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Effect of Substrate/Water Ratio on Biogas Production from the Mixture Substrate of Rice Straw and Salvinia molesta

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ABSTRACT

The substrate/water (S/W) ratio is one of the affecting parameters in anaerobic digestion (AD) since it affects the concentration of total solids (TS) in the biogas feedstocks. The appropriate S/W ratio has to be found to result in a high biogas yield. The goal of this study was to look into the influence of S/W ratio on biogas production from mixture substrate of rice straw and Salvinia molesta. Ratio of S/W was varied to be 1/7 w/v (TS 9.67%w/w), 1/10 w/v (TS 7.52%w/w), 1/13 w/v (TS 6.15%w/w), 1/16 w/v (TS 5.20%w/w). The results showed that S/W of 1/7, 1/10, 1/13, 1/16 resulted a total biogas yield of 22.86, 38.67, 42.71, 43.69 mL/g TS respectively. Decreasing TS from 9.67 %w/w (S/W of 1/7) until 6.15%w/w (S/W of 1/13) could increase the TS removal from 31.03% until 55.66%. However, at TS 5.20%w/w (S/W of 1/16), the TS removal was lower than that at TS 6.15%w/w (S/W of 1/13). The modified Gompertz (R^2 = 0.94 – 0.98) can predict evolution of biogas production with higher precision than the first order kinetic (R^2 = 0.91 – 0.98). The optimum TS was successfully predicted to become 5.40%w/w.

1. INTRODUCTION

Anaerobic digestion (AD) is one of the best methods to treat organic wastes. By AD, organic substances in the wastes will be degraded to biogas with the help of bacterial activity (Kougias & Angelidaki, 2018). Logically, the higher organic waste concentration in the digester, the higher concentration of biogas will be produced. However, study conducted by Budiyono et al., 2014) (Budiyono, Syaichurrozi, & Sumardiono, 2014) proved that when total solid (TS) of organic material was higher than 9%, total biogas yield decreased. Study by Shankar et al., 2013 (Shankar, Patil, Muralidhara, Ramya, & Ramya, 2013) found that a mixture of water hyacinth and water produced high concentration of biogas if the TS value was in range of 7-9%. Another study by Budiyono et al., 2010 (Budiyono, Widiasa, Johari, & Sunarso, 2010) had the same conclusion that TS of 7.4-9.2% was good concentration to generate biogas from cattle manure. Furthermore, the study from Yavini et al., 2014 (Yavini, Chia, & John, 2014) also informed that the good TS level in AD of agricultural wastes was 9%. Hence, in conclusion, some authors have agreed that the optimum range of TS was 7-9.2%.

On the other side, a study from Igoni et al., 2008 (Igoni, Abowei, Ayotamuno, & Eze, 2008) stated that TS of 10% (more than 9%) was better than that of 6-8% in AD

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of municipal solid waste. Furthermore, based on research conducted by Kalia et al., 2000 (Kalia, Sonakya, & Raizada, 2000) found that TS of 2-4% (lower than 7%) was the best level to produce methane from AD of banana stem waste. Moreover, the authors (Sinbuathong, Munakata-Marr, Sillapacharoenkul, & Chulalaksananukul, 2011) also proved that TS of 4.8% produced higher CH_4 yield than that of 9-13%. Based on information above, the optimum range of TS was not always in 7-9%, but the range can be lower than 7% or higher than 9%, but depends on the type of substrates as well.

The optimum TS concentration is not solely based on certain values but also depends on the kind of substrates used in AD. Thus, in this research, we used mixture substrate of rice straw (RS) and *Salvinia molesta* (SM). In the previous study, we found that the best chemical composition in the mixture substrate, producing the highest biogas yield, was obtained by the ratio of RS:SM was 60:40 (mass basis) (I. Syaichurrozi, 2018). The RS is a waste that resulted when Indonesian farmers harvest their rice plants. Approximately 58% of mass of single rice plant is to be the RS (I. Syaichurrozi, 2018; Iqbal Syaichurrozi, Suhirman, & Hidayat, 2018). Furthermore, the SM is alike water hyacinth, which is a free-floating aquatic plant having high doubling time and growth rate. It is one of the problems in Indonesian agriculture because it can decrease the irrigation system efficiency and disturb the rice plant growth (I. Syaichurrozi, 2018; Iqbal Syaichurrozi et al., 2018).

The existing studies have not reported about the effect of S/W in mixture substrate of RS and SM yet. Therefore, this study aims to investigate the influence of TS concentration on biogas yield from mixture substrate of RS and SM (with ratio of 60:40) (I. Syaichurrozi, 2018), to investigate the effect of ammonium, ammonia and VFA on the digestion process and to compare the biogas evolution through modified Gompertz and first order kinetic models. Finally, the prediction of optimum TS was estimated by making correlation between TS and biogas yield.

2. METHODS

2.1. Materials

The RS and SM used in this study were same as those used by the author (I. Syaichurrozi, 2018). They were collected from some paddy fields located in Bayah Regency (Indonesia). They were cleaned using water. Furthermore, they were dried under the sun. After dry, they were blended to reduce their size to be 18 mesh. Detailed chemical compositions of RS and SM were presented in Table 1. The rumen fluid (as inoculums) was collected from the cow slaughterhouse in Cilegon City (Indonesia). It had TS level of 4%w/v.

Table 1. Characteristics of RS and SM

Component	RS	SM
Total solid (TS) (%)	94.48	86.98
Crude fiber (%TS)	38.00	25.40
Crude carbohydrate (%TS)	67.93	53.95
Crude protein (%TS)	9.19	3.53
Crude lipid (%TS)	0.92	0.93
Lignin (%TS)	8.17	13.49
Hemicellulosa (%TS)	6.49	3.19
Cellulosa (%TS)	9.52	2.10
Volatile solid (VS) (%TS)	78.04	58.42

2.2. Experimental Set Up

Laboratory batch digesters used in this study were adapted from other authors (I. Syaichurrozi, 2018; Iqbal Syaichurrozi, Basyir, Farraz, & Rusdi, 2020; Iqbal Syaichurrozi et al., 2018). They were made by modifying the 600-mL-polyethylene bottles. To make anaerobic condition, the rubber was used to plug the bottles. The experimental schematic diagram in this study is shown in Figure 1.

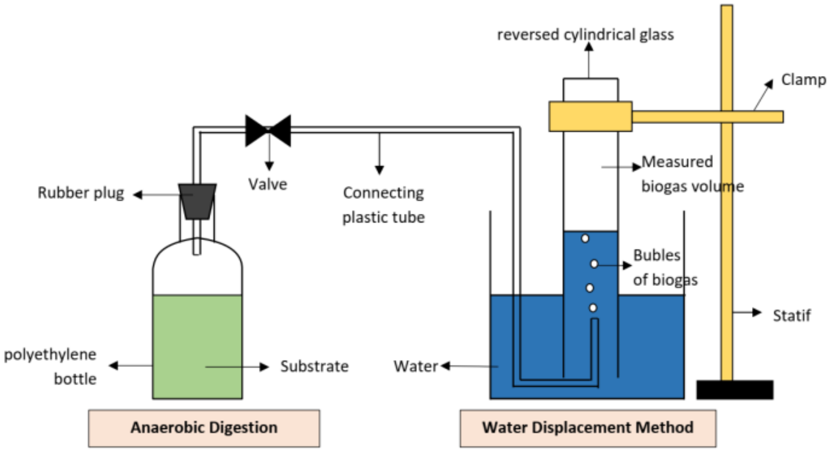

Figure 1. The experimental schematic diagram

Table 2. Total runs in this study

Substrate			S/W (w/v)	Water (mL)	Rumen fluid (mL)	Total Solid (TS)	
RS (g)	SM (g)	Total (g)				g	%w/w
6	4	10	1/7	70	25	10.15	9.67
6	4	10	1/10	100	25	10.15	7.52
6	4	10	1/13	130	25	10.15	6.15
6	4	10	1/16	160	25	10.15	5.20

Remarks: RS, Rice straw; SM, *Salvinia molesta*;; TS, Total solid; S/W, Substrate/Water ratio

2.3. Experimental Design and Procedures

Total mixture mass of RS and SM of 10 gram with the RS:SM ratio of 60:40 (mass basis) was used as substrates (I. Syaichurrozi, 2018). Water was mixed to adjust ratio of S/W to be 1/7, 1/10, 1/13, 1/16 w/v. Furthermore, 25 mL of rumen's fluid was added as inoculum (I. Syaichurrozi, 2018; Iqbal Syaichurrozi et al., 2018). For all variables, initial pH was conditioned at 7.0±0.1 by using NaOH 1 N. Total runs in this study were presented in Table 2.

The anaerobic digestion process was running for 40 days under room condition. Daily volume of biogas was determined using water displacement method, referred to Syaichurrozi et al., 2018 (Iqbal Syaichurrozi et al., 2018). Meanwhile, the change in pH was monitored using a digital pH meter (Hanna-Digital-PHEP-98107-1, Hanna instruments, Rumania) every two days. The concentration of ammonium ion (NH_4^+-N) was analyzed via Standard Methods (APHA, 2012). The concentrations of ammonia (NH_3-N) and volatile fatty acids (VFAs) were estimated using equation (1) (El-Mashad, Zeeman, Van Loon, Bot, & Lettinga, 2004) and (2) (Paul & Beauchamp, 1989). The TS removal was calculated using equation (3).

$$(\mathrm{NH_3 - N}) = (\mathrm{NH_4^+ - N}) \times \left[1 + \frac{10^{-\mathrm{pH}}}{10^{-\left(0.1075 + \frac{2725}{\mathrm{T}}\right)}}\right]^{-1} \tag{1}$$

, T in Kelvin (1)

$$\mathrm{pH} = 9.43 - 2.02\,\frac{\mathrm{VFAs}}{[(\mathrm{NH_3 - N}) + (\mathrm{NH_4^+ - N})]} \tag{2}$$

$$\text{TS Removal (\%)} = \frac{\text{initial TS (g)} - \text{final TS (g)}}{\text{initial TS (g)}} \times 100\% \tag{3}$$

2.4. Kinetic Model

The biogas evolution during AD was simulated via models of modified Gompertz (equation (4); (Iqbal Syaichurrozi et al., 2020) and first order kinetic (equation (5); (Tri Mardiani, Budiyono, & Sumardiono, 2015). The value of ym, λ, μ, k was searched by using non-linear regression with help of polymath 5.0 educational version.

$$\mathbf{y(t) = ym.\exp\left\{-\exp\left[\frac{\mu.e}{ym}(\lambda - t) + 1\right]\right\}} \tag{4}$$

$$\mathbf{y(t) = ym\left(1 - \exp(-k.t)\right)} \tag{5}$$

where: ym, maximum biogas yield (mL/g TS); y(t), biogas yield at t days (mL/g TS); λ, adaptation time (days); μ, biogas production rate (mL/g TS.day); t, digesting time (days); k, biogas rate constant (/day); e, mathematical constant (2.718282)

3. RESULT AND DISCUSSION

3.1. Biogas Production

The different values of the S/W ratio affected the difference of initial TS concentration in the substrates (Table 2). The more water was added, the lower the TS concentration of the substrates. The standard of S/W was 1/7, because this ratio was used in the previous study (I. Syaichurrozi, 2018).

The daily biogas yields (mL/g TS) during fermentation at different S/W ratios were shown in Figure 2(A). There were some zones in daily biogas yield patterns from all variables. In Zone 1, daily biogas yield increased from day 0 to 8. The non-fiber carbohydrates in substrates were converted to biogas in this zone because it was easy to be degraded in the first fermentation time (Iqbal Syaichurrozi et al., 2018). In Zone 2, the availability of non-fiber carbohydrates was low because a lot of that had been degraded in Zone I. Hence, daily biogas yield decreased from day 8 to 18. In Zone 3, daily biogas yield increased drastically from day 18 to 26. The biogas was resulted from degradation of complex organic matters (fiber carbohydrates) in this zone. It was difficult to be degraded so it could be converted into biogas after day 18. In Zone 4, daily biogas yield decreased from day 26 to 40 because the biodegradable substrate was limited.

Cumulative biogas yield was shown in Figure 2(B). It was 22.86±6.11, 38.67±3.00, 42.71±3.79, 43.69±2.51 mL/g TS for S/W ratio of 1/7, 1/10, 1/13, 1/16 respectively. The total biogas yield increased with decreasing TS from 9.67%w/w (S/W = 1/7) until 5.20%w/w (S/W = 1/16). The S/W of 1/10 resulted 69,18% more total biogas yield than S/W standard (1/7). Furthermore, the S/W of 1/13 and 1/16 produced 86.85% and 91.16% more total biogas yield than S/W standard. Based on Figure 2, the best S/W ratio for biogas production was 1/16 with TS 5.20%w/w because it resulted the most total biogas yield.

Figure 2(B) showed that biogas production at a period of day 0-18 (Zone 1 and 2) was almost same for all variables. That means, the difference in the S/W ratio did not affect the degradation rate of non-fiber carbohydrates to biogas. Furthermore, on day 18-40 (Zone 3 and 4), biogas production rate was different. That means the difference in the S/W ratio is very influential in degradation of fiber carbohydrate to biogas. By water addition, biogas production rate in period of day 18-40 was higher compared to standard S/W (1/7). Dilution could increase substrate solubility thus increase substrate consumption, and then increase the anaerobic digestion. This phenomenon indicated that substrate containing high fiber carbohydrate was suitable to be processed with TS concentration lower than 7%w/w. Meanwhile, substrate containing high non-fiber carbohydrates was enough using TS concentration of more than 7%w/w. The authors (Panico et al., 2014) also reported that chemical composition of substrates affects the hydrolysis rate. The substrate containing high readily biodegradable compounds (such as carbohydrates) is easy to be disintegrated in water. Meanwhile, the substrate containing high slowly biodegradable compounds (such as cellulose, hemicellulose, lignin) is difficult to be hydrolyzed. Therefore, the level of water was dominantly affected in Zone 3 and 4 where the degradation of non-fiber carbohydrates occurred.

The S/W ratio did not affect the pH changes significantly (Figure 2(C)). The pH level during AD for 40 days was in the range of 6.7 - 6.9 (Figure 2(C)). Furthermore, the final pH level was in range of 6.8 - 6.9.

The fluctuation of pH during AD period was due to production of VFAs and ammonium/ammonia. The pH value from beginning until end of fermentation was still in optimum range of biogas production which was 6-8, where pH in range of 6-8 did not give a significant impact on biogas yield (Iqbal Syaichurrozi et al., 2018).

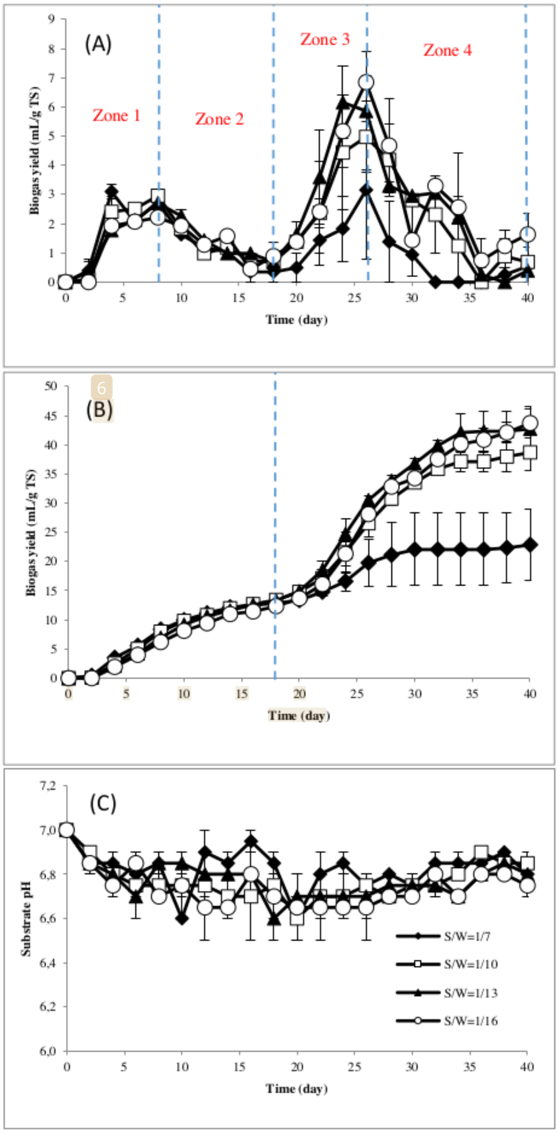

Figure 2. Effect of S/W ratio on (A) daily biogas yield, (B) cumulative biogas yield and (C) substrate pH

3.2. Ammonium, Ammonia, VFA

Ammonium ion (NH_4^+) and ammonia (NH_3) were generated by decomposition of nitrogen (protein) source in the substrates. They were uptaken by bacteria to make their cell structure. However, ratio of NH_4^+ and NH_3 in substrates relied on the pH level. Permanent equilibrium between NH_4^+ and NH_3 was shown in equation 6 and 7 (Sung & Liu, 2003).

$$NH_4^+ \boxed{\leftrightarrow} NH_3 + H^+ \qquad (6)$$

$$NH_4^+ + OH^- \boxed{\leftrightarrow} NH_3 + H_2O \qquad (7)$$

The more acidic pH level, the higher the ratio of $NH_4^+:NH_3$ in substrate. According to Deublein and Steinhauser (Deublein & Steinhauser, 2008), at pH level of 7.0, the ratio of $NH_4^+:NH_3$ was equal to 99:1. Furthermore, at pH below 7.0, ammonium ion is fully dominant (Iqbal Syaichurrozi et al., 2020). In this study, pH level during AD for all variables was 6.7 - 6.9 (close to 7.0) (Figure 2(C)) and the range of NH_4^+ and NH_3 during AD was 144.90±0.00 - 810.45±0.00 and 0.97±0.03 - 3.40±0.10 mg/L respectively (Figure 3(A and B)). Hence the ratio of $NH_4^+:NH_3$ was 99.22:0.78 - 99.69:0.31. It means the NH_4^+ was much more dominant than NH_3 in the AD process.

The sum of ammonium ion and ammonia is called total ammonia nitrogen (TAN). According to Figure 3(C), the TAN concentration increased from beginning fermentation until day 30 for all variables. S/W of 1/7 (TS 9.67%) resulted TAN easily than the other ratios. S/W of 1/7 had TAN of 573.30±0.00 and 561.16±0.20 mg/L at day 10 and day 20 respectively. Meanwhile, the other ratios had TAN of 329.88±0.04 - 354.46±0.27 mg/L and 341.75±0.12 - 378.44±0.08 mg/L at day 10 and day 20 respectively. On day 30, the peak value of TAN concentration was obtained to be 708.11±0.08, 813.85±0.10, 573.90±0.07, 695.74±0.00 mg/L for S/W ratio of 1/7, 1/10, 1/13, 1/16 respectively. From day 20 to 30, the TAN concentration increased drastically for S/W of 1/10-1/16. This path of TAN production was similar to the path of biogas production (Figure 2(B)). From Figure 2(A), biogas was generated drastically from day 20 to 30 for S/W of 1/10-1/16. Meanwhile, biogas production rate from S/W of 1/7 from day 20 to 30 was still low. This path was also similar to its low TAN production rate from day 20 to 30. Furthermore, after day 30 (which was at day 40), the TAN concentration decreased for all variables. As explained before, the anaerobic bacteria utilized TAN (ammonium ion and ammonia) as a direct nitrogen source to build their cell structure. From day 0 to 30, the TAN production rate was higher than its consumption rate. Meanwhile, on day 30 to 40, its production rate was lower than its consumption rate.

In the AD process, TAN concentration between 50-200 mg/L is considered to be good for bacterial growth. Meanwhile, when the value increased to 200-1000 mg/L, they still do not have negative effect on the growth (Rajagopal, Massé, & Singh, 2013). In this study, the TAN value ranges from 271.22±0.00 - 813.85±0.10 mg/L (Figure 3(C)). It means the TAN concentration during AD would not disturb the bacterial activity in this study due to a low TAN concentration (below 1000 mg/L).

Volatile fatty acids (VFAs) were resulted from degradation of carbon compounds in the substrates. High concentration of VFAs affected in dropping pH. The very low pH level could interrupt the AD process stability (Rajagopal et al., 2013). Methanogenic bacteria growth was more intolerant with acid condition than acidogenic bacteria growth. Based on Figure 2(C), pH level during digestion was 6.7 - 6.9. That value was still in good pH range for AD. The VFAs accumulation did not decrease the pH, because its concentration was not excessive. According to Figure 3(C and D), it shows that there is a positive correlation between TAN and VFAs. It illustrates that the higher the TAN concentration, the higher the VFAs concentration. This phenomenon was in line with the study of Syaichurrozi, 2018 (I. Syaichurrozi, 2018).

3.3. *TS Removal*

The mount of TS that was removed during AD was called TS removal. The results show that for S/W of 1/7, 1/10, 1/13, 1/16 were 31.03, 40.88, 55.66, 31.03% respectively. Generally, the higher TS removal was obtained, the higher the biogas yield was generated. However, this study showed interesting phenomena. The S/W of 1/16 produced the higher biogas but it had the lower TS removal than S/W of 1/7-1/13. In AD, the good collaboration between acidogenic and methanogenic bacteria was very important. Before biogas was produced, the organic substrate had to be degraded to VFAs by acidogenic bacteria. At S/W of 1/7-1/13 (TS 9.67-6.15%w/w), acidogenic bacteria degraded organic matters to VFAs easily so that the TS removal was high. However, the condition substrate of 1/7-1/13 was not good enough for methanogenic bacteria. S/W of 1/7, 1/10, 1/13, 1/16 contained lignin concentrations of 8.86, 6.89, 5.64, 4.77 g/L respectively. Substrates containing higher lignin concentrations were easier to produce phenolic compounds during AD. It might be more toxic against methanogenic bacteria than against acidogenic bacteria. The acidogenic bacteria were more dominant than methanogenic bacteria in the S/W of 1/7-1/13. Meanwhile, S/W of 1/16 gave a comfort condition for the methanogenic bacteria and acidogenic bacteria so that the both bacteria were in good syntrophic condition.

3.4. *Kinetic Analysis*

Simulation of biogas production during AD was successfully conducted. The kinetic parameters in the two models (such as ym, λ, μ, k) were presented in Table 3. Furthermore, a plot between experimental data and simulation data was depicted in Figure 4.

3.4.1. *Modified Gompertz Model*

S/W ratio of 1/16 (TS = 5.20%w/w) had more value of ym than ratio of 1/7-1/13 (TS = 9.67-6.15%w/w) (Table 3). That means the ratio of 1/16 resulted the maximum biogas yield in a larger amount (70.97 mL/g TS) compared with ratio of 1/7-1/13 (26.83-62.81 mL/g TS). It showed that bacteria were in the suitable metabolism conditions provided by the S/W of 1/16. The authors (Iqbal Syaichurrozi et al., 2020) stated that the value of μ is positively correlated with the value of ym. That means that the biogas production rate is in line with the total biogas yield. The substrate of 1/13-1/16 had a higher value of μ (1.53 mL/g TS.d) than the substrate of 1/7-1/10 (0.68-1.28

mL/g TS.d). The good range of S/W ratio was 1/13-1/16 and the best TS was 5.20%w/w obtained from S/W of 1/16.

The kinetic parameter of λ showed the adaptation time was needed by bacteria in the new environment. Bacteria in S/W ratio of 1/7 needed lower time to adapt which was 0.00 days. However, bacteria in substrate of 1/10-1/16 needed a longer time (5.72-8.71 days) than that in substrate of 1/7. This result was in line with a study conducted by Budiyono et al., 2014 (Budiyono et al., 2014) which reported that lag time to degrade substrate (vinasse) with TS 27.910% (0.423 days) was shorter than the need to degrade substrate with TS 7.015% (0.959 days).

3.4.2. First order kinetic model

The result from the first order kinetic model shows that the variable of S/W of 1/16 had ym value of 131.53 mL/g TS. Meanwhile, S/W of 1/7-1/13 had ym value of 33.82-126.34 mL/g TS. The S/W of 1/16 (TS=5.20%w/w) was a good ratio for bacterial activity. The k constant showed the biogas production rate per day, and it shows that the higher the k value, the faster the biogas production (Kafle, Kim, & Sung, 2013). Substrate of 1/7 had the highest k value (0.03/day) of all variables. Although S/W of 1/7 had the highest k value, it produced the lowest biogas yield. The S/W of 1/7 contained a higher TS concentration (which was 9.67%w/w) than the others, so the distance between organic matter and bacteria was closer and then the biogas was produced easily in the first digestion process. However, the high fiber carbohydrate in the substrate caused that the bacteria were difficult to degrade, so the biogas production process only lasted a short time and the biogas yield was low. The value of λ in modified Gompertz had a good correlation with the k value in first order kinetic model, which was the lower value of λ, the higher value of k would be.

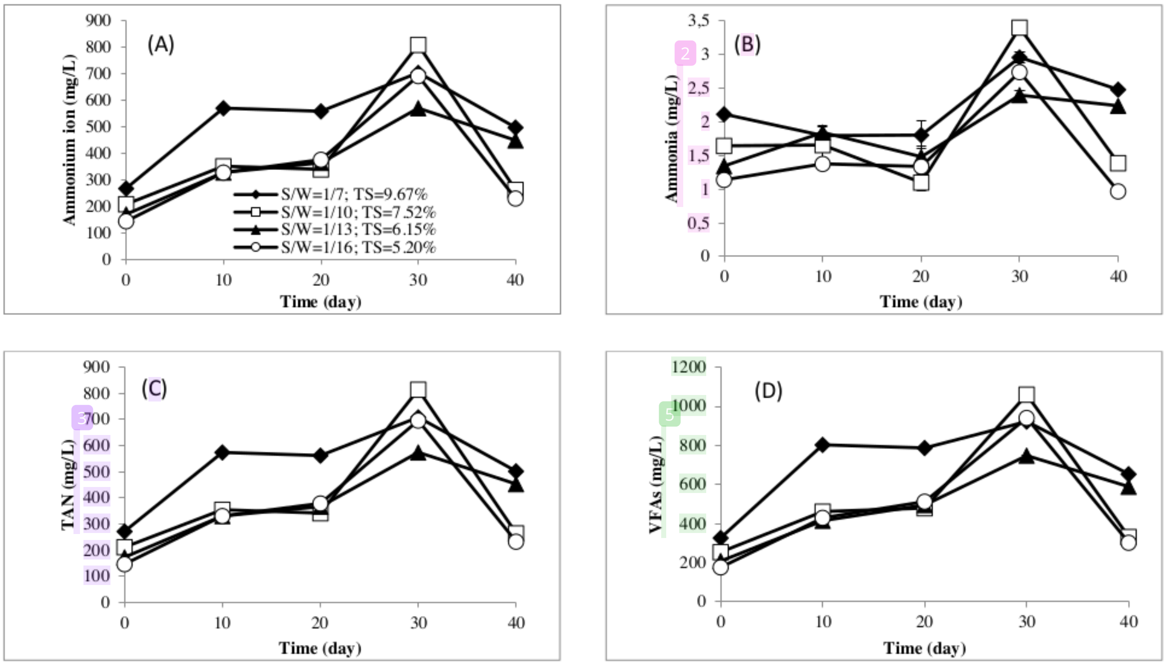

Figure 3. Concentration of (A) ammonium ion, (B) ammonia, (C) TAN, (D) VFAs during fermentation for 40 days at variation of S/W

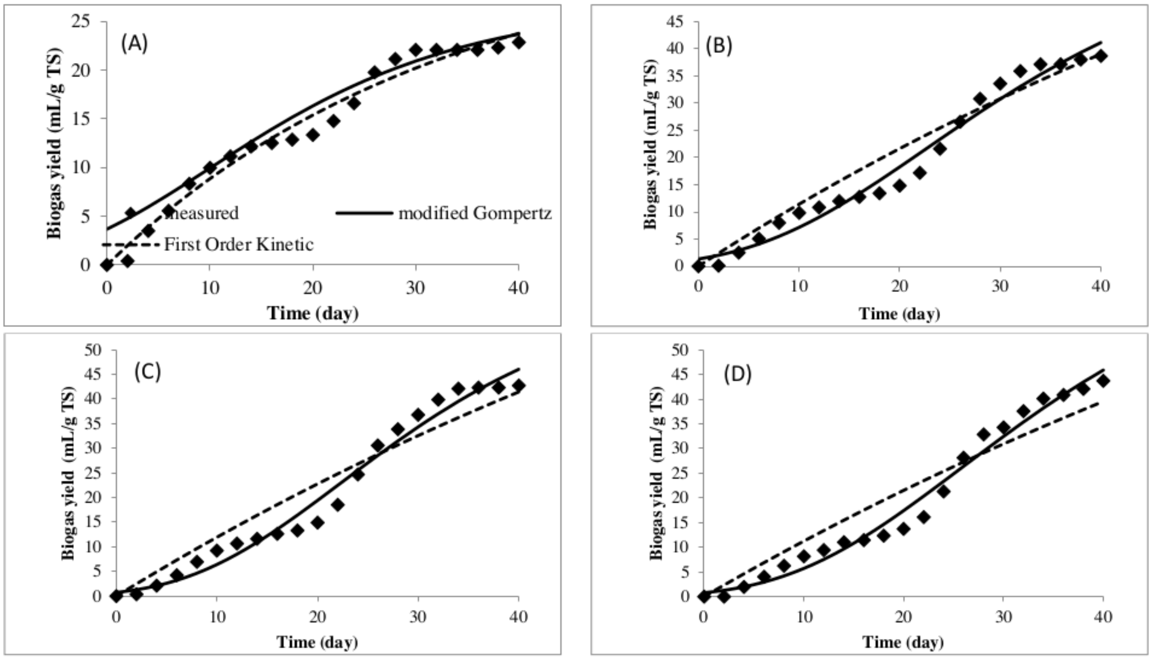

Figure 4. Comparison of measured and predicted biogas yield using modified Gompertz and first order kinetic at variation of (A) S/W=1/7 (TS 9.67%w/w), (B) S/W=1/10 (TS 7.52%w/w), (C) S/W=1/13 (TS 6.15%w/w), (D) S/W=1/16 (TS 5.20%w/w)

Table 3. Kinetic analysis results

	S/W Ratio			
	1/7	1/10	1/13	1/16
Modified Gompertz Model				
λ (days)	0.00	5.72	7.36	8.71
μ (mL/g TS.d)	0.68	1.28	1.53	1.53
R^2	0.94	0.98	0.98	0.98
ym (mL/g TS)	26.83	59.18	62.81	70.97
Predicted biogas yield (mL/g TS)-40 d	23.70	41.10	46.03	46.87
Measured biogas yield (mL/g TS)-40 d	22.86	38.67	42.71	43.69
Fitting error (%)-40 d	3.69	6.29	7.76	4.98
First-Order Kinetic Model				
k (/day)	0.03	0.01	0.01	0.01
R^2	0.98	0.94	0.92	0.91
ym (mL/g TS)	33.82	110.13	126.34	131.53
Predicted biogas yield (mL/g TS)-40 d	23.77	38.99	41.43	39.52
Measured biogas yield (mL/g TS)-40 d	22.86	38.67	42.71	43.69
Fitting error (%)-40 d	3.40	0.83	2.99	9.55

$$\text{Fitting error (\%)} = \frac{|\text{measured biogas yield} - \text{predicted biogas yield}|}{\text{measured biogas yield}} \times 100\%$$

3.4.3. Comparison between the two models

The error between the experimental data and simulation data of biogas yield for 40 days obtained from the modified Gompertz model was 3.69-7.76 % and in the first order kinetic model was 0.83-9.55 % (Table 3). Clearly, both kinetic models could fit in with the measured biogas evolution successfully because they have a low fitting error (below 10%). However, the former was better than the latter because the former had a higher R^2 value, which was 0.94 – 0.98 for the Gompertz model compared to 0.91 – 0.98 for first order kinetic.

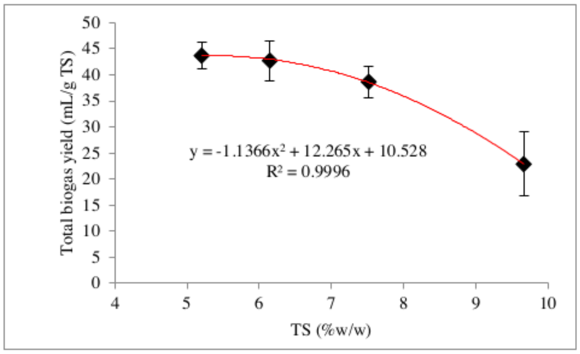

Figure 5. Correlation between TS and total biogas yield

3.5. Prediction of optimum TS

Correlation between TS and total biogas yield could be seen in Figure 5. The curve made by correlation between them had equation of $\boldsymbol{y = -1.136x^2 + 12.26x + 10.5}$ $(\boldsymbol{R^2 = 0.999})$ (equation (8)), where $\boldsymbol{y}$ was total biogas yield (mL/g TS) and $\boldsymbol{x}$ was TS (%w/w). This equation could be used to predict the optimum TS producing biogas maximally.

$$\boldsymbol{y = -1.136x^2 + 12.26x + 10.52} \qquad (8)$$

Differential of equation (8)

$$\boldsymbol{\frac{dy}{dx} = -2.272x + 12.26} \qquad (9)$$

Maximum $\boldsymbol{y}$ could be obtained at optimum $\boldsymbol{x}$. Hence, we had to obtain the value of $\boldsymbol{x}$. The optimum $\boldsymbol{x}$ could be obtained using equation (9) with $\boldsymbol{\frac{dy}{dx} = 0}$.

$$\boldsymbol{0 = -2.272x + 12.26}$$
$$\boldsymbol{-12.26 = -2.272x}$$
$$\boldsymbol{x = 5.4} \qquad (10)$$

By the calculation, the value of optimum $\boldsymbol{x}$ was 5.4. That means, the optimum TS was 5.40%w/w.

4. CONCLUSION

Variation of S/W ratio influenced TS concentration of substrates, where S/W of 1/7, 1/10, 1/13, 1/16 resulted the TS concentration of 9.67, 7.52, 6.15, 5.20%w/w respectively. The S/W ratio of 1/7, 1/10, 1/13, 1/16 resulted total biogas of 22.86, 38.67, 42.71, 43.69 mg/L respectively. The more the water was added into digesters, the more the biogas was produced. Compared to S/W of 1/7, The S/W of 1/10, 1/13, 1/16 could increase total biogas 69.18, 86.85, 91.16%. The TS 5.20%w/w (S/W of 1/16) resulted the highest biogas for all variables. Furthermore, the modified Gompertz and first order kinetic successfully simulated the biogas production from all variables, with the fitting error of 3.69-7.76% and 0.83-9.55% respectively. By prediction, the optimum TS concentration was 5.40%w/w.

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