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KINETICS OF BIOGAS GENERATION USING DOMESTIC WASTES AS FEEDSTOCK

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ABSTRACT

Anaerobically, biogas was generated from decayed organic substances through fermentation induced by microbial activities in the bio-reactor. This study reports a pilot project on the kinetics of the biogas produced from fresh pumpkin straws. The study was based on time at constant temperature of 35 ^oC and pH of 7. The result showed that 0.8 cm^3 biogas yield was made within the first six days of the production. The yield continuously increased till the 19th day with a maximum yield of 3.0 cm^3 but declined to a zero level on the 21st day. Further recovery of the gas yield was achieved by diluting the acidic slurry of the slurry with 380 cm^3 of water. The yield increased from 3.0 cm^3 to 3.7cm^3 on the 22nd and 23rd day respectively and later decreased to 3.2 cm^3 and it then leveled at 3 cm^3 in the rest of the production period. The biogas production followed initial rate Pseudo second order reaction with an average specific rate constant of 0.3212 cm^{-3} day^{-1}.

KEYWORDS: Kinetics; Biogas; Domestic Wastes; Rate Constant.

INTRODUCTION

Anaerobic fermentation is a process which stabilizes wastes of organic origin in the absence of oxygen converting them into biogas and fertilizer which could be used to improve agricultural produce [1]. Many factors influence the yield of biogas [2, 3, 4, 5]. Increasing need for energy change and conversion has become an integral part of human existence. A quest to achieve an effective and reliable form of energy has invariably brought civilization into the society of man. It therefore, implies that human existence is dependent on the accessibility of energy since it is a hallmark of economic, social and human development [6].

This technology indirectly offers sanitation of liquid organic wastes of organic origin. Wastes of organic origin sourced at different forms are microbialy disintegrated anaerobically leading to biogas generation which is invariably applied in heat and electricity generation [7]. Different unwanted organic materials can be used for biogas technology. Besides municipal solid waste, other solid and liquid wastes produced by the industries for example brewing companies, food processing industries, agricultural processing industries, sugar milling firms, paper and pulp producing firms can also be used for this purpose [8]. It also contains small amounts of hydrogen sulphide, moisture, hydrogen and siloxanes [9, 10]. (John and Twidell, 1987; Nagamani and Ramasamy, 2011).

But in all, poultry and kitchen wastes have the highest biogas potential [11]. The equations below illustrate that various products, by-products and intermediates products that are formed in the digestion process of an anaerobic state can be converted to the final product, which is methane. Anaerobic digesters can be designed and constructed based on a number of different process variables or configurations such as batch- or continuous- process; mesophilic- or thermophilic- conditions; high- or low- solid content and single stage- or multistage- complexity [10, 12, 13]. The biochemical processes that take place in a typical digester are classified into four distinct and sequential stages namely, hydrolysis, acidogenesis, acetogenesis and methanogenesis [14, 15, 16, 10]. The acids produced in Stage II are processed by methanogenic bacteria to generate methane, which is described in the following equations [17].

$CH_3COOH \longrightarrow CH_4 + CO_2$

Acetic acid Methane Carbon Dioxide

$2CH_3CH_2OH + CO_2 \longrightarrow CH_4 + 2CH_3COOH$

Ethanol Carbon Dioxide Methane Acetic acid

$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$

Equation for the overall process above is;

$C_6H_{12}O_6 \longrightarrow 3CO_2 + 3CH_4$

Many studies have been carried out on the kinetics of biogas production and developed kinetic models for the anaerobic digestion process [18]. Methane yield and kinetics were generally higher in leaves than in stems [19]. Monod model described a hyperbolic relationship existing between exponential microbial growth rate and substrate concentration [20]. In this model, microorganisms' growth rate and velocity constants are vital in the biogas reaction kinetics [21]. Biogas production reaction kinetics can also be evaluated using a model that considers several parameters such as the loading rate, hydraulic retention time, maximum specific growth of organisms and other kinetic parameters such as volume of biogas yield [22].

MATERIALS AND METHODS

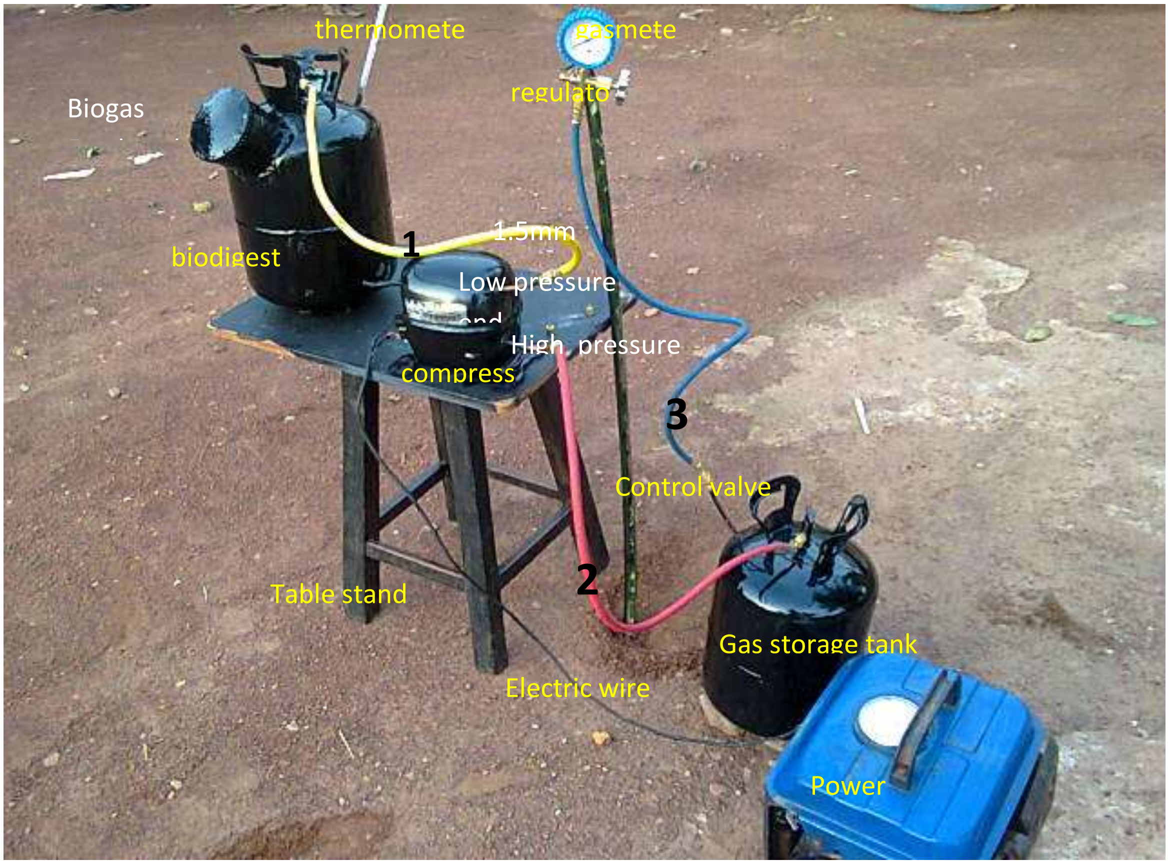
Materials and Equipment:

In this study, the materials used were; Fresh Pumpkin Straws, Distilled Water, Cow Dung and Animal Urine while the equipments include; Two Gas Cylinders, 1/8 S25 Gas Compressor, Laboratory Thermometer, Stop Watch bought from the market, Three pieces of 1.5mm Tubes, Digital Weighing Balance, Lighter, Agilent Gas chromatograph, model 7890A, Wooden Mortar and Pistol, 1000 cm^3 Measuring Cylinder, pH Meter and Power Generator.

Production of Biogas from Fresh Pumpkin Straw (Compost)

The slurry was fed into the 11322 cm^3 capacity bio-digester constructed (Figure 1). The capacity of the digester was obtained by filling the digester with water to the brim and emptying the water into a 1000 cm^3 measuring cylinder. The measurement was repeated until the volume of water in the digester was recorded. The temperature and pH of the reaction system were measured. The initial temperature was 29^oC while the pH was 6.7. The digester was covered with an air tight cover to prevent Oxygen from entering the digester thereby creating room for anaerobic digestion to take place, hence producing biogas as shown in Figure 1. The compressor was powered by a small energy generator. The gas-meter was connected to take the volume of the gas every 12 hr throughout the production.

Figure 1: Biogas Production Pilot Plant Assembly (plant)



RESULTS AND DISCUSSION

The pH of the slurry was 6.7 which was in agreement with [14] who stated that the permissible pH value for microbial activities in bio-digestion 6.8. The biogas ignited easily, burns efficiently with much sooth, odour and blue yellow flame which indicated that the gas was methane. The temperature of the digester was maintained at 35^o C during the production period.

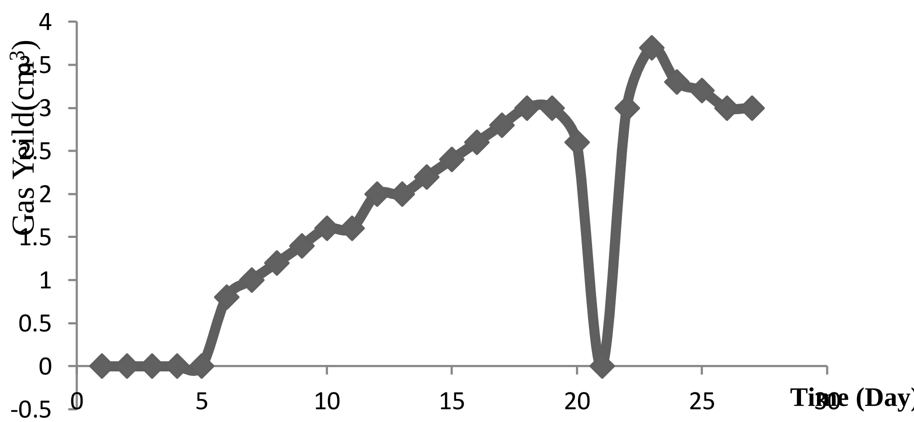


Figure 2: Biogas Yield with Time

Inclination of Reaction Time on Biogas Yield

Figure 2 showed the result of biogas yield with time. It was observed that no gas was produced within the first five days of the mixture which could be as a result of absence of hydrolytic and fermentative bacteria needed to break sugars into acetic acid and also methanogenic bacteria that could convert the acid into methane [23]. It was observed \that biogas generation started on the sixth day of production with 0.8 cm^3 gas yield. This value increased to 3.0 cm^3 on the 18th day. Thereafter the yield started decreasing and eventually dropped to zero on the 21st day. This gradual decrease could be attributed to either as a result of a drop in pH which may have inhibited the bacterial growth; hence making methane production impossible [24] Figure 2 equally shows that the biogas generation continued on the 22nd day with 3.0 cm^3 after the slurry had been diluted. It also showed that the biogas yield was highest on the 23rd day with 3.7 cm^3, after which it depreciated down to 3.2 cm^3 on the 25th day while 3.0 cm^3 was recorded on the 26th and 27th day respectively.

Table 1: Change in biogas yield with time and rate

T(Day)	Vo(cm^3)	Vt(cm^3)	V (cm^3)	1/V(cm^3)	lnV	(Vt-Vo)/Vt	(1/Vot) (cm^{-3})	K_2
6	0.2	1.0	0.8	1.25	-0.22	0.8	0.83	0.264
7	0.2	1.2	1.0	1.00	0.00	1.00	0.71	0.310
8	0.2	1.4	1.2	0.83	0.18	1.20	0.63	0.256
9	0.2	1.6	1.4	0.71	0.34	0.70	0.55	0.385
10	0.2	1.8	1.6	0.63	0.47	0.80	0.50	0.300
11	0.2	1.8	1.6	0.63	0.47	0.80	0.45	0.320
12	0.2	0.2	2.0	0.50	0.69	0.00	0.42	0.270
13	0.2	2.2	2.0	0.50	0.69	1.00	0.38	0.380
14	0.2	2.4	2.2	0.45	0.79	1.10	0.36	0.396
15	0.2	2.6	2.4	0.42	0.88	0.80	0.33	0.264
16	0.2	2.8	2.6	0.38	0.96	0.90	0.31	0.279
17	0.2	3.0	2.8	0.36	1.03	0.90	0.29	0.260
18	0.2	3.2	3.0	0.33	1.09	1.00	0.28	0.280
19	0.2	3.2	3.0	0.33	1.09	1.00	0.26	0.260
20	0.2	2.8	2.6	0.38	0.96	0.90	0.25	0.225
21	0.2	0.2	0.0	0.00	0.00	0.00	0.00	0.000
22	0.2	3.9	3.0	0.27	1.31	0.93	0.23	0.214
23	0.2	3.5	3.7	0.30	1.19	0.83	0.22	0.183
24	0.2	3.4	3.3	0.31	1.16	1.10	0.21	0.231
25	0.2	3.2	3.2	0.31	1.09	1.00	0.20	0.200
26	0.2	3.2	3.0	0.31	1.09	1.00	0.19	0.290
27	0.2	3.2	3.0	0.31	1.09	1.00	0.19	0.290

Average Specific Rate, K_2 = 0.3212, v = gas yield, v_t =volume of gas at time t, v = (v_t-v_o)

Determination of the Order of the Biogas Generation

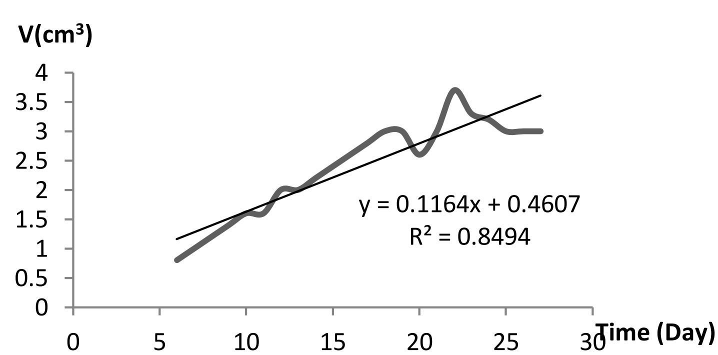


Figure 2a: Order of the reaction Kinetic of volume of gas yield with time

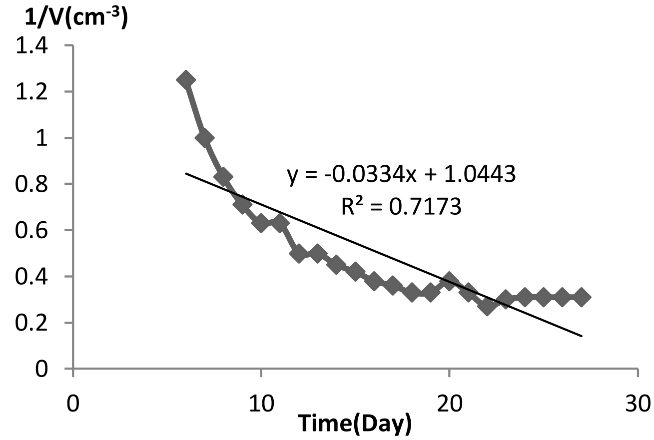


Figure 2b: Order of the reaction Kinetic of inverse volume of gas yield with time

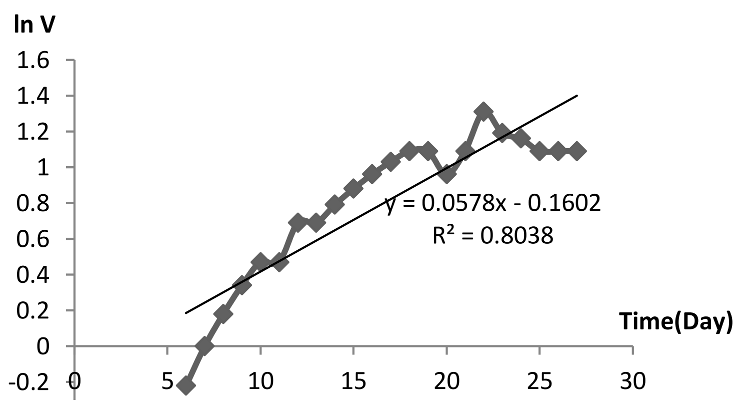


Figure 2c: Order of the reaction Kinetic of lnV of gas yield with time

The Kinetics of the Biogas Generation

Table 1, Figures 2a-c, present the changes in yield with time, graphical determination of the reaction order for the process and other quantities needed to calculate the rate of the reaction respectively starting from the 5th day to the 27th day of the production (the lag and exponential phase of bacterial growth). Figure 2a, b and c, the linearity of the graphs (correlation coefficient, R^2) tend to one and graphs 2a and 2c having positive slopes. It implies that production process followed initial rate pseudo second order. The reaction rate constant K_2, was evaluated using the Fixed- Time kinetics equation as showed in equations 3 (where K_2 is the Specific rate constant for second order reaction, t is the reaction time, V_o is the initial yield, V_t is yield measured at time, t and V is the change in volume of gas yield (V_t-V_o) . An average specific rate constant, K_2 of 0.3212 ml^{-1}day^{-1} was determined. This evaluation was in line with [24], who used a fixed- time method in finding out the rate constant of Biogas production from admixture of water hyacinth.

CONCLUSION

In this work, the biogas was generated from pumpkin straws using a digester of 11320 cm^3 installation capacity. The kinetics analyses indicated initial rate pseudo second order reaction while the average specific rate constant was 0.3212 cm^{-3} day^{-1}

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