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Effects of thermal pretreatment on degradation kinetics of organics during kitchen waste anaerobic digestion

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ABSTRACT

The influence of thermal pretreatment on degradation properties of organics in kitchen waste (KW) was investigated. The kinetics results showed that thermal pretreatment could enhance the degradation efficiency of crude protein (CP), fat, oil and grease (FOG), volatile solid (VS) and volatile fatty acids (VFA). Thermal pretreatment showed no significant difference in the final concentration of protein but could decrease the FOG degradation potential (7–36%), while increased the lag phase for degradation of protein and FOG respectively by 35–65% and 11–82% compared with untreated KW. Cumulative biogas yield increased linearly and exponentially with the removal efficiency of VS and other organics (CP and FOG) respectively. Additionally, the reduction of CP increased exponentially with FOG removal efficiency. The calculating methods of biogas yield, organics reduction and corresponding appropriate digestion retention based on FOG and CP reduction amount and pretreatment parameters were suggested.

1. Introduction

A large amount of kitchen waste (KW) is generated each year. Appropriate and effective treatment of KW has always been prominent concerns in recent years in order to avoid numerous problems, such as food safety and environmental quality due to the gutter oil and et al.

High biodegradability and water content make KW suitable for anaerobic digestion (AD) with the concomitant benefit of clean energy production (such as biogas) and organic waste reduction. However, the high content of macromolecular organic matters in KW, such as fat, oil and grease (FOG) and crude proteins (CP), which accounted for 30–70% of the total organic matter (dry basis), could easily lead to relatively longer started-up period when AD is applied. In addition, the content of FOG is usually higher (1–5% wet basis) in KW, causing excessive acidification and inhibition of nutrients transport, thus unfavorable to a sustained and stable degradation during the digestion process [1].

Previous researchers have mainly focused on optimizing the anaerobic treatment conditions of KW (single phase/two-phase/three stage, continuous/sequencing-batch digestion, temperature and retention time of digestion, mono-digestion/co-digestion, etc.) [2–4], factors influencing and inhibiting the digestion process (feedstock such as carbon and nitrogen ratio, organic compositions, ammonia nitrogen, salt content, long-chain fatty acid (LCFA), volatile fatty acid (VFA), organic loads, etc.) and pretreatment methods to enhance the organic reduction and methane production (e.g., thermal, thermochemical, ultrasonic, biological, microwave and chemical pretreatment) [5,6]. In addition, the long retention time of the AD process of KW is a major concern and numerous methods for pretreating KW prior to the AD process have been developed to accelerate the digestion process and to enhance the biomethane production [7,8]. Among these pretreatment methods, thermal treatment is one of the easiest and most studied pretreatment methods and has already been applied at a full-scale [7], which could be applied as the sole process or as a pre- or post-process sterilization phase. It can also effectively promote the solubilization and liquefaction of complex macromolecule solid organic matters, thus reducing the particle size of solid materials, enhancing the solubilization of organics, obtaining an improvement in the total soluble chemical oxygen demand, hence favoring

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for digestion of anaerobic microbes [1,9–13].

Additionally, anaerobic digestion of KW is a complex biochemical reaction process. The biomethane production and composition at different conditions can be estimated according to the establishment of biochemical reaction kinetics model and the numerical simulation of anaerobic digestion process [6,14]. It is beneficial for understanding the process of organic matter degradation and transformation controlled by microorganism when performing the investigation of reaction rate, mass transfer characteristics and the effect on the internal dynamics in the different stages of AD process, which can also be served as an effective method for guiding the design and operation of AD reaction system [5,15]. The first-order kinetics, modified Gompertz kinetics and methods provided by Koch and Drewes were common approaches to carrying out the kinetics study on the hydrolysis and the biogas production of AD process [16–18].

However, in previous researches and practice, thermal pretreatment was mainly used for the modification of sludge, and few researchers have studied the effect of thermal pretreatment on the physical and chemical properties of KW and efficiency of subsequent AD process. And the existing researches are mainly on analyses of the degradation efficiency of organic waste, such as KW, sludge, etc and achieving higher degradation efficiency by thermal pretreatment through AD tests, such as CP, FOG and volatile solid (VS). As for the degradation kinetics, most researchers centered on the sewage sludge [19–21], and few studies focused on the detailed degradation properties of organic degradation during AD process of KW. As for KW with thermal pretreatment, no previous study has investigated the variation in properties of anaerobic degradation kinetics.

In order to achieve a comprehensive understanding and comparative conclusions on the mechanism analysis of organics degradation enhanced by thermal pretreatment during AD process of KW, particularly the aim of demonstrating the relevant role played on the biodegradability performance by thermal pretreatment, the objective of this study was to assess the kinetic study of organics degradation efficiency by thermal pretreatment, investigate the inherent relationship between organics biodegradability and biogas production potential. The influence of thermal pretreatment on the degradation kinetics of organics (including CP, FOG, VS, and VFA), interactions between two main organics components in KW, and the relationship between organics degradation and biogas production during AD of KW were investigated. Additionally, the feasible strategies for enhancing the AD of KW by combined thermal pretreatment and AD system was suggested to optimize the operational parameters and provide a theoretical basis for engineering application.

2. Materials and methods

2.1. KW

Table 1 shows the basic characteristics of KW collected on a weekly basis from a canteen in Tsinghua University that can serve approximately 10,000 students and staff members per meal. After manual sorting in order to remove impurities, such as big bones, plastics, and metals, the KW was mixed with a kitchen blender to ensure uniform and representative experimental materials. It was then transferred to a food crusher and shredded into particles with an average size of 1–2 mm and stored at 4 °C in a refrigerator.

2.2. Thermal pretreatment

Thermal hydrolysis pretreatment was performed in a 20 L stainless steel hydrolysis reactor, which was constructed as a pressure vessel with a heating shell. It consisted of an electrical heating layer, a surface scrape agitator and a reaction chamber (effective volume 20 L, length 459 mm) with a switchable sealing valve for pressure control. The reactor was designed to withstand pressures as high as 2.0 MPa and temperatures as high as 220 °C. The temperature and agitator rotation speed were controlled by the Fuzzy-PID controller. A thermocouple was used to monitor the sample temperature, and a blender motor was used to mix the samples in the vessel completely during the whole heating process.

During the pre-treatment, approximately 1 kg of KW was transferred to the vessel, which had been preheated to a predetermined temperature. After hydrolysis at this temperature for a selected time, the heating process was terminated, and the samples were chilled by circulating 10 °C water until the vessel cooled to room temperature. After pre-treatment, the samples were stored at 4 °C in a refrigerator to minimize the volatilization of organic compounds prior to further analysis.

We have evaluated the influence of thermal pretreatment on physical and chemical properties of KW and the AD efficiency in our previous research [22]. In this study, the KW was pretreated for 70 min at 55–90 °C and 50 min at 120–160 °C. Discussion of the reasons for preferring the thermal pretreatment parameters can be found in our previous research [22].

Table 1
Characteristics of the KW.

Compositions of KW[a]		Characteristics of the KW[a]	
Parameters	Percentage[b] (%)	Parameters	KW
Cooked bone	2.7 ± 0.9	pH	6.5 ± 0.2
Cooked eggshell	1.0 ± 0.6	Total solids (%)	18.7 ± 0.4
Pasta & rice	29.1 ± 2.1	VS (%, dry basis)	93.2 ± 0.5
Fruit peeling	23.3 ± 1.2	Carbohydrate (%, wet basis)	11.8 ± 0.4
Cooked vegetable	19.5 ± 1.8	CP (%, wet basis)	2.5 ± 0.2
Vegetable peeling	23.0 ± 2.2	FOG (%, wet basis)	3.5 ± 0.1
Others	1.4 ± 0.2	Carbon (%, dry basis)	46.1 ± 1.7
		Hydrogen (%, dry basis)	6.9 ± 0.2
		Oxygen (%, dry basis)	37.8 ± 0.1
		Nitrogen (%, dry basis)	3.2 ± 0.3

[a] Each indicator was measured three times.
[b] Determined by weight, wet basis.

2.3. Anaerobic digestion

After removal of the floating oil via thermal pretreatment and subsequent centrifugation, the liquid and solid phases of KW were blended thoroughly for anaerobic digestion experiments, which were carried out in 250 mL glass bottles with an effective volume of 200 mL at 35 °C. The seed sludge was obtained from a steady-operation digester in a waste water treatment plant after two-day gravity sedimentation prior to inoculation. Furthermore, each digester was fed with a mixture of seed sludge and KW with a mass ratio of 14: 1 (with an F/I ratio of 1: 2 on a volatile solid (VS) basis). The upper space of each reactor was flushed with nitrogen for at least 3 min to assure the anaerobic conditions and then sealed quickly. In each experimental run, three control digesters were operated. Two blank digesters which contained inoculums only were also incubated at the same time to correct for the biogas yield from the inoculums. All bottles were put in a water bath set at 35 °C and shook manually twice a day, and the digestion experiments were run for 21 days. The volume of biogas produced during anaerobic digestion was calculated by a wet-type gas flowmeter and then collected in gas bags.