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Kinetics of Biogas Production from a Mixture of Water Hyacinth (Eichornia Crassipes) and Fresh Rumen Residue.

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Abstract: *Biogas is produced when organic matter breaks down anaerobically. This study reports a pilot project on the possibility of producing biogas from a mixture of water hyacinth and fresh rumen residue. The batch process bio-digester of installation capacity 7,500ml was designed and constructed for use in the study. The work also investigated the effect of reaction time and kinetics of biogas production. The results show that biogas production actually began on the 9th day of production with a yield of 2.0ml and then the yield increased continuously up to the 17th day with an optimal yield of 16.4ml. Thereafter, the yield of biogas decreased for the remaining production period. The total volume of biogas produced after 39days was 310.6ml, or approximately a mean yield of 7.9ml/day. Furthermore, the data obtained indicated that the bio-gas production reaction kinetics was second order and had an average specific rate constant of 0.02878 ml^{-1} day^{-1}. Water hyacinth has a potential for biogas production in Nigeria.*

Key words: *Bio-gas; Kinetics; Water Hyacinth; Rumen.*

I. Introduction

Biogas is a fuel that is produced when microbes degrade organic matter in the absence of oxygen. The organic matter could be of animal residue or plant waste. Some common materials which can be used to prepare biogas include animal dung such as cow dung, poultry droppings, pig dung; manure, sewage, municipal waste, crops and food processing by-products. Biogas consists primarily of methane and carbon dioxide (Abubakar, 1990). It also contains small amounts of hydrogen sulphide, moisture, hydrogen and siloxanes (John and Twidell, 1987; Nagamani and Ramasamy, 2011). Biogas composition varies depending upon the anaerobic digestion process utilized.

Interest in the production and use of biogas and other biofuels such as biodiesel and bioethanol has increased recently because these fuels are from renewable sources, relatively non-toxic, biodegradable, relatively cheap and eco-friendly. In developing countries such as Nigeria, biofuels are seen as perfect alternative and substitute for the conventional (fossil) fuels. Biogas can, therefore, be used for cooking and to generate electricity and heat particularly in the rural areas (Ramasamy, 2011) and even in the urban areas. Biogas can also be compressed, much like natural gas, and used to power motor vehicles. In the United Kingdom, for instance, biogas is estimated to have the potential to replace around 17% of vehicle fuel (John and Twidell, 1987).

Biogas can be produced practically as **landfill gas** or **digester gas** (Demirci and Demirer, 2004). Landfill gas is produced by wet organic matter decomposing anaerobically in a landfill whereas digester gas is produced by using an anaerobic digester generally referred to as **biogas plant**. 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 (Nagamani and Ramasamy, 2011; Callaghan et al., 1999). The biochemical processes that take place in a typical digester are classified into four distinct and sequential stages namely, **hydrolysis, acidogenesis, acetogenesis** and **methanogenesis** (Bailey and Ollis, 1977; Smith, 1980; Sans et al, 1995; Nagamani and Ramasamy, 2011). In each stage, particular microbes (bacteria) are used to aid or catalyze the digestion process. Anaerobic microorganisms access oxygen for their metabolic activities from sources other than the surrounding air. The microbes feed upon the biomass feedstock, which undergoes a series of reactions, converting it (the biomass) to intermediate molecules including sugars, hydrogen and acetic acid, before finally being converted to biogas. Overall the production reaction is simplified in the generic chemical equation (Eqn 1):

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

Some common fermentative bacteria species found in rumen-fed digester species include Ruminococcus sp, Bacteroides and Clostridium such as Ruminococcus flavefaciens, Bacteriodes cellulosolvens, Clostridium thermocellum, and Clostridium cellulosolvens (Nagamani and Ramasamy, 2011). It is a common practice to 'seed' the digester with materials that contain anaerobic microbes. This is usually done by introducing sewage sludge, rumen residue or cattle slurry into the digester. Generally, at the end of the digestion period, the microbes are completely eliminated and this observation was attributed to higher production of volatile fatty acids in the digesters with shorter retention period.

Several factors influence the yield of biogas (Yeole and Ranade, 1992; Zennaki et al, 1996; Demirci and Demirer, 2004; Kaparaju and Angelidaki, 2008). These factors include type and nature of feedstock, inoculums, design of biogas plant, C: N ratio of substrate and processing parameters such as pH of the medium, reaction time, reaction temperature, loading rate. Others are concentration of slurry, total solid content, agitation of slurry, volatile fatty acids and amount of water in the slurry. The pH of the biogas plant is a function of the amount of CO_2 produced, HCO_3^- alkalinity of the medium and concentration of volatile fatty acids produced (Bailey and Ollis,1977). For increased biogas yield a pH of 6.6 to 7.6 is adequate (Bailey and Ollis, 1977).

Animal wastes and residues are generally used as substrates for digesters but their availability is a major limitation. Many researchers have conducted work on alternate feedstock for biogas production using plant wastes such as forage grasses, roots and tubers and marine species (Yeole and Ranade, 1992; Gunaseelan, 1997). Gunaseelan (1997) noted that some plant wastes needed to be shredded to a particle size of 0.4 mm before being fed into the digester for better biogas yield; however, succulent leaves such as Mirabilis sp., and Ipomoea fistulosa can be fed without any reduction in their sizes. Some studies have been reported on biogas production from digesters fed with water hyacinth as the substrate (Kivais and Mtila, 2005, Singhal and Rai, 2003, Kumar, 2005). In these works and others it was observed that some additives such as metals Ni. Mn, Co, Mg, Fe, etc, borax, diborane increased the biogas production and methane content. This observation was attributed to higher activity of metallo-enzymes involved in the biogas production.

Many workers have studied the reaction kinetics of biogas production and developed kinetic models for the anaerobic digestion process (Nopharatan et al, 2007; Chynoweth et al. 1993; Hashimoto, 1981; Monod, 1941). Chynoweth et al 1993 reported that methane yield and kinetics were generally higher in leaves than in stems. Monod (1941) model described a hyperbolic relationship existing between exponential microbial growth rate and substrate concentration. In this model, microorganism growth rate and velocity constant are vital in the biogas reaction kinetics. The Hashimoto (1981) model described biogas production reaction kinetics in terms of several parameters such as the loading rate, biodegradability of the feedstock, hydraulic retention time, maximum specific growth of organisms and other kinetic parameters that influence the volume of methane produced.

The present paper reports a preliminary study on the kinetics of biogas production using water hyacinth as feedstock and rumen fluid as inoculum. The objective of the study was to investigate the effect of reaction time on biogas yield and to establish the reaction kinetics of digestion process. Water hyacinth is a common noxious aquatic weed that constitute environmental nuisance to rivers and aquatic life. The leaves have coating of wax over the entire surface to prevent it from getting wet (Opande and Onyang, 2004). The plant shows dense growth which prevents the entry of light below it and therefore adversely affects all the aquatic life in water in which it grows. It also hinders the use of the river water for transportation purposes. The use of water hyacinth as feedstock for biogas production will surely ameliorate these problems.

II. Materials And Method

Materials and Equipments: Distilled water. Fresh water hyacinth (Eichornia crassipes) leaves were obtained from Ebonyi River. Rumen residue was collected from abattoir houses in Abakaliki. A 7500ml capacity biodigester was designed and constructed using sheets of metals (Fig. 1). The digester was equipped with a non-rectum valve for gas outlet and to prevent air being drawn into the digester, an opening for thermometer and openings for material inlet and outlet. A gas measuring device and collection tank was also fitted to the digester (Fig. 1). Other items used were Universal pH papers and 100^{o}C mercury-in-glass thermometer.

Methodology

1.5 kg of fresh water hyacinth was pounded in a mortar. Next 500 ml (0.5 kg) of distilled water was added to the ground water hyacinth to obtain slurry. The mixture was transferred into the digester and 0.35 kg of fresh cow rumen residue was added. The temperature and pH of the reacting medium was measured. Thereafter, the cork of the digester was used to seal it and the contents of the digester were allowed for anaerobic digestion to occur, thereby producing biogas. One extremity of the tube containing water was connected to the digester while the other fitted to a burette is left open. Gas pressure from the digester gas causes a change in the water level of the tube indicating a displacement and showing bubbles of gas rising to the top of the measuring tube. Readings on the gasometer were taken on daily basis and was recorded for a period of 39 days. The biogas was collected and stored in a gas jar. Finally the presence of methane in the biogas product was tested by igniting a flame on a Bunsen burner connected to the digester gas outlet tube.

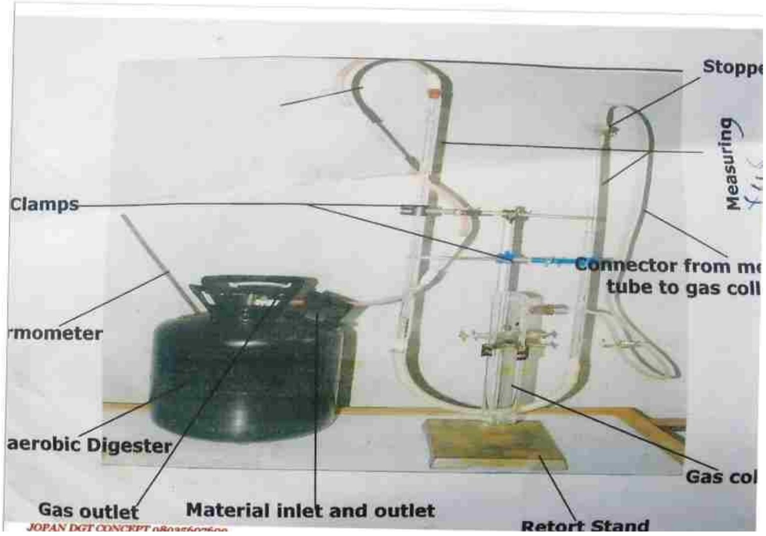


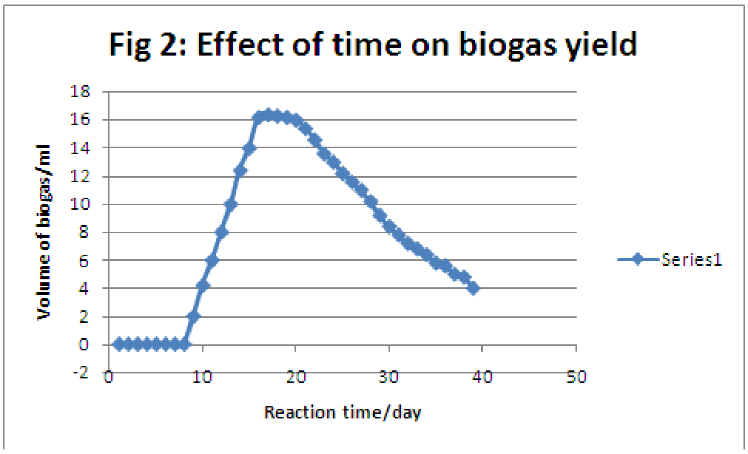
Fig1: Biogas plant used for the study

III. Results And Discussion

The pH of the slurry was 6.8. This value is consistent with the pH required for anaerobic bacteria to survive (Baily and Ollis, 1977). The biogas product was flammable and produces blue flame indicating the presence of methane. The gas product, however, has odour probably because of other gases such H_2S that may be present in it. The temperature of the digester was in the range 30 – 40 ^oC during the production.

Table 1: Yield of biogas as a function of reaction time

Reaction time/day	Yield of biogas/ml	Reaction time/day	Yield of biogas/ml	Reaction time/day	Yield of biogas/ml
1	0	14	12.4	27	11.0
2	0	15	14.0	28	10.2
3	0	16	16.2	29	9.2
4	0	17	16.4	30	8.4
5	0	18	16.3	31	7.8
6	0	19	16.2	32	7.2
7	0	20	16.0	33	6.8
8	0	21	15.4	34	6.4
9	2.0	22	14.6	35	5.8
10	4.2	23	13.6	36	5.6
11	6.0	24	13.0	37	5.0
12	8.0	25	12.2	38	4.8
13	10.0	26	11.6	39	4.0



Effect of Reaction Time on Biogas Yield

Table 1 and Fig. 2 show the yield of biogas as a function of reaction time. The data indicated that actual biogas production began on the 9th day and increased continuously up to the 17th day with an optimal biogas yield of 16.4 ml. thereafter the yield decreased continuously for the remaining production period. The total volume of biogas produced after 39 days was 310.6 ml, or approximately a mean yield of 7.9 ml biogas/day.

Kinetics of Biogas Production Reaction

The data in Table 2 show the changes in yield with time and other quantities needed to calculate the rate of reaction during the 9th day to the 17th day of production (the lag and exponential phase of bacterial growth).

Table 2: Change in biogas yield with time and rate calculation

Time(t)/day	V_o /ml	V_t /ml	(V_t-V_o) /ml	$(V_t-V_o)/V_t$	$1/(tV_o)$ / $ml^{-1}day^{-1}$	$K_2 = [(V_t - V_o)/V_t]/tV_o$
9	2	2.0	0	0	0.05555	0
10	2	4.2	2.2	0.5238	0.05000	0.02619
11	2	6.0	4.0	0.6666	0.04545	0.0303
12	2	8.0	6.0	0.7500	0.04167	0.03125
13	2	10.0	8.0	0.8000	0.03846	0.03077
14	2	12.4	10.4	0.8387	0.03571	0.02995
15	2	14.0	12.0	0.8571	0.03333	0.02857
16	2	16.2	14.2	0.8765	0.03125	0.02739
17	2	16.4	14.4	0.8780	0.02941	0.02582
Average specific rate constant, k_2						0.02878

The rate data (Table2) indicated that the reaction kinetics was second order using the fixed-time method kinetics equation given by

$$k_2 = [(V_t - V_o)/V_t]/tV_o \qquad (2)$$

where k_2 is the specific rate constant for second order reaction, t is time, V_0 is the initial yield is and V_t is yield measured at time, t. An average specific rate constant, k_2 of $0.02878 ml^{-1}day^{-1}$ was determined.

IV. Conclusion

In this work, biogas was produced in a batch-process digester of capacity 7500ml. The substrate used was water hyacinth and rumen residue as inoculum. An optimal biogas yield of 16.4 ml was obtained on the 17th day of production. The reaction kinetics followed a second order type with a specific rate constant of 0.0287 per ml per day. Water hyacinth has a potential for biogas production.

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