Nigerian Journal of Technology (NIJOTECH)
Vol. 32. No. 3. November 2013, pp. **478 – 484**
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University of Nigeria, Nsukka, ISSN: 1115-8443
www.nijotech.com

ASSESMENT OF MESOPHILIC CO-DIGESTION OF COW DUNG WITH LEMON GRASS FOR BIOGAS PRODUCTION

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Abstract

The scarcity of energy (fossil) and its attendant pollution menace have provided the avenue to consider alternative sources of energy. A study was carried out on the design and construction of an Anaerobic Digester system using 1mm galvanized steel for the production of biogas from co-digestion of Cow dung and Lemon grass sourced from the Zaria abattoir and the University campus respectively. The experiment lasted for 30 days using a 25-liter pilot scale anaerobic digester. A total of $0.146m^3$***(***$0.100m^3$***after scrubbing) were produced with a deviation and methane content of*** 0.003 m^3 ***and 68.53% respectively. The cooking test carried out revealed that the scrubbed gas had higher cooking rates for both water and rice (0.10L/min and 0.0048kg/min respectively) than the unscrubbed gas (0.07L/min and 0.0034kg/min respectively while the biogas flow rate was*** $0.0049m^3/min$***. An improvement of 42.86% and 41.18% was recorded for the cooking rates for water and rice respectively after the gas were scrubbed. The physico-chemistry of the feedstock in the digester revealed the digester temperature fluctuated between*** 28^0C ***and*** 36.7^0C ***while the pH of the medium fluctuated optimally between 5.81 and 7.73.The daily ambient temperatures varied from*** 31^oC ***to*** 42^oC***. The research demonstrated that anaerobic co-digestion of cow dung with lemon grass produced a high quality biogas.***

Keywords: Anaerobic digestion, Biogas, Co-digestion, Cow dung, Cooking rate, Lemon grass, Methane content

1. Introduction

Energy consumption in Nigeria has been increasing on a relatively high rate. On a global scale, Iwayemi [1] opined that the Nigerian energy industry is probably one of the most inefficient in meeting the needs of its customers. This is most evident in the persistent disequilibrium in the markets for electricity and petroleum products, especially kerosene and diesel. The dismal energy service provision has adversely affected living standards of the population and exacerbated income and energy poverty in an economy where the majority of the people live on less than $2 a day. Although the abundant hydrocarbon natural resource (crude oil and natural gas) in Nigeria is the mainstay of over 80% of revenues to the nation, it has not served as a catalyst for economic growth neither has it served as the major source of energy in the mix of energy supplies [2]. Furthermore, the ever increasing prices of petroleum products globally, has made kerosene, which is the most commonly used fuel for cooking and lighting unaffordable to many, especially the rural dwellers[3]. This therefore moves a larger percentage of the populace to seek solutions to their energy needs from other sources which in most cases are detrimental to the environment. As at 2008, 79.6% of the households in Nigeria still depended on Wood fuel for cooking [4]. The alarming population explosion in Africa and its concomitant effect on forest reserve due to increased wood-fuel/charcoal fuel production and consumption [5, 6] is not sustainable in the long term as it has resulted in deterioration of the quality and quantity of forests and has posed a serious threat in maintaining ecological balance, thereby manifesting various problems like deforestation, flood, Global warming, soil erosion, landslides, climate change etc. Thus, an alternative energy source that would be affordable and environmentally friendly becomes necessary if the green forest must be preserved.

One type of wastes that is of great concern in both urban and rural areas in Nigeria is abattoir or slaughter-house wastes [7]. Cattle slurry is known to introduce a range of pathogens including *Clostridium chavoie* (black leg disease), *Ascaris ova*, *E. coli* and *Salmonella spp*. as reported in cow dung slurries in Bauchi state, Nigeria and in poultry wastes in Cameroon [8, 9]. More so, the consequences of abattoir waste pollution are felt by both humans and the environment. Its adverse effects on air quality, agriculture, potable water supplies, and aquatic life negatively impact health and well-being. Poor local communities, in particular, have little or no choice but to consume water polluted with abattoir waste. Furthermore, millions of tonnes of dung is released daily from the enormous cattle population especially in the northern part of Nigeria. These emit a lot of methane gas when exposed to the atmosphere, which is 320 times more harmful to human health than carbon dioxide [10]. In addition Lemon grass (*Cymbopogon citratus*) is a well-known medicinal plant due to its citral content [11]. After it is boiled for medicinal purpose and the citral content is extracted, the remains of the grass become waste and could constitute nuisance to the environment. The main challenge of the present world therefore is to harness the energy source which is environment friendly and ecologically balanced. This need has forced the world to search for other alternate sources of energy. But unfortunately the new alternative energy sources like the solar, hydro, wind etc. require huge economical investment and technical power to operate, which seem to be very difficult for the developing countries like Nigeria [3]. In the present moment, biogas energy can be one reliable, easily available and economically feasible source of alternative and renewable source (relative to solar, hydro and wind sources) which can be managed by locally available sources and simple technology for these rural villages. Thus biogas technology could be an appropriate means for recycling organic waste thereby achieving the goal one of the Millennium Development Goals (MDGs) of eradicating extreme poverty [12] via waste to wealth initiative. Thus the organic waste becomes a channel for wealth creation as they are harnessed as feed materials for the production of biogas as well as biofertilizers that would accrue from the digestate. It is for these reasons that researches like the present one are desirable to chart a course for sustainable energy production and utilization while a cleaner and safer environment is enhanced.

Anaerobic co-digestion process with the addition of low-cost municipal organic wastes could also be given consideration and as such, municipally available organic wastes including fats, oils and grease (FOG) and kitchen waste (KW), could be employed as the potential co-substrates. A 50% increase in biogas generation was recorded at a full-scale digester using FOG as a co-substrate [13]. FOG as a co-substrate was also investigated and a significant higher methane generation was reported [14]. The evaluation of evaluated food wastes as co-substrates has been carried out and successfully enhanced methane yield production [15, 16, 17, 18, 19]. However, the physical and chemical nature of organic wastes and inocula can vary considerably, and the organic waste loading rate to the anaerobic digesters is critical in pilot or full-scale applications [20].

The objective of this study therefore, is to create a sustainable solid waste management system that supports greenhouse gas (GHG) emission reduction by the co-digestion of cow dung and Lemon grass for biogas generation.

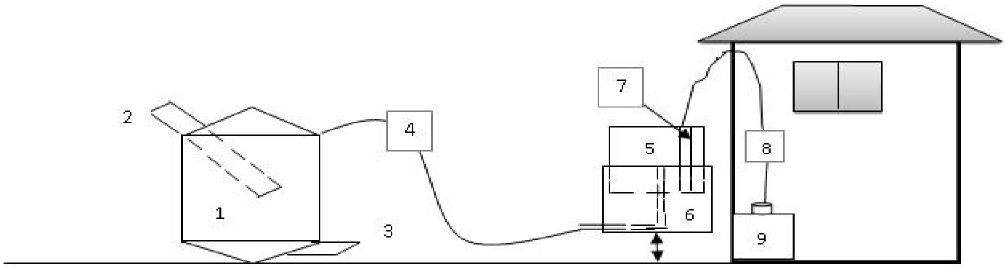
2. Materials and methods

2.1 Materials

The anaerobic digestion system comprises of a digester and a gas collection system which in turn is made up of the gas holder and water jacket designed and constructed. The details of the design of the anaerobic digestion system have been fully described previously [21].

The 25 litre - cylindrical biogas digester tank of height and diameter respectively 0.5m and 0.25m was fabricated from 1mm galvanized steel material. Similarly, a 12.1 litre gas holder tank of height 0.25m and diameter 0.25m was fabricated from thin sheet metal and used to temporarily store the biogas until it was used to produce heat or used to replace or supplement the supply of cooking gas. Plastic hose was used to connect the digester to the gas collection system and the biogas stove burner while plastic valves were installed to control the gas flow as shown in Figure 1.

Other materials used in this study include pH meter model pHS-2S, (Shanghai Jinyke Rex, China) for measuring the pH of slurry every week day throughout the retention period, and 2/1^{0}C thermometers used to obtain daily temperature of the digester as well as the ambient temperatures of the research environment and biogas stove burner used for the cooking tests.



Key:
1. Digester body
2. Feedstock inlet pipe
3. Effluent outpet pipe
4. Hose from digester to gas holder
5. Gas holder
6. Water jacket
7. Rule
8. Hose to cooking stove
9. Cooking stove in the kitchen

Figure 1: Schematic view of the plant set-up

2.2 Biomass collection, Slurry Preparation and Digester Loading

The Cow dung was collected in sacks (fresh and free from impurities) from the Zango abattoir and transported to the research ground. The *Cymbopogon citratus* (lemon grass) on the other hand was gotten from gardens around staff quarters, Ahmadu Bello University, Zaria. The grass was crushed to smaller particles using the Hammer mill before they were transported to the research field for further pre-treatment. The inoculation of the digester was carried using partly decomposed slaughter house waste. The Lemon grass (*Cymbopogon citratus)* was pre-fermented for a period of 40 days while cow dung was pre-fermented for a period of 15 days respectively in plastic drums[11]. The longer period of pre-fermentation for the Lemon grass was as a result of the slow rate of decomposition of succulent plants which had not undergone any prior digestion unlike the cow dung that had gone through the digestive systems of the cattle.

The digestion was a batch process. The biomass feed material was combined in a ratio 1:1 by weight of cow dung and lemon grass. 6kg of pre-fermented cow dung/Lemon grass was mixed with water to form slurry in the ratio 1:1 by volume and introduced into the digester through the inlet. The slurry is allowed to occupy three quarter of the digester space leaving a clear height of about 0.0625 m as space for the gas production. The inflow was directed downward to cause the solids to accumulate at the bottom of the tank where after digestion they were easily removed. Before feeding the digester, the flexible hose connecting the gas outlet from the digester to the gas holder was disconnected, such that the gas outlets from the digester were left open. This was done to prevent negative pressure build up in the digester. The gas was collected from the digester through a 10mm diameter flexible hose connected from the digester to the bottom of the gas collection system. The collected gas is allowed to pass through water and slaked lime respectively as scrubbers. Chen et al.,[23] noted that slaked lime ($Ca(OH)_2$) could be used to remove carbon dioxide (CO_2) from the flue gas, and that there is evidence that the $CO_2/Ca(OH)_2$ reaction also requires the uptake of water. The overall reaction is expressed by:

$$Ca(OH)_{2(s)} + CO_{2(g)} \rightarrow CaCO_{3(s)} + H_2O_{(ads)} \qquad (1)$$

The volumes of gas collected before and after scrubbing were taken and recorded following the method described in the succeeding section. The gases collected before and after scrubbing were used to boil water using Ahmadu Bello University biogas stove burner [24] to estimate and compare the cooking rates. The experiment was monitored for 30days digestion period. During this period, daily ambient temperature of Samaru- Zaria varied from 31°C to 42°C which is within the mesophilic temperature range.

2.3 Measurement of gas production

The gas holder was calibrated with the aid of a rule marked 7 in the figure 1 to enable the reading of the daily gas production from the co-digestion of cow dung with Lemon grass.

The volume of biogas produced was measured each day shortly before sunset, by computing the volume of the gas holder floating over water level in the water jacket.

The base area of the gas holder is expressed by eqn (2):

$$A = \frac{\pi d^2}{4} = \frac{\pi \times 0.25^2}{4} = 0.0491m^2 \qquad (2)$$

The height of cylinder above water level was read off on the calibration on the gas holder.

Let this height (h) = x, which varies.

Volume of biogas is obtained as the volume of cylinder above water level, given by eqn (3)

Volume,

$$V = \left(\frac{\pi d^2}{4}\right) h \qquad (3)$$

where h = x

Substituting for A in eqn (2), the volume of biogas, V $= 0.0491x\,\mathrm{m}^3$

In the evening, when the cooking test was concluded (about 7pm local time), the gas holder was completely emptied. The values given by the calibration were written down in order to obtain the daily production by subtracting this value by that of the previous day. It was assumed that other impurities apart from carbon dioxide was negligible, thus, the difference in volume of gas produced before and after scrubbing were used to estimate the methane content.

4. Results and discussions

The quantity of biogas produced daily from the co-digestion of cow dung and lemon grass over a period of 30 days is summarized in Figure 2 while the cumulative biogas production is represented in Figure 3.

Biogas production was observed on the first day (24 hours) after loading the digester and increased gradually until the peak was reached on 11thday. This fast rate of production could be attributed to long pre-fermentation period. The production dropped progressively after the 11th day except for a sudden rise on the 16th day after which production was steady until the 18thday when a progressive drop was observed. There was also a sudden rise in gas production on the 22nd and 26th day respectively. A total of 0.146 m^3 (0.100m^3 after scrubbing) of biogas was produced from the co-digestion of Cow dung and Lemon grass (*Cymbopogon citratus*) with a standard deviation of 0.003 m^{3}and methane content of 68.53% (see Table 1). The table further shows the total biogas produced, the biogas yield per day, the biogas yield per of kg slurry as well as the daily biogas yield per kg slurry.

Table 1 also shows the estimate of the methane content of the biogas produced on the basis of the decrease in volume after removal of carbon dioxide. The methane content of 68.53% obtained in this study corresponds with the values stated in literatures for animal wastes and succulent grass [25]. The values for biogas production obtained in this work (0.146 m^3 and 0.100 m^3 after scrubbing), corroborate with previous studies on biogas from cow dung [3, 26, 27] although the quality of the gas from co-digestion was observed to be better.

It was observed that the digester temperature fluctuated between 28^{0}C and 36.7^{0}C while the daily ambient temperatures varied from 31^{o}C to 42^{o}C (see figure 4).

The pH of the medium changed progressively from acidic to slightly alkaline fluctuating optimally between 5.81 and 7.73(see figure 5).This accounts for the nearly steady rate of biogas production recorded as the pH reveals equilibrium in the digester microbial habitat, a situation necessary for optimum biogas production[22,28]. Tables 2 shows the summary of the results for the cooking tests carried out on the gas produced before and after scrubbing. The times taken to boil 0.1L of water and parboil 0.18kg of rice were used to estimate the cooking rates in each case.

The results of the cooking tests carried out to estimate the minimum time it would take to boil water and rice respectively are presented on table 2. It shows that the scrubbed gas had higher cooking rates for both water and rice (0.10L/min and 0.0048kg/min respectively) than the unscrubbed gas (0.07L/min and 0.0034kg/min respectively. The biogas flow rate based on the design of the burner and the results obtained was 0.0049 m^3/min. The difference in the time of cooking reflects the quality of the gas in each case. An improvement of 42.86% and 41.18% was recorded for the cooking rates for water and rice respectively after the gas were scrubbed.

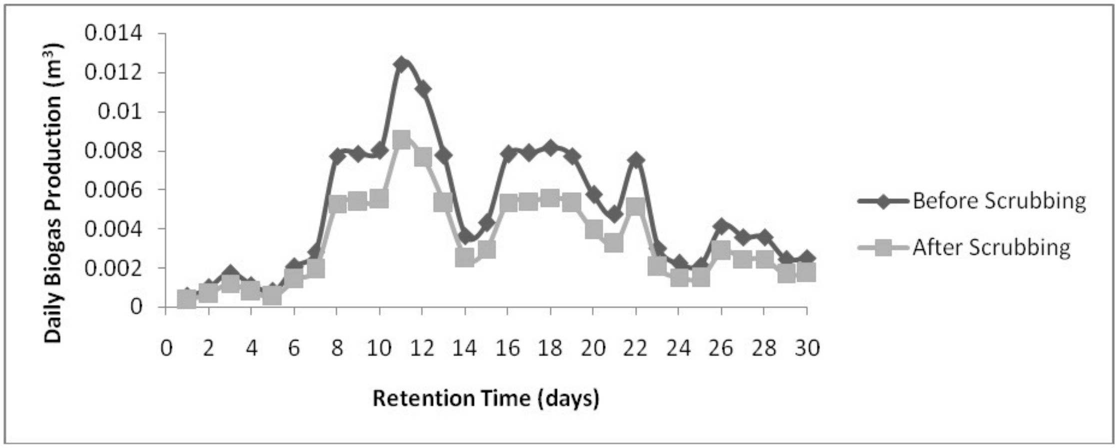


Figure 2: Daily Biogas production from Co-digestion of Cow dung and Lemon grass

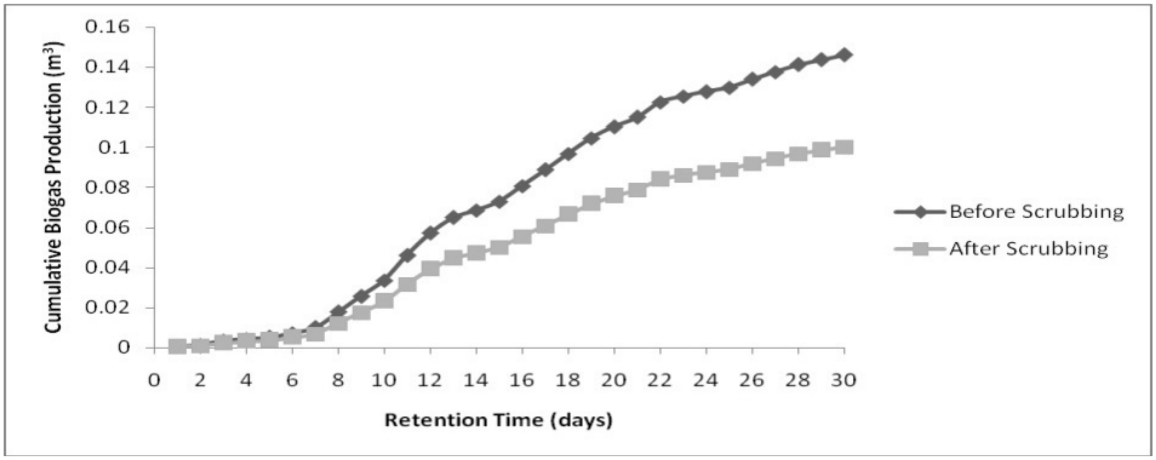


Figure 3: Cumulative Biogas production from Co-digestion of Cow dung and Lemon grass

Table 1: Biogas Yield from Co-digestion of Cow dung and Lemon grass before and after scrubbing

	Total volume of Biogas produced (m^3)	Average Biogas yield per day (m^3/day)	Average yield of Biogas per Kg of slurry (m^3/kg)	Average daily yield of Biogas per Kg of slurry (m^3/kg/day)	Deviation (m^3)	Estimated Methane Content (%)
Before Scrubbing	0.146	0.00486667	0.024333	0.000811	0.003203	68.53
After Scrubbing	0.100	0.003333	0.016667	0.000556		

Table 2: Summary of Cooking Test Results

Cooking Rates										Biogas Consumption Rate (m^3/min)
Water					Rice					
Before Scrubbing		After Scrubbing		%Increase	Before Scrubbing		After Scrubbing		%Increase	
Time (min)	Rate (L/min)	Time (min)	Rate (L/min)		Time (min)	Rate (kg/min)	Time (min)	Rate (kg/min)		
1.42	0.070	1.01	0.10	42.86	52.66	0.0034	37.45	0.0048	41.18	0.0049

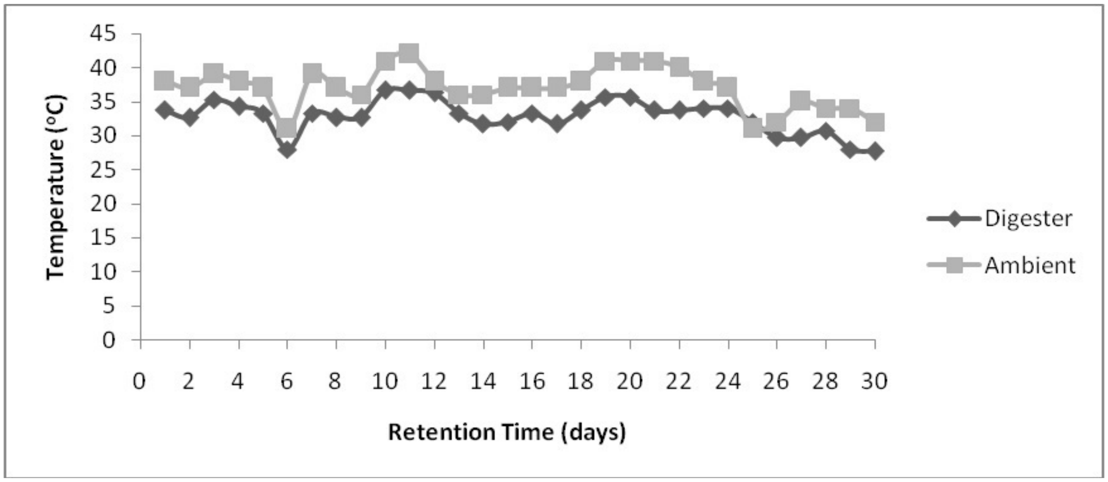


Figure 4: Daily Digester and Ambient Temperatures for the Co-digestion of Cow dung and Lemon grass

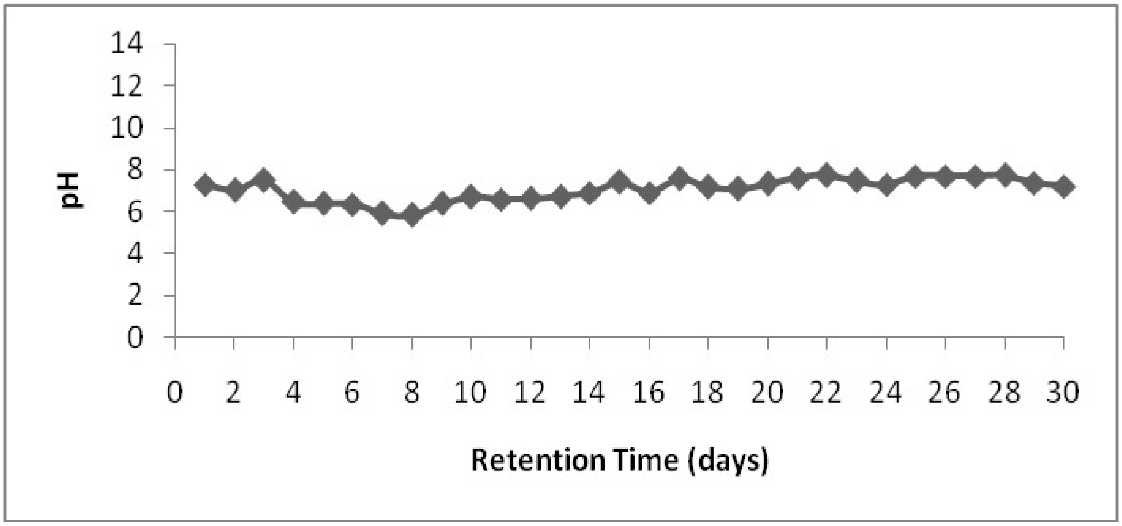


Figure 5: pH of the co-digestion of Cow dung and Lemon Grass at various times intervals

4. Conclusion

The study has demonstrated that biogas of good quality and quantity can be produced from the mesophilic co-digestion of cow dung and lemon grass. The total biogas yield for the respective substrates observed in this research is comparable with those from other substrates. The methane content recorded is comparable with those obtainable in literature. Although the energy outputs of the gases were not determined, the gases were able to boil potable water in a period of time comparable with those of kerosene, electrical and butane stoves.

This study could not establish if longer retention period for the co-digestion would increase the biogas yield although it is inferred that it could allow for proper decomposition of the lemon grass and consequently higher biogas yield.

Furthermore, the study revealed that scrubbing of the biogas for removal of impurities such as but not restricted to carbon dioxide and hydrogen sulphide improved the heating capacity of the gas as demonstrated by the increase in the cooking rates for water and rice respectively.

Acknowledgement

The authors wish to acknowledge the contributions of Prof C. A. Okuofu , Dr J. A. Otun and Dr S. B. Igboro all of the Department of Water Resources and Environmental Engineering for their immense contribution to the success of this study.

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