Research achievements and application in anaerobic treatment of organic solid wastes—A review*

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Abstract Anaerobic digestion is a good method, which possesses the optimal combination of volume reduction, probability of success and potential for resource and energy recovery. However, relatively little research has been done on the anaerobic digestion of organic solid wastes (OSW), especially in China. However, different substrates, start-up conditions, micro-organisms, processing technologies, pre-treatment methods could influence the result of anaerobic digestion. Anaerobic treatment of municipal OSW is less than that of wastewaters because some problems and obstructions need to be solved. Meanwhile, the application of anaerobic digestion of OSW is also discussed in the present paper.

Key words organic solid waste; anaerobic treatment; overview

1 Introduction

Solid wastes (SW) refer to all the wastes derived from human and animal activities, which are normally solid and are discarded as useless or unwanted (Juha-Heikki Tanskanen, 2000). Generally, the organic fraction accounts for more than 50% - 60% of SW. All of these materials contain much biological energy. How to use effectively the energy is important for sustainable development of the environment. The SW problem in China is becoming more and more serious, with an annual growing rate of 10%. Approximately 180 million tons of municipal solid wastes were generated in China in 2003 (Li Yanwei and Wu Yuehua, 2001). Anaerobic digestion is a biological technology, it has been now widely applied to the treatment of wastewater. However, relatively little research has been conducted on the anaerobic digestion of organic solid wastes (OSW), especially in China.

2 Achievements in research on anaerobic digestion of OSW

In the CNKI Chinese Journal Database (1994 - 2004), there are 1803 papers whose titles contain "anaerobic"; 5536 papers, "municipal solid waste" (or organic solid waste, or garbage, or refuse, or rubbish, or trash). Among these papers, only 31 papers whose titles contain "anaerobic + municipal solid waste" (or organic solid waste, or garbage, or refuse, or rubbish, or trash). It is shown that little research work has been done on anaerobic digestion of OSW in China. Similar results were also found in the "Elsevier SDOS" (1995 - 2004) Journal Database. Besides, the monographs dealing with the anaerobic digestion of SW are less in number than those concerning the anaerobic digestion of wastewater. Therefore, achievements in research on the anaerobic digestion of OSW are still less available. Further research should be strengthened.

The fundamental principles of anaerobic treatment of wastewater and organic solid wastes are similar in many aspects, so the anaerobic treatment of OSW may draw on the experience in wastewater treatment. In addition, it must be known that wastewater and OSW are different in some essential aspects, and they are also different in treatment technology.

Anaerobic digestion is a complex process. Bryant et al. (1979) put forward the theory of three-steps anaerobic digestion. The first step, also called the hydrolysis stage; the second step, the acidogenesis stage; and the third step, the methanogenesis stage. The methanogenesis stage is a limiting step for the anaerobic digestion of wastewater. However, the limiting step is the hydrolysis stage for OSW (Vavilin and Rytov,

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1997). The hydrolysis of organic matter has been well documented for the anaerobic treatment of OSW. For instance, the research achievements of Sanders et al. showed that the surface area of the particulate substrate is a key factor for the hydrolysis process. The larger the total surface area, the easier the hydrolysis will be. The simplest model of hydrolysis of organic matter is the first-order kinetic model. The first-order hydrolysis kinetic constants range from 0.003 – 0.15/day at 20℃ to 0.24 – 0.47/day at 40℃ (Sanders and Geerink, 1999). In addition, the parameters for anaerobic digestion include temperature, pH value, C∶N ratio of substrate, loading of substrate, hydraulic retention time (HRT), anaerobic microorganism, etc.

Other fundamental studies showed anaerobic digestion of substrate is also an important factor for the anaerobic treatment of OSW. Carbohydrates are digested fastly because carbohydrates can be hydrolyzed easily. Proteins and lipids are digested more difficultly than carbohydrates. The lignins and cellulose are most difficultly digested. Protein degradation will produce ammonia, the unionized form of which is inhibitory to anaerobic microorganisms in high concentrations (Lebrato, 1995). Anaerobic digestion of lipids may cause some problems because of their tendency to form floating scum and accumulate long-chain fatty acids (LCFA). Furthermore, in high concentrations LCFA and unionized volatile fatty acids (VFA) are inhibitory to anaerobic microorganisms (Sanders and Geerink, 1999). The lignins and celluloses are digested slowly and hardly. The physical association between lignin and cellulose is in many cases a limiting factor for anaerobic degradation (Salminen and Rintala, 2002a).

Anaerobic digestion is a process of decomposition of organic matter by micro-organisms. Micro-organisms play a very important role in this aspect. Hydrolytic, acetogenic and methanogenic bacteria have been detected in the process. Generally, inoculation is essential for the anaerobic treatment of OSW. It may enhance the generating rate of gas, and gas yields in the early phase of anaerobic digestion. The anaerobic degradation of MSW in a high solid-content reactor is more difficult to start up and control than that in a low solid-content digester (Lebrato, 1995). Previous work indicated that the start-up time could be as long as 4 months or more when digesters started in slurry mode (8% TS initial content) until they reached at least a 20% TS level inside the reactors (Nopharatana and Clarke, 1998). However, when residues of anaerobic digester in the operation are inoculated, start-up time may be shorter, only a few days. In addition, the process stability strongly depends on the start-up of the reactor, which is a period when the VFA concentrations must not become too high, so an equilibrium between the acid phase and the methane generation is achieved.

Anaerobic digestion technology may be divided into one-phase treatment and two-phase treatment. One-phase treatment means the whole reaction proceeds under one reaction container. Under such circumstances optimum conditions should be produced so that all reactions involved in the whole process are accelerated and VFA keeps lower concentrations to avoid a too low pH. Two-phase treatment means digestion proceeds under two reaction digesters. The environmental conditions of microorganisms in the two reaction digesters are different. It is impossible that hydrolysis and acidification in the process of anaerobic digestion cannot go lonely because microorganisms in the two phases are the same. Meanwhile, it is also impossible that the acetogenic and methanogenic stages are independent of each other because acetic acid formation needs methanogenic bacteria so as to maintain low H_2-pressure. Therefore, the separation of anaerobic digestion processes has only one possibility, that is, the separation of the acidification stage from the acetogenic stage, the digesters are acid-digester and methane-digester accordingly. Two-phase digestion also considered the right option for treating high-solid wastes, and the source-sorted organic fraction of MSW from fruit and vegetable markets (with very high biodegradability).

The study (Zhang Guangming and Wang Wei, 1996) showed that VFA was accumulated easily in the process of anaerobic digestion of OSW, leading to acid poisoning and thus restraining anaerobic digestion. Besides, free ammines also hold anaerobic digestion possibly, and they influence mainly the activity of methanogenic bacteria. In addition, anaerobic digestion should be stirred at regular intervals so that microorganisms are kept in touch with OSW.

Anaerobic digestion enhancement: Pre-treatment may improve the performance of anaerobic digestion. This treatment can be biological, mechanical or physico-chemical (Mata-Alvarez et al., 2000). Among the biological methods of improvement, compositing pre-treatment is often used and its effect is clearly visible through methane yields and solid reduction which is greater than in the digestion of untreated OSW. The mechanical method means that large particles of organic material become the comminuted small particles. The relatively large particles of organic matter may hinder a close contact between methanogenic bacteria and substrate. Size reduction of the particles can help increase the specific surface available to the medium, thus improving the biological process. Two effects have been reported: firstly, if the substrate has a high fiber content and low degradability, its comminution will improve gas production; and secondly, size reduction can lead to more rapid digestion. So large particles are often broken into small particles by using mechanical methods. In addition, the anaerobic digestion rate of solid wastes is limited by hydrolysis, so physico-chemical treatments are also often used to promote the solubilisation of organic matter.

Many biochemical reactions will occur in an oxygen-free sanitary landfill site, which convert organic matter to methane. To a certain extent, sanitary landfilling is also a process of anaerobic digestion. Sanitary landfilling aims at landfilling rather than anaerobic digesting because anaerobic digestion takes several tens of, even hundreds of years.

3 Application of anaerobic digestion of OSW

Anaerobic digestion has been used widely in the rural areas and towns of China and its application has a history of more than 100 years (Salminen and Rintala, 2002b). Luo Guorui (Taiwan, China) constructed the first household anaerobic digester (or methane tank) in China. The digesters have the advantages of simple construction and low cost. Such a digester generally consists of a below-ground digestion vessel with brick or masonry walls. It incorporates a mixing tank in which the waste to be digested is diluted with water to form a slurry before entering the digester. Waste is then fed to the digester periodically. Digested sludge is displaced into an outlet tank. The generated biogas is stored in the upper section of the digester vessel. On the basis of the investigation, 900 millions of households have constructed 1000 large- and medium-sized anaerobic digesters (Wang Xiewu, 2002).

Anaerobic digestion has been now essentially applied on a full scale in the treatment of liquid wastes. However, relatively few anaerobic digestion plants have been built to treat OSW in big cities, and many of those are no longer under operation. Nevertheless, the treatment of OSW is becoming more and more attractive as it produces energy and organic residues that can be used as soil conditioner. The Stormossen biogas digester in Finland, which was put into operation in 1990, is one of the first full-scale OSW processing anaerobic digesters in the world (Mata-Alvarez et al., 2000).

In the past, applications of anaerobic processes in treating high-solid streams were unsuccessful. However, recent developments have made it possible to handle wastes with solid levels so high as to be 40% (Rintala, 1996). The anaerobic co-digestion of sewage sludge and the organic fraction of municipal solid waste has been implemented in Europe as an alternative to conventional anaerobic sludge digestion, and is currently breaking into the North American market. For example, the Valorga full-scale plant in Netherlands is designed to handle 52000 tons per year of organic municipal solid waste separately collected (Bian Yousheng, 2000). The Valorga digestion process is a semi-continuous, high-solid, one-step, plug-flow type process.

4 Main problems of anaerobic digestion of OSW

Anaerobic treatment of OSW in cities is much less than that of wastewater because some problems and obstructions need to be solved.

(1) The sorting of municipal solid wastes is necessary for the anaerobic treatment of OSW. Sorting and recovery of organics are most economical and optimal. However, most Chinese people lack such consciousness.

(2) Hydraulic retention time of anaerobic digestion of OSW is long, thus leading to a great increase in treatment cost.

(3) Suitable water contents of OSW are important, as the control of water content could enhance the cost.

(4) Stirring is essential for anaerobic digestion, the stirring of OSW is more difficult than that of wastewater.

(5) Organic components of OSW per unit volume are higher than those of wastewater, and VFA generated in the stage of acidification is easily accumulated, inhibiting the activity of methanogenic bacteria and leading to "acid poisoning".

(6) High-effect micro-organisms are a very key factor. At present, such micro-organisms have not yet been found.

(7) Anaerobic digestion effluents may not generally be suited to being put directly on land. They are too wet and contain a notable amount of VFA, which are somewhat phytotoxic. If digestion does not occur within the thermophilic range of temperatures, they will not be hygienical. Thus, it is generally accepted that post-treatment after anaerobic digestion is needed to obtain a high quality finished product.

5 Perspectives of research and application

Anaerobic processing of OSW has the advantage of energy recovery, and it is also a suitable system for the reduction of wastes to be treated by the recycling materials, as well as by the reduction of the organic fraction. Furthermore, OSW are treated in an environment-friendly process. Taken together, these facts make it one of the most attractive alternative treatments of these wastes.

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