The Potential of Biogas Recovery from Anaerobic Co-digestion of Fecal Sludge and Organic Waste

Hoang Le Phuong and Nguyen Thi Kim Thai

Abstract According to some reports, the amount of fecal sludge (FS) that is also known as septic tank sludge or septage in urban areas of Vietnam is relatively high. It can be up to hundreds of tons per year in some big cities (Hanoi Urban Environment. The situation and solutions of management, collection and treatment of fecal sludge, International Conference on Management of sludge from the drainage system and sanitation (FS3 – 2015) – Proceedings sludge management in Vietnam opportunity to improve, pp 25–27, 2015). Therefore, the management and treatment of septic tank are an urgent problem currently. Ingredients of fecal sludge such as total nitrogen (TN), total phosphorus (TP), and alkalinity are high, but the ratio of C/N is often lower (Montangero A, Strauss M, Fecal sludge treatment, Eawag/Sandec, 2004; Klingel F et al, Fecal Sludge Management in Developing Countries, Eawag/Sandec, 2002; Thai et al, Fecal sludge management from the sanitation, Science and Technology Publishing, Hanoi, 2013). So, the anaerobic co-digestion fecal sludge with other organic wastes with C/N higher can recover biogas. This study was conducted with experiment model in mesophilic fermentation conditions during 40 days in the solid waste laboratory of National University of Civil Engineering. Fecal sludge (FS) and organic waste (OW) have mixed with the ratios of 4:1, 3:1, and 2:1 by weight in three parallel models. Experimental results showed that at ratio of 3:1, it yielded higher biogas production with 514.33 Nl/kgVS of feed. Also the ratio and parameters of process such as the change of its height, temperature, pH, and COD are consistent with anaerobic digestion process, and the amount of fecal sludge treated is high relatively.

Keywords Fecal sludge • Anaerobic digestion • Biogas

H. Le Phuong (✉)
Thai Nguyen University of Technology, Thai Nguyen Province, Vietnam
e-mail: phuongqtn@tnut.edu.vn

N.T.K. Thai
National University of Civil Engineering, Hanoi City, Vietnam

S.K. Ghosh (ed.), *Utilization and Management of Bioresources*,
DOI 10.1007/978-981-10-5349-8_11

1 Introduction

In urban areas of Vietnam, the majority of houses use septic tank as one-site sanitation because of its simplicity and stability. Besides, it also has public toilets in some cities. There are about 77% of households in urban, 40% in suburban, and 19% in rural which use septic tank (World Bank 2012). The efficiency of BOD and suspended solids treatment of the septic tank usually ranges from 0 to 50% depending on the design of septic tank, water discharge, and habit of emptying tanks so the organic matter in fecal sludge is usually high (World Bank 2012). Meanwhile, the amount of fecal sludge generated each year is quite large, specifically in Hanoi and Ho Chi Minh cities with about 500 tons per day (Ho Chi Minh City Urban Drainage Co., Ltd. 2015). Moreover, the quantity of this sludge will be increasing with the development of urbanization. According to the strategy of integrated management of solid waste in Vietnam up to 2025 and the vision to 2050 assigned by the Prime Minister until 2025, Vietnam must ensure that 100% of solid wastes are collected and treated, of which 90% are recycled, reused, recovered energy or produced organic fertilizer, and 100% of fecal sludge in urbans and 50% in suburban are collected and treated (The Prime Minister's Office 2009). However, in the most of urban, the majority of fecal sludge is not managed and treated properly; it is dumped directly into the environment in various forms. The private collectors often pour sludge into sewage system, fishponds, and lakes illegally. The public collectors usually buried fecal sludge in landfills. As the result, fecal sludge remains an unregulated environmental pollutant in Vietnam.

Vietnam has some urban cities such as Hanoi and Ho Chi Minh City, using co-composting method fecal sludge with organic waste. This method is simple but has some drawbacks such as needing dewatering of sludge before composting, supplying gas, and generating odors, leachate, and CO_2 during the composting (Strauss et al. 2003). To overcome these drawbacks, anaerobic digestion recovering biogas is a solution. According to some studies, anaerobic digestion of fecal sludge at a temperature of 15–30 °C can generate 15–90 ml biogas/g dry fecal sludge, and the biogas will be higher if conditions of the process are optimal (Strande et al. 2014). However, it has not yet been proven for fecal sludge itself in semi-centralized to centralized treatment in urban areas; because the composition of nutrients in fecal sludge is not optimal, the rate of C/N is often low (Sandec Training Tool 1.0 – Module 5, 2008; Strauss and Montangero 2002). Besides, market waste (MW) with high carbon content is also generated in a large amount from the markets. Anaerobic co-digestion of different wastes such as municipal waste solid, sewage sludge, animal dung and other biowaste can produce high volume of biogas with high metan content (Babel et al. 2009; Khai 2002; Völgeli et al. 2014). Therefore, anaerobic co-digestion of FS and MW can create biogas higher. This study was done to evaluate the potential of biogas recovery from fecal sludge when it is mixed with market waste at different ratios in laboratory, as a basis for further research on optimal operating conditions.

2 Materials and Methods

2.1 Raw Materials and Reactor Preparation

Collect Fecal Sludge (FS) Fecal sludge is drawn at the public toilets and the septic tanks in Hanoi and is gathered in the sludge tank at Cau Dien plant in Hanoi. This tank is brushed scum and stirred and then takes about 80 l and transferred to the laboratory.

Organic Waste (OW) Organic waste was collected at Dong Xuan and Long Bien markets in Hanoi. It included the fruits and vegetable removed. The organic waste was collected at 6–8am and was transferred to the experimental reactor immediately. The organic waste was chopped into sizes from 1 to 3 cm and mixed well.

Experiment Model The experiment models are prepared according to Fig. 1.

2.2 Determination Characteristics of Raw Materials and Co-digestion

FS and OW are analyzed for various parameters such as moisture content (MC), total solids (TS), volatile solids (VS), total nitrogen (TN), and total organic carbon (TOC).

FS and OW are mixed at different ratios of 4:1, 3:1, and 2:1 by weight, respectively. The reactors are operated under the temperature 30 °C, which represents mesospheric condition. The retention time is 40 days. The amount of biogas, temperature, pH, and COD are monitored every day.

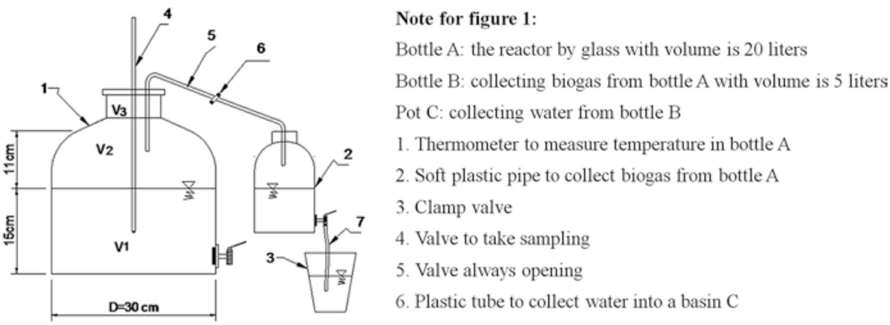

Fig. 1 The experiment model

3 Results and Discussion

3.1 Characteristic of Fecal Sludge and Organic Waste

The characteristics of fecal sludge and organic waste are shown in Table 1.

%MC and TN in FS is high, but the rate of C/N is 11.95, which is relatively low compared with conditions of anaerobic digestion; the optimum C/N ratio is in the range of 20–30 (Khai 2002; Parkin and Owen 1986), whereas, in OW the C/N rate is 47.41. Consequently, mixing FS to OW can have suitable nutrients appropriately for anaerobic digestion.

3.2 Results of Anaerobic Co-digestion Process

3.2.1 The Change of Temperature in the Reactors

The changes of temperature in reactors are shown in Fig. 2.

From Fig. 2, it can see that for FS to OW ratio at 3:1, the highest temperature was 36–37 °C on day 14–22 and then decreased to 31 °C on day 40. For FS to OW ratio at 4:1, the fastest increase in the temperature is observed during the first days; it could reach up to 35.5–36.5 °C on day 9–16 and then decreased to 30 °C on day 40. For FS to OW ratio at 2:1, the increase of temperature is slowest, it only could reach up to 36–37 °C on the day 17–23, and then it also dropped to 32 °C on day 40. The anaerobic digestion has made increase the temperature of the reactors; however, this temperature is also less than 40 °C that is suitable for mesospheric condition. This is similar to some researches that agree that energy released as heating during anaerobic digestion is enough to maintaining optimal temperature in mesopheric condition (Pohland 1968). The more quickly the digestion took place, the faster the temperature is raised and then falls rapidly. Therefore, it can see that at ratio 4:1, anaerobic digestion happened fastest and at ratio 2:1 was slowest in three ratios of this experiment.

3.2.2 The Change of pH in the Reactors

The changes of pH in reactors are shown in Fig. 3.

Table 1 Characteristics of FS and OW before digestion

Raw material	MC (%)	TS (%)	VS (%TS)	TN (mg/gTS)	TOC (mg/gTS)	C/N
FS	94.73	5.27	71.08	30.54	365.07	11.95
OW	48.3	51.7	78.2	9.2	436.14	47.41

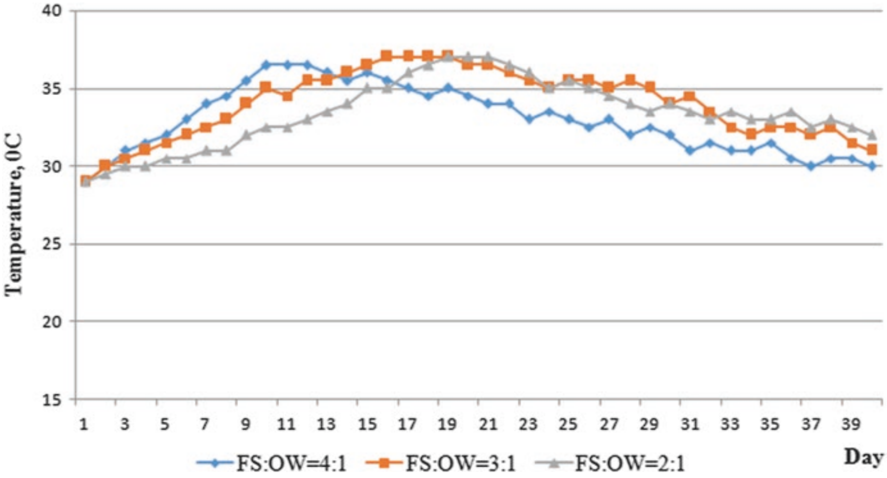

Fig. 2 The change of temperature in the reactors

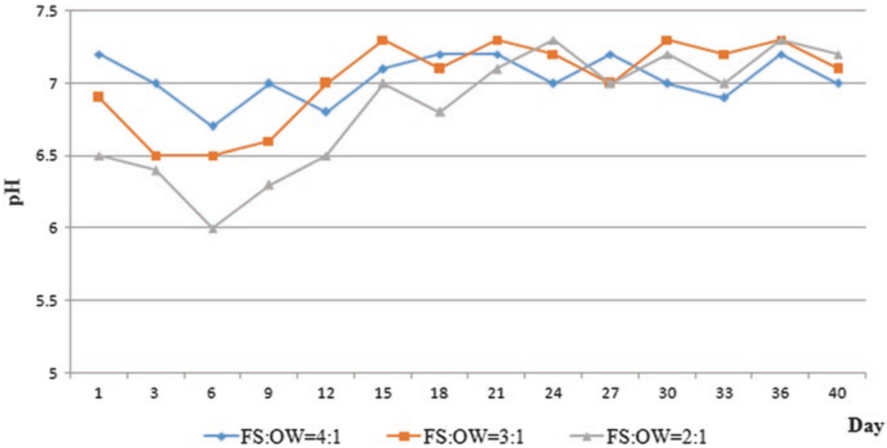

Fig. 3 The change of pH in the reactors

In the anaerobic digestion, pH is the most sensitive parameter. Most anaerobic bacteria operate at the suitable pH of 6.5–7.5, optimally from 6.8 to 7.2. The methane production can reduce if the pH is less than 6.3 or greater than 7.8 (Stronach et al. 1986; Jiunn-Jyi Lay et al. 1997). From Fig. 3, it can be seen that for FS to OW ratio at 4:1 and 3:1, pH dropped in the first days and then increased. However, it only ranged from 6.5 to 7.5 relatively suitable for anaerobic digestion process. Only for FS to OW ratio at 2:1 when pH was 6.0 on day 6, and then it rose and ranged from 6.3 to 7.3. For FS to OW ratio at 4:1, the lowest of pH was 6.7 and it fluctuated from 6.7 to 7.2; for ratio at 3:1, the lowest of pH was 6.5 on day 3 and day 6, and then it increased and fluctuated from 6.6 to 7.3. According to the result of some

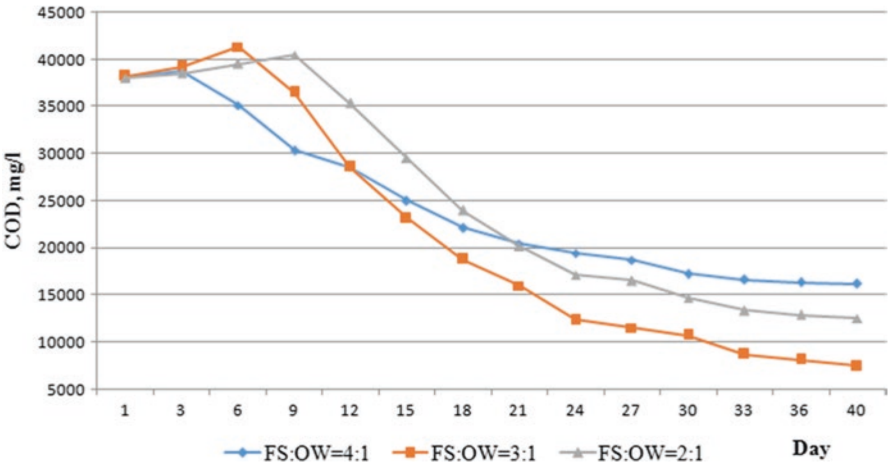

Fig. 4 The change of COD in leachate of the reactors

researches in the first stage of anaerobic digestion, the processes of hydrolysis and acid genesis occur and produce volatile fatty acids (VFAs) such as acetate, propionate, butyrate, and lactate that reduce pH; pH levels in the stages are usually 5.5–6.5, after that, the methanogenic phase occurs that used these acids to form CH_4 and made an increase of pH from 6.5 to 8.2 (Al Seadi et al. 2008). It can be seen that with FS to OW ratio at 2:1 with the largest of organic waste in three ratios, it produced the higher quantity of VFAs, and pH decreased in 6 which was not good for anaerobic digestion. For ratio at 4:1, it had the lowest of organic load so pH was not influent and maintained in the suitable range for anaerobic digestion. Besides, the buffering capacity of FS is quite good; it helps to stabilize pH in the anaerobic digestion process in the different ratios of FS to OW in this experiment, especially in ratio at 2:1 when pH dropped 6; it could slow growth to 6.5 that is relevant for methanogenic phase. It is probably suitable with some researches which illustrated that the high alkalinity of FS was imparted by the formation of ammonia bicarbonate (NH4HCO3) during the hydrolysis of urea (H_2NCONH_2). Therefore FS has high buffering capacity (Montangero and Strauss 2004).

3.2.3 The Change of COD in Leachate of the Reactors

The changes of COD in leachate are shown in Fig. 4.

Figure 4 shows that for FS to OW ratio at 4:1; 3:1, and 2:1, COD in leachate increased in the first stage and decreased after that. It can be seen that in the first stage of anaerobic digestion produced isolate organics such as VFAs (Cavinato 2011; Al Seadi et al. 2008), these substances increased COD in leachate; after that methanogenic microorganisms are feeding volatile fatty acids and release CH_4 and

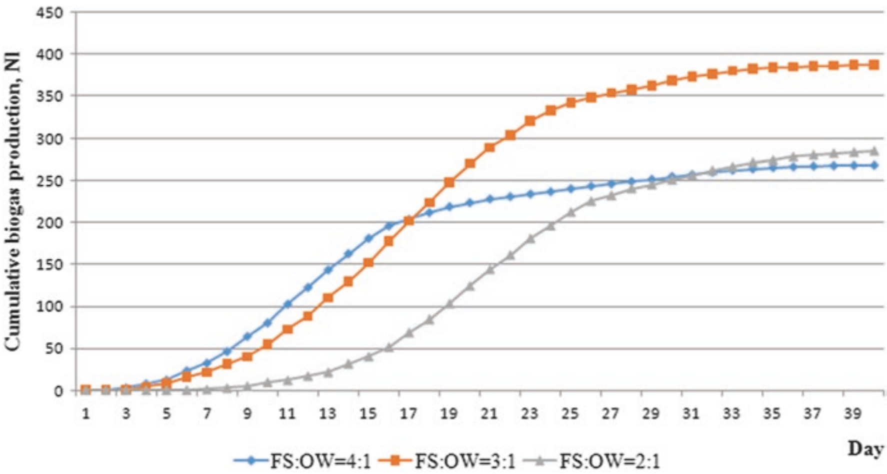

Fig. 5 Cumulative biogas production with time at different mixing ratios

CO_2 (Cavinato 2011; Al Seadi et al. 2008) so COD in leachate decreases. For FS to OW ratio at 3:1, COD rose on the first 6 days and degraded then. And the reduction total of COD at the ratio was highest at 80.5%. At ratio of 2:1, the increase of COD was observed during the first 9 days, and it only began to decrease then. After 40 days, the total COD reduction at this ratio is 67%; COD could continue to drop in the next days; however, the experiment finished on day 40. For FS to OW ratio at 4:1, COD only increased on the first 3 days and then decreased. But after 40 days, COD only declined at 59% the slowest in three ratios. The reason of this could be that the proportion of VFA produced was low so COD in leachate did not decrease as much as other ratios.

3.2.4 Biogas Production in the Reactors

Cumulative gas production at different mixing ratios with time is shown in Fig. 5.

From Fig. 5, it can be seen that biogas production for FS:OW at the ratio 3:1 was 387.98NL after 40 days equivalent to 514.33 Nl/kgVS of feed and was the highest among three mixing ratios used in this study. For FS to OW ratio at 4:1, biogas production was the lowest with 268.27 Nl after 40 days equal to 378.23 Nl/kgVS of feed. At the ratio of 2:1, cumulative biogas production was 285.21 Nl equal to 354.26 Nl/kgVS after 40 days. Therefore, the result of the highest COD decreased in leachate in ratio at 3:1 was the largest cumulative biogas in three mixing ratios of this experiment. And, in ratio at 4:1, the total COD reduction was the lowest so cumulative biogas production was the smallest.

4 Conclusion

This study shown that, when mixing FS with OW in the different ratios, the parameters of the anaerobic digestion changed and cumulative biogas production was very different at the ratios. It found that the maximum quantity of biogas generated at a mixing ratio of 3:1 was 387.98 Nl after 40 days.

FS to MW ratio at 3:1 was considered to be the optimum mix ratio. Because it generated the highest biogas production in addition, the change of parameters of anaerobic digestion process was pretty good, the removal COD in leachate was higher than other ratios. At this ratio, the biogas yield was 514.33 Nl/kgVS of feed, which is equivalent to biogas yield of poultry slurry (0.35–0.60 m3/kgVS) (Al Seadi et al. 2008). Thus, the potential of biogas recovery when mixing fecal sludge and organic waste is high relatively. However, it should be more specific to study about operating mode to achieve more efficiency results.

Acknowledgment This research was supported by Thai Nguyen University of Technology and National University of Civil Engineering, Vietnam.

References

Al Seadi T, Rutz D et al (2008) Biogas handbook, University of Southern Denmark Esbjerg, NielsBohrsVej 9–10, DK-6700 Esbjerg, Denmark

Babel S, Sae-Tang J et al (2009) Anaerobic co-digestion of sewage and brewery sludge for biogas production and land application. Int J Environ Sci Technol 6(1):131–140

Cavinato C (2011) Anaerobic digestion fundamentals 1, Summer school on biogas technology for sustainable second generation biofuel production

Hanoi Urban Environment (2015) The situation and solutions of management, collection and treatment of fecal sludge, International Conference on Management of sludge from the drainage system and sanitation (FS3–2015) – Proceedings sludge management in Vietnam opportunity to improve, pp 25–27

Ho Chi Minh City Urban Drainage Co., Ltd (2015) Sewer and feacal sludge management in Ho Chi Minh City. In: Proceedings of the 3rd international feacal sludge management conference, Focus on Vietnam

Khai NQ (2002) Biogas technology, Labour and Social Publishing

Klingel F, Montangero A et al (2002) Fecal sludge management in developing countries, Eawag/Sandec

Lay JJ, Li YY, Noike T (1997) Influences of pH and moisture content on the methane production in high-solids sludge digestion. Wat Res 31(6):1518–1524

Montangero A, Strauss M (2004) Fecal sludge treatment, Eawag/Sandec

Parkin GF, Owen WF (1986) Fundamentals of anaerobic digestion of wastewater sludges. J Environ Eng 112:867–920

Pohland FG (1968) Thermal energy interchange during anaerobic methane fermentation of waste organic substrates. Am Soc Microbiol 16(10):1518–1523

Sandec Training Tool 1.0 – Module 5 (2008) Faecal sludge management, Eawag/Sandec

Strande L, Ronteltap M et al (2014) Faecal sludge management systems approach for implementation and operation. IWA Publishing, London

Strauss M, Montangero A (2002) Fecal sludge management – review of practices, problems and initiatives, Eawag/Sandec
Strauss M, Drescher S et al (2003) Co-composting of faecal sludge and municipal organic waste – a literature and state – of – knowledge review, Eawag/Sandec
Stronach SM, Rudd T, Lester JN (1986) Anaerobic digestion processes in wastewater treatment. Springer, Berlin
Thai NTK, Nhue TH et al (2013) Fecal sludge management from the sanitation. Science and Technology Publishing, Hanoi
The Prime Minister's Office (2009) The strategy of intergated management of solid waste in Vietnam up to 2025 and the vision to 2050, Hanoi
Vögeli Y, Lohri CR, Gallardo A, Diener S, Zurbrügg C (2014) Anaerobic digestion of biowaste in developing countries, Eawag/Sandec
World Bank (2012) Assessment of the Urban Wastewater Management in Vietnam, Hanoi