〈Review paper〉

Anaerobic Biotreatment of Animal Manure

- A review of current knowledge and direction for future research -

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Summary

Anaerobic decomposition is one of the most common processes in nature and has been extensively used in waste and wastewater treatment for several centuries. New applications and system modifications continue to be adapted making the process either more effective, less expensive, or suited to the particular waste in question and the operation to which it is to be applied.

Animal manure is a highly biodegradable organic material and will naturally undergo anaerobic fermentation, resulting in release of noxious odors, such as in manure storage pits.

Depending on the presence or absence of oxygen in the manure, biological treatment process may be either aerobic or anaerobic. Under anaerobic conditions, bacteria carry on fermentative metabolisms to break down the complex organic substances into simpler organic acids and then convert them to ultimately formed methane and carbon dioxide.

Anaerobic biological systems for animal manure treatment include anaerobic lagoons and anaerobic digesters.

Methane and carbon dioxide are the principal end products of controlled anaerobic digestion. These two gases are collectively called biogas. The biogas contains 60~70% methane and can be used directly as a fuel for heating or electrical power generation. Trace amounts of ammonia and hydrogen sulfide (100~300 ppm) are always present in the biogas stream.

Anaerobic lagoons have found widespread application in the treatment of animal manure because of their low initial costs, ease of operation and convenience of loading by gravity flow from the animal buildings. The main disadvantage is the release of odors from the open surfaces of the lagoons, especially during the spring warm-up or if the lagoons are overloaded. However, if the lagoons are covered and gases are collected, the odor problems can be solved and the methane collected can be used as a fuel.

Anaerobic digesters are air-tight, enclosed vessels and are used to digest manure in a well-controlled environment, thus resulting in higher digestion rates and smaller space requirements than anaerobic lagoons. Anaerobic digesters are usually heated and mixed to maximize treatment efficiency and biogas production.

The objective of this work was to review a current anaerobic biological treatment of animal manure for effective new technologies in the future.

(**Key words** : Anaerobic decomposition, Anaerobic teatment, Animal manure)

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Factors influencing the anaerobic treatment

Major factors that may affect the performance of the anaerobic treatment process include temperature, pH, organic loading rate, nutrients and retention time.

Temperature

Anaerobic digestion occurs in a wide range of temperatures. Three temperature ranges have been explored for anaerobic digestion, the psychrophilic range (10~20℃), the mesophilic range (20~45℃), and thermophilic range (45~60℃). Psychrophilic digestion of animal manures has been primarily associated with covered lagoon digesters operating at ambient temperatures (Stevens and Schulte, 1979). Anaerobic digesters, however, are commonly designed to operate in either the mesophilic or thermophilic range.

pH and Alkalinity

The pH in an anaerobic digester should be maintained between 6.6~7.6. Alkalinity is a measure of buffering capacity. Bio-carbonate alkalinity in the range of 2500 to 5000 mg/L provides a safe buffering capacity. The volatile fatty acids level should be kept below 2000 mg/L for stable digestion (Kroeker et al, 1979).

Nutrients

Nutrients such as nitrogen, phosphorus, sulfur and trace elements (including sodium, potassium, calcium, magnesium and iron) are needed by the bacteria and animal manure usually contains all the required nutrients in adequate quantities. Hills (1979) stated that the optimum level of C/N for anaerobic digestion of agricultural wastes is around 25.

Mixing and Toxic materials

Digester mixing to speed digestion, maintain a uniform temperature and avoid digestion inhibition is an important design consideration. McCarty (1964) reported that at concentrations between 1,500 and 3,000 mg/L of total ammonia nitrogen and a pH greater than 7.4, ammonia concentration may inhibit methane production.

Retention time

In a digester, the retention time refers to solids retention time (SRT) and hydraulic retention time (HRT). The SRT is used to indicate the mean residence time of bacterial cells in the digesters. For mesophilic (35℃) digesters in HRT of 30 days, the SRT should be controlled for a minimum of 10 days (Pfeffer et al., 1967).

Types of anaerobic biological treatment systems

1. Anaerobic lagoons

Anaerobic lagoons are used as a treatment and storage structure. They are designed to provide partial decomposition of liquid manure before irrigation. There are two types of anaerobic lagoons: single stage and multiple stage.

Manure solids are degraded in an anaerobic lagoon in a series of complex physical and biochemical processes and reactions. In simplified form, solids degradation in an anaerobic lagoon can be described as a two stage process controlled by two different cultures of bacteria as acid forming stage and methane forming stage.

Uncovered anaerobic lagoons result in a

great loss of ammonia from the manure due to volatilization from large surface areas of the lagoons. Anaerobic lagoons can be covered for odor reduction and biogas collection. Covered anaerobic lagoons have been used as low cost anaerobic digesters for livestock farms in the United States. Floating covers for harvesting biogas has been successfully installed on lagoons in several locations in the United States. There are a number of reports in the literature on the successful operation of covered anaerobic lagoon digesters.

2. Anaerobic digesters

Conventional anaerobic digesters used for animal manure treatment include batch or fed-batch, completely mixed and plug-flow digesters. These digesters are suitable for treating solid or slurry manure collected from feedlots or confinement buildings with scrapers. To improve the economics of treating dilute wastewater such as flushed manure, a number of new biomass-retaining digesters, often called high rate digesters, are being developed and adapted for liquid manure treatment. These biomass-retaining digesters are designed to provide special mechanisms to keep bacterial cells and solids in the digesters longer than the treated liquid fraction. The biomass-retaining mechanisms include anaerobic contact reactor, anaerobic sequencing batch reactor (ASBR), up-flow sludge blanket reactor(UASB), anaerobic filter and fluidized bed reactor.

(a) Batch and Fed-Batch Digester

In batch digestion, all the feedstock is introduced into the digester at once, together with an inoculum of active anaerobic bacteria. Bacteria then grow and digest the feed stock. Batch digestion of animal manure mixed with crop residues has been successfully accomplished in laboratory-scale or pilot scale by a number of researchers(Sun et al., 1987).

Fed-batch digesters are an improved version of batch digesters for dealing with the continuous production of animal manure on livestock farms (Hill and Bolte, 1986; Demuynck et al., 1984; Zeeman et al., 1988; Hall et al., 1985).

(b) Completely Mixed Digester (Constantly Stirred Tank Reactor; CSTR)

The completely mixed digester contains a mixer to maintain good contact between bacteria and the organic material to be digested. The mixing in the digester can be achived with a mechanical mixer or by recirculating some of the biogas to the bottom of the digester from where it can rise to the top either as free bubbles or as bubbles confined in draft tubes. Mixing is usually intermittent at intervals of about an hour. Heating is generally by hot water in simple heat-exchangers as pipes or plates immersed in the digester. The hot water can come from a gas boiler or from an engine running on the biogas. The completely mixed digesters have been used for treating animal manure slurries of 5~9% total solids.

(c) Plug-Flow Digester

The mixing in the plug-flow digester is not occurred and the substrate is introduced at one end of a horizontal tube and flows as a plug through the tube. Some of the effluent liquid is recycled to the beginning of the digester to act as an inoculum for the feed. There may be some mixing occurring in the digester as the

waste travels through. The friction of the walls and the effects of gas production mix the contents of the digester; convection currents from the heating system add to the mixing. The solids in the slurries tend to settle out and have longer retention time than the liquids, resulting in more complete degradation as compared with the completely mixed digester. Plug-flow digesters can be designed as a long trough in the ground or as tubular configulations made of fiberglass.

(d) Anaerobic Contact Digester

The anaerobic contact digester system uses a completely mixed digester and a solids-settling tank that separates bacteria-containing suspended solids in the effluent of the digester and recycles them back to the digester. This then increases the system SRT which is longer than the HRT, resulting in a reduced digester volume and more favorable economics for treating dilute wastewater.

(e) Anaerobic Sequencing Batch Reactor (ASBR)

The ASBR uses a high rate anaerobic bioconversion process to stabilize animal liquid wastes for odor control and generate biogas for energy use. The ASBR has been evaluated extensively in the laboratory for treatment of animal manure at mesophilic temperatures ranging from 20 to 35℃ (Zhang et al., 1996). It has demonstrated a superior performance for treating dilute swine manure with short HRTs (down to 3 days) while maintaining the SRT longer than 10 days.

(f) Up-flow Anaerobic Sludge Blanket Digester (UASB)

The UASB digester features a bed of granular and flocculated sludge suspended by an up-flow of the wastewater. The digester consists of three distinct zones: a sludge bed, a sludge blanket and a settling/gas separation zone. The principle use of the UASB digester has been for treatment of municipal and industrial wastewater. It has only been tested in the laboratory for treating animal wastes (Foresti and Oliveira, 1995).

(g) Anaerobic Filter(Fixed Film Digester, Fix-Bed Anaerobic Reactor)

Anaerobic filter uses a porous media packed in the digester to immobilize bacteria to achieve biomass and solids retention. A variety of materials have been used for the packing media, including irregularly positioned lumps of stones, brick, plastic or regularly arranged tubes of pottery or similar material (Young and McCarty, 1969).

(h) Fluidized Bed Reactor (Expanded Bed Reactor, Moving Bed Bio-film Reactor)

The fluidized bed reactor is the development of anaerobic filter with improved packing structure to reduce the blocking problems associated with suspended solids in the wastewater. In a fluidized bed reactor, the bacterial support media are small granules (1~5 mm) of internal materials such as sand, plastic or glass. Bolte et al. (1986) and Hill and Bolte (1992) evaluated several other plastic materials for use as suspended media in terms of physical durability and biological properties.

Conclusions

Water quality issues, and odor and gas

emissions from animal manure anaerobic biological treatment are important issues facing animal producers. Public health issues related to animal manure disposal are emerging issues that animal producers will have to deal with in the near future. A number of technologies exist to treat animal manure to reduce its pollution potential. New technologies will provide producers with economically feasible options to manage manure and protect the environment.

Anaerobic digestion is an energy conservative biological treatment process. It produces biogas which can be used as a clean fuel for heat or electrical power generation and at the same time stabilizes manure for odor control. It is an effective primary treatment technology suitable for treating slurry or liquid animal wastewater. Covered lagoon digesters are limited to warm climates. For places with low ambient temperatures and limited land spaces, compact and well controlled digesters will be the choice. Due to presence of substantial suspended solids in the manure, high rate suspended growth digesters, such as completely mixed digesters and anaerobic sequencing batch reactors (ASBR), are more applicable than attached growth digesters, such as fixed film digesters and anaerobic biofilters. Low cost, highly reliable and robust anaerobic digestion systems still need to be developed and demonstrated.

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