Linear and Exponential Kinetic Modelling for Biogas Production in Municipal Waste

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Abstract

In this paper, the potential to harness biogas from municipal waste is investigated and possible models that explain the kinetics derived. Municipal waste was anaerobically digested over a 60 day period at 37°C in 250 mL digesters. The cumulative biogas produced increased with increase in the digestion time. The experimental data was modelled for both linear and exponential equations in Excel. The linear equation, y = 15.3 + 1.26 fully described the linear behaviour in biogas generation in comparison to the exponential model. This was also shown by the R^2 value which showed the superiority of the linear model against the exponential model.

Keywords: Biogas, exponential model, linear model, municipal waste

1. INTRODUCTION

Biogas production from municipal waste offers an alternative source of energy for cooking and heating purposes at the same a proper waste management initiative for municipalities. Biogas is mainly composed of methane with a major composition of around 65%, carbon dioxide 35% and minute composition of water vapor, nitrogen, oxygen and hydrogen sulphide (Yusuf *et al.*, 2011). Several kinetic models for sewage sludge digestion have been used to simulate the biogas generation from organic waste (Ghatak and Mahanta, 2014; Felailane *et al*., 2015). The kinetic models can be expressed as linear, exponential, logistics kinetic, exponential rise to a maximum, first order exponential model and the Modified Gompertz equation (Yusuf *et al*., 2011; Abu-Reesh, 2014; Latinwo and Agarry, 2015; Rodriguez-Chiang and Dahl, 2015). The linear kinetic model for biogas production can be expressed in the form indicated in Equation 1 (Latinwo and Agarry, 2015) for both the ascending and descending stages.

Where: is the cumulative biogas production rate in mL/day, t is the anaerobic digestion time in days and a and b are constants obtained from the intercept and slope of y vs. t

In the exponential kinetic model it is implied that the biogas production rate increases with increase in the anaerobic digestion time. After a certain period, after reaching the highest point biogas production rate, the biogas production rate will decrease exponentially with increase in time (Latinwo and Agarry, 2015). The exponential model for cumulative biogas production rate is represented in Equation 2.

Where: y is the biogas production rate in mL/day, t is the anaerobic digestion time in days, and b are constants in mL/day and c = constant in (per day)

This study focused on evaluating the linear and exponential models' potential to be used during determining the trends in biogas production from municipal waste.

2. MATERIALS AND METHODS

2.1 Materials

Municipal waste was obtained from a local landfill. The municipal waste was sorted to remove the non biodegradable components. Biogas composition was analysed using a Biogas

5000 gas analyser from GeoTech, United Kingdom. Microsoft Excel was used for determining the modelling coefficients. The pH was measured using a Hanna instrument pH meter, the total solids (TS) and the volatile solids (VS) were measured using a Memmert oven at 105 °C and 550 °C respectively.

2.2 Methods

Anaerobic digestion was conducted in 250 mL digesters under mesophilic conditions of 37 °C for a digestion period of 60 days. The amount of biogas produced was determined by the water positive displacement method. Experiments were replicated twice and an average value used. Kinetic modelling for the linear and exponential models was considered for these conditions and the coefficients of determinations were used to determine the accuracy of each model.

3. RESULTS AND DISCUSSION

3.1 Municipal waste characterization

Municipal waste used in this study had a TS and VS content of 33.21±0.5% and the high levels of the total solids with a composition of 31.21±0.6% and 28.1±0.3% respectively. The values were indication that the municipal waste is highly biodegradable and can be used for biogas. The other physicochemical characteristics of the municipal waste are shown in Table 1.

Table 1: Physicochemical characteristics of the municipal waste

Parameter	Value
pH	7.1±0.2
Total solids (TS)	31.2±0.6
Volatile solids (VS)	28.1±0.3

3.2 Biogas composition

The biogas that was produced from the municipal waste had a methane composition of 55-70% which is quite a high amount and if further methane upgrading processes are adopted this methane can be a huge alternative energy source. Furthermore, the biogas had a carbon dioxide composition of 25-35%. The other composition for the other smaller quantity gases like water vapor and hydrogen sulphide are shown in Table 2.

Table 2: Biogas composition

Gas	**Composition**
Methane (CH_4)	55-70
Carbon dioxide (CO_2)	25-40
Water vapor (H_2O)	1.0-10
Nitrogen (N_2)	0.03-0.05
Oxygen (O_2)	0.02-0.04
Hydrogen sulphide (H_2S)	0.01-0.03

3.3 Kinetic modeling of biogas production from municipal waste

3.3.1 Linear kinetic model

The linear kinetic model for biogas production suggest that the cumulative amount of biogas produced increases linearly with increase in digestion time (Equation 3). The linear kinetic model was fitted on the experimental data and coefficient of determination of R^2 = 0.93 was found, which showed it is a good model for use on explaining the rate of biogas generation. The linear model obtained is given by Equation 3 and its fit to the experimental data is shown in Figure 1 with *y* representing the cumulative biogas production in mL/day.

$$y = 15.274 + 1.2036t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

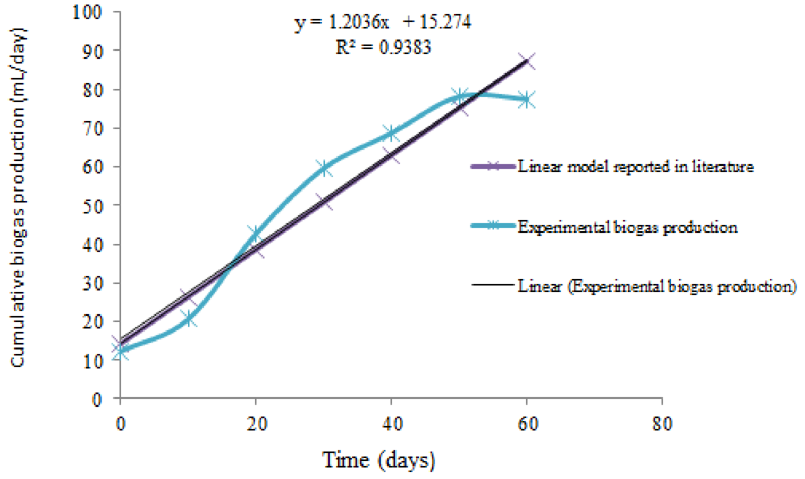

Figure 1. Comparison of the linear kinetic model to cumulative biogas experimental data

3.3.2 Exponential kinetic model

The exponential kinetic model suggests that cumulative biogas production increases exponentially with increase in digestion time (Equation 4). The exponential kinetic model obtained is represented by Equation 4 and its relation to experimental data is shown in Figure 2 with y representing the cumulative biogas production in mL/day. The coefficient of determination was R^2 = 0.83 which showed that in terms of accuracy in representing the experimental data, the exponential model was a better model than linear model.

$$y = 16.949e^{0.031t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

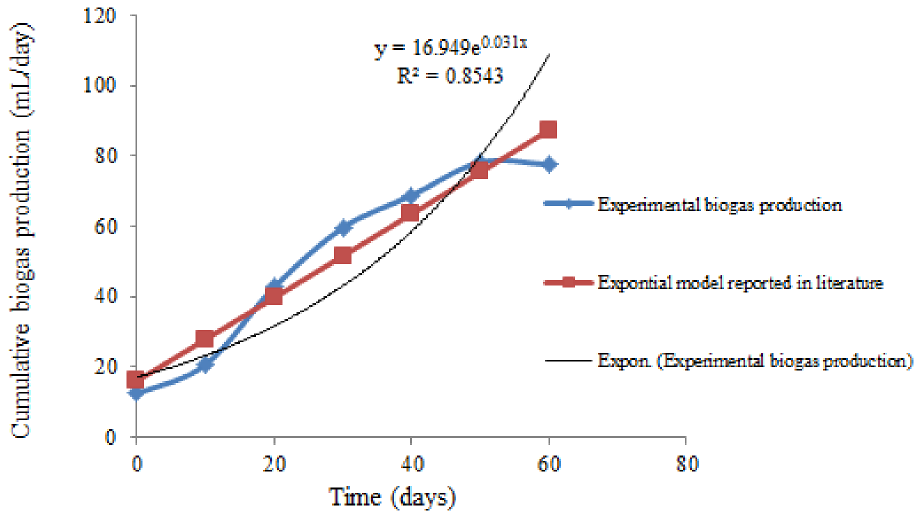

Figure 2. Comparison of the exponential kinetic model to cumulative experimental biogas data

The coefficient of determination was R^2 = 0.83 in the exponential model in comparison to R^2 = 0.93 in the linear kinetic model. The R^2 values showed that in terms of accuracy in representing the experimental data, the linear model was superior to the exponential model (Table 3).

Table 3: Summary of the kinetic models for biogas generation

Model	**Coefficient of determination (R^2)**
Linear model	0.93
Exponential model	0.85

4. CONCLUSION

The biodegradable wastes from municipalities offer an attractive raw material for biogas generation, an alternative source of renewable energy. Cumulative biogas generation from municipal waste can best be modeled by a linear model as opposed to an exponential model.

REFERENCES

Abu-Reesh, I. M., Kinetics of anaerobic digestion of Labaneh Whey in a batch reactor, *African Journal of Biotechnology*, vol. 13 (6), pp. 1745-1755 (2014).

Fedailaine, M., Moussi, K., Khitous, M., Abada, S., Saber, M. and Tirichine, N., Modeling of the anaerobic digestion of organic waste for biogas production, *Procedia Computer Science*, vol. 52, pp. 730-737 (2015).

Ghatak, M. D. and Mahanta, P., Comparison of kinetic models for biogas production from saw dust, *International Journal of Research in Engineering and Technology*, vol. 3 (7), pp. 248-254 (2014).

Latinwo, G. K. and Agarry, S. E., Modelling the kinetics of biogas generation from mesophilic anaerobic co-digestion of sewage sludge with municipal organic waste, *Chemical and Process Engineering Research*, vol. 31, pp. 43-53 (2015).

Rodriguez-Chiang, L. M. and Dahl, O. P, Effect of Innoculum to substrate ratio on the methane potential of microcrystalline cellulose production wastewater, *Bioresources*, vol. 10 (1), pp. 898-911 (2015).

Yusuf, M. O. L., Debora, A. and Ogheneruona, D. E., Ambient temperature kinetic assessment of biogas production from co-digestion of horse and cow dung, *Research in Agricultural Engineering*, vol. 57 (3), pp. 97-104 (2011).