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# Anaerobic digestion of food waste stabilized by lime mud from papermaking process

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## HIGHLIGHTS

- $CH_4$ production from food waste by a single-stage with LMP addition was proposed.
- Maximum $CH_4$ yield of 272.8 mL/g VS was obtained at 10 g LMP/L and 19.8 g VS/L.
- No VFAs, $NH_4^+$-N inhibition when LMP added and optimal VS removal (47%) were found.
- Alkalinity and elements of LMP favored anaerobic stability and $CH_4$ yield.

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## ABSTRACT

The effects of lime mud from papermaking process (LMP) addition as buffer agent and inorganic nutrient on the anaerobic digestion stability of food waste (FW) were investigated under mesophilic conditions with the aim of avoiding volatile fatty acids accumulation, and inorganic elements deficiency. When LMP concentration ranged from 6.0 to 10 g/L, the FW anaerobic digestion could maintain efficient and stable state. These advantages are attributed to the existence of Ca, Na, Mg, K, Fe, and alkaline substances that favor the methanogenic process. The highest $CH_4$ yield of 272.8 mL/g-VS was obtained at LMP and VS concentrations of 10.0 and 19.8 g/L, respectively, with the corresponding lag-phase time of 3.84 d and final pH of 8.4. The methanogens from residue digestates mainly consisted of *Methanobrevibacter*, coccus-type and sarcina-type methanogens with LMP addition compared to *Methanobacteria* in control. However, higher concentration of LMP inhibited methanogenic activities and methane production.

## 1. Introduction

In China, the disposal of organic wastes is becoming a severe problem: the daily Chinese urban waste production exceeded 65 million ton in 2013, containing about 30% of food waste (FW). In addition, the increasing consumption of paper adds an additional growing inorganic waste problem of the lime mud from papermaking process (LMP). LMP generated from the causticizing process in sulfate pulp production has a considerable fraction of $CaCO_3$ and slight amounts of elements, such as Mg, Na, Fe and mineral fillers, which makes it extremely difficult to deal with or reuse. Anaerobic digestion has been proven to be an efficient and green technology for the treatment of FW and animal manure due to the advantages of reducing waste and producing renewable energy in the form of biogas (El-Mashad et al., 2010).

Due to the characteristics of FW with high contents of volatile solids and moisture (Kim et al., 2011), it could be quite beneficial for energy recovery and reduction if treated by anaerobic digestion. However, anaerobic digestion of FW alone may suffer from low methane yield, instability and even process failure due to volatile fatty acids (VFAs) concentrations and inorganic elements deviations from optimality. There are few reports about successfully operating single-stage anaerobic digestion of FW alone at higher organic loading rate (OLR) due to the high biodegradability of FW and its sequent intermediates that could decrease pH within a short period. Anaerobic digestion of FW alone was not stable at the OLR of 4.0 g-VS/(L d), as indicated by high VFAs concentrations and low pH in the digestion system and low biogas production rate (El-Mashad et al., 2008). Meanwhile, co-digestion could be beneficial due to dilution of toxic chemicals, enhanced balance of

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nutrients, and synergistic effect of microorganisms (Li et al., 2010b; Mshandete et al., 2004; Parawira et al., 2004). Additionally, the digestion allowed higher organic loadings and gave a more stable process (Zhang et al., 2012). If sufficient buffering is provided, FW can be better utilized for energy production. Since proteins rich in substrates could provide good buffering capacity, highly nitrogenous wastes can be co-digested with FW to increase the stability of the anaerobic process. Zhang et al. (2013a) found that, at an optimum FW to cattle manure ratio of 2:1 (w/w), the total methane production in batch tests was enhanced by 41.1%, and the corresponding methane yield was 388 mL/g-VS. Furthermore, they indicated that the addition of cattle manure enhanced the buffer capacity of anaerobic system. Similar results were obtained that methane yield from FW and sewage sludge (SS) mixed in the ratio of 1:1 (w/w) at mesophilic (35 °C, 215 mL/g-VS) and thermophilic (55 °C, 280 mL/g-VS) temperature increased higher than those from SS alone at 35 °C (116 mL/g-VS) and 55 °C (163 mL/g-VS), respectively (Kim et al., 2003). Although co-digestion process of FW and nitrogen-rich organic wastes (e.g., animal slurry and SS) shows better stability and high methane yield compared to anaerobic digestion of FW alone, this digestion technology significantly restricts the FW disposal capacity.

Buffering is required to maintain pH within a desired range of 6.8–7.8 in the FW anaerobic digestion due to VFAs accumulation. pH plays a critical role in governing metabolic pathways of microorganisms, and methanogens are more liable to be affected by lower pH and grow slower than fermentative microorganisms. FW can be co-digested with highly nitrogenous wastes to enhance the stability of fermentation process, but it maybe also lead to N-accumulation, and associated inhibition when operating with an excess N-concentration of feedstock (Wang et al., 2013). Besides, the maximum hydrogen yield of 137.6 mL/g-VS was obtained when LMP was added to FW that reinforces the hypothesis of synergistic effects and provides a suitable buffering agent for a carbohydrate-rich to generate hydrogen (Zhang et al., 2013b). Trace elements are also necessary nutrients for cell growth in microbiology in order to improve the stability of anaerobic digestion, but the issue of lack of trace elements was often ignored in the practical application. Generally, FW contains low contents of trace elements, maybe leading to the failure of its anaerobic digestion (Zhang et al., 2011). Supplementation of essential trace elements (e.g., Ca, Mg, Fe, Cu, Zn, Mn, Mo, Co, Mo, Ni, and Se) has been shown to be important to maintain the stability of anaerobic process, and consequently increase methane production (Yadvike et al., 2004; Zhang et al., 2011).

In previous studies of anaerobic digestion, the formation and function of a buffer system were merely attributed the buffer to a common phenomenon without in-depth discussion (Zhang et al., 2013b; Nielsen and Angelidaki, 2008). The free $NH_4^+$-N converted from N-resource, and the $CaCO_3$ of LMP establishes a good buffer system combining with the VFAs produced by the hydrolytic acidification bacteria, thus enhance the tolerance of VFAs in the batch anaerobic fermentation system (Zhang et al., 2013b). Although it has been reported that the addition of LMP into FW can synergistically enhance bio-hydrogen performance (Zhang et al., 2013b), no study has been conducted to address the stability, the buffer capacity and the nutrient characteristics in FW anaerobic digestion with LMP addition for methane production.

The objectives of the present research were therefore to evaluate the performance of anaerobic digestion from FW in terms of stability by adding LMP. It includes threefold: (i) examine the buffering effect of LMP; (ii) identify the addition dosages of LMP for enhancing microbial consortia proximity; and (iii) assess the inorganic nutrients of LMP. The criteria for judging the success of anaerobic digestion of FW added with LMP were process stability, soluble chemical oxygen demand (SCOD), VFAs, acidity or alkalinity, and methane production.

## 2. Methods

### 2.1. Preparation of substrates and inoculum

Food waste (FW) was taken from a cafeteria at the Qilu University of Technology campus in China, which was made up of vegetables, rice, steamed bread, fruits and a small amount of meats. FW was shredded and masticated into smaller than 1.5 mm in diameter. Then it was further homogenized by using a blender in order to obtain uniform slurry, packed into 4-L plastic storage containers, and frozen at −16 °C. The frozen feedstock was prepared to thaw prior to using as experimental substrate, and stored at 4 °C for no more than one week. The characteristics of FW are given in Table 1, with the comparison of previous literature data. There are some differences in total solid (TS), volatile solid (VS), C/N, and contents of trace elements (e.g. Na, K and Ca) due to differences between eating habits and FW collection. However, the previous studies focus on the co-digestion of FW with cattle manure to improve the stability of anaerobic process (El-Mashad et al., 2010; Zhang et al., 2011, 2013a).

Sewage sludge (SS) was taken from a municipal wastewater treatment plant in Ji'nan, China, which handles an average 50 kilotons of wastewater and generates approximately 250 tons of SS daily. SS was stored at 4 °C prior to the usage. Then it was cultivated in the culture medium containing glucose (4500 mg/L), yeast extract (100 mg/L), $NH_4Cl$ (380 mg/L), $KH_2PO_4$ (43 mg/L), $Na_2HPO_4 \cdot 12H_2O$ (112 mg/L), $MgCl_2$ (0.1 mg/L), $CaCl_2$ (0.1 mg/L) and $CuCl_2$ (0.1 mg/L), under anaerobic and mesophilic (37 ± 1 °C) conditions for 40 d, before inoculation. Chemical characteristics of the inoculum are as follows: pH: 7.3 ± 0.2, total alkalinity (TA, mg $CaCO_3$/L): 3115 ± 20, total solid (TS, wt.%): 4.0 ± 0.1, volatile solid (VS, wt.% of TS): 56.3 ± 0.2, soluble chemical oxygen demand (SCOD, mg/L): 2150 ± 20, and ammonia nitrogen ($NH_4^+$-N, mg/L): 239 ± 5.0.

### 2.2. Collection and characteristics of inorganic additives

Lime mud from papermaking process (LMP) was collected from a pulp and paper factory in Rizhao, China, containing primarily $CaCO_3$, CaO and several other minerals. It was oven-dried at 105 °C for 3 h and was used as inorganic additives in anaerobic digestion of FW. The compositions of LMP are largely related to raw materials and treatment process (Martins et al., 2007). LMP elemental composition (wt.%) was as follows: Ca (35.4 ± 0.05), Si (2.97 ± 0.02), Mg (1.82 ± 0.02), Na (5.42 ± 0.02), K (0.13 ± 0.01), Fe (1.12 ± 0.01), Mn (0.56 ± 0.01), S (1.72 ± 0.01) and P (0.37 ± 0.01). Its specific surface area (4.95 ± 0.02, $m^2\ g^{-1}$) and surface microstructure have also been determined as previously described (Zhang et al., 2013b).

### 2.3. Anaerobic digestion experiments

A series of batch experiments were carried out in 800 mL glass digesters with an effective volume of 500 mL at a mesophilic temperature of 37 ± 1 °C for 40 d. These digesters were equipped with two ports for sampling slurry and gas, respectively. Fifty grams of FW (wet weight) added into each glass digester at different addition amounts of LMP (1, 3, 5 and 7 g), then they were fully mixed and diluted by the appropriate amount of deionized water to avoid damaging microbial growth due to the high alkalinity of LMP. Subsequently, 100 mL of inoculum was added into each glass digester, and filled up to the working volume of 500 mL with deionized water. Therefore, the LMP concentration in the corresponding