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Research paper

Methane Potential from the Digestion of Food Waste in a Batch Reactor

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Abstract

The anaerobic digestibility of a targeted substrate, measured as methane yield is conducted via biochemical methane potential (BMP). In this study, the batch BMP test was conducted using Automatic Methane Potential Test System (AMPTS II) for 25 days and focused on the methane production from the digestion of food waste (FW, in the form of raw and diluted) at inoculum to substrate ratio (I/S) ratio of 2:0 and under mesophilic temperature. The results showed that solids (TS and VS) concentration reduced significantly due to the dilution. The ultimate methane yields from the digestion of raw FW and diluted FW were 1891.91ml CH4/gVS and 1983.96 ml CH4/gVS respectively. This showed that the dilution significantly improved the methane yield. In addition, the lag phase of the methane yield curve for both BMP tests was less than one (1) day, showing the good biodegradability of FW. The kinetic methane production from laboratory data and Modified Gompertz modelling fitted well. However, the kinetic equation parameters such as Mo, Rm and λ from the model were slightly lower based on the observation of the laboratory data.

Keywords: *Anaerobic; BMP; Food Waste; Kinetic; Modelling*

1. Introduction

Food waste (FW) is one example of typical municipal biomass waste [1]. FW is an organic waste generated continuously from the households, restaurant, food court and canteen. The leftovers of food preparation and uneaten portions of meals are considered as food waste [2]. According to Kouichi [3] incineration was used for the disposal of FW in Japan. FW is expected to be a perfect substrate for anaerobic digestion because it contained high organic matter, high moisture content and it is readily biodegradable [4], [5] Due to the high organic content in FW, the conversion from conventional FW treatment to a sustainable FW treatment via anaerobic digestion should be conducted [5].
The research on anaerobic digestibility or biochemical methane potential (BMP) of FW is done in batch tests using laboratory or serum bottle [1], [4], [6]. BMP assay was conducted using any type of organic waste and inoculated with anaerobic sludge taken from an anaerobic digester. Recently, BMP assay was conducted using Automatic Methane Potential Test System (AMPTS II) [7]–[9].
The inoculum (anaerobic sludge) source and the inoculum to substrate (I/S) ratio affected the methane yield from the batch anaerobic digestion of FW. Batch anaerobic digestion of FW inoculated with anaerobic digested sludge from anaerobic digester in wastewater treatment plant showed the highest methane yield of 790 mL CH_4/ g VSS_{sub} at the I/S ratio of 2. On the other hand, the batch digestion of FW using anaerobic sludge from anaerobic digester treating source separated organic at the similar I/S ratio resulted in the lowest methane yield of 940 mL CH_4/ gVSS $_{sub}$ [6]. The methane yield from synthetic FW (different uncooked food were mixed and blended) was 426 mL CH_4/ gVS. While in another study, the ultimate methane production from digestion of FW was 531.3 mL CH_4/gVS [1]. The methane yield from treated FW generated in Malaysia was found ranging from 490 to 540 mL CH4/gVS. These values were observed from the diluted FW as the substrate for the batch digester inoculated with cow dung [10].
Based on literature search, it was found that no study has yet been conducted on the comparison of raw (undiluted) FW and diluted FW (generated in Malaysia) as the substrate for anaerobic digestion. Commonly, the anaerobic digestibility study was conducted either for raw FW or diluted FW without any comparison. Therefore, the main objective of the current study was to investigate the methane yield from the digestion of raw FW and diluted FW. A series of batch BMP tests were conducted to investigate the effect of the dilution and the kinetics of methane production was also evaluated.

2. Material and Methods

2.1. Substrate and Inoculum

Fresh FW was used in this study. The FW generation in Universiti Tun Hussein Onn Malaysia (UTHM) is approximately 620 kg/ day; which comes from several types of food mostly eaten by Malaysians and including Arabic food. The food waste was collected from a food court in our university. It was crush using a standard kitchen blender to homogenize the FW before use [11]. The blended FW was then stored in a refrigerator at 4°C until use [5]. The diluted FW was prepared using tap water (TW) at a ratio of 1:2 (FW: TW). Tap water was also used for dilution purposes by other researchers [5], [10]. The inoculum was collected from a full-scale anaerobic digester treating POME.

2.2. Experimental Setup

The batch BMP tests were conducted using 0.5 L Duran bottle using 2 types of substrate. The BMP assays was conducted using triplicate sample reactor (labelled as Raw FW reactor and Diluted FW reactor) and duplicate blank reactors; following the procedures as described previously by Seswoya & Karim [12]. The BMP assays were conducted at inoculum to substrate (I/S) ratio of 2.0 and at temperature of 37^{o}C. The BMP assays were conducted using Automatic Methane Potential Test System (AMPTS 11) in which only methane pass through to the gas volume measuring device and recorded [13]. Recently AMPTS II has been used for batch anaerobic digestibility study [9], [14].

2.3. Data and Statistical Analysis

All data presented in Table 1, and figures are representative of three independent experiments, and all tests were measured in triplicate for each experiment. However the data from blank reactor was an average from duplicate independent experiments.

2.4. Analytical Methods

The samples were measured for solids in g/L (TS and VS) and all tests were based on Standard Methods: procedure 2540G [15]. Meanwhile, VS in % was calculated following the calculation as shown by Bioprocess AB [13].

2.5. Batch Kinetics Modelling

The mathematical modified Gompertz model which has been widely applied in modelling batch methane production from FW digestion is shown in Equation 1 [16], [17]. This equation includes parameters for ultimate methane yield (Mo) and maximum methane production rate (R_m) and lag phase (λ) [17]–[19]. All the graphs and regression models were completed by Microsoft Excel, particularly Excel Solver to estimate M_o, R_m, and λ from the graphs which fit the experimental data set. Eskicioglu, et al., [20] also used Microsoft Excel Solver tool for nonlinear analysis.

$$M = M_0 . \exp\left\{- \exp\left[\frac{R_m . e}{M_0}(\lambda - t) + 1\right]\right\} \qquad (1)$$

Where,

M	= Cumulative methane yield (mL /g VS $_{added}$)
M_o	= Ultimate methane yield (mL /g VS $_{added}$)
R_m	= Maximum methane production rate (mL /g VS $_{added}$/day)
t	= digestion time (t)
e	= 2.718 [18]
λ	= The lag phase time (day)

3. Results and Discussion

3.1. Substrate Characteristics

The characteristics of substrates for this study were tabulated in Table 1. Due to the usage of tap water for dilution, the TS concentration of diluted FW was below than 100 g/L. Jianguo Jiang, et.al, [5] also used tap water for dilution to the FW to attain TS of 40- 100 g/L. The volatile solid to total solid (VS/TS) ratio from both substrate are exceeded 90 %. Meng, *et.al.*, [17] also the VS/TS ratio greater than 90% for FW obtained from university cafeteria.

Table 1.: Characteristics of FW analysed in this study (N =3)

Parameter	Types of substrates	
	Raw FW	**Diluted FW**
Total solids, TS (g/L)	171.44 ± 6.36	74.89 ± 1.39
Volatile solid, VS (g/L)	164.56 ± 4.83	73.00 ± 1.15
Volatile solid, VS (%)	4.60 ± 0.10	2.01 ±0.01

3.2. Methane Accumulation

The profile of cumulative methane during the 25 day assays is presented in Figure 1. The net cumulative methane, after subtracting the methane from blank for each substrate (raw FW and diluted FW) was approximately 800 mL. However, more than 90% of the methane production from raw FW and diluted FW were achieved after 13 and 10 days respectively. In other study, the maximum biogas (including methane) production was 1031.1 mL [17]. The maximum methane production was observed less than 25 days, the fastest was observed from the digestion of diluted FW at day 19; three (3) days earlier than what was observed for digestion of raw FW. Another researcher using FW for BP test observed the plateau condition before 20 days [1]. However for the synthetic FW, the maximum methane production was observed after 150 day [4].

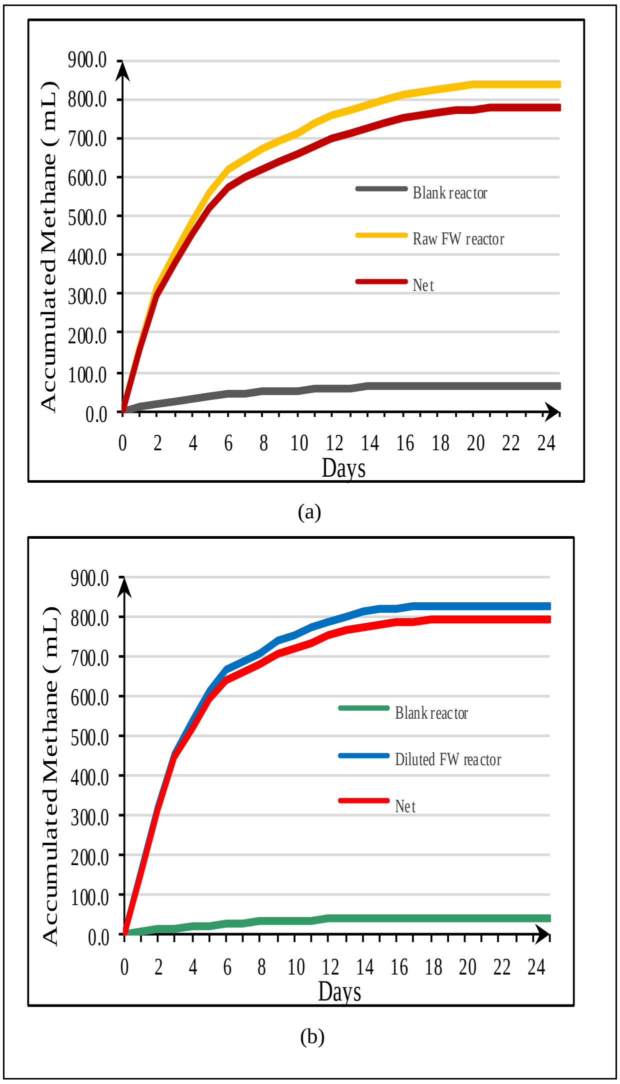


Figure 1. Methane accumulation from the digestion of FW (a) raw, and (b) diluted

3.3. Methane Potential

In this experiment, the raw and diluted FW was digested using anaerobic sludge (inoculum) obtained from a full- scale anaerobic digestion. Figure 2 depicted the methane yield of raw and diluted FW. As depicted from the figure, the methane yield from diluted FW is slightly higher than what was observed from raw FW. However, the ultimate methane yield was less than 2100 mL CH_4/g VS for each of them. Musa, et al., [10] showed that the different FW feed loading affected the methane yield. The FW feed loading at 3.5 g VS/L (or equals to ratio of the FW to water = 1:3) resulted in ultimate methane yield of 540 mL CH_4/ gVS. This value is quite low than what was obtained from this study probably due to the type of inoculum in which cow dung was used as inoculum. In addition, Elsayed, et al. [6] showed that the methane yield from the digestion of FW, conducted at I/S ratio of 2.0 was lower than 1000 mL CH_4/g VSS sub regardless of the sources of the inoculum.

Using the steepest slope of each methane yield curve, the methane production rate was calculated [12]. The methane production rates fluctuated between experimental setups, and it could differed significantly [6]. In this study the methane production rate from the digestion of raw and diluted FW were 362.9 mL CH_4/gVSd and 389.8 mL CH_4/gVSd respectively. However, the lower methane production rate at 296.9 mL CH_4/gVs was observed from FW taken from university cafeteria [17].

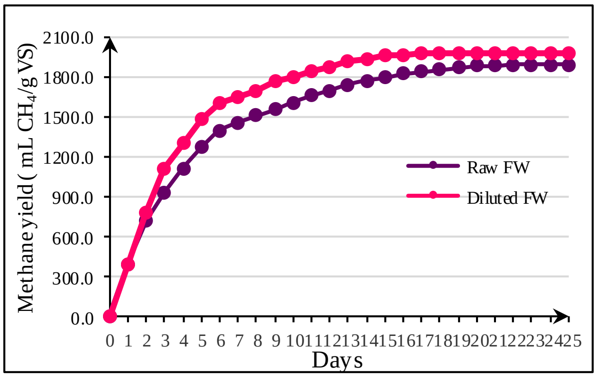


Figure 2: Methane yield

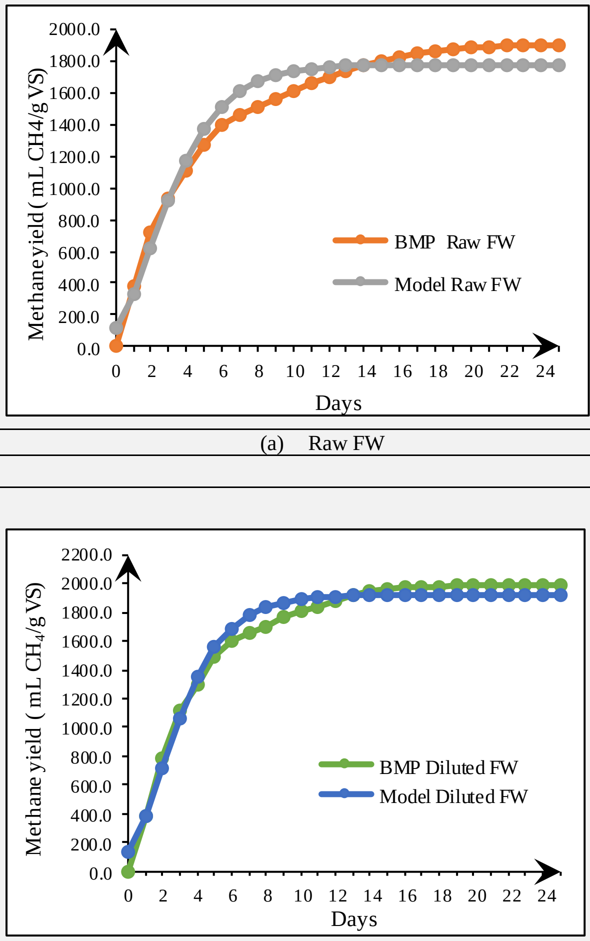
3.4. Kinetics of Methane Production

Table 2 and Figure 3 summarized the results of fitting the modified Gompertz model to the digestion data. M_o, R_m and λ were represented as the ultimate methane yield (in mL CH_4/g VS), methane production rate (in mL CH_4/g VSd) and lag phase (in day) and referred as kinetic equation parameters.

The kinetic equation parameters from the modified Gompertz modelling (G) are slightly lower than the values observed from the laboratory works. However it fitted well the laboratory data. In addition, from the modelling, more than 90% of the ultimate methane yield from raw FW and diluted FW were achieved at day seven (7). The lag phase of 0.04 day is low and could be neglected. In other study, the lag phase was 0.4 [17]. In addition no acclimation period of anaerobic microbes to the substrate were observed. Another researcher had also observed the absence of the lag phase from the digestion of FW [1].

Table 2: Kinetic equation parameters of methane production

	Raw FW (L)	Raw FW G)	Diluted FW (L)	DilutedFW (G)
M_o	1891.91	1779.50	1983.96	1921.30
R_m	362.87	308.43	389.77	360.45
λ	0.04	0.00	0.04	0.00



(a) Raw FW

(b) Diluted FW

Figure 3. Laboratory data and Modified Gompertz plots of methane yield curve

4. Conclusion

The ultimate methane yield from the batch digestion of raw and diluted FW at inoculum to substrate (I/S) ratio under mesophilic condition showed a significant difference between them. However, the highest ultimate methane yield was observed from diluted FW at 1983.96 mL CH_4 /g VS added, which is about 92 mL more than what was observed from the digestion of raw FW. This showed that dilution had slightly affected the methane yield. Despite this, the accumulated methane yield showed only slight difference between the two different types of FW (raw and diluted). In future, the various series of dilution factor and I/S ratio will be applied to estimate the methane yield from the digestion of FW.

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