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Analysis of Biogas Production Kinetics from Cow Dung and Food Waste

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ABSTRACT

The increasing volume of organic waste, such as cow dung and food waste, is a significant environmental problem. One potential solution is the utilization of these wastes as raw materials for biogas production through anaerobic processes. This study aims to analyze the rate of biogas production from a mixture of cow dung and food waste with a kinetic approach using three mathematical models: First-Order, Gompertz, and Logistic. The volume of biogas produced was measured periodically and analyzed using the three models to determine kinetic parameters such as the maximum rate of biogas production and time. Using secondary data from previous studies, three kinetic models, namely Gompertz, First Order, and Logistic, were applied to predict biogas. The best modeling results that have been obtained are in Logistic modeling. In this modeling, the SSE value of cow dung is 58.62 mL and potential biogas peoduction is 167.12 mL, lag phase period is 3.82 mL and maximum biogas production is 15.91 mL.

Keywords: *biogas, cow dung, food waste, co-digestion, kinetics, model, Gompertz, first-order, logistics*

1. INTRODUCTION

Biogas is an alternative energy source that is environmentally friendly and sustainable. In Indonesia, the potential for biogas development is very large, considering the availability of organic raw materials such as livestock manure and food waste is quite abundant, especially in agricultural and livestock areas. Cow dung contains natural anaerobic microorganisms that support the formation of methane, while food waste has the potential to produce biogas (Widarti *et al.,* 2013).

High organic matter content makes it an ideal substrate combination in the co-digestion process. Biogas production can be optimized through understanding the kinetics of substrate degradation in the anaerobic digestion process. Kinetics are instrumental in describing reaction rates and gas accumulation, and help in the design and optimization of biodigester systems. The first-order reaction model is one of the most widely used in describing the decrease in volatile solid (VS) concentration during the fermentation process (Widarti *et al.,* 2013). In addition, the kinetics approach can be used to estimate the optimum residence time and the amount of biogas that can be produced (Widarti *et al.,* 2013).

The volume of biogas produced from a mixture of food waste and cow dung varies depending on the mixing ratio and operating conditions. According to (Cahyono *et al.,* 2023). A mixture of vegetable waste and cow dung with a ratio of 70:30 can produce a blue flame for more than 100 seconds, with methane content reaching 93.78 %. This shows that substrate composition greatly affects the quality and quantity of biogas. On a laboratory scale, the volume of biogas production can also reach up to 26,70 mL in 36 days of fermentation (Kurniati *et al.,* 2021).

Biogas has a large capacity as a renewable energy source that can be utilized in the industrial and household sectors, as well as an effective alternative to overcome the global energy crisis. The process of biogas formation occurs through anaerobic fermentation of organic waste by microorganisms, which can be regulated to produce biogas in the form of methane gas (CH_4). As a by-product of microbial metabolic activity, biogas can be utilized in its raw state to generate heat and electricity, or it can be upgraded to biomethane for use in the production of value-added chemicals in various energy and industrial applications (Kumar *et al.*, 2021).

From an environmental perspective, the utilization of organic waste into biogas strongly supports the principle of the circular economy. In addition to reducing landfill loads and environmental pollution, this technology also provides alternative energy solutions for rural communities and small industries (Shitophyta *et al.,* 2022). Therefore, studies on the analysis of kinetics in biogas production from local wastes such as cow dung and food waste are very relevant to be developed (Kurniati *et al.,* 2021).

This study aims to evaluate the effect of variations in substrate composition on the rate and volume of biogas production, as well as to identify the most suitable kinetic model to describe the process between cow dung and food waste (Kurniati *et al.,* 2021).

Understanding the rate and mechanism of biochemical reactions in the biogas production process, such as the stages of hydrolysis, acidogenesis, and methanogenesis, relies heavily on kinetic analysis. This approach uses parameters such as microorganism growth rate (μ), biological adaptation time (λ), and reaction constants (k) to predict the behavior of the system under various operating conditions. Through kinetic modeling, system designers can develop more optimal reactor designs, reduce the frequency of laboratory trials, and estimate technical and economic feasibility for both small-scale and industrial applications. Kinetic modeling also enables quantitative analysis of the influence of environmental parameters such as pH and temperature, making it an important tool that links theoretical foundations with real-world practice in efforts to improve the efficiency of biogas processes (Angelidaki *et al.,* 2009).

Simple kinetic models are widely used in anaerobic processes to estimate biogas production potential because they are practical, data-intensive, and easy to apply. These models are empirical and derived from experimental data, allowing quantitative estimation of gas production volumes and rates without the need to simulate complex biological processes. In this study, three kinetic model approaches were used, namely modified Gompertz, logistic, and first-order reaction kinetics (Angelidaki *et al.,* 2009).

Research on the utilization of cow dung waste as raw material for biogas production has been carried out by various parties, one of which is by (Hassan *et al.,* 2022). On the other hand, a number of studies have also developed simulation models to predict biogas production, but most of these approaches rely on the simultaneous solving of complex mass balance equations, covering different types of substrates and microorganism populations. The complexity of such models leads to a system of equations involving many unknown variables, making the calculation process difficult. Therefore, a simpler but still accurate modeling approach is needed to describe the anaerobic digestion process (Hassan *et al.,* 2022).

This article makes a scientific contribution by simulating biogas production using three empirical models: a modified Gompertz, a logistic model and a first-order reaction model. These three models show good correlation coefficients in predicting biogas production outcomes. In addition, each model can be used to project the maximum gas production potential, the highest production capacity, as well as the lag phase under various experimental conditions. In particular, the modified Gompertz model has been widely recognized as a reliable approach in modeling biogas production kinetics (Hassan *et al.,* 2022).

2.2 METHODS

2.1 Secondary Experimental Data

The secondary data used in this study is from (Chibueze *et al.,* 2017), which in this study uses cow dung waste and food waste produced every day (Chibueze *et al.,* 2017)

Secondary data were obtained from research conducted by (Hassan *et al.,* 2022). This research was conducted by processing secondary data on biogas production at various volumes using cow dung and combined waste on a daily basis. Secondary data is presented in Table 1 (Hassan *et al.,* 2022).

Table 1. Cumulation Experiment Data

Days	Cow dung (ml)	Combined waste (ml)
1	1.2	2.40
2	3.6	4.25
3	7.60	8.53
4	9.0	12.20
5	10.0	15.30
6	10.3	16.45
7	11.0	19.25
8	14.8	21.18
9	14.4	24.25
10	15.5	25.28
11	16.1	26.28
12	16.9	27.28
13	17.2	28.12
14	18.0	28.82
15	19.2	30.8

Source : (Chibueze *et al.,*2017),

2.2 Kinetic Analysis

To know and understand the effect of biogas volume on biogas production. In this study, three models were used, namely the First Order Model, Logistic Model, and Gompertz Model. The purpose of using these three models is to determine the results of each model using secondary data through the comparison of existing data. In the analysis of kinetics related to the objective function, the objective function used is the type of objective function (SSE) where the data that has been obtained will be processed using Microsoft Excel software (Chibueze *et al.,* 2017).

In this study, the authors utilized secondary data that had been processed using Microsoft Excel software, then analyzed using three kinetic modeling approaches, as presented in Table 2. (Syaichurrozi, 2018).

Table 2. Kinetic models

Models	Equation	Citation
Gompertz	$y(t) = ym, \exp\left\{-\exp\left[\frac{U.e}{ym}(\lambda - t) + 1\right]\right\}, t \geq 0$	(Syaichurrozi, 2018)
First Order	$Y = A(-\exp(-k + t))$	(Syaichurrozi, 2018)
Logistic	$y = \frac{A}{[1 + exp\ exp\left[\frac{4\mu m}{A}(\lambda - t) + 2\right]]}$	(Syaichurrozi, 2018)
SSE	$SSE = \Sigma(Ydata - Ycount)^2$	(Mongomery, 2014)

Where:
y(t) = accumulation of biogas during fermentation time t days (ml)
ym = potential biogas production (ml)
U = maximum biogas production rate (ml/day)
A = maximum volume of biogas that can be produced during fermentation (ml)
µm = maximum biogas production rate (ml/day)
λ = lag phase period or minimum time required to produce biogas (days)
t = cumulative biogas production time (days)
e = mathematical constant (2.718282)
k = biogas rate constant (/day)
Ydata = Experimental Biogas Volume (ml)
Ycount = Model Biogas Volume (ml)

3. RESULT AND DISCUSSION

The results of modeling are shown in Figures 1-7.

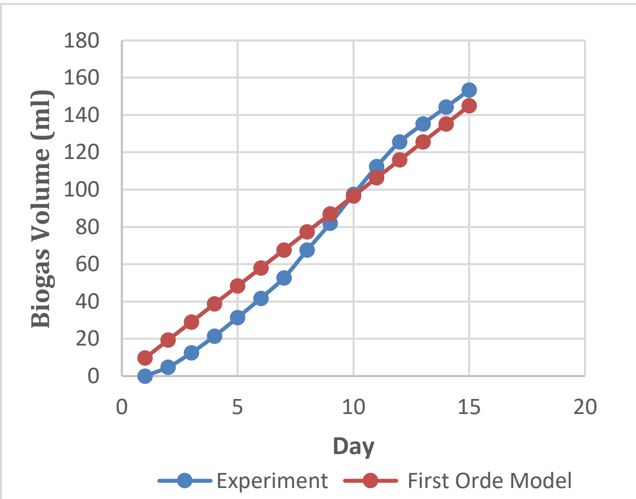

Fig 1. Plotting between experimental data and modeled data using first-order model. Biogas from cow dung

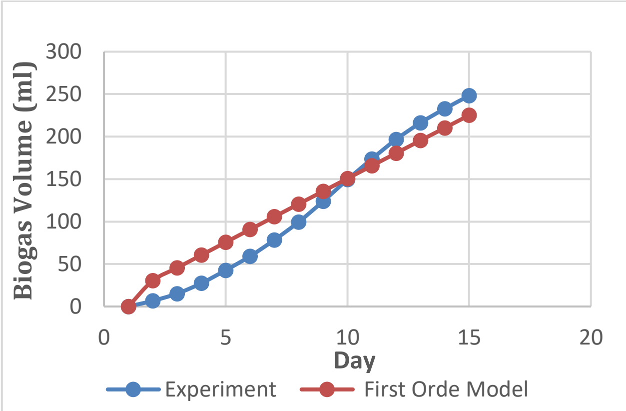

Fig 2. Plotting between experimental data and modeled data using first-order model. Biogas from combined waste

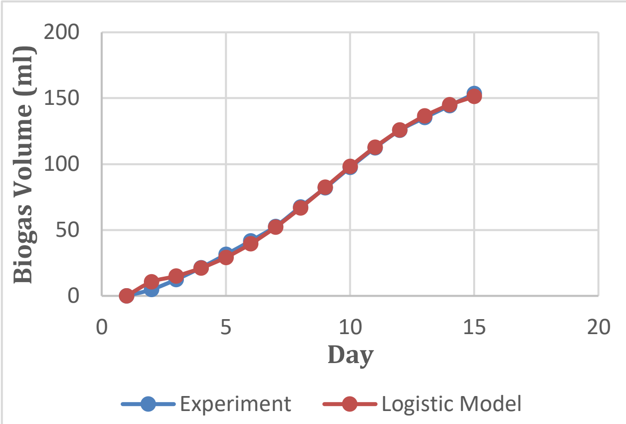

Fig 3. Plotting between experimental data and modeled data using logistic model. Biogas from cow dung

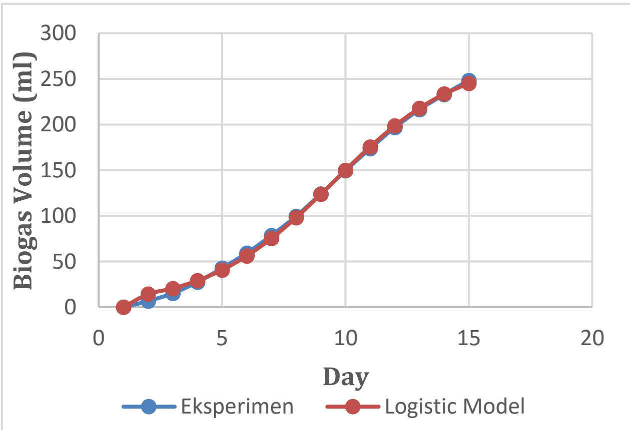

Fig 4. Plotting between experimental data and modeled data using logistic model. Biogas from combined waste

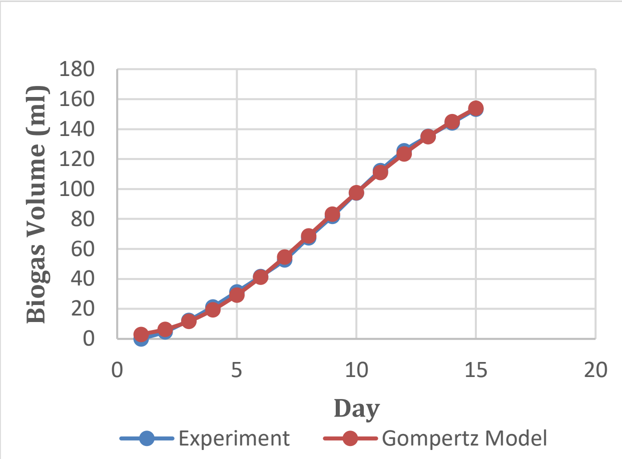

Fig 5. Plotting between experimental data and modeled data using gompertz model. Biogas from cow dung

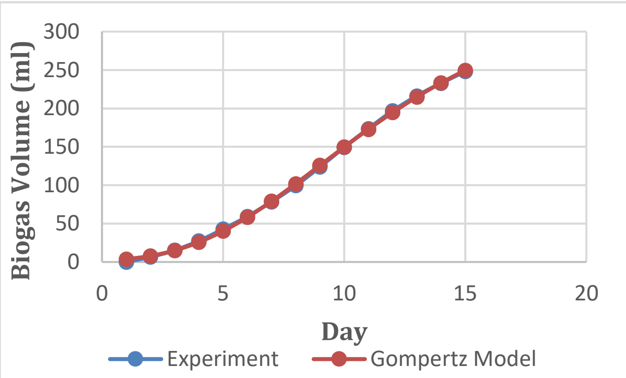

Fig 6. Plotting between experimental data and modeled data using gompertz model. Biogas from combined waste

Effect of volume on Biogas Production Based on Experiments, First-order modeling, Logistic Modelling, and Gompertz Modelling. The first graph describes the comparison between the biogas volume obtained from the experimental results and the predictions of the first-order kinetics model during the 150-day cow dung fermentation process (Mao *et al.,* 2015).

A significant increase in biogas volume was observed after the fifth day, indicating the intensified metabolic activity of microorganisms in the decomposition of organic compounds. The first-order model showed adequate accuracy in the early phase of fermentation (days 1 to 9), but showed experimental data in the mid-to-late phase (days 10 to 15), where actual biogas production exceeded model predictions (Mao *et al.,* 2015).

In this study, the effect of biogas volume in biogas production can be seen in the first-order modeling, where ml with a biogas volume of 248.19 ml. According to (Aich *et al.,* 2019) that the volume of the substrate affects the amount of organic matter available, where the greater the volume, the more biogas production will increase because organic compounds can be converted through the anaerobic fermentation process (Aich *et al.,* 2019).

In the second graph, which illustrates the fermentation of combined waste, the first-order model tends to overestimate the biogas production at the beginning of the process (days 1 to 6). This is likely due to the initial adaptation phase of microorganisms to variations in substrate composition. However, after day 7, the actual biogas volume showed a higher and more sustainable rate of increase than the model projection. This higher performance can be attributed to the synergistic effect between substrate components that accelerate the conversion of organic matter into biogas through a more complex fermentative pathway(Mao *et al.,* 2015).

Furthermore, the third and fourth graphs using the logistic model show the suitability of the experimental data for sali dung which has a constant volume value. In experiments that are in accordance with the theory that biogas production will approach the maximum value as the substrate concentration decreases or the activity of microorganisms decreases (Kafle *et al.*, 2013). In the graph above that describes the increase in product in this logistics modeling can be seen that every day has increased where the highest volume results in this modeling is 151.27 ml with a biogas volume value of 153.40 ml (Kafle *et al.*, 2013).

In the fifth graph, the results of biogas production tend to increase every day on day 13 the volume of biogas is 135.20 ml with a biogas production of 135.24 ml while on day 15 it experiences a high enough increase of 144.90 ml with a volume of 153.40 ml (Mao *et al.,* 2015) which is the effect of biogas volume on biogas production using Gompertz modeling which in this modeling is in accordance with the theory (Mao et al, 2015) which explains that cow dung substrates contain organic matter that is easily degraded by metagenetic organisms where the higher the substrate, the more biogas production will be obtained (Mao *et al.,* 2015).

The graph presented above illustrates a clear difference in the volume of biogas produced between day 10 and day 11 of the experiment. On the tenth day, the measured volume of biogas production was recorded at 149.39 milliliters, with a total cumulative volume reaching 150.67 milliliters. However, a significant increase was observed on the following day, the eleventh, where the biogas volume rose to 165.61 milliliters, and the total accumulated volume reached 173.67 milliliters. This sharp increase indicates a positive progression in biogas generation as the digestion process advances over time.

Moreover, when analyzing the sixth graph, which compares biogas production from different types of substrates, it becomes evident that the use of mixed organic waste results in a consistently higher biogas yield compared to the use of cow dung as a single substrate. This observation supports existing theoretical frameworks, which suggest that incorporating a variety of substrates in the anaerobic digestion process can significantly enhance the activity of hydrolytic and methanogenic enzymes. The increased enzymatic activity contributes to more efficient degradation of complex organic compounds, thereby improving overall substrate utilization. According to (Budiyono *et al.,* 2010).

4. CONCLUSION

The following are the conclusions obtained from this research, namely as follows:

1. Effect of biogas volume in biogas production
   The best Modelling is Gompertz Modelling where in this
   Modelling the best result is 153.98 mL with a biogas volume of 153.4 mL
2. First- Order Modelling
   In the First Order Modelling the volume of the substrate effects the amount of organic matter available, where the larger the volume, the more biogas production will increase because organic compounds can be converted through the anaerobic fermentation process
3. Logistics Modelling
   Logistics Modelling which states that biogas production will approach the maximum value as the substrate concetration decreases or microorganism activity decreases.
4. Gompertz Modelling
   In Gompertz modeling, it is stated that the volume of biogas produced from mixed waste tends to be higher than that of cow dung, which is in accordance with the existing theory that the type of substrate in mixed waste that can increase the substrate is the same as cow dung.

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