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Exploring the Potential of Organic Waste as a Source of Methane Gas for Electricity Generation in Nigeria

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Abstract

Open dumps and ill equipped landfills are some of the characteristics of solid waste management in Nigeria. This paper therefore seeks to investigate the viability of anaerobic digestion as part of an integrated waste management strategy for the city of Port Harcourt, Nigeria. In order to achieve this aim, the paper reviews literature on solid waste management in the study area. Alaboratory experiment was also conducted using organic solid wastefrom Port Harcourt.

From the findings, it was revealed that anaerobic digestion could play a major role towards the attainment of sustainable solid waste management in Port Harcourt. The small laboratory sample of 10 grams used for the experiment produced about 0.796 litres of methane gas, means that 1 tonne of organic waste in Port Harcourt will generate about 79600 litres of methane gas with energy equivalent of about 1592000_kj.

The paper concluded that in a city like Port Harcourt where several tonnes of solid wastes are produced every day, a substantial amount of methane gas could be recovered for electricity generation. It was therefore recommended that anaerobic digestion should be used in order to boost the electricity capacity of the city whilst also improving the quality of life of the people.

Keywords: anaerobic digestion, waste, Nigeria, methane gas, supernatant

1. Introduction

The generation of wastes is an integral part of human society. However, the management of the generated wastes present a major challenge to many countries (Sharma et al., 1999). These challenges are enormous particularly in developing countries where solid waste management poses serious problems to city authorities and environmental agencies (Adeyemi et al., 2001). Hoornweg and Bhada-Tata (2012) pointed out that environmental agencies are faced with the dilemma of managing waste in a manner that would be affordable, yet environmentally friendly and socially acceptable. Faced with this difficulty of maintaining a balance between the environment and affordability, most developing countries including Nigeria resort to open dumping, burning, landfilling and other methods of waste disposal (Adeyemi et al., 2001).

Omuta (1987) observed that waste management is one of the major sources of environmental degradation in Nigeria. He pointed out that poor urban structures as a result of uncontrolled development, lack of disposal sites, finance, poor infrastructures and equipment are some of the challenges that needs to be addressed in order to improve solid waste management operations in the country. Similarly, Agunwamba (1998) reported that the lack of adequate planning and implementation of environmental policies in Nigeria has resulted to failure in basic waste management operations;

Furthermore, Imam et al. (2009) reported that the high rate of population growth and the continuous rural-urban migration are some factors that has further exacerbated the problems of waste management in the country. In the same vein, Efe (2013) observed that, the rate at which wastes are being generated in Nigerian cities often surpass the ability of the waste management authorities to effectively collect, transport and dispose of the waste.

Agunwamba (1998) and Solomon (2009) argued that, in response to the failure of waste management operations in the country, the government of Nigeria established the Federal Environmental Protection Agency (FEPA). The agency was tasked with the responsibility of enforcing, monitoring and establishing safe environmental practice with regards to solid waste management. Agunwamba (1998) added that, in addition to the establishment of the Federal Environmental Protection Agency by the Nigerian government, environmental laws and policies were introduced in order to guarantee the protection of lives and properties. However, Agunwamba observed that despite these steps, waste management remain at a rudimentary level in the county. In most cities, wastes are simply transported away from the immediate environment in order to promote aesthetics. Similarly, Solomon (2009) observed that the practice of mixing up wastes from industries, household and other sources during waste collection have continued unabated. He argued that despite the measures taken by the government to address the waste management situation, uncontrolled burning of open dumps and indiscriminate waste disposal to water bodies has continued unabated.

Hence, Khalid et al. (2011) concluded that, the policing and develop of a clear policy and strategy of collecting, transporting, treating and disposing wastes in an environmentally friendly manneris necessary, in order minimize risk to human health, reduce environmental burdens and maintain an overall balance in the ecosystem.

In response to the waste management challenges in the city of Port Harcourt and indeed Nigeria as a whole, the present study seeks to investigate the viability of using anaerobic digestion as part of an integrated waste management system for solid waste produced in Port Harcourt.

Chen et al. (2008) described anaerobic digestion as an attractive waste management system capable of recovering energy from waste whilst also preventing environmental pollution. Ward et al. (2008) added that anaerobic digestion could be used as a form of treatment for industrial and municipal waste waters, food wastes, crop residues from farms, municipal wastes and other waste types. Ward et.al, added that the process of anaerobic digestion also occurs naturally in watercourses, sediments, waterlogged soils and the mammalian gut.

Hence, Khalid et al. (2011), concluded that the energy produced from anaerobic digestion could play a critical role in meeting the world's ever-increasing energy requirements in the nearest future.

1.1 Description of the Study Area

The state is located in the South South Geo-Political Zone of the country. Its capital town is Port-Harcourt. Other major towns are Bonny, Buguma, Ogoni, Bori, Elema and Degema. The state is a major producer of oil and natural gas. Other mineral resources found in the state are silica sand, glass sand and clay. The total population of the state is about 2,525,690 (National Population Commission, 2006).

Like other parts of the country, Port Harcourt, the state capital is characterized by two seasons, the wet and dry seasons. The wet season is characterized by heavy rainfall and occasional flooding in some coastal communities and urban centres. A typical example is the recurrent flooding on Aba road. The wet season begins in March and last till October while the dry season starts in November running through to March.

Due to the coastal nature of Port Harcourt occasional rains are observed during the dry season as a result of evaporation from surface water bodies due to the high intensity of the sun which characterize the dry season.

Unlike other part of the country Port Harcourt experience rainfall for most part of the year. The average temperature range of the city is between 22°C to 28°C therefore it is generally warm for most part of the year. The city has a flat topography and it is thought to be one of the most important cities in Nigeria with huge hydrocarbon reserve.

1.2 Existing Energy Profile in Nigeria

Table 1. Nigeria's energy capacity at 2005

Resource type	Reserves	Reserves (BTOE)[c]	Reserves ($\times 10^7$) TJ
Crude oil	36.2 billion barrels	4.896	20.499
Natural gas	166 trillion SCF[a]	4.465	18.694
Coal and lignite	2.7 billion tonnes	1.882	7.879
Tar sands	31 billion barrels of oil equivalent	4.216	17.652
Subtotal Fossil		15.459	64.724
Hydropower, large Scale	11,000 MW		0.0341/yea
Hydropower, small Scale	3,250 MW		0.0101/yea
Fuel wood	13,071,464 ha[b]		
Animal waste	61 million tonnes/year		
Crop residue	83 million tonnes/year		
Solar radiation	3.5 to 7.0 kW h/m^2/day		
Wind	2 to4 m/s (annual average) at 10 m in height		

[a]SCF, standard cubic feet; [b]forest land estimate for 1981; [c]BTOE, billion tonnes of oil equivalent. Adapted from ECN [18].

Source: Oyedepo, 2012.

Nigeria is one of Africa's biggest oil producers, which, along with Libya, accounts for two-thirds of Africa's crude oil reserves. The country is next only to Algeria in terms of natural gas. Primary energy resources dominate the nation's industrial raw material endowment (Oyedepo, 2012). There is several energy potential in Nigeria; hydroelectricity sites alone have an estimated capacity of about 14,250 MW. The country has significant biomass resources which can contributes significantly to the energy generation and other uses, including electricity generation (Ighodaro, 2010).

Table 2. Renewable energy potentials

Resource	capacity	Remark
Large Hydropower	11,500 MW	Only 1972 MW exploited
Small Hydropower	3,500 MW	Only about 64.2 MW exploited
Solar	3.5 Kw/M/day – 7.0 kW/m/day	Limited information available
Biomass	Fuel wood	11 million hectares of forest and woodland
	Animal Waste	245 million assorted in 2001
	Crop and Agricultural residue	72 million hectares of Agricultural land

Adapted from Sambo, 2010.

From table 1 and 2, it can be observed that Nigeria currently relies on hydrocarbon for its energy needsdespite the huge potential in renewable energy sources across the country. According to Oyedepo (2012), there is a huge gap in supply and demand with demand far exceeding supply; this has been attributed to the inadequate development and inefficient management of the energy sector. Therefore, urgent steps must be taken to explore the potentials inherent in renewable energy as table 2 shows that the country has abundant sources of renewable energy of which only a minor fraction has been exploited.

2. Materials and Methods

The main mode of this investigation is through laboratory analysis of the organic components of municipal solid waste produced in the city of Port Harcourt. Only the organic fractions of the waste produced in Port Harcourt (mainly food waste) were collected for this investigation.

In an experiment of this nature, inoculums are vital tools which supply the needed micro-organisms without which there will be no anaerobic digestion. The inoculumswas stored in a 500ml reactor bottle and placed in an incubator at a temperature of about 37^{o}C.In addition to the inoculum, a buffer medium was also used. The medium was prepared by dissolving 2.7g/l of KH2PO4, 3.5g/l of K2HPO4, 0.005g/l of MgSO4.7H20, 0.0005g/l of CaCl2, 0.0005g/l of FeCl3, 0.0005g/l of KCl3, 0.0001g/l of CoCl2 and 0.0001g/l of NiCl2 in water, about 1 litre of the medium was prepared.

3. Experimental Design

The experiment was conducted over a period ofsix days with a small laboratory sample of about 10g. This sample was transferred into a 500_ml reactor bottle, 290_ml of buffer medium and 100_ml of inoculums were alsoadded to the reactor bottle. The process was repeated to produce two samples (A and B) for the purpose of accuracy. A third reactor bottle which was labelled (C) had a mixture of 100_ml of inoculums and 300_ml of the buffer medium to serve as a control for the purpose of determining the activities of the micro-organisms in the absence of food waste. This is demonstrated below:

Reactor bottle (A) = 10g of feedstock + 290_ml of medium + 100_ml of inoculums.

Reactor bottle (B) = 10g of feedstock + 290_ml of medium + 100_ml of inoculums.

Control (C) = 100_ml of inoculums + 300_ml of medium.

The three mixtures (A, B and C) were put into the incubator for 24 hours at a temperature of about 37^{o}C. After the 24 hour period, the three bottles were removed from the incubator and the gas produced in each reactor bottle was measured using infrared gas analyser as shown in figure 1 below. The gases produced are recorded before removing 20_ml of solution from each reactor bottle.

The remaining solution (A, B, C) are returned to the incubator until the following day when the process is repeated, this process was repeated for the duration of the experiment. The 20_ml solution removed each reactor bottle is divided into twosmall test tubes of about 10_ml each. One of the test tubes with the 10_ml solution is centrifuged at 5300_pm for about 20 minutes after which the supernatant (the liquid part of the mixture) is carefully decanted and stored in the freezer for VFA (volatile fatty acid) measurement. Keeping a record of the VFA is important as they help to estimates the potential volume of methane gas present in the solution. The second 10ml solution is stored in the freezer so that the total solid and volatile solid can be measured for each day of the experiment.

4. Results and Discussion

From the data obtained during the experiment, it was revealed that the control which was a mixture of inoculums and buffer medium produced more methane gas than the other two samples (A and B) containing the food wastes as shown in table 3. One of the main reasons is the high accumulation of VFA in samples A and B during the digestion process, as shown in table 4. The accumulated VFA acted as an inhibitor or as a toxic compound to methane producing bacteria. Hence, the high concentration of VFA in the feedstock among other factors accounted for the low production of methane gas during this experiment. According to (Page et al., 2015) Volatile fatty acids play key role in the biodegradation of organic wastes and production of bioenergy under anaerobic digestion. However, an experiment by Wang et al. (2009) showed that the accumulation of VFA during anaerobic digestion inhibit the production of methane and could even lead to a complete cessation of methane production. Hence, the high accumulation of VFA explains the very little production of methane gas during the experiment.

Table 3. Percentage of gases generated per day (gases measured according to % of occurrence)

Gases.	Sample A	Sample B	Control
Day 1			
CH_4	0.1	0	0.9
CO_2	20.4	17.2	4.2
O_2	9.2	12.7	18.7
Balance	70.5	70.1	76.3
Day 2			
CH_4	0	0	0.6
CO_2	29.8	35.8	4.2
O_2	6.9	3.9	18
Balance	63.3	60.3	77.2
Day 3			
CH_4	0	0	0.7
CO_2	27.9	28.1	4.2
O_2	8.3	8.6	17.4
Balance	63.8	63.2	77.7
Day 4			
CH_4	0	0	0.5
CO_2	22.9	26.8	3.8
O_2	11.2	10	17.8
Balance	65.8	63.2	77.9
Day 5			
CH_4	0	0	1
CO_2	27.7	30	4.3
O_2	10.1	9.8	15.5
Balance	62.2	60.2	79.2
Day 6			
CH_4	0	0	0.6
CO_2	23	30	3.8
O_2	13.2	12.9	17.1
Balance	68.8	56.3	78.5

Table 4. VFA production (mg/l)

Samples	1	2	3	4	5	6
A	4690	4320	4880	4410	4960	4380
B	4160	4180	3830	3730	4580	5580
C	13	0	3	12	58	23
VFA Average (A +B/2)	4425	4250	4355	4070	4770	4980
pH Average (A+B/2)	4.81	4.81	4.87	4.80	4.88	4.87

Similarly, Table 5 shows the pH values obtained during the experiments, the table revealed that the pH medium during the digestion process was lower than the optimum pH level for anaerobic digestion. According to Ward et al. (2008), the optimum pH value for anaerobic digestion is between 6.8 and 7.2. However, the pH values obtained for sample A and B ranged from 4.79 to 4.95 as shown below. The low pH value and the high accumulation of VFA accounted for the low methane production. The fluctuation of the pH values of the mediums are represented in figure 3 below.

Table 5. PH values of samples

	A	B	Average (A+B/2)	C
1	4.8	4.82	4.81	7.55
2	4.82	4.79	4.81	7.57
3	4.82	4.92	4.87	7.54
4	4.79	4.8	4.80	7.5
5	4.8	4.95	4.88	7.43
6	4.81	4.93	4.87	7.46

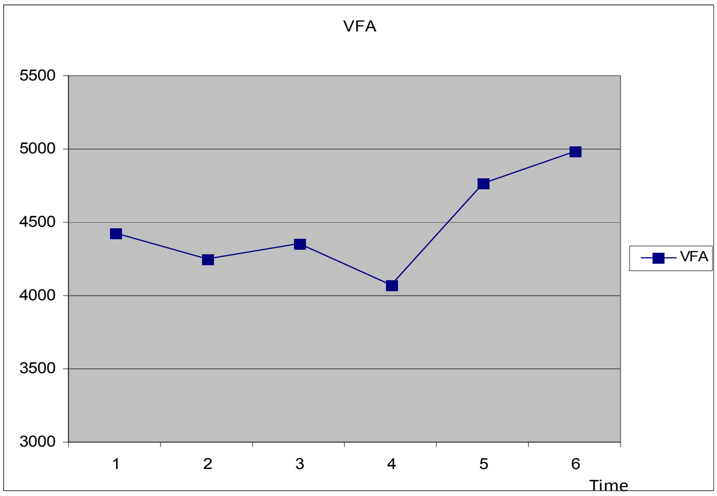

Figure 1. Graphical representation of VFA (mg/l)

Figure 1 shows that day 4 had the lowest production of VFA, while day 6 had the highest VFA production of about 4980mg/l. This value (highest value) was used for estimating the methane production potential of the feedstock.

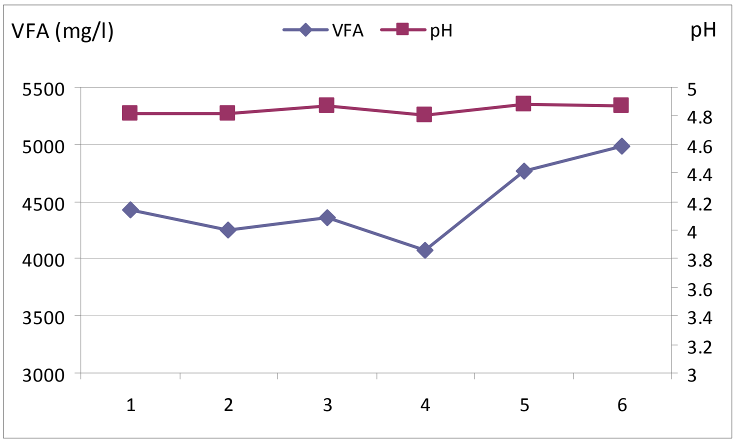

Figure 2. Graphical representations of VFA values and pH values

From figure 2, the highest VFA produced was 4980mg/l. This value was used to obtain the potential methane production of the feedstock using the stoichiometric relationship that allows methane production rate to be predicted from VFA values. This process is illustrated below:

$$CH3COOH \leftrightarrow CH4 + CO2$$

From the VFA data recorded in this experiment, taking the average of samples A and B as shown in table 2, it can be seen that the highest VFA production was at day 6 (4980).

Furthermore, 4980mg/l of VFA will contain 1.99g of VFA. 4980mg/l is the liquid form of VFA which is measured in litre whilst the solid form and is measured in grams, therefore 4980mg/l of VFA will contain 1.99g of solid VFA o 796ml of CH4.Therefore 0.796l of CH4 was obtained from the 10g of feedstock used for this experiment.

From the above, it can be inferred that, the organic component of municipal solid waste in Port Harcourt are suitable for anaerobic digestion. In addition, the methane production potential of the waste seems very promising.

The experiment revealed that 10_g of organic wastein Port Harcourt is capable of producing 0.796l of methane gas. Therefore in a city like Port Harcourt where several tonnes of food waste are produced every day, the methane gas that could be captured for reuse might translate into hundreds or thousands of litters per day. For instance, we could predict that 1 tonnes of the organic waste in Port Harcourt could generate 79600 litres of CH4.

The energy equivalent of this should be

$$79600 * 20\_kj = 1592000\_Kj.$$

Although, the experiment revealed that municipal solid waste in Port Harcourt could become a source of energy in the city whilst also promoting sustainability in the waste management sector. Certain factors such as the accumulation of VFA in the anaerobic digestion system must be taken into cognisance if anaerobic digestion is to be used. It appears from this investigation that organic fraction of municipal waste have a high level of VFA content. Therefore, if the gas production potential of the waste is to be harnessed, efforts must be made to control the accumulation of VFA during the anaerobic digestion process.

Another important revelation of the experiment is that as VFA accumulates during anaerobic digestion, the pH value of the system becomes lower. Hence, the medium becomes more acidic, this acidification of the process has an adverse effect on the micro-organisms responsible for the breakdown of organic components. These findings agree with other research on anaerobic digestion (Jiang et al., 2012; Raynal et al., 1998). We can therefore infer that, if pH value falls significantly lower than the recommended pH value for anaerobic digestion, very little or no methane gas will be produced. According to Ward et al. (2008), the optimum pH value for anaerobic digestion is between 6.8 and 7.2. In this experiment, the pH value ranged from 4.79 to 4.95 as shown in figure 2. These findings are consistent with other researches on anaerobic digestion (Gomec, 2006; Li et al., 2011; Ward et al., 2008).

5. Social Awareness and Responsibility

In order to harness the potentials inherent in organic wastes and other form of wastes in Port Harcourt and Nigeria as a whole, the concept of social inclusion must be explored. According to Charity Commission, UK (2001), social inclusion is a term used in relation to government initiatives and funding packages. The term results from positive actions taken to change the circumstances and habits that lead to social exclusion. Hence, Social inclusion is a process whereby communities or people are encouraged and allowed to participate in government or community led programmes. If a sustainable waste or environmental management is to be achieved in Nigeria, then programmes which encourage social inclusion must be embraced. A move towards increased social responsibility and awareness on environmental issues is likely to have a positive impact on environmental consciousness and increase the participatory roles of individuals in waste and environmental programmes. It has been shown (Amasuomo et al., 2015) that increasing awareness, increases the level of participation in sustainable waste management programmes. Hence, a robust social inclusion programmes involving both public and private sector backed by a robust national policy will be beneficial to the immediate area of study and the nation at large.

6. Conclusion

Port Harcourt has a lot to gain from the adoption of anaerobic digestion as part of an integrated solid waste management strategy. The city is currently in short supply of electricity and wastes are being churned out at an alarming rate. The use of anaerobic digestion for the treatment of wastes and production of methane gas will contribute energy to meet the ever increasing energy demand in the city whilst also promoting good environmental quality. Furthermore, the digestate from anaerobic digestion can be used for agriculture and planting of flowers for the beautification of Port Harcourt city; in line with the aspiration of the government to restore Port Harcourt to its former statues as “the garden city” of Nigeria.

In addition to providing electricity and bio fertilizers, the introduction of anaerobic plant is likely to generate employment for the people of the city, thereby creating a source of lively hood for residents and also boosting the local economy of the host community. The adoption of anaerobic digestion technology will improve the overall quality of life of the residents of the city through improved air, water and soil quality.

It is evident that Port Harcourt cannot continue with the present waste management practice; so as to safe guard the health of its populace. Hence, it is advisable that a more sustainable and efficient management system be embraced through the use of best available technologies for waste management.

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