Optimization of Parameters for Biogas Production from Bagasse Using Taguchi Method

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Original Research

Optimization of Parameters for Biogas Production from Bagasse Using Taguchi Method

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Abstract

Biogas production from lignocellulosic compounds is affected by several parameters. In the present article, Taguchi method was applied in evaluating the parameters including inoculums type (cow rumen and cow dung), pretreatment time (0, 24, 48 h), and total solid content (2, 5, 10 %). The L_{18} ($2^1 \times 3^2$) full factorial design with a mixed orthogonal array was selected to conduct the experiments. Furthermore, to find the percentage contribution of each parameter on biogas yield, the analysis of variance was applied. The analysis results showed that the best inoculum type was cow rumen (signal-to-noise 27.59), the best pretreatment time was 48 h (signal-to-noise 28.20) and the best total solid was 2% (signal-to-noise 31.98). Furthermore, the percentage contribution of inoculum type, pretreatment time, and total solid was 0.43, 7.97 and 83.51% respectively. It means the total solid was the most effective parameter and then it was followed by pretreatment and inoculums. The predicted maximum biogas yield of 42.59 L/kg resulted from an optimum condition of inoculum of cow rumen, pretreatment time of 48 h, and a total solid of 2%. In the confirmation test, the Taguchi method could predict biogas yield successfully with R^2 of 0.919.

Keywords: bagasse, biogas, inoculum, Taguchi method, total solid

Introduction

Because of limitation of non-renewable energy source accessibility, Indonesia will reduce their need and increase renewable energy production. Based on data from Dewan Energy Nasional [1], around 92% of total national energy consumption in 2013 was reinforced by fossil fuels and the remaining 8% by renewable energy. The government is focusing to cut down the level of fossil fuel consumption to be 69% by supplanting it with sustainable power sources in year 2050 [1]. Therefore, renewable energy is becoming one of the major topics in Indonesia. Furthermore, the conversion of wastes to renewable energy is a very thought-provoking idea [2-4]. Biogas is a renewable energy that could be potentially applied as alternative energy in Indonesia. Compared with other renewable energy sources, biogas has some superiorities: 1) it is easy to be produced; 2) it can be produced from wastes; 3) it can be utilized directly in gas form or converted

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to be other energy forms; 4) bottom product of biogas reactors can be used as biofertilizer; and 5) it is suitable to be produced at mesophilic temperatures in Indonesia [2, 5-7]. As an agricultural country, Indonesia is rich in agricultural wastes; one of them is bagasse. Bagasse, one of lignocellulosic wastes, is produced from sugarcane milling process in sugar factory [8]. Bagasse contains high cellulose, so it is very potential to be processed to biogas [9].

In anaerobic digestion (AD), there are some parameters that affect the biogas yield, i.e. inoculums type [10], chemical pretreatment [11] and total solids [6]. Previously some authors have reported about biogas production from bagasse. However, in all cases, every one of them simply considered the job of one parameter in a single time on biogas yield from bagasse [12-14]. In reality, some parameters are affecting the AD performance simultaneously [7]. Hence, optimization of the parameters for producing biogas from bagasse is necessary to do.

To optimize the parameters, there are many optimizing methods such as Genetic Algorithm (GA), Artificial Neural Network (ANN), Response Surface Method (RSM) and Taguchi method [15]. In present article, the Taguchi method was applied to study the different experimental parameters with the minimum number of trials as it exhibits an orthogonal array [16]. Besides this, It will provide the influence of each aspect and introduce the most effective and the optimum conditions on biogas yield [7, 15-16]. Therefore, this study has a goal to investigate the effect of several parameters on biogas yield from bagasse i.e. inoculums type (cow dung and cow manure), pretreatment time (0, 24, 48 h) and total solid content (2, 5, 10%) then optimization of these parameters through the Taguchi method. Syaichurrozi et al. [17] suggested that the chemical pretreatment for organic solid prior AD should be conducted for 48 h. Above that time, it was not effective. Therefore, this study set the low, middle and high level for pretreatment time on 0, 24 and 48 h. Furthermore, the optimum total solid content for agricultural wastes, municipal solid waste and banana stem waste was 9% [18], 10% [19] and 2-4% [20]. It means that the optimum range of total solid for solid waste is 2-10%. Based on that, this study set the low, middle and high level for total solid on 2, 5 and 10%. This idea was new and original as no previous author was conducting the Taguchi technique to evaluate the effect of parameters on biogas from bagasse. The anaerobic digestion was run during 84 d using anaerobic batch digesters.

Materials and Methods

Materials

The raw bagasse was obtained from sugar factories in Jatibarang, Brebes, Central Java Province (which was also utilized by Sumardiono et al. [14]) and dried under the sun for seven days. After drying, it was milled and sieved to obtain 22 mesh [14]. Then the raw bagasse was pretreated by soaking it in a solution of NaOH 2%v/v during 24 and 48 h. The inoculums (rumen fluid and dung of cow) were obtained from cow slaughterhouses located in Jatibarang, Brebes, Central Java Province. The total solid (TS) and volatile solid (VS) in the above mentioned materials could be seen in Table 1.

Experimental Setup

A laboratory batch of anaerobic digester (made form polyethylene) of volume 5L was used in this experiment (adapted from [21]). The digester was plugged with rubber and a valve was used to determine biogas volume [2, 6].

Experimental Design and Procedures

The bagasse was mixed with water to make a slurry with total solid (TS) of 2, 5, 10% and a total volume of 2 L. The obtained slurry was fed to digesters and inoculums (about 20% of the total slurry) were added in it. To maintain the substrate pH during fermentation, the buffer ($NaHCO_3$) was added. Fermentation was done for 84 d at the condition of mesophilic temperature (28-30ºC) and pressure of 1 atm. Biogas volume was measured every day by using the water displacement method. The digester was connected to the biogas collector (made from a

Table 1. TS and VS content in material and inoculums [14].

Biomass	Characteristics		
	TS %	VS %	VS/TS
Raw bagasse	79.64	78.83	0.99
Bagasse after pretreatment 24 h	79.07	77.00	0.97
Bagasse after pretreatment 48 h	78.50	76.83	0.98
Cow rumen	26.50	14.33	0.54
Cow dung	16.67	13.17	0.79

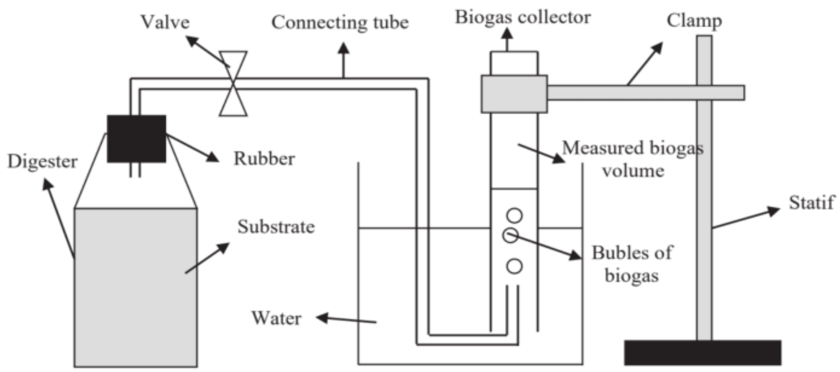

Fig. 1. The schematic diagram of the experiment.

reversed cylindrical glass) using a plastic tube. The biogas collector was immersed in water. Furthermore, the valve was used to close-open the plastic tube for measuring biogas volume. When the valve was opened, the biogas flew through the tubes and it was stored and replaced the amount of water in the gas collector [17]. Furthermore, the total biogas volume was the sum of daily biogas volumes from 0 until 84 d of fermentation. The schematic diagram of this experiment is shown in Fig. 1.

Taguchi Method

The Taguchi method uses orthogonal arrays to reduce the number of experiments and limits the effects of parameters. It gives a simple, proficient, and methodical approach to indicate the optimum parameters for biogas production [22-24]. A loss function is used by the strategy to compute the deviation between the experimental and targeted values. Furthermore, the loss function is expressed in value of signal-to-noise (S/N) ratio [25]. The S/N ratio has three quality characteristics which are: the smaller-the-better, the larger-the-better and the nominal-the-best [15]. In case of maximizing the biogas yield, the larger-the-better characteristic was applied using Eq. 1 [26].

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \quad (1)$$

...where, S/N is signal-to-noise ratio, y_i is the signal (biogas yield) measured in each experiment and n is the number of observations of the experiment.

Inoculums type, chemical pretreatment time and total solid were proposed parameters and then the levels from each parameter were presented in Table 2. Based on Table 2, the orthogonal array L_{18} ($2^1 \times 3^2$) was the most suitable to be applied in way to determine the optimal combination parameters and to investigate the influence of each parameter on biogas yield. Therefore, experiments were conducted based on the matrix of the orthogonal array L_{18} presented in Table 3.

Results and Discussion

Analysis of the Signal-to-Noise (S/N) Ratio

Total biogas volume (*Vb*) was measured through experimental design for each combination of the parameters by using the Taguchi method. The optimization of the parameters was provided by signal-to-noise (S/N) ratios. The most elevated estimation of biogas yield was the primary concern, therefore larger-the-better characteristic was applied to calculate the S/N ratio. The S/N ratio values for observations of the biogas yield are shown in Table 4. Furthermore, from Table 4, the average value of *Vb* and S/N ratio were calculated to be 26.35 L/kg and 27.4704 respectively. Analysis of the influence of each parameter (inoculums, pretreatment, total solid) on biogas yield was performed with an "S/N response table" for *Vb* which is shown in Table 5, and then graphically it is appeared in Fig. 2. The optimal parameter combination for maximizing the biogas yield

Table 2. Biogas production parameters and their levels.

Parameters	Symbol	Level 1	Level 2	Level 3
Inoculums	A	CR	CD	-
Pretreatment time (hours)	B	0	24	48
Total solid (%)	C	2	5	10

Table 3. Full factorial design with orthogonal array of Taguchi $L_{18}(2^1{\times}3^2)$.

Experiment No.	Parameter A	Parameter B	Parameter C
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3

could be easily determined from Table 5 and Fig. 2. The best level for each parameter was that it had the highest S/N ratio. The highest S/N ratio value was shown by value in bold mode in Table 5. The levels and S/N ratio for the parameters resulting in the best *Vb* value were specified as parameter A (Level 1, S/N = 27.59), parameter B (Level 3, S/N = 28.20), parameter C (Level 1, S/N = 31.98). That implies a maximum *Vb* was obtained by optimizing condition of inoculums of cow rumen (A1), pretreatment during 48 h (B3), and total solid content of 2% (C1).

Evaluation of Experimental Results

According to Fig. 2 and Table 5, using cow rumen (CR) as inoculums could produce more total biogas volume as compared to using cow dung (CD). The CD contained higher total microorganisms than CR [27]. However, the number of ruminant bacteria in CR was higher than CD [28]. The substrate used in this investigation was bagasse which is cellulosic biomass. The presence of ruminant bacteria in CR could increase the biogas production rate, which results in high biogas yield. However, the type of inoculums (CR or CD) did not influence the biogas yield significantly. The S/N value using CR and CD as inoculums is 27.59 and 27.35 respectively. Therefore, the factor of inoculums was not an effective parameter. Furthermore, the pretreatment also affected the biogas yield. The surface morphology of bagasse before and after pretreatment was analyzed using SEM (Fig. 3). After pretreatment using NaOH 2% during 24 and 48 h, the surface morphology of pretreated bagasse was more open than raw bagasse [14]. It was in line with Kong et al. [29] and Montgomery and Bochmann [30], where pretreatment using alkali could swell the surface lignocellulosic biomass. Lignin and hemicellulose in fiber would dissolve, leaving a smooth surface of the fiber [31]. It showed that lignin and hemicelluloses in the surface

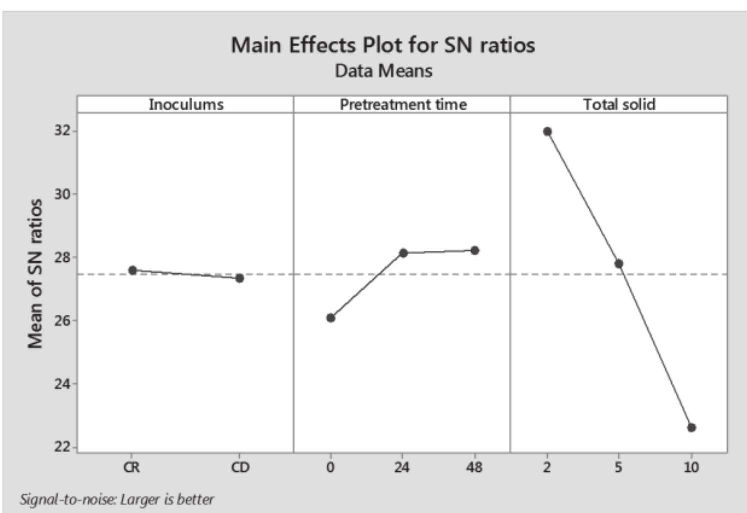

Fig. 2. Effect of parameters on average S/N ratio for *Vb*.

Table 4. The results of experiments and S/N ratio values.

Experiment No.	Parameter			Biogas yield, *Vb* (L/kg)	S/N ratio for *Vb*
	A Inoculums	B Pretreatment time (h)	C Total solid (%)		
1	CR	0	2	31.79*	30.0458
2	CR	0	5	18.89*	25.5246
3	CR	0	10	13.10*	22.3454
4	CR	24	2	51.04*	34.1582
5	CR	24	5	32.75	30.3042
6	CR	24	10	9.96	19.9652
7	CR	48	2	41.97*	32.4588
8	CR	48	5	27.37	28.7455
9	CR	48	10	17.27	24.7458
10	CD	0	2	35.04	30.8913
11	CD	0	5	17.74	24.9791
12	CD	0	10	13.53	22.6260
13	CD	24	2	39.33	31.8945
14	CD	24	5	28.35	29.0511
15	CD	24	10	14.89	23.4579
16	CD	48	2	41.92	32.4484
17	CD	48	5	25.93	28.2761
18	CD	48	10	13.41	22.5486

T_{Vb} (biogas yield total mean value) = 26.35 L/kg
$T_{Vb\text{-}S/N}$ (biogas yield S/N ratio total mean value) = 27.4704
*Data from Sumardiono et al. [14]

were dissolved by NaOH solution, and then only a less amount of cellulose reacted with NaOH. The suspension of lignin and hemicelluloses could decrease the VS/TS ratio in bagasse (Table 1). Delignification processes damaged the structure of lignin to make cellulose more accessible to anaerobic bacteria. Based on Table 5 and Fig. 2, increasing the pretreatment time from 0 to 24 h could enhance the S/N ratio from 26.07 to 28.14. Furthermore, pretreatment during 48 h resulted in S/N of 28.20. It indicates that the longer the pretreatment process, the more the lignin could be removed, which results in high yield.

Table 5. S/N response table for *Vb*.

Levels	Parameters		
	A	B	C
Level 1	**27.59**	26.07	**31.98**
Level 2	27.35	28.14	27.81
Level 3	-	**28.20**	22.61
Delta	0.24	2.14	9.37

Moreover, the total solid (TS) affected the total biogas volume significantly (Fig. 2). The best TS in this study was 2%. Generally, the optimum range of TS in anaerobic digestion relied upon the substrates. Budiyonoet al. [6] stated that the optimum range of TS was 7-9% using vinasse as a substrate. Furthermore, Kalia et al. [20] found that TS of 2-4% was the best in the digestion of banana stem waste. Hence, the results of our study were in line with Kalia et al. [20]. Bagasse and banana stems contained high fibers, but vinasse contained high simple organic compounds. Thus, more water was needed for digesting bagasse and banana stems than digesting vinasse. Consequently, the TS content in digesting bagasse and banana stems was lower than that in digesting vinasse. The substrate contained too high TS and was not good for anaerobic performance. The high TS content caused the high production of volatile fatty acids (VFAs) by acidogenic bacteria activity. Accumulation of VFAs inhibited the methanogenic bacteria growth so that biogas production was low [31, 32-34].

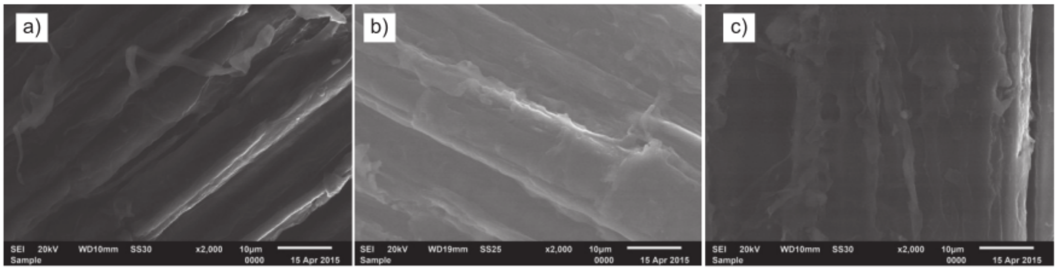

Fig. 3. SEM image of bagasse (magnification 500x), a) before pretreatment, b) after pretreatment during 24 h, c) after pretreatment during 48 h [14].

Analysis of Variance (ANOVA) Method

The statistical method of ANOVA was applied to determine the individual interactions of all parameters in the experiments. Therefore, ANOVA was applied to investigate the effects of inoculums type, pretreatment time and total solid on biogas yield. The ANOVA results for biogas yield are shown in Table 6. This analysis was conducted using Minitab software. The significance of parameters in ANOVA was determined by comparing the F values among the parameters. The parameter C had the highest F ratio of all parameters with a value of 61.95. The contribution rate (%) shows the percentage contribution of each parameter in the process. The more the contribution rate, the more dominant the parameter in the process. According to Table 5, the percentage contribution of parameters A, B, and C on the biogas yield is 0.43%, 7.97%, and 83.51% respectively. Thus, the most dominant parameter affecting the biogas yield was total solid (parameter C, 83.51%). The second dominant parameter was pretreatment (parameter B, 7.97%). On the other hand, the inoculums type was the most neglected parameter because of its very low contribution rate (parameter A, 0.43%). Furthermore, the percent of error was considered quite low which was 8.09%.

Regression Analysis of Total Biogas

Correlation between dependent and independent variables could be analyzed and predicted using regressions analysis [25]. In this study, the dependent variable was biogas yield (*Vb*), whereas the independent variables were inoculums (*In*), pretreatment time (*Tp*), and total solid (*TS*). By using linear and quadratic regression models, equations were made to predict the biogas yield and shown in Eq. 2.

$$Vbl \text{ (linear)} = 43.71 - 1.56\, In + 0.1312\, Tp - 3.207\, TS \qquad \text{R-Sq} = 84.65\% \qquad (2)$$

Vbl indicates the predicted biogas yield based on the linear regression model. Fig. 4a) shows correlation between the measured and predicted *Vb* based on the experiment and Eq. 2 respectively with correlation coefficient R^2 of 84.65%. Furthermore, the equation using quadratic regression model for predicting biogas yield is given in Eq. 3.

$$Vbq \text{ (quadratic)} = 50.51 - 2.69\, In + 0.694\, Tp - 7.59\, TS - 0.00791\, Tp^2 + 0.338\, TS^2 - 0.055\, InTp + 0.432\, InTS - 0.0179\, TpTS \qquad \text{R-Sq} = 93.43\% \qquad (3)$$

Vbq demonstrates the predicted biogas yield based on the quadratic regression model. Fig. 4b) shows correlation between the measured and predicted *Vb* based on the experiment and on Eq. 3 respectively, with correlation coefficient R^2 of 93.43%. As a result, the quadratic regression model is proved to be more effective for the estimation of biogas yield.

Table 6. Results of ANOVA for biogas yield.

Variance source	Degree of freedom (DoF)	Sum of squares (SS)	Mean of squares (MS)	F ratio	Contribution rate (%)
A	1	10.89	10.89	0.64	0.43
B	2	202.00	101.00	5.91	7.97
C	2	2117.37	1058.68	61.95	83.51
Error	12	205.07	17.09	-	8.09
Total	17	2535.32	-	-	100

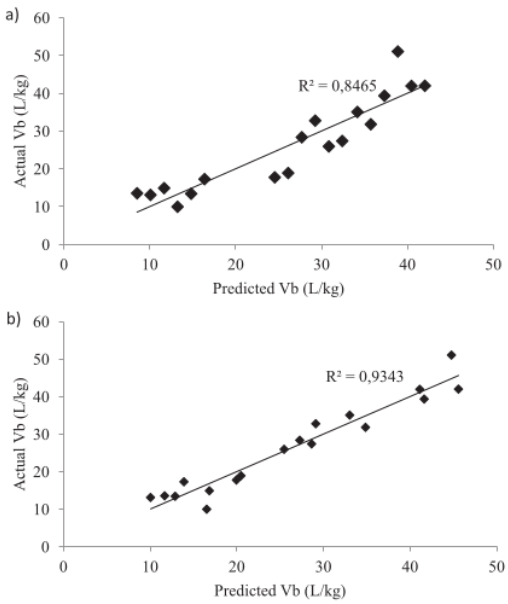

Fig. 4. Comparison of a) the linier regression model and b) quadratic regression model with experimental results for *Vb*.

Table 7. Mean response table for *Vb*.

Levels	Parameters		
	A	B	C
Level 1	27.13	21.68	40.18
Level 2	25.57	29.39	25.17
Level 3	-	27.98	13.69
Delta	1.56	7.71	26.49

Estimation of Maximum Biogas Yield

By using Taguchi method, a confirmation experiment was conducted for validating the optimization condition [25]. In the estimation of maximum biogas yield, Eq. 4 was used.

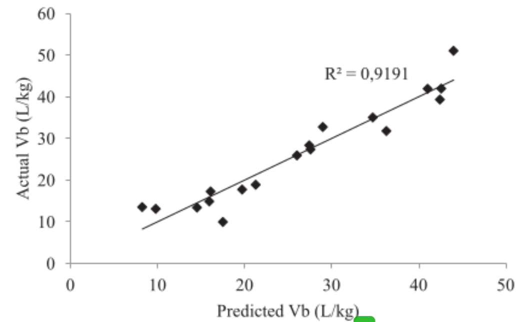

Fig. 5. Comparison of Taguchi model with experimental results for *Vb*.

$$Vb_{max} = (A_1 - T_{Vb}) + (B_3 - T_{Vb}) + (C_1 - T_{Vb}) + T_{Vb} \quad (4)$$

The A_1, B_3, C_1 represented the optimum average values of biogas yield. The value of Vb_{max} was calculated using data of A_1, B_3, C_1 shown in Table 7. Based on the calculations, the maximum biogas yield (Vb_{max}) from the optimum condition was estimated to become 42.59 L/kg.

Confirmation Test

Confirmation test about correlation between the parameters and biogas yield was made for the Taguchi method and regression equations (linear and quadratic) at optimum and random levels. In Table 8, the comparison of measured and predicted biogas yield obtained by using the Taguchi method (Eq. 4) and regression equations (Eq. 2-3) are given. The measured and predicted biogas yields are very close to each other. For reliable statistical analyses, error percent must be below 20% [25]. Therefore, the results obtained from the confirmation tests reflected successful optimization. In addition, Fig. 5 shows the comparison of measured and predicted biogas yield which were obtained by Taguchi model. The comparison resulted in a straight line with good R^2 which was 91.9%.

Table 8. Predicted biogas yield and confirmation test results by Taguchi method and regression equations.

Level	For Taguchi method			For linier regression equations			For quadratic regression equations		
	Experiment (L/kg)	Prediction (L/kg)	Error (%)	Experiment (L/kg)	Prediction (L/kg)	Error (%)	Experiment (L/kg)	Prediction (L/kg)	Error (%)
$A_1B_3C_1$ (Optimum)	41.97	42.59	1.48	41.97	42.03	0.14	41.97	45.58	8.60
$A_2B_1C_1$ (Random)	35.04	34.73	0.88	35.04	34.18	2.45	35.04	33.03	5.74
$A_2B_2C_2$ (Random)	28.35	27.43	3.25	28.35	27.70	2.29	28.35	27.26	3.84
$A_2B_3C_3$ (Random)	13.41	14.54	8.43	13.41	14.82	10.51	13.41	12.89	3.88

Conclusion

The Taguchi method was used to determine the optimal parameters in biogas yield from bagasse. Furthermore, the L_{18} ($2^1 \times 3^2$) full factorial design with a mixed orthogonal array was selected to conduct the experiments. The proposed parameters include type of inoculum (cow rumen and cow dung), NaOH pretreatment time (0, 24, 48 h), and total solid (2, 5, 10%). Maximum yield was obtained by adjusting signal-to-noise (S/N) ratio of larger-the-better characteristics. The best level for each parameter was A_1 (cow rumen), B_3 (48 h), and C_1 (total solid 2%). This conclusion was based on the S/N value in each parameter i.e. 27.59, 28.20, 31.98 for A_1, B_3, C_1 respectively. Cow rumen contained higher ruminant bacteria than cow dung, so bagasse was easier to degrade using the former one. Furthermore, the longer the pretreatment time, the more accessible the cellulose would be by bacteria. Hence resulted in a greater biogas yield. Moreover, too high total solid produce excess in VFAs, which were toxic for biological activity. Hence, the best total solid was 2%. Based on ANOVA, it was found that the total solid was the most dominant parameter on biogas yield with a contribution percentage of 83.51%. Which was followed by pretreatment time (contribution percent of 7.97%) and inoculum type (contribution percent of 0.43%). Prediction of biogas yield was conducted through developed linear and quadratic regression models which demonstrated a correlation coefficient (R^2) of 0.846 and 0.934 respectively. Meanwhile, the Taguchi method could predict the biogas yield successfully with R^2 of 0.919. According to the confirmation test, The Taguchi method and quadratic regression equation resulted in error prediction below 10%. Hence, it is recommended to apply in the optimization of many parameters for various wastes.

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Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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