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Biogas Production from Batch Anaerobic Co-Digestion of Night Soil with Food Waste

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Abstract

The objective of this study is to investigate the biogas production from Anaerobic Co-Digestion of Night Soil (NS) with Food Waste (FW). The batch experiment was conducted through the NS and FW with a ratio of 70:30 by weight. The experiment is mainly evaluated by the characteristic of Co-Digestion and Biogas Production. In addition of food waste was inflating the COD loading from 17,863 to 42,063 mg/l which is 135 % increased. As the result, it shows that pH has dropped off in the beginning of 7-day during digestion and it was slightly increased into the range of optimum anaerobic condition. After digestion of the biogas production was 2,184 l and 56.5 % of methane fraction has obtained within 31 days of experimentation. The investigation of Biochemical Methane Potential (BMP) and Specific Methanogenic Activities (SMA) were highly observed. And the results were obtained by 34.55 $mLCH_4/gCOD_{removal}$ and 0.38 gCH_4-COD/gVSS-d. While the average COD removal from the 4 outlets got 92%, 94%, 94 % and 92 % respectively. However, the effluent in COD concentration was still high and it needs further treatment before discharge.

Keywords: anaerobic digestion; methane production; co-digestion; night soil; food waste

1. Introduction

The economic growth has led rapidly increasing energy consumption (Zhang *et al*., 2014). Implement of renewable energy become attractive alternative for reducing fossil fuels through the development of sustainable energy. Through an investigation design and construction of an anaerobic digester system from locally available waste to produce of biogas, methane rich has received intense attention (Cai *et al*., 2013). Human excreta (night soil) is a good source of organic matter (Yadev, 2010), there are comprised of solid and liquid phase 0.4 kg/d and 1.5 L/d (Sayed, 2000). The rapid reproduction of population in Thailand, night soil has increased resulted in the increased amount municipal waste being treated. Recently, considering the energy recovery, interest has focused on anaerobic digestion (AD) (Zhang *et al*., 2014).

To improve the potential of biogas production, co-digestion of organic wastes could have the potential to improve the efficiency of anaerobic digestion process (Cheerawit *et al*., 2012) and dilution with toxic compound, improve balance of nutrients (C/N) and synergistic effect to microorganisms (Zhang *et al*., 2011). Locally, available municipal solid waste (MSW) such as food waste (FW), it has highly organic fraction interest to improve organic loading rate (Khanto and Banjerdkij, 2013).

The additional of food waste into night soil resulted in increasing of COD concentration which effect the potential of biogas production. The experiment of (Makamo *et al*., 2013) found the maximum biogas production obtained from anaerobic batch experiment conducted with Co-digestion of night soil and 20% food waste. However, the BOD/COD was still low (0.1) and indicated hardly degradable (Sirivitayaphakorn, 2008). The additional 30% of food waste into night soil was interesting and aimed to improve the organic loading, BOD/COD ratio result in increasing of potential of biogas production. Therefore, the anaerobic Co-digestion of night soil with 30% food waste was investigated in pilot scale batch experiment.

The objective of this research was investigated first with the characteristic of Co-digestion of night soil with food waste. Secondly, base on control parameters such as COD, pH, TP, TKN, VFA, ALK and other solid were evaluated. Lastly, the biogas production and methane ratio were analyzed.

2. Materials and Methods

2.1. Co-digestion substrates

The raw materials consist of two organic substrates which were night soil and food waste. The night soil samples were obtained from construction site located nearby Nongkhaem Night soil Treatment Plant. Food waste was obtained from canteen of Suansunandha University that covers over 50 food makers. The collected food wastes were considered impurities such as plastic, metal and glass. These are classified and remove by collector. The food wastes were ground by adding some water for dilution reason. Afterward, the Co-digestion substrates were filled up to 800 l. The digester was tightly closed with a rubber and transparently screw cap. To assure the absent oxygen condition, the screw tap was drench with silicone. Fig. 1 shows preparation of food waste and Co-digestion sample.

2.2. Experiment design

The batch anaerobic Co-digestion of night soil and food waste carried out in ratio of 70:30 (Table 1). The Co-digestion was performed by 800 l anaerobic batch model (Fig. 2). The diameter (D) and height (H) of digester have been taken as 55 and 110 cm, respectively. It was installed at Nongkhaem Night soil Treatment Plant. The reactor was comprised of inlet and outlet which made from of poly ethylene (PE) with a 4 inches diameter. Inside, the polyethylene plate was installed in the middle of the reactor to separate inner space into septic and anaerobic filter zones. The solid particle was sunk by sedimentation process within a septic zone, while liquid was flown into anaerobic filter zone wherein the microorganism were active within the plastic filter media (bio-ball). There was 95% of void and 200 m^2/m^3 specific surface area which provide the best condition for attachment in biofilm form. The bio-ball was placed into plastic bags due to convenience to replace in case the bio-ball was damaged by corrosion of H_2S produced from wastewater. The damage or loss of bio-ball resulted in low efficiency of COD removal. There were a totally of four sampling ports which divided into two sides: septic (Sep 1, 2) and anaerobic filter zone (AF 3, 4) to investigate the wastewater characteristic. The excess 2 bottom sampling ports installed for sludge drainage. The biogas production was counted by flow meter BK-G4.The water samples were fixed by nitric acid and the sediment samples were dried by air before analysis for the arsenic concentrations.

2.3. Analytical methods

Table 2 shows analytical methods of parameters such as pH, COD, TKN, TP, ALK, VFA, TS, VS and VSS. The laboratory was measured by using (APHA, 2012). The test was conducted at the room temperature that varied from 30-35^{o}C and non pH adjusted within 31 days of the experiment. The biogas production was determined by flow meter BK-G4 which installed on the top of the reactor. The proportional of methane and other production were measured by GC 6890 machine, which is CO_2, CH_4 and N_2 can be measured.

2.4. Measurement of biogas production

The theoretical methane yield was calculated based on Biochemical Methane Potential (BMP) and Specific Methanogenic Activities (SMA) as follows: BMP assays have been widely used to determine the methane yield of Co-digestion substrate (Delrisco, 2011) can be expressed as (1). BMP assays are mainly used to determine the concentration of organic to methane and evaluate the potential and efficiency of the anaerobic process with specific wastewater (Moody, 2011). Through stoichiometric conversation, CH_4 production is related to organic removal; 395 $mLCH_4$ equals 1 g COD reduction (Speech, 1996). However, methane production can vary by reactor feedstock and due to multiply digester system factors.

Figure 1. Grinding food waste and Co-digestion sample

Table 1. Co-digestion ratio

Co-digestion material	Ratio	Amount of Co-digestion material
Night soil	70	560 l
Food waste	30	69.12 kg (or 240l)

$$\frac{\text{BMP (ml } CH_4)}{gCOD_{removed}} = \frac{\text{Biogas (l)} \times CH_4\ (\%)}{(COD_{inf} - COD_{eff})\ (mg/L)} \quad (1)$$

SMA assays have been widely evaluates the anaerobic sludge capacity to convert an organic substrate into methane, in which escapes easily to the gas phase and reducing the chemical oxygen demand (COD) in the liquid phase show as (2) (Sinbuathong *et al*., 2007).

$$\frac{SMA\ (gCH_4 - COD)}{gVSS - d} = \frac{gCH_4 - COD}{t \times B} \quad (2)$$

Table 2. Analytical methods of parameters

Parameters	Methods
pH	pH Meter
COD	Closed Reflux
TKN	Macro-Kjeldahl
ALK	Titration
VFA	Titration
TP	Ascorbic Acid
TS	Gravimetric
VS	Gravimetric
VSS	Gravimetric

3. Results and Discussion

3.1. Characteristic of fermentation materials

As shown in the details above, some substrates have limitation and low-efficiency of biological anaerobic process. To increase the biogas production, food wastes were used to analyze the viability of the Co-digestion between substrates (Cheerawit *et al*., 2012). In this study, the additional 30% of food waste was experimented. Table 3 shows the characteristics of night soil and food waste from various experiments.

The Co-digestion of night soil with additional 30% food waste (by weight) was experimented in a pilot scale reactor. The additional of food waste into night soil results in increasing the organic matter from 17,863 to 42,063 mg/l which was 135% (2.35 times) increasing from night soil concentration and this may result in higher biogas production. It was in unidirectional tendency of (Makamo *et al*., 2013) which shows 1.2-1.5 times increasing of organic matter by an additional 10% of food waste. This was due to the high COD concentration which was obtained from food waste 139,061 mg/l (Limsuk *et al*., 2011).

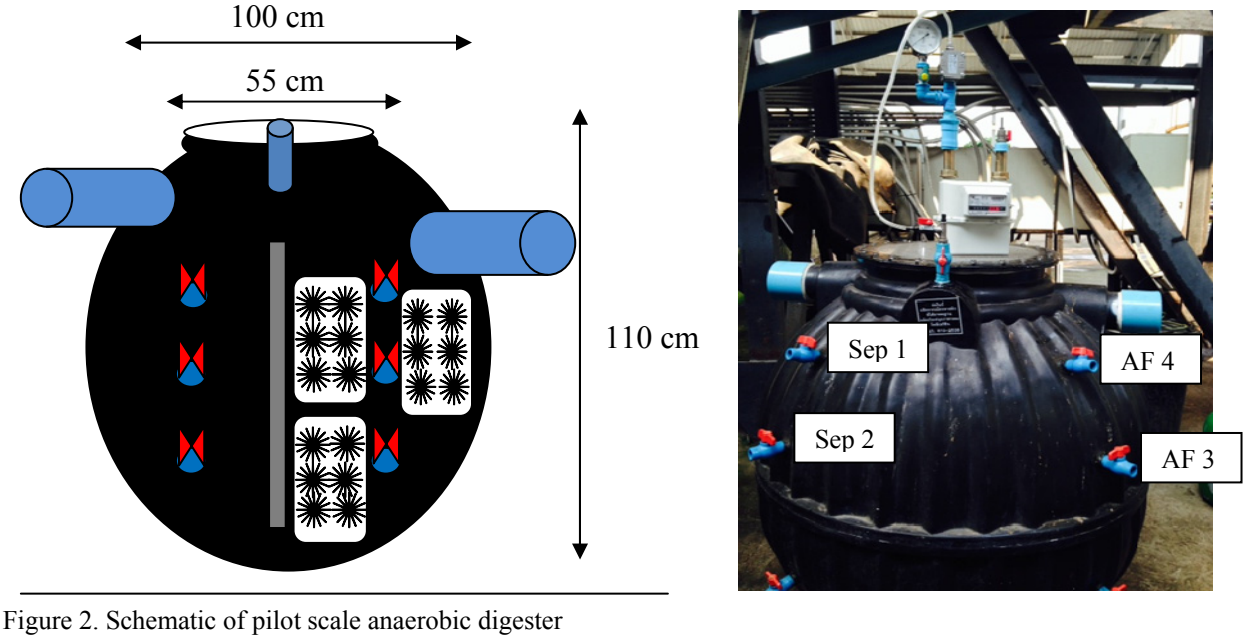

Figure 2. Schematic of pilot scale anaerobic digester

Table 3. The characteristics of Co-digestion of night soil and food waste

Parameter	Unit	NS (Makamo *et al*., 2013)	NS+10%FW (Makamo *et al*., 2013)	NS+10%FW (Mahawong *et al*., 2014)	NS+30%FW This study
COD	mg/l	16,516	23,200-27,676	19,344-28,276	17,863[1/]-42,063[2/]
BOD	mg/l	1,900	2,175-2,400	13,750	21,000
pH	-	7.40-7.59	7.45-7.48	3.93-5.40	6.8-7.2
TKN	mg/l	342-415	305-579	683-1,103	1,792
TP	mg/l	23.63-24.97	73.6-83.0	62	55
VFA	mg/l as CH_3COOH	-	-	900-2,038	1,125
Alkalinity	mg/l as $CaCO_3$	-	-	402-690	2,250

[1/]COD for night soil [2/] COD of Co-digestion NS:FW (70:30)

The addition of food waste provided more substrates for methanogenesis and improved the biogas yield (Zhang and Jahng, 2012). The COD concentration was in the proper range for biogas production without external energy by anaerobic condition indicated more than 1,270 mg/l (Tchobanoglous *et al*., 2003). The ratio between BOD/COD in this experiment was 0.5 which indicated easily degrade range between of 0.5-0.8 (Sirivitayaphakorn, 2008). The ratio obtained in this experiment was more suitable for anaerobic process than study of (Makamo *et al*., 2013) where BOD/COD ratio was 0.1 which indicated hardly degradable 0.2-0.4 (Tchobanoglous *et al*., 2003). Therefore, the additional 30% of food waste suitable for microorganism to degraded the organic substrates. It might result in increasing the biogas production. TP and TKN were 55, 1792 mg/l which were about 2 and 5 times higher than a night soil characteristic (Makamo *et al*, 2013). The VFA/ALK ratio was 0.5 which was higher than the range of 0.3-0.4 which was usually considered favorable without the risk of acidification. However, above 0.8 inhibit of methanogenesis occurs. The overall parameters of Co-digestion of night soil mixing with 30% FW were suitable in anaerobic conditions. The additional food waste into night soil results in formation more VFA and thus low pH was occurred in the initial period. The large amount of VFA leads to decrease of solution pH (Zhang *et al*., 2007). The pH is an important parameter affecting the growth of microbes during anaerobic fermentation kept in the range of 6.8-7.2 (Yadvika *et al*, 2004), around 7.0 - 7.2 (Khalid *et al*, 2011).

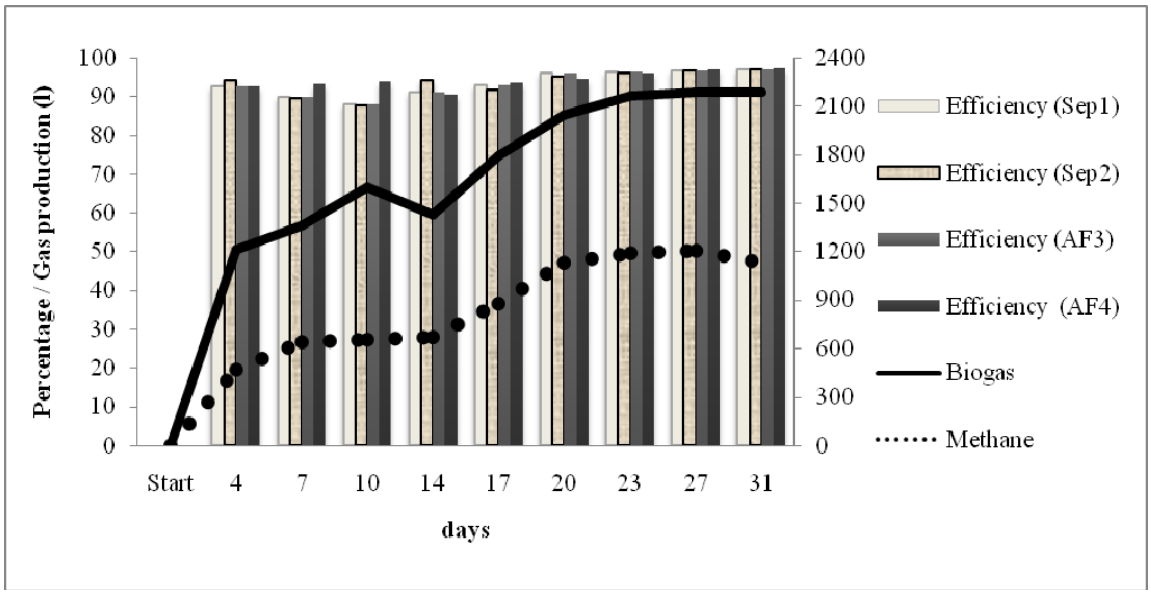

Figure 3. The comparison of biogas and methane production during the experiment.

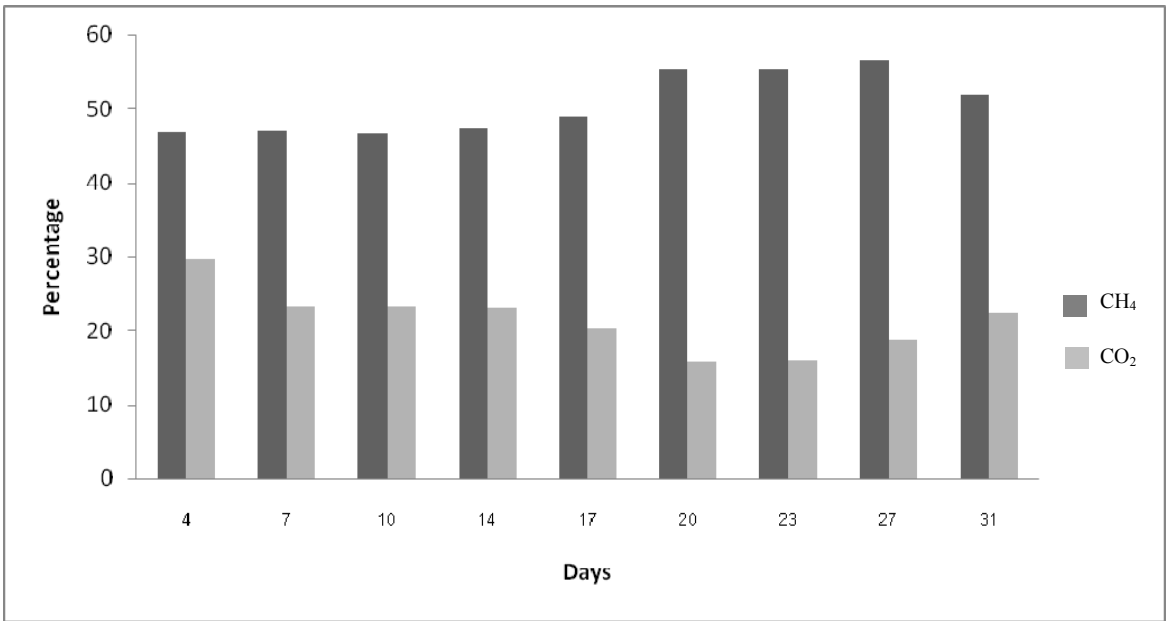

Figure 4. The relation of CH_4 and CO_2 from anaerobic digestion

3.2. The COD removal and biogas production

The COD concentration the 4 sampling ports (outlets) were 3,039, 2,453, 2,453 and 3,039 mg/l respectively, or 92%, 94%, 94% and 92 % of COD removal after 3 days of experiment (Fig. 3). The high efficiency of COD removal after 3 days of experiment was caused mainly by sedimentation process due to the major content of night soil was in solid particle 20-1500 (EU),100-200 (US) and 130-520 (Developing country) g/person-d (Makamo *et al*.,2013) or average 350 g/person-d. The 1,200 l of biogas production indicated that the biological anaerobic treatment was also active as well. The experiment was operated until 31 days of the experiment in which according to 30-60 days retention time of conventional anaerobic process (Sirivitayaphakorn, 2008). At the end of digestion process, the COD removal efficiency measured at 4 sampling ports (Sep1, 2 and AF 3, 4) were 96.9%, 96.8%, 96.9% and 97% respectively. The sampling port AF4 (Anaerobic filter section) which indicated as an outlet of reactor shows the highest COD removal efficiency due to the sedimentation for large particle and biological anaerobic treatment where the biogas production. The installation of Bio-ball was (25% of reactor volume) with 95% of void result in high wastewater treatment efficiency. However, the COD concentration at the end of the experiment is still high 1,273, 1,327, 1,273 and 1,110 mg/l respectively. Therefore, the effluent needed for further treatment before discharge.

The cumulative of biogas and methane production for the pilot scale experiment was shown in Fig. 3. The pilot scale started generating biogas on the 1st day and reached out to 1,005 l in the 4th day, respectively. The maximum biogas production was 2,184 l within 31 days of the experiment.

Fig. 4 shows the relation of CH_4 and CO_2 production from anaerobic digestion reactor during 31 days of the experiment. The proportional of CH_4 and CO_2 were measured. Methane was generated at 46.79% in the beginning of the experiment and was slightly increased to 55.3% within 18 days of the experiment and reached onto the maximum 56.5% within 29 days of the experiment. Methane production in this experiment was in the range of 55-65% (Tchobanoglous *et al*., 2003). Contrary to the CO_2 production was high in the beginning of the experiment because the reaction in the acidogenesis stage where soluble organic transferred to CO_2 result in a higher percentage of CO_2 (Sirivitayaphakorn, 2008) and was slightly decreased until the ends of the experiment. The research by (Dahunsi and Oranusi, 2013) was studied the biogas production from food waste mixing with human excreta (night soil) with 4:1 ratio by weight without mixing and the operating within 60 days of experiment. The result shows about 56.5% and 24% of CH_4 and CO_2 obtained from experiment. By adding more food waste might improve the biogas production and methane yield. However, the pH drop due to VFA obtained from food waste result in unconditional for anaerobic microorganism must be considered.

The BMP and SMA were determined the methane production yield. The BMP obtained from this experiment was 34.55 $mLCH_4/gCOD_{removal}$ in which harmoniously with BMP obtained from Co-digestion of food waste: domestic 6.68-61.72 $mLCH_4/gCOD_{removal}$ (Cheerawit *et al*., 2012). While SMA obtained from this experiment was 0.38 gCH_4-COD/gVSS-d which higher than SMA from sludge originating from a brewery wastewater treatment plant 0.128 gCH_4-COD/gVSS-d (Sinbuathong *et al.*, 2007). Therefore, Co-digestion of night soil and food waste may have alternative municipal waste sources for biogas production.

4. Conclusions

The result of this study was clearly that Co-digestion of night soil and food wastes are good substrate for biogas production for energy production. By addition of food waste increase at 2.35 time of COD loading and improving Co-digestion is a good characteristic. The anaerobic batch experiment shows 97% COD removal efficiency. On the other hand, TKN and TP remained constant due to the limit of anaerobic treatment conditions. The maximum cumulative biogas production was 2,184 l and 56.5 % methane accounted for biogas produced. The optimum of BMP and higher SMA compared with industrial substrate which can be indicated successfully implemented of the anaerobic digestion from Co-digestion night soil and food waste as a method of waste treatment leading to utilization of renewable energy resource. To improve the biogas production and methane yield, more fraction of night soil and food waste such as 65:35 and 60:40 are interested for the further experiment. However, the pH drop must attentive to control in anaerobic process. In conclusion, the Co-digestion of night soil and food waste were proper materials for biogas production from municipal waste.

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