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Biogas Production from Solid Jamu Waste Production Traditional with Anaerobic Process Liquid State – Anaerobic Digestion (LS - AD) Method

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Abstract - *Biogas is a flammable gas produced from the fermentation process of organic materials by anaerobic bacteria. The principle of making biogas is the anaerobic decomposition of organic matter (closed from free air) to produce gas, mostly methane (CH4) and carbon dioxide (CO2). One source of organic material that can be used as raw material for making biogas is the waste contents of the beef rumen. The anaerobic decomposition process is assisted by a number of microorganisms, especially methane-producing bacteria. The first generation of biogas is biogas produced by food derivatives and the process is still conventional. One of the agricultural wastes that can be developed into biogas is jamu waste. Jamu dregs contain high crude fiber, which is 39.72% of the dry weight. Where crude fiber is thought to help in the fermentation process. This research will examine the effect of time on biogas production with the composition of the raw material for jamu waste, the effect of pre-treatment of C/N ratio on biogas production and the effect of Total Solid Substrate on biogas production. Biogas production is carried out through hydrolysis, acidogenesis and methanogenesis stages. The total solid ratio are set in Liquid State condition with 3, 7, 11 and 15% variant of total solid content and the pretreatment of the nutrient ratio of the substrate C/N 20, 22, 24 and 26. The biogas formation process was carried out for 2 months, with a quantitative test response in the form of biogas volume and CODMn removal per 2 days.*

Keywords *– Biogas, total solid, jamu waste, cow rumen, C/N ratio*

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1. Introduction

Over the past few decades, the world has relied heavily on fossil fuels (for example, oil, coal and natural gas) as the main energy source, the fuel is expected to run out in 200 years. In addition, large quantities of the house gas carbon dioxide (CO_2), a survivor of fossil fuels, cause serious environmental problems including global warming and climate change. For example, 136 billion tonnes of CO_2 were calculated for the atmosphere in 2018 caused by the burning of fossil fuels (Le Quré et al., 2018). Indonesia is a developing country with significant economic growth which requires sufficient energy supply for further national development. However, current domestic energy production is unable to meet domestic demand, which has resulted in increased import demand. population Based on nearly 270 million inhabitants (with an annual growth rate of 1.1-1.2% in recent years) (Badan Pusat Statistik, 2019), it is expected to grow to more than 320 million by 2050 (WPP, 2019).

Therefore, exploring new, reliable, renewable and sustainable energy sources is the main effort to overcome the energy shortage crisis around the world. Global interest in renewables has increased rapidly in recent decades due to climate change, the desire for energy independence from major oil and gas producers, and the significant instability of the cost of fossil resources. A renewable energy transition is needed to reduce the depletion of fossil fuels and dramatically reduce the global carbon footprint. The level of use of fossil fuels greatly exceeds their filling and therefore alternative fuels such as bioethanol, biodiesel, biogasolin, and biogas are needed (Vasantha et al., 2021). Energy production from biomass can reduce greenhouse gas (GHG) emissions, mitigate climate change, promote environmental sustainability, and improve human health and well-being (Kang et al., 2021). It is estimated that the total global biomass production is 150 billion metric tons per year, but most of the biomass ends up in waste streams, including food waste, straw, stems, horticultural residues and livestock manure. Indonesia has committed to varying the range of energy sources by 2025 as stipulated in the Presidential Regulation of the Republic of Indonesia No. May 2006. The developed renewable energy segment covers 17% of the energy generated including 5% biofuels, 5% geothermal energy, 5% biomass, nuclear power, hydro and solar energy and 2% liquefied coal (Roubik and Mazancova, 2020).

The energy embedded in biomass can be recovered through anaerobic digestion (AD), a powerful and widely applied bioprocess that converts carbon into biogas, an important biofuel with methane (CH_4) as the main component. It is estimated that at least 25% of all bioenergy is the main component. It is estimated that at least 25% of all bioenergy can come from biogas in the future (Lai et al., 2021). The main nutrient content for biogas filler is nitrogen, phosphorus and potassium. The nitrogen content in the material should be 1.45%, while phosphorus and potassium are 1.10% each. Manure is rich in organic matter and nutrients, and leaching of nutrients into water can cause eutrophication and large and odorous greenhouse gas (GHG) emissions (Zubair et al., 2020). One of the things that affect the production of methane gas (CH_4) in biogas is the relationship between the amount of Carbon (C) and Nitrogen (N) contained in organic matter expressed in terms of the C/N ratio. A good C/N ratio on the substrate is in the range of 25 – 30 (Zulkarnaen, 2018). If the C/N ratio is too high, it indicates that increasing the C/N of the biogas slurry can prevent N leaching, thereby increasing N fixation and denitrification. In addition, with an increase in C/N, soil microbial communities will have higher diversity and increase soil CO_2 emissions while reducing soil N_2O and CH_4 emissions, nitrogen will be consumed very quickly by methanogenic bacteria to meet protein needs and will no longer react with the remaining carbon. As a result, gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and collected in the form of NH_4OH (Yan, 2021).

One of the agricultural wastes that can be developed into biogas is herbal waste. Jamu is a national cultural heritage that has been used for generations. Indonesia has advantages in terms of developing herbal medicine with types of medicinal plants that can be used as herbal ingredients. the increase in the number of herbal consumers is not accompanied by the treatment of herbal waste. The rest is just thrown away. Only waste of kencur rice, tamarind turmeric, and chili puyang are used as chicken feed.

2. Materials and Methods

Material

The main ingredients are mashed traditional herbal waste from Wedang Ginger Spice Warung Mbah Jo Semarang, microbes from cow rumen (rumen RPH Semarang) and cow dung (FPP Undip Semarang) to test the C/N ratio. As well as auxiliary materials include NaOH, H_2SO_4, $CuSO_4.5H_2O$, anhydride Na_2SO_4, $K_2Cr_2O_7$, MO indicator, difinelamin indicator, H_3PO_4, HCl, $FeSO_4$, and Zn powder, obtained from the Chemical Store Indrasari Semarang.

Substrate Preparation

Prepare tools and design according to research variables. Take the jamu dregs and weigh each gram of total solid and put it in a container as much as the total number of variables (16 variables). Table 1 shows the variables and the treatment of each variable. At the stage of preparation of solid waste raw materials for traditional herbal medicine taken at Warung Wedang Jahe Rempah Mbah Jo Jl. Minister Supeno, Mugassari, Semarang in size reduction for 5 minutes using a blender and sieved. The sample after being in the blender was dried. Jamu pulp contains nutrients with organic C and N ingredients that have been mashed mixed with beef rumen as a source of methanogenic bacteria at a ratio of 2:1. The biodigester used has a total volume of 2.5 liters with a slurry volume of 60% of the total volume of the biodigester obtained from the Banyumanik Market, totaling 16 units. Mixture of herbal waste with cow dung added with distilled water until the volume reaches 60% of the total biodigester. The function of water is to change the sample phase (herbal waste) from the solid phase to the liquid phase. Adjust the pH to neutral using Acetic Acid and NaOH. The fermentation process begins. Record the volume of gas formed in the gas collector every two days for up to 60 days. Furthermore, the analysis of carbon and nitrogen levels on the substrate was carried out using the Walkley and Black (Carbon) and Kjeldahl (Nitrogen) methods.

Table 1 Sample variants used in this study

Variable	Operation Condition				C/N Ratio			
	Liquid State							
	3% gr TS/v	7% gr TS/v	11% gr TS/v	15% gr TS/v	20	22	24	26
1	√				√			
2	√					√		
3	√						√	
4	√							√
5		√			√			
6		√				√		
7		√					√	
8		√						√
9			√		√			
10			√			√		
11			√				√	
12			√					√
13				√	√			
14				√		√		
15				√			√	
16				√				√

Experimental Procedure

The pretreated substrate was mixed with cow rumen and cow dung according to the predetermined ratio of solid waste of jamu waste to rumen and dung. The prepared samples were placed in 2.5-L anaerobic digesters made from polyethylene bottles. To achieve anaerobic conditions, rubber plugs were used to tightly seal the reactors, which were equipped with valves for biogas measurement. The volume of the biogas produced was monitored every two days for 60 days. The biogas volume was calculated by passing the gas into a water-filled measuring glass utilizing Boyle law. The gas from the digester presses in all directions, and hence by opening the digester valve, the gas directly moves into the measuring glass and the volume difference is observed.

Kinetic Model of Biogas Production

The kinetics constant of biogas production rate (U), maximum biogas production (A), and minimum time for biogas formation (λ) were determined using non-linear regression techniques. The data obtained from this study were solved numerically by non-linear regression techniques using the Minitabs Program.

The kinetics of deep biogas production is studied by developing an equation that most closely approximates the basis for biogas production in a batch system. By assuming the biogas production rate in batch conditions is in accordance with the specific growth rate of methanogenic bacteria in the biodigester, the biogas production rate is predicted to follow several equations such as: the modified Gompertz equation (Sunarso et al., 2010), the first order kinetics of the reaction equation assuming a decrease in levels. COD in the slurry is proportional to biogas production (Zhang et al., 2018) and the logistic function assumes that methane production is proportional to the size of the microbial population and digestible substrate (Pramanik et al., 2019). This equation represents a mathematical model for time series observations, which takes into consideration the slowest microbial growth that occurs at the beginning and end of the observation period. The Gompertz equation takes the following general form (Siripatna et al, 2016).

$$Y = A \times exp\left\{-exp\left[\frac{U\,.\,e}{A}(\lambda - \mathrm{t}) + 1\right]\right\}$$

Y = Cumulative biogas production (ml/g TS) at time t (days)
A = Maximum biogas production (ml/g TS)
U = The maximum biogas production rate constant (ml/g TS.hari)
λ = Long lag phase (minimum time for biogas formation) (days)
t = Cumulative time for biogas production (days)
e = Euler number (e = 2.71828)

The first order kinetics takes the following general form (Donoso-Bravo et al., 2010).

$$\text{-rA}=\ln\frac{CA_0}{CA}=\text{k.t}$$

-rA = substrate reduction rate
CA = final COD rate (ppm)
CA0 = initial COD rate (ppm)
k = biogas production rate constant
t = time (day)

The Logistic equation takes the following general form (Donoso-Bravo et al, 2010).

$$V_{CH4}(t) = \frac{P_{max}}{1 + \exp\left[\frac{4R_{max}(\lambda - t)}{P_{max}} + 2\right]}$$

V_{CH4} = cumulative biogas production per unit time t day (mL/day)
Pmax = maximum biogas production that can be produced (mL)
Rmax = maximum biogas production rate (mL/day)
λ = Long lag phase (minimum time for biogas formation) (days)
t = Cumulative time for biogas production (days)

3. Results

The effectiveness of the total solid percentage (%TS: 3, 7, 11 and 15%) and ratio of carbon per nitrogen (C/N ratio: 20, 22, 24 and 26) of the slurry inside the biogas digester to biogas production from jamu waste are presented and discussed in this section.

Effects of Total Solid Percentage on Biogas Production

The effects of total solids percentage on the daily and cumulative biogas productions were assessed in various C/N ratios are shown in figure 1. From fig. 1 shows that the rate of biogas production is similar to the rate of microbial growth where there is lag phase, logarithmic phase, stationary phase and death phase. In the initial phase (lag phase), it shows that there has been no biogas production for the first few days, this is because at the beginning of biogas production, microbes are still adjusting to the new substrate/medium so that there is still no biogas production. Biogas production was slow at the beginning and end of the experimental observations. Biogas production is generally slow in the first few days of the experiment due to the lag phase of microbial growth in which methanogens (microbial communities) become the medium in the digester (Imologie et al., 2017). This lag phase is accompanied by a stationary phase where the microbial community is minimum and then exponential growth which will lead to biogas production reaching its maximum volume. Growth is visible, but living cells are preserved. The rate of biogas production in batch conditions mainly depends on the growth of methanogenic bacteria that produce methane (Nopharatana et al., 2007).

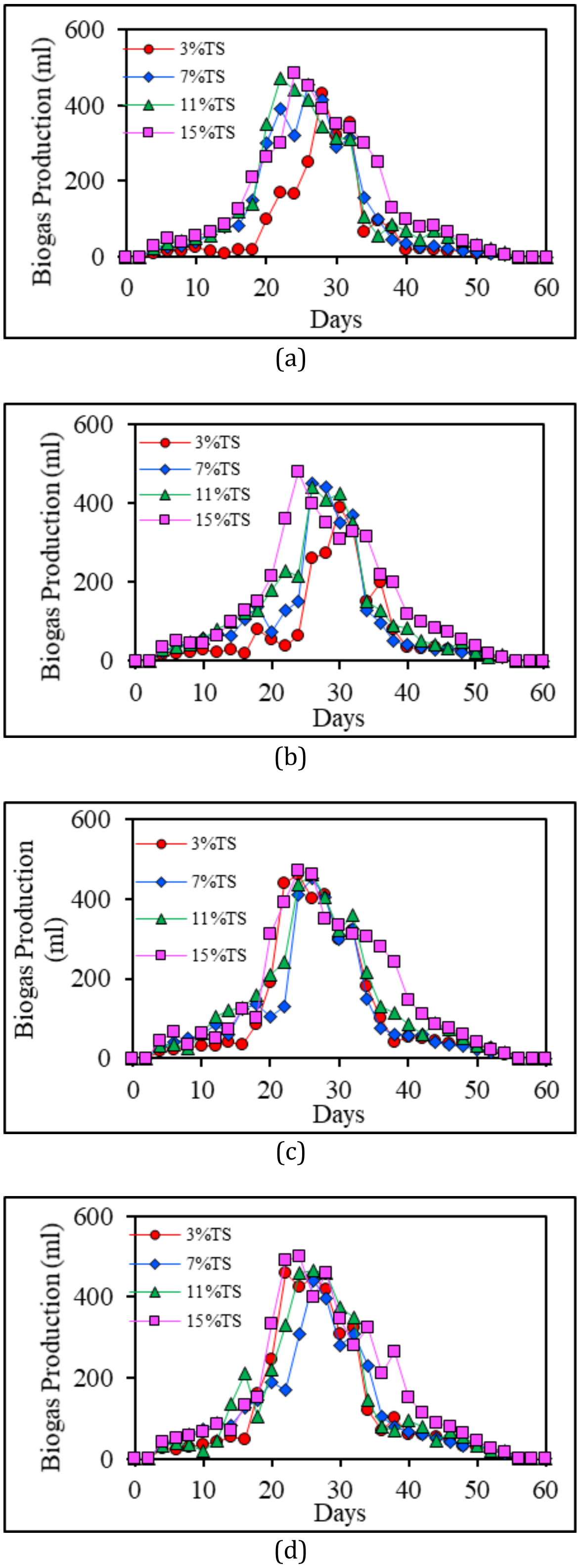


Figure 1 Daily biogas production of jamu waste with variation of total solid percentage (%TS) in C/N ratio of (a) 20, (b) 22, (c) 24 and (d) 26

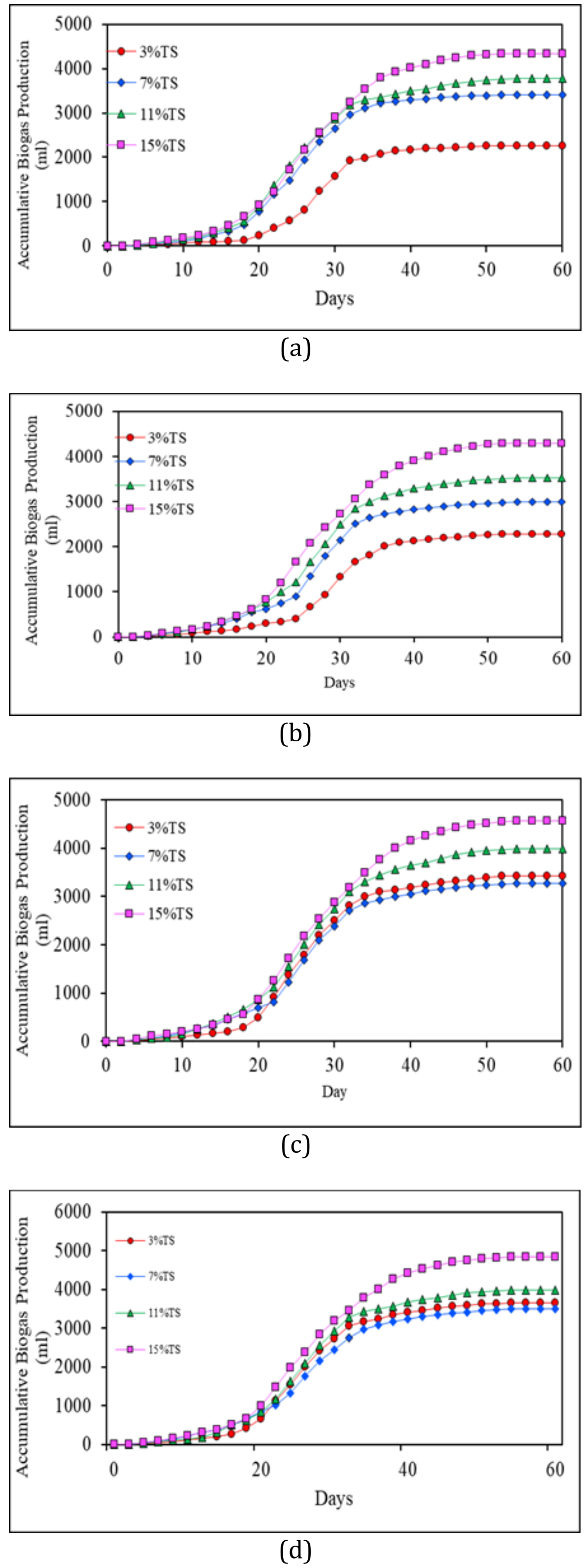


Figure 2 Total biogas production of jamu waste with variation of total solid percentage (%TS) in C/N ratio of (a) 20, (b) 22, (c) 24 and (d) 26.

In our study the microbes had reached the death phase on day 60 which was marked by the absence of biogas production. Fig. 1 (a) shows that the cumulative biogas volume obtained from 3%, 7%, 11% and 15% of total solid inside the biogas digester. The largest total volume of biogas produced from jamu waste with variation of total solids percentage obtained at the percentage of total solid 15%. This is because there is a possibility that at 15% TS, it contains enough water (liquid state conditions) which encourages hydrolysis reactions in the reciprocal interactions of microorganisms to break down complex organic materials into soluble monomers such as amino acids, fatty acids, simple sugars, and so on. glycerol. And also, the substrate content is large enough to form a large total biogas as well (Anukam et al., 2019). As for the reaction process based on the following reaction:

$$\text{VS} \xrightarrow{\text{Asidogen Mikroorganism}} \text{VFA} \xrightarrow{\text{Methanogen Mikroorganism}} CH_4 + CO_2$$

(Zuliyana et al., 2015)

In addition, the presence of sufficient water also dilutes the reaction system so that there is no surge in VFA which will act as a self-inhibitor against anaerobic microorganisms (Angelin & Fatimah, 2017).

Effects of Carbon per Nitrogen (C/N) Ratio on Biogas Production

The effects of C.N ratio on the daily and cumulative biogas productions were assessed in various %TS shown in figure 3. From fig. 3 shows that the rate of biogas production is similar to the rate of microbial growth where there is lag phase, logarithmic phase, stationary phase and death phase. In the initial phase (lag phase), it shows that there has been no biogas production for the first few days, this is because at the beginning of biogas production, microbes are still adjusting to the new substrate/medium so that there is still no biogas production. Biogas production was slow at the beginning and end of the experimental observations. Biogas production is generally slow in the first few days of the experiment due to the lag phase of microbial growth in which methanogens (microbial communities) become the medium in the digester (Imologie et al., 2017). This lag phase is accompanied by a stationary phase where the microbial community is minimum and then exponential growth which will lead to biogas production reaching its maximum volume. Growth is visible, but living cells are preserved. The rate of biogas production in batch conditions mainly depends on the growth of methanogenic bacteria that produce methane (Nopharatana et al., 2007). In our study the microbes had reached the death phase on day 60 which was marked by the absence of biogas production.

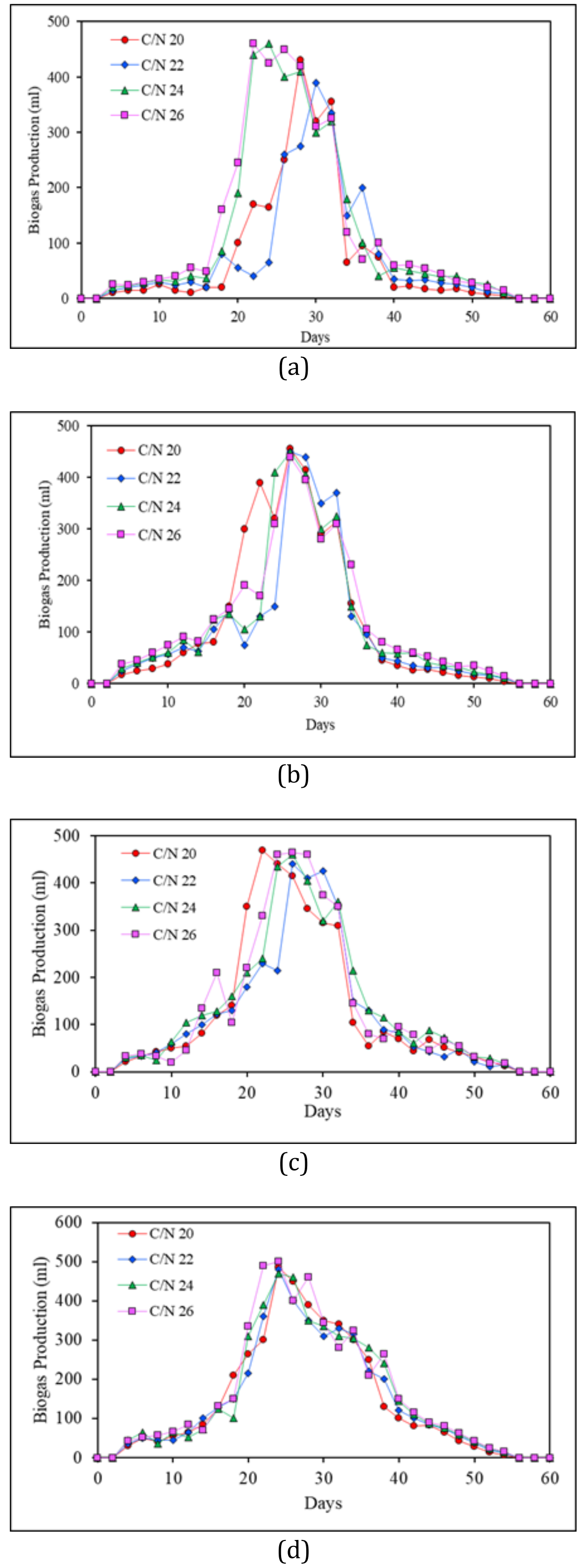
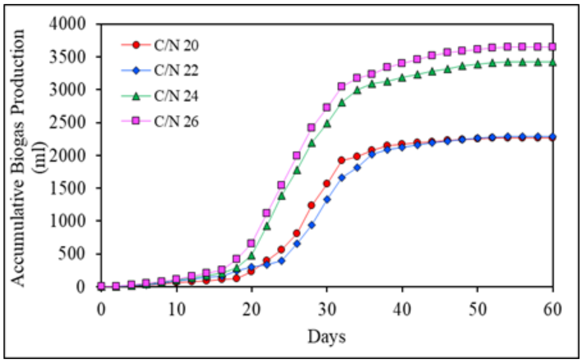
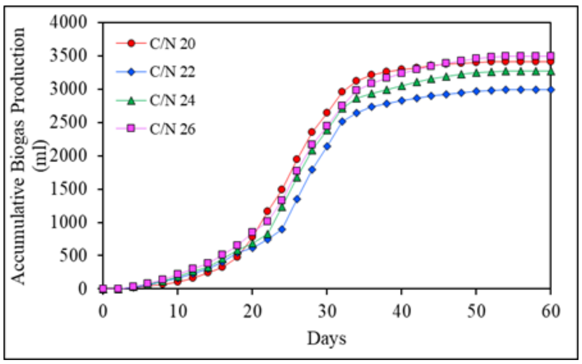


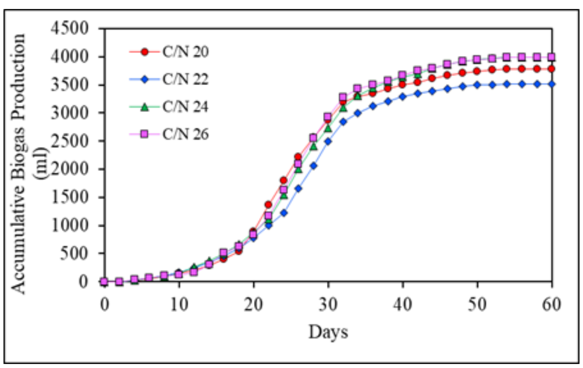
Figure 3 Daily biogas production of jamu waste with variation of carbon per nitrogen (C/N) ratio in total solid percentage (%TS) of (a) 3%, (b) 7%, (c) 11% and (d) 15%.



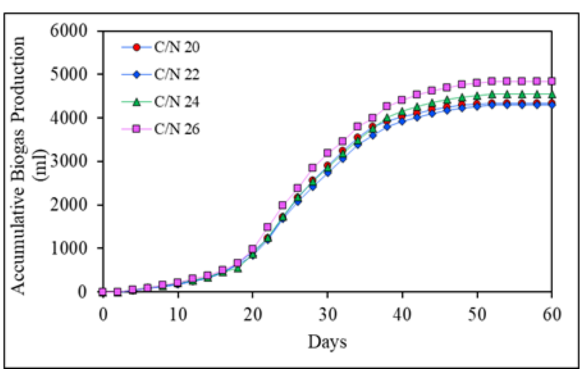
(a)



(b)



(c)



(d)

Figure 4 Total biogas production of jamu waste with variation of carbon per nitrogen (C/N) ratio in total solid percentage (%TS) of (a) 3%, (b) 7%, (c) 11% and (d) 15%.

Fig. 4 shows that the cumulative biogas volume obtained from 20, 22, 24 and 26 of carbon/nitrogen (C/N) ratio of the slurry inside the biogas digester. The largest total volume of biogas produced from jamu waste with variation of C/N ratios obtained at the ratio of 26. The C/N ratio serves as both food and nutrition for bacteria, so that the maximum growth of nutritional elements must be balanced. Destroying microorganisms can operate optimally if the C/N ratio is 20-30 (Kangle et al., 2012; Teghamar, 2013). If the value of the C/N ratio is too low, it causes an increase in ammonia production and will inhibit methane production and if it is too high, the decomposing bacteria will lack nitrogen which will be used for the metabolic processes of microorganisms (Teghammar, 2013). So that the smaller the C/N ratio, the amount of nitrogen cannot be assimilated which will be lost through volatilization as ammonia (denitrified). Ammonia is an important nutrient for microorganisms, but can be toxic to methanogenic microorganisms if present in high concentrations (Derilus, 2014). In line with that, the most optimum biogas production in this study was obtained at a C/N ratio of 26.

Kinetic Model of Biogas Production

Table 1 shows the kinetic data of the digested waste obtained using a non-linear regression method (Gompretz equation).

Table 1 The kinetic data of biogas production process obtained using the Gompretz equation*

Variable	A (ml/g TS)	U (ml/g TS.day)	λ (day)
1	2409.416	163.5365	20.215
2	2818.965	128.4050	19.973
3	3434.718	221.1594	17.722
4	3667.871	223.2329	16.829
5	3693.260	198.5731	15.957
6	3816.963	140.7005	15.555
7	3799.674	156.2143	15.079
8	4303.340	147.8286	13.884
9	3808.835	212.7975	15.387
10	4311.198	158.7498	14.973
11	4513.108	178.3978	14.700
12	4223.977	204.0006	15.462
13	4992.309	196.2781	15.102
14	4993.005	183.3764	14.969
15	5252.263	194.5818	15.195
16	5346.912	209.9773	14.761

* A: maximum biogas production, U: maximum biogas production rate constant, and λ: lag phase time.

Based on the Table 1. it is known that the highest biogas production rate is in the variable with total solids percentage of 15% and the C/N ratio of 26. This shows that the biogas production process in this variable runs fast. While the value of the lowest biogas production rate according to the Gompertz and logistic methods is a variable with total solids percentage of 3% and a ratio of C/N content of 22. The value of the production rate contant (U) is directly proportional to the maximum biogas production value produced (A). The greater the value of the production rate constant (U), the greater the value of the maximum biogas production (A). Thus, the total solids, water content and C/N ratio affect the course of the biogas production process, the speed at which biogas is formed is also influenced by the nutritional factors given to the substrate used as raw material because nutrients are toxic which can increase pH and can affect the activity of bacteria to break down. organic compounds into biogas (Ikrimah and Pramianshar, 2014).

Then Mao et al. (2015) in his study found that through the Gompertz kinetic equation the greater the C/N content of a sample, the longer the lag phase time. This is because the greater the ratio of C/N levels in a sample, the microbes will need more time to adapt. In addition, nitrogen sources are an important component for microbial development so that the smaller the ratio of C/N content, which means the larger the nitrogen source, the faster the lag phase.

Table 2. Two Way ANOVA results

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-value	P-Value
%TS	3	5779780	73.27%	5779780	1926593	21.42	0.000
C/N	3	1298782	16.47%	1298782	432927	4.81	0.029
Error	9	809500	10.26%	809500	89944		
Total	15	7888062	100.00%				

This is inversely proportional to the results obtained from this experiment where the greater the ratio of the C/N content of the sample, the faster the lag phase time is obtained. This is because in large quantities nitrogen is toxic, thus making the lag phase longer than it should be.

Two-way ANOVA results show in figure 2, that each of total solid percentage (%TS) and ratio of carbon per nitrogen (C/N) content variations gives a significant difference in biogas production (p-value is less than 0.05). These results shown that each of total solid percentage (%TS) and ratio of carbon per nitrogen (C/N) content affects the biogas production with. 73.27% contribution from total solids percentage variation and 16.47% contribution from ratio of carbon per nitrogen.

5. Conclusion

From this study of biogas production using solid waste production of traditional jamu, we can conclude that:

- The percentage of Total Solid in the liquid state Biodigester significantly affects biogas productivity. Based on statistical analysis, the most optimum percentage of total solid was 15% followed by 11%, 7% and 3%.
- The ratio of C/N content in the liquid state Biodigester significantly affects biogas productivity. Based on statistical analysis, the most optimum ratio of C/N content for biogas production is 26, followed by the ratio of C/N content with C/N ratio of 24, 22 and 20.
- The kinetics of the gas production rate using the Gompertz Equation is the largest in variable 16 with a liquid state fermentation condition (15% TS) and a C/N ratio of 26.

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