The Kinetic of Biogas Rate from Cow Dung and Grass Clippings

Anthony Njuguna Matheri[1], Mohammed Belaid[2], Tumisang Seodigeng[3], Catherine Jane Ngila[4]

***Abstract*— In this study, we investigated the use of laboratory batch anaerobic digester to derive kinetics parameters for anaerobic co-digestion of cow dung and grass clippings. The Carbon/Nitrogen (C/N) ratio of cow dung was found to be 17.17 and grass clippings to be 20.54. Through co-digestion, the C/N ratio settled at 19.08. Laboratory experimental data from 10 litres batch anaerobic digester operating at mesophilic temperature of 37 ^{0}C and pH of 6.9 was used to derive parameters for Modified Gompertz model. The actual biogas yield was found to be 4370 ml/g COD. In the model of biogas production prediction, the kinetics constants of A (ml/g COD), μ (ml/g COD. day), λ (day) were 4319.20, 939.71, 1.91 respectively with coefficient of determination (R^2) of 0.996.**

***Keywords* – Anaerobic digestion, Co-digestion, Kinetic Models, Mesophilic Temperature, Modified Gompertz.**

I. INTRODUCTION

THE economic development of African Nations depends on the large extent on wheels of transport and power generation. With the fast depletion of non-renewable energy sources such as coal and fossil fuel which has led to environmental degradation, human health problems and global climate change, the commercial production of biogas and other alternative energy source such as solar energy, wind energy, hydropower, geothermal will definitely give a drive for the development of the economy. Biogas is used in the form of heat, electricity and fuel for manufacturing different kinds of products. It is desirable to create a world-wide energy system which is sustainable and with zero carbon emissions. This results to environmental protection and resource conservation [1, 2].

Biogas is a mixture of gases such as Methane, Carbon dioxide, Hydrogen sulphide, Ammonia and trace amount of Oxygen, Carbon monoxide and Hydrogen [3]. It is produced by break down of organic materials using bacteria under controlled conditions (parameters). The organic source is composed of biodegradables such as municipal solid waste, agricultural waste, industrial waste and animal waste [4, 5].

Biogas production takes place in series of four fundamentals steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis [6]. Figure 1 shows degradation steps of anaerobic digestion process. In hydrolysis, large organic polymers such as fats, carbohydrates and proteins are broken into fatty acids, simple sugar, amino acids respectively. This step is carried out by bactericides. Hydrolysis is followed by acidogenesis where low alcohol and organic acids are produced through fermentation process utilized by fermentative bacteria. This includes volatile fatty acids (acetic acid, butyric acid and propionic acid), gases like Carbon dioxide, Ammonia and Hydrogen and Aldehydes. In third step (acetogenesis), the products of acidogenesis are converted to acetic acid, Hydrogen and Carbon dioxide by acetogenic bacteria. Methanogenesis is the final stage whereby methanogenes bacteria converts Hydrogen, acetic acid and Carbon dioxide to Methane and Carbon dioxide [7, 8]. Equation 1 shows a simplified generic anaerobic digestion [9].

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4 \qquad (1)$$

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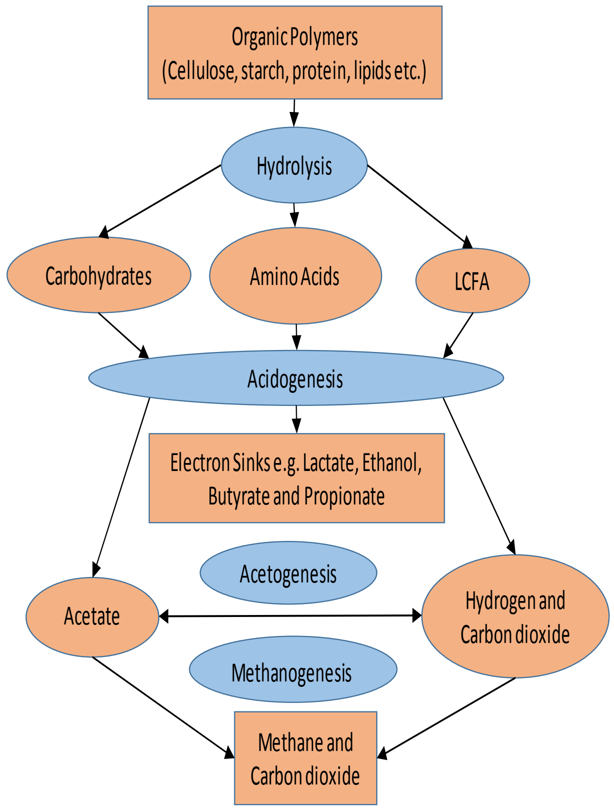

Fig 1: Degradation steps of anaerobic digestion process [8].

The rate of biogas production depends on a number of parameters that include; temperature, partial pressure, pH, hydraulic retention time, nature of substrate, C/N ratio, microbes balance, digester size and Oxygen exposure to anaerobic [10].

The main objective of this study was to investigate the effect of co-digestion in biogas production from cow dung and grass clippings. Biogas modelled kinetics were developed using modified Gompertz models with cumulative biogas production.

II. METHODOLOGY

A. Substrate Characterization

Cow dung and grass clippings were collected at the farm in Gauteng Province. Waste characterization was done to ascertain the composition. This included physical and chemical composition with regards to C/N ratio, volatile solids, total solids and elemental analysis for Carbon, Nitrogen, Sulphur and Hydrogen in accordance with the standard methods (APHA 1995) [11].

To determine biogas production rate, a batch digester was fed with the co-digested substrates and inoculum under pre-set conditions of 37 ^{0}C and pH of 7 as shown in Figure 2. pH was neutralized by a solution of 8g NaOH in 100 ml and H_2SO_4. The digester was flushed with Nitrogen to expel the Oxygen to create an anaerobic condition. The digester was immersed in the water bath and kept under the set conditions. The gas produced was measured using downwards displacement method on a daily basis until the end of retention time. Figure 2 shows the biogas digestion set up.

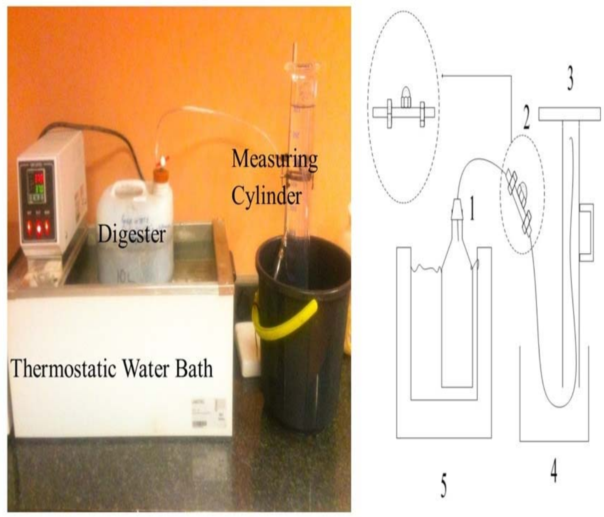

Fig 2: Biogas Production set-up

Where:

1 - Digester

2 - T-union

3 - Measuring Cylinder

4 - Water Bucket

5 - Thermostatic Water Bath.

The scope of this research was to evaluate kinetics of biogas production with regards to prediction of biogas production. Modified Gompertz equation was used to model cumulative biogas production. Equation 2 shows modified Gompertz equation:

$$Y(t) = A\exp[-\exp(\frac{\mu e}{A}(\lambda - t) + 1)] \qquad (2)$$

Where:

Y = Cumulative of specific biogas production (ml)

A = Biogas production potential (ml)

μ = Maximum biogas production rate (d^{-1})

λ = Lag phase period

t = Cumulative time for biogas production (days)

e = Mathematical constant (2.718282)

The kinetics constants A, μ and **λ** were determined using non-linear regression approach for the best fittings with the aid of solver command in Microsoft excel [12-14].

III. RESULTS AND DISCUSSION

In this study, co-digestion of cow dung and grass clippings were evaluated for the purpose of getting the bio methane potentials and bio-chemical kinetics at optimum temperature (37 ^{0}C) and initial pH of 7. Table 1 shows the substrate characterization. Grass was found to contain less volatile solids compared to cow dung which had more nutrients. The elemental analysis of cow dung indicated low C/N ratio of 17.7 compared to grass clippings of 20.54. Through co-digestion, the C/N ratio increased to 19.08.

Table 1: Substrate Characterization

Substrate	C	H	N	S	TS (g)	VS (g)	VS (%)	TS (%)	C/N ratio
Grass clippings	19.1	1.04	0.93	0.00	0.88	0.64	64.08	87.88	20.54
Cow Dung	14.87	1.65	0.84	3.66	0.77	0.92	0.79	91.55	16.16

Where:
C – Carbon
H – Hydrogen
N – Nitrogen
S – Sulphur
TS – Total Solids
VS – Volatile Solids

TS is the sum of dissolved solids and suspended solids. TS and pH are important to assess anaerobic digestion process efficiency [14, 19]. VS is the organic portion of TS that biodegrade in anaerobic process. C/N ratio is an important factor in bacteria stability in anaerobic process. The C/N ratio required for production of biogas is from 15-30 [15, 16]. TS and VS are calculated using equation (3) and 4) respectively while C/N ratio is calculated using equation (5).

$$VS(\%) = \frac{M_{dried} - M_{burned}}{M_{wet}} * 100 \quad (3)$$

$$TS(\%) = \frac{M_{dried}}{M_{wet}} * 100 \quad (4)$$

Where:

M_{dried} = Amount dried sample (mg)

M_{wet} = Amount of wet sample (mg)

M_{burned} = Amount of burned sample (mg)

$$\frac{C}{N} = \frac{(F * C_f) + (S * S_f)}{(F * N_f) + (F * N_f)} \quad (5)$$

Where:

F = First substrate

S = Second substrate

C_f = Carbon composition for the first substrate

C_s = Carbon composition for the second substrate

N_f = Nitrogen composition for the first substrate

N_s = Nitrogen composition for the second substrate

The study of biogas production from cow dung and grass clippings were conducted in a laboratory batch anaerobic digester. Biogas production was monitored and measured until there was no more biogas produced. The modified Gompertz model was used to fit the cumulative biogas production using non-linear regression as shown in Figure 2. The estimated kinetics parameters evaluated are shown in Table 2. The kinetics constants A (ml/g COD)-Biogas production potential, μ (ml/g COD. day)-maximum biogas production rate, λ (day)-lag phase period were 4319.20, 939.71, 1.91 respectively with R^2- coefficient of determination of 0.9989 [12].

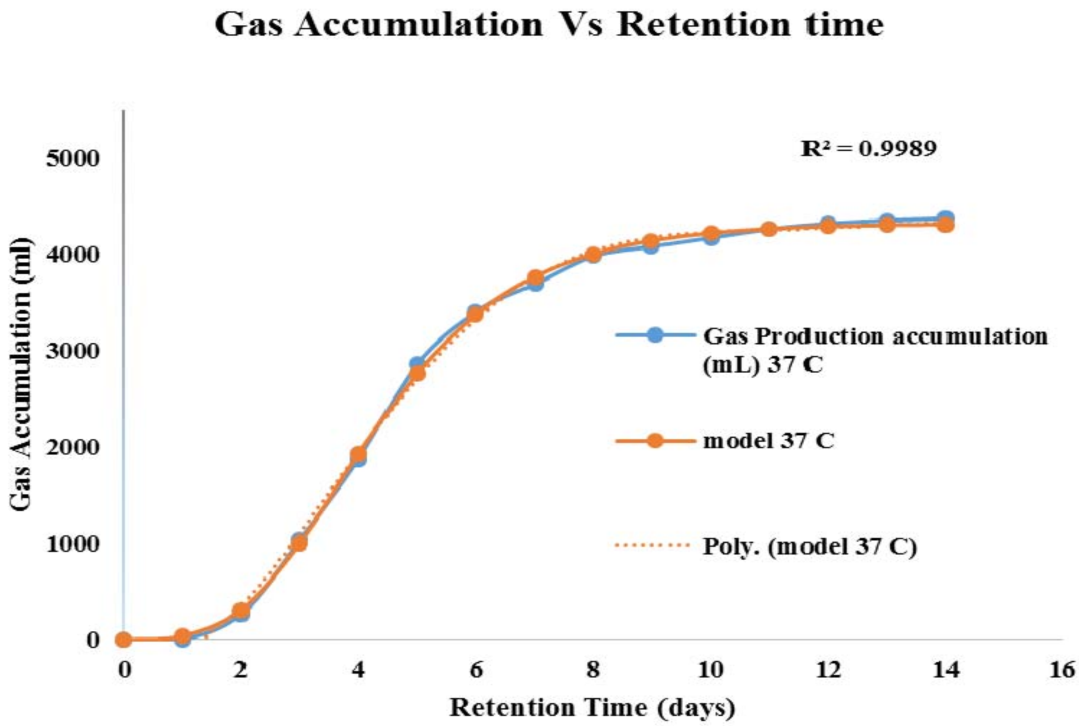

Fig 2: Biogas Prediction using Modified Gompertz model for cow dung/grass.

Table 2: Modified Gompertz parameters

Substrate	Temp	Biogas Yield (ml)	Modified Gompertz parameters (model)			R^2
			A ml	λd	μd^{-1}	
Cow dung and Grass Clippings	37 ^{0}C	4370.00	4319.23	940.84	1.94	0.996

IV. CONCLUSION

Biogas production from co-digestion of cow dung and grass clippings was established to be feasible at temperature of 37 ^{0}C. The application of modified Gompertz equation in studying the biogas production was able to predict biogas production with retention time.

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