Biogas Production from Co-digestion of Domestic Wastewater and Food Waste

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ABSTRACT: This research was to investigate the potential of biogas production from the co- digestion of domestic wastewater and food waste. Batch experiments were carried out under various substrate ratios of domestic wastewater and food waste at 10:90, 25:75, 50:50 and 70:30 at room temperature. The results revealed that the highest biochemical methane production (BMP) and chemical oxygen demand (COD) removal efficiency were 61.72 ml CH_4 g^{-1} COD and 75.77 %, respectively, at the ratio of 10:90 for domestic wastewater and food waste. These primary results indicated the significance of co-digestion of domestic wastewater with food waste for biodegradation and biogas production.

Keywords: Anaerobic treatment, co-digestion, biogas, domestic wastewater, food waste.

Introduction

Demographic growth, urbanization, higher living standards and technological advances have led to an unprecedented increase in the demand for water, not only for domestic but also for agricultural and industrial use (Agrafioti and Diamadopoulos, 2012). In many places of the world, fresh water supply is not sufficient to meet the growth in demand; therefore alternative water sources must be explored. High water consumption also means that there will be an increase in the volume of wastewater generated (Meneses *et al.*, 2010; Quadir *et al.*, 2010).

Domestic wastewater, in particular generated in decentralized areas experiencing population fluctuations, such as during high tourist season or seasonally operating activities, could be treated anaerobically as a pre-treatment step to conventional aeration methods (Manariotis and Grigoropoulos, 2008). Untreated wastewater generally contains high levels of organic materials with numerous pathogenic microorganisms, trace heavy metals, nutrients and toxic compounds. Therefore, the ultimate goal of domestic wastewater treatment is to protect the environment that has impact on protection of the environment with public health and socio-economic matters (Al-Sarawy *et al.*, 2001).

Since demand for energy is expected to increase by more than 50% by 2025, there is an ongoing search to develop sustainable, affordable, environmentally friendly energy from renewable sources (Deublein and Steinhauser, 2008; Khanal, 2008). Biofuels derived from plant-based feedstock are renewable and serve as an environmentally clean energy source which could significantly decrease fossil fuel consumption (Ersahin *et al*., 2011). Among biofuels, biogas from biological treatment plants has been considered as one of the most important renewable energy sources.

Several researches (Melidis *et al.*, 2009; Gao *et al.*, 2011) recommended that anaerobic treatment of domestic wastewater is considerably feasible. However, domestic wastewater treatment with anaerobic process suffered from poor treatment efficiency and post-treatment was therefore essential (Melidis *et al.*, 2009) especially for poorly biodegradable wastes that cannot be digested alone due to their characteristics such as low solubility or unbalanced carbon to nitrogen (C/N) ratio (Ponsá *et al.*, 2011). Nevertheless, when mixed with other complementary wastes, these degradation resistant materials become suitable for anaerobic “co-digestion” (Alatriste-Mondragón *et al*., 2006). Hence, the co-digestion can improve the treatment efficiency of domestic wastewater using anaerobic process.

Co-digestion has been defined as the anaerobic treatment of a mixture of at least two different substrates with the aim of improving the efficiency of the anaerobic digestion process (Álvarez *et al.*, 2010). Several literature reported about the co-digestion processes, such as co-digestion of the organic fraction of municipal solid waste and agricultural residues (Kübler *et al.*, 2000), organic wastes and sewage sludge (Neves *et al.*, 2009; Zhang *et al.*, 2008) or more specific wastes (Bouallagui *et al*., 2009; Buendı´a *et al.*,2009). However, our literature search shows that there is no report on anaerobic co-digestion for domestic wastewater.

Food waste is a highly desirable substrate for anaerobic digestion because of its biodegradability and high nutrient contents. A typical food waste contains 7–31 wt.% of total solid, and the biochemical methane potential (BMP) of the food waste is estimated to be about 0.44–0.48 m^3 CH_4/kg of the added volatile solid (VS_{added}) (Heo *et al.*, 2003; Han and Shin, 2004; Zhang *et al.*, 2007). Anaerobic digestion of the food waste attracts strong interest, and many novel anaerobic digestion systems have been developed and applied to treat the food waste.

Several studies (Romano and Zhang, 2008; Creamer *et al*., 2010; Wu *et al.*, 2010) showed that the sensitivity of the anaerobic digestion process to the environmental changes may be improved by combining several waste streams. These practices suggest that anaerobic co-digestion of the food waste and the domestic wastewater could potentially solve the operational problems and low economic feasibility found in anaerobic digestion of food waste or domestic wastewater alone. Therefore, the aim of this study was to investigate the potential of anaerobic co-digestion for biogas production between the domestic wastewater and food waste in a batch experiment according to at various ratios of co-substrates and to evaluate its process performance.

Materials and Method

Co-substrates and inoculums

Domestic wastewater used in this study was obtained from storage ponds of Hatyai municipal treatment system in Songkhla province, Thailand. Food wastes were collected from a cafeteria center in Hatyai campus of Prince of Songkla University, Songkhla, Thailand. The anaerobic sludge used in this study as inoculums were taken from an anaerobic digester treating the food waste for a cafeteria center of Hatyai campus of Prince of Songkla University, Songkhla, Thailand. The substrates and inoculums were individually homogenized and subsequently stored at 4 °C until use.

Batch experiment procedure

The biogas production potentials of co-digestion between the domestic wastewater and food wastes used in this study were determined in anaerobic batch digesters (**FIGURE 1**). Duplicate laboratory batch reactors were set up in sealed glass vessels with an effective volume of 1: l. To initiate the biogas potential measurement of co-digestion of the domestic wastewater and food waste, 10 % (v/v) of inoculums were added to sealed anaerobic digesters.

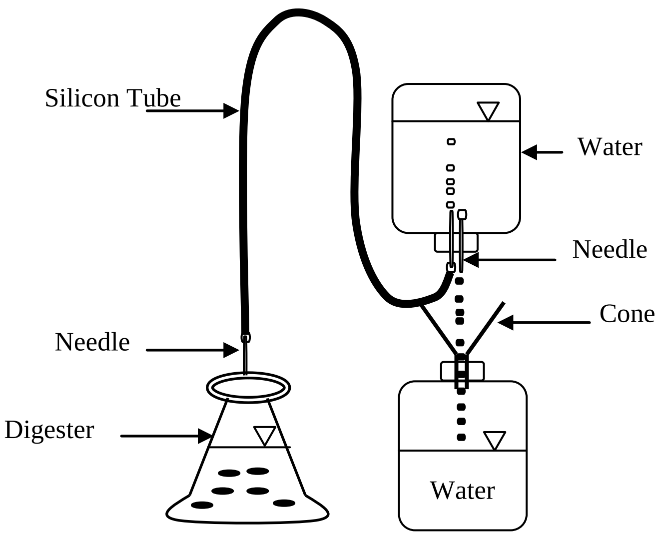

FIGURE 1: Schematic diagram of the digester.

The ratios of co-substrates between the domestic wastewater and food waste were at 10:90, 25:75, 50:50 and 70:30 (% TS) respectively to determine the optimum ratio of biogas production. After filling, all digesters were closed with a rubber cap and the atmospheric oxygen in the gas phase was purged with N_2. During the experiments, all digesters were operated at room temperature (27–32°C) and were shaken once a day. Biogas production was monitored periodically until gas production became negligible. An outlet in the stopper was used for collecting biogas in gas tight glass jars and the daily biogas production was recorded through the measurement of water displacement (Zhu *et al.*, 2011).

Analytical analysis

The samples were taken from each digester before and after the experiments. Analysis of the chemical oxygen demand (COD), biological oxygen demand (BOD), total nitrogen (TN), ammonia nitrogen (NH_4-N), total phosphorus (TP), total solid (TS), volatile solid (VS), suspended solid (SS), total dissolved solid (TDS) and volatile fatty acids (VFA) were performed according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

Results and Discussion

As detailed above, some substrates have limitations and appear to be low-efficient when they are degraded anaerobically (Astals *et al*., 2011). The main constraint of the domestic wastewater was the imbalance of its nutrient content - low carbon to nitrogen ratio which decreased the microorganism activity. In this study, food wastes were used to avoid interferences from the minority compounds, and to analyse the viability of the co-digestion between substrates.

Waste characterization

To evaluate the potential of food waste as a co-substrate for the anaerobic digestion of domestic wastewater, the characteristics of food waste and domestic wastewater were analyzed and compared to those reported in the literature.The results of the feedstock characterisation are summarised in **TABLES 1** and **2**. As shown in **TABLE 1**, the majority (54%) of food waste composition was carbon. This finding was almost similar to literature reports (Han and Shin, 2004; Zhang *et al.*, 2007; Zhang *et al.*, 2011).

TABLE 1: The characteristics of the food waste as compared to the literature reports.

Parameters	Han and Shin (2004)	Zhang *et al*. (2007)	Zhang *et al.* (2011)	This study
pH	-	-	6.50	5.50
Moisture (% w/w)	-	-	-	72.31
Nitrogen, N (% of TS)	3.5	3.16	3.54	2.72
Phosphorus, P (% of TS)	-	-	-	0.78
Potassium, K (% of TS)	-	-	-	0.04
Carbon, C (% of TS)	51.4	46.78	46.67	54.95
C:N ratio	14.7	14.6	13.2	20.24

In addition, the results of nitrogen composition in food waste well were in accordance to the literature reports (Han and Shin, 2004; Zhang *et al.*, 2007; Zhang *et al.*, 2011). The C/N ratio of food waste in this study was 20.24, which was higher than previous studies (**TABLE 1**). The C/N ratio suggested that the food waste was at the optimal range (15.5–25.0) (Wu *et al.*, 2010). The food waste used in this study contained significant concentrations of nitrogen. However, most of nitrogen in food waste existed as the organic nitrogen like proteins (Zhang *et al.*, 2011), which may be affected by the biodegradation of microorganism in seed sludge.

TABLE 2 shows the characteristics of the domestic wastewater as compared to literature reports. Domestic wastewater in this study had high COD concentration (516 mg/L) compared to the literature reports (Bodkhe, 2009; Ismail *et al.*, 2012). The nitrogen composition in the domestic wastewater was similar to Bodkhe’s (2009) findings. Our study found that the ratio of C/N was not suitable for biogas production because of low COD concentration. Therefore, the co-digestion is an alternative way for enhancing biogas production from domestic waste water.

TABLE 2: The characteristics of the domestic wastewater as compared to the literature reports

Parameters	Bodkhe (2009)	Ismail *et al*. (2012)	Current study
pH	7.5–8.2	7.44	6.87
COD (mg/l)	350–450	360	516
BOD_5 (mg/l)	200–300	140	70.62
TKN (mg/l)	30–45	-	39
NH_4^+-N (mg/l)	-	27.3	0.51
TP (mg/l)	5–6	4	7.20
TS (mg/l)	-	-	324
VS (mg/l)	-	-	267
SS (mg/l)	300–450	-	13
TDS (mg/l)	-	-	311
Alkalinity(mg/l)	230–300	-	185.74
VFA (mg/l)	-	-	50

Batch test experiments

The ultimate biogas production of the co-substrates was determined through biodegradability batch tests. **FIGURE 2** below showed that the biogas production value of co-digestion according to various ratio compositions of co-substrates i.e. 10:90, 25:75, 50:50 and 70:30 (% TS). The biogas production of each ratio was similar during the first three days. After this first period, the co-substrates of 10:90 and 25:75 continued generating methane for the following 12 days suggesting the adaption of the microorganisms (Astals *et al.*, 2011).

The co-substrates of 10:90 produced the highest biogas production with 1,583 ml CH_4 g^{-1} COD. In contrast, the co-substrates of 70:30 had the lowest biogas production. As reported by many studies (Parkin and Owen, 1986; Kayhanian and Hardy, 1994), the optimum C/N ratio fell between 20 and 40. The co-substrates of 10:90 had a C/N ratio of 39.6, which was within the optimum range. This could be the reason why the highest biogas production from those co-substrates was obtained.

TABLE 3 showed the final biochemical methane production (BMP) of the biodegradability batch tests and the COD removal of each tested sample. As can be seen, the co-substrates of 10:90 presented the highest COD removal percentages and BMP value than other ratios. In addition, this result shows that the co-digestion of domestic wastewater and food wastes had a high trend of the biogas production. Therefore, the co-digestion of the domestic wastewater with food waste should be enhanced for biogas production.

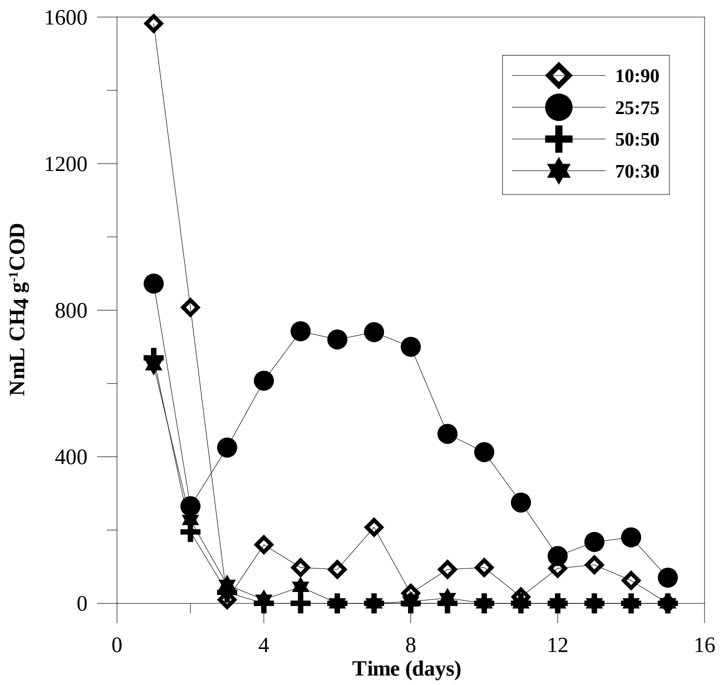

FIGURE 2: Cumulative biogas production for domestic wastewater and each mixture

TABLE 3: Ultimate biogas production and matter removal of each dplicated samples tested.

Parameters	Food waste : Domestic wastewater			
	10:90	25:75	50:50	70:30
COD removal %	75.77	54.42	18.93	5.53
Biochemical methane production (ml CH4/g COD)	61.72	41.64	9.93	6.68

Conclusion

Our results show that co-digestion of domestic wastewater with food wastes was very promising for the production of renewable energy in the form of methane gas. The biochemical methane production (BMP) and chemical oxygen demand (COD) removal efficiency were 61.72 ml CH_4 g^{-1} COD and 75.77 %, respectively. Moreover, the addition of food waste to the anaerobic digestion of domestic wastewater showed an increasing trend of the biogas production. The laboratory batch study revealed that the use of food wastes as co-substrate in the anaerobic digestion of domestic wastewater also has other advantages: i.e. the improvement of the balance of the C: N ratio and efficient process stability.

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