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Key factors affecting on bio-hydrogen production from co-digestion of organic fraction of municipal solid waste and kitchen wastewater

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HIGHLIGHTS

- Co-digestion of OFMSW with KWW is a promising substrate for hydrogen yield.
- SRT and dilution ratio is the key factors affecting on hydrogen production.
- Hydrogen yield is SRT and dilution ratio dependant.
- H_2 production is mainly due to the conversion of COD in a particulate form.
- The ratio of COD_t to biomass (C/X) is optimized for H_2 production.

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ABSTRACT

The effects of sludge residence time (SRT) and dilution ratio (DR) on the continuous H_2 production (HP) from co-digestion of organic fraction of municipal solid waste (OFMSW) and kitchen wastewater (KWW) via mesophilic anaerobic baffled reactor (ABR) was investigated. Increasing DR from 1:2 to 1:3 significantly ($P < 0.1$) increased the H_2 yield (HY) from 116.5 ± 76 to 142.5 ± 54 ml H_2/g $COD_{removed}$ d, respectively. However, at a DR of 1:4, the HY was dropped to 114.5 ± 65 ml H_2/g $COD_{removed}$ d. Likewise, HY increased from 83 ± 37 to 95 ± 24 ml H_2/g $COD_{removed}$ d, when SRT increased from 3.6 to 4.0 d. Further increase in HY of 148 ± 42 ml H_2/g $COD_{removed}$ d, was occurred at a SRT of 5.6 d. Moreover, hydrogen fermentation facilitated carbohydrate, lipids, protein and volatile solids removal efficiencies of 87 ± 5.8%, 74.3 ± 9.12%, 76.4 ± 11.3% and 84.8 ± 4.1%, respectively.

1. Introduction

Hydrogen is a promising energy source due to its clean product and high-energy yield (122 kJ/g) (Chang and Lin, 2004). Water electrolysis, steam reforming of hydrocarbons and auto-thermal processes are well known technologies for H_2 production, but it is cost-intensive due to high-energy consumption (Ming et al., 2008). In contrast, dark fermentation process is low cost technology for hydrogen production from waste materials (Tawfik et al., 2012, 2013; Tawfik and El-Qelish, 2012). Moreover, bio-hydrogen production from OFMSW has gained great attention due to energy generation while reducing the unwanted wastes (Tawfik et al., 2011). The main problems for bio-hydrogen production from bio-wastes using dark fermentation process are the low generation rates and yields. Therefore, several factors must be considered for maximizing H_2 production in the dark fermentation process, such as avoiding the loss of H_2 to hydrogen-consuming anaerobes, e.g., methanogens (Ming et al., 2008). The SRT is one of the important design parameters for maintaining hydrogen producing bacteria in dark fermentation processes. The substrate uptake efficiency, microbial population and metabolic pathways is mainly depends on the imposed SRT. It is assumed that a long SRT causes the growth of H_2 consumers, including methanogens, and competitors for substrates, such as non-H_2-producing acidogens (Hawkes et al., 2002). On the other hand, a short SRT may reduce substrate uptake efficiency, active biomass retention and the overall efficiency of the fermenters (Oh et al., 2003). SRT in the range of 8–12 h, was the optimum conditions for continuous H_2 production from easily biodegradable substrates such as glucose or sucrose (Zhang et al., 2006). However, in the case of complex substrates such as OFMSW, a longer SRT may be required due to the slowly degradable organic compounds such as proteins and lipids (Shin and Youn, 2005; Vijayaraghavan et al., 2006; Lay, 2000). Little is known about the effects of SRT on H_2 co-fermentation of OFMSW and KWW except the study of Kim et al. (2008).

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OFMSW is largely produced in Egypt (35 million ton/year) from municipalities, clubs, industry and the business sector and represents 60% of the total solid waste. Several studies on the feasibility of using OFMSW for H_2 production have shown promising results (Han and Shin, 2004; Jo et al., 2007; Zhu et al., 2008). This is mainly due to its high content of biodegradable organic matter. Supplementation of an adequate amount of pH buffer and minerals is typically essential to optimize the pH condition and nutrient balance for hydrogen production (Han and Shin, 2004). However, this will inevitably increase the cost of operation. A study on co-digestion of municipal food waste (MFW) and sewage sludge to produce hydrogen has been reported and concluded that the addition of sewage sludge to MFW supplied a more balanced carbohydrate/protein ratio and buffering capacity (Kim et al., 2004).

The concept reported here for H_2 production from co-digestion of OFMSW and KWW is especially significant as it could integrate the management of solid waste and kitchen wastewater as a heavily polluted portion of household liquid wastes (Tawfik et al., 2012). The addition of KWW to OFMSW would be beneficial in field-scale operation by reducing dilution water and alkaline dosage. However, the optimal mix of KWW with OFMSW for hydrogen production remains unknown. Therefore, the main objective of this investigation is to assess the effects of sludge residence time (SRT) and dilution ratios (DR) on the continuous H_2 co-fermentation of OFMSW and KWW with emphasis on the conversion efficiency of COD, carbohydrate, lipids and volatile solids into useful gas in the form of hydrogen.

2. Methods

2.1. Characteristics of feed stock

OFMSW was daily collected from some houses and cafeteria situated at 6th October club, Egypt. The harvested wastes consist of a variety of cooked grains, rice, vegetables residues, paper, breads and some meats. OFMSW were mixed with KWW at different ratios of 1:2, 1:3 and 1:4 and homogenized using a warring blender and mixed in a container with a capacity of 200 L. The latter was supplemented with a mixer (30 rpm) to avoid the precipitation of coarse suspended solids. The resulting slurry was continuously fed to the ABRs.

The mean characteristics of the mixture of OFMSW and KWW as follows in (g/l): COD_t = 59 ± 12.9; COD_s = 25 ± 7; COD_p = 34 ± 12; total solids (TS) = 80 ± 27.6; volatile solids (VS) = 66 ± 23; acetate (HAc) = 1.4 ± 0.7; butyrate (HBu) = 0.9 ± 0.43; lipids = 1.64 ± 0.9; carbohydrate = 138.4 ± 96.6; proteins = 13.7 ± 7.8 and total phosphorous (TP) = 0.346 ± 0.15.

2.2. Reactors and experimental set-up

Four identical ABRs were used in this study. The reactors were manufactured from transparent Perspex with a capacity of 42 L as described earlier by Tawfik et al. (2011). The temperature of the reactors was maintained at 40 °C in a controlled room. A gas meter (Model LML-1, Changchun Filter Co., LTD) was used to quantify the amount of hydrogen gas generation. The inoculum sludge used in this investigation was obtained from dark fermentation reactor fed with municipal food waste (MFW). Volatile solids (VS) content of the inoculums sludge was 60 g/l. Two continuous experiments were conducted to assess the effect of dilution ratio (DR) and SRT on the H_2 production and yield.

2.2.1. 1st experiment

One of the anaerobic baffled reactors was continuously fed for 345 days with OFMSW diluted with KWW at different mixing ratios of 1:2, 1:3 and 1:4. HRT was kept constant at 2.9 d. The reactor was operated without addition of buffering agents. However, the pH was maintained at a level of 5.0 ± 0.3 in the digestate. Statistical analysis at different DRs has been carried out according to Snedecor and Cochran (1980).

2.2.2. 2nd experiment

To facilitate data analysis, three ABRs were parallel investigated at different SRTs of 5.4, 4 and 3.6 d. Prior starting the experiments, the reactors (ABR-1, ABR-2 and ABR-3) were supplied with 14, 18 and 23 L sludge accounting sludge loading rate (SLR) of 20, 26 and 33 kgVSS/m^3. The SRT was changed by controlling the retained biomass and withdrawn the excess sludge from the reactors. HRT and organic loading rate (OLR) was kept constant at 2.9 d, and 20 g COD/l d, for all reactors. SRT was calculated according to the following equation;

$$SRT = [(V * X)/(Q_w * X_w + Q * X_e)]$$

where, V: reactor volume (l), X: average sludge concentration in the reactors (gVS/l), Q_w: excess sludge flow rate (l/d); X_w: concentration of the excess sludge (gVS/l); Q: mixture of OFMSW and KWW flow rate (l/d); X_e effluent concentration (gVS/l).

2.3. Analytical methods

Grab samples at certain time of the feedstock and the digestate of the reactors were collected and immediately analyzed. Two times analysis per week were carried out. COD fractions (COD_t, COD_s and COD_p); TS; VS; total Kjeldhal nitrogen (TKj-N); total phosphorous (TP) and lipids were measured according to APHA (2005). Soluble COD (COD_s) was determined by filtration using 0.45 μm membrane. Particulate COD (COD_p) was calculated by the difference between COD_t and COD_s respectively. The carbohydrate concentration was measured according to the phenol–sulfuric acid method, using glucose as the standard (Dubois et al., 1956). The biogas constituents (H_2, CO_2 and CH_4) were analyzed by gas chromatography (GC, Agilent 4890D) with a thermal conductivity detector (TCD) and a 2 m stainless column packed with Porapak TDS201 (60/80 mesh). The concentrations of volatile fatty acids (VFAs) in terms of acetate (HAc), butyrate (HBu) and propionate (HPr) were measured using another gas chromatography (GC, Agilent 4890D) with a flame ionization detector (FID) and a 2 m stainless column packed with Porapak GDX103 (60/80 mesh).

3. Results and discussion

3.1. Results of 1st experiments concerning H_2 production from co-digestion of OFMSW and KWW at different dilution ratios

Fig. 1a shows the variations of HP and HY at different dilution ratios (DRs) of 1:2, 1:3 and 1:4 (OFMSW:KWW) respectively. The results obtained revealed that increasing the dilution ratio (DR) of OFMSW with KWW from 1:2 to 1:3 significantly ($P < 0.1$) increased the HP from 3.5 ± 1.2 to 8.0 ± 2.3 l H_2/d, respectively. However, the HP dropped below 3.7 ± 1.7 l H_2/d at increasing the DR up to 1:4. This mainly can be due to a decrease of OLR from 18.3 to 12.6 g COD/l d. However, these results are higher than those obtained (4.99 l H_2/d) by Mohan et al. (2009) and 10.41 l H_2/d, by Wang et al. (2011) for co-digestion of press mud feed and sweet sorghum. Hydrogen fermentative of food waste in leaching bed reactor achieved also a lower HY of 21.2–41.5 ml H_2/g $COD_{removed}$ at an HRT of 25 h. (Kim et al., 2004). This indicates that the addition of KWW to OFMSW enhanced H_2 production since it yields 116 ± 76 ml H_2/g $COD_{removed}$ d, with a 1:2 diluted feed. When,