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DETERMINATION OF DIGESTION RATE OF BIOGAS PRODUCED FROM COW DUNG BIOMASS USING SINGH AND DIFFUSIONAL MODEL

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Abstract

Biogas production from biomass of plant and animal sources has become more pronounced in the last few decades as alternative source of energy and replacement for fossil fuels because of increasing problem of environmental pollution and ozone layer depletion. Biogas was produced from cow dung under mesophilic temperature range (32 – 37°C), pH of 7.5 and volume from 5cm^3 on the 4th day to a maximum of 505cm^3 on the 10th day and sudden decline to 305cm^3 on the 11th day and later rose to a peak of 410cm^3 and final decline to 150cm^3 on the 23rd day. The total solid % of the cow dung was 0.8 which was low and enhanced biogas production. From results, biogas production is directly proportional to the concentration of the cow dung slurry.

Keywords: Biogas, Cow Dung, Biomass, Diffusional Model, Digestion Rate.

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Introduction

The desperate need and urgency for an alternative and less costly energy source and environmental friendly energy supply in Nigeria and Africa South of the Sahara has become clearly visible and apparent now. The epileptic power supply and distribution of gasoline and other fossil fuels has risen beyond the reach of average and low income Nigerians as well as those in rural communities.

Between May, 2023 and December, 2024, the price of Nigeria motor gasoline and other fossil fuels like butane cooking gas and kerosene rose to more than 400% keeping gasoline and cooking gas and above the reach of average Nigerians and thus subjecting most Nigerians to economic hardships and psychological trauma. This was brought about by the removal of petroleum subsidy by the president Bola Ahmed Tinibu administration in May, 2023.

The present high cost of energy and scarcity in some areas in Nigeria present time, opportunity to source for alternative energy that is renewable, cheaper and sustainable in order to make power easily available to average Nigerians and also to boot economic and industrial growth and enhance rural development as well.

Energy is the bedrock of an economic and social development in any country and solving the problem of energy generation and distribution is central to implementing the plans for economic development especially in the rural areas (Ilochi et al.1989).

Nigerian rural areas usually have large supplies of materials (biomass) such as plant residues and animal waste which are sustainable for conversion into usable source of energy (biogas). These materials are potential for methane generation and can be sourced from various wastes such as crop waste of sugar cane, cassava stem, weeds, corn stubble etc. Animal wastes like horse waste, goat waste, cow dung, fishery waste, poultry droppings, human waste etc. are potential biomass for biogas generation. Biological degradation of these waste into biogas remains

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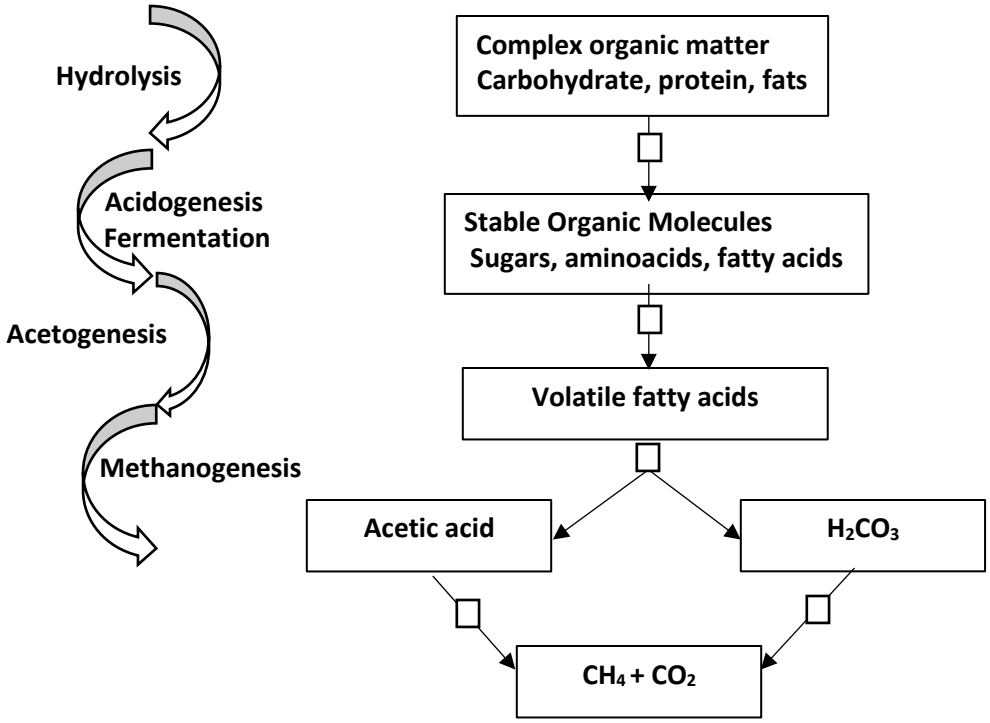
the simplest, cheapest and most environmental friendly technology of treating organic waste to minimize public health hazard associated with their disposal and transportation and this technology is known as anaerobic digestion (Eze,2002). Anaerobic digestion is the world's oldest method of gasifying organic waste material. It involves bacteria that requires an environment that is void of oxygen to generate biogas which typically contains between 50- 60% methane.

This high methane content makes biogas an excellent source of renewable energy to replace natural gas and other fossil fuels (Zupanic, 2002). Biogas is a mixture of gases obtained by subjecting different organic materials to anaerobic fermentation under optimum temperature (Mosophilic or Thermophilic), pH, moisture content, humidity and total solid content. Biogas burns with blue flame. Its heat value is 500-700 Btu/ft^3 when it's methane content is in the range of 60-70%. Biogas is very stable, non-toxic (the carbon dioxide produced along the biogas is consumed by bacteria). It is colourless, odourless with little traces of hydrogen sulphide which is not usually noticed when being burned.

Moreso, the effects of physical and chemical conditions which affects anaerobic biological processes such as pH, total solids (TS), temperature etc. has been explored and studied (Lay et al., 1996; Kythreotou et al., 2014; Deepanraj et al., 2015). These effects have been modelled and expressed by many kinds of kinetic models including the growth kinetics, kinetics of biogas production and kinetics of substrate degradation (Kythreotou et al., 2014) Among these listed above, the most important model is the kinetics of biogas production. Digestion processes relies on the growth of anaerobic bacteria, hence many studies have used the growth kinetics of bacteria to express the biogas production (Lay et al., 1996; Lo etal., 2010; Van, et al., 2018).

This study will help to highlight the processes involved in biogas production and the kinetics of its production it will also identify some of the microorganisms involved in biogas generation.

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Flow Chart of Anaerobic Digestion Process

Materials and Methods

The study was conducted in Federal Polytechnic, Mubi located in the North Eastern region of Nigeria. The cow dung was collected from the commercial cattle ranch of the Federal Polytechnic, Mubi, Adamawa State, Nigeria.

The following materials were purchased and made available for the bio-digester construction and experimental set up.

Four (4) litre plastic container bio-digester, PVC tube, rubber cocks, water trough, polystyrene box, thermometer, measuring cylinder, pH meter, litmus paper, retort stand, Araldite adhesives, Buchner flask, distilled water, silica gel drying apparatus, NPK fertilizer, Biomass (cow dung).

Methodology

The pilot microscale bio-digester was constructed and set up according to the method adopted by Asiagwu and Ukachukwu (2009).

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Digester preparation:

Four (4) litre cylindrical plastic container was cleaned thoroughly and used as digester. Two holes were bored on top of the cylindrical plastic digester and a PVC (Polyvinylchloride) rubber tube was inserted into one of the holes and a thermometer into the other hole. Both were glued properly using araldite adhesives. The unattached end of the PVC tube of the digester was channeled into a Burchner flask containing silica gel to absorb mositure from the biogas produced.

The mouth of the flask was covered with rubber cork while the side outlet of the Burchner flask was connected to another PVC tube. The free end of this PVC tube was positioned under an inverted measuring cylinder filled with water in a water trough by a retort stand such that the outlet of the PVC tube was directed upward. The digester was put in a polystyrene box in order to maintain constant temperature.

Sampling:

the cow dung was collected from the commercial cattle ranch of the Federal Polytechnic, Mubi, Adamawa State at 9:00am.

It was located behind the Environmental Technology Complex. The waste from the faeces were collected from the herd's stubble before the cattle was taken out for grazing. The samples were collected in a clean transparent plastic bucket.

Digestion and monitoring:

120grams of cow dung waste was weighed on a digital balance. The waste was mixed with 200cm^3 of clean water to form slurry and was placed in the digester. Then 5g of N:P:K fertilizer was dissolved into the slurry to provide nutrients support for the medium. The pH of the slurry was also determined immediately. The set up was stood still and the temperature and gas volume was monitored daily at various time intervals. The downward displacement of water in the measuring cylinder was used as measure of volume of biogas produced.

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Physiochemical Analysis

Total solid

The total solid (TS) was determined by weighing 10g of the sample and then oven dry at 105°C for 24hours to remove all moisture and then re-weigh the dried sample. TS% was determined by dividing the "dry weight" by "wet weight"

TS = dry weight/wet weight = weight after drying/10g

Volatile solids

Volatile solids (VS) are determined by burning the dried TS sample which removes the "volatile components" and what remains is the "non-volatile solid". The sample is weighed again to determine the "Ash weight" which is subtracted from TS to determine VS.

VS is formed by dividing VS by TS

TS - Ash Content = VS

Non - volatile solid

Non-volatile solids (NVS) is what remains in the sample after removing VS in a furnace.

NVS% is determined by dividing NVS by TS

% MVS/TS x 100/1

Kinetic model of biogas

The actual mechanism inside the bio-digester shows that different types of bacteria both aerobic and anaerobic bacteria contributes to the production of biogas.

However, it is very complex and complicated to define accurately, so therefore a kinetic model can be used to predict biogas production. Two kinetic model are applied here;

(a) Diffusional model and (b) Singh model.

(a) Diffusional model: this is the combination of the Monod's rate equation and mass transfer limitation equation resulting in the following overall rate equation

$ds = KS^{0.5}$

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Where K = Apparent kinetic constant

S = Substrate concentration (g/m^3)

(b) Sing model

This is given by the following equation

ds/dt = -KS/1+t

Where K= first order kinetic constant (g/m^3)

S = Substrate concentration

T = Time (day)

Result and Discussion

Table 1: Accumulation of yield of biogas from cow dung waste for a period of 23 days

No. of days (t)	Time (pm)	Temperature	Biogas produced (cm^3)
1	1.00	36.0	0.00
2	1.00	36.0	0.00
3	1.00	36.0	0.00
4	1.00	36.0	0.00
5	1.00	35.0	10.00
6	1.00	35.0	18.00
7	1.00	37.0	27.00
8	1.00	36.0	48.20
9	1.00	36.0	84.40
10	1.00	34.0	505.00
11	1.00	34.0	305.00
12	1.00	34.0	40.40
13	1.00	34.0	46.00
14	1.00	33.0	49.00
15	1.00	33.0	54.00
16	1.00	33.0	63.50
17	1.00	34.0	65.80
18	1.00	34.0	68.00
19	1.00	34.0	89.00
20	1.00	34.0	144.00
21	1.00	33.0	410.00
22	1.00	34.0	240.00
23	1.00	32.0	150.00

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Table 2: Determination of Kinetic Constant (K) using Singh Model

t (days)	S (cm³)	ds	Dt	ds/dt	S/1+t
1	0.00	0.00	1	0.00	0.00
2	0.00	0.00	1	0.00	0.00
3	0.00	0.00	1	0.00	0.00
4	5.00	5.00	1	5.00	1.00
5	10.00	5.00	1	5.00	1.67
6	18.00	8.00	1	8.00	2.57
7	27.00	9.00	1	9.00	3.38
8	48.20	21.20	1	21.20	5.36
9	84.40	36.20	1	36.20	8.44
10	505.00	420.6	1	420.60	45.90
11	305.00	-200.00	1	-200.00	25.42
12	40.40	-264.6	1	264.60	3.11
13	46.00	6.00	1	6.00	3.29
14	49.00	3.00	1	3.00	3.27
15	54.00	5.00	1	5.00	3.38
16	63.50	9.50	1	9.50	3.74
17	65.80	2.30	1	2.30	3.66
18	68.00	2.20	1	2.20	3.58
19	89.00	21.00	1	21.00	4.45
20	144.00	55.00	1	55.00	6.86
21	410.00	266.00	1	266.00	18.64
22	240.00	-170.00	1	-170.00	10.43
23	150.00	-90.00	1	-90.00	6.25

Table 3: Determination of Apparent constant (k) using Diffusional model

4day	S(cm³)	ds	Log ds	0.5 logs
1	0.00	0.00		
2	0.00	0.00		
3	0.00	0.00		
4	5.00	5.00	0.69	0.35
5	10.00	5.00	0.69	0.5
6	18.00	8.00	0.90	0.63
7	27.00	9.00	0.95	0.72
8	48.20	21.20	1.33	0.84
9	84.40	36.20	1.51	0.96
10	505.00	420.6	2.62	1.35
11	305.00	-200.00	2.30	1.24
12	40.40	-264.6	2.42	0.803
13	46.00	6.00	0.78	0.83
14	49.0	3.00	0.47	0.84
15	54.00	5.00	0.69	0.86
16	63.50	9.50	0.97	0.90
17	65.80	2.30	0.36	0.92
18	68.00	2.20	0.34	0.92
19	89.00	21.00	1.32	0.97
20	144.00	55.00	1.74	1.08
21	410.00	266.00	2.42	1.31
22	240.00	-170.00	2.23+	1.19
23	150.00	-90.00	1.95+	1.09

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Discussion

Table 1 shows the cumulative biogas yield from cow dung waste for the period of 23 days. The results shows that cow dung waste takes up to 4 days before production of biogas. This could be due to the fact that during digestion, aerobic organisms which predominate at this time still utilize the traces of oxygen in the digester to release carbon (iv) oxide. Another reason is that lignin in the cow dung waste prevents the access of the enzymes to the cellulose thereby slowing down the breakdown of complex organics. Moreso, complex organics are also not readily degradable. The process is slow due to slow conversation of these to organic fatty acid.

Biogas production increases geometrically from 5cm^3 on the 4th day to maximum peak of 505cm^3 on the 10th day and then drops to 305cm^3 on the 11th day and begins to increase marginally from 54cm^3 on the 15th day to 2nd peak of 410cm^3 on the 21st day and slides down to 150cm^3 on the 23rd day.

The geometrical increase occurs as a result of the methane forming bacteria such as actrinomycite colonies which increased at this point because they thrive at favourable environment which become more pronounced at this later stage of decay (Birnin Kebi et al., 2006).

The pH required for aerobic digestion of organic materials lies within the range 7.5 - 8.5 of which the environmental bio-digester is within the range. The temperature throughout the experiment is within the range of 32^{o}C – 37^{o}C, in the mesophilic temperature range. As fermentation progressed at the last days, glycerol, amino acids, volatile organic acids are here converted to methane and ammonium compounds. The ammonium compounds turns the pH to higher values favourable for methanogenesis and finally yielding more biogas (Zeeman 1997).

From experimental physical analysis, total solid (TS) from cow dung which is 0.8 is an important parameter that affects biogas production in this experiment which enable the biogas to start coming out at shorter retention time at the 4th day.

High total solids should lead to accumulation of inhibiting acids produced during digestion which could affect microorganisms responsible for biogas convertion.

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(Birnin Kebi et al., 2006, Eze, 2002, Zupanic, 2002). Microbiological assays on cow dung waste was conducted and biochemical analysis is ongoing.

Conclusion

The study shows that temperature variation within the mesophilic range has little or no effect on biogas production from cow dung. The retention time in days really had great effects on biogas production. Anaerobic digestion of cow dung is very energy efficient and also cost effective source no extra cost is involved in purchasing microbial samples (eg. bacteria, algae etc.). Cow dung has been effectively utilized to produce biogas which can be used for domestic energy source which is a cheap, clean and environment friendly alternative to fossil fuels.

Conflict of interest: The authors declares no conflict of interest.

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