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DESIGN OF AN ANAEROBIC DIGESTER FOR BIOGAS PRODUCTION FROM COW MANURE BASED ON THE INTERNET OF THINGS (IOT)

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ABSTRACT

The continuously increasing energy demand drives the utilization of renewable energy, one of which is biogas from cow dung. Biogas production is generally not optimal because fermentation is conducted at room temperature, which is less suitable for methanogenic bacteria. This research designs an Internet of Things (IoT) based anaerobic digester that can monitor and control temperature in real time, while also examining the effect of fermentation temperature on biogas volume and Chemical Oxygen Demand (COD). The temperature of 25°C produced the lowest volume (0.3 L) and COD (9600 mg/L). The optimal fermentation condition is found at a temperature of 35°C. The research results indicate that temperature significantly affects the fermentation process. A temperature of 35°C yields the highest biogas volume (3.7 L) and the lowest COD (6400 mg/L), whereas a temperature of 27°C results in the lowest volume (0.3 L) and COD (9600 mg/L). The optimal fermentation condition is at a temperature of 35°C. The application of IoT facilitates the monitoring of the process and enhances the efficiency of biogas production.

Keywords: Biogas, Anaerobic Digester, Internet of Things (IoT), Chemical Oxygen Demand (COD)

1. INTRODUCTION

1.1 Background

Rapid population growth has increased energy demand, while oil reserves continue to decline. Dependence on fossil fuels places pressure on countries to produce and utilize renewable energy. Furthermore, the rise in global oil prices, reaching $100 per barrel, presents a serious challenge, particularly for many countries including Indonesia (Arifin Jainal, 2023).

To address energy scarcity, efforts in the search, development, and implementation of environmentally friendly alternative energy technologies are of paramount importance, particularly to support the poor groups most affected by rising fuel prices. One solution that can meet this need is biogas technology (Holik et al., 2020). Biogas is an alternative energy source in the form of gas produced from organic materials. As a renewable energy, biogas can be generated using various types of organic waste, such as biomass waste, human excrement, and animal manure. The formation process involves the breakdown of organic material by anaerobic bacteria (Irawan & Suwanto, et al., 2016). Cow dung is one of the sources of organic compounds that can be processed into biogas. Currently, many communities only utilize cow dung as manure, while the energy content in cow dung goes to waste. Some researchers have attempted to convert cow dung into biogas. Arifin Jainal (2023) has designed a biogas tool as an alternative energy source on a household scale for utilizing cow dung waste. Singgih (2018) has implemented biogas technology from livestock waste to meet household energy needs. Nonetheless, from these studies, it is evident that the level of biogas production from cow manure has not yet reached its maximum potential. This is due to the fact that the degradation process of organic compounds in cow dung occurs at room temperature (psychrophilic conditions), while the groups of bacteria responsible for methane formation work most effectively within the mesophilic temperature range (30 – 35°C). Additionally, the biodigesters that are typically designed do not incorporate any stirring mechanisms, which results in suboptimal contact between the bacteria and the substrate within the reactor. Therefore, this research aims to design a reactor that operates within the mesophilic temperature range and incorporates stirring. To maintain the system's temperature, an Internet of Things (IoT)-based control method will be implemented. Through this system, the conditions of the digester can be monitored at all times, making it easier to identify any issues that may arise in the digester.

2. RESEARCH METHODS

Research methodology

2.1 Research Place

This research was carried out at the Biotechnology and Food Laboratory. Chemical Engineering Department Process Unit, Lhokseumawe State Polytechnic.

2.1 Tools and Materials

2.2.1 Tools used

Equipment used in this research includes The ESP32 is a microcontroller that serves as a control device for input and output data. The pH Sensor Kit E 201C (BNC) is used to determine the pH value. The DS18B20 temperature sensor is utilized to measure temperature values. The Arduino IDE is a program used to command the ESP32, which acts as the motherboard connecting the entire system. Blynk is used as a conduit for relaying information from the ESP32 to be displayed on a smartphone screen. The heater is a device used to generate heat. A reactor tube serves as a container for conducting the anaerobic process. A laptop or smartphone serves as a tool for monitoring IoT data in real-time.

2.2.2 Materials used

Cow dung as raw material. Water as a medium for mixing with cow dung. Jumper cables as a connecting medium for the sensor to the ESP32. Solder is used to join the wires to the equipment.

2.3 Experimental Treatment Design

2.3.1 Fixed Variables

- Cattle dung : 2 Kg
- Water : 6 L
- Volume reactor : 10 L
- Fermentation time: 30 days
- Complaint: 60 rpm

2.3.2 Independent Variables

Temperature: 27.5°C, 30.5°C and 35.5°C

2.3.3 Dependent Variable

1. Biogas volume
2. Flame testing
3. testing of content Chemical oxygen demand

2.4 Experimental and Testing Procedures

2.4.1 Making Production Biogas

1. Cow manure is collected from the farm.
2. For the raw material for biogas production, cow manure is mixed with water in a 1:3 ratio.
3. The mixture is stirred until it is uniform to ensure good distribution of the organic material
4. Next, blend the red guava fruit by adding around 100 ml of water in the blender until smooth.
5. Then strain the red guava smoothie using a fine sieve over a container.
6. After that, the filtered smoothie is put into a saucepan, and the dissolved sugar is added.
7. Then cook on the stove for 30 minutes at 80°C, stirring evenly.
8. Then cool to room temperature.

2.4.1 Production Reactor Biogas

1. the bioreactor is ensured to be clean.
2. Temperature and pH sensors are installed on the reactor, ensuring

all sensors are connected to the IoT system

3. Bioreactor Filling a. A mixture of cattle manure and water is introduced into the biodigester and is ensured to be tightly sealed to prevent the entry of oxygen.
4. Parameters measured, such as temperature and pH, are recorded before the degradation process of organic compounds begins.
5. Organic Compound Degradation Process a. Continuous stirring within the reactor is conducted to ensure the mixture remains homogeneous.
6. The IoT platform is utilized to monitor data from the sensors in real-time.
7. Data Collection a. Measurement of temperature and pH, with periodic recording of temperature and pH to ensure optimal fermentation conditions.
8. Gas production is monitored and recorded daily.

3. RESULTS AND DISCUSSION

3.1 Research Results

Table 3.1 Data from Test Results and Observation Analysis

Suhu (°C)	**Hari ke**	**pH**	**Suhu Digester (°C)**	**Volume Biogas (L)**	**COD (mg/L)**
27	1	4	26.2	0	
	2	4	26.6	0	
	3	4	26.4	0	
	4	4	26.7	0	
	5	4	26.4	0	
	6	4	26.3	0	
	7	4.2	26.2	0	
	8	4.2	26.6	0	
	9	4.2	26.2	0	
	10	4	26.5	0	
	11	4.5	26.4	0	
	12	4.5	26.5	0	
	13	4.6	26.7	0	
	14	4.1	26.5	0	
	15	4.2	26.2	0	
	16	4.3	26.3	0	
	17	4.2	26.6	0	
	18	4.6	26.9	0	
	19	4.4	26.9	0	
	20	4.3	26.9	0	
	21	4.1	26.3	0	
	22	4.8	26.2	0	
	23	4.2	27	0	
	24	4.2	26.7	0	
	25	4.8	26.6	0	
	26	4.7	26.8	0	
	27	5.5	26.4	0.3	
	28	5.7	26.2	0.3	
	29	5.9	26.1	0.3	
	30	6.4	27.4	0.3	9600
30	1	4.3	30.5	0	
	2	4.6	30.5	0	
	3	4,6	30.4	0	
	4	4.3	30.5	0	
	5	4.4	30.3	0	
	6	4.4	30.7	0	
	7	4.4	30.2	0	
	8	4.5	30.3	0	
	9	4.6	30.7	0	
	10	4.6	30.2	0	
	11	4.6	30.7	0	
	12	4.7	30.1	0	
	13	4.1	30.1	0	
	14	4.5	30.9	0	
	15	4.5	30.6	0	
	16	4.6	30.3	0	
	17	4.1	30.3	0	
	18	4.5	30.2	0	
	19	4.3	30.2	0	
	20	4.2	30.3	0	
	21	4.6	30.1	0	
	22	5.4	30.5	0	
	23	6.2	30.4	1.1	
	24	6.1	30.7	1.1	
	25	6.2	30.8	1.1	
	26	6.2	30.4	1.1	
	27	6.2	30.5	1.1	
	28	6.8	30.2	1.1	
	29	6.7	30.6	1.1	8533
	30	6.8	30.6	1.1	
35	1	4	35.4	0	
	2	4	35.7	0	
	3	4	35.4	0	
	4	4	35.8	0	
	5	4	36.2	0	
	6	4	36.1	0	
	7	4.2	35.3	0	
	8	4.2	35.5	0	
	9	4.2	35.6	0	
	10	4	35	0	
	11	4.5	35	0	
	12	4.5	35.4	0	
	13	4.6	35.4	0	
	14	5.1	36.1	0	
	15	5,9	35.4	0	
	16	6.3	35.5	3.7	
	17	6.2	35.4	3.7	
	18	6	35.5	3.7	
	19	6.4	35.8	3.7	
	20	6.3	35.6	3.7	
	21	6.1	35.9	3.7	
	22	6.2	35.1	3.7	
	23	6.2	35.6	3.7	
	24	6.2	35.7	3.7	
	25	6.5	35.9	3.7	
	26	6.7	35.3	3.7	
	27	6.8	35.5	3.7	
	28	6.7	35.8	3.7	
	29	6.7	35.6	3.7	
	30	6.9	35.5	3.7	6466

3.2 Discussion

Research on making jam from red guava with variations in pectin content and mixing time on the characteristics of the jam product has been tested, including organoleptic tests with a total of 20 panelists, results from water content tests, viscosity tests and vitamin C tests.

3.2.1 Analysis of Biogas Production Observation Results

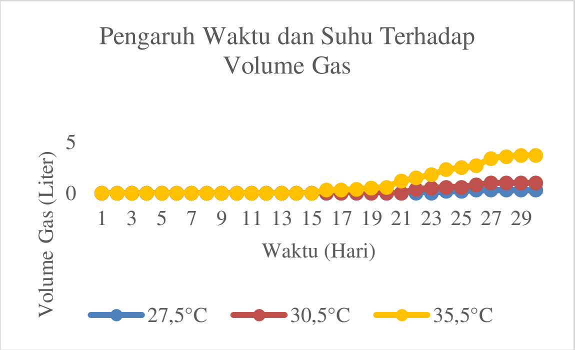


Figure 3.1 The Effect of Time and Temperature on the Volume of Biogas Produced

From the three graphs of biogas volume at temperatures of 27.5°C, 30.5°C, and 35.5°C, it can be seen that the highest biogas production occurs at 35.5°C, while at 27.5°C the biogas volume produced is relatively small. This is due to differences in the activity of microorganisms operating at each temperature.

At 35.5°C, which falls within the upper mesophilic temperature range, the activity of hydrolytic, acidogenic, acetogenic, and especially methanogenic bacteria is optimal. This temperature supports the rapid degradation of organic matter into volatile fatty acids (VFAs), which are subsequently converted to methane by methanogenic bacteria. The more optimal methanogenic activity, the greater the volume of biogas produced. Conversely, at 27.5°C, which is closer to the lower mesophilic temperature range, the metabolic rate of microorganisms slows down. This results in less efficient organic matter degradation and the conversion of VFAs to methane, resulting in a relatively small volume of biogas produced.

Furthermore, pH stability, which is achieved more quickly at 35.5°C, also supports the growth of methanogenic bacteria. This condition accelerates the methanogenesis phase, thereby increasing biogas production. Meanwhile, at 27.5°C, pH stability tends to be achieved more slowly, delaying methanogenesis activity and reducing gas production. Therefore, higher fermentation temperatures in the mesophilic range (30–35°C) are crucial for optimal biogas-producing microbial activity and producing larger biogas volumes.

3.2.2 Monitoring Results of the Effect of Fermentation Days on pH

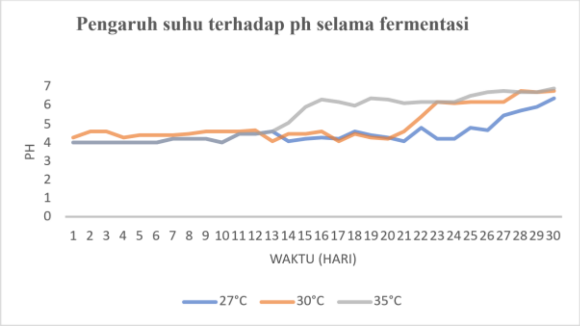


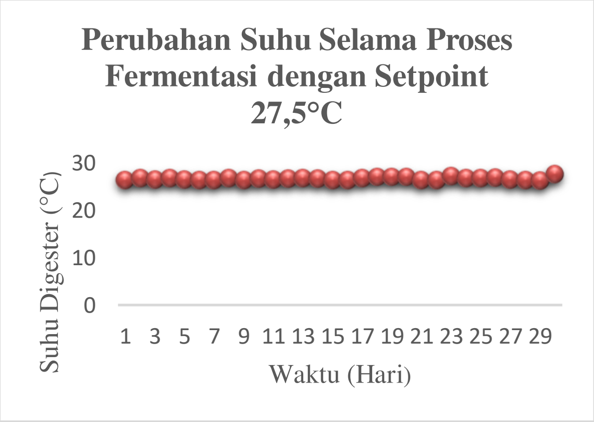
Figure 3.2 Effect of Temperature on pH during the Fermentation Process

The pH value increased significantly on the 16th day, particularly at 35°C, reaching a pH of around 6. This increase in pH indicates that the methanogenesis process has begun to activate. At this stage, methanogenic bacteria consume volatile fatty acids (VFAs) that had accumulated during acidogenesis. Consumption of VFAs by methanogenic bacteria reduces the acid content in the digester, causing the pH to rise closer to neutral.

A temperature of 35°C, which falls within the mesophilic temperature range, tends to support methanogenic bacterial activity more optimally than a temperature of 27°C. This is because at mesophilic temperatures, the rate of biochemical reactions in the fermentation process increases, accelerating the conversion of VFAs to methane. Therefore, the stability of the pH at 35°C after the 16th day indicates that the digester system is entering a stable phase, supporting efficient biogas production.

Conversely, at 27°C, the pH increase was less significant, indicating that methanogenesis activity was slower. This highlights the importance of controlling the fermentation temperature to achieve pH stability and support a more efficient biogas process.

3.2.3 Monitoring Results of the Effect of Fermentation Time on Temperature



Picture. 3.3 Graph of the Relationship Between Stirring Time and Vitamin C

Based on the graph in Figure 4.7, the digester temperature for 30 days shows fluctuations between 25.5°C and 27.5°C with a relatively stable trend around the ambient temperature of 27.5°C. At the beginning of fermentation (days 1 to 10), the temperature tends to be stable in the range of 25.5°C–26.5°C, indicating initial microbial adaptation to the substrate. Entering days 11 to 20, an increase in temperature is seen approaching 27°C, indicating that microbial activity is increasing as the fermentation process progresses. On days 21 to 30, the temperature experiences a slight decrease and fluctuation but remains close to the ambient temperature, which may be caused by a decrease in microbial activity due to the reduction in easily decomposable substrates. The temperature peak occurs on day 30 (27.5°C), possibly due to the accumulation of heat from fermentation activity in the final phase of the process. Overall, the graph shows that the digester temperature tends to follow the ambient temperature with a slight increase due to microbial activity, which is important to support the anaerobic fermentation process so that biogas production remains optimal.

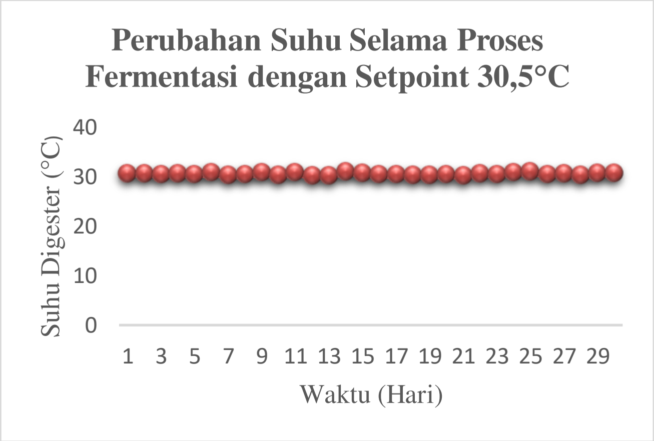


Figure 3.4 Change in Setpoint Temperature of 30.5 °C During the Fermentation Process.

The graph in Figure 4.8 shows the fluctuation of digester temperature between 30°C and 30.8°C during 30 days of fermentation. At the beginning of fermentation (days 1 to 10), the digester temperature was relatively stable, approaching ambient temperature (30°C–30.6°C), with a slight increase on days 5 and 9, indicating increased microbial activity. Entering days 11 to 20, the temperature remained in the same range with small fluctuations, indicating that the fermentation process was stable at mesophilic temperatures. On day 13, a temperature peak occurred near 30.8°C, indicating increased substrate degradation activity by microbes. On days 21 to 30, the temperature showed a similar fluctuation pattern, with the average remaining close to ambient temperature. This indicates that the ambient temperature of

30°C is quite stable in maintaining the digester temperature during the fermentation process, supporting microbial activity for the biogas production process.

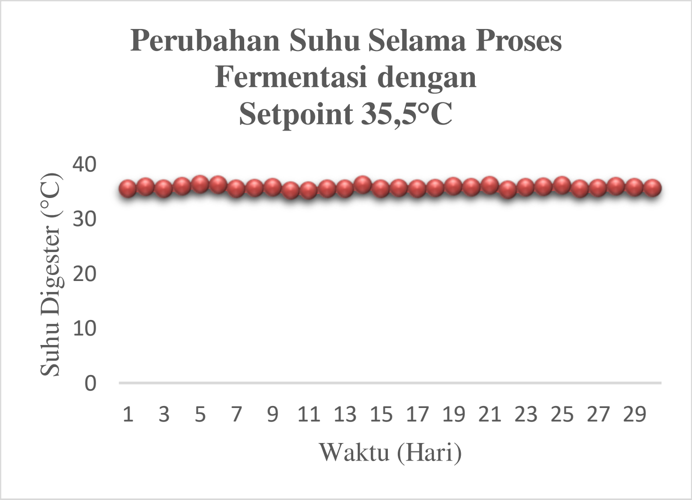


Figure 3.5 Changes in Setpoint Temperature of 35.5°C During Fermentation

The graph in Figure 4.9 shows that the digester temperature ranged from 34.8°C to 36.1°C during the 30-day fermentation period. From days 1 to 10, the digester temperature briefly rose to near 36°C on days 3 and 5, indicating adaptation and increased microbial activity in the initial phase. From days 11 to 20, the temperature showed small but stable fluctuations around 35.0°C–35.8°C, indicating an active fermentation phase with a stable temperature in the upper mesophilic optimal range, supporting faster conversion of the substrate to biogas. Temperature peaks occurred on days 14 and 20, approaching 36°C, indicating peak fermentation activity. From days 21 to 30, the temperature remained relatively stable, approaching the ambient temperature of 35°C with small fluctuations, indicating activity.

3.2.3 COD Test Results

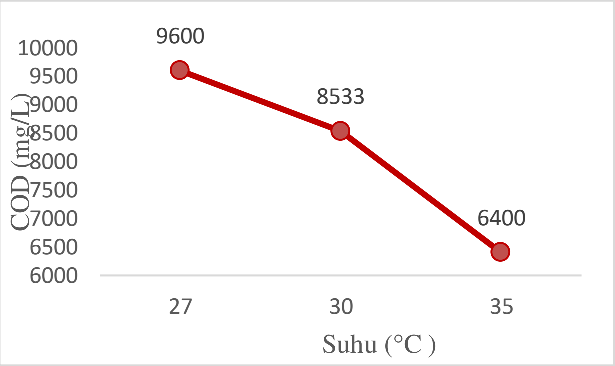


Figure 3.6 Effect of Fermentation Temperature on COD Values

It can be seen that the Chemical Oxygen Demand (COD) value decreased as the fermentation temperature increased from 27°C to 35°C. At 27°C, the COD value remained high at 9600 mg/L, while at 35°C, the COD value dropped drastically to 6400 mg/L. This decrease in COD indicates that more organic matter was degraded during the fermentation process.

The decrease in COD values is directly related to the activity of microorganisms during the biodegradation of organic matter into simpler compounds, ultimately producing methane gas. At 35°C, which is close to the optimum temperature for mesophilic methanogenic bacteria, microbial activity is more optimal in breaking down complex organic compounds into volatile fatty acids, which are then converted into methane and carbon dioxide.

The greater the methane gas production, the more organic compounds are consumed by the methanogenic bacteria, resulting in a decrease in COD concentration in the digester. Conversely, at 27°C, microbial activity is slower, resulting in incomplete degradation of organic matter, resulting in high COD values.

Therefore, the decrease in COD values at higher temperatures (35°C) indicates a more efficient fermentation process, maximizing the conversion of organic matter into biogas (especially methane). This confirms that optimal fermentation temperatures significantly contribute to successful biogas production with improved quality and quantity.

3.2.4 Biogas volume measurement results

Figure 3.7 Measuring biogas volume

The bottle is connected to the digester via a hose that channels the fermentation gas. When biogas begins to form, it flows into the bottle and automatically pushes water out through the mouth. The volume of water exiting the bottle is equal to the volume of biogas entering.

This method was chosen because it is simple, practical, and uses readily available materials such as used bottles, buckets, and plastic tubing. Furthermore, it is accurate enough to determine the amount of biogas produced on a laboratory or small scale. The collected biogas volume can then be read directly on the plastic bottle scale or by collecting the released water in a measuring cup for a more precise value.

The measurement results show that the volume of biogas produced varies with each temperature treatment and fermentation duration. At the optimal temperature (for example, 35°C), the measured biogas volume is higher, at 3.7 liters, compared to 0.3 liters at a lower temperature (27°C). This indicates that temperature significantly influences the activity of microorganisms in degrading organic matter. The better the fermentation conditions, the greater the volume of gas produced and measured using this method.

3.2.5 Flame test

Figure 3.7 Flame Test

The flame formed in biogas is an important indicator that the decomposition of organic matter by methanogenic microorganisms is proceeding smoothly. Methane (CH_4) is the main component of biogas, accounting for 50–70% of the biogas, while the remainder consists of CO_2, H_2S, and other gases in small amounts. The higher the methane content, the better the biogas quality due to the higher calorific value produced.

The results of this combustion test reinforce the data from biogas volume measurements. Measuring volume alone cannot determine the methane content of the gas. However, a combustion test can demonstrate that the biogas produced is not simply carbon dioxide (CO_2) or non-combustible gases, but actually contains fuel components.

The limitation of this combustion test is its qualitative nature, so it cannot accurately indicate the percentage of methane in the biogas. To determine the methane content more precisely, further analysis using Gas Chromatography (GC) or other biogas analysis tools is required. However, in laboratory or simple scale research, combustion tests are sufficient to provide evidence of successful biogas production that can be used as an alternative energy source.

4. CONCLUSION

4.1 Conclusion

Based on the research results and discussion regarding the effect of temperature on the anaerobic fermentation process of cow dung waste using an IoT system, the following conclusions can be drawn:

1. An IoT-based anaerobic digester system has been successfully designed and built using an ESP32 microcontroller, a DS18B20 temperature sensor, an E201C pH sensor (BNC), a heater, and a Blynk application-based monitoring system. This system is capable of monitoring and controlling fermentation temperature in real time to support optimal biogas production.
2. The highest biogas volume was achieved at a fermentation temperature of 35°C, with a final accumulation of 3.7 liters. The lowest volume was achieved at 27°C, at 0.3 liters. This demonstrates that the optimal fermentation temperature for increasing biogas production is 35°C.

4.2 Suggestions

1. Further research can be conducted by adding a thermophilic temperature variable (>45°C) to compare the effectiveness of the fermentation process and biogas production in two different temperature ranges (mesophilic vs. thermophilic).
2. The system can be further developed by adding gas pressure and pH sensors to improve the accuracy of monitoring and control of the biogas fermentation process.

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