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Review

A comprehensive review on food waste anaerobic digestion: Research updates and tendencies

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ABSTRACT

Anaerobic digestion has been practically applied in agricultural and industrial waste treatment and recognized as an economical-effective way for food waste disposal. This paper presented an overview on the researches about anaerobic digestion of food waste. Technologies (e.g., pretreatment, co-digestion, inhibition and mitigation, anaerobic digestion systems, etc.) were introduced and evaluated on the basis of bibliometric analysis. Results indicated that ethanol and aerobic prefermentation were novel approaches to enhance substrates hydrolysis and methane yield. With the promotion of resource recovery, more attention should be paid to biorefinery technologies which can produce more useful products toward zero emissions. Furthermore, a technological route for food waste conversion based on anaerobic digestion was proposed.

1. Introduction

Food waste (FW) is one of the most important components of municipal solid waste, including household food waste, food-processing waste, canteen and restaurant waste. The stacking of FW has gradually become a global problem (Capson-Tojo et al., 2017). It is estimated that the amount of FW sharply increased from 2.78 billion tons to 4.16 billion tons in Asian countries by 2025 (Melikoglu et al., 2013). Especially in China, the growth rate of FW has increased more than 10% with the acceleration of industrial development and urbanization processes (Zhang et al., 2016).

At present, FW regarded as municipal waste is sent to landfills and incineration plants as final disposal points. In some ways, these processes release some stress from garbage siege; at the same time, a series of problems are emerging including the rising cost of waste disposal, the lack of land space, groundwater pollution by leachate, and the emission of toxic and greenhouse gases (Uçkun Kiran and Liu, 2015). The collection rate of landfill gas is generally less than 60% in the developed countries, whereas there are only 20% achieved in China. USEPA estimated that the total anthropogenic emission of methane was 282.6 million tons in 2000, in which 13% (36.7 million tons) was due to landfill emissions. Schott and Andersson (2015) used life cycle assessment from production, transportation, and fosod preparation modeling to assess global warming potential of food waste, and found that incineration and landfill can be replaced by anaerobic digestion or composting. Moreover, FW with high concentrations of organic matter (volatile solids/total solids [VS/TS]: 0.8–0.9), high moisture content, and good biodegradability have been regarded as the most promising anaerobic substrates (Ohkouchi and Inoue, 2007; Zhang et al., 2011).

Anaerobic digestion (AD) is a complex process that involves a diverse assemblage of bacteria and methanogenic archaea (Jang et al., 2015). The decomposition process of organic matter can be divided into four stages. Macromolecule organic matter in solids is firstly broken into easily dissolved monomers including the transformation from carbohydrates, protein and fat to sugar, amino acid and long-chain fatty acid, and this process is called hydrolysis. The hydrolysis step is generally considered as the rate-limiting step for complex organic substrates degradation reported by most researchers, resulting from the formation of toxic by-products (complex heterocyclic compounds) or non-desirable volatile fatty acids (VFAs) during the hydrolysis step (Yuan and Zhu, 2016). In the second stage, called acidogenesis, monomers further decompose into short-chain fatty acid including VFA;

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lactic acid, pyruvic acid, acetic acid, formic acid. And then, in the process of acetogenesis, acids like lactic acid and pyruvic acid start to be digested into acetic acid and hydrogen. In the last stage, called methanogenesis, hydrogen and acetic acids are transformed into methane by methanogenic archaea.

Bibliometric analysis as a common research tool using quantitative analysis and statistics to describe the research trend of a specific field has been applied widely in studies to compare scientific production and research trends in many fields. And the structure of this paper is based on the results of bibliometric analysis.

2. Research tendencies analysis by bibliometric

In this study, keywords such as (food* waste* or foodwaste*) and (Anaero* or (biogas or methane)) were used as topic search phrases to acquire all the index of articles published from 1992 to 2016 from the Web of Science database. The records of all index were downloaded into spreadsheet software (Microsoft Office Excel 2016) to conduct a digital logical analysis (Fu et al., 2011). Particularly, some keywords which had the same meanings such as "methane" and "methane production" had been combined together in the datum treatment process. After all relevant datum were categorized, the tendencies of publication outputs were analyzed using five-year intervals to minimize year-to-year fluctuations (Xie et al., 2008). After the analysis of keywords, it was easy to find the keyword "Anaerobic Digestion" was referred to the most frequently and ranked first among all keywords. Furthermore, keywords such as "pretreatment", "inhibition", "co-digestion", "microbial community", showed a sustainable growth tendency and specific data has been shown in Table 1.

Through analysis of the tendencies of keywords, some conclusions were drawn. The problem of poor treatment resulted from inhibition is one of the major factors limiting the large-scale popularization of anaerobic digestion. With regard to mitigation of system inhibition which has been a focus of research for a long time, many related subjects have developed rapidly. Pretreatment can largely alleviate the problem of system collapse caused by poor hydrolysis. Co-digestion can adjust the C/N ratio and water content of food waste, and ensure the smooth production of gas. The study of microbial community can be used as an important indicator to monitor the process of anaerobic digestion. These basic researches provide a solid foundation for the development and upgrading of anaerobic digestion. This paper analyzes the latest treatment methods and related problems about anaerobic digestion and provides some advice for future researches.

3. Inhibition factors during anaerobic digestion process

Food waste has a high potential to produce renewable energy in the anaerobic digestion process because of its high biodegradability and rapid hydrolysis. The rapid hydrolysis of FW often results in some inhibition factors affecting the stability and sustainability of anaerobic digestion. The main inhibition factors are ammonia and VFA.

3.1. Ammonia inhibition and mitigation

Some substrates like food waste which have low C/N ratio and high nitrogen content will produce excessive ammonia in the process of anaerobic digestion. Excessive ammonia leads to an increase of pH, inhibitory effects, and eventually, process deterioration (Drennan and DiStefano, 2014; Akindele and Sartaj, 2017). The total ammonia nitrogen is mainly composed of free ammonia nitrogen (FAN) and NH_4^+. In an anaerobic system, FAN and NH_4^+ can be converted into each other. And under high pH and high temperature conditions, it is beneficial to the transformation to FAN (Zhang et al., 2017a,b,c). FAN is the most toxic species of TAN. Because FAN has the ability to penetrate the bacterial cell membrane, causing proton imbalances, increasing maintenance energy requirements, altering intracellular pH and inhibiting specific enzyme responses (Akindele and Sartaj, 2017). It was reported that the inhibitory concentrations of FAN and TAN were related to substrate, inoculum and environmental conditions, ranging from 53 mg/L to 1450 mg/L and 1500–7000 mg/L, respectively. Shi et al. (2017) observed the inhibitory effects of free ammonia on methanogenesis due to the low C/N ratio of each substrate (15.6 and 17.2, respectively). It was found that high concentrations of ammonia resulted in the accumulation of VFAs with acetic acid as the main type in the batch test, and co-accumulation of ammonia and VFAs, resulted in a stable and neutral pH value, but a low BPR known as an "inhibited steady state" in the semi-continuous experiment.

Furthermore, numbers of studies have reported that the effects of

Table 1
Top 20 most used author keywords.

Author keyword	92–16 TP	R (%)					
		92–16	92–96	97–01	02–06	07–11	12–16
Anaerobic Digestion	671	1 (27.66)	1 (27.58)	1 (29.24)	1 (27.73)	1 (26.38)	1 (28.06)
Methane	586	2 (24.15)	2 (25.86)	2 (18.86)	2 (20.81)	2 (22.86)	2 (25.46)
Food Waste	441	3 (18.17)	#N/A	3 (9.44)	3 (18.32)	3 (14.53)	3 (21.01)
Co-Digestion	239	4 (9.85)	#N/A	30 (1.89)	4 (7.93)	4 (14.18)	4 (9.31)
Hydrogen	284	5 (5.93)	9 (3.45)	4 (6.61)	5 (5.94)	5 (6.84)	5 (5.61)
Sewage Sludge	83	6 (3.42)	9 (3.45)	7 (3.77)	10 (3.47)	22 (1.84)	6 (4.04)
Municipal Solid Waste	77	7 (3.17)	4 (6.9)	5 (6.6)	22 (1.98)	11 (2.84)	7 (3.08)
Volatile Fatty Acids	69	8 (2.84)	3 (12.07)	16 (2.83)	6 (5.45)	22 (1.84)	8 (2.53)
Fermentation	58	9 (2.39)	37 (1.72)	#N/A	10 (3.47)	14 (2.67)	10 (2.33)
Thermophilic	47	10 (1.94)	9 (3.45)	16 (2.83)	10 (3.47)	11 (2.84)	24 (1.23)
Dark Fermentation	47	11 (1.94)	#N/A	#N/A	#N/A	15 (2.5)	11 (2.19)
Renewable Energy	44	12 (1.81)	#N/A	69 (0.94)	122 (0.5)	10 (3.34)	15 (1.51)
Wastewater	42	13 (1.73)	9 (3.45)	5 (6.6)	10 (3.47)	18 (2.17)	38 (0.89)
Biomass	42	14 (1.73)	9 (3.45)	30 (1.89)	30 (1.49)	11 (2.84)	24 (1.23)
Microbial Community	41	15 (1.69)	#N/A	#N/A	#N/A	44 (1)	9 (2.4)
Life Cycle Assessment	39	16 (1.61)	#N/A	#N/A	122 (0.5)	104 (0.5)	7 (3.7)
pH	37	17 (1.53)	#N/A	7 (3.77)	30 (1.49)	22 (1.84)	21 (1.3)
Organic Loading Rate	36	18 (1.48)	#N/A	#N/A	49 (0.99)	29 (1.34)	12 (1.78)
Pretreatment	35	19 (1.44)	#N/A	69 (0.94)	30 (1.49)	29 (1.34)	13 (1.57)
Mesophilic	33	20 (1.36)	9 (3.45)	#N/A	8 (4.46)	28 (1.5)	38 (0.89)

TP: Total numbers of publications.
R (%): Rank (the percentage of articles in total publications is given within brackets).
#N/A: None appeared.