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Evolution of Multiple Kitchen Waste Components and Each Components Anaerobic Digestion

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A laboratory procedure is described for measuring the methane potentials of kitchen waste and each of its components. Triplicate reactors with about 20 grams of fresh material were incubated at 37! with 300ml inoculum for 50-days for each feed. The total volatile fatty acids (VFAs) concentration showed an initial increase from day 0 to day 3 to a maximum value of 3426 mg/L. The last 9 days ranged from 2907 to 2359 mg/L and then later decreased to 1329 mg/L on day 12. Finally, the total VFAs stabilized at 650 mg/L. On day 6, the kitchen waste achieved its maximum methane production rate of 32.32 mL/g. The cumulative methane production for all the kitchen waste at the end of day 50 was 218.15 L/kgVS_{feed}, whereas the protein and animal fats achieved their maximum methane production rates of 23.27 and 15.91 mL/g on day 15 and day 19, respectively. The final methane potentiality of the kitchen waste was 194.2 and 257.82 L/kgVS_{feed}, respectively. The average methane concentration of all the feeds is about 55-58%. The kitchen waste removal efficiency of the total solids (TS) and the volatile solids (VS) in anaerobic digestion was 28.64% and 56.88%. Compared to other components, starch, protein, paper, and animal fats achieved the following removal efficiencies: 9.79%, 14.67%, 21.00%, and 17.64% for TS and 31.23%, 37.33%, 34.59%, and 46.38% for VS, respectively.

Key words: Kitchen waste; Anaerobic digestion; Total VFAs; Removal efficiency.

Kitchen waste generation is rapidly increasing in large Chinese cities, where the production of municipal solid waste (MSW) was 150 million tons[1]. Consequently, waste management has become one of the largest environmental concerns over the last few years. Landfilling[2] was once the primary method of waste disposal, but is no longer an option in China due to the scarcity of land and the unregulated gas and leachate emission contaminations. However, biologically treating the waste proposes an alternative and has been demonstrated to be one of the most advantageous methods for maximizing recycling and recovering various components. The anaerobic digestion of the sorted organic fraction of municipal solid wastes, especially food waste, is the most attractive and cost-effective alternative[3].

A critical factor affecting the anaerobic digestion of kitchen waste is temperature[4-5]. Generally, the anaerobic digestion process is operated under mesophilic or thermophilic conditions; however, of the two, the thermophilic digestion is reported to be the more efficient method[5]. Additionally, there is both wet and dry anaerobic digestion. Compared with wet anaerobic digestion, dry anaerobic digestion benefits its respective compact digester with a high organic

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loading rate and its energetically effective performance[6]. This process also results in a lower leachate concentration and easily handles the digested residues that can either be further treated through a composting process or can be used as fertilizer[7].Thus far, few reports exist that study the evolution of multiple organic components and also attempt to explain the relationship between biogas production and the multiple components in kitchen waste as well as each of the components' anaerobic digestion. Hence, the aims of this study are to investigate the kitchen waste performance as well as each of its components anaerobic digestion with an emphasis on the relationship between biogas production and the multiple components under mesophilic conditions in a lab-scale batch experimental process.

MATERIALS AND METHODS

Experimental reactor

The experimental reactor was self-designed; two wide-mouth bottles (1L) acted as the fermentation tank and the gas collector, respectively. The bottles were sealed with rubber stoppers and sealant, and a volumetric flask (1L) served as the water collector. Finally, the bottles were connected with glass tubing and an anti-aging latex tube, and an air-tight seal was ensured after the device was connected. An automatic, constant temperature water bath thermostat functioned as the reactor's heating device.

Substrate and inoculum preparation

The fresh kitchen waste was obtained from Shenyang Huanggu District source separation pilot families and contained primarily food and vegetable residuals; no garden waste was included. About 100 kg of homogenous wet kitchen waste was taken to the laboratory. Egg whites, rice, mince fat, and lettuce were selected as the fermentation materials to stand for the proteins, starches, lipids, and celluloses. The waste was fully blended so as to have the same VS content as manure and, afterwards, was kept frozen (-20°C) in 2 L portions. One part of the samples was used for a material analysis, and the remaining part was used as a substrate for the anaerobic digestion. Characteristics of the kitchen waste and each of its components are shown in Table 1.

An active inoculum was needed for the experiment. The inoculums used were from the Sheyang North Wastewater Treatment Plant, which operates at 37°C. We had the inoculums transported in 25-liter containers by a delivery service. The temperature drops to an ambient temperature during delivery, but is always actively kept. The inoculums needed to be readapted to 37°C so as to ensure the degradation of easily degradable organic matter still present in the inoculums and to remove dissolved methane. Therefore, the inoculums were stored with an anaerobic headspace for three days in the 37°C incubator.

Table 1. Characteristics of the kitchen waste and each of its components

	Kitchen Waste	Starch	Protein	Paper	Animal Fats
w/%	30.55	67.80	74.20	94.75	81.64
vs/%	71.33	90.25	85.35	78.98	82.37

Operating conditions

The mixed kitchen waste experiment used 1-2mm size samples for anaerobic digestion. Each group contained samples in triplicate. In the sequencing batch anaerobic digestion, egg whites, rice, mince fat, and lettuce were selected as the fermentation materials to stand for the proteins, starches, lipids, and celluloses in the single component digestion experiments. Each group used three devices, including pure inoculums as blanks. Fifty grams of fermentation material (fresh sample) and 300ml sludge were added to each reactor, expect for the blank. Then, water was added to the fermentation tank so as to equal a final volume of 1L, and afterwards, was allowed to ferment for 36 days at 37°C. The fermentation broth was measured every 2-3 days, and the corresponding fermentation tank was removed after measurement.

Analytical methods

The total solids (TS) and volatile solids

(VS) were determined using standard techniques [8]. Biogas production was measured by the displacement of water. The amounts of methane, carbon dioxide, and others in the biogas were measured by a gas chromatograph (Shimadzu, GC14B, Japan) that was equipped with a thermal conductivity detector. Specifically, a GC column with TDX-01 (2m×3mm) and GDX-502 (2m×4mm) was used. The temperatures of the injector, column, and detector were set at 40, 120, and 120°C, respectively. Helium was used as a carrier gas at a flow rate of 30 mL/min[9-11].

The liquid sample was centrifuged at 6000 rpm/min at 0–4°C and then filtered with 0.45 lm cellulose acetate membranes. The VFAs concentration[10-11] was measured by HPLC (Shimadzu, GC14B, Japan) using a gas chromatograph equipped with a flame ionization detector (FID) and a 30 m× 0.25 mm×0.25 lm fused silica capillary column (DB-FFAP). Nitrogen was used as the carrier gas at a flow rate of 30 mL/min, and the split ratio was 1:50. The operational temperature at the injection port and the detector were 250 and 300°C. The oven's initial temperature was 100°C for 5 min but was then increased to 250°C at a rate of 10°C/min and maintained for 12 min.

The pH was determined by a pHS-3C pH meter. All tests were carried out three times, and the data presented in this paper are all mean values.

RESULTS AND DISCUSSION

Evolution of pH and VFAs

Fig. 1 illustrates the evolution of pH and the total VFAs as well as the evolution of acetate, butyrate, formate, and propionate. The initial pH of the kitchen waste anaerobic digestion was 4.5. In order to prevent a low pH-induced toxicity for the methane-producing bacteria, a 300 mL hydroxide sodium solution (3 N), which was the only addition in this experiment, was added into all the reactors at the end of first day, and as expected, the pH increased to 6.9 on day 4.The pH change of the starch and protein was similar to that of kitchen waste. However, the initial pH of paper and fats is higher, at 6.5-6.8, and with the ongoing anaerobic digestion, the pH value declined to 5.5 on day 12; therefore, 300 mL of hydroxide sodium solution (3 N) was added on day 12.14, The pH increased to 7.4 during the fifteenth day and then, decreased until it stabilized at 7.0.

The profiles of the temporal evolution of the total VFAs illustrated three different stages: first, the total VFAs increased from day 0 to day 3 to a maximum value of 3426 mg/L; second, during the last 9 days, the total VFAs ranged from 2907 to 2359 mg/L until they decreased to 1329 mg/L on day 12; and finally, the total VFAs stabilized at 650 mg/L for the kitchen waste anaerobic digestion. The volatile fatty acids concentration in the reactor was determined by their generation rate and their consumption rate.During the first stage, hydrolysis and acidogenesis occured, and the easily biodegradable fraction of organic waste was converted into volatile fatty acids (such as propionate and acetate). However, the methanogens were in the adaptation period. During the second stage, aceticlastic methanogens were in their exponential growth phase, and the acetic acid consumption rate was higher than its generation rate even though the hydrolysis and acidogenesis were still on-going. Hanaki et al. (1994) pointed out that the oxidation of propionate to acetate is more difficult than that of butyrate and valerate to acetate. This explains why the propionate concentration is initially higher than the others during the first and second stage in the present study. During the final stage, the equilibirum between the hydrolysis/acidogenesis and methanogenesis was reached. The produced VFAs were immediately consumed in order to generate methane. This indicates that the hydrolysis of the organic waste is the rate-limiting step. This situation usually occurs in the later period when the remaining substrate is the hard biodegradable fraction, such as lignocellulose, feathers, and leather[12-13].

Biogas production, efficiency, and composition

After 50 days of sequencing batch anaerobic digestion, the biogas or methane production rate (BPR or MPR), methane content, cumulative biogas, and methane production are used to describe the biogas production process, and the results of which are illustrated in Fig. 2. The BPR or MPR profile (data not displayed in this paper) was similar for each feed. From the very first day, the kitchen waste sample generated gas, and by day 6, it achieved its maximum methane production rate of 32.32 mL/g. The cumulative

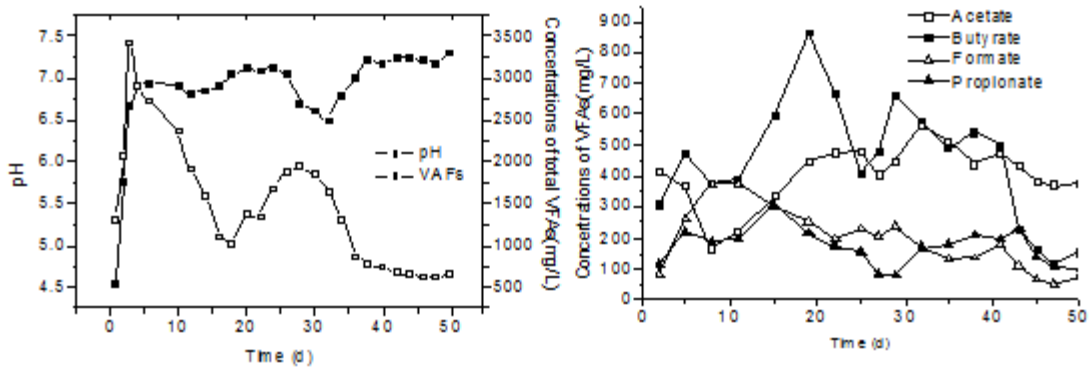

Fig. 1. Evaluation of total VFAs, pH and VFAs for kitchen waste AD

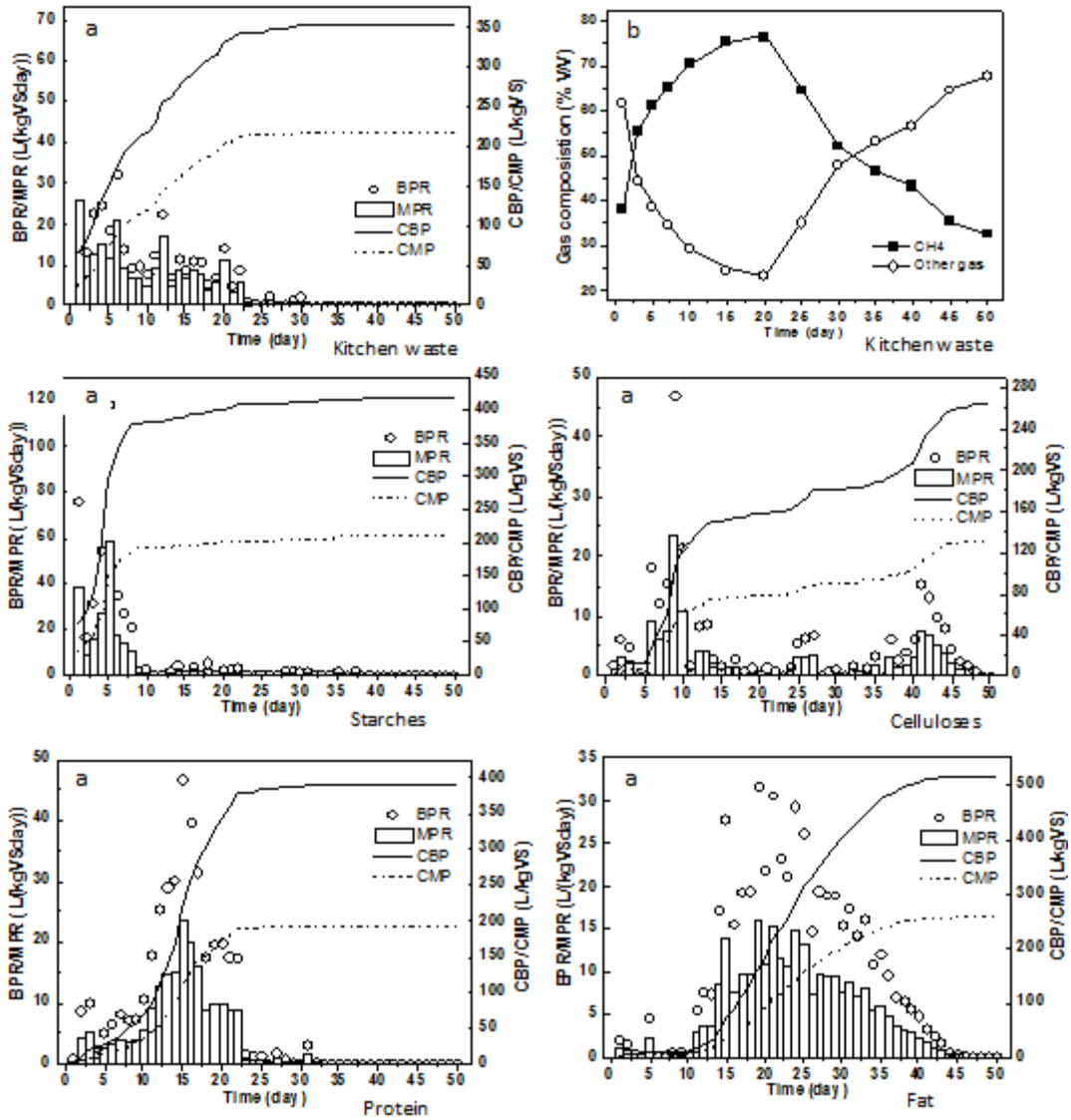

Fig. 2. Evolution of the biogas/CH_4 production rate (BPR/MPR), cumulative biogas/CH_4 production (CBP/CMP) (shown as a) and gas composition (shown as b) for kitchen waste and its components' anaerobic digestions

methane production of the kitchen waste after fifty days was 218.15 L/kgVS_{feed}. Compared to the other four feeds, the protein, paper, and animal fats had less initial gas productionÿand protein and animal fats achieved their maximum methane production rates of 23.27 and 15.91 mL/g on the15th and 19th days, respectively. The final methane potentiality of the kitchen waste was 194.2 and 257.82 L/ kgVS_{feed}, respectively. The protein and starch were similar to the kitchen waste. Fig. 2 also indicates that there was no obvious inhibition of metals on the anaerobic digestion. As Figure 2 shows, for the whole anaerobic digestion process, the methane gas concentration increases at first but then this trend slows. At the start of the digestion phase, all the feeds' methane concentrations are very low, about 30 ~ 40%; however, as the gas production increases and the methane gas concentration also gradually increases, the methane concentrations of kitchen waste, starch, protein, paper, and animals fats, on days 11, 21, 22, 23, 33, and 28 reached 70-80% and then drops down to around 35%. The average methane concentration is about 55-58%.

Biogas production and evolution of organic ingredients

Compared to the evaluation of biogas production, efficiency,and FAs, there were two distinct peaks of biogas and methane production rates that were detected in all the reactors. The first small peaks were observed on day 1 to 5, and the second peaks were observed on day 15 to 25. Charles *et al*.[11] also observed two peaks of methane production rates in his batch thermophilic anaerobic digestion of organic municipal solid waste. He believed that the second peak corresponded with the acetate consumption; however, the first peak of the methane production was related to H_2/CO_2 consumption. In this study, the first peak coincided with an acetate accumulation (Fig.1) and with a decrease in the H_2/CO_2 concentration (Fig.2). This suggests that, unlike continuously fed anaerobic digesters (operating at a steady state), the batch anaerobic digestion of solids waste systems creates a dynamic condition change. The hydrolysis and acidogenesis of the easily biodegradable organic fraction generates both volatile fatty acids and H_2 during its start-up. Since the methanogenesis from acetate (aceticlastic methanogenesis) was limited in the presence of high H_2 partial pressure [14015], it is most likely that, in start-up stage, the methane formed purely from the H_2/CO_2 (hydrogenotrophic methanogenesis) rather than from acetate [16].

Comparative process efficiency

After 50 days of anaerobic digestion, the kitchen waste's digested residue characteristics and each of its components in all the reactors were analyzed, and the results are presented in Table 2. The kitchen waste removal efficiency of TS and VS in anaerobic digestion was 28.64% and 56.88%. Compared with its other components, starch, protein, paper, and animal fats achieved a removal efficiency of 9.79%, 14.67%, 21.00%, and 17.64% for TS and 31.23%, 37.33%, 34.59%, and 46.38% for VS, respectively.

Table 2 shows the overall anaerobic digestion performance for different feeds. The highest VS removal rate maxed at 56.88%, which was much higher than any single component. The

Table 2. Comparison of anaerobic digestion performance for different feeds

	Kitchen waste	Starch	Protein	Paper	Fats
Feed(gTS)	6.11	7.56	4.84	18.95	16.33
Feed(gVS)	3.27	2.69	2.25	11.91	6.49
Residue(gTS)	4.36	6.82	4.13	14.97	13.45
Residue(gVS)	1.41	1.85	1.41	7.79	3.48
TS removal (%)	28.64	9.79	14.67	21.00	17.64
VS removal (%)	56.88	31.23	37.33	34.59	46.38
Biogas yield(L/kgTS_{feed})	127.90	107.21	121.01	119.30	120.51
Biogas yield(L/kgVS_{feed})	395.49	395.22	354.46	229.26	465.77
CH_4 yield(L/kgTS_{feed})	70.55	56.72	66.30	68.38	66.71
CH_4 yield(L/kgVS_{feed})	218.15	209.11	194.2	131.41	257.82
Average CH_4(%)	55.16	52.91	54.79	57.32	55.35

methane yield was approximately equivalent to each feeds per TS. However, the methane yield of kitchen per VS was slightly higher than the others feeds expected the fats sample. Generally speaking, anaerobic digestion has significant potential for progressing the study of kitchen waste and each its components in China. The organic fraction can be effectively separated from the municipal solid waste by separation and then used as substrate for biogas production by anaerobic digestion. Therefore, the separation is important for anaerobic digestion[17-18]; however, there is still room for improving the separation effect. The first task would be to minimize the amount of inorganic components, such as small gravel and sand, which are contained in the organic fraction. The second would be to effectively separate out the combustible but hard biodegradable organic matter, such as chopstick, small piece of branches, wood and bamboo. Meanwhile, pretreating kitchen waste in order to enhance biodegradability as well as thermophilic anaerobic digestion for improving the biogas production performance have been proposed and are currently being carried out[19-21].

CONCLUSION

The profiles of the total VFAs temporal evolution indicated an initial increase from day 0 to day 3 to a maximum value of 3426 mg.L. During the last 9 days, the VFAs concentration ranged from 2907 to 2359 mg/L before it decreased to 1329 mg/L on day 12. Finally, the total VFAs stabilized at 650 mg/L for the kitchen waste anaerobic digestion.

From the very first day, the kitchen waste sample produced gas, and by day 6, it had achieved its maximum methane production rate of 32.32 mL/g, and the cumulative methane production for the kitchen waste after 50 days was 218.15 L/ $kgVS_{feed}$.Compared to the other four feeds, protein, paper, and animal fats produced less initial gasÿand the protein and animal fats at day 15 and 19achieved the maximum methane production rate by 23.27 and 15.91 mL/g. The final methane potentiality of the kitchen waste was 194.2 and 257.82 L/ $kgVS_{feed}$, respectively. The average methane concentration is about 55-58%.The kitchen waste removal efficiency of TS and VS in the anaerobic digestion was 28.64% and 56.88%. Compared with the other components, starch, protein, paper, and animal fats achieved a removal efficiency of 9.79%, 14.67%, 21.00%, and 17.64% for TS and 31.23%, 37.33%, 34.59%, and 46.38% for VS, respectively.

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