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The Effect of Sawdust Concentration on Biogas Production from Chicken Dung in Anaerobic Co-Digestion

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Abstract - *Resources of oil and natural gas which are derived from fossil energy are wane more and more. One of the research of alternative energy are the production of biogas. Biogas is formed when organic material is degraded by microorganisms in anerobic conditions. Biogas consists of methane gas (50-70%), carbon dioxide (30-50%), and also includes small amounts of other compounds such as hydrogen sulfide (H_2S), nitrogen gas (N_2) and water vapor. The purpose of this study is to examine the effect of pretreatment on the biogas yield produced, examine the effect of adding nutrients to the biogas yield produced, and examine the effect of the C/N ratio value on the biogas yield produced. Anaerobic fermentation is a series of biological processes that convert organic matter into CH_4 and CO_2 and also convert S compounds to H_2S in the absence of oxygen (O_2) by anaerobic microorganisms consisting of four primary stages. In biogas production research, the variables used are the C/N ratio, pretreatment of raw materials, and the addition of nutrients. This research includes three processes, there are the preparation process, the operation process, and the result analysis. It is known that chemical pretreatment using acids results in greater biogas products. Then, the results were obtained that biogas with C/N 30 produced more biogas products. The liquid state (L-AD) method produces more biogas than the solid state (SS-AD) method. The HCl pretreatment variable with C/N ratio of 30, and TS 10% produces the largest kinetics rate compared to other variables.*

Keywords *– Biogas, Chicken Dung, Sawdust, Anaerobic Co-Digestion*
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1. Introduction

Renewable energy sources are being promoted around the world in response to growing concerns about climate change. In recent years, one of the options that can be a source of renewable energy is biogas. Energy and climate policies in the European Union and the introduction of various schemes to promote the utilization of renewable resources have stimulated the development of biogas plants for energy production. Anaerobic fermentation provides an opportunity for biogas to be used to produce energy, such as electricity, heat, and fuel. In Europe, most of the anaerobic digesters are capable of supplying the electricity and heat needs of a plant, whether it is a heat generator, a power plant, or a combination of heat and power generation.

Biogas is formed when organic matter is degraded by microorganisms under anaerobic conditions. Anaerobic fermentation converts organic matter into biogas, a renewable fuel that can be used to generate electricity, heat or fuel vehicles (Scarlat et al., 2018). Biogas consists of methane gas (50-70%), carbon dioxide (30-50%), and also includes small amounts of other compounds such as hydrogen sulfide (H_2S), nitrogen gas (N_2) and water vapor. Anaerobic fermentation is a series of biological processes that convert organic matter into CH_4 and CO_2 and also convert S into H_2S in the absence of oxygen (O_2) by anaerobic microorganisms consisting of four primary steps capable of breaking down complex compounds. The four primary stages consist of Hydrolysis, Acidogenesis, Acetogenesis, and Methanogenesis, where the four processes above are crucial processes in biogas production (Wang, Larson, & Runge, 2019).

In the process of Anaerobic Digestion there is a final process called methanogenesis. Methanogenesis is the process of forming methane gas (CH_4) with the help of methanogenic microorganisms from the genera

Methanosarcinaceae and Methanosaetaceae. There are two steps in the process of methanogenesis, namely Hydrogenotropic Methanogenesis, where CH_4 is formed by the reduction of CO_2 with H_2 and Acetatelastic Methanogenesis, where acetate is converted to CH_4 and CO_2 which produces 70% CH_4 (Ali et al., 2019).

Wood sawdust has the same properties as wood, only in a different form. Wood is a material that is obtained from the cutting of trees in the forest, which are part of the tree and is collected, after calculating which parts are more likely to be used for a specific purpose. Along with the development of science, there is a need for technology that can process sawdust into a product that is useful for the community, namely by making it a raw material for biogas which is useful as an alternative fuel, a substitute for LPG gas, can be used as organic fertilizer, and so on. This research was conducted with the hope that the public could find out about one of the benefits of sawdust which is a waste as an additive in making an energy source in the form of biogas (Nuhardin, 2018). The chemical components in wood have an important meaning, because they can determine the usefulness of wood species. The composition of wood is 50% carbon, 6% hydrogen, 0.04 - 0.10% nitrogen, 0.20 - 0.50% ash, and the rest is oxygen. The chemical components of wood vary greatly, because it is influenced by growth factors, climate and its location in the trunk or branches, and wood sawdust has a calorific value of 4,046 cal / gram (Billah, n.d.).

One of the problems often faced by the community is waste and livestock manure that are not handled. As a result, the surrounding environment will be polluted. Often the people around the farms complain because of the strong smell coming from the farms. Therefore, good handling is needed so that the smell doesn't arise, or at least it doesn't spread. Basically, the disturbance caused by livestock and plant waste can be overcome by producing biogas. This is because livestock manure is very good for use as a raw material for the process of making biogas. One way is to use chicken manure which contains high N and is slightly dry. Therefore, if using chicken manure should be mixed with sawdust or wood shavings. The quality of laying hen manure is different from that of cut chickens and native chickens. In addition, if a lot of chicken manure is mixed with feathers or unhusked floor, the quality will be poor (Djaja et al., 2006). Chicken manure is one of the organic materials that affect the physical, chemical and plant growth properties. Chicken manure has high levels of nutrients and organic matter and low water content.

Biogas is a flammable gas produced from the fermentation (decomposition) 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, for example waste and animal manure (cows, goats, pigs and chickens). This fermentation process actually occurs naturally but requires a relatively long time. Biogas is a renewable energy source because the existence of raw materials will continue to exist as long as this life continues. Biogas is different from fossil fuels (petroleum and coal) which are non-renewable fuels (Pertiwiningrum, 2012).

Biogas mostly contains methane (CH_4) and carbon dioxide (CO_2) gases, and some other compounds in small amounts include hydrogen sulfide (H_2S), ammonia (NH_3), hydrogen (H_2), and oxygen (O_2). The energy contained in biogas depends on the concentration of methane (CH_4). The higher the methane content, the greater the energy content (calorific value) in the biogas, and conversely, the lower the methane content, the lower the calorific value. The quality of biogas can be improved by treating several parameters, namely: removing hydrogen sulfur (H_2S) and the content of water and carbon dioxide (CO_2) or what is called the purification process (Pertiwiningrum, 2012). The basic principle of biogas technology is the process of decomposing organic materials by microorganisms in conditions without oxygen (anaerobic) to produce a mixture of several gases, such as methane and CO_2. Biogas is produced with the help of methanogenic or methanogenic bacteria. These bacteria are naturally present in waste containing organic matter, such as livestock waste and organic waste. This process is known as anaerobic digestion or anaerobic digestion. Generally, biogas is produced using a device called a biogas reactor (digester) which is designed to be airtight (anaerobic), so that the decomposition process by microorganisms can run optimally (Wahyuni, 2011). Microorganisms that help ferment organic matter to form biogas are known as methanogenic bacteria. These bacteria function to decompose organic matter and produce methane gas under anaerobic conditions. Generally, methanogenic bacteria occur naturally in the contents of the rumen of livestock and human feces. Apart from being contained in feces, methanogenic bacteria can also be in the form of liquid methanogenic bacteria and solid methanogenic bacteria which are added to organic matter. The addition of these bacteria aims to accelerate the process of overhauling and forming biogas (Wahyuni, 2011).

The kinetics of biogas production follows the Gompertz equation model which is a mathematical model for time series observations, namely growth is slowest at the beginning and end of the observation time period (Sarlinda et al., 2018). This equation is used when the bacteria experience a lag phase or adjustment time to reactor conditions before finally producing methane gas. In the biogas production process, it is suspected that there will be a lag phase (adjustment phase) at the beginning of the start-up time because there is a difference in composition between the enrichment medium and the conditions in the reactor with the assumption that the biogas production rate in the batch biodigester is proportional to the specific growth rate of methanogenic microorganisms in the biogas production process in the biodigester (Sarlinda et al., 2018).

This research is very important to study the process of biogas production using sawdust and chicken manure as a starter with variations in chemical pretreatment, %TS, and C/N ratio. Through these various variables will be determined the optimum conditions that can produce optimum biogas production.

2. Materials and Methods

This research was carried out at the Chemical Engineering Waste Management Laboratory, Diponegoro University Faculty of Engineering and Diponegoro University UPT Laboratory. The research was carried out with reference to the process of anaerobic digestion in various kinds of chemical pretreatment (NaOH or HCl) and nutrients using batch feed intake. The sample used in this study was sawdust mixed with chicken manure to produce biogas.

2.1 Research Materials

The materials used in this study were sawdust substrate obtained from sawdust solid waste collection in Semarang at the Furniture Store "Ligna Furniture" from pine wood. For the inoculum, microbes derived from chicken manure were used, obtained from the Faculty of Agriculture and Animal Husbandry, Diponegoro University, Semarang. Then the reagents that will be used in this study are NaOH p.a, HCl 37% p.a, Urea $[CO(NH_2)_2]$ p.a, distilled water.

2.2 Research Tools

The equipment used in this study is presented in Figure 1. The digester as the reactor used was a modified 2 liter jerry can equipped with a hose to drain the biogas and a clamp as a valve. In addition, there is a basin and measuring cup that is used to measure the biogas produced (water displacement method).

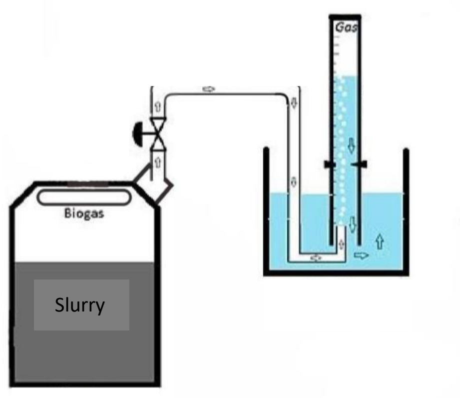

Figure 1. Series of research tools

2.3 Research Procedures

The work steps of this research include three stages, including:

a) Preparation Stage

Prepare and design tools according to the research variables. Then weigh the sawdust waste according to the variables and then do the pretreatment on the sawdust.

Physical pretreatment

At this stage, physical pretreatment is carried out by size reduction of sawdust which is still large and irregular in size to become smaller with the same size.

Chemical pretreatment

As an independent variable, 0.1 N NaOH or 0.1 N HCl was added to sawdust waste for delignification at a constant temperature of 90℃ for 1 hour accompanied by 200 rpm stirring. Sawdust waste that has gone through chemical pretreatment, adjusted the pH to neutral and then dried again in the oven at 100-120℃ for one night.

b) Operational Stage

The substrate (sawdust waste) that has undergone physical and chemical pretreatment is then mixed with chicken manure according to the predetermined C/N ratio of sawdust and chicken manure, and added urea according to the variables up to a predetermined volume and water with a maximum volume in jerrycans as much as 1000 mL (can be seen in Table 1).

Samples that are ready can be put into jerry cans, closed tightly to obtain anaerobic conditions and ready to operate. The fermentation process begins after the mixture is homogeneous. During the processing process, the volume of biogas produced was observed for 60 days every 2 days.

The volume of biogas is calculated by flowing the gas into a measuring cup filled with water by utilizing the properties of the gas, namely pressing in all directions from the jerry can (Boyle's law), so that when the reactor valve is opened, the gas moves directly into the measuring cup to observe the difference in volume.

Table 1. Research Variable

Run	TS	Delignification	C/N Ratio
1	10	NaOH	20
2	10	NaOH	30
3	10	HCl	20
4	10	HCl	30
5	25	NaOH	20
6	25	NaOH	30
7	25	HCl	20
8	25	HCl	30

c) Data Analysis Phase

Biogas volume data was analysed in the form of a graph of the relationship between biogas volume and time. Data analysis was carried out graphically accompanied by a theory of phenomena that occur due to the influence of chemical pretreatment, %TS, as well as a comparison of the C/N ratio through the addition of different urea for each variable to the results obtained on the graph of the research results. To determine the biogas production rate, the research data were statistically analysed using a non-linear regression test using SciLab 5.5.2 software and Microsoft Excel.

3. Results and Discussion

3.1 Effect of Chemical Pretreatment on Biogas Production

In this study the chemical pretreatment used for the delignification process of sawdust substrates was alkaline pretreatment using 0.1 N NaOH and acid using 0.1 N 37% HCl. Both of these pretreatments have their respective advantages and disadvantages. In the study, the substrate used was sawdust. Sawdust is a type of lignocellulosic biomass. Lignocellulosic biomass generally consists of three types of polymers: cellulose, hemicellulose, and lignin. The carbohydrate components (cellulose and hemicellulose) can be fermented after hydrolysis, which makes lignocellulosic biomass a suitable feedstock for bioenergy production. However, the inherent characteristics of native lignocellulosic biomass, such as structural and chemical properties, make it resistant to biodegradation by enzymes and microbes. Lignin is a major barrier to the utilization of lignocellulosic biomass in bioconversion processes. Therefore pretreatment aims to increase the ease of interaction of biomass against enzymes and microbes (Zheng et al., 2014).

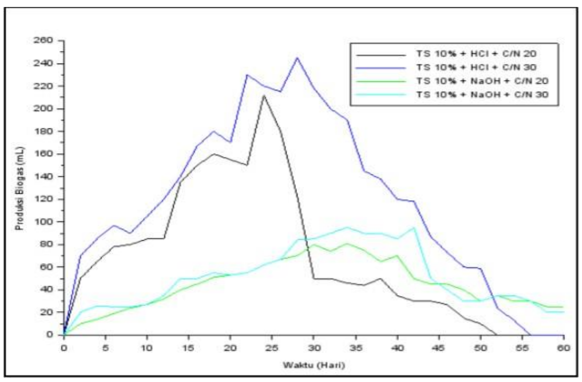

Figure 2. Effect of chemical pretreatment at 10% TS with a C/N ratio of 20 & 30 on biogas production

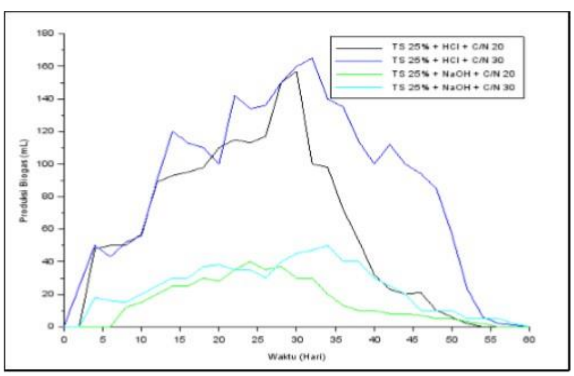

Figure 3. Effect of chemical pretreatment at 25% TS with a C/N ratio of 20 & 30 on biogas production

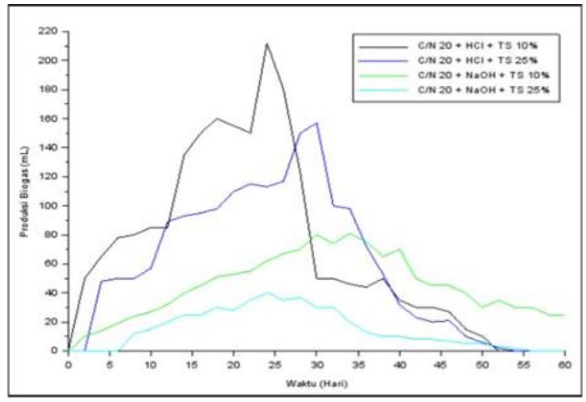

Figure 4. Effect of chemical pretreatment on the ratio C/N 20 to %TS 10 & 25 on biogas production

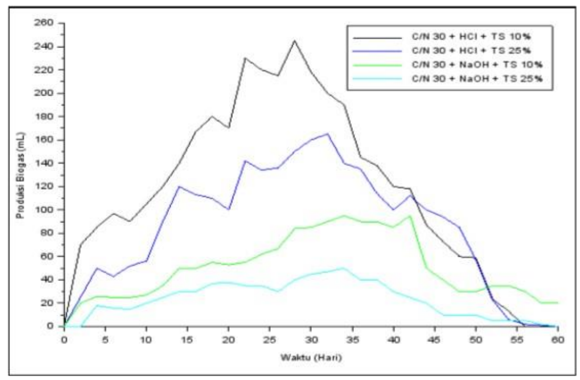

Figure 5. Effect of chemical pretreatment on the ratio C/N 30 to %TS 10 & 25 on biogas production

In the HCl pretreatment, the log phase occurred from day 8 to 32 with the largest production of 245 mL (± 28th day). Whereas in the NaOH pretreatment the log phase occurred from day 16 to 36 with the largest production of 95 mL (± 36th day). Furthermore, the increase in biogas production has begun to approach a constant state because the bacteria have entered the stationary phase and the nutrient content in the fermenter has decreased. According to Ihsan, et al (2013), that the decrease in biogas production occurs due to the decomposition process of the material (substrate) starting to run out or decrease and is converted into other products by enzymes produced by methanogenic bacteria and other bacteria. In addition, methanogenic bacteria also experience a death phase where fewer and fewer bacteria survive to produce biogas.

Biogas production produced by the two samples fluctuated but had the same phenomenon, namely biogas production increased until the optimum time and then decreased gradually until the last day of fermentation. Viewed from the overall biogas production, samples with HCl pretreatment produced more biogas and more biogas than samples with NaOH pretreatment. This is because in the delignification process using HCl, more cellulose is converted compared to delignification using NaOH, because the HCl pretreatment not only decomposes lignin in the raw material but also converts hemicellulose into cellulose so that more and more cellulose is formed. In addition, the use of acidic reagents does not cause inhibitors, such as alkaline pretreatment, which can interfere with the anaerobic digestion process later. Judging from the graph, the highest production of biogas occurs in the HCl pretreatment variable + C/N ratio 30 + 10% TS.

3.2 Effect of C/N Ratio on Biogas Production

In this study, the C/N ratio used as a variable was a C/N ratio of 20 and a C/N ratio of 30. Adjustment of the C/N ratio in slurry was carried out by adding urea. At a C/N ratio of 20 (%TS 10 & 25) 4.73 gr & 11.83 gr were added. Meanwhile, at a C/N ratio of 30 (%TS 10 & 25) 0.29 gr & 0.74 gr were added. One of the factors that affect biogas production is the ratio of organic carbon to nitrogen (C/N ratio). The C/N ratio of organic matter is the ratio between the amounts of elemental carbon (C) to the amount of elemental nitrogen (N) present in an organic matter. Microorganisms need carbon and nitrogen for their life activities. The optimum C/N ratio for biogas production is around 25-30 (Saputra, Triatmojo, & Pertiwiningrum, 2010). If the C/N ratio is too high, the biological activity of microorganisms will be reduced. This can lead to low biogas production and methane content in it because the methanogenesis process is not perfect (Ratnaningsih, Widyatmoko, & Yananto, 2009).

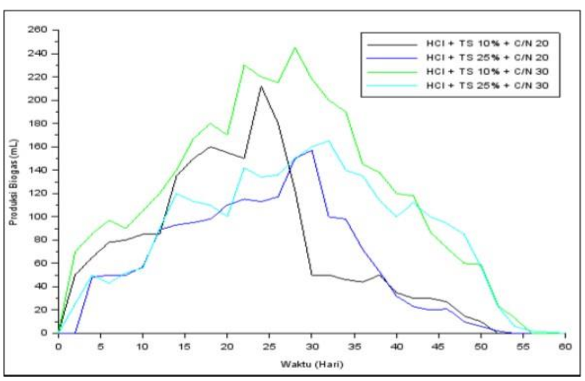

Figure 6. Effect of C/N ratio 20 & 30 on HCl pretreatment with %TS 10 & 25 on biogas production

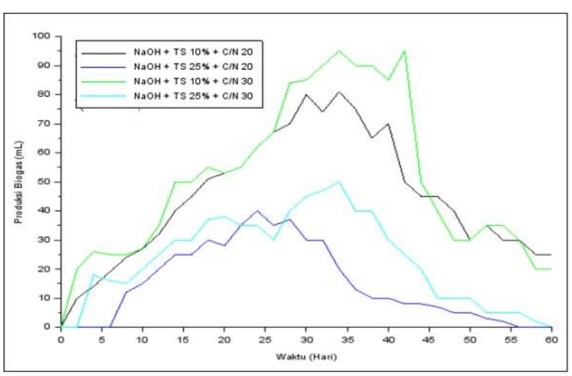

Figure 7. Effect of C/N ratio 20 & 30 on NaOH pretreatment with %TS 10 & 25 on biogas production

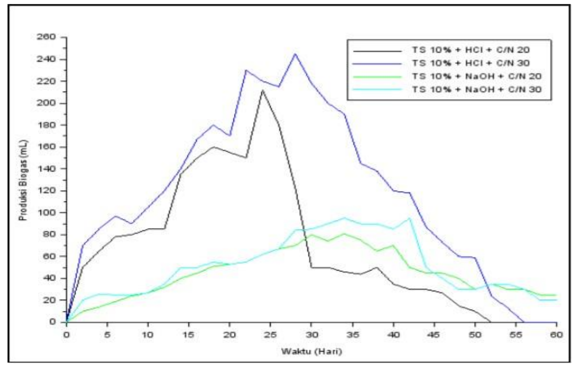

Figure 8. Effect of C/N ratio 20 & 30 on %TS 10 with HCl/NaOH pretreatment for biogas production

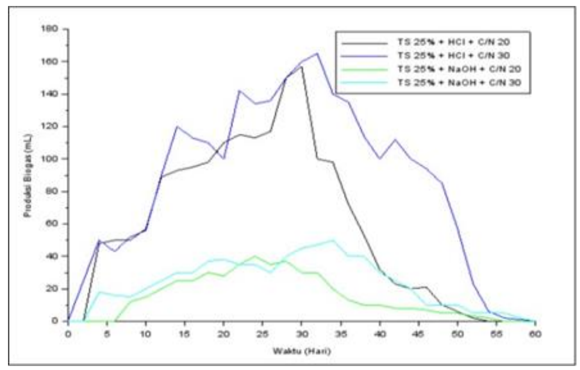

Figure 9. Effect of C/N ratio 20 & 30 on %TS 25 with HCl/NaOH pretreatment for biogas production

Meanwhile, if the C/N ratio is too low, excess nitrogen that is not used by microorganisms cannot be assimilated and will be lost through volatization as ammonia or denitrification (Purnomo et al., 2019). From Figure 6 to Figure 9 shows that the C/N ratio 20 & 30 with chemical pretreatment NaOH / HCl and the %TS variable (10 & 25) both experienced an increase and decrease in biogas production at certain times. The increase in biogas production with increasing fermentation time is due to the fact that after experiencing an adaptation phase, bacteria will then experience a growth process (log phase). At this stage of growth, bacteria need a lot of nutrients which will then be converted into biogas. In addition, sawdust waste is difficult to biodegrade. Furthermore, the increase in biogas production has begun to approach a constant state because the bacteria have entered the stationary phase and the nutrient content in the fermenter has decreased. According to Ihsan, Bahri, & Musafira (2013), that the decrease in biogas production occurs due to the decomposition process of the material (substrate) starting to run out or decrease and is converted into other products by enzymes produced by methanogenic bacteria and other bacteria. In addition, methanogenic bacteria also experience a death phase where fewer and fewer bacteria survive to produce biogas. In samples with a C/N ratio of 20, the average death phase began to occur on the 34th day. Whereas in samples with a

C/N ratio of 30, the average death phase began to occur on the 40th day.

Biogas production produced by the two samples fluctuated but had the same phenomenon, namely biogas production increased until the optimum time and then decreased gradually until the last day of fermentation. Viewed from the overall biogas production, samples with a C/N ratio of 30 produced more biogas than samples with a C/N ratio of 20. This was due to the possibility that at a C/N ratio of 20, the amount of nitrogen could not be assimilated which would be lost through volatilization as (denitrified) ammonia. This ammonia will be toxic to bacteria, causing the bacteria to die and their death phase is faster than usual. The C/N ratio of 30 is the best ratio because the amount of nitrogen is not too little or too much which is a source of energy for methanogenic bacteria so they don't enter the death phase too quickly and the bacteria produce biogas production longer. Judging from the graph, the highest production of biogas occurs in the C/N ratio variable 30 + HCl pretreatment + 10% TS.

3.3 Effect of L-AD and SS-AD Methods on Biogas Production

In this study, two methods were used, namely L-AD with 10% TS and SS-AD with 25% TS. In the L-AD method (10% TS), the composition of sawdust and chicken manure in a jerry can is 142.45 gr and 243.09 mL. While for the SS-AD method (TS 25%) the composition of sawdust and chicken manure in a jerry can is 356.13 gr and 607.74 mL.

Anaerobic digestion processes are classified into two based on total solid content (TS), namely liquid anaerobic digestion (L-AD) and solid-state anaerobic digestion (SS-AD) (Natalyn et al., 2017). Liquid anaerobic digestion (L-AD) is used with a total solid content of <0.5-15%, while materials with a total solid content of >15% use a solid-state anaerobic digestion (SS-AD) process. Biogas production using lignocellulosic biomass using both the L-AD and SS-AD methods must pay attention to the total solid content (TS) concentration because it affects the process performance and the amount of biogas produced. Higher TS content can reduce biogas production.

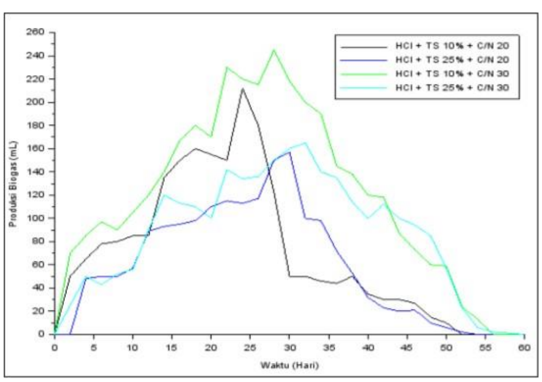

Figure 10. Effect of 10% & 25% TS in HCl pretreatment with a C/N ratio of 20 & 30 on biogas production

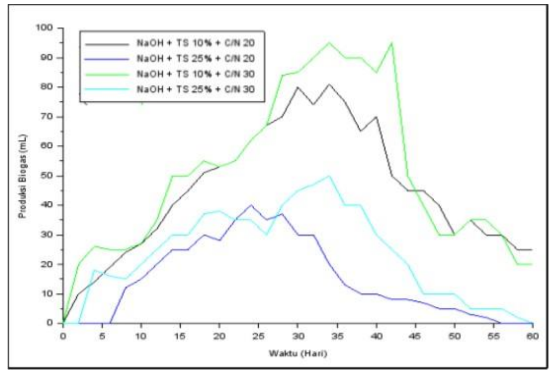

Figure 11. Effect of 10% & 25% TS in NaOH pretreatment with a C/N ratio of 20 & 30 on biogas production

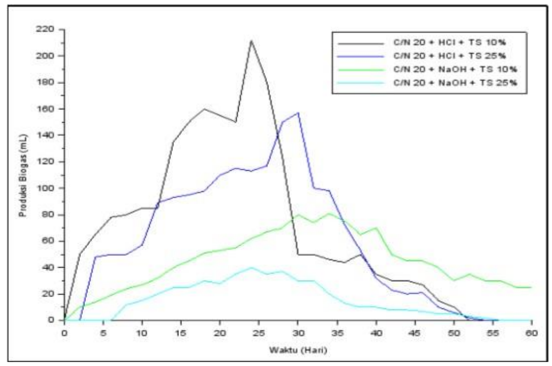

Figure 12. Effect of 10% & 25% TS at C/N ratio 20 with HCl/NaOH pretreatment on biogas production

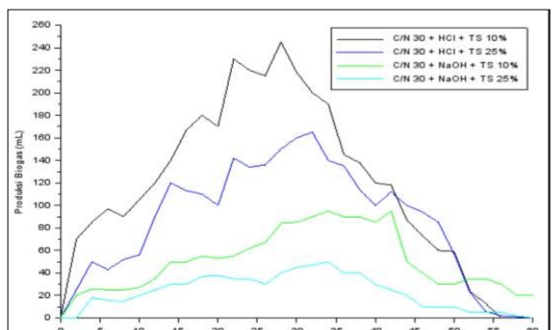

Figure 13. Effect of 10% & 25% TS at C/N ratio 30 with HCl/NaOH pretreatment on biogas production

TS content greater than 30% will reduce biogas production by around 17%. According to Natalyn et al (2017), a higher TS content has a minimal effect on TS efficiency and a decrease in biogas production. From Figure 10 to Figure 13 shows that at 10% and 25% TS with variable C/N ratios 20 & 30 and chemical pretreatment of NaOH / HCl both experienced an increase and decrease in biogas production at certain times. The increase in biogas production with increasing fermentation time is due to the fact that after experiencing an adaptation phase, bacteria will then experience a growth process (log phase). At this stage of growth, bacteria need a lot of nutrients which will then be converted into biogas. In addition, sawdust waste is difficult to biodegrade. According to Ihsan, Bahri, & Musafira (2013), that materials with low water content will degrade longer than materials with high water content. To accelerate the degradation of materials, it is necessary to add water to materials with low water content or materials with high water content do not need to add water. Furthermore, for samples with 10% TS, the average stationary phase occurred during the 8th to 12th day of fermentation and in samples with 25% TS during the 14th to 18th day of fermentation, the increase in biogas production has begun to approach the state constant and the nutrient content in the fermenter has reduced. According to Ihsan, Bahri, & Musafira (2013), that the decrease in biogas production occurs due to the decomposition process of the material (substrate) starting to run out or decrease and is converted into other products by enzymes produced by methanogenic bacteria and other bacteria. In addition, methanogenic bacteria also experience a death phase where fewer and fewer bacteria survive to produce biogas.

Biogas production produced by the two samples fluctuated but had the same phenomenon, namely biogas production increased until the optimum time and then decreased gradually until the last day of fermentation. In terms of overall biogas production, samples with 10% TS produced biogas faster and produced more biogas than samples with 25% TS. This is because sawdust with a low water content will degrade longer than materials with a high water content, therefore the liquid state (L-AD) method is very suitable for sawdust with a low water content because with this method the addition of water is much more than solid state method (SS-AD). In addition, according to Natalyn et al (2017) states that too high a TS content can inhibit the activity of methanogenic bacteria and reduce biogas production. The more %TS contained, the easier it is to decrease the pH and vice versa. The excess of substrate fed into the bioreactor causes acidogen and acetogen bacteria to become more active and grow faster, causing an imbalance between acidogenesis and methanogenesis. Materials that contain small TS decompose more quickly making methanogenic bacteria work optimally in producing biogas due to a small decrease in pH (Natalyn et al., 2017). Judging from the graph, the highest production of biogas occurs in the variable TS 10% + C/N ratio 30 + HCl pretreatment.

3.4 Assessment of Biogas Production Kinetics

Kinetic studies are needed as a basis for understanding every fermentation process. The kinetics of microbial growth describes the speed of cell (biomass) production and the factors that influence its speed. Growth measurements can be observed from various parameters where these parameters are obtained with the help of graphs and derived with mathematical equations. A low k value indicates slow growth of microorganisms. According to Saputro (2017), the k value is an indicator of the level of biodegradability of the anaerobic fermentation process.

The Gompertz equation is used when the bacteria experience a lag phase or adjustment time to the reactor conditions before finally producing methane gas. In this study it is suspected that there will be a lag phase (adjustment phase) at the start-up time because there is a difference in composition between the enrichment medium and the conditions in the reactor with the assumption that the biogas production rate in the batch biodigester is proportional to the specific growth rate of methanogenic microorganisms in the biodigester. (Sarlinda, Sarto, & Hidayat, 2018).

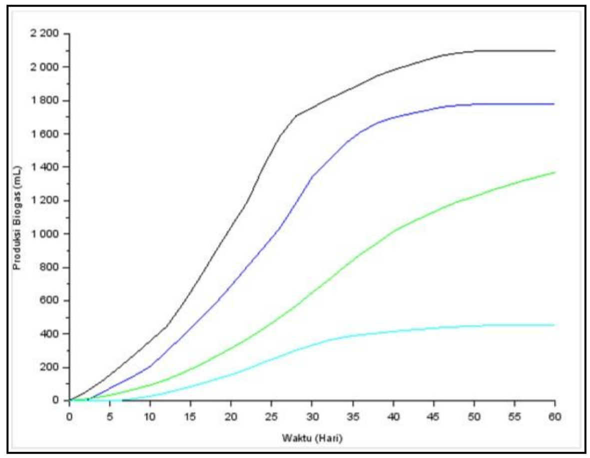

Figure 14. Effect of various variables %TS, C/N ratio, and chemical pretreatment on the kinetics of biogas production

Table 2. Kinetic Constants of Various Variables on Biogas Production

Variabel			A	U	λ
C/N 20	TS 10%	HCl	2148.48	83.78	6.687
		NaOH	1575.39	35.98	11.538
	TS 25%	HCl	1841.55	40.85	11.399
		NaOH	465.02	18.75	11.229
C/N 30	TS 10%	HCl	3891.09	110.88	8.174
		NaOH	2963.62	75.61	9.736
	TS 25%	HCl	1875.59	67.04	9.009
		NaOH	787.75	21.67	9.549

*)A = mL/grTS.day ; U = mL/grTS/day ; λ = day

As seen from Table 2, it shows the effect of various C/N ratio variables, %TS, and chemical pretreatment on the values of A, U, and λ. Sawdust delignified using HCl resulted in a higher rate of biogas production compared to delignification using NaOH at the same concentration of 0.1 N. This was because the acid pretreatment not only decomposed lignin in the raw material but also converted hemicellulose to cellulose so that cellulose formed will be more and more. Fermentation of materials using a C/N ratio of 30 results in a higher rate of biogas production than fermentation of materials using a C/N ratio of 20 because the C/N ratio of 30 is the best ratio where the amount of nitrogen is not too little or too much which is a source of energy for methanogenic bacteria so that the bacteria do not enter the death phase too quickly and the bacteria produce biogas production longer. Fermentation using the L-AD method produces a higher rate of biogas production compared to fermentation using the SS-AD method because sawdust with a low water content will degrade longer than materials with a high water content, with this the liquid state (L-AD) method very suitable for sawdust with low water content because with this method the addition of water is much more than the solid state method (SS-AD).

From Figure 14 and Table 2 it can be concluded that the results with the highest biogas yield were HCl + C/N 30 + 10% TS with maximum biogas production (A) of 3891.091 mL/grTs.day; biogas production rate (U) 110.884 mL/grTs.day ; and minimal formation of biogas (λ) at 8.174 days.

4. Conclusion

From the results of the study it can be concluded the following things: 1. Chemical pretreatment using acid produces a larger biogas product because acid pretreatment not only decomposes lignin in the raw material but also converts hemicellulose to cellulose so that more cellulose is formed. 2. A C/N ratio of 30 produces more biogas products because the optimum C/N ratio for biogas production is around 25-30. If the C/N ratio is too high, the biological activity of microorganisms will be reduced. Meanwhile, if the C/N ratio is too low, excess nitrogen that is not used by microorganisms cannot be assimilated and will be lost through volatization as ammonia or denitrification. 3. The liquid state method (L-AD) produces more biogas than the solid state method (SS-AD) because the substrate used contains a small amount of water. So the L-AD method is more profitable because the cumulative biogas yield per TS will be higher if the amount of solids is small. 4. From the analysis of experimental data, it was found that the variable HCl pretreatment with a C/N ratio of 30 and 10% TS produced the most optimum kinetic rate, namely the maximum biogas production (A) 3891.091 mL/grTs.day ; biogas production rate (U) 110.884 mL/grTs.day ; and minimal formation of biogas (λ) at 8.174 days.

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