Co-digestion of OFMSW with WAS Effect on Bio-Hydrogen Production under Dry Anaerobic Digestion Conditions

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The Asian Conference on Sustainability, Energy & the Environment 2014
Official Conference Proceedings
0742

Abstract
Total amount of municipal solid waste (MSW) is continuously rising. Consequently, environmental management of MSW produced every year has to be safely disposed without any negative impact on the environment. On other hand, usage of this waste as sustainable source for energy became a great point of interest. In Egypt, Municipal solid waste (MSW) produced from household only estimated to be about 20 million tons annually. Organic fraction of municipal solid waste (OFMSW) represents 60% of (MSW). In this study, anaerobic batch experiment conducted to explore effect of changing OFMSW to waste activated sludge (WAS) co-digestion ratio on bio-hydrogen production under thermophillic dry anaerobic digestion condition. The experiment was carried out at different co-digestion ratios between OFMSW and WAS as following sequence 0:100, 30:70, 45:55, 55:45, 60:40, 67:33, 70:30, 75:25 and 100:0% (v/v). The highest bio-hydrogen production achieved at co-digestion ratio of 70:30% (v/v). This was 5.2, and 3.1 times higher than co-digestion ratio of 0:100% (v/v) (sludge alone), and 30:70% (v/v), respectively. The maximum cumulative bio-hydrogen production of 23.40 mmol and bio-hydrogen production rate of 1.81 mmol/h were achieved at co-digestion ratio of 70:30% (v/v). This relates to maximum bio-hydrogen yield of 15.11 $mmol_{H2}/gCOD_{consumed}$, and was mainly due to consumption of COD (19.4%). The modified Gompertz equation model was highly fitted to the experimental data with correlation coefficient ($R^2 > 0.986$).

Keywords: Dry anaerobic digestion; thermophillic; OFMSW; co-digestion and metabolite products.

1. Introduction

Municipal solid waste (MSW) generation is increasing worldwide by rate of 2-3 % per year [1]. In Egypt, Total amount of generated municipal solid waste estimated to be about 21 million ton annually. The major biodegradable organic fractions represent 50-60%. Most of these waste disposed by throw in Dumpsite or landfill. Which Threatens the environment due to odor emanation, vermin attraction, toxic gas emission, and groundwater contamination [2]. However, Anaerobic digestion has been proven to be a reliable and economically feasible technology in full scale operations [3]. Anaerobic digestion is more attractive due to low energy consumption, cost effective, and can deal with several types of substrate for the production of hydrogen or methane, and eco-friendly [4]. Currently, interest in anaerobic digestion has grown due to technological developments in bioreactor design for the treatment of solid organic waste [1].

Nowadays, the environmental problems have brought the interests toward the development of alternative energy. Among the alternative energy sources, hydrogen has been receiving an increasing attention due to its environmentally friendly characteristic and high energy content [5]. Hydrogen is a promising alternative to fossil fuels. As a clean fuel it can be directly used to produce electricity in fuel cells and/or burnt with minimal pollutants emissions [6]. Hydrogen has a high energy yield of 122 kJ/g, which is 2.75 times greater than that of hydrocarbon fuel [7]. Generally, there are four available basic processes for the production of hydrogen from non-fossil primary energy sources. These processes include: (1) water electrolysis; (2) thermo-chemical processes; (3) radiolytic processes; and (4) biological processes. For global environmental considerations, bio-hydrogen production from renewable organic waste represents an important area of bioenergy production [8]. Hydrogen production from biological processes can be divided into two types i.e. photo-fermentation by cyanobacteria, algae, photosynthetic and chemosynthetice fermentative bacteria and dark fermentation by anaerobic bacteria. Hydrogen production from the dark fermentation process has advantages over the photo-fermentation process which is a low operating cost because light is not required and the rate of hydrogen production is greater [9].
Conventional Anaerobic digestion proceeds under wet state (Total solids <5%), which means a large amount of external water is required for diluting solids. This will accordingly not only increase the energy consumption for digester heating and feed slurry pumping, but also the volume of digester effluent that should be dewatered. To overcome these drawbacks, dry digestion or ‘‘high-solids digestion’’ can be employed in which solids with over 20% of TS are directly fed to the reactor [10]. In addition, operation temperature defines three different process conditions: thermophilic range (50-60°C), mesophilic range (20-40°C) and psychrophilic range (10-20°C) [11]. Thermophilic conditions are assumed to optimize the enzymatic activity of hydrogenase during fermentation by Clostridia, to inhibit the activity of hydrogen consumers and also to suppress the growth of lactate-forming bacteria [12]. On other hand, microbial analysis of the fermentation medium also indicated that the dominating species were lactic acid bacteria at 35°C and hydrogen-producers at 50°C, thus confirming the role of temperature in dictating the nature of microbial consortium during the process [13].

However, co-digestion involves the digestion of two substrates together as a way to improve digestion efficiency and increase the energy output [14]. OFMSW may have suffered from nitrogen shortage which is an essential nutrient for hydrogen producers.

Therefore, the concept of co-digestion of OFMSW and waste activated sludge (WAS) has been investigated to improve bio-hydrogen production, since the addition of WAS to OFMSW supplied a more balanced carbon to nitrogen (C/N) ratio [15]. As a result, the aims of this study are evaluation the effect of changing co-digestion ratio on hydrogen production and substrate fermentation process of organic fraction of municipal solid waste. Also, study the variations in volatile fatty acids production related to co-digestion ratio. Finally, study the effect of volatile solids content on hydrogen production and hydrogen yield.

2. Methodology

2.1. Substrates

The substrate was a mixture of organic fraction of municipal solid waste (OFMSW) and waste activated sludge (WAS). OFMSW, sampled from restaurant of the campus of Egypt-Japan University of Science and Technology, Alexandria. OFMSW was crushed by an electrical blender. WAS was taken from a gravity sludge thickener into which secondary sludge were added. WAS pre-heated at 100 °C for 15 minutes to inhibit the bioactivity of hydrogen consumers and to harvest spore-forming anaerobic bacteria [16]. All the substrates were filtered through a stainless steel sieve (US Mesh No. 10 with corresponding sieve opening of 2.00 mm), of which the characteristics are summarized in Table 1.

Table 1 characteristics of OFMSW and WAS.

Parameters	Unit	OFMSW	WAS
Density	kg/m^3	1008.4 ± 21.4	804.2 ± 35.9
Total solids (TS)	%, (w/w)	32.29 ± 2.99	4.89 ± 0.31
Volatile solids (VS)	%, (w/w)	30.07 ± 2.03	3.11 ± 0.05
VS/TS	%	93.12 ± 3.02	63.78 ± 3.70
COD	g/L	65.78 ± 0.61	16.67 ± 1.59
Carbohydrate	g COD/L	37.69 ± 2.32	1.32 ± 0.05
Total Kjeldahl nitrogen (TKj-N)	g/L	2.1 ± 0.1	1.9 ± 0.0
Ammonia (NH_4-N)	mg/L	328.7 ± 28.3	411.5 ± 36.1
Lipids	g COD/L	2.97 ± 0.12	---
Proteins	g COD/L	19.72 ± 0.94	17.84 ± 0.63
C/N		31.36 ± 1.29	8.77 ± 0.84
Salinity	ppm	1.1 ± 0.2	---
Total volatile fatty acids (TVFAs)	mg/L	1642.5 ± 162.3	618.26 ± 47.5

2.2. Experimental procedures

Batch tests were conducted in 250 ml serum bottles with working volume 150 ml as shown in Fig. 1. The working volume was firstly filled with pretreated waste activated sludge (WAS) (the volatile suspended solid (VSS) of the sludge was 15.0 g/L). The volume percentages of WAS used in this study were 100, 70, 55, 45, 40, 33, 30, 25, and 0%. Then, the bottles filled with organic fraction of municipal solid waste till reach 150 ml. The initial pH of the mixture in each bottle was adjusted to 5.5 by 1 mol/L HCl or 1 mol/L NaOH. Each bottle was flushed with nitrogen for 3 min to provide anaerobic condition, capped with a rubber stopper, and placed in oven. The batch tests were conducted at 55°C. Each batch test was done three times (triplicate).

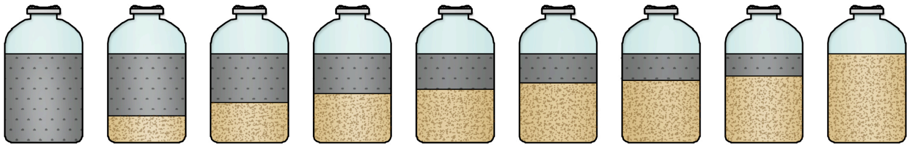

Fig. 1 Experimental batch serum bottle design

2.3. Analytical methods

Table 2 illustrate measurements taken in this research, and the method followed for each one.

Table 2 Methodology of measurements.

Parameter	Method
Gas volume	Displacement method
Gas composition	Gas chromatograph (GC) (GC-2014, Shimadzu, Japan)
Volatile fatty acids (VFAs)	High performance liquid chromatography (HPLC) (LC-10AD, Shimadzu, Japan)
Total solids (TS) , Volatile solids (VS), Chemical Oxygen Demand (COD), Total Kjeldahl nitrogen (TKj-N), Ammonia, Salinity and Lipids	According to APHA [17]
Protein	6.26 × TKj-N [18]
Carbohydrate	Phenol–sulfuric acid method [19]

2.4. Kinetic model

The hydrogen production curve was fitted to a modified Gompertz equation (1), which was used as a suitable model for describing the hydrogen production in batch tests [20].

$$H = P \times \exp\left(-\exp\left[\frac{R_m \times e}{P}(\lambda - t) + 1\right]\right) \qquad (1)$$

Where: H was cumulative hydrogen production (ml), P was ultimate hydrogen production (ml), R_m was maximum hydrogen production rate (ml/hr), λ was lag-phase time (hr), and e was exponential 1.

3. Results and discussion

3.1. Effect of co-digestion on hydrogen production

The cumulative hydrogen production at different co-digestion ratios between OF-MSW and WAS for all batches are shown in Fig. 2. Maximum and minimum deviations of the triplicates are shown also in the figure. The results showed that hydrogen production in batch tests increased with increasing co-digestion ratio from 0:100 to 70:30%. However, it decreased with increasing co-digestion ratio from 70:30 to

100:0%. In this study, the maximum hydrogen production potential of 23.40 mmol was obtained at the co-digestion ratio of 70:30%. This demonstrated that in an appropriate range, increasing substrate concentration could increase the hydrogen production potential during the fermentative hydrogen production, but substrate at much higher concentration could decrease it with increasing concentration.

In this study, the modified Gompertz model eq. (1) was used to fit the cumulative hydrogen production data obtained from each batch test to obtain R_m and λ. The correlation coefficient between the experimental and simulated data was relatively high (R^2 = 0.986), which indicated that the modified Gompertz model could describe the progress of cumulative hydrogen production in the batch tests of this study successfully. The maximum hydrogen production rate (R_m) was 1.81 mmol/hr. achieved at co-digestion ratio of 70% OFMSW to 30% WAS. In which, lag phase was 7.5 hr.

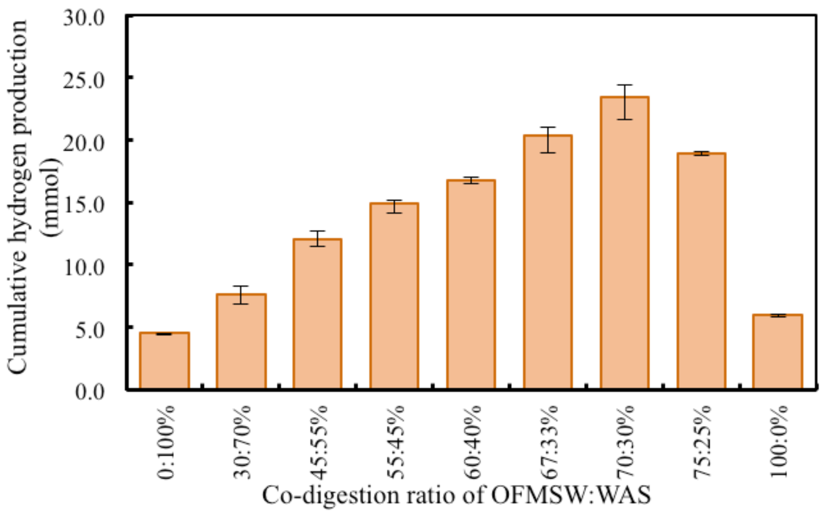

Fig. 2 Hydrogen production due to changing co-digestion ratio.

3.2. Effect of co-digestion on substrate degradation

The effect of co-digestion ratio on COD removed and efficiency of removal shown in Fig. 3. The results showed that increasing the percentage of OFMSW increase the removed COD from 0.66 g at 0% till reached 1.55 g at OFMSW percentage of 70%. Further increase in OFMSW (%) decrease the removed COD till reached 1.41 g at 100% OFMSW. However, the removal efficiency percentage calculated by dividing the removed COD on the initial COD decreased with increasing OFMSW percentage. As, removal efficiency percentage started with 30.1% at OFMSW 0% till reached 14.3% at OFMSW 100%.

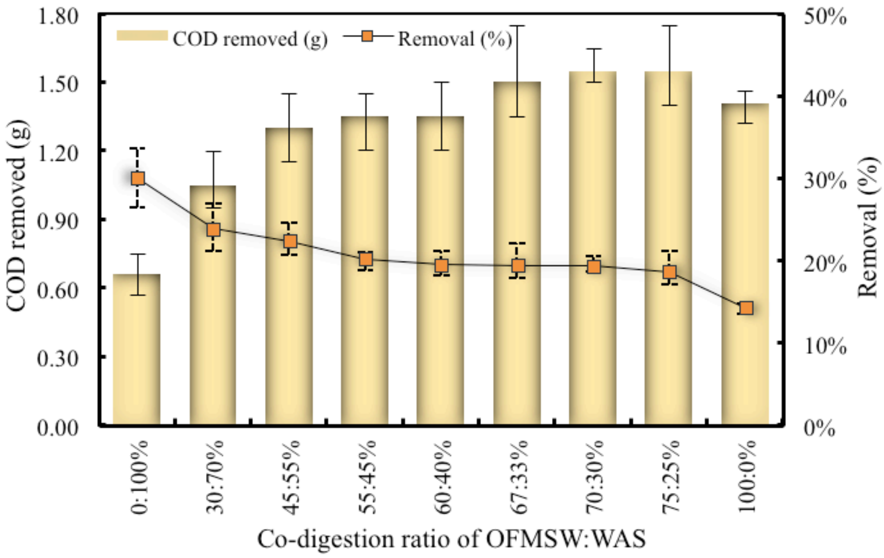

Fig. 3 COD removal due to changing co-digestion ratio.

3.3. Effect of co-digestion on hydrogen yield:

The hydrogen yield was calculated by dividing the cumulative hydrogen production by the amount of COD removed in each batch test. Fig. 4 shows the effect of co-digestion ratio on hydrogen yield. Hydrogen yield increased from 6.93 $mmol_{H2}/gCOD_{consumed}$ at co-digestion ratio (OFMSW: WAS) of 0:100% till reached 15.11 $mmol_{H2}/gCOD_{consumed}$ at 70:30%. Additional increase in OFMSW beyond 70% decrease hydrogen yield.

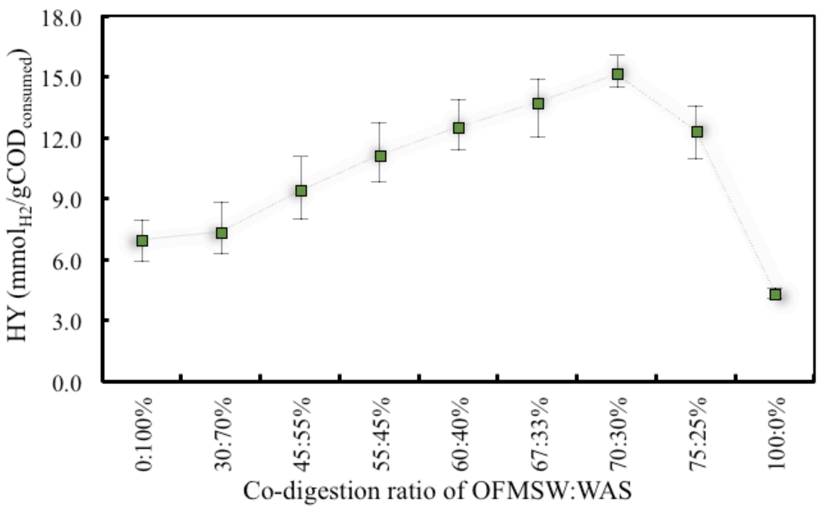

Fig. 4 Hydrogen yield due to changing of co-digestion ratio.

3.4. Effect of volatile solids content (%) on hydrogen production and yield

Changing co-digestion ratio between OFMSW and WAS, significantly effect on initial volatile solid content. As a result, Fig. 5 shows the effect of initial VS content (%) on hydrogen production and hydrogen yield. Results indicated that VS content of 24.1% achieved maximum hydrogen production of 23.40 $mmol_{H2}$ and hydrogen yield of 15.11 $mmol_{H2}/gCOD_{consumed}$.

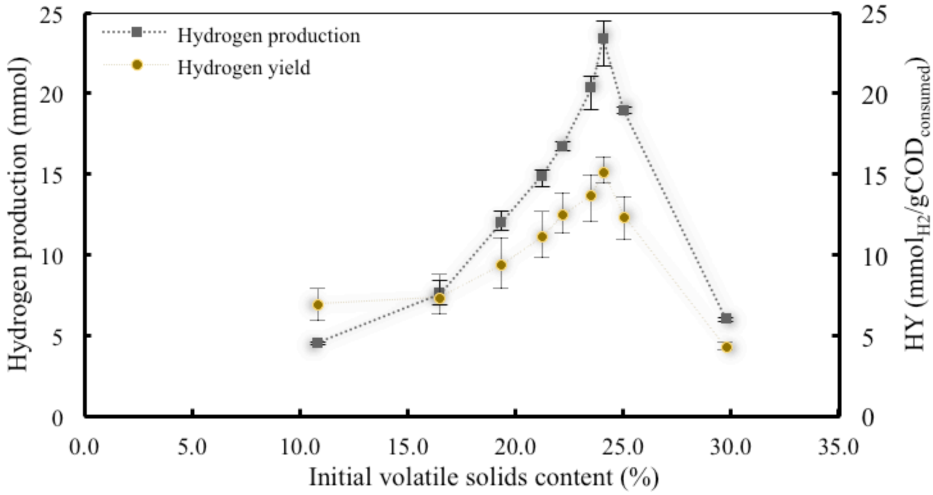

Fig. 5 Hydrogen production and yield with different initial VS content (%)

3.5. Effect of co-digestion ratio on total volatile fatty acids production.

The volatile fatty acid produced as intermediate product accompanied with hydrogen production. Total volatile fatty acids (TVFAs) generated from different co-digestion ratio are presented in Fig. 6. Maximum volatile fatty acid (VFAs) was 1.36 g registered at co-digestion ratio of 70% OFMSW to 30% WAS.

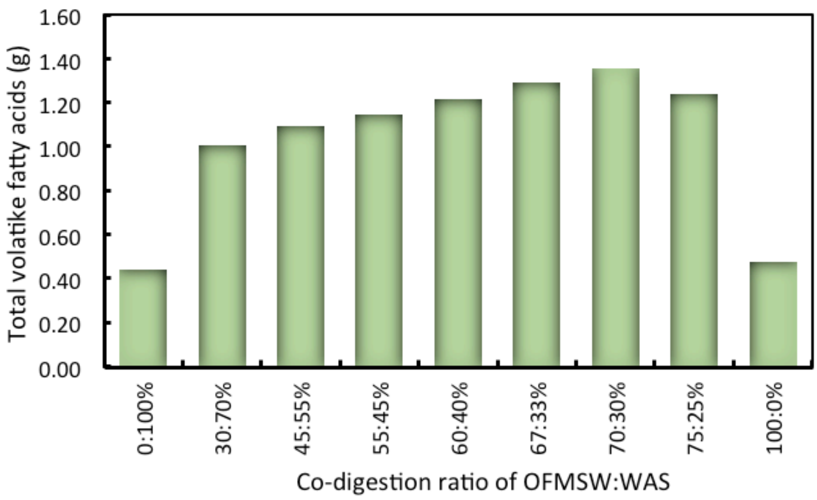

Fig. 6 Volatile fatty acids production due to different co-digestion ratio.

4. Conclusion

This study investigated the effect of different co-digestion ratio on hydrogen production and its metabolite products. The main achievements of this study are as follows:

- Maximum hydrogen production and hydrogen yield were 23.40 mmol and 15.11 mmol$_{H2}$/gCOD$_{consumed}$ achieved at optimum co-digestion ratio of 70% OFMSW to 30% WAS.
- Volatile solids content has great impact on hydrogen production and the proper percentage was 22%.
- Maximum volatile fatty acids were 1.36 g achieved at co-digestion ratio of 70% OFMSW to 30% WAS.

Acknowledgment
The first author would like to acknowledge Ministry of Higher Education (MoHE) of Egypt for providing a scholarship to conduct this study as well as the Egypt Japan University of Science and Technology (E-JUST) for offering the facility and tools needed to conduct this work.

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