The Optimum Mesophilic Temperature of Batch Process Biogas Production from Animal-based Wastes

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Abstract
The optimum temperature of biogas production from blends of animal-based wastes was determined under controlled heat supply to the digester in a batch digestion process. Cow Dung (CD) and Poultry Droppings (PD) were blended in the ratio of CD: PD::1:3. The digester was operated at average ambient temperature of 30°C as baseline. Biogas production from the waste blends was monitored under the temperatures of 32°C to 45°C. Results obtained indicate maximum cumulative gas yield was observed at the temperature of 40°C.The 40°C temperature gave the highest biogas yield of 2685 ml followed by the 35°C temperature with the cumulative yield of 2535 ml. The ambient temperature of 30°C had the least cumulative biogas yield of 185 ml. These results indicate that increased and steady biogas production can be achieved under the optimum mesophilic temperature of 40°C when these animal-based wastes are digested in batch digestion process.

Keywords: Mesophilic Temperature, Batch Anaerobic Digestion, Biogas Yield.

1.0 Introduction

Energy forms one of the most vital requirements of mankind. It is the climate crisis that is the forcing mechanism for a change from conventional sources to small, diversified and renewable sources of energy, ranging from wind energy and solar energy to second-generation bio-liquid and gas, and biodiesel-production facilities. By preventing the emission of methane while producing clean energy, biogas makes a twofold contribution to climate protection. The usual unchecked discharge of methane into the atmosphere is prevented, and the burning of fossil fuels is replaced with an unlimited supply of clean, renewable energy (biogas).

Although biogas production technology has established itself as a technology with great potential which could exercise major influence in the energy scene in rural areas, it has not made any real impact on the total energy scenario worldwide. Biogas, the gas generated from organic digestion under anaerobic conditions by mixed population of microorganisms, is an alternative energy source which has been commenced to be utilized both in rural and industrial areas at least since 1958[1]. One of its serious limitations is the availability of feedstock followed by operational temperature levels for anaerobic digesters, which are determined by the species of methanogens in the digesters, and microbiological failure.

The process of anaerobic digestion employs specialized bacteria to break down organic waste, converting it to a stable solid and biogas, a mixture of carbon dioxide and Methane. Anaerobic digestion can be carried out under ambient (<30 °C), mesophilic (32~45 °C) and thermophilic (>45 °C) conditions [1]. The gas generally composes of methane (50-75%), carbon dioxide (25-50%), nitrogen (0-10%), hydrogen (0-1%), and hydrogen sulphide (0-3%) [2]. Animal waste has been mainly used for the biogas production, and several kinds of waste materials have been reported to be exploited [3, 4, 5, 6]. Cow dung and Poultry droppings, the cheap and abundant agriculture waste in Nigeria, are investigated to be applied as a raw material for the bio-energy production in this study. In this study, the maximum production of biogas from the blended waste is determined in laboratory scale using the simple single-state digesters. A batch system is the simplest form of digestion. Slurry is added to the digester at the start of the process and sealed for the duration of the process. [7]

2.0 Experimental setup

Three identical conical flasks were used. A conical flask of 4000 ml capacity with the top corked, was used as the digester, and placed in a water bath. The cork was drilled in two places for an opening to fix a thermometer and a plastic tube for gas collection. A thermostat with heater line system was used to control digester temperature of production. The digester setup was made air tight. The plastic tube from the digester was connected to the second flask containing brine (NaCl solution) as illustrated in fig. 1. The volume of biogas produced in the digester was measured by the displacement of brine in the second flask compartment to the third conical flask. Stirring was done by hand shaking the digester to break the scum.

To obtain the consistency of the raw material for biogas production experiments, Cow dung (CD) and poultry droppings (PD) were prepared by blending 100g of fresh Cow dung (CD) with 300g of fresh poultry droppings (PD) that is a ratio of 1:3. Tap water was stirred into the mixture and then sieved to make slurry. The digesters were fed on a batch basis with 300ml of slurry, leaving some space for gas to collect. The system was then left to 'run'. The digesters were operated at ambient temperature, 32°C, and 34°C, for 30 days. The digesters were then setup to determine the biogas yield for temperatures of 35°C, 36°C, 37°C, 38°C, 39°C, 40°C, 41°C 42°C, 43°C and 45°C. Two 10ml samples were taken to the laboratory for chemical analysis. Nitrogen content was determined using digestion and distillation apparatus. Total phosphorus was also determined using Spectrophotometer. Potassium content was detected by Atomic Absorption Spectrophotometry.

3.0 Test Results

3.1 Mesophilic Temperature.

Methanogenic (biogas producing) bacteria are divided into mesophilic and thermophilic strains according to their optimum temperature ranges. Both mesophilic and thermophilic strains are used for biogas generation. However, thermophilic digesters are highly sensitive to changes in feed materials and temperature, and therefore do not have the same reliability as mesophilic digesters. The optimum range for the mesophilic strains is 30°C to 45°C, while for the thermophilic strains it reaches 50°C to 60°C [8].

3.2 Batch Anaerobic Digestion

A batch system is the simplest form of digestion. Biomass is added to the digester at the start of the process in a batch and is sealed for the duration of the process. Batch digesters suffer from odour issues that can be a severe problem when they are emptied. Typically biogas production will be formed with a normal distribution pattern over time. The operator can use this fact to determine whether the active materials are still available in the slurry. As the batch digestion is simple and requires less equipment and lower levels of design work it is typically a cheaper form of digestion.

3.3 Biogas Yield

3.3.1 Biogas production at temperatures of 30 °C, 32 °C, 34 °C, and 35 °C.

Fig. 2 shows the superimposed relative biogas batch production process for the temperatures of 30^0C, 32^0C, 34^0C and 35^0C respectively. The graph show that the rate of bacteriological methane production increases with temperature. The unheated biogas digester at ambient temperature of 30^0C performed only satisfactory. Production started on the fifth day and peaked on the ninth day. It rapidly dropped again after the tenth day, and continued in this unsteady pattern for the duration of experiment. In some days biogas yield was zero due to the slow metabolism of the methanogenic bacteria. Within the ambient range of 28-31°C temperature, gas production was minimal. Only 185ml of biogas was recorded at the ambient temperature. When the temperature of the slurry in the digester was raised to 32°C, the gas production increased significantly, though so low that biogas production was not economical. The peak of gas production occurred earlier. Production started on the third day, peaked on the fourth and stayed reasonably constant for the duration of experiment. The total volume of 1260ml biogas was recorded for the temperature of 32°C. When the temperature was increased to 34 °C, the relative biogas production improved a little, but the production still lagged having similar trend with 32 °C. 1295.55ml of biogas was recorded at this temperature.

Biogas production at 35 °C improved and 2535ml was recorded. Biogas production started the first day and peaked on the fourth. The higher methane yield at this temperature was probably due to more metabolisms of methanogenic bacteria caused by favourable temperature and pH of 7.1. The delay time for commencement of methane production was clearly shown in the graphs, it further shows that higher temperature led to faster metabolism of methanogenic bacteria, and quicker methane formation. The delay in commencement was probably due to the slow degradation of methane-yielding materials at ambient and lower temperatures. The methanogenic bacteria had responded considerably more faster to the temperature rise than some other environmental factors.

3.3.2 Biogas production at temperatures of 36 °C, 37 °C, and 38 °C.

Fig.3 shows the comparisons of biogas batch production at temperatures of 36^0C, 37^0C, and 38^0C respectively. Biogas production decreased slightly when temperature was further increased from 35 °C to 36^0C. The relative biogas production still dropped at production temperatures of 37 °C and 38°C. Biogas yield of 2415ml, 2324ml, and 2406.5ml were recorded for batch production temperatures of 36^0C, 37^0C, and 38^0C respectively. The trend of the graphs show a rapid rise in biogas yield at the start of production during the acid forming stages and is maximum within four days when methanogenesis dominates the processes. Afterwards unsteady biogas production was observed and towards the end of the duration of experiment, biogas production dropped.

3.3.3 Biogas production at temperatures of 39 °C, 40 °C, and 42 °C.

The biogas production at the temperatures of 39^0C, 40^0C and 42^0C was superimposed as shown in Fig. 4.

The plots showed optimum increase in biogas produced at a temperature of 40^0C. This indicates that a batch process biogas digester should be maintained at 40°C for most favourable batch production functioning. When the temperature was further increased to 42^0C, biogas production decreased from 2685 ml at 40^0C to 2085 ml at 42^0C, indicating that biogas production was adversely affected with an increased temperature.

3.3.4 Biogas production at temperatures of 30 °C, 40 °C, and 45 °C.

Biogas production yields at temperatures of 30 °C, 40 °C and 45 °C are superimposed as shown in fig. 5. When the production temperature was further increased to 45^0C, the gas yield of 2060 ml was obtained indicating another drop in production compared to the high yield of 2685 ml recorded at 40°C. It further shows that increase in temperature higher than the optimal 40°C, metabolic rate is reduced and biogas production dropped considerably until a standstill is reached. This is probably due to the fact that exceeding the optimal temperature led to damage to the bacteria strains even though an initial high biogas yield could be noted, leading to the death of the biogas creators in the fermenter (driving the bacteria to their death), "biological collapse".

The trend of the graph shows unsteady gas production at 45 °C after an initial low rise and towards the end of the duration of experiment, biogas production dropped. It was maximum on the fourth day and dropped from fifth day to the end of experiment. These results can also be attributed to the fact that different species of methanogenic bacteria are able to survive at different temperature ranges. A rise in temperature to a certain point increases the biological activity of these bacteria, evidenced by an increase in growth rate and the specific biogas production. At temperatures falling below the corresponding optimum temperature, metabolic activity – that is biogas production - decreased significantly. Conversely, excessive high temperatures harm the bacteria, and ultimately kill off the biogas-producing bacteria in the digester. The batch digesters started producing biogas after one to five days dependent on the temperature, slowly increasing production and then dropped off after three or four weeks. The dropped biogas yields after an initial rise could also be attributed to volatile fatty acid accumulation resulting in acidification of the digester which inhibited further methane formation as only the least digestible material remains. The higher temperature digestion systems are considered to be less stable. However, the increased temperatures facilitate faster reaction rates by increasing the activation energy of the bacteria and hence faster gas yields.

3.4 Effluent

Total NPK values of slurry added to the digester in the batch digestion process were evaluated and it was observed that the total nitrogen (N) and total potassium (K) were recovered after biogas production, but total phosphorous (P) showed a 30% decrease compared to the influent. Slurry after digestion indicated Nitrogen (N) 2.34, Phosphorous (P) 1.24 and Potassium (K) 0.67 Composition. The digested sludge is a high quality organic fertilizer which is stable when used on the soil.

Conclusion

The experimental results showed that biogas could be efficiently produced from Cow dung (CD) and poultry droppings (PD) blend using batch production process. The experimental results showed that the optimum production temperature for the batch digestion process is 40^0C. The analysis of the effluent slurry indicates that it is rich in nutrients and can be used as an organic fertilizer.

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