Waste Management 79 (2018) 607–614

Contents lists available at ScienceDirect

Waste Management

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

# Effects of disposable plastics and wooden chopsticks on the anaerobic digestion of food waste

Jun Wei Lim [a], Daphne Wan Qing Ting [b], Kai-Chee Loh [b], Tianshu Ge [c], Yen Wah Tong [a,b,*]

[a] NUS Environmental Research Institute, National University of Singapore, 5A Engineering Drive 1, Singapore 117411, Singapore
[b] Department of Chemical and Biomolecular Engineering, National University of Singapore, 4 Engineering Drive 4, Singapore 117585, Singapore
[c] Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai 200240, China

ARTICLE INFO

*Article history:*
Received 31 January 2018
Revised 1 August 2018
Accepted 15 August 2018

*Keywords:*
Anaerobic digestion
Food waste
Contamination by disposable plastics
Batch study

ABSTRACT

A common challenge for the anaerobic digestion (AD) of food waste (FW) is the contamination by disposable plastic materials and utensils. The objective of this batch study was to investigate the effects of disposable plastic materials – polystyrene (PS), polypropylene (PP), high density polyethylene (HDPE) and wooden chopsticks (WC) on the AD of FW. Results showed that methane production from the AD of FW was inhibited to different extents when different materials were present in FW. PS and PP were found to reduce methane production from food waste more than HDPE and WC. The reduction in methane production was hypothesized to be due to the production of toxic plastic by-products or due to reduced contact between microbes and FW. Pyrosequencing and Field Emission Scanning Electron Microscope (FESEM) results indicated that the reduction in methane production was more likely due to the interference of good contact necessary between microbes and FW for biodegradation, and that the biological processes of AD were not affected by the contamination of plastics. Greater reductions in methane yields were also observed when the surface areas of the disposable materials were increased. Studying the effects of disposable materials on the AD of FW would provide plant operators with more information that could optimise the process of resource recovery from food waste.



## 1. Introduction

The total amount of solid waste generated in Singapore in the year of 2017 was close to 8 million tonnes, more than 10 percent of which was food waste (FW) (National Environmental Agency, 2018). FW is an environmental and social problem that continues to grow as more is produced every year. In Singapore, FW has increased by about 48 per cent over the past 10 years and this is expected to rise further with the country's growing population. According to waste statistics, FW ranked the second highest after plastics among all types of wastes disposed in Singapore. However, the recycling rate of FW is one of the lowest, at 16% (National Environmental Agency, 2018). The low recycling rate is caused by the lack of infrastructure, manpower and logistical costs to separate FW from its contaminants (Tay, 2011). Despite the low recycling rate, there was an increase in the amount of FW recycled by food manufacturers and wider adoption of FW digesters since 2016 (National Environmental Agency, 2018). Anaerobic digestion (AD) is a biological process that converts organic matter in FW into biogas to achieve waste stabilisation. AD has been proposed to be a sustainable alternative to manage increasing levels of disposed FW (Linville et al., 2015). AD of FW in Singapore faces the challenge of contamination since FW from eateries is commonly collected together with disposable plastic materials and utensils. Disposable materials and utensils are cheap, easy to use, and convenient for serving food. In addition, using these disposable materials requires no maintenance and is suitable for the Singapore context where there is a lack of manpower for cleaners. The problem of contaminated FW is not unique to Singapore. According to Gomez and Michel (2013), many waste management systems are commonly affected by high volumes of plastics that are often commingled with FW, making it difficult and impractical to recycle both organic fractions and/ or the plastics mixed with them without expensive cleaning, separation and sanitizing procedures.

There have been conflicting findings among the limited number of studies that investigated the effects of plastics on the AD process. Muthuswamy and Nemerow (1990) conducted a study in the 1980s to identify the effect of plastic refuse on the AD of municipal solid wastes. The authors found that plastics

* Corresponding author at: NUS Environmental Research Institute, National University of Singapore, 5A Engineering Drive 1, Singapore 117411, Singapore.

*E-mail addresses:* eriljw@nus.edu.sg (J.W. Lim), chelohkc@nus.edu.sg (K.-C. Loh), baby_wo@sjtu.edu.cn (T. Ge), chetyw@nus.edu.sg (Y.W. Tong).

https://doi.org/10.1016/j.wasman.2018.08.033
0956-053X/

accumulated at the liquid surface of digesters and the presence of plastics caused a decrease in biogas production. On the other hand, Gomez and Michel (2013) found that no significant degradation was observed for both non-biodegradable and biodegradable plastics over 50 days of AD. Another recent study on the co-digestion of FW, wastepaper, and plastic found that plastic could be efficiently co-digested and the presence of plastics did not inhibit the AD process (Wan et al., 2013). However, the study did not discuss the individual effects of waste paper and plastic on the AD process. There are also studies that reported AD facilitated the breakdown of plastics. Talvitie et al. (2015) found that more biogas was produced from anaerobic digesters when plastics were present. Another study by Shah et al. (2008) showed evidence of microbial breakdown of polymers during the AD of plastics.

Information related to the effects of plastics in the AD process is limited. In addition, the findings reported are not conclusive and require further investigation. The objective of this study was to determine the extent to which each of the four more commonly used disposable food packaging materials and utensils in Singapore (i.e., polystyrene (PS), polypropylene (PP), high density polyethylene (HDPE) and wooden chopsticks (WC)) affected the AD of FW. Results from this study would enable future FW recycling companies to plan for necessary pre-sorting steps which will help in optimising the performance of anaerobic digesters and their operating costs.

## 2. Materials and methods

### 2.1. Disposable plastics, wooden chopsticks, food waste, and inoculum

This study investigated the impact of disposable plastic materials – (1) HDPE; (2) PS; (3) PP; and (4) WC on the AD of FW. These materials were selected because they are commonly used as disposable packaging and cutleries in Singapore food centres. Soft plastic bags, styrofoam box, and hard plastic containers were used to represent HDPE, PS, and PP, respectively.

There are two different sets of experiments conducted in this study – experiment A and experiment B. The experimental set-up and operating conditions for both sets of experiments were exactly the same other than increasing the exposed surface areas of the disposable materials for experiment B.

New and clean plastic materials and WC bought from stores selling disposable wares were used in this study. For experiment A in this study, HDPE, PS and PP were cut into squares measuring 10 mm (width) by 10 mm (depth) by 1 mm (height) while WC was sawed into 10 mm (length) by 1 mm (diameter) long rods. For experiment B, HDPE, PS and PP were cut into squares measuring 5 mm (width) by 5 mm (depth) by 1 mm (height) while WC was sawed into 3.3 mm (length) by 1 mm (diameter) long rods. These plastics and WC were co-digested with FW collected from the canteen located at UTown within the campus of National University of Singapore. A total of 10 kg FW was collected and it consisted of a mixture of mainly rice and noodles with smaller portions of meat and vegetables. The pH value of FW collected was 4.3, and the total solids (TS) and volatile solids (VS) contents were 35%, and 25%, respectively. The C/N ratio of FW was 21. The composition of FW was 4.96% total fat, 18.84% available carbohydrate, and 5.35% protein.

The collected FW was blended into puree form using a household blender and mixed well to ensure a homogeneous mixture. Blended FW was packed into 10 separate portions of 300 g each and preserved by storage in the freezer at −20 °C. FW in this study were stored in the freezer for 2 days before thawing and used for experiment A. Experiments A and B were not conducted in parallel. Instead, experiment B was carried out 28 days after the start of experiment A because experiment B was initiated by the results of experiment A. Although experiments A and B were not conducted in parallel, the same FW was used as substrate for both experiments. Therefore, FW used as substrate for experiment B was stored in the freezer for 30 days before thawing. The inoculum used was anaerobic sludge collected from an anaerobic digester used to treat palm oil mill effluent (POME) in Johor, Malaysia (Keck Seng (M) Berhad). POME sludge was selected as inoculum because it resulted in a more consistent biochemical methane potential (BMP) with FW as substrate, as compared to the anaerobic sludge collected from a digester treating activated sludge from a wastewater reclamation plant in Singapore (PUB, Singapore). This was possibly due to the more consistent characteristics of POME sludge since the POME digester plant treats a specialised substrate (i.e., POME). POME sludge had a pH value of 7.6, and TS and VS value of 25 g/L and 12 g/L, respectively. The inoculum was "degassed", i.e. pre-incubated for 2 weeks at 35 °C to deplete the residual biodegradable organic material present in it. As the inoculum was taken from a POME reactor fed with relatively high fat/oil concentration, a much longer incubation time was required as compared to the 2 to 5 days as recommended by Angelidaki et al. (2009).

### 2.2. Batch study on effect of disposable materials on FW digestion

The experiments were carried out in glass reactors with total volume of 1,000 mL. The reactors were incubated at 35 °C over a period of 35 days for experiment A and 30 days for experiment B. The study period for both experiments ended when the cumulative methane production curves started to plateau. 600 mL of inoculum was added to all reactors and the digestion tests were performed at a substrate loading of 2 g-VS/L. Reactor contents were stirred manually for 1 min three times a day including once before sampling. The inoculum (POME sludge) to substrate (FW) VS ratio was 2:1 to avoid inhibition of the AD process due to rapid acidification of the FW. A total of 32 reactors were prepared for each of experiments A and B in this study. For both experiments A and B, two reactors were filled with only inoculum (duplicate blank sets) to record background methane produced from the inoculum. The average methane background value was then subtracted from the methane production recorded by other reactors to normalise the biogas data. The other 30 bottles were allocated for the reactors filled with substrates - six replicates for each of the following conditions: A1 (FW); A2 (FW and HDPE); A3 (FW and PS); A4 (FW and PP); and A5 (FW and WC). Similarly, the conditions for experiment B was: B1 (FW); B2 (FW and HDPE); B3 (FW and PS); B4 (FW and PP); and B5 (FW and WC). Methane yield was expressed in terms of mL/g-$VS_{FW}$ and was calculated on the basis of FW added to the reactor.

A1 and B1 (FW only) represented the ideal case of AD of uncontaminated FW while A2 to A5 and B2 to B5 served as a comparison to investigate the effects of each material on the AD of FW. The FW to disposable materials VS ratio were set at 2:1 for sets A2 to A5 and for sets B2 to B5. This ratio of FW to disposable materials was derived from the average data of FW (both table and kitchen FW) and plastics generated per person per day collected from 2 food centres in Singapore.

The reactors were flushed continuously with $N_2$ while transferring the substrate and inoculum accurately by volume (inoculum) and weight (FW and disposable materials). After transferring the inoculum and substrate, the reactors were closed with a thick butyl rubber stopper, which had a stainless steel rod drilled into it. Gas bags were attached to the rods for the collection and analysis of biogas produced by each reactor.