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A model based on feature objects aided strategy to evaluate the methane generation from food waste by anaerobic digestion

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ABSTRACT

A model based on feature objects (FOs) aided strategy was used to evaluate the methane generation from food waste by anaerobic digestion. The kinetics of feature objects was tested by the modified Gompertz model and the first-order kinetic model, and the first-order kinetic hydrolysis constants were used to estimate the reaction rate of homemade and actual food waste. The results showed that the methane yields of four feature objects were significantly different. The anaerobic digestion of homemade food waste and actual food waste had various methane yields and kinetic constants due to the different contents of FOs in food waste. Combining the kinetic equations with the multiple linear regression equation could well express the methane yield of food waste, as the R^2 of food waste was more than 0.9. The predictive methane yields of the two actual food waste were 528.22 mL g^{-1} TS and 545.29 mL g^{-1} TS with the model, while the experimental values were 527.47 mL g^{-1} TS and 522.1 mL g^{-1} TS, respectively. The relative error between the experimental cumulative methane yields and the predicted cumulative methane yields were both less than 5%.

1. Introduction

An ever-increasing amount of food waste is produced due to the rapid development of catering services in China. Traditional treatments such as incineration, landfill and composting were unsuitable for food waste because of its characteristics of high moisture, organic content and high salinity (Chen et al., 2012; Kim et al., 2008; Shen et al., 2013). Potential environmental pollution problems and health threat would be raised if food waste is treated improperly (Chen et al., 2012; Meng et al., 2014; Shen et al., 2013). The attractiveness of anaerobic digestion lies in the fact that it can not only disposal of food waste, but also can recycle environmental friendly energy-biogas and achieve resource utilization (Li et al., 2013c; Li et al., 2013d; Zhou et al., 2014).

In order to obtain the biochemical methane potential (BMP) of organic substrates, the traditional method is to take BMP tests, but these tests are time consuming, which often take 30–60 days (Liu et al., 2016; Shujun et al., 2015; Yeshanew et al., 2016). Some models to obtain quick BMP results do not offer necessary information about the kinetic degradation of the material, such as the Buswell formula based on elemental composition (Meng et al., 2015) and empirical relationships based on the material's chemical and biochemical properties (Rafieenia et al., 2017). As it is known, suitable kinetic models are widely used to evaluate the methane production performance with certain kinetic parameters (Meng et al., 2015; Zhou et al., 2015). An alternative approach to obtain quick BMP results is the combination of material's biochemical and numerical prediction models. Moreover, the biomethane production and kinetic constant of real waste in anaerobic digestion could be predicted through FOs that included glucose, peptone and microcrystalline cellulose aided strategy, which was proposed by Zhou et al. (2015) and was used to investigate the co-digestion of actual waste.

Food waste is characterized by organic matter and complex ingredients. The content of each composition in food waste may various due to the geographical differences, seasonal differences and eating habits, which may cause the different methane yields. It is very hard to identify each composition precisely in food waste, but the compositions can generally be divided into several parts such as starch, proteins, lipids and cellulose etc. This study was aimed at evaluating and predicting the methane yield from food waste by using feature objects (FOs) aided strategy and relevant models. In particular, (1) evaluating the methane yield of FOs

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with first order kinetics model and modified Gompertz model, including rice, tofu, vegetable and fat, (2) studying the effect of the content of FOs on methane yield and the reaction rate for food waste, and (3) modeling the methane yield of food waste based on its own characteristics and the methane yield of FOs with a multiple linear regression model.

2. Materials and methods

2.1. Substrates and inoculum

Food waste contained large amounts of organic substances, which was mainly carbohydrates, protein, as well as fat. In addition, food waste was usually composed of rice, vegetables, soybean products, eggs, meat and other components. Compared with starch, cellulose and peptone which were used as feature objects in Zhou's study (Zhou et al., 2015), rice, tofu, fat and vegetable could better reflect the actual methane generation process of food waste by anaerobic digestion. Therefore, rice, tofu, fat meat and vegetable were selected as feature objects to simulate the methane performance from food waste more precisely. In this experiment, rice, tofu, fat meat and vegetable were represented as starch, protein, fat and cellulose, respectively.

The food waste in this work was collected from the first and the second dining room in Jiangnan University in Wuxi, China. The indigestible materials such as chopsticks, bones, paper towels and plastics were initially separated from the food waste by hand. Rice, vegetables, tofu and fat meat were available from the nearby supermarket, and then cooked for the experiment. All samples were homogenized into slurry by a food processor, and stored at -4 °C for later anaerobic digestion tests.

The inoculum was anaerobic sludge, which was collected from a UASB reactor in a bakery company in Wuxi, China. Prior to use, the sludge was activated at 37 °C for 1 week by the synthetic glucose wastewater (Alzate-Gaviria et al., 2007), and then was acclimated and degassed at 37 °C for 3 weeks to minimize the effect of methane production from seed sludge on the methane yield of digesters (Li et al., 2013a; Li et al., 2013b). The sludge was centrifuged at 2800g for 5 min, sealed after the supernatant was removed and stored at 4 °C. The characteristics of substrates and seed sludge were shown in Table 1.

2.2. Anaerobic digestion batch tests

Two experiments were performed: (1) investigating the methane generation potential from four feature objects (R1-R4) to understand the methane generation of actual food waste, (2) evaluating the effect of different content of feature objects on the degradation of food waste (R5–R9). The experimental design is presented in Table 2.

Table 2
Experimental design.

Group	Starch:protein:fat:cellulose (dry base)	Food waste
R1	1:0:0:0	–
R2	0:1:0:0	–
R3	0:0:1:0	–
R4	0:0:0:1	–
R5	–	Food waste[a]
R6	–	Food waste[b]
R7	1:1:1:1	–
R8	3:3:2:2	–
R9	4:7:3:6	–

[a] From the first canteen.
[b] From the second canteen.

All the BMP tests were carried out in triplicates with the AMPTS ⅡIat 37 °C (Kong et al., 2016). Reactor bottles with 400 mL working volume were used in all tests. Except for tofu group, the solid content of 8.06%, inoculum-to-substrate ratio (ISR) of 2.66 and the substrate of 8 gTS were used for all tests. After adding the required amounts of substrates and seed sludge, tap water was also added to each bottle. In order to avoid the inhibition of ammonia nitrogen, 5 gTS tofu and the corresponding seed sludge were added in the tofu group, and the bottle was filled up to 400 mL. Then the initial pH value was adjusted to 8.87 with 2 M sodium hydroxide solution and hydrochloric acid solution in all the tests. After the air tightness was checked, nitrogen gas was introduced for 3 min to maintain the anaerobic environment in the reactors. At last, a mixing stir with slow mechanical rotation was used in each bottle. The rotation consisted of 120 s of stirring and was stopped for 60 s for one round.

2.3. Analytical methods

2.3.1. Characteristics of substrates and inoculum

All the BMP tests were carried out in triplicates with the AMPTS ⅡIat 37 °C for 22 days. At the end of the process, a report presented the normalized methane flow rate and cumulative methane volume. Total solid (TS) and volatile solid (VS) were determined according to the standard methods (APHA, 1999). The content of lipids was measured by weight difference after extraction with diethyl ether in a soxhlet system. The content of protein was calculated by multiplying the total determined organic nitrogen by a factor of 6.25 (Hattingh et al., 1967). The content of cellulose was determined by a cellulose analyzer. Organic acids were analyzed using a high performance liquid chromatography equipped with a UV detector and a ZORBAX SB-A column (300.0 × 7.8 mm) according to the procedures proposed by Zhao and Ruan (2013). The concentration of total organic acids was calculated as a sum of butyric acid, acetic acid, propionic acid and lactic acid. Dissolved carbohydrates were measured by phenol–sulfuric acid method

Table 1
Characteristics of substrate and inoculum.

	TS (%)	VS(%)	VS/TS (%)	Starch (%)[c]	Protein (%)[c]	Raw fat (%)[c]	Cellulose (%)[c]
Rice	40.96	40.80	99.61	100[d]	–	–	–
Vegetable	7.11	6.72	94.51	–	–	–	100[d]
Tofu	17.60	16.52	93.86	–	100[d]	–	–
Fat meat	85.38	84.97	99.52	–	–	100[d]	–
Food waste[a]	24.13	22.60	93.66	31.87	21.02	17.56	23.21
Food waste[b]	25.95	24.46	94.26	35.61	18.72	19.11	20.82
Inoculum	16.21	14.22	87.72	–	–	–	–

[a] From the first canteen.
[b] From the second canteen.
[c] As TS of sample.
[d] FOs.