Chapter

Biogas Production from Water Hyacinth

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Abstract

The current existence of water hyacinth as a waterweed is very unsettling and detrimental, so various alternatives were made to utilize its existence. One of the alternatives is biogas fuel. Water hyacinth leaves can be used as biogas fuel because of its cellulose, nitrogen, essential nutrients, and high fermentation contents. Through this chapter, two kinds of methods used to test the optimization of biogas production from water hyacinth leaves will be explained, namely, the liquid anaerobic digestion (L-AD) and solid-state anaerobic digestion (SS-AD) methods using total solid (TS), food to microorganism (F/M), and carbon to nitrogen (C/N) parameters. The research was conducted by using biodigester in batch anaerobic operation at room temperature. Degradation process was done in 60 days. The results showed that the use of the L-AD method with TS 3.38% produced more biogas yields than using the SS-AD method. Based on the results of the research on the effect of the C/N ratio on biogas productivity using L-AD method, the optimum C/N ratio was 30. The optimum C/N ratio for biogas production from water hyacinth leaves by the SS-AD method was 32.09.

Keywords: biogas, water hyacinth, liquid anaerobic digestion (L-AD), solid-state anaerobic digestion (SS-AD), total solid (TS), carbon to nitrogen (C/N), food to microorganism (F/M)

1. Introduction

Recently, energy has become a basic need for modern society. The need of using energy was increased due to population and consumption growth and because the community used various kinds of equipment in supporting convenience in life [1]. The current global energy supply is highly dependent on fossil sources (crude oil, lignite, hard coal, natural gas). These are fossilized remains of dead plants and animals, which have been exposed to heat and pressure in the Earth's crust over hundreds of millions of years. For this reason, fossil fuels are nonrenewable resources in which reserves are being depleted much faster than the new ones being formed [2].

Indonesia as a tropical country has abundant renewable energy sources as alternative energy to replace fossil energy. One alternative energy is biogas. Biogas is the final gas product of anaerobic digestion/degradation (in an environment without oxygen) by methanogenic bacteria [1]. Biogas is very potential as the latest energy source because its methane (CH_4) content itself has a heating value of 50 MJ/kg. Methane (CH_4) has one carbon in each chain, which can produce combustion more environmentally friendly than that of the long carbon chain fuels. This matter is caused by the less amount of CO_2 produced during short carbon chain fuel combustion [3]. One of the main advantages of biogas production is the ability to transform waste material into a valuable resource, by using it as a substrate for AD [2].

Anaerobic digestion (AD) has been extensively used to convert organic waste streams from various sources, such as agricultural, industrial, and municipal solid waste, to biogas. The AD process can operate in both liquid and solid states in terms of total solid (TS) content. In general, the TS content of liquid AD (L-AD) systems ranges from 0.5 to 15%, while solid-state AD (SS-AD) systems usually operate at TS contents of higher than 15% [4].

Anaerobic digestion (AD) relies on efficient conversion of organic matter into a valuable product known as biogas, with methane (CH_4) as its main combustible constituent. The biogas can be used as energy for household cooking, lighting, heating, and other applications. The process is heavily dependent upon the mutual and syntrophic interaction of a consortium of microorganisms to break down the complex organic matter into soluble monomers such as amino acids, fatty acids, simple sugars, and glycerols. For AD process optimization, it is vital to understand these biological processes and their associated chemical reactions [5].

There are four basic stages involved in AD. These four basic stages make up the process of biogas production from various organic materials as it occurs in an anaerobic digester. These four stages are the hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The AD process is characterized by the decomposition of organic matter into methane, carbon dioxide, inorganic nutrients, and compost in an anaerobic environment [6].

Many different types of anaerobic digesters are available. These vary in configuration, retention time, pre- and posttreatment requirements, and operating temperature, among other things, depending upon the principal feedstocks being treated. During AD, the breakdown of organic compounds is achieved by a combination of many types of bacteria and archaea (microbes). The biomass added to the digester is broken down into sugars, amino acids, and fatty acids (hydrolysis), fermented to produce volatile fatty acids and alcohols (acidogenesis) followed by the conversion into hydrogen, carbon dioxide, and ammonia. In addition, methanogens produce biogas from acetic acid and hydrogen [7].

The addition of biostarter can maximize biogas production. The selection of a good starter is very important to speed up the process overhaul of organic matter. Rumen fluid can be used as a good biostarter because in it there are cellulolytic and methanogenic bacteria. Cellulolytic bacteria degrade an organic material to become a substrate of methanogenic bacteria [8]. The addition of rumen fluid can also shorten the time to reach peak production of methane gas compared to substrates that are not given rumen fluid [9].

2. Biogas production from water hyacinth

Water hyacinth (*Eichhornia crassipes*) is a water plant that grows in swamps, lakes, reservoirs, and rivers and that flows calmly. The leaves of the water hyacinth are bright green, have an ovate shape, and widen with a diameter of up to 15 cm [10]. The water hyacinth (*Eichhornia crassipes*) is generally considered as a waterweed, which has become a problem that damages the environment, the system irrigation, and agriculture [11]. Water hyacinth is a type of weed that grows very fast. The growth of water hyacinth can reach 1.9% per day with a height between 0.3 and 0.5 m. Its rapid growth is felt to be very detrimental because water hyacinth plants that covered the surface of the water will cause the oxygen content to decrease [12].

Water hyacinth has attracted attention to scientists to use it as a potential biomass because its rich in nitrogen, essential nutrients, and high fermentation contents [13].

In Indonesia, most of the major lakes are also facing environmental problems such as eutrophication, sedimentation, and a decline in surface area. Indonesia has determined that 15 lakes have become a national priority to be restored and preserved [14]. Behind its beauty, Rawa Pening Lake keeps a pile of concerns. The 2667 hectare natural reservoir located in Ambarawa, Bawen, Tuntang, and Banyubiru, Semarang Regency, is currently being staked out by sedimentation, not to mention the uncontrolled growth of water hyacinth that takes up lake land. The decline in water storage capacity due to the sedimentation process results in a decrease in reservoir function and effectiveness. Rawa Pening Lake has even been included in the list of 15 critical lakes in Indonesia [15].

Rawa Pening Lake has been facing an invasion of macrophytes indicated by a massive growth of water hyacinth that covers more than 40% of the lake surface [16]. Although the water hyacinth is often used, it does not reduced. Their growth is so fast causing water hyacinth plants become into waterweeds. Water hyacinth is being utilized as a biogas raw material because it has carbohydrate and cellulose contents. Cellulose will be hydrolyzed into glucose by bacteria which will produce methane gas as biogas [10]. An image of a massive growth of water hyacinth in Rawa Pening Lake, Indonesia, is shown in **Figure 1**.

Biogas contains methane, and it is the combustion of methane which constitutes the energy component of biogas [7]. It consists mainly of methane (CH_4) and carbon dioxide (CO_2) and is formed from the anaerobic bacterial decomposition of organic compounds, i.e., without oxygen. The gases formed are the waste products of the respiration of these decomposer microorganisms, and the composition of the gases depends on the substance that is being decomposed. If the material consists of mainly carbohydrates, such as glucose and other simple sugars and high molecular compounds (polymers) such as cellulose and hemicellulose, the methane production is low. However, if the fat content is high, the methane production is likewise high [17].

Figure 1.
A massive growth of water hyacinth in Rawa Pening Lake, Central Java, Indonesia.

Biogas may be used in many different ways:

1. Combusted directly in domestic stoves for cooking or used in gas lamps for lighting

2. After minor treatment, combusted in boilers to generate heat, internal or external combustion engines to produce electricity, combined heat and power (CHP) plants to produce both heat and electricity, and tri-generation systems to provide cooling via absorption chillers in addition to heat and electricity

3. Upgraded into biomethane to be used as vehicle fuel in gas-powered vehicles; to be used in place of natural gas in industrial, commercial, and domestic uses; or to be pumped into gas grids to substitute natural gas supplied to households and businesses [7].

There were a lot of researches about biogas production that used various parameters that effected to it. These were food to microorganism (F/M) ratio, carbon to nitrogen (C/N) ratio, and total solid (TS). In the production of biogas from anaerobic digestion, the value of the food to microorganism (F/M) ratio shows the ratio between the mass of food available in the substrate and the mass of microorganisms that act as decomposers. A food to microorganism (F/M) ratio that is too small can cause microbes to be not metabolized completely, and if the value of the F/M ratio is excessive, it results in an unbalanced metabolism [18].

In addition to the organic content of the substrate, the carbon to nitrogen (C/N) ratio was stated as an important factor for the biogas process. The C/N ratio should be in the range between 10 and 30 and, as an optimal ratio, between 25 and 30 for digesters operating at full potential. When the C/N ratio is low, there is a risk of ammonia obstruction, the process of methanogenesis being more sensitive. High ratios can lead to low methane yields equivalent to the lack of nitrogen available for cell growth [19].

According to Brown and Li (2013) in the production of biogas from biomass raw materials, lignocellulose is appropriate to be produced from using the SS-AD method because lignocellulosic biomass has a total solid concentration of >15% and has low moisture content. According to Malik (2006) water hyacinth contains 95% water and consists of networks that are hollow, and this is the reason why L-AD method is well applied to water hyacinth because of its TS content which is relatively low [20].

Some researches about biogas production of water hyacinth have been done by students of the Environmental Engineering Diponegoro University. The researches were about biogas production from water hyacinth using liquid anaerobic digestion (L-AD) and solid-state anaerobic digestion (SS-AD). The part that was used from water hyacinth was the leaves.

2.1 Measurement methods

2.1.1 Preliminary methods

Preliminary methods were conducted before doing the main researches to know about the contents of each component that will be used. Various parameters will be used in biogas researches.

2.1.1.1 Total solid

According to the American Public Health Association (APHA) standard method, the formula for total solid content can be seen in Eq. (1):

$$\left[\frac{W3 - W1}{(W2 - W1)}\right] \times 100\% \quad (1)$$

Description: $W1$, cup weight; $W2$, cup weight and sample weight; $W3$, cup weight and sample weight after being ovened.

2.1.1.2 Measuring C-organic content using the Walkley and Black method

The procedure carried out in this test was taken from several references, namely, Black (1965); Graham (1948); Page et al. (1982); Rayment et al. (1992) in Sulaeman et al. (2005) "Technical Guidelines for Soil, Plant, Water, and Chemical Chemical Analysis of Soil Research Institute Indonesian Ministry of Agriculture." With the following method of work, 0.500 g soil of size <0.5 mm was weighed and put in a 100 ml volumetric flask. 5 ml of $K_2Cr_2O_7$ 1 N was added and then mixed. 7.5 ml of concentrated H_2SO_4 was added, mixed, and let to sit for 30 min. Diluted with ion free water, the mixture was allowed to cool and squeeze. In the next day, absorbance of the clear solution was measured with a spectrophotometer at a wavelength of 561 nm. As a comparison standard, 0 and 250 ppm were made, by piping 0 and 5 ml of the 5000 ppm standard solution into a 100 ml volumetric flask with the same treatment as the working sample [21].

2.1.1.3 Measuring N-total levels using a spectrophotometer

In this test, the procedure was taken from several references, namely, Black, (1965); Page et al. (1982); Burt (2004); and Lisle et al. (1990) in Sulaeman et al. (2005) "Technical Guidelines for Soil, Plant Chemical Analysis, Water and Fertilizers, Indonesian Ministry of Agriculture Soil Research Institute." This test was divided into two stages: the destruction stage and the measurement stage [21].

2.1.2 Biogas measurement

Samples that had been researched in preliminary methods could be inserted into the reactor and mixed with other components that are related; then the reactor must be sealed in order to obtain anaerobic digestion. During the treatment process, the volume of biogas production was observed in an interval of 2 days throughout 60 days.

To find out the amount of biogas, place the reversed cylinder glass in the container that is filled with water (reversed cylinder glass must be filled with water). Place the plastic tube into the reversed cylinder glass. Record the initial volume from it. Open the clip that clipped the plastic tube (the clip's function was to avoid the oxygen entered into the digester). The biogas will go out through the plastic tube and will make the water volume to decrease. Record the final volume. Lastly, record the biogas volume by counting the water level difference. The digester is shown in **Figure 2**.

2.2 Liquid anaerobic digestion (L-AD) method

2.2.1 The effect of total solid (TS)

TS content of liquid anaerobic digestion (L-AD) systems ranges from 0.5 to 15% [4]. The research about "Biogas Production from Water Hyacinth (*Eichhornia crassipes*): The Effect of F/M Ratio" [22] was conducted to know about the effect of F/M ratio to biogas production from water hyacinth leaves using the liquid anaerobic digestion (L-AD) method. In biogas production anaerobically, the value of F/M shows a comparison between the amount of substrate that is contained in waste (medium)

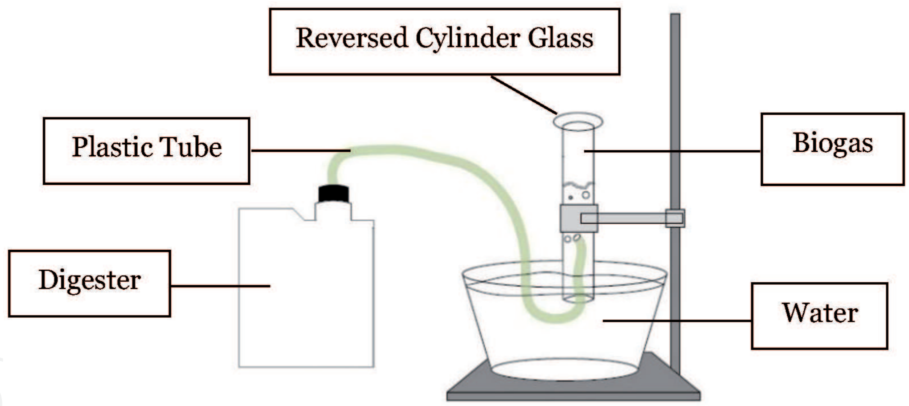

Figure 2.
Schematic diagram of series laboratory batch assessment of L-AD and SS-AD [23].

F/M ratio	Initial total solid (%)	Cow rumen fluid volume (ml)	Final total solid (%)
39.76	13.52	50	10.82
20.03	13.52	100	9.06
13.32	13.52	150	7.73
10.01	13.52	200	6.76

Table 1.
Initial and final total solid of water hyacinth leaves.

and the amount of microorganism used [18]. The variation of F/M ratio depends on the existence of rumen volume variation and total solid from each materials.

The main substrate used in the research [22] was water hyacinth leaves as much as 200 g. The initial total solid of water hyacinth leaves that has been calculated using (Eq. (1)) was 13.52. When it is combined with a different cow rumen fluid volume in each reactor, the total solid of water hyacinth leaves will be changed. To find out the F/M ratio, a comparison of the total solid of water hyacinth leaves with cow rumen fluid was multiplied by the weight and volume of each ingredient. The data is shown in **Table 1**.

After the research had been done, results show that the biogas production with F/M ratio of 10.01 and TS of 6.76% produced more biogas in the amount of 127.071 ml/g TS. **Figure 3** shows the graphic of cumulative biogas yield.

A research has also been conducted [20] using water hyacinth leaves as much as 200 g as the main substrate combined with water and rumen fluid. The combination is shown in **Table 2**.

In this study to get a low total solid content, rumen was added to the first variable, and water and rumen were added to the second variable. This is consistent with the research conducted by Astuti (2013) which states that the stuffing material must contain about 6–9% dry matter. This situation can be achieved by dilution [20]. From the graphic below, the final result of biogas production with a TS variable of 6.76% was 177.33 ml/g TS and for a TS variable of 3.38% was 369 ml/g TS. The graphic of cumulative biogas yield/TS is shown in **Figure 4**.

2.2.2 The effect of C/N ratio

In addition to total solid and F/M ratio, biogas production is also affected by carbon to nitrogen (C/N) ratio. Various C/N ratio researches have been done [23] by adding organic compound that contained high nitrogen such as urea.

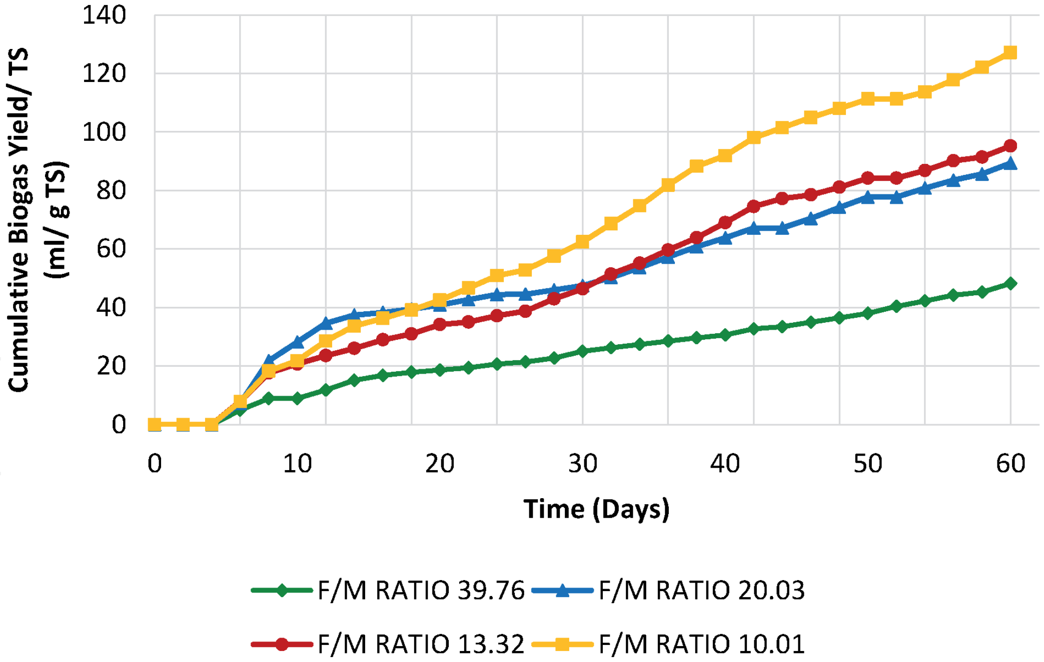

Figure 3.
Cumulative biogas yield per g TS based on F/M ratio.

Initial total solid (%)	Cow rumen fluid volume (ml)	Water volume (ml)	Final total solid (%)
13.52	150	—	6.76
13.52	150	300	3.38

Table 2.
Initial and final total solid of water hyacinth leaves.

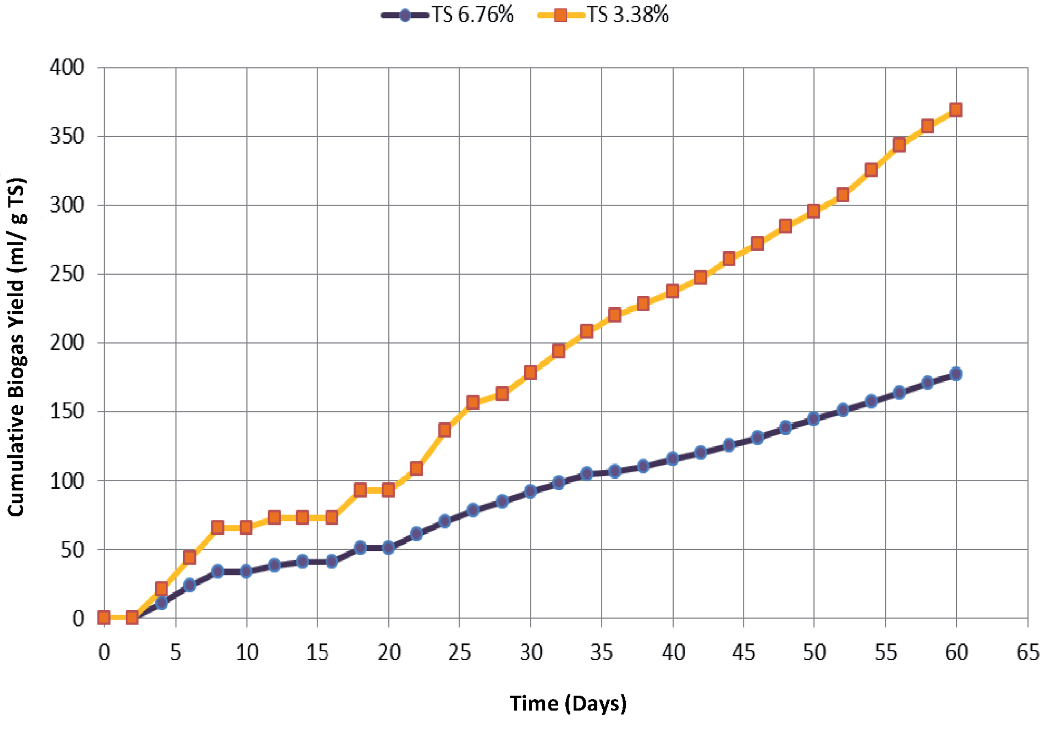

Figure 4.
Cumulative biogas yield per gram TS.

In the variation of N elements, C/N ratios of 20, 25, 30, and 35 were produced. The material components of the variables are shown in **Table 3**.

The equation for C/N ratio had a real influence on the production of biogas with water hyacinth leaves as a raw material. A variation of C/N ratio of 30 gave the best rate of biogas production among other C/N ratio variables, with biogas yield generated at 191,423 ml/g TS [23]. The result of biogas cumulative yield with C/N ratio can be seen in **Figure 5**.

2.3 Solid-state anaerobic digestion (SS-AD)

2.3.1 The effect of total solid (TS)

Solid-state anaerobic digestion (SS-AD) systems usually operate at TS contents of higher than 15% [4]. A research has been conducted [20] about the effect of

Variable	Cow rumen fluid volume (ml)	Water hyacinth leaves (g)	Urea (g)/C/N ratio			
			20	25	30	35
1	200	200	4,9			
2	200	200	4,9			
3	200	200		3,4		
4	200	200		3,4		
5	200	200			3,0	
6	200	200			3,0	
7	200	200				2,5
8	200	200				2,5

Table 3.
Research material needs.

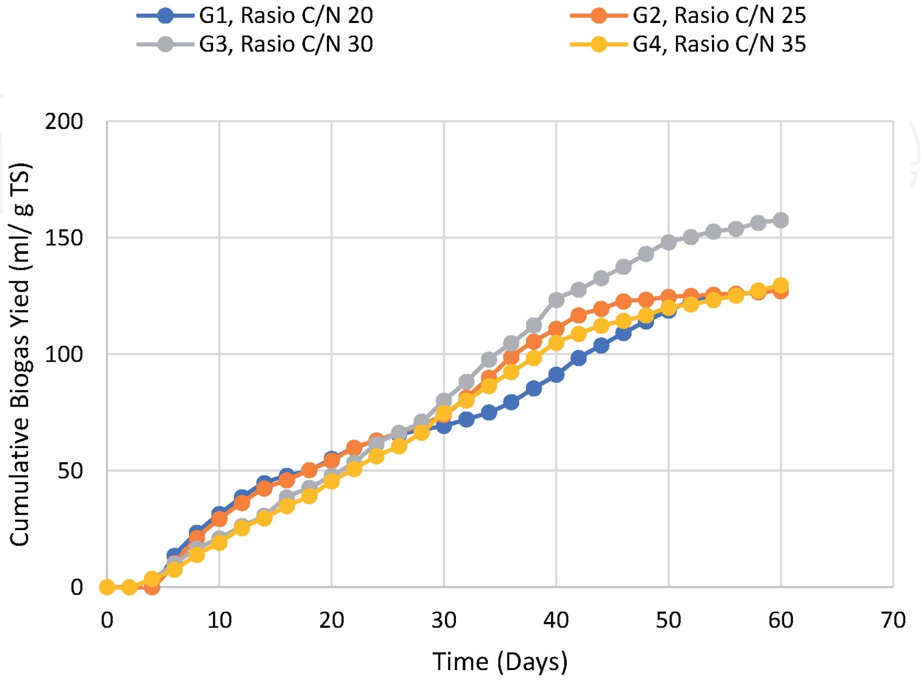

Figure 5.
Cumulative biogas yield per g TS based on C/N ratio.

solid-state anaerobic digestion (SS-AD) on biogas production using water hyacinth leaves. In this study to make the total solid content increased, drying method was used. The water hyacinth leaves from Rawa Pening Lake have an initial total solid content of 13.52%. The first variable was dried for 2 days, and the second variable was dried for 1 day. After that, the water hyacinth leaves that have been dried in the sun were examined for their total solid content using Eq. (1). For the first variable, the total solid content was 48.26% and for the second variable was 36.36%. After that the water hyacinth leaves that have been dried in the sun were added to the cow rumen in a ratio of 1:1. In studies using the SS-AD method, no additional water was given [20]. The combination of the variables is shown in **Table 4**.

The variable with TS of 24.34% produced biogas with a total of 34.79 ml/g TS, and the variable with TS of 17.67% obtained 52.98 m/g TS. The result is shown in **Figure 6**.

Further research had been conducted [24] to know about the optimization of total solid (TS) and carbon to nitrogen (C/N) ratio of biogas production from water hyacinth leaves by adding microbial consortium as much as 3%, 6%, and 9%. Meanwhile the total solid contents from the research were 15%, 27.5%, and 40%. And the C/N ratios were 20, 35, and 50. To get the optimum conditions, calculation had been done by the central composite design method with the following variables in **Table 5**.

Variations of variable values in each reactor were obtained using Statistica software as shown in **Table 6**.

Initial TS (%)	Final TS after being dried in the sun (%)	Cow rumen fluid (ml)	Final TS (%)
13.52	48.26	150	24.13
13.52	36.36	150	17.67

Table 4.
Initial and final total solid of water hyacinth leaves.

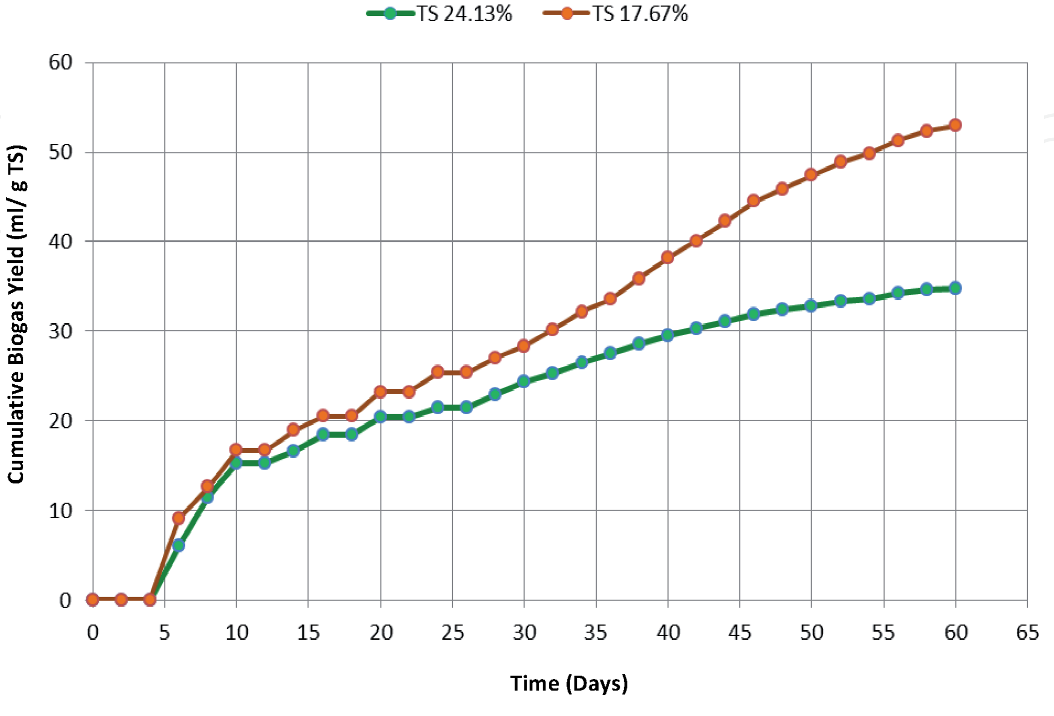

Figure 6.
Cumulative biogas yield per gram TS.

Parameter	−1.682	−1	0	+1	+1.682
Microbial consortium (%)	0.7085	3	6	9	11.2915
C/N ratio	8.54249	20	35	50	61.45751
Total solid (%)	5.45207	15	27.5	40	49.54793

Table 5.
Variable values in the central composite design.

Reactors	Total solid	C/N ratio	Microbial consortium
1	15	20	3
2	15	20	9
3	15	50	3
4	15	50	9
5	40	20	3
6	40	20	9
7	40	50	3
8	40	50	9
9	27.5	35	6
10	5.45207	35	6
11	49.54793	35	6
12	27.5	8.54249	6
13	27.5	61.45751	6
14	27.5	35	0.70850
15	27.5	35	11.29150
16	27.5	35	6
17	27.5		

Table 6.
Variable values in experiments using central composite design.

In this SS-AD method, variations in the total solid concentration used were 15%, 27.5%, and 40%. The total solid for each reactor was adjusted to the total solid of the water hyacinth. Water and rumen were added to regulate the total solid in each of the reactors. **Figures 7–9** show the graphs of biogas results produced at certain reactors which were compared between reactors with the same C/N and microbial consortium ratio values against different TS values [24].

The graph in **Figure 7** shows the production of biogas produced from Reactor 1 and Reactor 5 where the reactors had the same concentration variations for the same C/N ratio and microbial consortium variables, with the lowest value of each variation of 20 for the C/N ratio and 3% for the concentration of the microbial consortium. The difference was in the total solid concentration (**Table 6**). Based on the graph in **Figure 7**, the total cumulative biogas production for Reactor 1 was 27.367 ml/g TS while for Reactor 5 was 5.1 ml/g TS. Reactor 1 with a lower TS which was 15% produced biogas with a greater total than that of the Reactor 5 with TS of 40% [24].

Reactors 4 and 8 had varying concentrations for the same C/N and microbial consortium variables (**Table 6**), namely, a C/N ratio of 50 and a microbial consortium concentration of 9%. Both of these variation values are the highest values

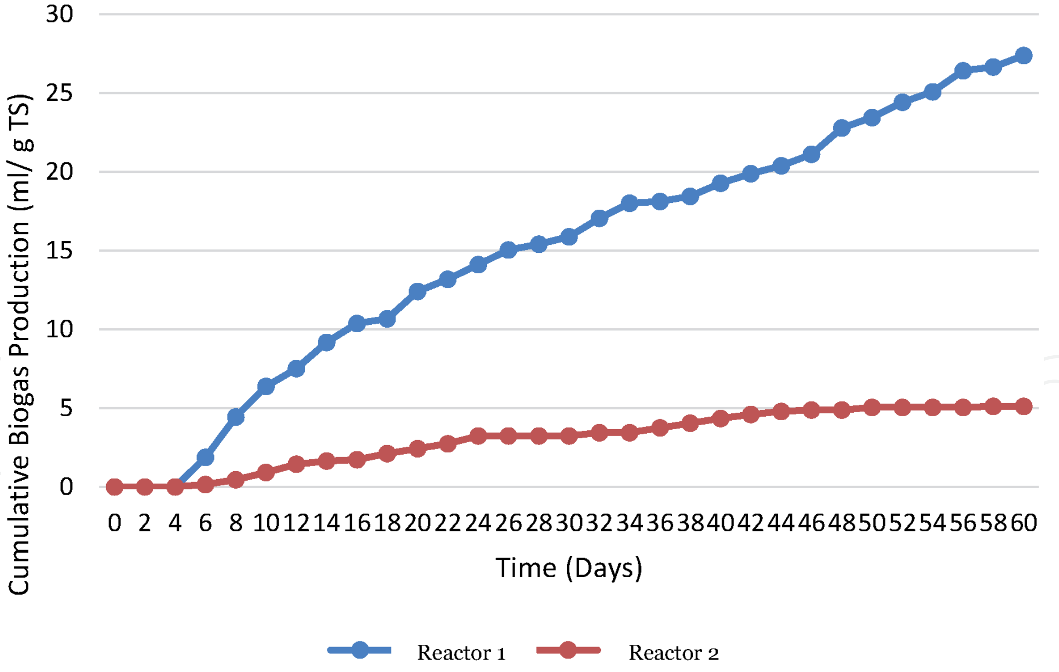

Figure 7.
Effect of TS on biogas production (Reactors 1 and 5).

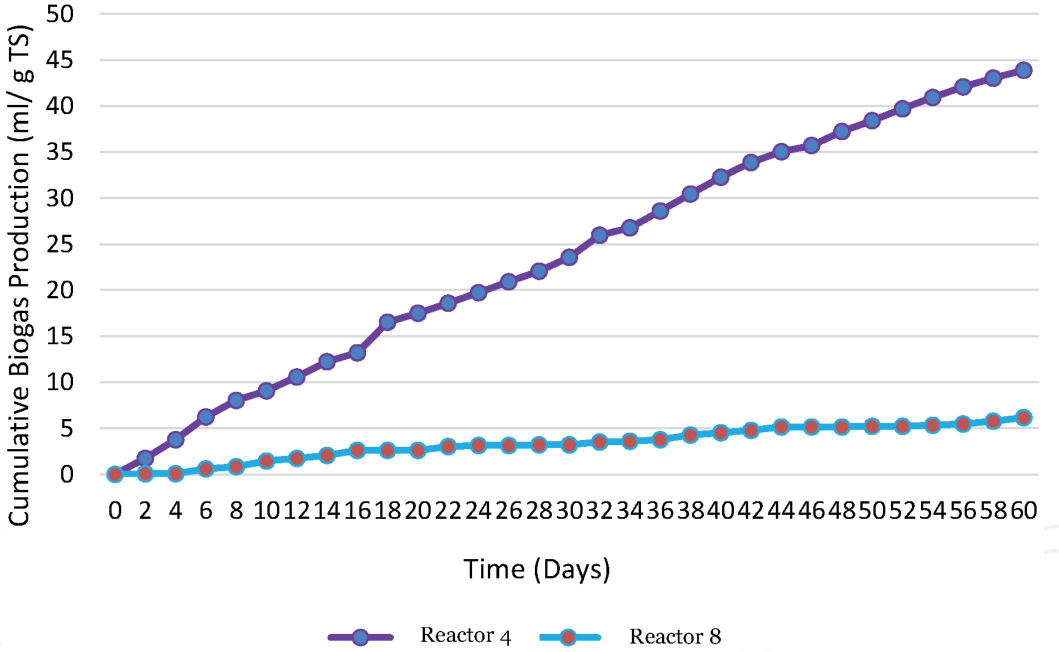

Figure 8.
Effect of TS on biogas production (Reactors 4 and 8).

among the range of values for these variables. The TS concentrations in Reactors 4 and 8 were 15% (lowest value) and 40% (highest value). Reactor 4 with a lower TS value of 15% produces more biogas production than Reactor 8 with a higher TS value (40%). **Figure 8** shows that the total biogas production for Reactor 4 was 43.87 ml/g TS and for Reactor 8 was 6.15 ml/g TS [24].

The biogas production graph in **Figure 9** came from a reactor with a C/N ratio of 35 and a microbial consortium concentration of 6% (**Table 6**). This value was the middle value of the variation of concentration for each of these variables. Biogas production varies in each of the reactors. It can be seen in **Figure 9** that the total biogas production for Reactors 9, 10, and 11 was 22.65 ml/g TS, 87.85 ml/g TS, and 10.09 ml/g TS. Reactor 10 with TS concentration of 5.45%, C/N ratio of 35, and

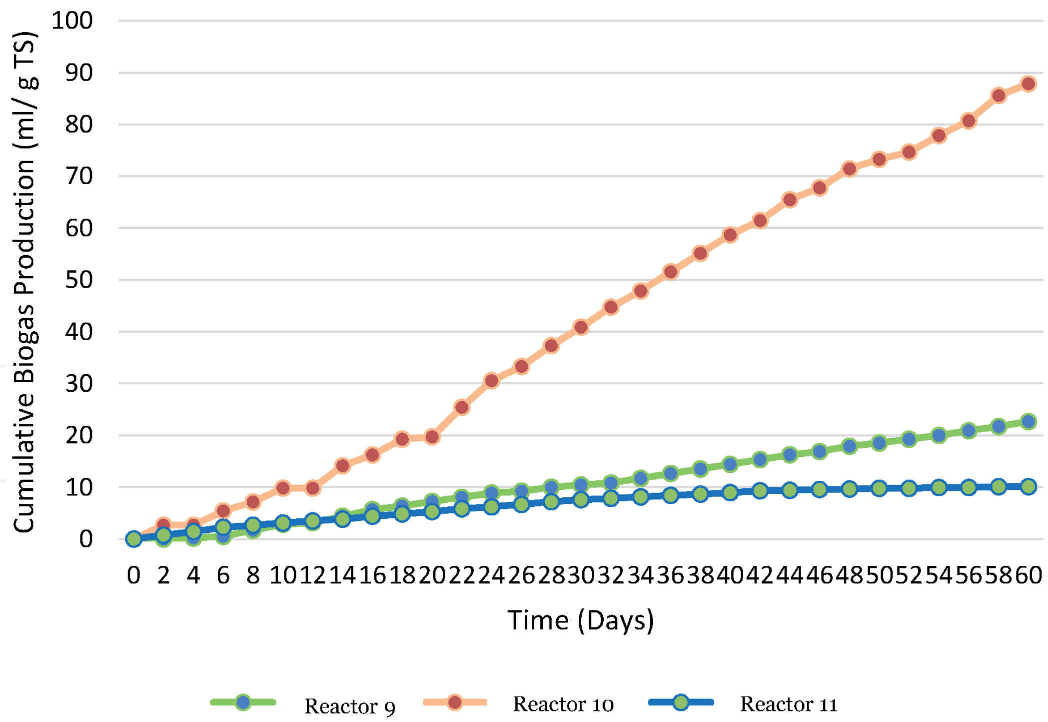

Figure 9.
Effect of TS on biogas production (Reactors 9, 10, and 11).

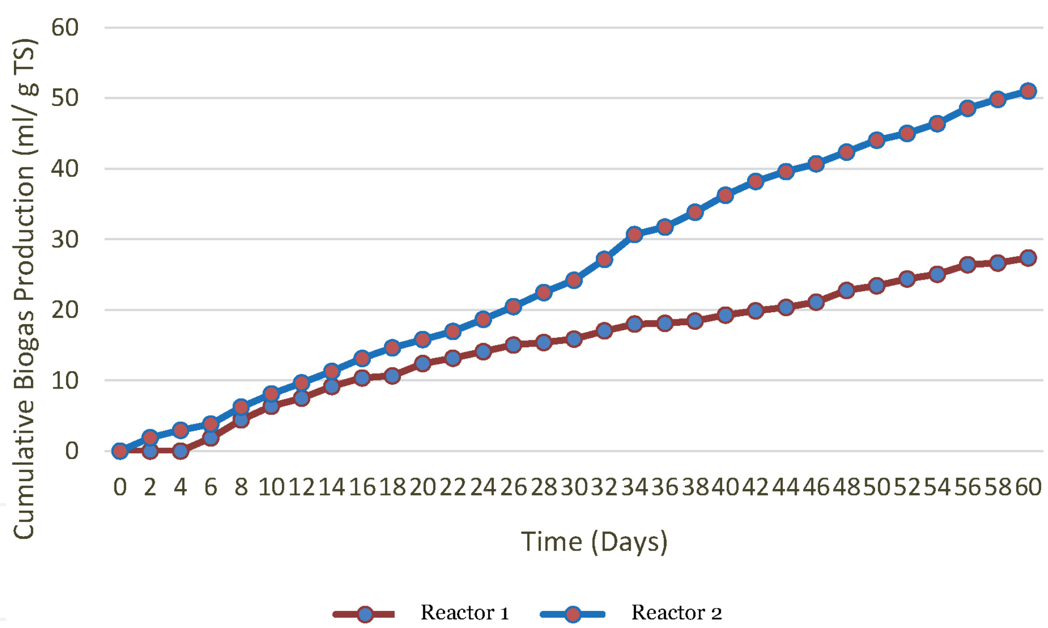

Figure 10.
Effect of C/N ratio on biogas production (Reactors 1 and 3).

microbial consortium concentration of 6% produces the largest biogas production when among Reactors 10 and 11 [24].

2.3.2 The effect of C/N ratio

The variations in the C/N ratio used in this study were 20, 35, and 50. First the C/N ratios of the water hyacinth leaves were tested. To obtain variations in the concentration of the C/N ratio as determined, urea was used to adjust the N value of the water hyacinth leaves [24].

Different C/N ratios were tested with the same total solid and microbial consortium concentration in Reactor 1 and Reactor 3 (**Table 6**). Reactor 1 with a C/N ratio of 20, total solid of 15%, and microbial consortium concentration of 3% produced a total biogas of 27.37 ml/g TS. Reactor 3 with a C/N ratio of 50, total solid of 15%, and microbial consortium concentration of 3% produced biogas with a total of 51 ml/g TS. Reactor 3 with a higher C/N ratio of 50 produced more biogas volume than the Reactor 1 with a C/N ratio of 20. The graph is shown in **Figure 10** [24].

The graph in **Figure 11** was a biogas graph produced from Reactors 6 and 8. The concentrations of the total solid and microbial consortium variables in Reactor 6 were the same as those in Reactor 8 which were 40% and 9%, respectively (**Table 6**). The C/N ratio of Reactor 6 was 20, while Reactor 8 is 50. For the total biogas production produced, based on the graph in **Figure 11**, it can be seen that Reactor 6 has a higher biogas than that of the Reactor 8 which was 13.14 ml/g TS for Reactor 6 and 6.15 ml/g TS for Reactor 8. Thus, reactors with lower C/N ratios produce higher biogas under conditions of total solid concentration of 40% and microbial consortium of 9% [24].

The graph in **Figure 12** was taken from the calculation of biogas production produced in Reactors 9, 12, and 13. The reactors have the same total solid concentration and

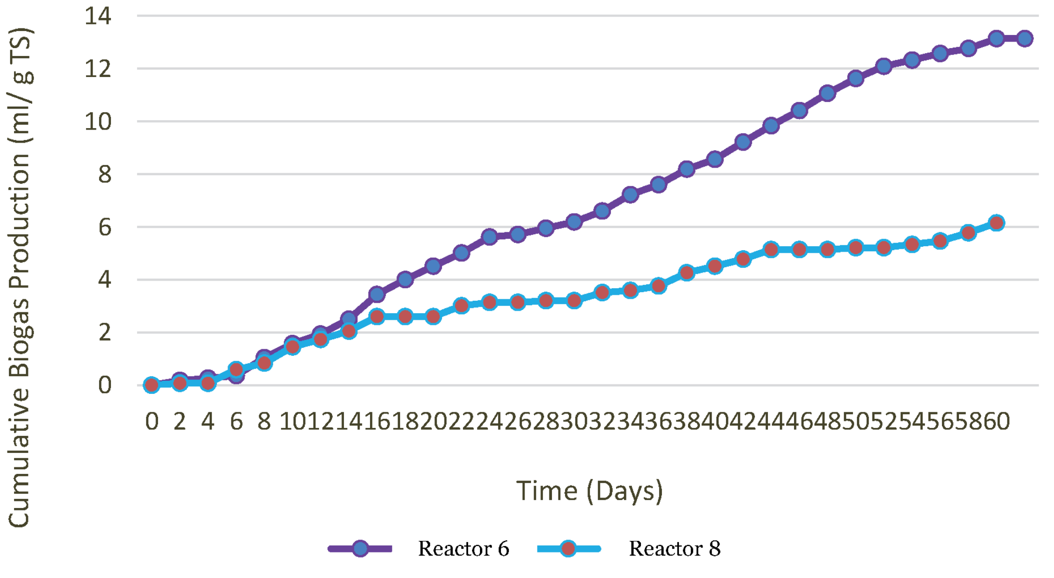

Figure 11.
Effect of C/N ratio on biogas production (Reactors 6 and 8).

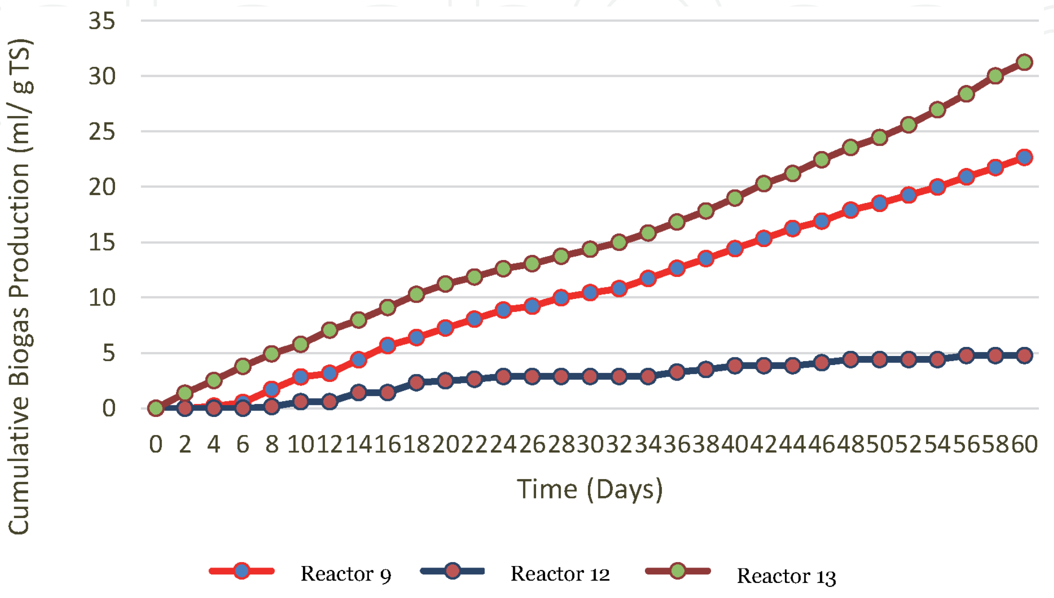

Figure 12.
Effect of C/N ratio on biogas production (Reactors 9, 12, and 13).

microbial consortium (**Table 6**) of 27.5% and 6%, respectively, with a C/N ratio different from Reactor 9 with a C/N ratio of 35, Reactor 12 with a C/N ratio of 8.54, and Reactor 13 with a C/N ratio of 61.45. The total biogas production in Reactor 9 was 22.65 ml/g TS, whereas in Reactor 12, the total biogas production was 4.76 ml/g TS. For Reactor 13, the total biogas production was 31.24 ml/g TS. The volume of biogas production in Reactor 13 was greater than the volume of biogas production in Reactors 9 and 12 [24].

3. Conclusions

Water hyacinth was considered as waterweed, which has become a problem that damaged the environment, the system irrigation, and agriculture. Water hyacinth leaves that contained cellulose, nitrogen, essential nutrients, and high fermentation contents can be used for biogas production. The use of the L-AD method with TS 3.38% produced the most biogas yields than using the SS-AD method with TS 24.13 and TS 17.67 or the L-AD method with TS 6.76%, with the amount of biogas yield for TS 3.38% was 369 ml/g TS.

Based on the results of research on the effect of the C/N ratio on biogas productivity using L-AD method, the optimum C/N ratio was found in the C/N ratio 30 with the resulting biogas yield of 157.544 ml/g TS. The optimum C/N ratio for biogas production from water hyacinth leaves using the solid-state anaerobic digestion method was 32.09.

Acknowledgements

We would like to say thank you to the Diponegoro University for the funding of this research under the Research Professorship Program (RPP) (2017).

Notes/thanks/other declarations

Praise and gratitude for the presence of Allah SWT who has bestowed His mercy and grace so that the author can complete the part of the book with the title Biogas Production from Water Hyacinth chapter. In completing this chapter, we would like to thank the Environmental Engineering Diponegoro University and the water hyacinth biogas research team for their guidance and support. We hope the research that has been done can bring benefits to all people.

Appendices and nomenclature

AD	anaerobic digestion
	biogas
C/N	carbon to nitrogen
	cumulative biogas yield
F/M	food to microorganism
	Rawa Pening Lake
L-AD	liquid anaerobic digestion
	methane
SS-AD	solid-state anaerobic digestion
TS	total solid
	water hyacinth

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