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Production of biogas from goat dung and determination of total solid concentration

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Abstract
The use of biogas as an energy source has numerous applications. However, all of the possible applications require knowledge about the composition and quantity of constituents in the biogas stream. Global energy demand is rapidly increasing. In contrast, fossil fuel reserves are decreasing. Today, one of the major challenges is energy supply for the future. Furthermore, effects of global warming cannot be neglected anymore. Alternative energy sources such as biogas should be developed. The biomass has huge biogas potential. However, arable area in the world is limited. Therefore, substrate which will be used for biogas production should be chosen carefully. The aim of this study was to determined biogas yield using thermally treated goat dung. Also this study examined the total solid depletion rate as the digestion process progress. The maximum biogas volume generated from the experiment was 9.1 litres. There was no production of biogas in day 1 of control, 10 ^{0}C, 20 ^{0}C and 30 ^{0}C pre-treated time. The maximum average temperature of the day recorded was 30 ^{0}C. The maximum total solid concentration from the experiment was 15% while the minimum value obtained was 4.2%.

Keywords: Biogas, Average Temperature, Global Energy, Goat dung, Fossil Fuel

1. Introduction

The quantity of waste generated every day in the world is increasing due geometric population increase [1]. Biogas production is an anaerobic digestion process which involves microbial activity on the substrate [2]. From the beginning of the industrial revolution, global energy demand has been rapidly increasing [3]. As a consequence, fossil fuel reserves are rapidly decreasing which causes an increase in energy prices [4]. Effects of global warming are no more negligible. Emissions of carbon dioxide and methane should be reduced and temperatures must not be allowed to rise by more than two degrees. Both the UN and the EU have set the climate goals. The Swedish government has also introduced stricter targets; no biodegredable waste should be put in landfills after 2005 [5]. For these reasons, one of the major challenges for industrialized countries is energy supply for the future. Recently, numerous ideas have been considered to develop alternative energy sources such as biogas production [6]. Biomass has a huge potential for biogas production. The future biofuel demand of Sweden can be met by biomass production and waste [7]. There are many types of substrates that can be used in biogas plants to obtain biogas. They all have different biogas production potentials. However, arable land in the world is limited. Therefore, selection of the substrate should be made carefully.

It has been written widely that the Swedish government gives much attention to climate issues [8]. Emissions of carbon dioxide and methane should be reduced and temperatures must not be allowed to rise by more than two degrees. Both the UN and the EU have set the climate goals. The EU has own emissions targets by 2020 are:

- a 30% decline in greenhouse gas emission,
- a 20% increase in use of renewable energy,
- a 10% increase in proportion of renewable fuel,
- a 20% increase in effecient energy use [9].

The Swedish government has introduced stricter targets such as no biodegredable waste in landfills after 2005 [10]. The potential for biogas production in the world is very large [11] and in Sweden this potential is approximately 10 times higher than the present production [12]. In the 1970s, many biogas plants were constructed in municipal wastewater treatment plants. The main aim was to reduce the biomass that was produced from anaerobic digestion, and it was not to obtain methane. Biogas was often released into the atmosphere. The number of farm-size biogas plants increased in the 1970s due to an oil crisis but farmers often had problems with the operation. The methane recovery from landfills started in the 1980s. This was an important issue, since methane released into the atmosphere is nearly 30 times much more effective than CO_2 in trapping the earth's radiated heat and contributes 18% to the greenhouse effect [13]. Today, in Sweden there are more than 233 biogas plants. Due to carbon abatement policies and in order to achieve energy policy targets, use of bioenergy is projected to increase in Sweden [14]. The Swedish Energy Agency has distributed SEK 100 million in support the use, production and distribution of biogas and other renewable gases. The future biofuel demand of Sweden can be met by biomass production. Biomass for energy in agriculture such as many types of liquid manure and energy crops can be considered to be an increasing interest. Using anaerobic digestion, biomass can biologically be converted into methane and hydrogen [17]. By 2020 it might be possible to obtain 22 TWh/yr based on energy crops such as straw, maize, hay, sugar beets. Global production of sugar beet and sugar cane was estimated as 0.4 billion tons of dry matter in 2000. Therefore, in the near future with a predicted decline in fossil fuel, there will be a huge increase in use of energy crops as renewable energy. However, energy crops are not the only way to obtain bioenergy. Through anaerobic digestion, solar energy stored in the algal biomass as a result of the photosynthesis reaction could be released as biogas.

There are also many types of substrates that can be used in biogas plant to obtain biogas. They all have different biogas production potentials.

From the beginning of the industrial revolution, global energy demand has been rapidly increasing. As a consequence, fossil fuel reserves are rapidly decreasing which causes an increase in energy prices. For these reasons, one of the major challenges for industrialized countries is energy supply for the future. Recently, numerous ideas have been considered to develop alternative energy sources such as biogas production.

Biogas is a renewable gas. It contains methane, which is produced when biological material is broken down by microorganisms in an anaerobic environment. The proper range of C/N in anaerobic digestion ratio is 20-30:1 preferably25/1.Methane is the energy-rich component of both biogas and natural gas. Biogas can be generated from a large numbers of raw materials and can be used for variable energy services such as heat, power or as a vehicle fuel [16]. It could replace approximately 20 - 30% of the natural gas consumption.

Process and Mechanism of Biogas

Biogas digestion process is divided into four stages. In all these different stages, different microbial activities occur. These stages are hydrolysis, acidogenesis, acetogenesis and methanogenesis. Process proceeds without any problems, if degradation of all of the stages occurs well. If one of them is inhibited, then the methane production decreases or all the process may be shut down. Biogas digestion process consists of different groups of bacteria that work in sequence.

Stage 1 Hydrolysis: Hydrolysis is the breaking (“lysis”) of a large compound into small compounds by adding water (“hydro”). Insoluble components such as carbohydrates, fats and proteins undergo hydrolysis in this stage. Complex components are degraded into small soluble components by breaking their chemical bonds. Hydrolytic or facultative anaerobes or anaerobes are responsible for this stage.

Complex carbohydrates →simple sugars
Complex lipids →Fatty acids
Complex proteins →Amino acids

- **Stage 2- Acidogenesis:** In this stage, soluble components that were produced through hydrolysis; are degraded by facultative anaerobes and anaerobes. During degradation, carbon dioxide, hydrogen gas, alcohols, organic acids, some organic-nitrogen compounds and some organic-sulfur compounds are produced. Some of the other compounds are used to form new bacterial cells.
- **Stage 3 Acetogenesis:** Acetogenesis occurs in the acid-forming stage. Many of the acids and alcohols such as butyrate, propionate and ethanol may be degraded into acetate that will be used as a substrate by methane-forming bacteria and also carbon dioxide and hydrogen can form directly acetate by fermentative bacteria.
- **Stage 4 Methanogenesis:** In this step, methane is mainly produced from acetate and carbon dioxide and hydrogen gas. Here all of the compounds must be converted into compounds that can be used by methane forming bacteria. Acids, alcohols and other organic-nitrogen compounds cannot be used directly by methane-forming bacteria, as a result these components accumulate in the digester supernatant.

Main Bacteria which are Responsible for Biogas Process

Acetate-forming bacteria: Acetate-forming bacteria have a symbiotic relationship with methane-forming bacteria. Acetate which is produced by acetate-forming bacteria is directly used as a substrate for producing methane by methane-forming bacteria. When the acetate is produced, hydrogen is also produced. This hydrogen creates pressure that affects acetate-forming bacteria adversely in the system. Acetate-forming bacteria are so sensitive to hydrogen. They can only survive if their metabolic waste (hydrogen) is continuously removed. However, methane forming bacteria use this hydrogen to produce methane and significant hydrogen pressure is prevented. The growing rate of acetate-forming bacteria is very slow.

Sulfate-reducing bacteria: Sulfate-reducing bacteria are also found in the biogas digestion system. When sulfate is in the system, they start to multiply themselves by using hydrogen and acetate. This situation causes a competition between sulfate-reducing bacteria and methane-forming bacteria. Under low acetate concentrations, substrate to sulfate ratios < 2, sulfate forming bacteria obtain hydrogen easier than methane-forming bacteria. When substrate to sulfate ratios are 2 and 3, competition is particularly intense. At substrate to sulfate ratios > 3, methane forming bacteria obtain hydrogen and acetate easily.

Methane-forming bacteria: Methane-forming bacteria are some of the oldest bacteria with many types of shapes, growth, patterns and sizes. They are oxygen sensitive and their cells have unique chemical composition that makes the bacteria sensitive to toxicity. All type of methane forming bacteria can produce methane. However, they have different structures, enzymes, substrate utilizations and temperate range of growth. In nature, methane-forming bacteria participate in the degredation of many organic compounds. Methane forming bacteria can grow well in the strict anaerobic environment. Their generation times range from 3 days at 35 ^{o}C to 50 days at 10 ^{o}C. In order to obtain a large population of methane-forming bacteria at least 12 days are needed. There are three types of methane-forming bacteria which are different from each other by substrate utilization.

Group 1 Hydrogenotrophic methanogens: They use hydrogen to transform carbon dioxide into methane. As a result they help to reduce hydrogen pressure.

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

Group 2 Acetotrophic methanogens: They convert acetate into methane and carbon dioxide. This carbon dioxide can be used by hydrogentrophic methanogens. This group of methanogens are affected more by hydrogen pressure.

$$4CH_3COOH \rightarrow 4CO_2 + 2\ H_2$$

Group 3 Methylotrophic methanogens: They produce methane from methyl groups such as methanol (CH3COH) and methylamines [$(CH_3)_3$-N].

$$3CH_3COH + 6H \rightarrow 3CH_4 + 3H_2O.$$

An appropriate choice of seed inoculums for a fermentative process is a very important pre-condition for a successful digester operation start-up. T.S range of 6.10% is always recommended for anaerobic digestion. The seed Inoculum is shown in the table 1 below. The amount of water required in the digestion process is calculated using the formula.

$$Mo=\frac{W2X100}{W1} \quad ......1$$

Table 1

Sources of seeding material	Amount of seed (%)
Sewage sludge	10-15
Digester slurry	>30
Sewage sludge with stalks and straw in feedstock	>50

2. Materials and Methods

Collection of feedstock

The feedstock used was collected from Animal Science Department at University of Nigeria, Nsukka. The Inoculum was also collected from Crop science Department University of Nigeria, Nsukka. The Inoculum was combination of rabbit and goat waste that was charged into a digester for some days to accumulate much of the anaerobic bacteria that will stimulate anaerobic digestion.

Experimental Method

The experiment was conducted at Agric Department, University of Nigeria, Nsukka. Five biogas digesters of 45 litres volume were charged with goat dung that was thermally pretreated at Temperature of 10°C, 20°C, 30°C and 40°C respectively. The fifth one represents the control experiment. The ratio of each waste to water to Inoculum is 2:3:1. The mixture of the dung, water and Inoculum were charged into the digester and allowed for anaerobic digestion. The volume of biogas yield and atmospheric temperature were measured daily.

Determination of Moisture Content

The A.O.A.C method (1990) was used. Porcelain crucibles were washed and dried in an oven at 100ºC for 30 minutes and allowed to cool in a desiccator. One gramme of the raw waste was placed into weighed crucibles and then put inside the oven set at 105ºC for 4 hours. The samples were removed from the oven after this period and then cooled and weighed. The drying was continued and all the samples with the crucibles weighed until a constant weight was obtained.

$$\% \text{ moisture} = \frac{A-B}{A} \times \frac{100}{1}$$

A = Original weight of sample
B = Weight of dried sample.

Determination of Total Solids

Total solid is made up of the digestible and non digestible material in the waste. Meynell (1982) method was used. 3g of the raw waste was dried in an oven at 105ºC for 5 hours. The dried sample was cooled in a dessicator and then weighed. The weight obtained after all moisture loss is the total solid.

$$\% \text{ T.S} = \frac{B-C}{g} x \frac{100}{1}$$

T.S = Total solid
B = Weight of crucible + dry residue
C = Weight of crucible
g = Original weight of sample.

Determination of Volatile Solids

The volatile solid is the true organic matter available for bacterial action during digestion. The method of Meynell (1982) was used. The solid residue from the total solid determination was heated in a muffle furnace at 600ºC for 2 hours. The heated residue was cooled in a dessicator and weighed.

$$\text{Volatile solid (VS)} = \frac{B-C}{g} x \frac{100}{1}$$

B = Weight of dried residue from total solid determination
C = Weight of residue after further heating at 600 ºC
g = Original weight of sample.

Ash Content Determination

The residue remaining after all the moisture have been removed and the fats, proteins, carbohydrates, vitamins and organic acids burnt away by ignition at about 600 ºC is called ash. It is usually taken as a measure of the mineral content of the raw waste.

Using AOAC (1990) method, 1g of the finely ground samples were weighed into porcelain crucibles which have been washed, dried in an oven at 100 ºC, cooled in a desiccator and weighed. They were then placed inside a muffle furnace and heated at 600 ºC for 4 hours. After this, they were removed and cooled in a desiccator and then weighed.

$$\% \text{ Ash} = \frac{A-B}{C} \times \frac{100}{1}$$

A = Weight of crucible + ash
B = Weight of crucible
C = Weight of original sample

Energy Content Determination

A.O.A.C (1975) method was used. This was done with bomb calorimeter (model XRY-1A, make: Shanghai Changji, China). It involves igniting the waste sample in oxygen bomb calorimeter (under a high pressure of oxygen gas). The heat energy that was released was absorbed by the surrounding water inside the bomb calorimeter. This gave rise to a temperature increase of the surrounding water and this was used to estimate the energy value of the sample. 1g of the sample was pelleted and turned in the oxygen bomb calorimeter. The heat of combustion was calculated as the gross energy.

$$\text{Energy content} = \frac{E\Delta T - 2.3L - V}{g} \text{ (KJ/Kg)}$$

Where

E = energy equivalent of the calorimeter
ΔT = temperature rise
L = length of burnt wire
V = titration volume
g = weight of sample

3. Result and Discussion

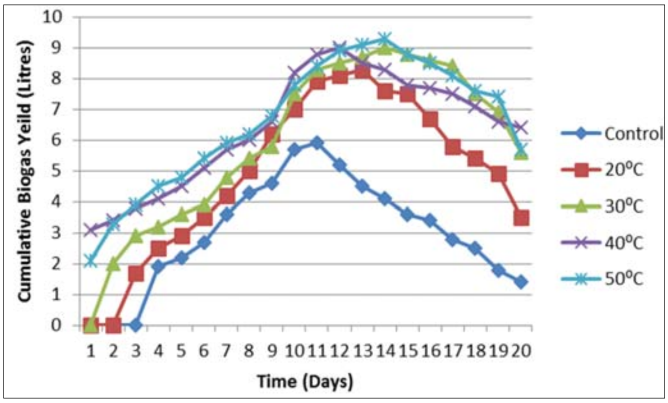

Fig 1: A graph of cumulative biogas yield (Litres) versus Time (Days)

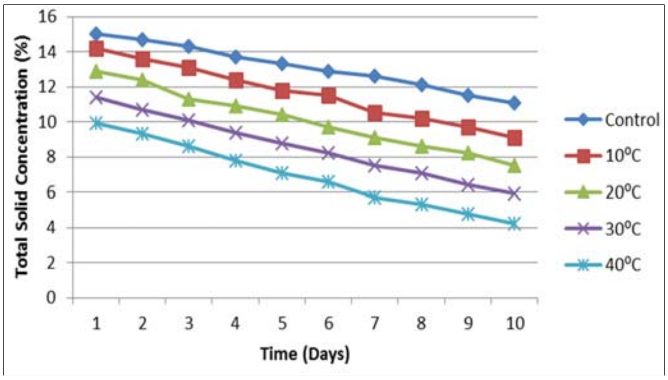

Fig 2: A graph of Total Solid Concentration (%) versus Time (Days).

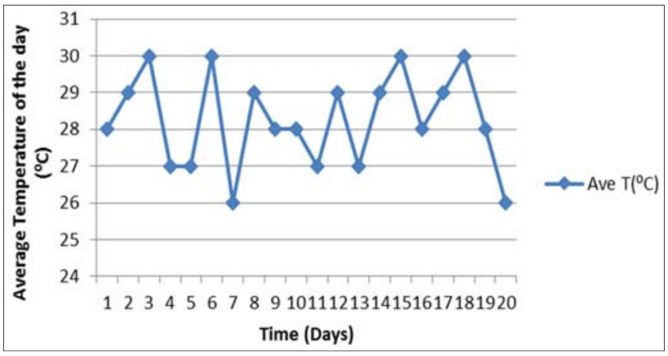

Fig 3: A graph of average Temperature of the day versus Time (days).

The effect of thermal pretreatment was significant, it had positive effect on the methane yield with the substrate especially with goat dung which increased methane yield by 54%. Goat dung contains rich lignin and hemicelluloses, this is not hard to degrade. During thermal pre-treatment, a part of hemicellulose is hydrolyzed and forms acids during thermal processes. These acids catalyzed the further hydrolysis of the hemicellulose (Gregg, 1996) [17]. Thermal pretreatments can also enhance hydrolysis rates and reduce HRT days which became clear in most results that after thermal pretreatment, the increasing rate of biogas production is higher than the untreated ones. According to Rafique (2010) [18] that thermal pretreatment showed enhancement in the temperature from 50 ^{0}C to 100 ^{0}C. Also Deublein and Steinhauser (2008) [20] found 30% increase of biogas yield if substrate is thermally treated before it entered the reactor.

Although, chemical pretreatment had positive effect on methane yield of all kinds of substrates, harmless to the residual and easily operation, the energy input of thermal pretreatment should also be taken into consideration if applied in large-scale.

4. Conclusion

Biogas could be produced through anaerobic degradation of animal dung/waste. This study aimed at generating biogas from anaerobic digestion of goat dung and determination of volatile solid concentration. The atmospheric temperature of the day was also measured during the course of this study. The maximum biogas volume produced from the experiment was 9.1 litres.

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