Enriching Methane Content from an Anaerobic Digestion Process of Cow Manure

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Abstract. High use of energy in Indonesia becomes one of issues encouraging innovation to create energy that is easily obtained and can be renewable sources. In addition, the use of energy derived from fossils has a negative effect on the environment such as global warming. Biogas is an alternative energy used to reduce the use of energy derived from fossils. Due to high content of biogas in form of methane (CH_4) and its calorific value is quite high. Making biogas can be said to be cheap because it utilizes anaerobically fermented biomass. Utilization of biomass into biogas can support a new and renewable energy sources. One of the wastes used as raw material for biogas production is cow manure. This research is intended to obtain biogas with high methane gas content and calorific value. Fermentation time is a very important variable in the formation of biogas. The fermentation time parameters were carried out at 5, 10, 15, 20, and 25 days. The biogas formed was analyzed for the content of methane gas and its calorific value. Based on the results of the study, the optimal biogas fermentation time occurred on the 25th day, the methane gas content was 54.16% with an optimal heating value of 22.20 MJ/m^3 for HHV and 19.80 MJ/m^3 for LHV.

Keywords: Biogas · Methane gas · Caloric value

1 Introduction

In recent years, generating power from renewable energy resources has become increasingly important in socio-economic development of a country in the world. In Indonesia, the high use of energy is influenced by increasing industrial development and increasing population growth. Energy derived from fossils causes scarcity because fossil energy cannot be renewed [1]. In addition, the burning of fossil fuel resources to meet these energy needs leaves a negative trail. It might cause global warming due to the emission of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). All are classified as

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greenhouse gases (GHGs). To reduce the use of fossil fuels, innovations were made in producing alternative energy, namely the production of biofuels. The materials used in the production of biofuels are waste from organic materials or commonly referred to as biomass. One of the biofuel productions that can be done is the production of biogas from cow manure. Biogas production from locally available renewable organic resources can be a good alternative as it contributes to the reduction of GHG emissions. Biogas technology is a good step for utilizing various categories of biomass to meet energy needs [2].

Biogas is gas produced by bacteria when organic matter undergoes a fermentation process in a reactor (biodigester) under anaerobic conditions (without air). In the process of biogas formation, microorganisms require adequate environmental conditions for optimal growth, such as pH, temperature, nutrients and others [3].Cow manure contains high enough organic matter for biogas production so that it is suitable for biogas production. The formation of biogas is influenced by several parameters such as fermentation time, pH, substrate concentration of COD (Chemical *Oxygen Demand)*, alkalinity, and C/N ratio [4]. Fermentation time is a very important parameter in the formation of biogas. However, it does not mean that the longer the fermentation time will produce a high content of methane gas. Based on several research results, there is an optimal time to produce high methane gas content. In a study conducted by [5] the highest methane gas composition occurred on the 20th day. However, the biogas that is formed sometimes has a high content but low calorific value. For this reason, this study used several parameters that are known to be quite optimal, such as the *ratio* of cow manure and water, which was 1: 2, then for temperature using room temperature, and for the degree of acidity (pH) the substrate used was 7.

Biodigester is the most important component in biogas production. Biodigester is a place where bacteria brake down organic material anaerobically into CH_4 and CO_2 gases. The biodigester must be designed so that the anaerobic fermentation process can function properly. Biogas can be formed in 4–5 days after the digester has been filled. Large amount of biogas were typically produced in 20 to 25 days, after which production decreased if the biodigester was not refilled.

Biogas is a flammable gas *produced* from the fermentation process (decay) of organic materials by anaerobic bacteria (bacteria that live in conditions without oxygen in the air). Organic materials are materials that can be decomposed back into soil, such as garbage and animal wastes (cows, goats, pigs, and chickens). This fermentation process actually occurs naturally but requires a relatively long period. Biogas is one of the renewable energy sources because the existence of raw materials will continue to exist as long as this life is still ongoing. Biogas is different from fossil fuels (petroleum and coal) which are non-renewable fuels [6]. Anaerobic digestion provides opportunities for biogas to be used to produce energy, such as electricity, heat, and fuel with additional economic, environmental and climate benefits [7]. Biogas is clean, blue, smokeless, and dark in addition to having a higher degree of heat than kerosene, charcoal, and firewood fuels and can be stored for future use [8].

Biogas mostly contains methane (CH_4) and carbon dioxide (CO_2), with trace amounts of nitrogen (N_2), hydrogen sulfide (H_2S), carbon monoxide (CO), and oxygen (O_2) and other composition of biogas in general [9] (Table 1).

Table 1. Biogas composition in general

Component	%
Methane (CH_4)	54–70
Carbon dioxide (CO_2)	27–45
Nitrogen (N_2)	0.5–3
Carbon monoxide (CO)	0.1
Hydrogen sulfide (H_2S)	Least
Oxygen (O_2)	0.1

The general reaction for biogas formation [10]:

$$\text{Organic matter} + H_2O \xrightarrow[\text{anaerob}]{\text{mikro organisme}} 1\,CH_4 + CO_2 + \text{energy} + \text{other products}\,(H_2S, SO_4^{-2}, NO_3^{-})$$

The anaerobic breakdown of organic matter that occurs in the digester consists of four stages:

1. Hydrolysis

Hydrolysis is the first step for almost all decomposition processes where organic matter will be broken down into simpler forms so that it can be broken down by bacteria in the fermentation process [8]. At this stage, complex polymeric organic compounds such as polysaccharides, proteins, and fats, are degraded by hydrolytic microorganisms into sugar monomers, amino acids, and peptides. A large number of anaerobic and facultative microorganisms are involved in the hydrolysis process, namely *Clostridium* [10].

2. Asedogenesis

At this stage the products hydrolyzed are converted into volatile fatty acids (VFA), alcohol, aldehydes, ketones, ammonia, carbon dioxide, water and hydrogen by acid-forming bacteria [8].

3. Acetogenesis

In the acetogenesis stage, most of the products of acid fermentation must be oxidized under anaerobic conditions to acetic acid, CO_2, and hydrogen which will become substrates for methanogenic bacteria. Acetogenesis also includes the production of acetate from hydrogen and carbon dioxide by acetogens and homoacetogens. Sometimes the processes of acidogenesis and acetogenesis are combined as one step only [8].

4. Methanogenesis

Methanogenesis is an important step in the whole process of anaerobic digestion, because the process of biochemical reactions is the slowest. Methanogenesis is strongly influenced by operating conditions. Composition of raw materials, feed rate, temperature, and pH are examples of factors that influence the process of methane gas formation. Digester over loading changes in temperature or large influx of oxygen can result in cessation of methane production [8]. The last stage of the biogas formation process is the methane gas formation stage. This stage involves 2 different groups of methanogenic bacteria [10].

In addition, according to [4] there are factors affecting the performance of the stability and efficiency of anaerobic digestion, including temperature where temperature affects the reaction rate of biogas production. The next factor is the length of the process. Theoretically, a long fermentation time will cause low process efficiency. At high temperature, the particle kinetics rate and reaction rate will increase. Then the degree of acidity (pH), pH is an important parameter in biogas production. The optimal pH range is 6.6–8.0. Next, nitrogen inhibitor and Carbon Nitrogen ratio. To achieve better process stability during the digestion process, the process must increase the value of the C/N ratio. Another factor is stirring. Stirring is conducted so that there is contact between bacteria and organic matter so it becomes homogeneous. As a result, biogas production increased by 10–15%.

One of the biogas content that can be seen to determine the increase in methane gas is the calorific value. The calorific value of biogas is one of the characteristics of biogas in producing heat energy which allows its flammability, which can be converted into energy [11]. There are two types of calorific value:

1. Higher Heating Value (HHV). The upper calorific value is determined when the H_2O in the combustion product forms liquid [12]. The upper calorific value also known as Superior Heating Value (Hs) or Gross Calorific Value (GCV) is determined by bringing all combustion products back to their original pre-combustion temperature and specifically condensing any steam generated [13].
2. Lower Heating Value (LHV) or lower heating value. The lower calorific value is determined when the H_2O in combustion product forms gas [12]. The lower calorific value also known as the Inferior Heating Value (Hs) or Net Calorific Value (NCV) is determined by subtracting the heat of vaporization of water vapor from the higher beating value. Assumes that the latent heat of vaporization of water in the fuel and reaction products is not recovered [13].

The main components of the biodigester are the *slurry* inlet, the *digestion* chamber (fermentation chamber), the residue outlet (*sludge*), and the biogas storage tank. The biodigester must be designed in such a way that the anaerobic fermentation process can run well. In general, biogas can be formed in 4–5 days after the digester is filled. A large amount of biogas production generally occurs in 20–25 days and then production decreases if the biodigester is not refilled [12]. The biodigester used was a *Fixed Dome type biodigester*. This type of reactor has two parts, the digester as a place for digesting biogas material and as a home for bacteria, both acid-forming bacteria and methane-forming bacteria [8]. This type of digester has a fixed volume. Therefore, in the construction of a fixed dome type of biodigester, the gas formed will be immediately flowed to the gas collector outside the reactor. The gas production indicator can be done by installing a pressure indicator. The advantages of a *fixed dome type biodigester* are simple, can be done easily, low construction costs, no moving parts, long life, can use rust-resistant materials, and can be made in the ground so that it saves space. While the disadvantages of this biodigester are that the inside of the reactor is not visible and the gas pressure can fluctuate [12].

2 Materials and Method

2.1 Materials

The raw materials for biogas production in this study were cow manure taken from farms, water, and probiotics. The main tools used in this research were: Fixed dome digester, Tedler bag, Gas analizer, and pH meter.

2.2 Method

Biogas production procedure by anaerobic digestion process in Fixed dome digester as follow:

1. Cow manure taken from CV. Pandawa Farm, Palembang was first separated from grass clippings mixed with cow manure, and then a small amount was taken to analyze the pH of the sample.
2. The separated cow manure and water were put into a mixing bath in a ratio of 1: 2, then added probiotics.
3. After it put into the mixing tank, the mixing was done manually.
4. The anaerobic process occurred in the fixed dome digester and produced biogas which accommodated in storage bags/balloons. Biogas composition, biogas pressure, biogas pH, digester temperature and biogas slurry were observed every 5 days for 25 days to control the optimum operating conditions.
5. Sampling of biogas was taken using a biogas sample bag or teddler bag and brought to the laboratory for analysis of the biogas content.
6. Slurry biogas sampling was taken using a sample bottle taken from the fixed dome biodigester (Fig. 1).

The operating conditions of the anaerobic digestion process were observed to control the optimum operating conditions, with the observed parameters, pressure, pH, and temperature which aimed to produce high methane gas. The biogas produced was analyzed to determine the content of CO_2, CH_4, and the calorific value.

Fig. 1. Cow Manure and Fixed Dome Biodigester

Table 2. Results of Observation of Pressure and pH in Biogas

No.	Sample Date	Sample Composition	Pressure (bars)	pH
1.	April 23, 2022	Cow Manure: Water (1: 2)	0	6
2.	April 28, 2022		0.1	6
3.	May 3, 2022		0.25	6
4.	May 8, 2022		0.2	7
5.	May 13, 2022		0.4	7
6.	May 18, 2022		0.45	7

3 Results and Discussion

Biogas was obtained from research conducted with a 1:2 of cow manure and water and the addition of prebiotics as additional microorganisms to accelerate the fermentation process in the biodigester. The biodigester used was a fixed dome biodigester. This research was conducted with a fermentation time of 5, 10, 15, 20, 25 days and observed and checked the operating conditions of the biodigester and slurry. The following are the results of observations made with fermentation times of 5, 10, 15, 20, 25 days in biogas production (Table 2).

The pressure parameter was observed from the *pressure gauge* on the biodigester. Pressure on the biodigester as a parameter to determine how much methane content was formed while the pH was obtained by checking the *slurry* using pH paper. To increase the production of methane content, the degree of acidity (pH) must be in the optimum pH range of 6.6–8.0. The pH value obtained in this study was still in the optimum pH range. In addition to pressure and pH observations, the biogas collected in the biodigester was accommodated into a gas bag which will then be analyzed for the composition of the biogas using a *biogas analyzer*. The results of the analysis of the biogas content can be seen in Table 3.

In addition to the composition of biogas, the *biogas analyzer* also identified the calorific value contained in the biogas with fermentation times of 5, 10, 15, 20, and

Table 3. Biogas Composition in form of CH_4, CO_2, and O_2

Time (Day)	Biogas Composition		
	CH_4 (%)	CO_2 (%)	O_2 (%)
5	8.79	12.02	20.31
10	11.79	0.04	20.18
15	44.07	31.09	9.31
20	50,16	38.78	11.72
25	54.16	37.34	8.28

Table 4. The Results of the biogas calorific value

Time (Day)	HHV (MJ/m^3)	LHV (MJ/m^3)
5	4.3	3.4
10	9.1	8.2
15	14.9	13.3
20	20	18.1
25	22.2	19.8

25 days. The heating value of biogas was divided into two, High Heating Value (HHV) and Low Heating Value (LHV). The results of the analysis of the calorific value of biogas can be seen in Table 4.

In this study, the production of biogas used raw materials from cow manure and water in a ratio of 1:2 by adding probiotics. The probiotics used were methanogenic bacteria to help speed up the fermentation process of biogas. A study conducted by [14] in the manufacture of biogas, adding probiotics in the form of EM4 was very influential in accelerating the fermentation process compared to without using EM4. The equipment used in biogas production was a *fixed dome biodigester*. This type of biodigester has a fixed volume. The gas formed was first accommodated in the biodigester until there was an increase in pressure in the biodigester, and then the gas formed immediately flowed to the gas collector outside the biodigester. This biodigester had been equipped with a *pressure gauge* to determine the pressure in the biodigester. In this biodigester there was also a space on the outside to be filled with water so that the temperature in the biodigester was maintained between 30–40 °C. This temperature is one of the optimum temperatures that is widely used in the anaerobic fermentation process in biogas production or commonly called the mesophilic temperature.

After the biogas was collected in the biodigester, the biogas pressure was monitored every 5 days for 25 days. In addition to pressure, the biogas formed was also analyzed using a *biogas analyzer* to determine the composition contained in the biogas. Figure 2 depicts some of the compositions found in biogas including CH_4, CO_2, and O_2 as shown in Fig. 2.

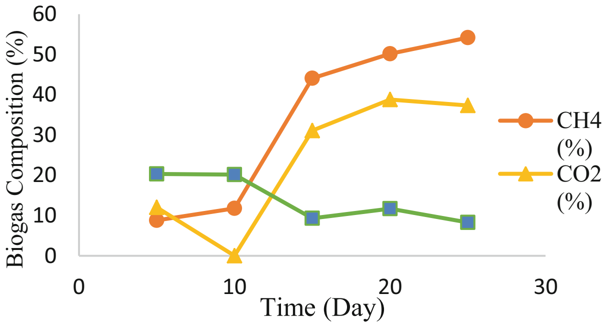

Fig. 2. The Effect of Fermentation Time on Biogas Composition

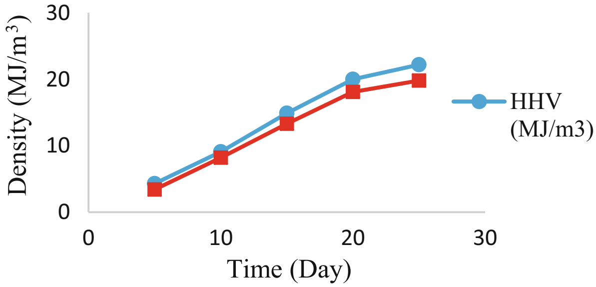

Fig. 3. The Effect of Fermentation Time on the Biogas Calorific Value

In Fig. 2 it can be seen that the levels of CH_4 and CO_2 increased simultaneously with the increasing of fermentation time. However, CO_2 decreased on day 25th, in contrast to CH_4 which continued to increase. The content of CO_2 in biogas affected the quality of biogas. The CO_2 contained biogas without undergoing purification usually ranged from 25–45% [15]. Meanwhile, the CO_2 content produced in this study was 37,34%. In contrast to the CH4 content, the increase occurred due to the length of fermentation time combined with the dilution of the raw materials [1]. The highest CH_4 value was at the 25th fermentation time, which was 54,16%. From research conducted by [16], biogas had a composition between 50–70% methane, 30–40% carbon dioxide, and other gases with small levels. To get an increasing value of CH_4, the degree of acidity (pH) must be in the range of 6.6–8.0. The degree of acidity is the optimal pH for microorganisms to carry out the fermentation process in the formation of biogas. In O_2 gas, it is inversely proportional to the decrease during biogas formation. This is due to anaerobic conditions in the formation of biogas. Research conducted by [17] in biogas production obtained the highest methane gas composition and biogas volume at the 20th and 22nd fermentation times. It was because the composition of raw materials from cow manure and water used a ratio of 1: 2 and there was a stirrer in the biodigester.

In addition to the gas composition, there was a calorific value of biogas which was analyzed using a *biogas analyzer.* The calorific value of the biogas is shown in Fig. 3.

The caloric value is one of the indicators used to determine the quality of biogas. The higher the calorific value, the higher the volatile content burned [10]. The calorific value of biogas is divided into 2, *High Heating Value* (HHV) and *Low Heating Value* (LHV) [12]. In Fig. 3. The calorific value of biogas was obtained for the fermentation time of 5, 10, 15, 20, and 25 days. From Fig. 4. Shows that the highest calorific value of biogas was on the 25th day, which was 22.2 MJ/m^3 for HHV and 19.8 MJ/m^3 for LHV. A study conducted by [17], the calorific value of biogas obtained was 4800–6200 kcal/m^3. It can be seen that the longer the fermentation time for biogas formation, the higher the calorific value of biogas, both for HHV and LHV. In addition, the calorific value of biogas is also influenced by the gas composition. The higher the CH_4 content formed, the calorific value also increased, conversely the higher the CO_2 content formed, the calorific value obtained will decrease.

4 Conclusion

Base on the study result of the anaerobic digestion process in fixed dome biodigester of cow manure in producing biogas with high gas CH_4 content, it can be concluded that to increase the methane content, it is very important to set the right time of fermentation time at fixed dome biodigester. At the time of fermentation of 25 days with the pH condition at 7, the highest methane was at 54.16%. The heating value of at this condition were 22.2 MJ/m^3 for HHV and 19.8 MJ/m^3 for LHV. The higher the CH_4 content formed, the calorific value also increased.

References

1. C. Afrian, A. Haryanto, U. Hasanudin, and I. Zulkarnain, "Produksi biogas dari campuran kotoran sapi dengan rumput gajah (pennisetum purpureum) [production of biogas from a mixture of cowdung and elephant grass (Pennisetum purpureum)]," *J. Tek. Pertan. Lampung*, vol. 6, no. 1, pp. 23–30 (2017).
2. N. Nwokolo, P. Mukumba, K. Obileke, and M. Enebe, "Waste to energy: A focus on the impact of substrate type in biogas production," *Processes*, vol. 8, no. 10, pp. 1–21, doi: https://doi.org/10.3390/pr8101224 (2020).
3. L. Kalsum, A. Zikri, W. E. Islamiyata, and F. Hibatullah, "Kotoran Sapi Dengan Variasi Jumlah Mikroba Design Building and Testing Biogas Production Equipment From Cow Dung With Various Microbial Variations," *J. Kinet.*, vol. 9, no. 02, pp. 31–35 (2018).
4. B. Trisakti, Irvan, and D. B. Sitompul, "Jurnal Teknik Kimia USU Stabilitas Digester Anaerobik Satu Tahap dalam Produksi Biogas pada Variasi," *J. Tek. Kim. USU*, vol. 10, no. 1, pp. 25–30 (2021)
5. P. Iriani, Y. Suprianti, and F. Yulistiani, "Fermentasi Anaerobik Biogas Dua Tahap Dengan Aklimatisasi dan Pengkondisian pH Fermentasi," *J. Tek. Kim. dan Lingkung.*, vol. 1, no. 1, p. 1, doi: https://doi.org/10.33795/jtkl.v1i1.16 (2017).
6. Pertiwiningrum, A., Harto, A. W., Wuri, M. A. dan Budiarto, R. Assessment of Caloric Value of Biogas After Carbon Dioxide Adsorption Process Using Natural Zeolite and Biochar. International Journal of Environmental Science and Development. Vol. 9, No. 11, 327–330. doi: https://doi.org/10.18178/ijesd.2018.9.11.1123.

7. N. Scarlat, J. F. Dallemand, and F. Fahl, "Biogas: Developments and perspectives in Europe," *Renew. Energy*, vol. 129, pp. 457–472, doi: https://doi.org/10.1016/j.renene.2018.03.006 (2018)
8. Prihatiningtyas, S., Sholihah, F.N., dan Nugroho, M.W. "Biodigester Untuk Biogas," Fakultas Pertanian (2019)
9. L. A. Wardana *et al.*, "Pemanfaatan Limbah Organik (Kotoran Sapi) Menjadi Biogas dan Pupuk Kompos," *J. Pengabdi. Magister Pendidik. IPA*, vol. 4, no. 1, doi: https://doi.org/10.29303/jpmpi.v4i1.615 (2021)
10. M. M. T. A. M. D. R. S. C. A. L. Hardoyo, *Panduan Praktis Membuat Biogas Portabel Skala Rumah Tangga dan Industri*. Yogyakarta: ANDI, (2018).
11. L. K. P. Toribio, G. O. Castro, J. W. V. Flores, C. A. C. Olivera, and E. G. Benites-Alfaro, "Calorific value of biogas obtained by cavia porcellus biomass," *Chem. Eng. Trans.*, vol. 80, no. March, pp. 271–276, doi: https://doi.org/10.3303/CET2080046 (2020)
12. Suyitno, M. Nizam, and Darmanto, "Teknologi Biogas," *Teknol. Biogas*, p. 118 (2009).
13. R. Luque, J. Campelo, and J. Clark, *Handbook of biofuels production*. doi: https://doi.org/10.1533/9780857090492 (2011)
14. M. Megawati, "Pengaruh penambahan em4 (effective microorganism-4) pada pembuatan biogas dari eceng gondok dan rumen sapi," *J. Bahan Alam Terbarukan*, vol. 3, no. 2, pp. 42–49, doi: https://doi.org/10.15294/jbat.v3i2.3696 (2014)
15. L. Kalsum, Rusdianasari, and A. Hasan, "The Effect of the Packing Flow Area and Biogas Flow Rate on Biogas Purification in Packed Bed Scrubber," *J. Ecol. Eng.*, vol. 23, no. 11, pp. 49–56, doi: https://doi.org/10.12911/22998993/153569. (2022)
16. Iswanto, A. Ma'arif, B. Kebenaran, and P. Megantoro, "Design of gas concentration measurement and monitoring system for biogas power plant," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 22, no. 2, p. 726, doi: https://doi.org/10.11591/ijeecs.v22.i2.pp726-732 (2021).
17. M. Mara, "Analisis Penyerapan Gas Karbondioksida (CO_2) Dengan Larutan NaOH Terhadap Kualitas Biogas Kotoran Sapi I Made Mara** Dosen Teknik Mesin Fakultas Teknik Universitas Mataram Jl Majapahit