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**Research Paper**

# Biochemical Conversion of Food Waste for Energy and Agricultural Applications: Towards Sustainable Restaurant Operation in Nigeria

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***Abstract***
*One of the major problems faced by many restaurants in Nigeria is high operational cost resulting from high cost of energy, food ingredients and waste disposal. Indiscriminate disposal of food wastes contribute to environmental problems such as global warming and the spread of diseases. This paper presents the design and fabrication of a biogas plant for the conversion of biodegradable food wastes into biogas and agri-supplements which can be used for domestic and commercial purposes such as cooking/heating and agricultural applications respectively. This study is geared towards the domestication of an existing technology that has not been taken seriously in Nigeria. the anaerobic digester consists mainly of the slurry inlet, the digester, gas holder and effluent discharge pipe. The slurry, a mixture of food waste and water was fed in to the digester and allowed to digest anaerobically to generate biogas consisting mainly of methane. The digestate, a harmless solid/liquid mixturewas applied as organic manure to a small portion of land in an agricultural experiment.Results of combustion tests in a locally fabricated torch presented a long, blue and quite flame, similar to that of LPG. Digested fed crops grew faster and yielded better. This projecthas the potential to enhance the operational sustainability of restaurants by lowering the cost of cooking and heating, while also supplementing vegetable supply.*

***Keywords:*** *Sustainability, Food Waste, Energy, Restaurant*

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## I. Introduction

The fact that food is very important to human survival cannot be overemphasized. This has made it to be listed among the biological needs of man (Maslow, 1954). Many types of food require some form of preparation such as cooking. Cooking and food storage accounts for most (up to 91 %) of the energy consumed by households and restaurants in developing countries such as Nigeria (Bisu *et al,* 2016;Kichonge *et al,* 2014;Oyedepo, 2012; Bioenergylists, 2012). The situation is similar in the United States where 56 – 67% of the energy consumed by restaurants goes to cooking, refrigeration and water heating (E Source, 2002)unfortunately in Nigeria, the issue of Energy supply has become a big problem that even the government seems to be finding it difficult to resolve. This is evident by the failure of successive administrations to ensure steady power supply despite huge budgetary allocations.

The poor and costly energy supply has forced businesses to resort to or continue the use of fossil fuels such as kerosene, liquefied petroleum gas, and biomass fuels such as wood and charcoal (Baiyegunhi and Hassan, 2014). This, apart from increasing the cost of business, also contributes to environmental problems such as deforestation, soil erosion, and greenhouse gas emission, which has a negative impact on the environment (Rajendran, *et al.* 2012)

Another problem that bedevils restaurant operators is the disposal of their wastes, usually in open fields or landfills, eventually contributing to the spread of diseases and releasing methane into the environment, which contribute to global warming (Chen, *et al.* 2010). The cost of disposing of those wastes in terms of labor and machines cannot be neglected (Wilkin, 2008), especiallyconsidering land scarcity in some areas.

Due to the increasing prices of energy, environmental and health problems associated with the use of traditional fuels keep increasing, buttressing thefact that economic prosperity and quality of life of a nation are usually linked to energy accessibility. Energy availability in an economy is usually measured by per-capita energy consumption, a determinant and indicator of economic development of nations (Zhou *et al*, 2008, Pagar, 2008, Amigun *et al*, 2008, Sing and Sooch, 2004 and Rajendram *et al*., 2012); it'stherefore necessary for restaurants to find alternative, clean and economical sources of energy. This has therefore resulted in efforts being made to convert organic wastes into biogas (Via anaerobic digestion) to supplement energy supply.

Food waste is one of the largest components of municipal solid waste generated in the world, (US EPA, 2008; Chen *et al*, 2010). Several attempts at the anaerobic digestion of different types of food wastes have produced promising results. Ryan and Wilkie (2008) and Zyang, *et al* (2005) obtained 0.16 $m^3$/kg and 0.14$m^3$/kg respectively of biogas generated by mixtures of various food wastes. Using batch digestion at 37ºC and 28 days retention period, Cho *et al* (1995) obtained methane yields of 0.48, 0.29, 0.28 and 0.47 L/g VS (volatile solid) for cooked meat, boiled rice, fresh cabbage and mixed food wastes, respectively. Heo *et al* (2004), while studying the biodegradability of some traditional Korean food waste made up of 15 – 20 % meat and eggs, 65 – 70 % vegetables and 10 – 15 % boiled rice at 37ºC through 40 days retention period, obtained a methane yield of 0.49 L/g VS.

Biogas has proved useful for cooking and heating by direct combustion. The quantity of biogas used for cooking varies between 30 to 45 $m^3$ per month for an average family size. This compares favorably with kerosene and LPG with consumption rates of 11 – 20 L and 11 – 15 kg respectively per month. The energy equivalent is about 300 kWh (biogas), 200 kWh (kerosene) and 150kWh [LPG] (Rajendran *et al*, 2012). Biogas burning is however not possible with the commercial butane and propane burners because of its physicochemical properties. Some modificationis required to accommodate biogas/air ratio of 1:10 required for effective combustion (Subramanian, 1977; Bond and Templeton, 2011). Special stoves designed to burn biogas are already available in the market, putting the trouble of modification to rest.

The technology decomposes biodegradable wastes in a device devoid of oxygen, called the 'anaerobic digester' to generate biogas whose major constituents are methane and carbon dioxide, with some traces of Hydrogen Sulphide, moisture and siloxanes (Royput, 2008). The foothold of this technology is the discovery by researchers that food and other biodegradable wastes possess high potential for biogas generation (Ryan and Wilkie, 2008, Zyang, *et al*., 2005). More so, up to 70% of the waste fed into the digester comes out as odorless sludge and can be used as organic fertilizer (Singal, 2011). It has also been found that anaerobic treatment of waste minimizes the survival of pathogens (Weilan, 2009), thereby reducing the outbreak of diseases. This technology is being used widely in countries such as Kenya, India, and Nepal for cooking, lighting, pumping water in irrigation farms, electricity generation, etc (Rajendran, *et al.*, 2012).However, in spite of its numerous advantages and widespread application in many countries, the technology is surprisingly unpopular in Nigeria and Bauchi in particular,hence the need for itsdomestication to ease the stress of restaurants in for energy to meet their demand.

The aim of this work is to create awareness in the local community through the domestication of the technology (anaerobic digestion) for harnessing the energy in food waste for domestic and commercial use. This is capable of reducing environmental pollution and energy cost of households and restaurants, making their cooking operations sustainable. Specifically, the objectives of the studyt included Designing a biogas plant consisting of a digester and associated accessories; fabrication and assembly of the plant and testing it for gas generation and combustibility. The study also observed the effect of the digester effluent on vegetable plant performance.

Restaurants stand to benefit from this work as follows:

a. Savings on food waste disposal; as it would not need to transport the waste to any distant location anymore, and no digging of pits for landfill.

b. Saving on energy cost. The biogas can be used for cooking through direct combustion or electricity generation via internal combustion engines after further purification.

c. Reduction in deforestation and its attendant challenges due to substitution of wood or charcoal with biogas as cooking energy.

d. Positive public image resulting from better waste disposal method.

e. Deploying this technology will make the restaurants a model for sustainable facility management, which is yet to be fully embraced in the country.

f. Cut down on possible disease outbreaks due to poor waste disposal, as anaerobic treatment minimizes the survival of pathogens (Weilan, 2009).

g. The effluent could be used as fertilizer for local farming, therefore reducing the cost of farming. This, while increasing the availability of local food, may also increase the revenue of the household or restaurant if they sold it. Local food production reduces greenhouse gas emission due to shipping of imported food.

h. The project will make the households and restaurants a closed loop system that conserves energy and nutrients requiring less external sources for energy and fewer sinks for waste.

This project is limited to the design of a biogas plant consisting of a continuous biogas digester to generate biogas for direct combustion as cooking fuel. It also involved the testing of the plant in terms of the biogas production and combustion.The effect of the effluent on plant growth rate and yield was also monitored.

## II. Design and Fabrication of the Biogas Generator

**2.1 Design of the Biogas Generator**

The biogas generator consists of two major components: the digester and gas holder. These components were designed as explained in the following sections.

**2.2 Design of the biogas digester**

This is the container in which the waste food is digested to produce the biogas required for heating, cooking or electricity generation. The parameters used in this design include:

- ✓ Food waste with 10% solid concentration (For Conventional wet anaerobic digestion technology)
- ✓ Daily rate of waste to be digested 10 kg.

This would be diluted with 90 kg of water, making the total feedstock to be 100 kg/day

Considering the fact that the density of water is 1000kg/m$^3$, the total feedstock is going to be 100 Liter/day (Approximately four buckets per day)

- ✓ Climatic condition – Bauchi has a warm climate (temperature usually between 27-43°C) which is within the range of mesophilic digester operation (Saeed and Sharma, 2012), so no heating is required.
- ✓ Quantity of effluent (70% of feed stock) [Saeed and Sharma, 2012]

Using a retention period of 28 days, Capacity (Volume) of digester, C $= \left(\frac{Q1+Q2}{2}\right) \times t$ Liters (Singal, 2011)

Where

$Q_1$ = Daily supply of raw waste = 100 Liters

$Q_2$ = Daily volume of effluent = 70% x 100 = 70 Liters

t = Hydraulic retention time = 28 days

$\therefore$ C = $\left(\frac{100+70}{2}\right) \times 28 = 2380\ Litres$

1 gal = 4.55 liters; 1m$^3$ = 220gal (Saeed and Sharma, 2012)

$\therefore$ C = $\frac{2380}{4.55} = 523.08\ gal,$

Then C = $\frac{523.08}{220} = 2.38\ m^3$

For a cylindrical digester, the recommended diameter to depth ($D : l$) ratio is 0.6:1 (Saeed and Sharma, 2012)

$C = 2\pi rl$ Where$r$ = Radius of digester; $l$ = Depth of digester

But $D : l = 0.6{:}\,1, andD = 2r$

$\therefore \quad l = \frac{2r}{0.6},\ and C = \pi r^2 \times \frac{2r}{0.6} = \frac{2\pi r^3}{0.6}$

And,

$r = \sqrt[3]{\frac{0.6 \times 2.38}{2\pi}} = 0.61\ m$

$D = 2r = 2 \times 0.61 = 1.22\ m$

$$l = \frac{2r}{0.6} = \frac{2 \times 0.61}{0.6} = 2.03\ m$$

$\therefore \{\boldsymbol{D = 1.22m};\ \ \boldsymbol{l = 2.03m}\}$

i.e the digester is cylindrical with a diameter of 1.22 m and 2.03 m deep.

**2.3 Design of the Gas Holder**

Since a continuous supply of gas at constant pressure is required, the continuous biogas plant with floating gas holder was chosen; this requires daily feeding. The gas holder is usually half the volume of the digester. Therefore, it was taken as1.19 $m^3$.

The following parameters were used in the design of the gas holder:

- ✓ Volume, $V$ = 1.19 $m^3$
- ✓ Diameter, $d$ = 1.18 (0.04 $m$ less than the diameter of the digester, as clearance)
- ✓ Height of gas holder, h (Required).

$$\therefore V = \frac{\pi d^2 h}{4}$$

$$\rightarrow h = \frac{4V}{\pi d^2}$$

Substituting the values of the parameters yields

$$h = \frac{4 \times 1.19}{\pi \times (1.18)^2} = 1.09\ m$$

ie the gasholder is cylindrical with a **diameter** of ***1.18 m*** and ***1.09 m*depth**.

**2.4 Fabrication, Assembly and Testing of the Biogas Generator**

**2.4.1 Materials and Instruments**

The materials used for this project include:

a. 3 mm Stainless steel plate b. 2 mm Stainless steel sheets c. H – Channel steel

d. Angle bar e. Welding electrodes f. Body filler g. Rubber hose h. Flow control valves

i. Adhesives

Instruments used include

h. Thermometers and thermocouples

i. Digital balance

j. Digital PH meter

k. Digital TDS metre

l. Laddle

m. Mixing Basins

n. Mixers

o. torch

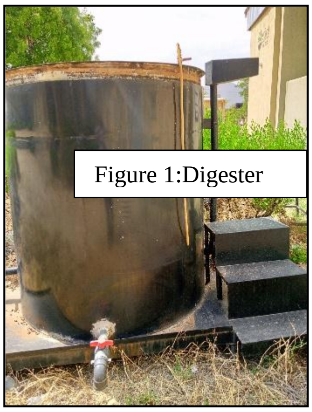

Figure 1:Digester

The digester and gas holder were fabricated from 3 mm and 2 mm stainless steel sheets respectively using appropriate fabrication tools and processes. Since this digester was intended to be mobile, a supporting frame with castle rollers was constructed to ease its movement to the point of use.Rubber hoses were used to transport the biogas from the digester to the biogas burner. Figure 1 shows the fabricated digester with the grey color at the upper part indicating the rising digester.

**2.4.2Collection of Food Wastes**

The food waste samples were collected manually from restaurants within the Polytechnic community, properly mixed and stored in plastic buckets. The fruit waste was ground to form a paste for easy mixing with water and feeding into the digester.

**2.4.3Testing for Biogas Generation, Combustion and Agricultural Use of Effluent**

A mixture of food wastes was created based on the fact that a centralized digester is being envisioned to accommodate many types of food wastes and of larger capacity. The digester was seeded with the same mixture of food waste with 10 % solid concentration, and then allowed to stabilize for two days before actual feeding. Thirty days was taken as the Hydraulic Retention Time (HRT). Mesophilic batch digestion was done for thirty days, then a continuous digestion test followed for another thirty days. Feeding and effluent removal was done manually once daily. The PH of the digester content was maintained between 6.8 and 7.2. Biogas generation was measured by calculating the volume of the gas holder as it rose every day using the relation $V = \frac{\pi d^2 h}{4}$ $(m^3)$.

A locally fabricated torch was used to test the biogas' combustibility.

The effect of the effluent on plant growth rate and yield was monitoredby planting kenaf (Hibiscus cannabinus L.) on two plots of land with dimensions of 2m × 2m each and similar soil composition. One of the plots (A) was taken as the control with only water applied to it throughout the experimental period (30 days), while the effluent from the digester was applied to the experimental plot (B) every time it was evacuated. Plant color and growth rate was observed on weekly basis and the overall yield was measured by weighing the harvested kenaf.The distance between the soil surfaces to the apex of the plant (height) was measured using meter rule.

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## III. Results and Discussion

The gas holder started rising on the fourth day, an indication that gas generation had started.Table 1 shows the daily biogas yield and average daily yield. It shows that the yield started on day 4 as $0.67m^3$, and increased gradually to $2.85m^3$on day 17, then declined gradually to $0.1m^3$ on day 30. The average daily biogas yield was calculated as 1.77m3, equivalent to 11.79 kWh. This will translate to a financial savings of about two hundred nineteen thousand, three hundred forty four naira fifty five kobo (N219344.55) only, based on the electricity price of N59.64/kWh. The biogas burned with a fairly long, blue flame. The flame was visibly smokeless and noiseless,looking much like the LPG flame. These findings corroborate those of Zyang *et al*. (2005) and Rajendran *et al.* (2012). This is good enough to supplement the energy needs of a restaurant. The savings can be used to further improve the business for better profitability.

Table 2 presents the effects of effluent application on kenaf. It shows that the kenaf on which the effluent was applied (B) grew better (more height and better color) and yielded betterthan the one on the control plot (A). This result corroborates reports by Makádi, Tomócsik and Orosz (2012). This shows that biogas generation can also supplement the vegetable supply of the restaurant, resulting in further financial savings.

**Table 1: Daily Biogas Yield**

| Day | Yield ($m^3$) | Day | Yield ($m^3$) |
|---|---|---|---|
| 1 | 0 | 16 | 2.82 |
| 2 | 0 | 17 | 2.85 |
| 3 | 0 | 18 | 2.71 |
| 4 | 0.67 | 19 | 2.52 |
| 5 | 1.31 | 20 | 2.43 |
| 6 | 1.82 | 21 | 2.41 |
| 7 | 2.01 | 22 | 2.30 |
| 8 | 2.13 | 23 | 2.15 |
| 9 | 2.26 | 24 | 2.11 |
| 10 | 2.42 | 25 | 1.68 |
| 11 | 2.51 | 26 | 1.41 |
| 12 | 2.62 | 27 | 0.89 |
| 13 | 2.71 | 28 | 0.41 |
| 14 | 2.75 | 29 | 0.32 |
| 15 | 2.78 | 30 | 0.10 |
| **Average Daily Yield** | | **1.77 $m^3$** | |

**Table 2: Effect of Effluent on Performance of Kenaf**

| Plot | Average Height (cm) | Leaf Color | Yield (kg) |
|---|---|---|---|
| A (Control) | 54.4 | Yellowish green | 47.3 |
| B (With Effluent application) | 72.3 | Deep green | 59.7 |

The biogas obtained was of high quality, containing 73% methane, 21% carbon dioxide and 6% moisture and other compounds. This compares to the results obtained by Mohan and Jagadeesan (2013) who obtained 76 % methane and 24% carbon dioxide from the anaerobic digestion of food waste.

## IV. Conclusion and Recommendations

The study has proved that bioenergy conversion of food waste is a viable endeavor that every restaurant should embrace. The cost savings in terms of energy and stuff supplement is glaring. The technology is simple and straight forward.The several benefits earlier outlined can now be enjoyed with the full deployment of this technology in the restaurants or other industries for cooking and heating. The positive performance of vegetable plant with application of the effluent also presents a potential for savings in stuff cost for those that have sufficient land. The huge biogas potential of the community can now be harnessed.

Based on the results of this study, it is recommended that full deployment of this technology be encouraged by the relevant authorities to enable the better understanding and fine tuning while reaping its benefits. This encouragement can be by way of incentives, grants, and intensive awareness campaigns.

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