complete mix** digesters evenly distribute the substrate to improve bacterial activity, to reduce solids settling, and to prevent scum formation on the surface of the substrate. Mixing can be accomplished through various methods, including mechanical mixers, recirculation of digester content, or by recalculating biogas to the bottom of the digester. (K. Karim et al. 2005)

Plug flow systems have an advantage in reducing operating costs; they are mechanically simpler and require no energy for mixing. Substrates are fed into one end of the digester and slowly pass through the length of the digester, and the material is positively displaced out the other end. Ideally there is no mixing during passage of substrate through the digester, although in reality some mixing occurs. The concentration of biodegradable organic substrate decreases as it moves through the digester, and the microbial mass increases.

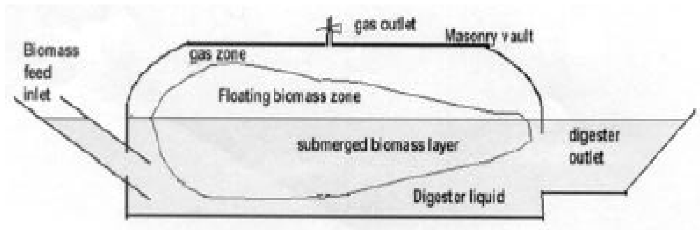

Figure 2. Plug flow reactor (PFR) process (Chankaya H. N., et al. 2004)

A compromise between a **complete mix digester** and plug flow digestion is the **partially mixed** concept. Substrate can be mixed at regular intervals (for example 2min/hr). Different mixing regimes depend on digester shape and the TS content of the substrate (for example swine manure has different TS content based on the type of production technology – deep pit, flash system, dry feeding, liquid feeding etc.). The effect and mode of mixing becomes more prominent when digesters are fed with higher TS manures (above 8%). Typically mixing is credited with higher biogas production than unmixed digesters (Karim K. et.al. 2005). However, manures with lower total solids (TS 2%-6%) also require periodic mixing to avoid solids settling and to keep substrate more homogenous for better microbiological activity. Figure 3 shows two models of mixing in anaerobic digesters.

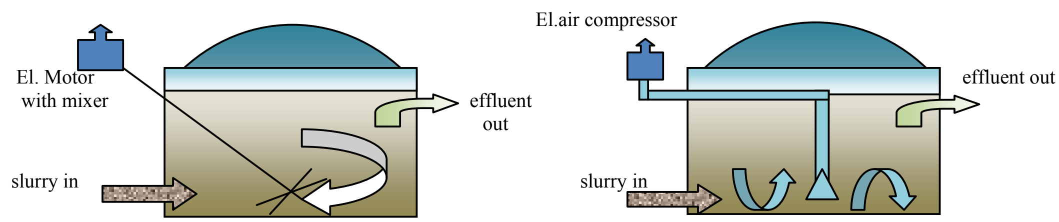

Figure 3. Stirring mixing (el. motor) and mixing with gas (air compressor)

Fixed-film AD systems utilize a support matrix to grow anaerobic biomass upon. A common fixed-film configuration is the anaerobic filter. While anaerobic filters can be either up-flow or down-flow design, they both contain a packing material to provide surface area to grow biomass upon. While fixed-film digesters provide excellent biomass immobilization, and hence relatively short HRTs, they can only operate with very low TS substrates due to plugging problems. While the use of fixed-film digesters has been researched for use with very low TS (less than 2% TS) flushed dairy manure systems, the plugging problem has kept them from being commercially adopted for manure digestion at this time.

Digestion systems can be configured as either single-stage or **two-stage digesters.** Following hydrolysis, anaerobic microbiological activity occurs in two separate steps (acidogenesis and methanogenisis), because of this digester staging is also an option. If we look at the AD process (easier control of each group of bacteria) it is easy to conclude that this type would be more efficient than the single-stage digester. However, research and practical activity on two-stage digesters shows they do not necessarily produce higher overall methane quantities than single-stage digesters. They are mainly used in municipal waste water digestion where solids content is lower than in animal manures and slaughter waste. Generally, multi-stage digesters are constructed to provide lower **hydraulic retention times (HRT)** through the digester. Hydraulic retention time represents average residence time that a given molecule of substrate spends within the digester.

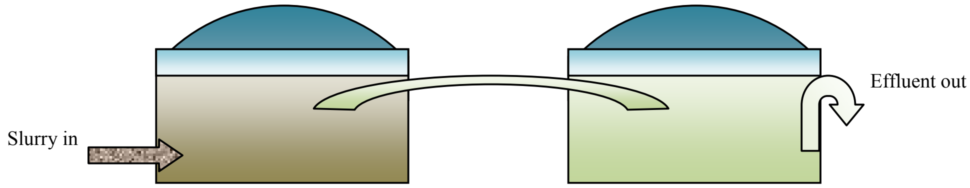

Figure 4. Two-stage or multistage digester

Two temperature ranges are common for AD systems, mesophilic and thermophilic. Temperature range influences the methanogenic species present in the digester (Song Y.C. et al 2004). The optimal mesophilic temperature range is 37º-41ºC, and the optimal thermophilic temperature range is 50º-52º. Thermophilic ranges can go as high as 70ºC where thermopiles are the primary microorganisms present. Even though the thermophilic process is enhances gas production, it is more sensitive to changes of quality and quantity of substrate inputs, and the higher required temperature requires more energy, which is typically generated by parasitically consuming a portion of the biogas generated by the digestion process. It is also important to keep **pH level** between 6.6 and 7.6 (ideal pH= 7.0 ± 0.5), because bacteria prefer neither very acid nor very alkaline conditions otherwise biogas production can be greatly retarded. Digesters operated in the mesophilic range are considered easier to control and have lower operating costs, and in general are more preferable for manure digestion than thermophilic systems.

Recommendations and conclusions

If we consider the characteristics of manure generated by large Croatian swine production systems in light of the AD system operational parameters reviewed above, recommendations can be made suggesting which AD system types are most appropriate for large Croatian swine farms. Based on numerous analysis of the swine manure produced on these swine farms, the range of TS content for these facilities is noted to range from 2-8%. The manure TS content will vary by production system type and the technology used on each farm. Dry feeding system manures will have higher TS contents, in the range of 6-8%, while liquid feeding system manures will have TS contents ranging from 3-6%. The type of manure handling and storage system used on each farm will also influence manure TS. Typically systems using shallow pull-plug (50 cm deep pits) systems where the manure is stored under the animals can be expected to have TS contents of 2-4%. Systems that utilize direct collection via pipes that transfer manure into an external collection pit can be expected to have a TS content ranging from 4-6%. Slaughter- house waste will also vary, but depending on the amount of water being used for washing equipment and dilution of waste at the collecting pit, the TS of slaughter waste will range from 2-10%.

Given the TS range of large-scale Croatian swine manures and slaughter wastes that may be co-digested with swine manures, complete-mix and partially-mixed AD systems are best suited for these wastes. Both plug-flow and fixed-film AD systems would be poor choices for Croatian swine systems for the following reasons. Plug-flow systems require manures with TS contents ranging from 12 – 14% to prevent short-circuiting within the digester, and the manures being considered here will be too low in TS to meet this requirement. Fixed-film digesters require manures with TS contents less than 2% to prevent plugging, and the manures in consideration here have higher TS contents that would result in plugging problems.

In order to maintain a constant biogas production, the use of a continuously fed (or in this case very frequently fed digesters) is recommended over a batch fed process. In order to maintain a uniform effluent that can be frequently loaded into the system, is it recommended that manure be discharged from pull-plug manure systems into an equalization (EQ) tank. In as much as possible, we propose to schedule that the plugs be pulled from the barns timed in order to equalize the manure load into the EQ tank. Additionally we propose that fresh slaughterhouse waste be mixed with the swine manure on a daily basis at the appropriate proportion to provide a constant organic load to the digester. Finally, in regards to the use of a single-stage versus a two-stage system, we recommend that pilot-scale reactors be established to provide adequate data to base this decision on.

The recommendation of this paper is that a mesophilic, continuously fed AD system be investigated to digest a mix of Croatian large-scale swine manure and slaughter waste. Initially we propose that a matrix of biochemical methane potential assays be conducted to determine the optimal mix of swine manure and slaughter house wastewater for co-digestion. Additionally, we recommend that both single-stage and two-stage bench-scale reactors be established and operated to provide data to determine which of these options will optimize methane production with the specific manure being considered.

References

Chankaya, H.N., Pajabapaiah, P., 2004. Envolving biomass-based biogas plants: The ASTRA experience. Current Science, Volume 87, No.7.

Ciborowski, P., 2007. Anaerobic Digestion in the Dairy Industry, Minnesota Pollution Control Agency, Air Innovations Conference, www.epa.gov.

Humanik, F. et al. 2007. Anaerobic digestion of animal manure. www.epa.gov.

Jerger, D., Tsao, G., 2006. Feed composition in Anaerobic digestion of biomass, p 65

Karim, K., Hoffmann, R., Klasson, K.T., Al-Dahhan, M.H., 2005. Anaerobic digestion of animal waste: Effect of mode of mixing. Water research 39 (2005) 3597-3606

Kricka, T., Grbesa, D., Varga, B., Svečnjak, Z., 2006. Production of Biofuels nad its impact on Agriculture. 43rd Croatian and 3rd Internationall Szmposium on Agriculture. Opatija 2007. Croatia (17-23), Plenary Sessions

Lemmer, A., Oeschsner, H. Co-fermentation of grass and forage maize, Energy, Landtechnik, 5/11, p56

Lusk, P., 1998. Methane Recovery from Animal Manures, The current opportunities Casebook, National Renewable Energy Laboratory NREL/ SR – 580-25142

Müller, C., 2007. Anaerobic digestion of biodegradable Solid Waste in low-and Middle-Income Countries, Eawag aquatic research – Sandec-Water and Sanitation in Developing Countries

Parsons, R.A., 1984. On Farm Biogas production, Cooperative extension, Digester Construction NRAES-20.

Song, Z.C., Kwon, S.J., Woo, J.H. 2004. Mesophilic and thermophilic temperature co-phase anaerobic digestion compared with single-stage mesophilic and thermophilic digestion of savage sludge, Water Research, 2004. April, 38(7), 1653-62