Development of IoT Based Monitoring of Anaerobic Biogas Production

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Abstract. Biogas is a mixture of gases produced from the fermentation process of organic matter derived from animal waste. This research uses a measurement system to monitor conditions in the biogas reactor. Three variations were carried out, namely 1:1:0 (variation 1); 1:1:0.1 (variation 2); 1:0.5:0.2 (variation 3) ratios of cow dung, water and EM_4 mixture. Monitoring was carried out using a digital thermometer to detect temperature, the MQ-4 sensor to detect methane gas, the MG-811 sensor to detect carbon dioxide gas, and the MQ-136 sensor to detect hydrogen sulfide (H_2S). In variation 1 produces 12650.342 mg/m^3 of methane content, in variation 2 produces 15042.905 mg/m^3 of methane and in variation 3 produces 3198.674 mg/m^3 of methane content. Overall, methane levels always increase and tend to be constant. This is in accordance with the theory. Where the peak formation of biogas occurs on day 7-15. The biogas combustion test requires a large gas pressure. Therefore, it is advisable to use plastic for the gas holder in order to adjust the gas pressure. Monitoring the gas content in the tank obtained from the sensor is displayed on the Blynk platform using a communication module that can be accessed on a smartphone or gadget.

Keywords: biogas; anaerobic; batch; internet of things; renewable energy.

1. Introduction

The increase in fuel prices has encouraged some people to use alternative energy sources to replaced their energy needs. Alternative energy source is renewable energy which is the main energy source and can be recycled in the environment. One of the most environmentally friendly and sustainable sources of renewable energy in Indonesia is biogas. Biogas is energy produced from organic waste such as animal manure or kitchen waste such as used and decomposing vegetables. An enclosed indoor process known as an anaerobic digester will be used to decompose this waste. Biogas can be used in small-scale, industrial and household power plants.

The biogas production process involves mixing raw materials in the form of animal feed (cattle) and water with the addition of a catalyst which acts as an accelerating agent for methane production at the same level and is stored anaerobically in the digester. Inside the digester, biogas containing CH_4, CO_2 and H_2S is produced anaerobically. Biogas processing time is about 4-5 weeks. Biogas is produced in the

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fourth week. The raw materials used to produce biogas include household waste, animal feed, and organic waste [1].

Five factors that affect the biogas production process include: temperature, pH, substrate, stirring and starter. The pH of the biogas varies from 5.5 to 7.5, while the temperature of the methanogenic bacteria varies from 27 to 36 ^{0}C. In the process of making biogas, the substrate in the digester can settle to the bottom of the digester and form scale. This scale deposit can inhibit biogas production. Prevention can be done by stirring, where stirring is included in the determining factor of biogas production [2].

In this study, the authors designed and built a prototype of a portable smart biogas system that can be controlled and monitored in real time and accessed using a smartphone. The digester process used in this digester is batch in nature, where the materials used are put into the digester in a certain form, and observed within 1-2 weeks after completion [3]. Currently the raw materials for making biogas are cow dung and elephant grass. Cow dung is believed to produce more biogas than other types of animals. Elephant grass is used as a mixture because it contains cellulose and lignin which take a long time to decompose which determines the production of the resulting biogas [4].

2. Literature Review

2.1. Biogas

Biogas is a gaseous fuel produced by anaerobic activity or the fermentation of organic matter, including human and animal waste, domestic waste, or the decomposition of anaerobic organic matter by anaerobic microbes. The methane in biogas is thought to burn cleaner than coal, creating more power and producing less carbon dioxide [5].

Biogas is a gas produced from anaerobic fermentation of biomass carried out by bacteria through several stages, namely hydrolysis, acidification and methanogenesis. The main ingredients of biogas are methane and carbon dioxide [14]. The biogas component mixture consists predominantly of CH_4 (45-75%) and CO_2 (25-50%), together with water vapor (1-5%), N2 (0-5%), and lesser amounts of ammonia (NH_3) and hydrogen sulfide (H_2S), as well as small amounts of hydrogen (H_2) and carbon monoxide (CO) [2], [3] The composition contained in biogas is shown in the following table.

TABLE 1. BIOGAS COMPOSITIONS

Componen	% Volume
Methane (CH_4)	50-75
Carbon Diokside (CO_2)	25-45
Nitrogen (N_2)	0-0.3
Hidrogen (H_2)	1-5
Hidrogen Sulfida (H_2S)	0-3
Oksigen (O_2)	0.1-0.5

The chemical reaction for making biogas (methane gas) consists of 3 stages, namely:

1) Hydrolysis reaction / Dissolving stage

At the hydrolysis stage, an enzymatic breakdown occurs from insoluble materials such as fats, polysaccharides, proteins, nucleic acids and others into easily soluble materials. At this stage, insoluble materials such as cellulose, polysaccharides and fats are converted into water-soluble materials such as carbohydrates and fatty acids. The dissolution stage takes place at a temperature of 25˚C in the digester.
Reaction:

$$(C_6H_{10}O_5)n\ (s) + n\ H_2O(l) \rightarrow n\ C_6\ H_{12}O_6$$

Cellulose Water Glucose

$$(C_6H_{10}O_6)x + Xh_2O \rightarrow (C_6\ H_{12}O_6)$$

Carbohidrate Water Glucose

2) Acidogenic reaction / Acidification stage

Under anaerobic conditions the resulting product will become a substrate for the formation of methane gas by methanogenic bacteria. This stage takes place at a temperature of 25-30˚C in the digester.
The acidogenic reactions of glucose compounds are as follows:

- $n\ (C_6H_{12}O_6) \rightarrow 2n\ (C_2H_5OH) + 2n\ CO_2(g) + heat$

  Glucose ethanol Carbohydrate

$$2n\ (C_2H_5OH) + 2n\ CO_2 \rightarrow 2n\ (CH_3COOH) + nCH_4$$

Ethanol carbon dioxide acetic acid methane

3) Methanogenic Reaction / Methane Formation Stage

At this stage, methanogenic bacteria slowly form methane gas. Acid-producing bacteria and methane gas work in symbiosis. Acid-producing bacteria form an ideal atmosphere for methane-producing bacteria, while methane-producing bacteria use the acid produced by acid-producing bacteria. This process lasts for 14 days with a temperature of 25˚C to 35˚C in the digester. This process produces 70% CH_4, 30% CO_2, a little H_2 and H_2S. In general it will be shown in the following reaction [8]:

$$2n\ (CH_3COOH) \rightarrow 2n\ CH_4 + 4n\ CO_2$$

Acetic Acid Methane carbon dioxide

2.2. Research Method

In conducting this research there is a working process which is described according to Figure 1

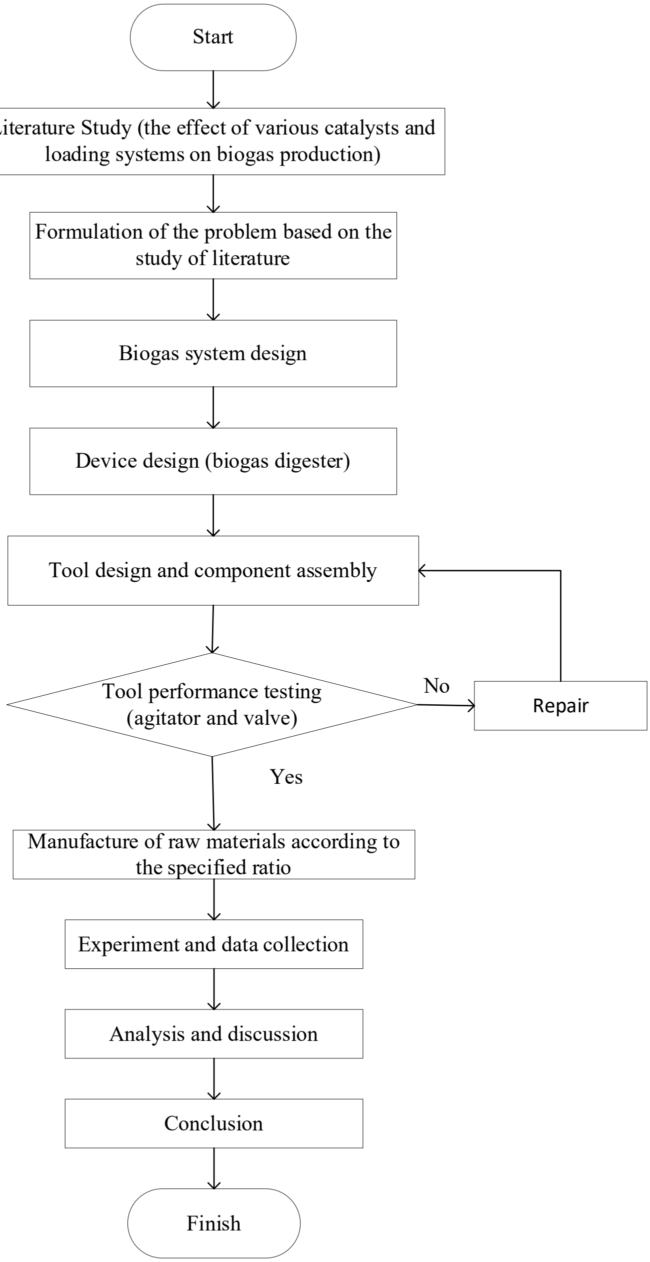


Fig 1. Research Flow Chart

2.3. Design Fabrication Tools

The biogas digester functions as a place for the fermentation of raw materials for the biogas production process. In this study the authors did not only focus on the biogas reactor used, but the authors also developed a portable intelligent biogas system consisting of sensors and controllers that can be monitored via gadgets.

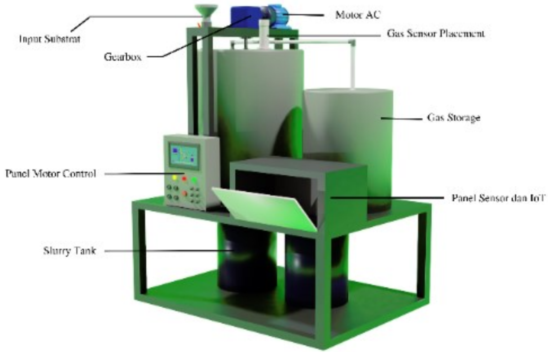
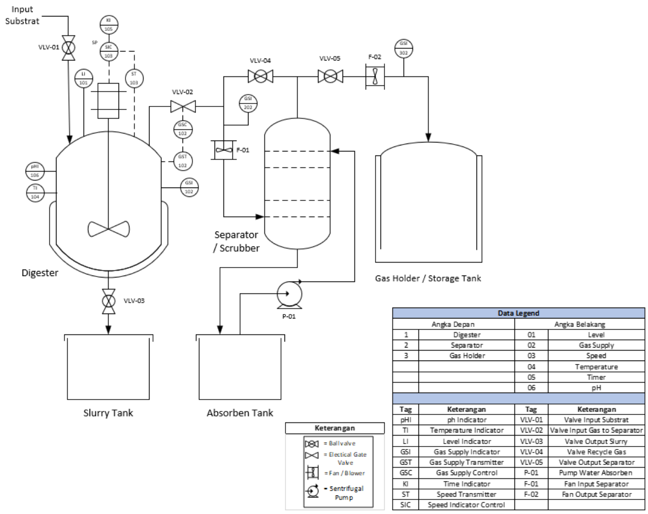


Fig 2. Design Fabrication Tools



Data Legend			
Angka Depan		Angka Belakang	
1	Digester	01	Level
2	Separator	02	Gas Supply
3	Gas Holder	03	Speed
		04	Temperature
		05	Timer
		06	pH
Tag	Keterangan	Tag	Keterangan
pHI	ph Indicator	VLV-01	Valve Input Substrat
TI	Temperature Indicator	VLV-02	Valve Input Gas to Separator
LI	Level Indicator	VLV-03	Valve Output Slurry
GSI	Gas Supply Indicator	VLV-04	Valve Recycle Gas
GST	Gas Supply Transmitter	VLV-05	Valve Output Separator
GSC	Gas Supply Control	P-01	Pump Water Absorben
KI	Time Indicator	F-01	Fan Input Separator
ST	Speed Transmitter	F-02	Fan Output Separator
SIC	Speed Indicator Control		

Fig 3. Process Flow Diagram (PFD) Biogas

The substrate in the form of cow dung and water and catalyst (EM_4) are put into the digester simultaneously. Stirring is carried out continuously to keep the mixture homogeneous and maximize the formation of biogas. Furthermore, the mixed material is left for 1 week and the resulting gas content data is collected. The finished gas will flow through the pipe to the gas holder. As for the sludge waste, it will be disposed of in a sludge tank to be used as a good quality fertilizer for plants.

2.4. Internet of Things

IoT is used to monitor biogas productivity results. we can monitor it in nominal form and the graphs that have been provided. Monitoring of biogas results can be done on a gadget that can be accessed from anywhere. Data is obtained from sensor readings which are then processed by ESP32 and the readings are sent via the Arduino IDE software.

Fig 4. Arduino IDE and Mobile IoT

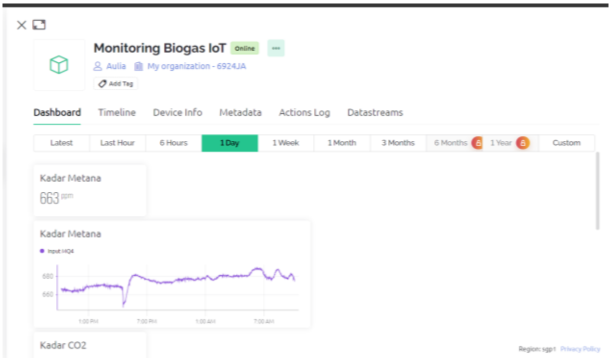


Fig 5. PC interface IoT

2.5. Biogas Monitoring Process

In this sub-chapter, the biogas monitoring process is carried out, there are four variables that are measured, including: CH_4 levels, CO_2 levels, H_2S levels, pH and temperature.

TABLE 2. DATA OF GAS CONCENTRATION AT VARIATION 1, 1: 1 COW DUNG : WATER

No	Day	CH_4 (ppm)	CO_2 (ppm)	H_2S (ppm)	pH	T (^0C)
1	7	14072.82	1304	175	4.59	27.02
2	14	14982.24	1216	175	4.05	27.26
3	21	19283.0	1360	157	4.43	27.34
4	28	19283.0	1360	157	4.43	27.91

TABLE 3. DATA OF GAS CONCENTRATION AT VARIATION 2, 1: 1 : 0.1 COW DUNG : WATER : EM4

No	Day	CH_4 (ppm)	CO_2 (ppm)	H_2S (ppm)	pH	T (^0C)
1	7	22280	1267	109	4.3	30.0
2	14	22740	1863	163	4.1	29.1
3	21	22800	1866	163	4.3	29.9
4	28	22930	1866	163	4.4	30.8

TABLE 4.DATA OF GAS CONCENTRATION AT VARIATION 3, 1: 0.5 : 0.2 COW DUNG : WATER : EM4

Day	CH_4 (ppm)	CO_2 (ppm)	H_2S (ppm)	pH	T (^0C)
1	912.4962664	8866.113	186.7288	4	26
2	243.187373	356.3171	108.1339	4.2	28.4
3	473.3265259	1929.556	175.1832	4.1	29
4	728.626456	1929.556	182.2854	4.5	29.1
5	707.957529	1906.739	167.4124	4.3	30
6	688.1948024	1863.398	163.3015	4.3	30
7	677.1414256	1836.518	160.7977	4.3	30.1
8	676.5092527	1781.305	160.5363	4.3	30
9	680.816722	1516.595	170.1738	4.4	30.4

The first variation on week-1 data collection, CH_4 was detected at 14072.82 ppm or 9232.277 mg/m^3. On the 14th day the methane level increased to 14982.24 ppm or 9828.889 mg/m3 and continued to increase on the 21st day which was 19283.0 ppm or 12650.342 mg/m3. The same level was also found on the 28th day, but on the 28th data collection, the resulting temperature conditions were different, which was 0.57˚C higher.

25-45% biogas composition contains CO_2. In this phase, CO_2 was obtained at 1304 ppm or 2347,212 mg/m3. The CO_2 concentration fluctuated in the four data collection. This can occur due to reactions that occur in the digester which form more methane levels and reduce CO_2. However, other factors can also affect it, namely the existence of air leaks in the tank and gas channels which are very small/smooth so that there is almost no leak detected. The following is a graph of variation 1 with observations of gas concentrations.

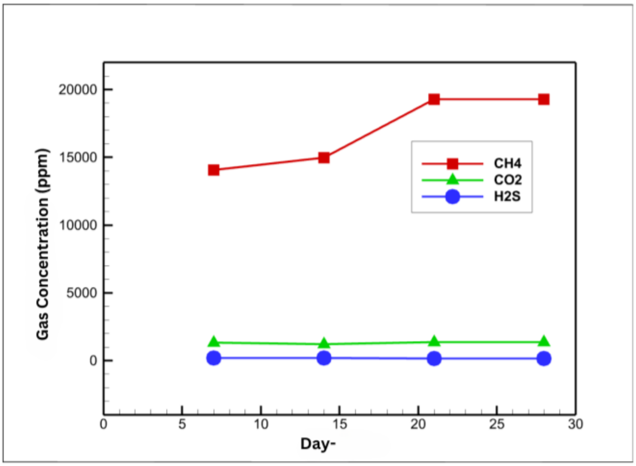


Fig 6. Gas concentration at variation 1, 1: 1 Cow dung : Water

In the third week, CO_2 increased again to 1360 ppm or 2448,012 mg/m^3. This value was constant until the fourth week. But the difference is in the resulting temperature. On monitoring the 3rd week or 21st day, the resulting temperature is 27.24˚C. While in the fourth week it was 27.91˚C. This proves that at any time, the temperature in the digester will be higher because of the methanogenic reaction which causes the temperature in the tank to increase.

Other gas contents that were observed in this study were not only methane and CO_2, but H_2S. A small part of the composition of biogas is H_2, which is around 0-3% of the total volume of biogas. On the first to the last day of observation, the H_2S content was detected at 175 ppm or only 315,002 mg/m3 and decreased with increasing HRT. So that in the end it becomes 157 ppm or only 218,838 mg/m3 of the total volume of biogas produced.

The mixture that has been put into the digester tank will go through the stages of dissolution or hydrolysis reactions in which insoluble materials such as fats, polysaccharides, proteins, nucleic acids and others occur enzymatically into easily soluble materials. The dissolution stage generally takes place at a temperature of 25˚C in the digester. However, in the weekly data collection table, the temperature inside the digester was detected at 27.02-27.91˚C. Temperatures of 25-30˚C usually occur during the acidification process or when an acidogenesis reaction occurs, where at this stage the bacteria produce acid which is an anaerobic bacteria that can grow and develop in acidic conditions. The following graph is generated from the comparison of temperature and its effect on pH in the digester.

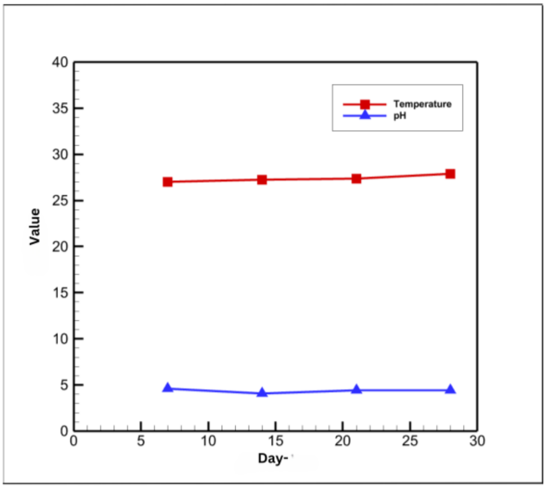


Fig 7. Temperature to pH at 1st variation , 1: 1 Cow dung : Water

The process of converting a polymeric organic substance into a simpler compound in the reactor is affected by temperature. If the anaerobic reactor is operated at a lower temperature, for example 20˚C, the microbial growth under these conditions is very slow and difficult at the start of operation for some bioreactors. However, in this study, the temperature was in the range of 27˚C constantly for 28 days and only experienced an increase of 0.89˚C. Reactor with a substrate that has a low pH indicates an excess of protons. The protons in the reactor will eventually become H_2. While the core output in this study is the effectiveness for methane levels. A good pH in the fermentation process in reactor operation is 6.0-7.5. pH lower than 5 and higher than 8.5 growth is often inhibited, although in some microbes there are exceptions, namely in a small number of Acetobacter SP. The best microbial growth from the process of changing the anaerobic system at the start of operation or at the time of inoculation pH in water can decompose to 6 or lower. In variation 1, cow dung tends to be dry and mixed with a little grass. Unlike the cow manure in variation 2 which tends to be wet and runny. So the experimental results may not match the theory.

In theory, EM_4 is a mixed culture of microorganisms that is beneficial and beneficial for soil fertility and plant growth and production, as well as being environmentally friendly. Microorganisms added will help improve the biological condition of the soil and can help absorb nutrients.

The concentration of gas content in the second variation produces biogas quickly within a retention time of 7 days. In the first 7 days, it was 22,280 ppm or 14,616,482 mg/m^3. Methane levels increased significantly for 28 consecutive days, namely 22740 ppm or 14918.259 mg/m3, 22800 ppm equals 14957.621 mg/m^3 and 22930 ppm or 15042.905 mg/m3. The increase in methane levels is in accordance with the theory, where the longer the retention time is given, the more biogas will be produced. However, the difference from the previous variation is that biogas is produced more quickly, given the amount of content produced. The catalyst use factor is proven to be able to accelerate the productivity and amount of biogas.

While CO_2 concentrations ranged from 1267 ppm or 831.198 mg/m3 to 1863 ppm equal to 1222.195 mg/m3 constant. This can happen considering the retention time that has been running is quite long, but still results in an increase in methane levels.

Conditions on H_2S tended to be constant as evidenced in week-1 it produced 109 ppm H_2S or 151,932 mg/m^3. Then in the following week until the last week, H2S was constant at 163 ppm or 227,201 mg/m3. However, this is inversely proportional to the data for variation 1, where H_2S decreases over time even under constant conditions. The ability of the adsorbent to absorb the H_2S contained in the biogas will decrease over time. This is because the adsorbent will reach its saturation condition. The adsorbent is said to be saturated if the H_2S gas passing through the adsorber column cannot be adsorbed again.

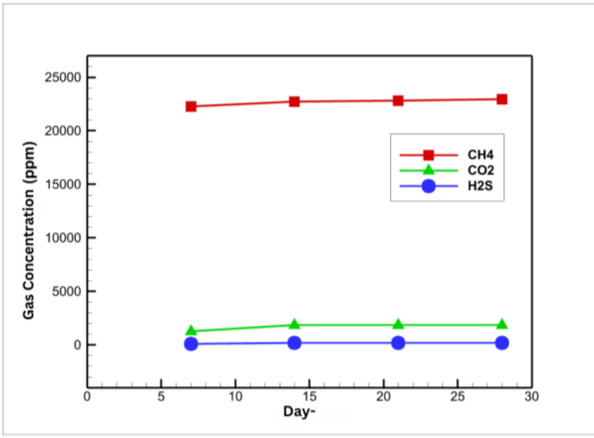


Fig 8. Gas concentration at variation 2, 1: 1 : 0.1 Cow dung : Water : EM_4

It can be seen from the graph in Figure 8 that in just 7 days, quite a lot of methane levels have been produced. This has experienced a significant increase in each data collection. The CH_4 that has been formed will then be removed or tested for combustion. So that in the next gas formation, it can be seen that the longer the retention time is given, the more biogas is produced.

The concentration of CO_2 gas also increases as new methane is formed from the methanogenesis reaction that occurs in the digester. The increase in CO_2 was significant from day 7 to day 28. Meanwhile, H_2S gas tends to be flat, both in variation 1 and in variation 2 because it does not experience much change in concentration levels after reaching its saturation condition.

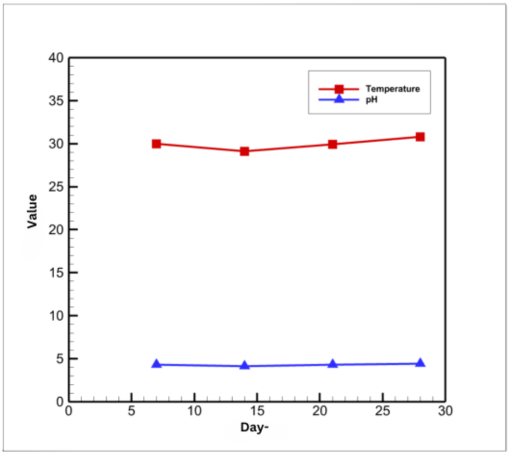


Fig 9. Temperature to pH at 2nd variation , 1: 1 : 0.1 Cow dung : Water : EM_4

The temperature in this second variation has increased from the previous variation. Where the average temperature produced is 29.95˚C. This shows that the substrate in the digester has bacteria that are more active in making methane or its acidification. However, this does not have a significant impact on changes in pH. Where the average pH produced is still around 4.275. It has been mentioned previously that pH conditions below 5 are not good conditions for a process in the reactor. pH lower than 5 and higher than 8.5 growth is often stunted.

The third variation of the experimental process uses 67.5 kg of cow dung. 22.5 liters of water and 9 liters of EM_4 mixture. The third variation is the variation with the highest amount of cow dung compared to the previous variation. However, the water given included the least of the experiments in the first and second variations. The treatment for variation 3 is without stirring. It was pointed out in variations 1 and 2 that combustion could not occur, even though the gas levels were well read. Following are the results of monitoring gas concentrations for 9 days since biogas was first formed.

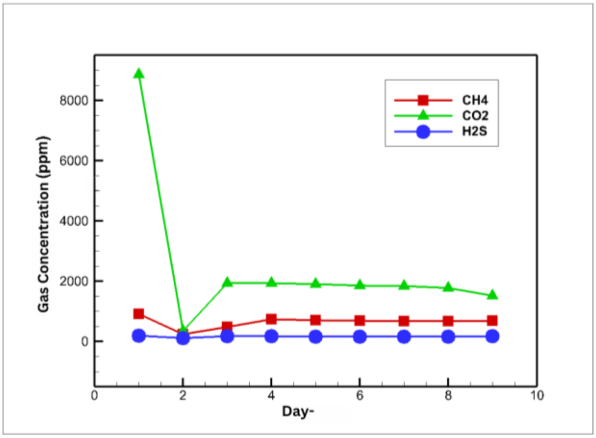


Fig 10. Gas concentration at variation 3, 1: 0.5 : 0.2 Cow dung : Water : EM4

Based on the graph presented, the concentration of methane gas tends to increase with increasing retention time or waiting time. In the first period reading, it experienced a very large jump at 912 ppm. This is considered abnormal on the first reading. Factors that influence include sensors that are still adapting to the conditions in the tank, so that gas readings do not match. However, in the following period, sensor readings began to return to normal with levels of 243 ppm and continued to increase until the 4th period. The 4th period was the peak of biogas formation during this experiment, which reached 728 ppm. This is in accordance with the theory of biogas formation, namely the peak of formation is 7-15 days after the input of raw materials.

However, in the following period, methane levels tended to decrease to 688 ppm. During this period, the third variety of substrate also determines the saturation point for biogas formation. So it could be that biogas will continue to be constant at a certain value or even decrease. It can be proven in graph 4.5 that methane gas is in a position that tends to be constant at 688, 677, 676, and rises again to 680 ppm.

Meanwhile, the concentration of CO_2 gas in variation 3 experienced an abnormal reading. This is due to the reliability of the sensor is not in good condition, because there is rust and sensor lifetime.

The graph above shows an unusual CO_2 content. Where based on the composition of biogas, CO_2 has a percentage of 25-45% of the volume of biogas, the graph shows that it exceeds the methane content. In actual conditions, the sensor module is very sensitive to the slightest change. In this case, the CO_2 sensor is in a bad condition. Then it's time to replace the sensor with a new one.

The percentage of H_2S is only 0-3%, which is the smallest gas content formed from the biogas process. The H_2S content tends to be constant from the beginning of the formation process to the saturated mass of the substrate.

From the first period, H_2S was read at 186 ppm which then decreased to 108 ppm in the second period. In this stage, H_2S decreases due to an acidification process where methanogenic bacteria start working to produce methane. H_2S will also cause ferrous sulfide (FeS) corrosion on ferrous metals. The FeS is pyroporic, which when it reacts with oxygen in the air will produce heat.

The temperature conditions in each period can also be an indication of whether or not the treatment given is appropriate. The temperature graph can be shown in the following figure.

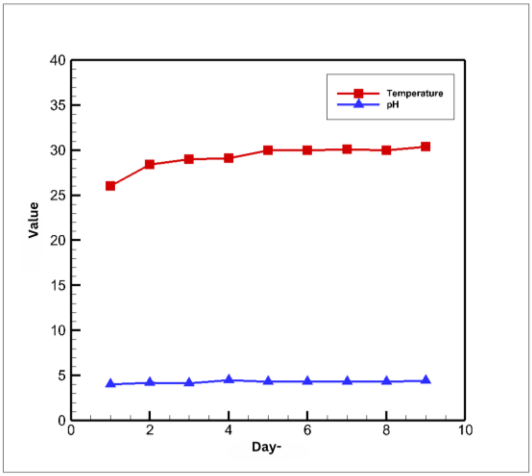


Fig 11. Temperature to pH at 3rd variation , 1: 0.5 : 0.2 Cow dung : Water : EM_4

The graph shows a significant increase every day. Starting on the first day, the temperature in the tank was around 26˚C which then increased on the second day with a temperature of 28.4˚C. On the 3rd day, when biogas was visible even in small amounts, the temperature increased again at 29˚C and continued to rise at 29.1˚C to 30.4˚C on the 9th day after a retention time of 1 week. Under anaerobic conditions the resulting product will become a substrate for the formation of methane gas by methanogenic bacteria which takes place at a temperature of 25-30˚C in the digester. Therefore, on the temperature side, the temperature is in accordance with the theory and the treatment given. The reaction that occurs at this time is the acidogenesis reaction.

In contrast to the methanogenic reaction, the acidogenesis reaction is not yet the culmination of biogas formation. There are still a few days to 15 days to see the peak of biogas formation that occurs. In the methanogenic stage, methanogenic bacteria form methane gas slowly. Acid-producing bacteria and methane gas work in symbiosis. Acid-producing bacteria form an ideal atmosphere for methane-producing bacteria, while methane-producing bacteria use the acid produced by acid-producing bacteria. This process lasts for 15 days with a temperature of 25˚C to 35˚C in the digester.

3. Qualitative Experiment Results Test

The last test in biogas research lies in the combustion test. However, after experimenting with variations 1 and 2, none of them caught fire. In this problem, there are several diagnoses that make the fire unburnable in the gas line, which is as follows:

1. Less or no gas pressure in the digester, so that the gas cannot be channeled properly
2. There is a leak in the gas holder
3. Lack of methane levels formed to become a fuel supply
4. With the possibility of a small flame, burning is carried out in an open room that is prone to wind

Based on the evaluation of non-combustible variations 1 and 2, the 3rd variation was carried out as a combustion trial by injecting gas from the tank into the plastic with the aim of a smaller space for low pressure gas. Where later the pressure can be adjusted by pressing the plastic that has been filled with gas to push the gas out with great pressure. As a result, successful combustion occurred for 9 seconds with a flame large enough and reddish-blue in color.

Fig 12. Combustion Test

Design Quality Comparison

1. Agyeman FO, 2014

In Agyeman FO's research, 2014 using a semi-continuous system and food waste as nutrients, a digester with a capacity of 1.8 liters. The design of the Agyeman FO digester is equipped with a Duran GLS80 glass reactor with a magnetic impeller in the stirring system. With a system that has been designed in such a way, the biogas produced is 510ml/g.

2. Diyono Ikhsan

The digester design in the study of Diyono Ikhsan et al used a horizontal type digester using a semi-continuous system. In a semi-continuous system, we have to enter raw materials periodically. Where it is less effective on the power side. However, in this study, it produced ± 35 liters of biogas per 100 kg suspension.

3. Agus Haryanto, 2019

The digester in Agus Haryanto's research has a capacity of 28 liters using a semi-continuous system. The nutrients used are rice straw. A horizontal type digester is made to facilitate input, where semi-continuous requires the user to use more power. With this design, the amount of biogas that can be produced is 9.5 liters in stable conditions.

4. Aria Wicaksono, 2019

In Aria Wicaksono's research, the digester used was a vertical type using a batch system. The digester has a capacity of 200 liters using continuous stirring. The nutrients used are a mixture of EM_4. However, the substrate used is only 100 liters. By using this tool, Aria Wicaksono produces 0.07 kg of biogas for 25 days.

5. Aulia Lailatul Fitri, 2023

The differences in the designs of each researcher are the writer's consideration in starting the research. In this case, the author uses a batch system for more energy efficiency. Then the stirring system is carried out continuously to keep the raw material/substrate homogeneous. Placement of the measuring instrument above the digester tank to keep the sensor away from splashes of raw materials that can corrode or misread data.

In this research, the total methane produced in variation 1 was 44361.850 mg/m3 with a period of 28 days. Whereas in variation 2 it is 59535.267 mg/m3 with a retention time of 28 days. In the third variation, with a retention time of 9 days, the methane produced is 3797.305 mg/m3. The flame test in this study also proved the high quality of the gas produced. The color of the flame determines the ongoing combustion reaction. The more efficient the combustion, the hotter the resulting temperature.

The following is the level of combustion in terms of its efficiency level.

- Blue fire color: very efficient (> 1500 C)
- Yellow: Efficient (1200 C - 1500 C)
- Orange : Quite efficient (1000 C - 1200 C)
- Red: not efficient (600 - 1000 C)

4. Conclusion

Based on the analysis that has been described it can be concluded that:

1. A biogas digester with a volume of 200 liters has been made with a stirrer system and measuring instruments for gas levels as well as temperature and pH.
2. In accordance with the theory, the levels of methane produced continued to increase significantly in the three variations 1, 2 and 3 experiments with retention times of 28 and 9 days.
3. EM_4 has a significant effect on the rate of formation and the amount of biogas productivity. It is proved that variations 2 and 3 produce a total methane content of 59535.267 mg/m3.
4. To get an optimal combustion test, a large gas pressure is needed. Small gas pressure must not be transferred to a larger space.

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