International Journal of Technology (2018) 2: 267-274
ISSN 2086-9614 

# EFFECT OF THE ADDITION OF FAT OIL AND GREASE (FOG) ON THE PERFORMANCE OF A DRY ANAEROBIC DIGESTION FOOD WASTE REACTOR

Dwita Fitriani Wijayanti[1], Nyoman Suwartha[1*], Cindy Rianti Priadi[1]

[1]*Environmental Engineering Study Program, Department of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Kampus UI Depok, Depok 16424, Indonesia*

(Received: December 2017 / Revised: February 2018 / Accepted: March 2018)

## ABSTRACT

Organic waste mostly comes from food waste, which has characteristics of high concentrations of nitrogen and fat, and high humidity. Domestic waste in Indonesia has a high organic content, which is suitable for anaerobic conditions. Waste oil and fat can be used as co-substrates and are helpful in yielding biogas in an anaerobic digestion (AD) process. The aim of this research is to analyze the performance of a food waste dry anaerobic digestion reactor after the addition of fat oil and grease (FOG) waste. The research was conducted using a semi-continuous stirred tank reactor (SCSTR) with an active volume of 400 L, operated at an average temperature of 27.8±1.07°C. Two experimental scenarios were performed, using varying types of food waste, food waste with cow dung as substrate, and FOG waste as co-substrate. The experiment was conducted using an Organic Loading Rate (OLR) of approximately 10 kg VS/m$^3$, with a constant mixing intensity of 30 rpm. The results show that there was a significant difference between the input of food waste substrate with and without the addition of FOG ($p<0.05$). The average reduction of volatile solids (VS) and chemical oxygen demand (COD) removal in the substrate input with FOG addition was higher than without the addition. The mean percentages of COD removal and VS reduction in the substrate input with FOG addition were 63.3±2.71% and 89.30±1.55%, whereas those for substrate input without FOG addition were 59.45±4% and 77.65±1.46%, respectively. The study concludes that the use of FOG as a co-substrate in a dry AD food waste reactor is not only beneficial in reducing FOG waste generation, but also has a significant impact on reducing COD and VS, which can enhance potential biogas yield.

*Keywords:* Anaerobic digestion (AD); Fat oil and grease (FOG); Food waste; Waste management

## 1. INTRODUCTION

Solid waste is any waste product arising from the activities of humans and animals. It is normally in solid form and disposed of when it is not wated for reuse; it contains both organic and inorganic waste components (Tchobanoglous, 1993). The average level of waste generation in 23 developing countries is about 0.77 kg/person/day (Troschinetz & Mihelcic, 2009). This high rate of waste generation has great potential for reuse or recycling at source in order to reduce the volume of final disposal into landfill. One of the waste fraction that can be reused as compost or energy is organic waste (food/kitchen waste).

In general, solid waste in Indonesia has a high organic content of about 60.5‒80% of the total waste generated (Damanhuri & Padmi, 2010; Aprilia et al., 2013). It is derived from municipal

*Corresponding author's email: nsuwartha@eng.ui.ac.id, Tel: +62-21-7270029, Fax: +62-21-7270028
Permalink/DOI: https://dx.doi.org/10.14716/ijtech.v9i2.1139

food waste, which has characteristics of high nitrogen and fat concentration, high pH and low humidity, which cause problems for its application in waste processing technology (Zarkadas et al., 2015). Moreover, domestic waste in Indonesia has a high organic content, which makes it suitable for anaerobic conditions with an organic loading rate (OLR) of around 3.2-32 kg COD/m$^3$day (Metcalf & Eddy, 2014), and pH values ranging from 6.5−8.2 (Zhai et al., 2015); it would therefore be more effective to treat domestic waste with an anaerobic system.

Food waste degrades well and forms biogas due to optimum nutrition, temperature, pH and anaerobic conditions (Gomez et al., 2006). One of the widely used technologies for processing domestic waste is anaerobic digestion (AD). The main characteristic of AD is that it is specifically used to convert waste to energy from various biodegradable sources of organic solid waste. The AD process contributes efficiently to reducing waste and waste production (Metcalf & Eddy, 2014).

Many researches have studied the use of anaerobic digestion (AD) to convert waste to energy from various types of reactor (Kothari et al., 2014; Zarkadas et al., 2015; Tassaka, 2016; Kurnianingsih & Priadi, 2017), with a range of varying substrates and co-substrates (Gomez et al., 2006; Zhang et al., 2013; Zhai et al., 2015; Afifah & Priadi, 2017). The co-substrate is a very important parameter that can accelerate the decomposition process and which affects biogas formation. However, very few researches have focused on the use of fat and oil grease (FOG) as co-substrate (Davidsson et al., 2008; Kabouris et al., 2009; Martin-Gonzalez et al., 2010). This research aims to utilize the unused FOG waste from domestic activities as the co-substrate of food waste dry anaerobic digestion. The novelty of the research is that it investigates the effect of substrate and co-substrate variation on AD performance.

## 2. EXPERIMENTAL METHODS

### 2.1. Preparation of Feedstock

The feedstock input used was a mixture of substrate and co-substrate. The substrate was food waste collected from the canteen of Universitas Indonesia (UI) and cow dung collected from the cattle farm near the UI campus. The co-substrate was fat and oil grease (FOG) waste collected from the canteen of the Faculty of Engineering UI. A selection process of unwanted food waste such as bones and fruit skin was conducted to avoid obstruction of the AD operations. The selected food waste was chopped and enumerated for sorted to a size of 2-3 mm, with the aim of facilitating the process of waste degradation and acidification, and to expand the contact surface between the microorganisms and food waste. The chopped waste was stored in a cooler so that the substrate characteristics remained constant and was then liquefied at room temperature on the day before use (Zhang et al., 2013).

In many AD process cases, one of the important parameters for biogas production from any substrate is the carbon to nitrogen (C/N) ratio of the material, as well as the concentration, pH, and temperature (Dioha et al., 2013). Bacteria need a suitable ratio of carbon to nitrogen for their metabolic processes. The suitable C/N ratios for optimal digestion are in range of 10:1 to 23:1 (Marchaim, 1992). Therefore, before operating the AD reactor, the feedstock characteristics of the C/N ratios for food waste, FOG and the mixture (food waste, cow dung and FOG) were tested. The mixed feedstock aimed to achieve optimum AD operational conditions, which can improve the pH parameters and C/N ratios.

### 2.2. AD Reactor Specifications

The reactor used was made from cylindrical stainless steel, which has resistance to high pressure, corrosion and aggressive substances, as well as a low leakage rate (Tassakka, 2016). The reactor capacity was about 500 L, with an active reactor volume of 400 L. At the top of the reactor there was an inlet channel made of a 3" stainless steel pipe equipped with a functioning valve to allow feedstock to be poured into the reactor. It was connected to a 1" recirculation pipe used to recycle the reactor contents. At the side of reactor there was a 1" effluent channel, equipped with a valve functioning as a reactor effluent duct. A 2" sludge valve was installed at the bottom of the reactor to discharge the reactor contents. The reactor was connected to a control, stirring, gas and recirculation system. The outer surface of the reactor was coated with an insulator (aluminum foil) to maintain the temperature inside the system at a mesophilic state. Figure 1 shows the schematic design of the dry AD reactor, and the reactor specifications are presented in Table 1.

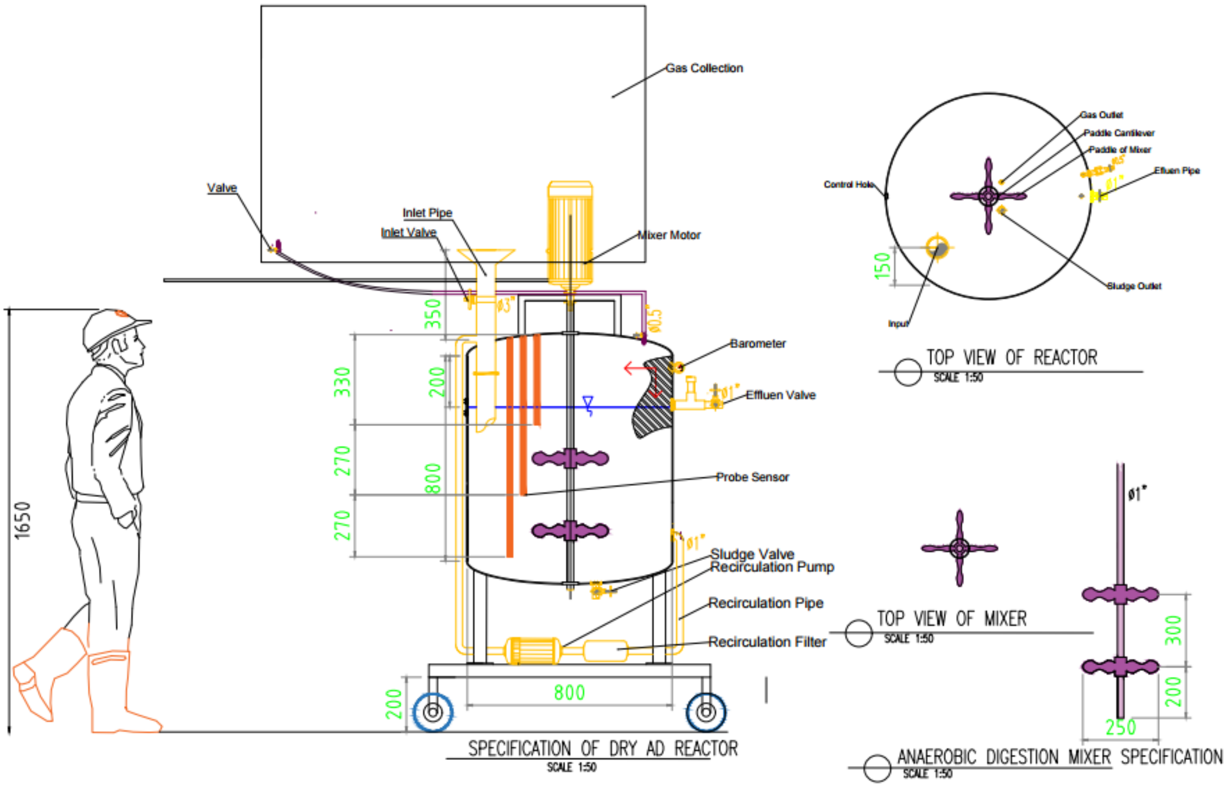



Figure 1 Schematic design of dry anaerobic digestion reactor

Table 1 Reactor specification data

| Parameter | Dimension | Unit |
|---|---|---|
| Diameter of reactor | 0.8 | m |
| Height | 1.0 | m |
| Diameter of inlet pipe | 0.3 | inch |
| Diameter of effluent channel | 0.1 | inch |
| Diameter of recirculation pipe | 0.1 | inch |
| Diameter of sludge valve | 0.2 | inch |

### 2.3. AD Operational Stages

The research was conducted on a pilot scaled semi-continuous stirred tank reactor (SCSTR) using a dry AD system. The operation of the AD reactor can be divided into five steps: from acclimatization to pre-operational and operational stages, with two input feeder scenarios, as shown in Figure 2.

Each stage of the AD process was carried out using different inputs and durations, with the organic content loading such as chemical oxygen demands (COD), total solids (TS), volatile solids (VS), and C/N ratios observed daily. These organic loadings have a significant influence on the characteristics of food waste, FOG and cow dung used as feedstock to produce biogas, which contains methane and carbon dioxide. The operation of the dry AD was conducted daily, using varied organic loadings, ranging from 13.98-20.07 kg/day (with an organic loading rate of OLR 10 kgVS /$m^3$day), and stirred at a constant rate of 30 rpm.

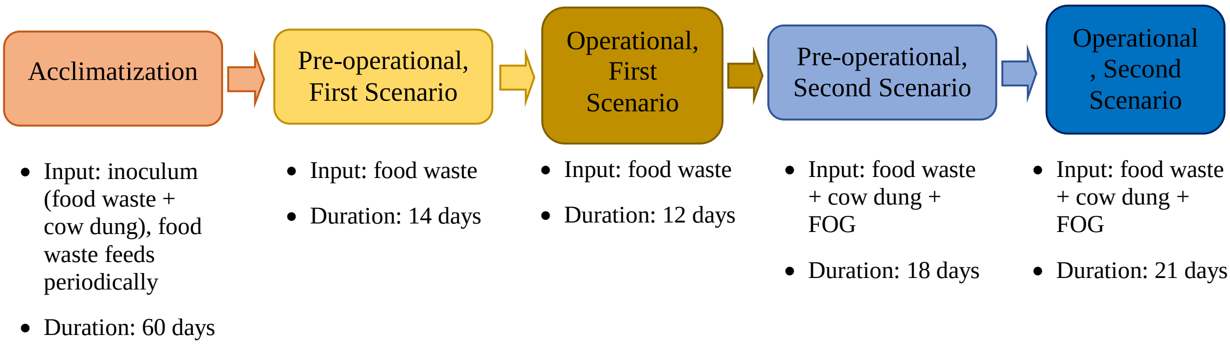



Figure 2 Operational stages of the AD process

## 3. RESULTS AND DISCUSSION

### 3.1. Characteristics of the Feedstock

The food waste used as substrate had a TS value of 24.3%, which according to Kothari et al. (2014) is in the optimal TS (20−50%) range, so that it can be processed using dry AD. Table 2 shows that food waste has a very high organic content (VS concentration) of 99.9% TS. When compared to previous studies, the VS concentration of the substrate used in this study was very close to that in Tassakka's (2016) findings, with a 94 %TS. The COD concentration of food waste was very high (264 g/L), which can be classified as a degradable feedstock (Curry & Pillay, 2012), so it has the potential to be processed using a dry AD reactor.

Table 2 Characterstics of the feedstock

| Parameter | Unit | Food Waste | FOG | Mixture (food waste, cow dung, FOG) |
|---|---|---|---|---|
| COD | (g/L) | 264 | 133 | 23 |
| TS | (%) | 24.3 | 18.0 | 28.9 |
| VS | (%TS) | 99.9 | 99.1 | 92.6 |
| C | (mg/L) | 52.0 | 62.7 | 90.0 |
| N | (mg/L) | 4.41 | 0.07 | 3.50 |
| C/N | - | 11.8 | 89.5 | 25.7 |

The feedstock characteristic of the C/N ratio is considered to be in optimum condition, influenced by a high nitrogen concentration due to the protein content in the food waste, which dominates by organic waste. FOG waste can be a help in the AD process as a co-substrate having stable C/N ratio when mixed with the substrate (food waste and cow dung) approximately 21.4−25.0. The C/N ratio of the mixed feedstock (25.7) is considered ideal for AD since it is in the optimum ratio range of 10:1 to 23:1 (Marchaim, 1992). With this optimum C/N ratio, the mixed feedstock with the addition of FOG has a high possibility and potential to produce biogas. This is supported by Davidsson et al. (2008), who found that the addition of oil and fat waste co-substrate can increase the level of methane gas by 9−27%.

## 3.2. Organic Loading Anaerbic Digestion Performance

During the acclimatization process, the food waste was added periodically. The addition of substrate aimed to feed the microorganisms in preparing a stable metabolism. From days 1−16 along with the addition of 30 kg of substrate, the hydrolysis and acidogenesis processes were obviously observed. The pH value of the inoculum on days 1 to 24 was very low, at around 3.5−5.1. This low pH value makes the methanogenesis process unstable, as the optimal pH range for methanogen bacteria is about 6.8−8.2 (Kothari et al., 2014). The acclimatization process was dominated by acidogenesis rather than a methanogenesis process, so in the next stage of the AD process the reactor was re-acclimatized for 2 weeks before the operation began.

After the acclimatization process ended, the operational experiment of the AD reactor was started. Figure 3 shows the fluctuation in temperature and pH values during the operation. It can be seen that temperature had a stable average value of around 28.4°C.

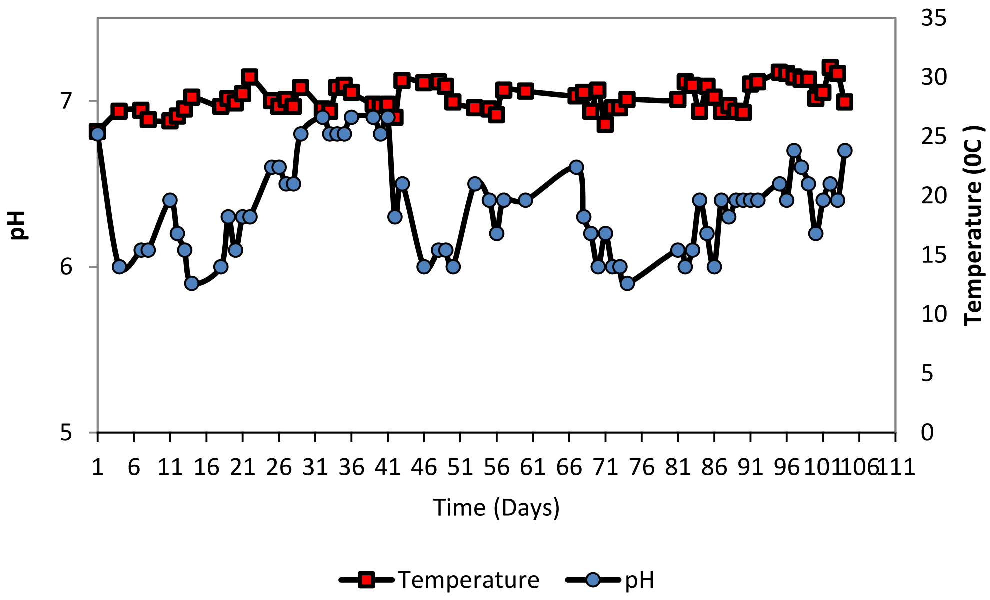
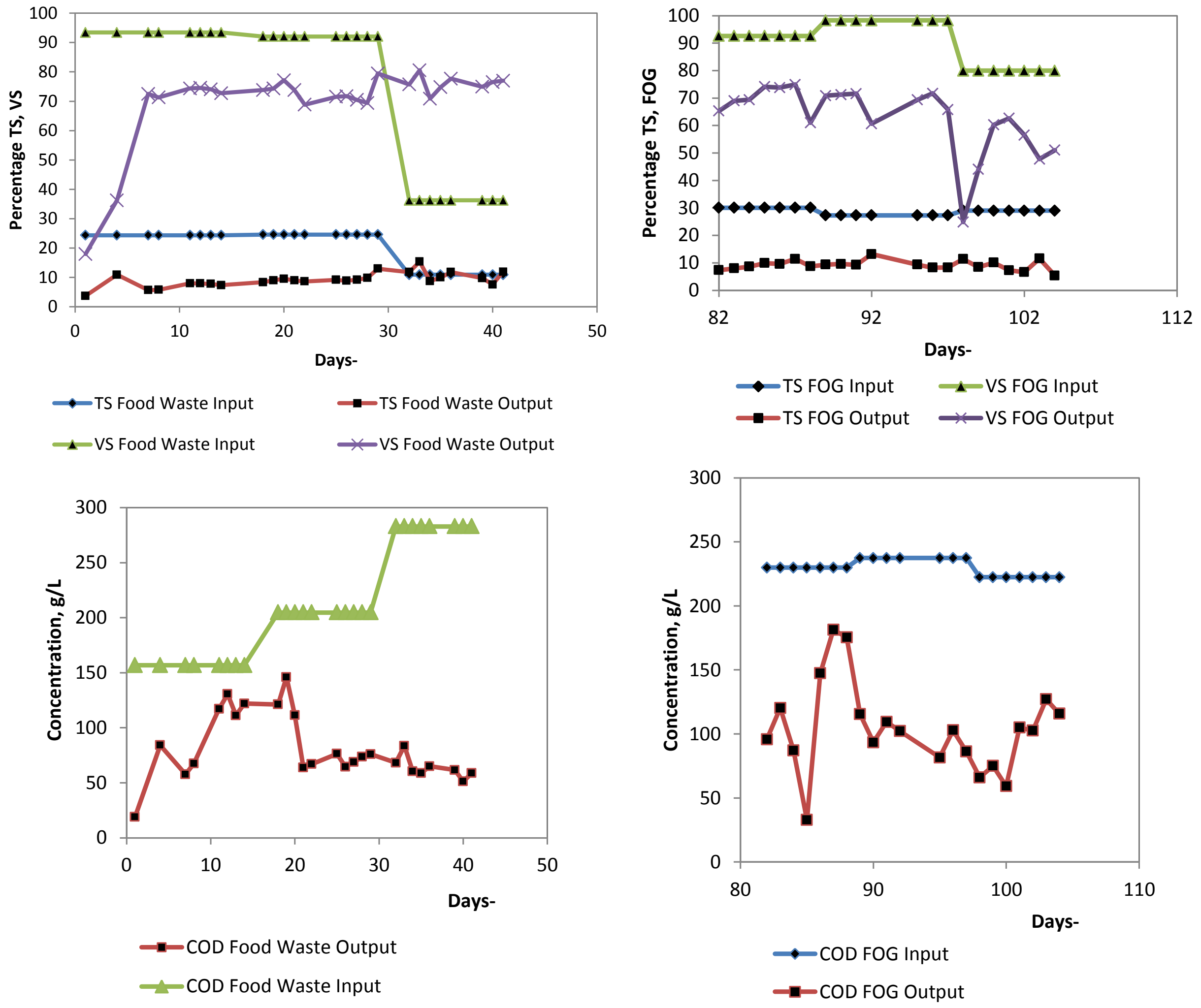



Figure 3 Relation between pH and temperature inside the AD reactor

The pH value in the first operational scenario (Days 1 to 50) was initially 6.8 because the inoculum had a high pH. However, on the following day this value decreased to 6.4 and then gradually rose and fell. The pH parameter is essential for biogas production because most methanogens grow best in the pH range of 6.7-7.5. The average pH value during the first scenario was 6.5±0.06 and in the second scenario (days 80 to 104) 6.3±0.03, while the average temperature value in the first scenario (27.8±0.2°C) was not significantly different to the average temperature in the second scenario, which was around 28.5±0.19°C.

Figure 4 shows the results of the dry AD operation, containing the main parameters observed for each scenario. The maximum COD reduction during the first operational scenario was about 88.0%, while for the second scenario it was around 88.4%. The COD input content before the addition of FOG waste had an average value of 219±9.9 g/L, while the output decreased to about 79.7±5.5 g/L. The average values of COD input and output were higher during the second scenario period, at about 230±1.4 g/L and 104±7.7 g/L, respectively.




(a) first scenario without FOG (b) second scenario with FOG

Figure 4 Observed parameter changes over time during operation of the AD reactor

High COD concentrations indicate that the substrate used has the potential to be processed using AD because it has a very high level of organic content which can be converted into biogas. The performance of the decomposition process of organic matter in the reactor can be seen from the volatile solids destruction (VSD) value. The average VSD value in the first scenario was the smallest, approximately 77.6±1.46%, compared to that of the second scenario approximately 89.3±1.55%. The feedstock in the first scenario (with food waste substrate input) had an average TS input of around 20.3±1.25% and an output approximately 9.2±0.47%. In the second scenario, the TS input (mixture of food waste substrate, cow dung and FOG waste) had an average value greater than in the first scenario, at about 28.8±0.25%, and the TS output produced was smaller, approximately 9.13±0.4 %. VS is the organic fraction of total solids, normally expressed in percentage terms, volatile at a temperature of 550 $^{o}$C. VS input in the first scenario had a value of 75.3±5.21% and output of 70.5±2.6%, while in the second scenario (with the addition of FOG waste) average VS input and output values were approximately 90.3±1.7% and 62.7±2.7% respectively. VS has organic matter as part of the degradable solid waste, while the TS of food waste has a high organic content and is easily soluble and degraded, with a higher energy content.

## 4. CONCLUSION

The performance of the dry anaerobic digestion food waste reactor had an average temperature of 28.38°C (mesophilic), and average pH of 6.5±0.06. The input of food waste substrate had a COD value of 218.98±9.9 g/L, which decreased at output to about 79.7±5.50 g/L. High COD concentrations indicate that the substrate used has the potential to be treated using an AD reactor. The addition of FOG waste to the dry AD reactor noticeably maintained average pH, although it was not significantly different in the first scenario, at about 6.3±0.03. In addition, the value of COD removal due to the addition of FOG waste was not significantly different, at about 88.4%. The average COD value at the inlet was higher than at the outlet during the addition of FOG waste, at about 230±1.4 g/L and 104±7.7 g/L respectively. The average VSD value in the first scenario was smaller than in the second, at about 77.6±1.46%, while the highest VSD was found in the second scenario, at about 89.3±1.55%. In addition, the COD removal of gas formation was found to be inversely proportional to biogas production. The AD operation in dry conditions with TS content was found to be greater than 15%. In this study, the addition of FOG waste did not produce any significant increase in biogas production at the initial stage, but at the end of the fourth day significant differences (according to the t-test statistic of $p<0.05$) were shown. This might have been caused by the fact that FOG waste has the property to behave as an inhibitor.

## 5. ACKNOWLEDGEMENT

The authors would like to thank the Directorate Research and Community Service Universitas Indonesia for providing the International Indexed Publication Grants for Students' Final Project (Hibah PITTA) No. 824/UN2.R3.1/HKP.05.00/2017. We would also like to thank M. Irpan Sejati Tassakka for the valuable discussion and Septiana Kurnianingsih and Ismail for the collaboration in feedstock loading.

## 6. REFERENCES

Afifah, U., Priadi, C.R., 2017. Biogas Potential from Anaerobic Co-digestion of Faecal Sludge with Food Waste and Garden Waste. Renewable Energy Technology and Innovation for Sustainable Development, *AIP Conference Proceeding*, Volume 1826, pp. 020032-1–020032-8

Aprilia, A., Tezuka, T., Spaargaren, G., 2013. Inorganic and Hazardous Solid Waste Management: Current Status and Challenges for Indonesia. *Procedia Environmental Sciences*, Volume 17, pp. 640–647

Curry, N., Pillay, P., 2012. Biogas Prediction and Design of a Food Waste to Energy System for the Urban Environment. *Renewable Energy*, Volume 41, pp. 200–209

Damanhuri, E., Padmi, T., 2010. Waste Management (*Pengelolaan Sampah*). Institut Teknologi Bandung (in Bahasa)

Davidsson, Å., Lövstedt, C., la Cour Jansen, J., Gruvberger, C., Aspegren, H., 2008. Co-digestion of Grease Trap Sludge and Sewage Sludge. *Waste Management*, Volume 28(6), pp. 986–992

Dioha, I.J., Ikeme, C.H., Nafi'u, T., Soba, N.I., Yusuf, M.B.S., 2013. Effect of Carbon to Nitrogen Ratio on Biogas Production. *International Research Journal of Natural Sciences*, Volume 1(3), pp. 1–10

Gómez, X.M., Cuetos, J., Cara, J., Morán, A., García, A.I., 2006. Anaerobic Co-digestion of Primary Sludge and the Fruit and Vegetable Fraction of the Municipal Solid Wastes: Conditions for Mixing and Evaluation of the Organic Loading Rate. *Renewable Energy*, Volume 31, pp. 2017–2024

Kabouris, J.C., Tezel, U., Pavlostathis, S.G., Engelmann, M., Dulaney, J., Gillette, R.A., Todd, A.C., 2009. Methane Recovery from the Anaerobic Codigestion of Municipal Sludge and FOG. *Bioresource Technology*, Volume 100(15), pp. 3701–3705

Kothari, R., Pandey, A.K., Kumar, S., Tyagi, V., Tyagi, S.K., 2014. Different Aspects of Dry Anaerobic Digestion for Bio-energy: An Overview. *Renewable and Sustainable Energy Reviews*, Volume 39, pp. 174–195

Kurnianingsih, S., Priadi, C.R., 2017. Pilot Scale Anaerobic Digestion of Food Waste Process Performance under Various Mixing Intensities. *In*: Proceeding of the 1st International Conference on Science, Mathematics, Environment and Education 2017

Marchaim, U., 1992. Biogas Processes for Sustainable Development. FAO Agricultural Services Bulletin 95, p. 38

Martín-González, L., Colturato, L.F., Font, X., Vicent, T., 2010. Anaerobic Co-digestion of the Organic Fraction of Municipal Solid Waste with FOG Waste from a Sewage Treatment Plant: Recovering a Wasted Methane Potential and Enhancing the Biogas Yield. *Waste Management*, Volume 30(10), pp. 154–1859

Metcalf & Eddy, 2014. *Wastewater Engineering Treatment and Resource Recovery*. Fifth-Edition. New York: McGraw-Hill

Tassakka, M.I.S., 2016. Optimization of Organic Waste Processing to Enhance Volatile Solid Destruction using Anaerobic Digestion. Case Study: Organic Waste Processing at Universitas Indonesia). *Master The*sis. Environmental Engineering Study Program, Universitas Indonesia (in Bahasa)

Troschinetz, A.M., Mihelcic, J.R., 2009. Sustainable Recycling of Municipal Solid Waste in Developing Countries. *Waste Management*, Volume 29(2), pp. 915–923

Tschobanoglous, G., 1993. *Integrated Solid Waste Management – Engineering Principles and Management Issues*. New York: McGraw-Hill

Zarkadas, I.S., Sofikiti, A.S., Voudrias, E.A., Pilidis, G.A., 2015. Thermophilic Anaerobic Digestion of Pasteurised Food Wastes and Dairy Cattle Manure in Batch and Large Volume Laboratory Digesters: Focussing on Mixing Ratios. *Renewable Energy*, Volume 80, pp. 432–440

Zhai, N., Zhang, T., Yin, D., Yang, G., Wang, X., Ren, G., Feng, Y., 2015. Effect of Initial pH on Anaerobic Co-digestion of Kitchen Waste and Cow Manure. *Waste Management*, Volume 38, pp. 126–131

Zhang, C., Xiao, G., Peng, L., Su, H., Tan, T., 2013.The Anaerobic Co-digestion of Food Waste and Cattle Manure. *Bioresource Technology*, Volume 145, pp. 170–176