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Article

Review: Biogas Fermentation Process

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Abstract

Biogas is a gas generated through anaerobic processes that involve the decomposition of organic materials. Various sources of methane can be utilized to produce biogas, including household waste, biodegradable waste, animal waste, or organic materials that can break down under anaerobic conditions. The objective of this study is to investigate how different conditions, such as time, pH levels, stirring duration, and the type and concentration of inoculum, influence biogas production, with the aim of identifying the optimal conditions for the biogas production process. This research focused on examining the factors that impact the biogas production process, which includes several stages like hydrolysis, acetogenesis, acidogenesis, and methanogenesis. The findings from prior experiments showed that the optimal biogas production was achieved using tofu liquid waste, resulting in a volume of 26,700 ml over a 36-day period. This was achieved by maintaining an operating temperature between 35-40°C and employing cow dung as the inoculum, along with a 36-liter digester.
Keywords: fermentation[1], biogas[2], domestic waste[3], optimum condition[4]

1. Introduction

The need for fuel which is a source of energy every day continues to increase along with the increase in population. One of them is the fuel used in society, namely fuel oil. This increasing fuel consumption cannot be matched by its increasingly depleting availability, especially for fossil fuels [1]

This is due to the increasing demand for energy but on the contrary, the raw materials for producing it are very minimal and the manufacturing process also takes a very long time. In addition, excessive use of non-renewable energy can cause energy crisis problems. One of the problems of the recent energy crisis is the lack of fuel oil (BBM), such as gasoline, diesel and oil. The cause of this scarcity is the very high level of demand for fuel and the rate of increase is very fast every year, while the main raw materials for making fuel are not available in abundant quantities and do not require a short time for the formation process [2]

To overcome these energy problems, it would be nice for us to convert and conserve energy in accordance with Presidential Decree No. 5 of 2006 concerning the National Energy Policy (KEN). KEN aims to realize energy security with a target that by 2025, energy sourced from oil is 20%, gas is 30%, coal is 33%, and new and renewable energy is 17%. Seeing such conditions, it is necessary to study alternative energy that is suitable and can be produced in Indonesia [3].

One alternative energy that is easy and applicable is biogas. Biogas is an energy that deserves consideration both technically, socially and economically, especially to overcome energy problems in Indonesia [4].

Biogas is a gas produced through the fermentation or methanization process, which involves the decomposition of organic materials. These organic materials are derived from a variety of sources, including animal waste, human waste, garbage, tofu liquid waste, and more. Biogas is a flammable (flammable) gas and is produced from the fermentation process of organic materials with anaerobic bacteria, namely bacteria that can survive without oxygen [5]. Production of biogas is an effective and economical solution to the provision of alternative energy sources [6].

2. Biogas

Biogas is a gas generated through the anaerobic fermentation of organic matter by bacteria that can thrive in oxygen-free environments. All types of organic materials contain protein, fat, carbohydrate compounds that can be used in the biogas production process [7]. There is no specific Indonesian National Standard (SNI) for biogas; instead, it is characterized by its composition. The primary constituents of biogas are methane gas (CH_4) and carbon dioxide (CO_2), with trace amounts of other components including water vapor, hydrogen sulfide (H_2S), carbon monoxide (CO), and nitrogen (N_2) [8].

Biogas is also an environmentally friendly alternative energy. This is because the largest content of biogas is methane gas (CH_4) which, if released into the atmosphere, can contribute to the greenhouse effect. However, by utilizing CH_4, the gas undergoes complete combustion and forms CO_2 which will then be released into the environment. The CO_2 gas will then be used for the process of photosynthesis in plants. This shows that releasing CO_2 gas into nature can be said to be more environmentally friendly than releasing methane gas (CH_4) directly into nature, because CH_4 cannot be absorbed by plants [9].

2.1. Properties of Biogas

The main component of biogas is methane, where methane is very useful for fuel because it has a high calorific value, which is around 4800 to 6700 Kcal/m^3. Due to its high energy content, biogas finds applications in various fields such as lighting, cooking, powering machinery, and more. In terms of energy equivalence, 1 cubic meter of biogas is roughly equivalent to 0.46 kilograms of LPG, 0.62 liters of oil, 0.52 liters of diesel oil, 0.80 liters of petrol oil, 1.50 cubic meters of city gas, and 3.50 kilograms of firewood [10].

The weight of biogas is approximately 20% lighter than air. The combustion temperature in biogas ranges from 650-750°C. Biogas has no smell and color, the color of the flame produced from combustion is bright blue like LPG gas. The efficiency of burning biogas is 60% on conventional biogas stoves [2]. When the combustion process is carried out, the flame that is formed will be blue like the flame from LPG and the heat energy (heat) produced is 5,200-5,900 kcal/m^3 of gas or the same as heating a quantity of water with a volume of 65-73 liters from a temperature of 20°C until it reaches its boiling point [11].

2.2. Biogas Production Process

The production of biogas involves a sequence of stages, including hydrolysis, acidogenesis, acetogenesis, and methanogenesis. These represent the phases of biogas generation in anaerobic digestion [12].

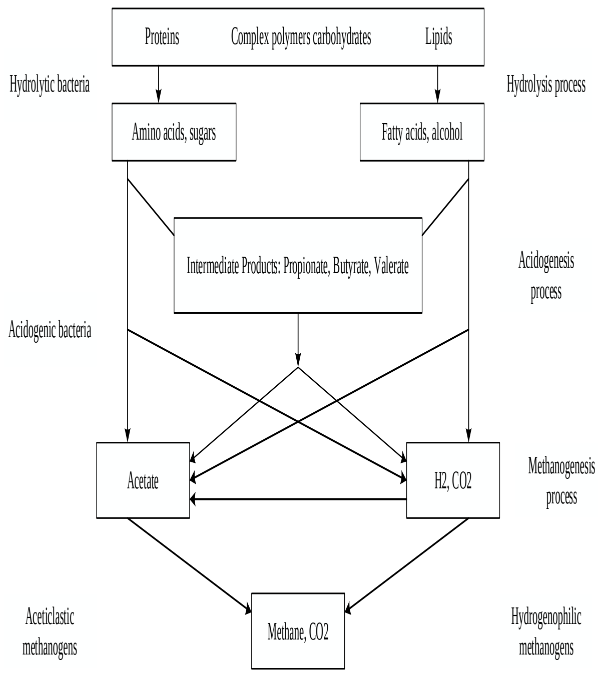

Figure 1. diagram of methane production

Hydrolysis

In theory, the initial phase of biogas formation is hydrolysis. During this hydrolysis stage, complex organic compounds (polymers) break down into smaller components (mono and oligo). In this process, polymers like carbohydrates, lipids, nucleic acids, and proteins transform into glucose, glycerol, purines, and pyrimidines. Hydrolytic microorganisms release enzymes that facilitate the conversion of polymers into simpler compounds, following the equation as demonstrated below:

$$\text{Lipids} \xrightarrow{\text{Lipase}} \text{Fatty acids, Glycerol} \quad \text{(i)}$$

$$\text{Polysaccharide} \xrightarrow{\text{cellulase, cellobiase, xylanase, amylase}} \text{Monosaccharide} \quad \text{(ii)}$$

$$\text{Lipids} \xrightarrow{\text{Lipase}} \text{Fatty acids, Glycerol} \quad \text{(iii)}$$

(Hydrolysis reaction to form methane gas)

The hydrolysis process requires the mediation of exo-enzymes which are excreted by fermentative bacteria. The microorganisms involved in the process further decompose the products generated by hydrolysis and utilize them for their own metabolic activities. However, the anaerobic decomposition process is very slow and limited in the decomposition of cellulolytic waste containing lignin. In this process, acid-degrading bacteria decompose glucose compounds according to the following reactions [13] in the journal [14]:

$$C_6H_{12}0_6 + 2H_20 \longrightarrow 2CH_3COOH + 2CO_2 + 4H_2 \text{ (acetic acid)} \quad \text{(iv)}$$

$$C_6H_{12}0_6 \longrightarrow CH_3CH_2CH_2COOH + 2CO_2 + 2H_2 \text{ (butyric acid)} \quad \text{(v)}$$

$$C_6H_{12}0_6 + 2H_2 \longrightarrow 2CH_3CH_2COOH + 2H_20 \text{ (propionic acid)} \quad \text{(vi)}$$

(Decomposition of glucose compounds)

Acidogenesis

In the acidogenesis phase, acidogenic bacteria transform the products of hydrolysis into substrates suitable for methanogenesis. This conversion involves the breakdown of simple sugars, amino acids, and fatty acids into acetate, carbon dioxide, and hydrogen (comprising 70% of the transformation), as well as into Volatile Fatty Acids (VFA) and alcohol (constituting the remaining 30%).

Acetogenesis

In the acetogenesis phase, the byproducts of acidogenesis that cannot be directly converted into methane by methanogenic bacteria are transformed into substances suitable for methanogenesis. This transformation involves the oxidation of Volatile Fatty Acids (VFA) and alcohol into methanogenic substrates like acetate, hydrogen, and carbon dioxide. The production of hydrogen as a byproduct of acetogenesis increases the partial pressure of hydrogen, and it is considered a waste product that can inhibit the metabolic processes of acetogenic bacteria. Subsequently, in the methanogenesis stage, hydrogen is converted into methane. Acetogenesis and methanogenesis typically occur in parallel, representing a symbiotic relationship between these two groups of organisms.

Methanogenesis

Methane and carbon dioxide are generated from intermediate products through the activities of methanogenic bacteria. Approximately 70% of the methane produced originates from acetate, while the remaining 30% is generated by the conversion of hydrogen (H_2) and carbon dioxide (CO_2), as described in the following equation:

$$CH_3COOH \longrightarrow CH_4 + CO_2 \quad \text{(vii)}$$

$$2H_2 + CO_2 \longrightarrow CH_4 + 2H_2O \quad \text{(viii)}$$

(Methane production from acetic acid)

Methanogenesis plays a crucial role in the complete anaerobic digestion process, as it represents the slowest biochemical reaction within this process. Methanogenesis is notably sensitive to operational conditions, with factors such as the composition of raw materials, the food-to-waste ratio, temperature, and pH levels exerting significant influence on this process. Factors like digester overload, fluctuations in temperature, and the introduction of substantial amounts of oxygen can lead to the cessation of methane production.

2.3. Fermentation Process

Fermentation refers to the utilization of microbial metabolism to transform raw materials into valuable products, including organic acids, single-cell proteins, antibiotics, and biopolymers. It can also be seen as a process of cellular energy generation under anaerobic conditions, which means without the presence of oxygen. Essentially, fermentation is a type of anaerobic respiration. Typically, sugars serve as common substrates in fermentation. Examples of fermentation products include ethanol, lactic acid, and hydrogen. Nevertheless, various other substances can also result from fermentation, such as butyric acid, acetone, and biogas [15].

2.4. Matters Needing Attention In Fermentation

1. Stirring

The stirring process will be very beneficial because if the solid is not stirred it will settle to the bottom of the tank and foam will form on the surface which will make it difficult for the gas to escape. This problem occurs more in processes that use vegetable waste raw materials than those that use livestock manure. In the continuous system this problem is smaller because when the raw material is added it will break the foam on the surface as if there was stirring. In digesters located in Europe where heating is required if the process is carried out in winter, air circulation is also the agitation process.

2. Temperature Control

In hot areas, the use of a roof will help keep the temperature at an ideal condition, but in cold areas it will cause problems. The steps generally taken are to line the tank with a pile of straw or wood shavings with a thickness of 50 to 100 cm, then cover with a waterproof wrap, if that is not enough then use a heating coil. High digester temperatures will be more susceptible to damage due to temperature fluctuations, therefore careful maintenance is required.

3. Gas Collection

In order to collect the biogas produced, a drum that is mounted upside down is used. The drum must be able to move so that it can be adjusted to the volume of gas required. Biogas will flow through a small hole above the drum. A one-way valve is used to prevent outside air from entering the digester tank which will damage bacterial activity and allow an explosion in the drum to occur. Large installations require good control of weight and pressure measurements.

4. Digester Position

Biogas digesters built above ground must be made of steel to withstand pressure, while those built underground are generally simpler and cheaper. However, from a maintenance point of view, the above-ground digester will be easier and the digester can be covered with a black layer which functions to capture the sun's heat.

5. Retention Time

Another factor that needs to be considered is retention time, this factor is strongly influenced by temperature, dilution, mixing rate of materials and so on. At high temperatures the fermentation rate takes place quickly, and reduces the processing time required. Under normal conditions, the fermentation of manure lasts between two and four weeks [16].

2.5. Starter Type

Decomposing bacterial products are a collection of modified bacteria that have been given additional nutrients that can help the process of decomposing organic matter. The following are several types of decomposing bacterial products, namely:

1. EM4

EM4 is a mixed culture of microorganisms that are beneficial for plant growth, capable of increasing the decomposition of waste and organic waste, accelerating the composting process of waste or animal manure, increasing the availability of plant nutrients, and suppressing attack activity from pathogenic microorganisms. EM4 consisted of a large number of bacteria of the genus Lactobacillus (lactic acid producing bacteria), as well as a small amount of photosynthetic bacteria Streptomyces sp, and yeast which were cultured in liquid medium at pH 4.5. Microorganisms contained in the solution amounted to 10 g/liter.

2. Envirosolve

Is a solution of microbiological spectrum concentration that works in the Bioremediation process. The concentration of these microbes works by consuming the organic content in wastewater and reducing it to a decomposed liquid element. In this process, microbes continuously multiply and reproduce as long as their food source is available. Active microbial colonies produce enzymes that assist in providing the nutritional needs of these microbes. The contents of this decomposing bacterial product include the following:

Amino Acids	: 3 – 4 %
Nitrogen (N_2)	: 4 – 5 %
Glucose	: 6 – 7 %
Microorganisms	: 10^2– 10^5/ml

Microorganisms

a) Cellulitic, carbolitic, proteolytic decomposing microbes
b) Lactobacillus sp.
c) Nitrogen Binder
d) Phosphate Decomposition

3. Biodextran

Is a collection of probiotic bacteria (beneficial) and anaerobic (can live in very minimal oxygen conditions) and can decompose toxic organic materials (waste) into simple organic materials that do not pollute the environment and eliminate the smell of waste. If applied to tofu waste, it can decompose complex organic matter (proteins, carbohydrates and fats) both solid and liquid into simple organic materials that do not pollute the environment biologically. The bacterial content contained in this decomposing bacterial product is as follows [17]:

a) Nitrosomonas sp.
b) Nitrobacter sp.
c) Pseudomonas sp.
d) Bacillus sp.

3. Previous Researchers

No	Journal Title	Operating Conditions	Biogas Volume (L)	Reference
1	Utilization of Household-Scale Tofu Waste to Become Biogas as a Clean Technology Effort at the Environmental Technology Center Laboratory – Bppt	Fermentation time = 10 days Inoculum = cow dung Cow manure: LCT = 14% : 86% pH = 6.56-6.62	0.6	[18]
2	Identification of Biogas Production Potential from Tofu Liquid Waste with Upflow Reactor Anaerobic Sludge Blanket (UASB)	Fermentation time = 12 days Inoculum = granule microorganisms pH = 4 - 7.5 Reactor volume = 8.5 L (8500 ml)	13	[19]
3	Making Biogas from Tofu Liquid Waste Using Indigenous Bacteria	Fermentation time = 20 days Inoculum = indigenous bacteria Indigenous bacteria : LCT = 30% : 70% Reactor = 50L anaerobic digester	5	[20]
4	Digestion of Mixture of Vinase Waste and Tofu Liquid Waste to Increase Production Biogas	Fermentation time = 20 days Inoculum = Rumen Cow LV:LCT = 20% : 80% pH = 7 - 5.1 Digester volume = 250 ml	0.1255	[21]
5	Biogas Production From Tofu Liquid Waste On Treated Agricultural Wastes	Fermentation time = 21 days Inoculum = Sheep Manure pH = 6.4 - 7.2 Reactor volume = 60 L	14,183	[22]
6	Effect of Variations in Composition of Starter Horse Manure, Yeast and EM4 on the Quality of Tofu Liquid Waste Biogas Fuel	Fermentation time = 21 days Inoculum = Horse Manure + Tape Yeast LCT:Horse Manure: Yeast Tape = 50:48:2 % pH = 6-7 Digester volume = 19 L (19000 ml)	0.83	[23]

No	Journal Title	Operating Conditions	Biogas Volume (L)	Reference
7	Effect of Starter Taking Time on Biogas Production	Fermentation time = 25 days Inoculum = Cow Manure collection time (1, 7, and 14 days) Cow Manure: LCT = 19% : 81% Digester volume = 20 L (2000 ml)	1.057	[24]
8	Biogas Production and Cod Removal From Tofu Liquid Waste	Fermentation time = 28 days Inoculum = cow dung (take 7 days) Cow manure : LCT = 50% : 50% pH = 6.1 - 6.7 Reactor = 20L anaerobic digester Temperature = 32°C-30°C	0.43	[25]
9	Biogas Potential of Tofu Waste Using Batch Type Digester Circulating Liquid At 35°C - 40°C	Fermentation time = 36 days Inoculum = Cow Manure LCT:LPT:Cow Manure = 40%:30%:30% Digester volume = 36 L (36000 ml) Temperature = 35°C- 40°C	26,7	[26]
10	Utilization of Water Hyacinth as a Catalyst in Anaerobic Processing of Tofu Industry Liquid Waste	Fermentation time = 60 days inoculum = cow dung inoculum concentration = 2.5% cow dung:LCT=2.5% : 97.5% temperature = 30°C-45°C	0.13	[27]

Discussion

Several stages in the anaerobic fermentation process are hydrolysis, acid formation (acidogenesis), acetate formation (acetogenesis), and methane gas formation (methanogenesis) [28].

Based on observations made in several studies that have been conducted, it can be seen that in several studies the volume of biogas was produced in the range of 125.5 ml – 26,700 ml. In the table it can also be seen that the best research can be seen in the highest chart, namely the results of the largest volume at 36 days, namely in the study of [26] using cow dung inoculum. It can be seen in the table, although the fermentation time in table 10 is longer, there are other factors that affect the volume of biogas produced. The first factor is temperature, because methanogenic bacteria are very sensitive to temperature. Optimally, methanogenic bacteria are able to grow and develop at 35°C [2].

In table 9, that is from the study of [26]shows that the temperature used in the fermentation process is closer to stable when compared to the research in table 10, so that in the study of [26], the longer the time, the greater the number of methanogenic bacteria that play a role in the fermentation process, so that the volume of biogas produced will also be greater. The second factor affecting the volume of biogas produced is the inoculum concentration. In the study [26], the concentration of inoculum they used was higher when compared to the study in table 10, so that as time increases, the methanogenic bacteria that will play a role in the fermentation process will also increase, so that the volume of biogas produced will also increase.

4. Conclusion

The conclusions obtained based on the research that has been done are as follows:

1. The biogas production process consists of several processes such as hydrolysis, acetogenesis, asedogenesis, and methanogenesis.
2. The longer the fermentation time, the greater the production of biogas produced. However, at certain times, the addition of time cannot increase the volume of biogas production, this is due to the amount of organic matter in the substrate that has been used up.
3. The more neutral the fermentation pH (pH close to 7), the more optimum the biogas production process occurs, so that the greater the biogas produced.
4. The existence of stirring shows that the biogas production process is getting better, so that the biogas produced is also getting bigger. The longer the stirring time, the higher the biogas production.
5. The greater the concentration of inoculum used, the greater the production of biogas produced. On the other hand, if the inoculum content is too high, it can reduce the rate of biogas production, because the greater number of microorganisms will lead to a high level of competition between microorganisms, so that the decomposition of organic matter will take place less than optimally.

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