

Comparison of Kinetic Models for Biogas Production from Rice Straw

By Lukhi Mulia Shitophyta

**Comparison of Kinetic Models for Biogas Production from Rice Straw**Lukhi Mulia Shitophyta^{✉,1}, Maryudi¹, Budiyo²

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¹Department of Chemical Engineering, Faculty of Industrial Technology, Universitas Ahmad Dahlan, Jl. Supomo, Janturan, Yogyakarta 55164²Department of Chemical Engineering, Faculty of Engineering, Diponegoro University, Jl. Prof. Soedarto, SH, Tembalang, Semarang 50275**Article Info**

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Abstract

The rising of global energy demand has led to an energy crisis, especially fossil energy. The development of renewable energies is needed to overcome the energy crisis. Biogas is one of renewable energies (biofuels) which is developed to minimize the dependency on fossil fuels. Biogas can be derived from agricultural wastes such as rice straw. The aim of this research was to compare the kinetic models of biogas production from rice straw using the linear and exponential equations models. This research was conducted at the total solid (TS) content of 20%, 22% and 24%. The result showed that the exponential equation had a better correlation than the linear equation on the ascending period of biogas production, while linear equation was better than exponential equation during descending period.

INTRODUCTION

The global energy demand is continually increasing due to rising of the world's population (Surendra et al., 2014; Sawatdeenarunat et al., 2015). The total consumption of world's energy reaches 549 quadrillion Btu in 2012, it will be predicted to increase about 815 quadrillion Btu in 2040 (EIA, 2016). The dependency on fossil fuels as a primary energy has resulted in several negative impacts such as: climate change, degradation of environment, and health problem (Aragaw et al., 2013). The climate change and energy crisis are the main issues facing almost all over the world (Jigar et al., 2013). The total emission of carbon dioxide increases from 32.3 billion metric tons in 2012 to 35.6 billion metric tons in 2020 (EIA, 2016).

Renewable energy has an important role to prevent the global warming and climate change (Pohl et al., 2013). The consumption of bioenergy increases significantly, along with energy security affairs and efforts to minimize environmental impact of fossil fuels (Mao et al., 2015). The renewable energy is a resource which able to regenerate in a short time (Cesaro & Belgiorno, 2015).

Renewable sources are originated from water, sun, wind, geothermal heat, tides and biomass (Ersahin et al., 2011). The utilization of biomass as bioenergy feedstock is processed by anaerobic digestion. Anaerobic digestion is a process that converts organic material into biogas (Surendra et al., 2014). Biogas feedstock can be derived from several agricultural wastes, including rice straw. Anaerobic digestion is affected by several

factors such as: temperature, ratio feedstock/inoculum (F/I), total solid content, pH, and C/N ratio (Boontian, 2014). This study focuses on the kinetic rate of biogas production at the variation of total solid contents. Therefore, the aim of this study was to compare kinetic models for biogas production from rice straw using linear and exponential equations.

RESEARCH METHODOLOGY

Feedstock and inoculum

Rice straw as a feedstock was collected and dried. After drying, the rice straw was ground into ± 2mm. The ground rice straw was stored at the room temperature prior to use. Cow’s rumen fluid was used as an inoculum.

Biogas production

This research used batch digester 1.5 L. Rice straw and inoculum were fed into the digester. Water was added to obtain the TS content of 20%, 22%, and 24%. The initial pH was 7. This research was carried out at the initial pH of 7 and room temperature. Biogas volume was measured daily by water displacement method. The correction calculation of biogas volume is shown in Equation 1.

$$V_s = V_A \times F_P \times F_T \tag{1}$$

Where, V_s = volume at standard conditions of pressure and temperature, V_A = actual volume (displaced volume); F_P = the factor for pressure; F_T = the factor for temperature. The scheme of biogas production is presented in Figure 1.

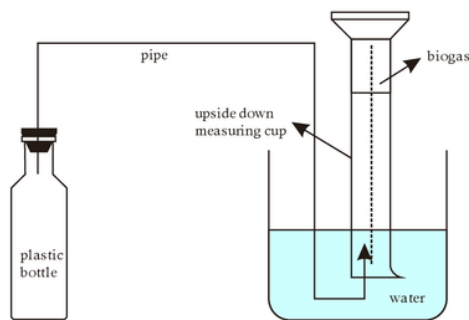


Figure 1. The scheme of biogas production

Table 1. Biogas volume at the TS contents of 20%, 22% and 24%

| Day | Biogas volume (ml/g) | | |
|-----|----------------------|--------|--------|
| | TS 20% | TS 22% | TS 24% |
| 0 | 0 | 0 | 0 |
| 1 | 1.6 | 2 | 1.1 |
| 2 | 2 | 2.4 | 1.6 |
| 3 | 2.6 | 4 | 2 |
| 4 | 3 | 6 | 2.4 |
| 5 | 5 | 7.5 | 3.5 |
| 6 | 7 | 8.3 | 5 |
| 7 | 7.8 | 8.9 | 5.6 |
| 8 | 10.7 | 16 | 8 |
| 9 | 9 | 13 | 6.8 |
| 10 | 8.5 | 11.5 | 6 |
| 11 | 8.3 | 10.5 | 5.5 |
| 12 | 8 | 10.1 | 5.5 |
| 13 | 7.7 | 9.7 | 5.2 |
| 14 | 7.5 | 9.5 | 5 |
| 15 | 7.2 | 9 | 5.2 |
| 16 | 6.8 | 8.2 | 4.9 |
| 17 | 6.6 | 8 | 5.1 |
| 18 | 7.2 | 6.6 | 4.6 |
| 19 | 6.9 | 6.3 | 4.4 |
| 20 | 6.5 | 6 | 4.2 |
| 21 | 5.4 | 5.5 | 4.1 |
| 22 | 5.1 | 5.2 | 4.7 |
| 23 | 4.3 | 4.6 | 4.9 |
| 24 | 3.6 | 4.2 | 4.5 |
| 25 | 3 | 3.7 | 3.8 |
| 26 | 2.5 | 3 | 3 |
| 27 | 2 | 2.5 | 2 |
| 28 | 0.8 | 1.8 | 1.4 |
| 29 | 0.5 | 1 | 0.7 |
| 30 | 0.2 | 0.6 | 0.3 |
| 31 | 0.06 | 0.3 | 0.2 |
| 32 | 0.05 | 0.2 | 0.1 |

Kinetic Models of Biogas Production

The rate of biogas production was simulated by linear and exponential equations. At the linear equation, the rate of biogas production will increase linearly along with the increase of digestion time. Then it will reach a peak value and will decrease linearly to a zero point as the time of biogas production increases. The linear equation is stated in Equation 2 (Ghatak & Mahanta, 2014).

$$y = a + bt \tag{2}$$

Where, y = the biogas production rate (ml/g/day); t = the biogas production time (day); a = the intercept (ml/g/day); b = the slope (ml/g/day). On the ascending graph of biogas production, b is positive, while on the descending graph, b is negative.

The exponential equation is assumed that the rate of biogas production increases exponentially with the time and after reaching a peak value, it will decrease exponentially to a zero point along with the increase of time. The exponential equation is expressed in Equation 3 (Lo et al., 2010):

$$y = a + b \exp(ct) \quad (3)$$

Where, y = the biogas production rate (ml/g/day); t = the biogas production time (day); a , b = constants (ml/g/day); c = constant (ml/g/day). c will be positive on the ascending graph of biogas production, while c will be negative on the descending graph.

RESULTS AND DISCUSSION

This research was conducted at the various TS contents of 20%, 22%, and 24%. The study of the biogas production at the variation of the TS content has been reported previously by Shitophyta et al. (2015). The data on biogas volume of each TS contents are shown in Table 1.

As presented in Table 1, the rate of biogas production increased in the period of 0 to 9 days. However, it decreased from day 10 to day 32. The increase of biogas production occurred due to the exponential phase on the microorganism growth, whereas the decrease of biogas production occurred due to the stationary phase of microorganism growth (Budiyo et al., 2010). The kinetic study was performed by dividing the periods of rate into two, namely the ascending rate period and the descending rate period.

The biogas production kinetic study was conducted using linear and exponential equation models, as shown in Figure 2 and 3 respectively.

Figure 2 (a) and (b) shows the linear graph of biogas production rate at the TS contents of 20%, 22%, and 24%. As seen in Figure 2(a), the regression coefficient (R^2) ranged from 0.91 to 0.94, while in Figure 2(b) the R^2 ranged from 0.81 to 0.99. In Figure 3(a) the R^2 varied about 0.93-0.95. The R^2 on the exponential graph was greater than the R^2 on the linear graph. Hence, the modeling using the exponential equation on the ascending graph of biogas production had a better simulation than the linear equation. The similar result was also reported by Ghatak & Mahanta (2014) and Lo et al. (2010) who stated that the exponential equation model had a larger R^2 compared to the linear equation model. However, from Figure 3(b) showed that the R^2 on the exponential graph was smaller than the linear graph.

The ascending biogas production graph of the linear equation had the $R^2 > 0.9$ at the TS contents of 20%, 22%, and 24%. On the contrary, the descending biogas production graph obtained the $R^2 > 0.9$ only at TS contents of 22% and 24%. Similarly, on the ascending graph of the exponential equation, the $R^2 > 0.9$ was obtained at TS contents of 20%, 22%, and 24%, but on the descending graph of the exponential equation gave the $R^2 < 0.9$.

The highest biogas production rate in this study was obtained at the TS content of 22% both in linear and exponential equation as shown in Figure 2 and 3. The result of this study was comparable to the study reported by Shitophyta et.

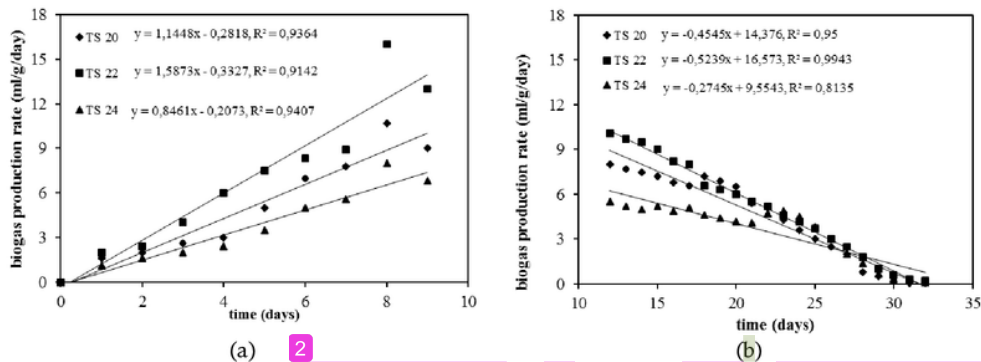


Figure 1. The linear graph of biogas production rate (a) the ascending period of biogas production rate (b) the descending period of biogas production rate.

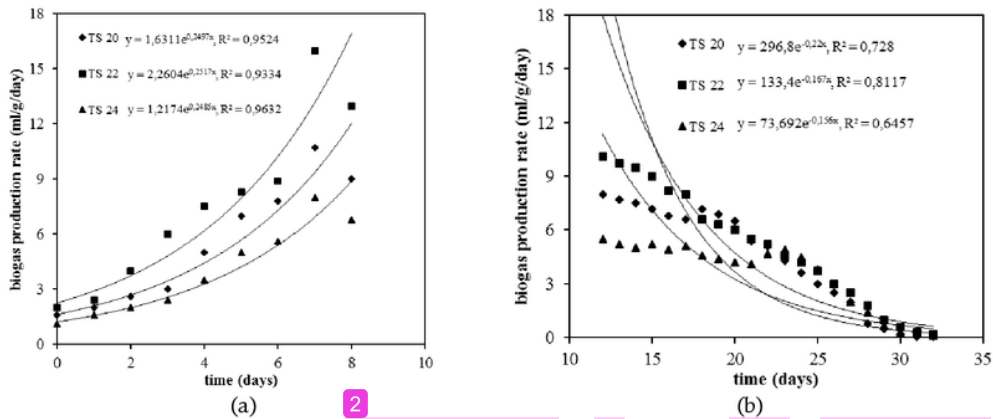


Figure 2. The exponential graph of biogas production rate (a) the ascending period of biogas production rate (b) the descending period of biogas production rate

al. (2015) who also found that the highest rate was obtained at the TS content of 22% simulated by first-order kinetic model.

CONCLUSION

The TS content affects the biogas production rate of rice straw. The highest biogas production rate is obtained at the TS content of 22%. The exponential model gives a better correlation value than the linear model during ascending period of biogas production. While linear model has better correlation than exponential model, during descending period of biogas production.

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