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Research Article

Home Biogas Production using Homemade Bio-activator with Chicken Manure

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Abstract

Food waste is a significant constituent in municipal solid wastes, and its disposal is an environmental concern. Previous research suggested that food waste can be turned into a homemade biogas activator to treat the waste itself. Chicken manure is rich in nitrogen that may enhance biogas production. Therefore, the current research adds chicken manure as a co-activator in the batch process. It aims to activate bacteria for degrading the food waste in the semi-continuous process to produce biogas. Food waste to chicken manure was set at 2 : 1 (digester #1), 3 : 1 (digester #2), and 4 : 1 (digester #3), while digester control was feed with food waste only. Digester #2 gives the highest biogas with a cumulative biogas volume of 120.77 liters, 71.01% CH_4, 26% CO_2, 2.9% O_2, and 0.088% H_2S. The potential of methane volume per TS and VS is at around 18.72 L/kg and 34.68 L/kg, respectively, which are around 2 times higher than digester without chicken manure.

Keywords: Biogas, digester, food waste, homemade activator, chicken manure

1. Introduction

The rapid economic growth of big cities and medium cities often creates new problems in managing cities related to infrastructure provision. One of the new problems is the increasing volume of waste, which impacts the need for sustainable management. In particular, the problem of cities in Indonesia is about solid waste and its management. This condition is per the development results always accompanied by a growth in the volume of solid waste. Solid waste will continue to be produced as long as humans are still alive and carry out activities related to daily life in the areas they live.

In general, various cities in Indonesia still use the old collect-transport-waste paradigm viewed from the solid waste management system applied. Applying this old paradigm negatively impacts waste because waste is not managed, and there is no effort to reduce waste generation. As a result, the final waste processing site (landfill) becomes full quickly even though the current condition, finding a new location for landfill is challenging and generally always rejected by the community.

The other problems that arise are relating to leachate pollution and the potential for gas generation in landfills which continues to increase because the amount of waste also continues increasing. Handling of waste management requires a good arrangement/ management as an effort to overcome existing problems. These problems include the limited funds owned by the government to finance solid waste management and the level of solid waste services to the community, which is still low/ not optimally served.

Its management must be sufficiently feasible to be implemented simultaneously accompanied by efforts to utilize it so that it is expected to have added value benefits to obtain a high level of effectiveness and efficiency in handling waste in the city. It is necessary to choose the proper method and technology, and it needs active participation from the community where the waste source comes from. Domestic waste is the largest waste producer compared to other waste sources, which is 65-70%, more significant than the waste generation from markets which is only 5-10% (Jayasiri, 2017). 57% of household waste is dominated by organic waste, which is dominated by food waste, wood, twigs, and leaves. The large percentage of household waste is both a problem and an opportunity to solve solid waste from its source.

One of the technologies used for the handling of organic waste is biogas. Biogas technologies are the complimentary feature for energy supply (Sawyerr et al., 2020). Fossil fuel could not be expected as the primary energy for the future. Biogas yielded is converted into renewable energy. Currently, utilizing food waste to produce biogas is carried out to convert the energy using an anaerobic digester. Some researchers conducted an anaerobic process in various designs to treat food waste using the homemade activator and commercial activator (Green Phoskko-7, Effective Microorganisms-4). Based on the result, the homemade activator showed superior performance in biogas production among commercial activators (Raharjo et al., 2019). Fixed dome digester type is design for further research by mixing the homemade activator with chicken manure as a co-activator.

This study was conducted through biomethane potential (BMP) testing for seven chicken manure samples in Lithuania in 2018. The BMP test showed that chicken manure is an alternative source for anaerobic digestion biogas due to the high biomethane potential to produce 508 ± 36 mL biogas g-1 VS (Jurgutis et al., 2020). Biogas is produced during the first 10 days of anaerobic digestion. The current study is using chicken manure as a co-activator to food waste. It is expected to produce biogas faster and obtain a higher methane gas concentration than the previous research.

2. Methods

The material for the biogas process waste was obtained from the market of Bandar Buat, Padang City, while the chicken manure was obtained at UPT. Andalas University Farm. Food waste is taken at the market to make it easier to collect and simulated based on the composition of food waste generated in the household. The research location was carried out at the Research Laboratory of the Department of Environmental Engineering, Unand. The type of digester used in this study is a fixed dome digester with a capacity of 16 liters. There are 4 digesters consist of one control digester and three test digesters. This research was carried out on a laboratory scale so that the digester capacity did not base on the amount of waste generated by each individual per day. Each digester is equipped with a floating drum to collect biogas. The fermentation process occurs in a fixed dome digester. The biogas formed will flow and collect in the floating drum.

Digester variance was based on the homemade activator and chicken manure ratio, including the one without chicken manure (digester control). The experiment was divided into the preparation stage (batch process) and the operational stage (semi-continuous process). The process of forming a natural activator from food waste and chicken manure to prepare for microbial activity in the anaerobic condition is called a batch process for 20 days. Homemade-activator is prepared from the household food waste in anaerobic condition before the preparation stage (Raharjo et al., 2019). Household food waste was introduced periodically for 6 days (day 21st - 26th; day 36th - 41st; day 46th - 51st), 1 kg/digester/d/cycling during the operation stage. It was mixed based on the compositions in Table 1. The ratio between the filling material and the water used is 1 : 2 in units of weight. The composition of household waste that will be used as stuffing material is based on previous research data (Raharjo et al., 2021). This data was obtained from the simulation of household waste composition by distributing questionnaires and direct interviews with homemakers in Kapalo Koto Village, Pauh District, Padang City. The simulations are carried out so that the composition of the stuffing material in each digester is the same. The size of the stuffing is one of the factors influencing the fermentation process to support bacterial growth and maximize the fermentation process. The fermentation process will be optimal if the size of the stuffing is getting smaller. Therefore, the stuffing ingredients are chopped using a blender. Table 2 shows the experimental setup. Figure 1 displays schematic of the digester.

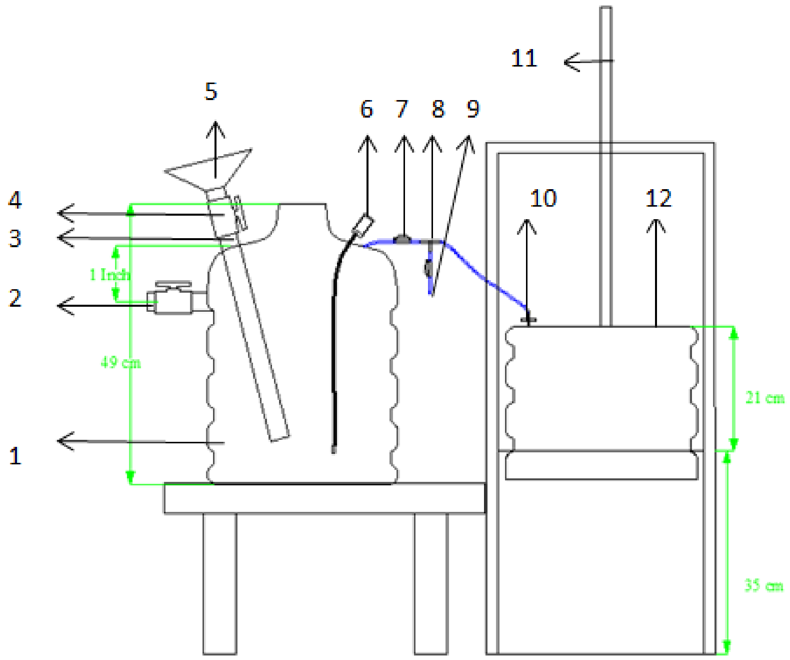
Table 1. The composition of scenario household waste (Raharjo et al., 2019)

Item	Composition (weight %)
Vegetable waste	51
Fruit waste	40
Rice waste	9

Table 2. Experimental set up for preparation stage

No.	Treatment	Preparation Stage			
		Digester control	Digester #1	Digester #2	Digester #3
1	Digester volume (L)	16.00	16.00	16.00	16.00
2	Food waste (kg)	6.60	4.00	4.58	4.95
3	Food waste: chicken manure	1:0	2:1	3:1	4:1
4	co-activator (Kg)	0.00	2.00	1.53	1.24
5	Substrate volume (L)	2.87	4.03	3.79	3.65
6	Total substrate (kg)	6.60	6.00	6.11	6.19
7	Substrate: water (weight)	1 : 2	1 : 2	1 : 2	1 : 2
8	Water (Liter)	13.20	12.00	12.21	12.38
9	Lime (Gr)	38.00	38.00	46.36	46.74
10	Last pH	7.50	7.50	7.50	7.50

The running process started on the 1st day. The measurements recorded daily include temperature using thermometer digital and volume of biogas using floating drum, while the cumulative volume of biogas and biogas concentration was determined in the last process. The cumulative volume of biogas was obtained by accumulating the gas produced from day 1st - 55th each digester. Measurement of methane gas concentration using the IRCD4 biogas analyzer detector. Biogas yielded was expelled by using a compressor and collected in the Tedlar bags. During the operation stage, the biogas was sampled depends on the biogas yielded and the optimum limit of the floating drum, which is 14 liter. Hence, measuring the quantity of biogas concentration in each digester was a different day.



1. Fixed Dome Digester	5. Funnel	9. Air Outlet
2. Outlet Pipe	6. Thermometer	10. Metal Gate Valve
3. Inlet Pipe	7. Valve	11. Vertical Measuring Pipe
4. Gate Valve Pipe	8. Tee Branch	12. Floating Drum

Figure 1. Schematic diagram of the biogas digester

3. Result and Discussion

3.1. Biogas and Methane Production

The laboratory-scale of the anaerobic digestion process was analyzed for 55 days. The length of this process was conditioned according to the results of the previous research (Raharjo et al., 2021), which was 20 days of batch process and 35 days of the semi-continuous process. Mixing homemade-activator and chicken manure increased the biogas production and shortened the hydraulic retention time (HRT) to around 6 days. This time was shorter than previous research without chicken manure that around 10 days on the preparation stage. The previous research took time to produce biogas in the preparation stage for 25 days. Figure 2 displays daily biogas production during the preparation and operation stage. Biogas was produced from day 1st to day 9th on the preparation stage. Biogas was not produced after more than 10th days. The decreased biogas production indicates that the substrate as an energy source of bacteria was reduced (Rafiee et al., 2021). The fresh substrate must be supplied into the digester for biogas production to stabilize (Kougias and Angelidaki, 2018). Digester control produces biogas faster than other digesters because the anaerobic bacteria in the digester still survive, while the other digester bacteria might have died. The highest biogas production was the digester control and digester 2 that reached on peak day around 9.56 L/d and 7.96 L/d, respectively.

Biogas production is short in both the control digester and the test digester. Biogas is not produced after more than 10 days. The reduced production of biogas indicates that the filling material as a nutrients source for bacteria is reduced or even depleted. The bacteria will fight over each other for food to stay alive. Biogas production is reduced due to the availability of nutrients or carbon sources from the filling material so that the growth of methane bacteria will also decrease, and more bacteria die. Biogas is no longer produced, and methane bacteria will enter the death phase (Jurgutis et al., 2020).

Biogas production of bacteria (methanogens) at the beginning of the fermentation process undergo a period of adjustment to the conditions in the raw materials, then grow due to the utilization of nutrients to produce maximum biogas production. In the final stage, fermentation enters a stationary phase where bacteria begin to lack nutrients and die so that biogas production tends to be constant and begins to decline (Wang et al., 2014). Batch process conditioning for 20 days only produces gas in the first 10 days. The death phase continues in the semi-continuous cycle 1 process in digesters 1 and 3, where for 15 days, no biogas is produced, meaning that the bacteria in both digesters are entirely dead. While the control digester and digester 2, biogas is still formed, indicating that the bacteria are still alive. Even though the bacteria have fasted for the last 10 days in the batch process, the bacteria can still survive in these conditions. The biogas in the control digester started to appear on the 23rd day, while in the 2nd digester, the biogas started to appear on the 27th day.

Vegetables as the dominant component of the filling material could cause the non-formation of biogas in the semi-continuous cycle 1 process, especially in digesters 1 and 3. Vegetables have fiber and cellulose that are firmly bound so that it will be difficult for bacteria to break down and impact biogas production (Morales-polo and Soria, 2019). The chicken manure was added again to activate the bacteria in the second cycle based on the death phase condition. Biogas begins to form in digesters 2 and 3, but in digester 1, bacteria still need time to be active again. Cycle 2 lasts for 10 days because, in the previous cycle, biogas production stopped for only 10 days, so that it became a reference in refilling fresh waste. In cycle 3, fresh waste was added back, and it can be seen in the graph that biogas was formed in all digesters, both control digesters, and test digesters. In this cycle, the nutrients of bacteria supply are enough so that the volume of biogas can be produced.

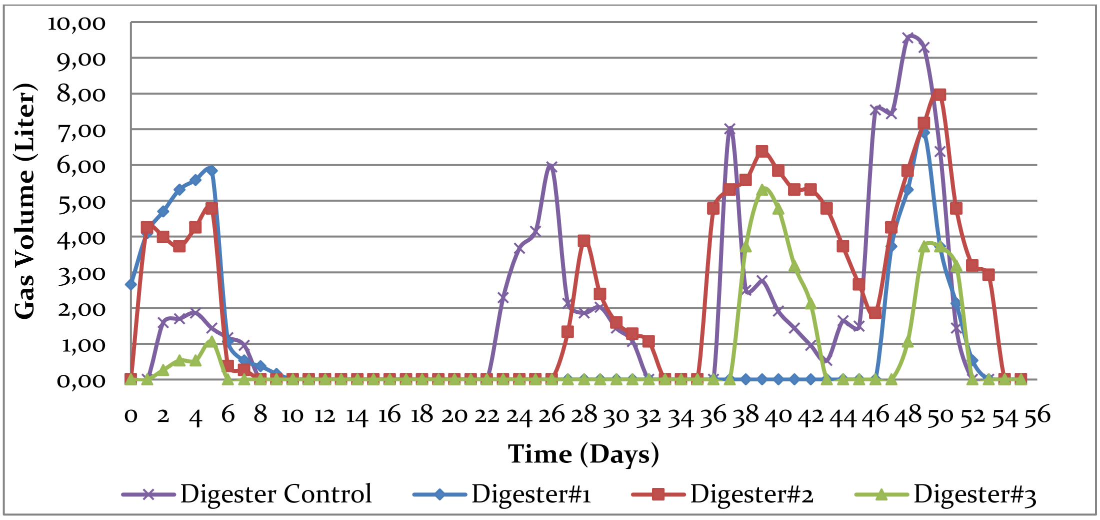


Figure 2. Daily biogas production of operation and condition stage

The graph above shows that the greater the ratio of food waste and chicken manure, the greater the volume of biogas produced. It can be seen in this study that digester 2 with a composition of 3 : 1 (food waste: chicken manure) produces a high average daily gas volume of 2.19 liters. The composition of digester 3 is too high (4 : 1) or digester 1 is too low (2 : 1) causes the process to run not optimally so that biogas production will be below. There will be an excessive buildup of organic matter if the stuffing material is too concentrated (Jo et al., 2018). The bacteria are unable to decompose the organic matter, so that the fermentation process will be disrupted. The composition of digester 1 is not optimal because it contains excess water, which prevents bacterial contact with the stuffing.

In the control digester, the average daily volume of biogas is 1.72 liters, digester 1 is 0.95 liters, and digester 3 is 0.60 liters. High solids content will cause the water content to be too low, inhibiting bacterial growth (Jo et al., 2018). Fresh waste is included in the semi-continuous process does not mean increasing the solids content in the digester. The fast fermentation process will produce a residue in the form of brown sludge. The volume of stuffing that enters will be equal to the volume of sludge that comes out through the outlet so that the digester stuffing remains balanced and the ratio of water to stuffing is maintained at 1 : 2. The other factors that influence the biogas production stirring. Stirring in this study was done manually. Stirring causes contact between the stuffing and bacteria. There will be a deposition of organic matter at the bottom of the digester and even floats on the surface if stirring is not carried out. It also causes the stuffing material and bacteria not to contact, whereas if the stuffing material is homogenized, the decomposing process will be optimal (Morales-polo and Soria, 2019).

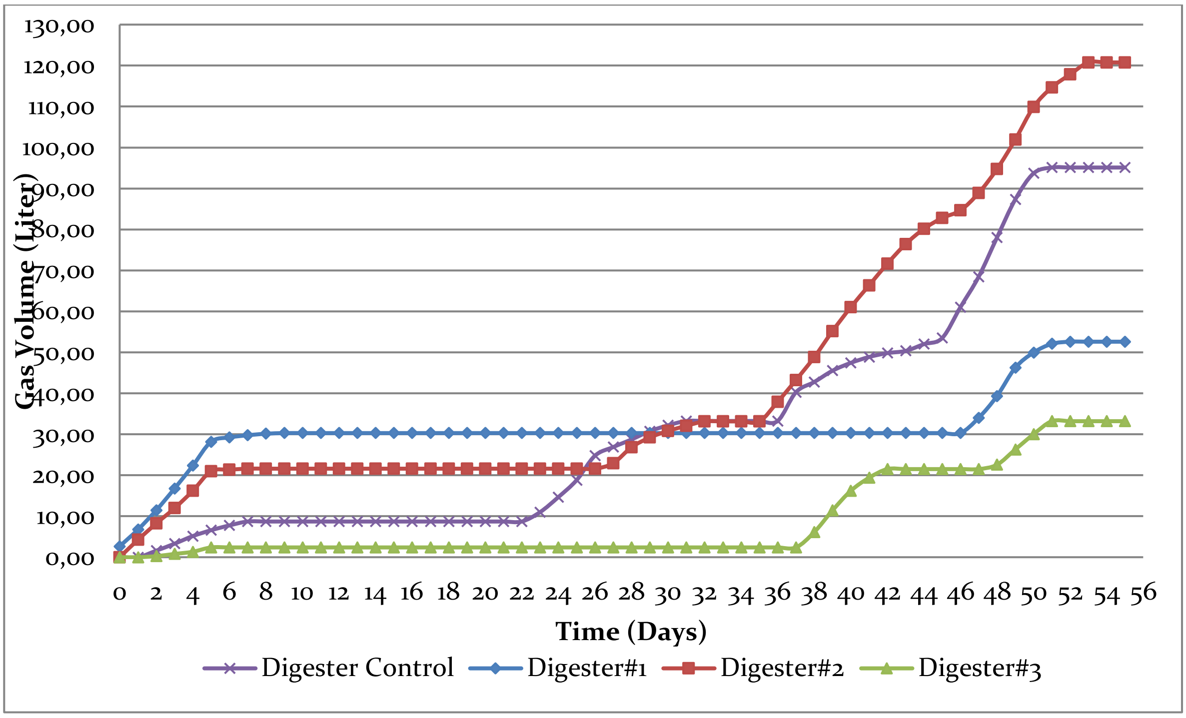


Figure 3. Cumulative biogas production

Figure 3 shows cumulative biogas production of both stages. The figure displays that digester 2 gives the highest biogas production of around 120.77 L, followed by digester control of around 95.12 L. The amount of substrate will affect the volume of biogas produced. Digester 2 ratio 3 : 1 (food waste: chicken manure) shows the best ratio to produce the optimum biogas, while the digester 1 ratio 2 : 1 and digester 3 ratios 4 : 1 show the low biogas produce. The substrate of digesters 1 and 3 were low and high, respectively. The increase in solids concentration may result in poor biogas production. The high substrate will disrupt the fermentation process cause the bacteria could not decompose the organic waste. At the same time, the low substrate contains excess water, which blocks the bacteria with the substrate. The anaerobic process of household food waste has high biogas produced. However, when the food waste was mixed with chicken manure, even the higher biogas was produced. Household food waste is rich in nutrients for bacteria to grow and produce biogas. The methane gas was considered as a biogas quality.

Chicken manure as a co-activator is considered effective in producing high biogas. This can be proven from the research results that have been carried out by comparing the control digester with digester 2. The control digester without using chicken manure produces less biogas than digester 2. This shows that a mixture of food waste and chicken manure that was decomposed previously is effective in processing the organic waste that increases biogas production. Chicken manure contains a lot of cellulose material that has been digested in the chicken intestine so that it is more easily broken down by bacteria which play an essential role in the methanogenesis process to produce methane gas (CH_4).

Chicken manure contains higher nitrogen of 1.03% than other livestock manure (Zhang et al., 2013). It helps the balance of the C/N and pH during the anaerobic process by producing ammonia.

Utilizing chicken manure for biogas production provides rich nutrients as a microbial energy source (Jurgutis et al., 2020). Chicken manure is also available in urban and rural areas. Chicken manure was used because the previous research had a low methane gas concentration and needed a long retention time to produce biogas. It is expected to produce biogas quickly and obtain a high methane gas concentration. Table 3 shows methane gas concentration during the operation stage.

Table 3. Biogas concentration in the operation stage using IRCD4

Variations	Biogas concentration (% Vol)			
	CH_4	**CO_2**	**O_2**	**H_2S**
Digester Control	65.21	25.00	9.70	0,09
Digester 1	52.41	46.00	1.50	0,09
Digester 2	71.01	26.00	2.90	0,09
Digester 3	51.91	41.00	7.00	0,09

Table 3 shows the highest methane gas concentration produced in the operating stage using the ICRD4 biogas analyzer detector. This quantity test was conducted on a different day depending on the biogas yielded in each digester. It was measured on the 47th, 27th, and 38th days respectively. Percentage of biogas composition displays the methane gas yielded more 50% based on biogas composition consist of CH_4 50-80%, CO_2 15-50%, O_2 0-1% and lowest H_2S (Petersson, 2013). This is displays that anaerobic bacteria work optimally at the operating stage after activating anaerobic bacteria in the preparation stage. Chicken manure rich in nitrogen with household waste rich in carbohydrates can significantly enhance biogas production (Surendra et al., 2014). Organic Fraction Municipality Solid Waste (OFMSW) has high moisture that favors biogas produced since it allows bacteria to release methane and metabolic processes to occur (Matheri et al., 2017). The addition of fresh food waste also affects the increase in methane gas concentration. The bacteria get additional substrates that help increase methane gas production. This suggests that the methane gas concentration can continue to increase if the addition of fresh food waste is carried out continuously. The highest methane gas concentration was recorded from digester 2 in the operation stage. The digester was using a homemade bio-activator that was prepared previously from household food waste and chicken manure. Therefore, the bio-activator may have contained specific decomposing anaerobic bacteria for treating the waste.

3.2. Temperature

The activity of anaerobic bacteria depends on the temperature. Daily temperature measurements are carried out every day. This daily temperature was measured using a digital thermometer that was installed on the digester. This measurement is carried out to monitor and observe how the temperature changes during the fermentation process. Different species of methanogens function optimally in three different temperature ranges: 45–60°C thermophilic, 20–45°C mesophilic) and below 20°C psychrophilic. The rate of biogas production increase with an increase in temperature. Only mesophilic and thermophilic temperature ranges are essential in the biogas digestion process because the anaerobic digestion reaction essentially stops below 10°C (Deepanraj et al., 2014). The bacteria available for the digestion process are sensitive to temperature fluctuation, so it is necessary to maintain a constant temperature. The digesters were run at room temperature and mesophilic digestion. The influence of temperature on the rate of the anaerobic digestion process is shown in Figures 4 and 5.

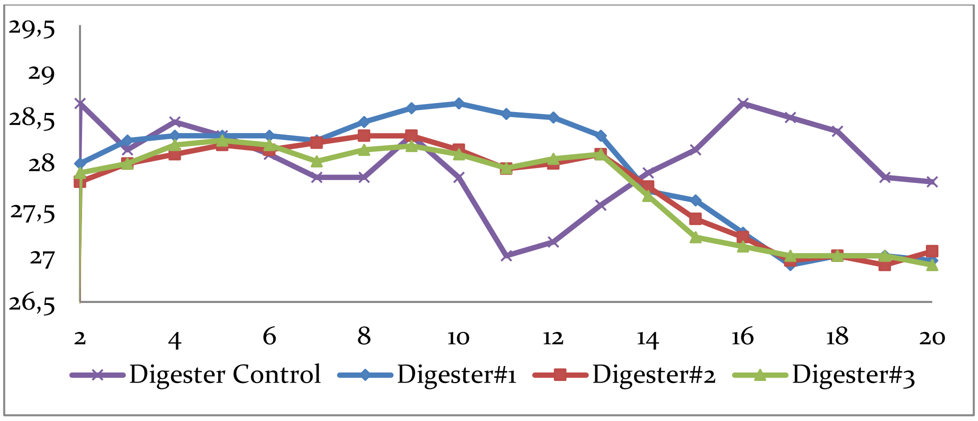


Figure 4. The temperature profile of the preparation stage

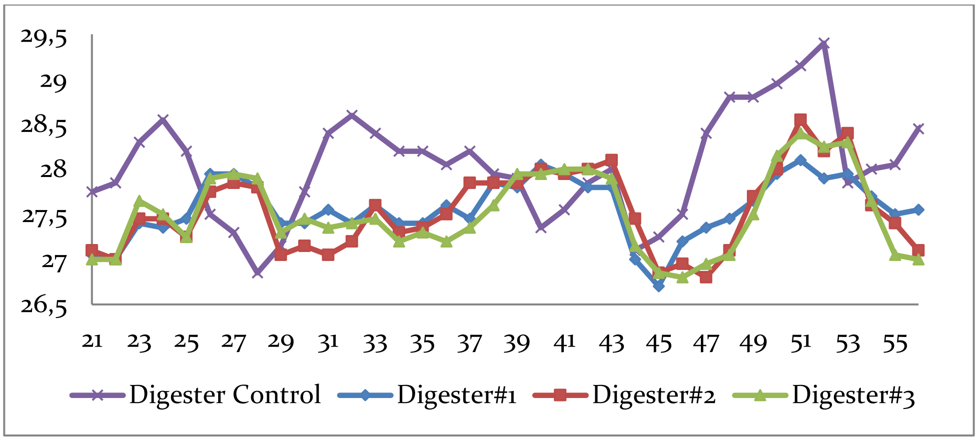


Figure 5. The temperature profile of the operation stage

The optimum performance of biogas production is when the temperature is in the mesophilic range of 20-45°C (Adelekan B.A, 2012). The operation stage based on Figures 4 and figure 5 shows the temperature profile of both stages is in the range of 25 to 45°C. The higher temperature can cause the metabolic of bacteria to decline, which could fail the biogas yield, while the lower temperature causes the bacteria culture was not adapted (Mckeown et al., 2015). High temperatures also cause the methane composition in the biogas to decrease (Wang et al., 2014). However, all digester temperature was still in the optimum range.

The biogas volume shows the optimum value at the mesophilic temperature. The temperature increased after adding the stuffing, but the temperature slowly decreased as the fermentation process progressed. The increase in temperature indicates that anaerobic decomposition of organic matter is underway (Kumar et al., 2018). In addition, it can accelerate the rate of the overhaul of organic matter so that the biogas produced is optimal and efficient. The graph above also shows that the fluctuating data of the two processes. Temperature fluctuations in the digester are due to organic matter's decomposition process, which produces heat and water vapor. The decomposition of organic matter causes the increase of temperature, while the decrease in temperature is caused by water vapor (Peces and Astals, 2013).

3.3. Digester Analysis

Table 4 summarizes the biogas production performance of each digester for both stages. Table 4 suggests that digester 2, with a ratio of 3 : 1 between food waste and chicken manure, shows a better performance than the digestion control without chicken manure. The potential of methane volume per TS and VS are around 18.72 L/kg and 34.68 L/kg, respectively, which are 2 times higher than digester control. Total Solid (TS) content is the amount of solid material contained in the organic waste during the digester process, indicating the rate of destruction/decomposition of the solid organic waste material. TS also indicates the number of solids in organic matter, and the TS value significantly affects organic matter's digestion process (HRT). While Volatile solid (VS) is the solid part (TS) that turns into a gas phase in the acidification and methanogenesis stages as in the organic waste fermentation process (Waskito, 2011).

Table 4. Biogas production analysis

No.	Parameter	Digester control	Digester #1	Digester #2	Digester #3
1	Cumulative biogas volume (L)	95.12	52.60	120.77	33.20
2	Methane concentration average (Vol %)	65.30	52.41	71.01	51.91
3	Methane volume (L)	62.11	27.57	85.76	17.23
4	Total solid (TS) (kg)	6.60	4.00	4.58	4.95
5	Volatile solid (VS) (kg)	3.56	2.16	2.47	2.67
6	Methane volume/ TS (L/Kg)	9.41	6.89	18.72	3.48
7	Methane volume/ VS (L/Kg)	17.43	12.76	34.68	6.45

Based on Table 4, it can be concluded that the current research development from previous research shows the use of chicken manure as an effective co-activator in producing optimum biogas quality. This can be compared based on the methane volume/total solid food waste (L/kg). The potential for methane gas in digester 2 is higher than in the control digester and previous studies. The potential for methane gas in digester 2 is 18.72 L/kg, while the digester control is 9.41 L/kg. The high potential of methane gas produced is due to the use of chicken manure which has high biogas potential.

4. Conclusions

The mixing of homemade bio-activator and chicken manure produces the best biogas produced to process the household food waste. Chicken manure as a co-activator generally increased the daily methane production, and improved waste decompose. It shows that a ratio of 3 : 1 between food waste and chicken manure may speed up the anaerobic process. The chicken manure may have provided the specific decomposing anaerobic bacteria that is suitable for treating the waste. Digester 2 has the highest average of methane volume per TS and VS at around 18.72 L/kg and 34.68 L/kg, respectively. Biogas production from organic substrates is strongly affected by the temperature where anaerobic digestion takes place. The temperature on biogas yield from the study shows the range of 25 to 45°C. It was still in the optimum range for the mesophilic temperature. However, the higher or lower temperature is adequate to the biogas yielded. Many household food wastes can be processed to produce biogas if the digester capacity is developed for an applicable scale. Moreover, there will be more organic waste that can be reduced in the landfill. Therefore, this research can be continued from a labor scale to an applicable scale as an alternative in processing household food waste with a larger digester capacity.

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