Review of research on anaerobic fermentation of food waste

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Abstract. Food waste (FW) is one of the most important components of municipal solid waste, including household food waste, food processing waste, canteens and restaurant waste. The accumulation of FW has gradually become a global problem. The FW has the characteristics of high organic matter content, high moisture content, easy spoilage and deterioration, and is easy to produce toxins and malodorous gases during transportation and treatment, thereby polluting the environment. Anaerobic digestion can effectively recover energy from organic waste, and is a common method of handling FW. Anaerobic fermentation techniques, including traditional anaerobic digestion and two-phase anaerobic digestion, are common methods for handling FW. This paper describes the current status of these two methods in FW treatment.

1. Introduction
Food waste (FW) refers to the food waste generated in the activities of residents, food processing, food service, etc. It is an important part of urban domestic waste and the second largest source of garbage after construction waste. Owing to global economic development and population growth, FW from residential, commercial (e.g., restaurants), institutional (e.g., school cafeterias), and industrial (e.g., food-processing factories) sources is being generated at an increasingly high rate [1,2]. The FW has the characteristics of high organic matter content, high moisture content, easy spoilage and deterioration, and is easy to produce toxins and malodorous gases during transportation and treatment, thereby polluting the environment.

At present, the main treatment and disposal methods of FW include crushing straight row, sanitary landfill, high temperature aerobic composting, solid state fermentation, biological treatment machine, anaerobic fermentation. The use of FW as the raw material of anaerobic fermentation technology can not only obtain clean energy, but also reduce pollutant emissions, and it is currently the main method for the treatment and utilization of large-scale FW. The technology for recovering energy from FW by anaerobic fermentation mainly includes traditional anaerobic digestion, two-phase anaerobic digestion and anaerobic fermentation hydrogen production technology.

2. Application of traditional anaerobic digestion technology
Traditional anaerobic digestion mainly includes three stages, i.e.,(i) hydrolytic fermentation microorganisms decompose complex organic compounds into alcohols, acetate and other volatile fatty acids (VFAs); (ii) syntrophic bacteria convert these VFAs to H₂ and acetate under a low H₂ partial pressure; (iii) at last methanogens convert CO₂, acetate and H₂ into CH₄ [3]. Studies have shown that using anaerobic digestion technology to treat FW is a practical method. Its theoretical methane production rate typically ranges from 0.4 to 0.5 L CH₄ g VS⁻¹, suggesting great potential for energy recovery [4,5,6]. Although the anaerobic digestion process was relatively simple, the number of bacteria
involved in the reaction was large and the process was complicated, which caused many factors affecting the internal reaction, resulting in system instability. The characteristics of FW (high labile organic matter, salt, oil, and protein contents; low C/N ratio; and insufficient trace elements) make anaerobic digesters prone to acidification, ammonia, salt, and long chain fatty acid inhibition, and nutrient deficiency. Therefore most of the research have focused on improving system stability and methane production.

2.1 Pretreatment process
The pretreatment process of raw materials could be divided into mechanical pretreatment, chemical pretreatment, and biological pretreatment. Mechanical pretreatment and chemical pretreatment were mainly to convert complex organic matter into small molecular organic matter that was easily biodegradable, increased specific surface area and the probability of contact between microorganisms and substrates, thus significantly increased biogas production and degradation rate of organic matter and shorten digestion time. Izumi et al. studied the relationship between particle size and VFA accumulation in anaerobic digestion. They found that when the FW particle size decreased from 0.843 mm to 0.391 mm, methane production increased by 28%. However, the undersize particle will result in excessive accumulation of VFAs and reduced methane yield.

Biological pretreatment was mainly to add high-concentration biological strains, and used microorganisms to hydrolyze the substrate. Meng et al. removed fat, oil and oil from FW and then studied the effects of lipase pretreatment on methanogenesis during anaerobic digestion. They found that the reaction time of lipase-1 and lipase-2 was 24 hours, the concentration was 1000-1500 μL and the reaction temperature was 40-50 °C to obtain the best hydrolysis effect. The methane production of animal fat, vegetable oil and flotation oil increased by 80.8-157.7%, 26.9-53.8% and 37.0-40.7%, respectively, and the digestion time was shortened by 10-40 d.

2.2 Accelerators
Studies have shown that the use of suitable additives could increase biogas production. Michele et al. invested nickel, cobalt and iron ions in the sludge and founded that more methane was obtained as long as the input was lower than the toxic concentration. The addition of metal cations could promote the enrichment of microbial populations, thereby increasing the residence time of microorganisms and the concentration of microorganisms, increasing biogas production. Appropriate natural plant additives could stimulate the physiological activities of microorganisms, increase the local concentration of fermentation substrates, and create an environment more suitable for microbial activities, thereby increasing the yield of biogas. Sharma et al. added 1% of onion slag during the anaerobic digestion of organic waste and found that biogas production increased by 40%-80%.

2.3 Digestion effluent reflux process
The digestion effluent reflux process reduces the loss of microorganisms by refluxing the digested effluent into the bioreactor, thereby promoting the complete degradation of the substrate and increasing biogas production. Malik et al. found that in a 1 m³ continuous feed drum reactor, when the substrate reflux ratio was controlled to 0.3 m³/(m³·d) and the HRT was controlled for 30 d, the gas production increased by 18.8%.

2.4 Co-digestion of fermentation materials
Low C/N ratio and high biodegradability were some of the characteristics of food waste, and this will inhibit the entire system anaerobic digestion. Therefore, co-digestion with different substrates was a common way to balance the C/N ratio in an anaerobic system. Mixing with cellulosic waste was a common method of solving these problems. Cogan et al. found that co-digestion of FW with seaweed waste resulted in a faster and more stable reaction, and showed that anaerobic co-digestion had the highest methane yield (252 cm³ / g-VS) when the FW:SW ratio was 9:1. Improvements in anaerobic fermentation process conditions have a large impact on methane production. Applying the optimum
process conditions to the anaerobic treatment of daily FW could effectively increase the recycling degree of waste.

3. Application of two-phase anaerobic digestion

Anaerobic digestion is a complex biological process in which acid-producing bacteria can be classified as acid-producing phases, and hydrogen producing acetogens and methanogens can be classified as methanogenic phases. Two-phase anaerobic digestion separates the acid-producing and methanogenic bacteria, allowing the two types of bacteria to have optimal growth and metabolism conditions, thereby improving the activity and processing capacity. Therefore, the two-phase anaerobic digestion process has higher processing efficiency than the conventional anaerobic digestion process. Operating temperature, pH, etc. have a certain impact on two-phase anaerobic digestion.

3.1 Operating temperature

Ventura et al. compared the mesophilic-mesophilic, mesophilic-thermophilic, and thermophilic-mesophilic two-phase anaerobic fermentation systems of FW. The results showed that the methane yield and VS removal rate were the highest in the mesophilic-thermophilic system. At the same time, the richness, diversity and dominance of bacterial community structure were also the best[16].

3.2 pH

pH was one of the important factors affecting the two-phase anaerobic fermentation of FW. Hydrolyzed acidified bacteria and methanogens could maintain normal life activity only in a suitable pH condition. The methanogens were very sensitive to pH, and the suitable pH range was between 6.5 and 7.8, while the suitable pH range for the hydrolyzed acidified bacteria was wide, which mainly affected the type of acidification products. Wang et al. studied the effect of pH on the hydrolysis and acidification stage of two-phase anaerobic fermentation of FW. The results showed that the hydrolysis was most effective at pH 4, while the yield of VFAs was the highest at pH 6[17].

3.3 Co-digestion of fermentation materials

Adding waste activated sludge, feces and other wastes to the FW could effectively improve the alkaline buffer capacity of the fermentation system, and at the same time adjust the C/N ratio and nutrient composition of the system, thereby improving the efficiency and stability of the fermentation system. Lee et al. found that the methanogenic amount of 0.22-0.29 L CH4/g VS was obtained in a two-phase anaerobic fermentation system in which the FW and activated sludge were used as a mixed substrate. The degradation rate of organic matter could reach about 60%, which was significantly higher than the two-phase anaerobic fermentation system that the sludge as a single substrate[18]. Bouallagui et al. mixed activated sludge with slaughterhouse wastewater and fruit and vegetable wastes for two-phase anaerobic fermentation. The results showed that methane production increased by 43.8% and 51.5% respectively, and organic matter degradation rate increased by 11.7% and 10% respectively[19].

4. Conclusion

Traditional anaerobic digestion and two-phase anaerobic digestion are effective methods for disposing FW. This paper introduces in detail the principles, characteristics and improvement methods of traditional anaerobic digestion and two-phase anaerobic digestion. At the same time, the existing related research was also analyzed.

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