Science of the Total Environment 643 (2018) 21–27

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Evaluation of anaerobic digestion of food waste and waste activated sludge: Soluble COD versus its chemical composition

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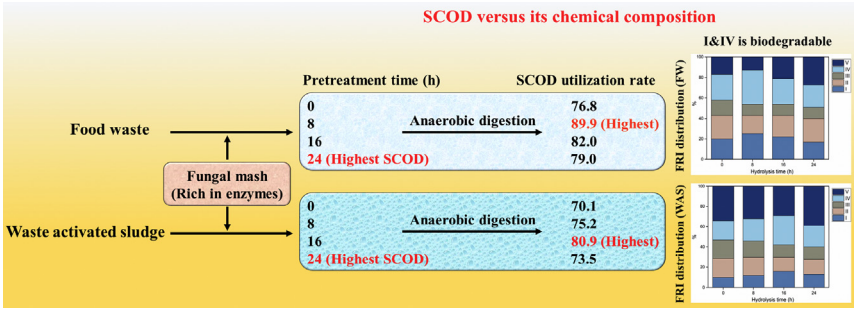
HIGHLIGHTS

- Biodegradability of SCOD released from FW and WAS was evaluated.
- Non-biodegradable organics in SCOD were accumulated with prolonged hydrolysis.
- SCOD is not a suitable parameter to alone determine the AD performance.
- The compositions of SCOD have a great impact on the methane yield.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 24 April 2018
Received in revised form 14 June 2018
Accepted 14 June 2018
Available online xxxx

Editor: Zhen (Jason) He

Keywords:
Anaerobic digestion
Soluble COD
Food waste
Waste activated sludge
Fungal mash

ABSTRACT

The hydrolysis as an essential step in anaerobic digestion has been commonly evaluated according to the extent of soluble chemical oxygen demand (SCOD) released from biosolids. However, little information is currently available for the effect of chemical compositions of SCOD on anaerobic digestion. This study showed that the non-biodegradable, recalcitrant organics in SCOD released from food waste and waste activated sludge pretreated with fungal mash rich in various enzymes were accumulated with the prolonged hydrolysis, while the methane production was closely related to the chemical compositions of the feed. The analyses by excitation emission matrix and size exclusion chromatography-organic carbon detection-organic nitrogen detection clearly revealed that the biodegradability of SCOD and the performance of anaerobic digestion were both determined by the chemical compositions of SCOD. These in turn challenged the present practice with SCOD concentration as a sole indicator in the selection and optimization of the pretreatment methods of biosolids prior to anaerobic digestion. It is expected that this study can offer useful insights into future design, optimization and operation of anaerobic digestion system in consideration of both SCOD concentration and its chemical compositions.

1. Introduction

The generation of food waste (FW) and waste activated sludge (WAS) has been continuously increasing with the expansion of global population and economic activity, which accounted for about 30–40% of total municipal solid waste (Guo et al., 2013; Ong et al., 2017; Raheem et al., 2017). The treatment and disposal of FW and WAS have posed a very serious emerging environmental challenge globally (Gu et al., 2017; Ma et al., 2017a). Currently, anaerobic digestion has been considered as a feasible technology for treating these two major types of organic wastes with the aims of solid reduction and biogas recovery (Hobbs et al., 2018; Qin et al., 2018; Scaglia et al., 2014; Eduok et al., 2017). However, only about 35–60% of total organic matter in FW and

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https://doi.org/10.1016/j.scitotenv.2018.06.187
0048-9697/

WAS could be anaerobically degraded due to the low hydrolysis efficiency (Yin et al., 2016). Evidence has clearly shown that hydrolysis of FW and WAS is a rate-limiting step in anaerobic digestion, thus many pretreatment methods, such as enzymatic (Ziemiński and Kowalska-Wentel, 2015), extruding (Panepinto and Genon, 2016), ultrasonic (Cesaro et al., 2014; Riau et al., 2015), mechanical (Ruffino et al., 2015), physical (Holmström et al., 2015), chemical (Song et al., 2014), and thermal (Li et al., 2017; Noguera-Oviedo and Aga, 2016; Ennouri et al., 2016) pretreatments, have been explored for enhancing biosolid hydrolysis prior to anaerobic digestion. For example, micro-aerobic hydrolysis combined with the addition of microelements had been reported as a pretreatment method for improving SCOD solubilization and subsequent methane production in anaerobic digestion of the sewage sludge, and ultimately the methane production was increased by 162–200% (Montalvo et al., 2018). Meanwhile, Ariunbaatar et al. (2015) reported a thermal pretreatment method prior to anaerobic digestion of food waste, and the biomethane production was increased by 44–46% after the thermal pretreatment. However, it should be noted that among all the methods, enzymatic pretreatment of biosolids exhibits various benefits, e.g. highly efficient breakup of biosolid, environmentally friendly, no use of chemicals etc. (Ometto et al., 2014; Yu et al., 2013). Recently, a fungal mash rich in various high-activity hydrolysis enzymes was produced from FW with nearly zero-cost (Ma et al., 2017a,b).

So far, the release extent of soluble chemical oxygen demand (SCOD) has been commonly considered as an essential indicator for evaluating the hydrolysis efficiency of various pretreatment methods. Obviously, such a practice is largely based on the assumption that biomethane yield is solely related to SCOD concentration. However, it should be noted that the concentration of SCOD and its anaerobic biodegradability are two totally distinct concepts. In order to generate high SCOD concentration, prolonged and even harsher pretreatments of biosolids have been adopted in the present practice. As a result, some highly recalcitrant soluble organics (e.g. high-molecular polymer) or inhibitory/toxic intermediates (e.g. long-chain volatile fatty acids, ammonia nitrogen etc.) may inevitably be generated, which in turn repressed the biomethane production in subsequent anaerobic digestion (Wilson and Novak, 2009). For example, during the thermal pretreatment of WAS, the generation of non-biodegradable organic compounds was observed at the temperature higher than 80 °C (Sun et al., 2016). The problem is when those recalcitrant or inhibitory compounds were returned back to the mainstream wastewater treatment process via digester liquor, they would negatively impact on the process performance and subsequently on the effluent quality. Thus, it is reasonable to consider that the compositions of SCOD should be seriously accounted towards proper selection and optimization of pretreatment methods of biosolids in addition to its concentration.

Therefore, this study aims to explore the effects of the chemical compositions of SCOD released from the enzymatic pretreatment of FW and WAS on anaerobic digestion. For this purpose, the chemical compositions of released SCOD were characterized by three dimensional excitation emission (3D EEM) and size-exclusion chromatography coupled with organic carbon detection and organic nitrogen detection analysis (LC-OCD-OND), and their changes over anaerobic digestion were also determined. It is expected that this study can offer useful information for future design, optimization and operation of anaerobic digestion system.

2. Materials and methods

2.1. Food waste and waste activated sludge

FW (22.2 ± 0.4% total solid) and WAS (10.8 ± 0.2 g/L total solid) collected from a university canteen and a local water reclamation plant were used as the feedstocks in this study, while the anaerobic sludge collected from a local municipal wastewater treatment plant was used as inoculum with 17.5 g/L of total solid and 12.6 g/L of volatile solid. The food waste used in this study mainly contained 635 ± 11 g of starch, 135 ± 3 g of protein, 62 ± 1 g of cellulose and 47 ± 3 g of lipid per 1000 g of dry mass.

2.2. Fungal mash production

Fungal mash rich in various enzymes was in-situ produced from FW by *Aspergillus oryzae*. Details can be found elsewhere (Ma et al., 2017a, b). The produced fungal mash was directly used for hydrolysis of FW and WAS without further separation.

2.3. Hydrolysis and anaerobic digestion

The collected FW was adjusted to a solid concentration of 100 g/L dry mass and was then mixed with 5% (w/w) of the produced fungal mash. The WAS directly mixed with the fungal mash in a way similar to the FW, without concentration adjustment. Hydrolysis of the FW and WAS were conducted in 1 L of Duran bottles (SCHOTT, German) with an operation volume of 500 mL, which were placed in a water bath shaker at 100 rpm and 60 °C. Samples were taken at different hydrolysis times of 0, 8, 16 and 24 h, respectively. After the hydrolysis, the solid and liquid in hydrolysate were separated by a filter with the mean pore diameter of 0.5 μm. SCOD, glucose, protein, volatile fatty acid and some other organic compounds (e.g. biopolymer, humic acid etc.) in the liquids were all analyzed. The biochemical methane potential (BMP) tests of the liquids from FW or WAS were conducted by using the automatic methane potential test system (AMPTS) II (Bioprocess Control AB, Sweden). In these tests, the liquids and 238 mL of anaerobic inoculum were filled into a series of 500-mL bottles, and the initial SCOD in the bottles were adjusted to 2000 mg/L. The anaerobic condition in the bottles was maintained by nitrogen gas sparging. A blank test with the anaerobic inoculum only was also performed. The BMP tests were conducted at 35 °C and 100 rpm. Lastly, all the experiments were performed in triplicate.

2.4. Analytical methods

2.4.1. Components analysis of liquids

SCOD and glucose were measured by the Hach kits (Hach, US) and Fast Multi-Assay Analyser GL6 (Analox Instruments Ltd., UK), respectively. Protein was determined by the Micro BCA™ Protein Assay Kits (Thermo Fisher Scientific, US), while volatile fatty acids (VFAs) in the liquids were analyzed with a gas chromatography (Agilent Technologies 7890A GC system, USA) equipped with a column (Zebron ZB-FFAP 30 m × 320 μm × 0.5 μm) and a flame ionization detector (FID). Prior to the analysis, 0.9 mL of filtered sample (0.2 μm) and 0.1 mL of 10% formic acid were added into a test vial. The temperatures for the injector and detector were set to 260 °C and 250 °C respectively. The oven temperature was step increased from 60 °C to 240 °C at a rate of 20 °C/min, with helium as a carrier gas at a constant pressure of 80.96 kPa. The split ratio was set at 20:1.

2.4.2. Three dimensional excitation emission matrix (3D EEM) analysis and humification index (HIX)

Organic compounds in the liquids were analyzed by Cary Eclipse Fluorescence Spectrophotometer (Model G9800A, Agilent, USA). In general, EEM spectra can be used to distinguish fluorescent compounds in complex mixtures (Wang et al., 2009). The operating conditions of the EEM were set according to Sun et al. (2016). HIX as an indicator of the humification degree was calculated according to the method by Bai et al. (2015).