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Optimization of Biogas Production by Solid State Anaerobic Digestion (SS-AD) Method from Water Hyacinth with Response Surface Methodology (RSM)

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Abstract. Water hyacinth is one of the rapid growth rate water weed in Rawapening Lake. Water hyacinth contains high hemicellulose which can be used for biogas production. This research aims to know the optimum value of total solid (TS), C/N ratio and microbial consortium for the biogas production with SS-AD from water hyacinth. The variations used for TS are 15%, 27.5%, and 40%, for C/N ratio are 20, 35, and 50, for microbial consortium are 3%, 6%, 9%. Sixteen reactors of 2 litres volume used with the variations inside are determined by Central Composite Design in Statistica software. Results of the biogas production are then analysed using Response Surface Methodology for optimization. Based on the analysis, the optimum value of TS is in the range of 5%-10%, value of C/N ratio is 32.09, and microbial consortium is 7.26%. Reactor 10 with the TS 5.45%, C/N ratio 35, and microbial consortium 6% has the closest value to the optimum value. The production rate of reactor 10 then analysed using Polymath 6.0. The constant kinetics rate of biogas (U) production rate is 1.88mL/g TS day; maximum biogas production is 108.41 mL/g TS; the minimum time to form the biogas is 8.87 days.

Keywords: **biogas; water hyacinth; RSM; solid-state anaerobic digestion; optimization**

1 Introduction

Water Hyacinth (*Eicchornia crassipes*) is a type of weeds with a very fast growth and has become a big problem for some water bodies in Indonesia one of them is Rawapening Lake. Rawapening Lake is one of the lakes that are included in 15 priority lakes in the RPJMN 2015-2019. The blooming of water hyacinth in this lake has increased, reached until 7.1% per year or 37.6 times in a year [14]. To solve the problem, water hyacinth has been used for various things, one of them is for producing biogas because it has a considerable hemicellulose content compared to another single organic component [8]. Hemicellulose if hydrolysed will produce mixed derived product which can be treated using anaerobic digestion method and produce biogas with high content of methane and carbon dioxide [11].

Various researches have been conducted before about the effect of some variables such as C/N ratio, F/M ratio, and total solid for the biogas production. Based on the previous research, the highest production of biogas from water hyacinth will be obtained if the C/N ratio is 30 [5], and the total solid content of 17,67% for SS-AD method [3]. Microbial consortium such as *Streptomyces sp., Trichoderma sp.,* and *Geobacillus sp.* are often used for enhancing the production of biogas. Those microbes help to degrade cellulose, hemicellulose, lignin and kittin [1, 12, 6].

Based on those researches, further research is needed to optimize the production of biogas produced. Biogas optimization in this research was done by using response surface methodology (RSM) with the variables are total solid, C/N ratio and microbial consortium. This research aims to determine the optimum of total solid, C/N ratio and microbial

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consortium for the production of biogas using SS-AD method from water hyacinth.

2 Materials and methods

This research was conducted through 2 stages. First is the preliminary study, it is to know the characteristics of the materials used in this research. In this study we determine the total solid of the water hyacinth and the cow manure using method from NREL/TP-510-42621 about Determination of Total Solids in Biomass and Total Dissolved Solids in Liquid Process Samples and the concentration of C-organic using Walkley and Black method and N-total using spectrophotometry with the method from the Balai Penelitian Tanah manual book. Second is the research implementation to determine the optimum condition of the production of biogas using SS-AD method from water hyacinth.

Leaves of water hyacinth as substrate are taken from Rawapening Lake with diameter of approximately 15cm; cow manure (fluid rumen) as inoculum from Penggaron slaughtering house, Pedurungan subdistrict, Semarang city; microbial consortium in Decoprima packing powder; and urea obtained from farm shop in Karangrejo, Banyumanik. The materials used refers to previous studies conducted by [3, 5, 8, 13].

Biogas volume sampling done once every 2 days. Reactor used as in figure 1 below. There are 16 reactors used where the variation variables are the total solid concentration of 15%, 27.5%, and 40%; C/N ratios of 20, 35, and 50; concentration of microbial consortium of 3%, 6%, and 9%. The value of the variables contained in each reactor are determined using Central Composite Design from RSM. Those value can be seen in Table 1.

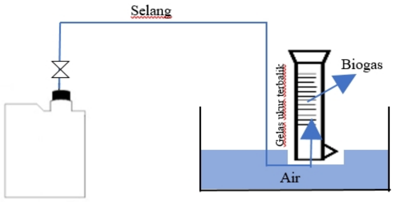

Figure 1. Schematic diagram of the research

After measuring for 60 days, the results then processed with RSM for optimization and *Polymath 6.0* to study the rate of biogas production.

3 Result and discussion

3.1 Optimization of Total Solid, C/N Ratio, and Microbial Consortium on Biogas Production Using Response Surface Methodology (RSM)

Based on the research conducted, the results obtained can be seen in table 1.

Table 1. Biogas Production Results of each Reactor

Reactor	*Total Solid*	C/N Ratio	*Microbial Consortium*	Biogas Production (mL/gr TS)
1	15	20	3	27.37
2	15	20	9	26.23
3	15	50	3	51.00
4	15	50	9	43.87
5	40	20	3	5.10
6	40	20	9	13.14
7	40	50	3	7.97
8	40	50	9	6.15
9	27.5	35	6	22.65
10	5.45	35	6	87.85
11	49.54	35	6	10.09
12	27.5	8.54	6	4.76
13	27.5	61.45	6	31.24
14	27.5	35	0.70	19.11
15	27.5	35	11.29	17.49
16	27.5	35	6	17.80

The biogas produced in each reactor is different for every reactors. The highest biogas produced in reactor 10 with the yield of 87.85mL/g TS with the variation values of the variables contained in the reactor are 5.45% for TS concentration, 35 for C/N ratio and the 6% for microbial consortium. The result of biogas production in Table 1 above then inputted for calculation with RSM in Statistica 10 which then resulting the equation as follows:

$$Y = 22.2950 - 35.6143x_1 + 15.0815x_1^2 + 11.7911x_2 - 4.8279\,x_2^2 - 0.6902x_3 - 4.6351x_3^2 - 11.3448x_1x_2 + 3.6198x_1x_3 - 3.9655x_2x_3 \quad (1)$$

Y = Biogas Production (mL/gr TS)
X_1 = Concentration of Total Solid (%)
X_2 = C/N Ratio
X_3 = Concentration of microbial consortium (%)

The coefficient of X1 (L) with negative sign means that the total solid will linearly decrease the biogas production while X1 (Q) is positive means it will increase the biogas production quadratically. For the X2 (L) with positive sign means that the increasing of C/N ratio linearly will increase the production of biogas. While the negative sign of X2 (Q) means that the increasing value of the C/N ratio will quadratically decrease the biogas production. As for the coefficient of X3 either (L) or (Q) is negative, it means that the increasing of microbial consortium either linearly or quadratically will decreases biogas production. It can also be seen from the pareto chart in Figure 2 below.

Figure 2 shows the level of significance for each variable either linear or quadratic, and the relationship between two variables. The overall significance level for all variables is 95.083%. The red line in the chart of figure 2 is the value of P = 0.05. If the chart of the variable passes the red line it means that the variable is significantly affect the biogas production, where

P<0.05. On the contrary, if the chart of the variable does not pass the red line, means that the variable is not significantly affect the biogas production with the value of P > 0.05.

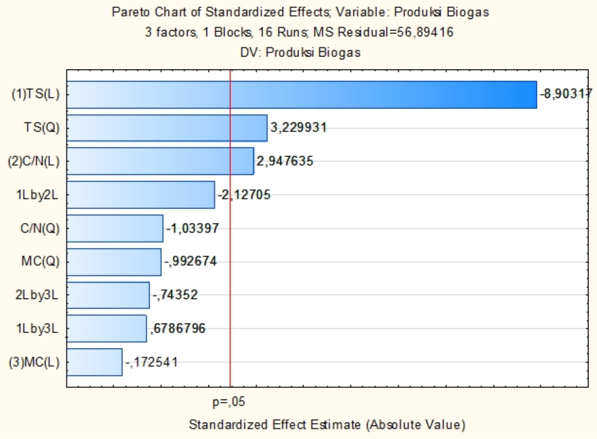

Figure 2. Pareto Chart Result of RSM Analysis

The variables which affect the production of biogas significantly with the value of P<0.05 are TS (linearly and quadratically), and C/N ratio linearly. Microbial consortium both linear and quadratic, and the interaction between 2 variables have the value of P>0.05 which means that they do not affect the production of biogas significantly.

Figures 3 and 4 shows the surface plot (3 Dimension) and contour plot (2 Dimension) of variable TS and C/N ratio on MC 6%, and variable TS and MC on C/N ratio 35 respectively based on analysis by RSM. Based on Figures 3 and 4 it can be seen that the optimum value for variable TS is in the range of **5% - 10%**. The values obtained were not in the range of variations of the variables determined for the research due to optimum biogas production at concentrations below 15%, whereas for SS-AD method, the TS concentration used is > 15%. As well as based on research conducted by Orhorhoro, et al. [9] which resulted that the optimum TS concentration value of 10.16% to produce high biogas production. While based on research conducted by E.Suryaning, et al. [2] TS concentration was obtained at 5% to produce high biogas production followed by TS concentration value of 7% and 9%.

It can be seen also that the higher the TS value is, the lower the cumulative production of biogas will be. This is indicated by blue spherical dots that are scattered to green contours as TS values increase. The results is similar with the research conducted by F. Natalyn, et al [3] that the higher the TS in reactor the lower the biogas produced.

Figures 3 and 5 respectively show the surface plot and contour plot from RSM of TS and C/N ratio on MC 6%, and C/N ratio and MC on TS 27.5%. Based on the figures, the optimum C/N ratio is in the range 30-40. It is in the red area which means that the biogas production is high. Based on the analysis from RSM, the specific value of the optimum C/N ratio for biogas production is **32,09**.

Previous research by G. Munkar, et al. [5] using C/N ratio with the range of 30-35 produce the higher biogas production comparing to the other value of C/N ratio. The production of biogas will be high if the C/N ratio is 30 with the yield of biogas is 157,54mL/gr TS. While based on research using rice husk as the substrate conducted by Syafrudin, et al. [13] resulted that the biogas production is high if the C/N ratio is 35 with the yield biogas reaches 18.2mL/g TS. Nitrogen will be consumed fast by the methanogen bacteria if the C/N ratio is too high, then it makes the nitrogen will no longer reacting with the carbon. It makes the biogas production will be decreased [4]. On the contrary, nitrogen will be accumulated in the form of ammonia (NH4) if the C/N ratio is too low. Higher NH4 values will make the pH if the C/N ratio is too low value increase. If the pH is more than 8.5 it would be toxic to methanogenic bacteria [4].

Figures 4 and 5 show the surface plot and contour plot of TS and MC on C/N ratio 35, and ratio C/N and MC on TS 27.5% respectively. Based on the graph and RSM analysis, the optimum value of MC concentration is **7.26%.** The microbial consortium used contains *Streptomyces sp., Trichoderma sp*., and *Geobacillus sp*. Based on research conducted by R.K. Ratnan, and M. Ambili. [10] *Streptomyces sp*. producing cellulase enzymes used to degrade existing cellulose in water hyacinth. In addition, bacteria *Geobacillus sp*. co-enzyme producing cellulase [6]. *Trichoderma sp*. including in microbes that can degrade biopolymers such as cellulose, hemicellulose, lignin, and kittin [7].

Therefore, based on the research and data processing, it can be concluded that the maximum biogas production can be obtained at optimum condition for TS concentration in the range 5% -10%, C/N ratio of 32.09, and enzyme concentration 7.26%. Reactor 10 contains the value of the variables close to the value of the optimum value resulted from the analysis of RSM with TS 5.45%, C/N ratio 35, and MC 6%.

3.2 Biogas Optium Production Rate from Hyacinth with the SS-AD Method

Biogas production from reactor 10 with the value of the variables is closed to the optimum value (TS concentration of 5.45%, C/N ratio 35 and MC concentration 6%) then calculated its kinetics constant of biogas production rate, maximum biogas production and time needed for biogas production using Polymath 6.0, then obtained the following results.

Table 2. Kinetic Constants for Optimum Biogas Production

Constants	Value
A (ml/grTS)	108,4152
U (ml/grTS.hari)	1,884468
λ (hari)	8,869806

The value of those constants then input in the equation 2 for determining the production of biogas with t filled with time (day) to be calculated.

$$P = 108,415 \exp\left\{-exp\frac{1,884 \cdot 2,718}{108,415}(8,869 - t\right\} + 1 \quad \ldots(2)$$

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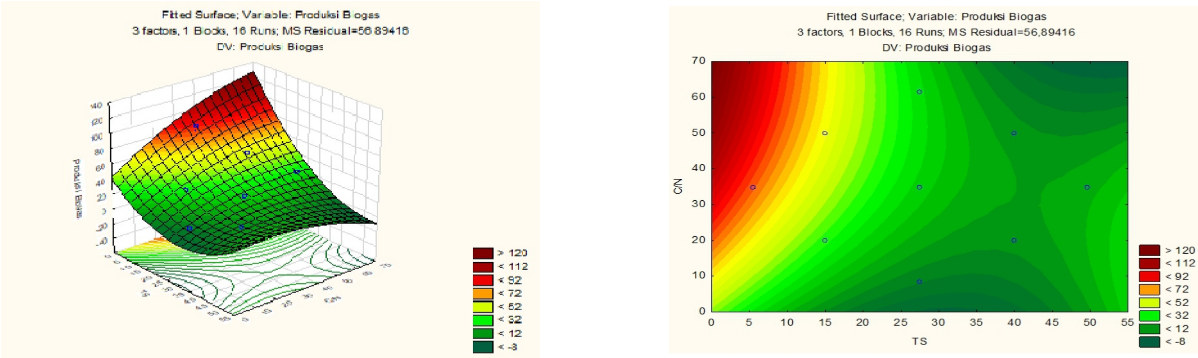

Fig 3. Three Dimensional / Surface Plot (left) and 2 Dimensional / Contour Plot (right) graphs Variable TS and C / N Ratio at Microbial Consortium Concentration 6% RSM Analysis

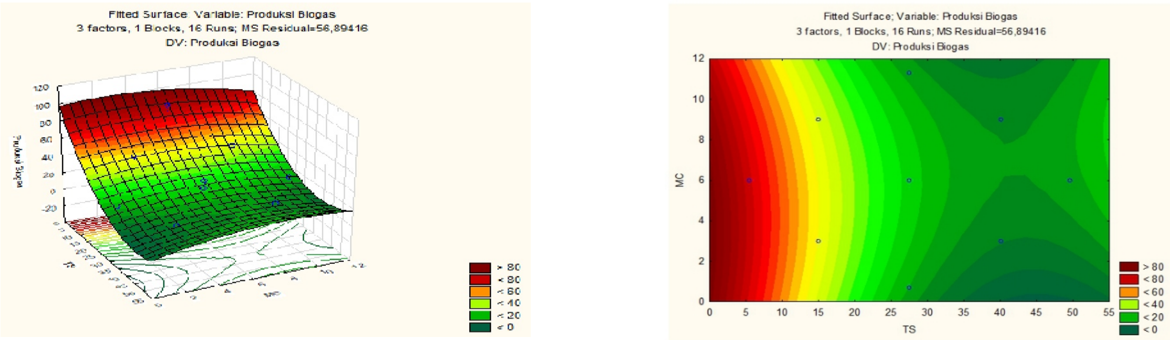

Fig 4. Three Dimensional / Surface Plot (left) and 2 Dimensional / Contour Plot (right) graphs Variable TS and Microbial Consortium Concentration on C / N Ratio 35 RSM Analysis

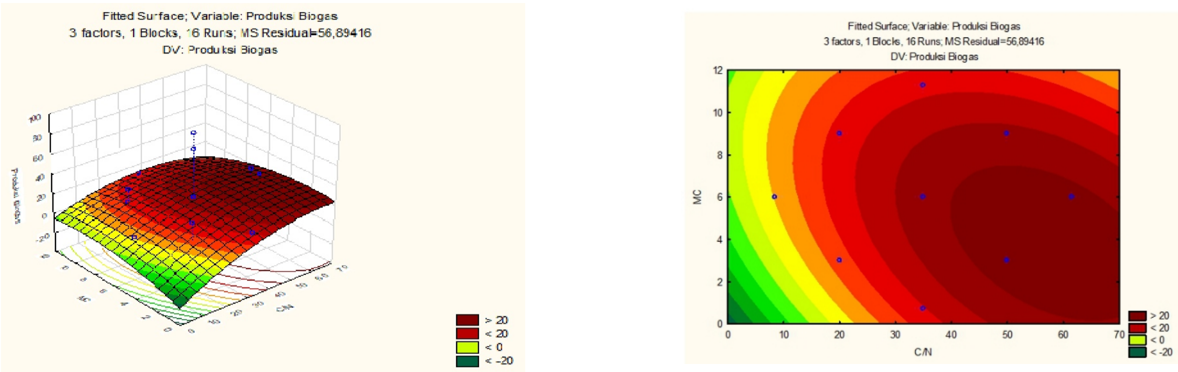

Fig 5. Graph of 3 Dimensional / Surface Plot (left) and 2 Dimensional / Contour Plot (right) Variable Ratio C / N and Microbial Consortium Concentration at TS Concentration 27.5% RSM Analysis

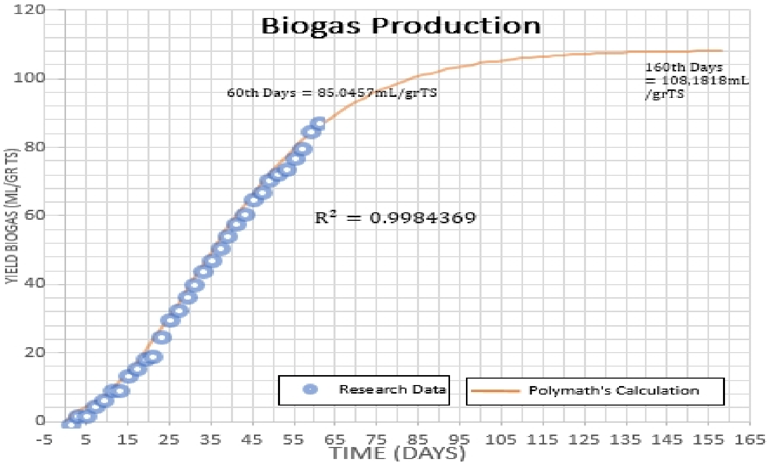

Fig 6. Relationship between Trial Data and Polymath 6.0 Calculation Results on Optimum Biogas Production

Figure 6 shows the graph of the biogas production until days 160 from analysis of Polymath 6.0. It can be seen from the graph that the value of R^2 is 0.9984369 which means that the data from research obtained and the data from Polymath calculation is not significantly different. The maximum biogas production under optimum condition is 108.1818 mL/g TS on 160th days. There is still biogas production on the day after that but with a very small amount, which equals to ± 0.03 mL/gr TS so it is considered no longer significant for biogas production.

4 Conclusion

The maximum biogas production can be obtained at optimum condition from several variables: TS concentration in the range of 5% -10%, C/N ratio of 32.09, and microbial consortium 7,26%. The highest biogas production rate in the reactor with the variable close to the optimum value obtained (reactor 10 with TS 5.45%, C/N ratio 35, MC concentration 6%) produce biogas yield of 108.1818 ml/g TS. Daily production constant (A) is 108,4152 mL/g TS, biogas production rate constant (U) is 1,884468 mL/g TS and minimum time to produce biogas is 8,87 days.

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