STEAM EXPLOSION PRETREATMENT FOR ENHANCING BIOGAS PRODUCTION OF GROUNDNUT SHELL AND COWDUNG

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Abstract

The demand, high costs and health implications of using energy derived from hydrocarbon compound have necessitated the continuous search for alternative source of energy. Groundnut shell (GS) and Cow dung (CD) as renewable source of energy supply have been proven to be very efficient. This study investigated the production of biogas using steam explosion (SE) of GS and CD. Ten (10) plastic digester of size 4,000cm^3 was constructed, the digester were labelled A to J. The result of chemical analyses shows that SE reduces the total solid of GS from 87.90% to 79.42% while the volatile solid was increased from75.11% to 86.32% as a result of SE pre-treatment. Though the nitrogen content of GS increases after SE the carbon content remain barely constant even after SE. Lignocelluloses content of the substrate are: Hemicellulose before and after pre-treatment are 34.11% and 40.20% respectively, Cellulose are 30.50% and 28.80% while lignin before and after pre-treatment are 35.39% 31.00% respectively. Hemicellulose consists of several type of sugar unit and sometimes referred to by sugars they contain. Digester A been the control containing 100% of CD have pH of 7.00 and 7.20 before and after digestion respectively. This shows that the pH values of CD was neutral before digestion and slightly alkaline after digestion while digester E containing 100% of GS also a control have pH of 7.10 and 7.20 respectively before and after digestion. There was fluctuation in the quantity of gas produced from each substrate possibly due to variation in the ratio of the substrates. The co-digestion of 25%CD-75%GS, 50%CD-50%GS, and 75%CD-25%GS have their highest gas production around sixteen and twenty-first day of retention period respectively while their least were also recorded toward the end of the retention period. Also, digester A and E containing 100% each of CD and GS have their highest biogas production around eighteen and twenty first day of retention period respectively and the least is also seen in toward the end of the digestion. Also, from the results it was observed that digester A and F containing 100%CD each produced the highest biogas and this could be attributed to multiplication of microbial organism within the methanogenesis stage, the digester E and J containing 100% each of GS digested alone produce the least biogas. So, pre-treatment of GS before digestion enhance gas production. Thus biogas production from CD is a good and cheap alternative source of energy.

Keywords: *AD-Anaerobic Digestion, CD-Cow Dung, GS-Groundnut Shell, MSWM-Municipal Solid Waste Management, MSW-Municipal Solid Waste, SF-Steam Explosion.*

1.0 INTRODUCTION

World population is growing rapidly, and this explosion has led to rapid consumption of oil resources and a tremendous increase in the volume of wastes generated. Globally, about 17billion tonnes of total solid wastes are generated per year (Chattopadhyay *et al., 2009)*, and the amount is estimated to reach 27billion tonnes in 2050 (Karak *et al.,* 2012). Continuous emissions of carbon dioxide, methane, and other greenhouse gases from these waste streams and the burning of fossil fuels has led to a global environmental crisis. The intensive agriculture practised to produce food also damages the environment through the use of chemical fertilisers. Additionally, about 16% of the global population does not have access to electricity and about 38% of the population (REN21, 2017) uses solid wastes (forest residue, animal manure, crop and other wastes residues) for residential heating and cooking in poorly ventilated areas, which results in environmental and health hazards. Concerns about these environmental pressures and energy insecurity have increased the need for research on energy generation from renewable sources. The undervalued and abundant solid wastes that are generated have great potential as sources of biomass for energy production if properly harnessed and could lead to reduced environmental pollution and increased renewable energy production.

Although Nigeria's natural resource (including renewable energy potentials) has been well documented and acknowledged, the contribution of renewable energy sources to the total national energy supply and demand is currently very low or negligible (NNPC, 2005). The use of fossil fuels by a large proportion of the population for public automobile transport, domestic cooking, and lighting and so on, also aggravates the existing ecological degradation. The rural populace relies heavily on biomass as a source of energy. However, traditional bioenergy which is derived mainly from the combustion of wood and agricultural residues has severe negative impacts which include severe health consequences on the women and children who are the prime users of this product. Combustion of wood in confined spaces produce indoor pollution of greenhouse gases (CO and CO_2) which cause respiratory illness and premature deaths. The use of this type of biomass also increases pressure on local natural resources as communities must satisfy increasing demand for energy services.

2 Aims and Objective

The study is aimed at producing biogas through steam explosion as a pretreatment for enhancing co-digestion of groundnut shell with cow dung. The objectives are:

i. To determine the rate of lignocellulose reduction using steam explosion pretreatment method.

ii To investigate the potential of biogas production using pretreated substrate.

iii To determine the influences of operating parameters in anaerobic production.

3.0 Scope of the Research

The ever increasing demand for energy, the diminishing energy source and the problem of environmental pollution have raise public awareness to the need for a non-polluting renewable energy source. Biowaste, a potential renewable energy source of different origin are associated with a negative value due to disposal and pollution cost. Biological waste of different origins (agricultural, industrial, municipal and domestic) undergo slow and uncontrolled degradation, which lead to environmental pollution and their disposal is a big problem due to high transportation cost and scarcity of dumping site. The study is limited to production of biogas using steam explosion of groundnut Shell and cow dung.

4.0 Literature Review

There is an urgent need for alternative energy sources as a result of the dwindling energy resources which has become a global concern. This has made it imperative to search for new sources of domestic energy. The quest for wood as a source of domestic energy has led to deforestation and erosion in the southern parts and near desertification in the northern parts of the country (Ilochi *et al.*, 1989). Raw materials for biogas production cover a wide range of feedstock including animal wastes, household wastes, crop residues, sewage sludge, food waste, and wastewater (Suneerat *et al.*, 2009). Manure component (carbohydrates, proteins, and lipids) carbon is ultimately transformed into methane (CH_4) and CO_2 (carbon dioxide) (Masse *et al.*, 2011), and its emission contribute to Green House Emission (GHE).

In Nigeria, identified feedstock substrate for an economically feasible biogas production includes water lettuce, water hyacinth, dung, cassava leaves and processing waste, urban refuse, solid (including industrial) waste, agricultural residues and sewage (Ubalua, 2008). It has been estimated that Nigeria produces about 227,500tons of fresh animal waste daily. Since 1kg of fresh animal waste produces about 0.03m^3 of biogas, then Nigeria can potentially produce about 6.8 million m^3 of biogas every day from animal waste only. In addition, 20kg of municipal solid waste (MSW) per capital has been estimated to be generated in the country annually (Mathew, 1982). Groundnut shell is found in large quantities as agricultural farm wastes in Northern parts of Nigeria such as Sokoto, Kebbi, Niger, Zaria, Borno and Yobe States (Sadaa *et al.*, 2013).

5.0 MATERIAL AND METHOD

The waste materials that were used for the study are cow dung and groundnut shell. Groundnut shell was collected from a milling station at Pati Shabakolo, a village in

Lavun local government area of Niger State during the 2019/2020 harvest season. The sample was collected into clean bags and was transported to the site of the experiment while cow dung was sourced from Federal University of Technology, Minna farm. Both were manually sorted to remove foreign materials and groundnut shell was sun dried for about fourteen (14) days in order to reduce the moisture content and for easy handling. Groundnut shell was further crushed mechanically using pestle and mortar for size reduction and milled into powdered form and finally sieved with about 1.18µmm sieve tray.

The following equipment were used in the study.

i. Digital weighing balance: to determine the weight of the samples.
ii. pH meter: to measure the pH of the digested materials daily throughout the retention period.
iii. Measuring cylinder: to measure the volume of water displaced by the biogas generated.
iv. Mixing tank: a big plastic container for mixing the substrate.
v. Thermometer: for measuring the temperature
vi. Mortar and pestle: for size reduction
vii. Sieve: for sieving purposes
viii. Funnel: for feeding the slurry into the digester so as to minimize spillage
ix. Waterproof sacks for conveying of the substrates
x. Shovels: for ensuring proper mixing and packing of the substrates
xi Nose mask: for prevention of inhalation of particulate and odor.
xii Protective gloves: were worn to protect the hands from contamination

Pre-treatment is the first step toward effective conversion of lignocelluloses materials to biogas, which makes up one third of the total production cost and remains one of the barriers preventing commercial success. In this study, steam explosion which is one of the physical forms of pre-treatment was used. The lignocellulosic content determination was carried out according to Datta (1981) method as modified by Arora and Sharma (2009). Also, Total solid and volatile matter were determined following standard test methods ASTM E1756-08, and E872-82(Reapproved 2006) respectively. Carbon and Nitrogen content of the biomasses were determined.

6. EXPERIMENTAL SET-UP AND PROCEDURE

The schematic diagram of the experimental set-up is shown in Fig. 1. It consists of a laboratory bio-digester made of borosilicate glass of capacity 1000ml with air tight rubber cork fitted into its opening. Thermometer and copper tube were fitted through the rubber cork for measuring the slurry temperature and fitting the connecting tube. The other end of the connecting tube was passed through a 500ml solution bottle containing brine solution. Thus, the biogas produced in the bio-digester by the anaerobic digestion process was delivered through the connecting tube to the solution bottle containing brine. The pressure of the biogas produced caused displacement of the brine solution which is then collected in a 200ml beaker placed on the other side of the solution bottle. The amount of solution collected in the beaker represented the amount of biogas produced in the biodigester. A sampling port was provided through the cork fitted with a valve to take out sample from time to time testing of sample for total solid, volatile solid and pH.

Figure 1: The Digester and the Gas Holder

7.0 Fermentation Procedures for Physical Pre-treatment and not Treated Substrate

a) The slurry combination was formulated to contain about 5% solid content and the bio digester was filled with the slurry to 75% of the digester volume.

b) 100% of cow dung and 0% of groundnut shell were mixed with water for Digester A.

c) 75% of cow dung and 25% of groundnut shell were mixed with water for Digester B.

d) 50% of cow dung and 50% of Groundnut shell were mixed with water for Digester C.

e) 25% of cow dung and 75% of groundnut shell were mixed with water for Digester D.

f) 0% of cow dung and 100% of groundnut shell were mixed with water for Digester E

g) The slurry was stirred properly to avoid lump, and poured into Bio-digester A, B, C, D and E respectively for steam explosion (physical pre-treatment) and Bio digester F, G, H, I and J respectively for non pre-treatment.

h) The fermentation was allowed for a period of 30days under mesophilic temperature.

i) The pH of the medium was measured daily in order to ensure that the pH value is within the range at which the biogas can be produce.

j) The temperature of the medium was taken 1time daily.

8.0 RESULTS AND DISCUSSION

The results of the physico-chemical analyses of the substrates prior to anaerobic digestion are shown in tables 1a and b. The result of chemical analyses shows that steam explosion reduces the total solid of groundnut shell from 87.90% to 79.42% while the volatile solid was increased from75.11% to 86.32% as a result of steam explosion pre-treatment. Though the nitrogen content of GS increases after steam explosion the carbon content remain barely constant even after steam explosion.

Table 1a Characteristics of the Substrates

Properties	**Cow Manure**	**Groundnut Shell**	**Steam exploded pre-treated**
Moisture Content (%)	89.50	25.89	81.21
TS (%)	19.60	87.90	79.42
VS (%)	54.01	75.21	86.32
VS/TS ratio	2.76	0.86	1.09
Carbon Content	42.00	62.02	61.90
Nitrogen Content	0.91	0.40	0.70
C/N ratio	0.02	0.01	0.01

Table 1b: Lignocellulose Content of Groundnut Shell

Properties	Not treated	Physically pre-treated
Hemicellulose (%)	34.11	40.20
Cellulose(%)	30.50	28.80
Lignin(%)	35.39	31.00

Also, in table 1b lignocelluloses content of the substrate are: Hemicellulose before and after pre-treatment are 34.11% and 40.20% respectively, Cellulose are 30.50% and 28.80% while lignin before and after pre-treatment are 35.39% 31.00% respectively. Hemicellulose consists of several type of sugar unit and sometimes referred to by sugars they contain. Hemicellulose is associated with cellulose and contributes to the structural component of the plant (Rowell, 2012). Cellulose is a main structural component in a plant cell.

8.1 Monitoring of Operational Parameters

The pHs for each of the digesters were measured before and after digestion. The daily ambient and digesters temperatures were adequately monitored.

1. pH Before and After Digestion.

Table 2: pH of the Slurry before and after Biogas production

Digester	pH before Biogas production	pH after Biogas production
A	7.00	7.20
B	6.90	6.70
C	7.01	6.90
D	7.11	6.70
E	7.30	7.30
F	6.90	7.40
G	7.10	7.11
H	7.15	6.90
I	7.20	6.80
J	6.70	7.00

From table 2, digester A been the control containing 100% of Cow dung have *p*H of 7.00 and 7.20 before and after digestion respectively. This shows that the *p*H values of cow dung was neutral before digestion and slightly alkaline after digestion while digester E containing 100% of groundnut shell also a control have pH of 7.10 and 7.20 respectively before and after digestion. The *p*H of the digester C containing 50% each of cow dung and groundnut shell increases from day one of the digestion to day 7 of the digestion as shown in appendix 1 and toward the end of the digestion, the *p*H shows slightly alkaline solution. Digesters A and E have the highest *p*H of 7.6 in day five of the digestion and 7.5 in day 30 of the digestion respectively.

8.2. Digester Temperature during Biogas Production

Table 3: Digesters and Ambient Temperature (^{0}C)

Time (Days)	Steam exploded					Non exploded					Ambient
	A	B	C	D	E	F	G	H	I	J	Temp.
1	30.0	31.1	29.0	30.0	30.1	31.0	30.0	28.9	32.0	31.1	33.0
2	31.1	29.8	30.1	32.0	31.1	28.8	31.0	30.0	28.9	29.9	32.0
3	32.1	31.1	33	31.1	29.9	30.1	32.0	31.1	29,8	33.0	34.0
4	33.2	31.1	30.1	31.0	33.0	31.0	30.0	28.9	32.0	31.1	33.2
5	32.1	31.1	33.2	30.1	32.0	32.1	32.0	31.0	30.0	28.9	33.9
6	35.0	34.1	32.1	35.1	34.0	30.1	32.0	31.1	32.1	32.0	37.0
7	32.0	30.0	31.1	33.1	34.0	29.3	30.1	32.0	31.1	33.0	35.8
8	29.0	32.2	34.0	31.0	32.0	31.0	30.0	28.9	32.0	31.1	36.0
9	32..0	31.1	33.0	31.1	30.2	31.0	30.0	28.9	29.9	30.1	34.8
10	33.0	32.1	32.1	32.0	34.0	30.1	32.0	31.1	33.0	28.7	35.0
11	31.1	33.2	30.1	32.0	33.0	32.1	32.0	30.1	32.0	31.1	36.6
12	33.3	31.1	33.2	30.1	32.0	30.1	32.0	31.1	28.9	29.9	35.0
13	29.8	30.2	32.0	30.0	31.1	29.3	30.1	32.0	31.1	33.0	33.0
14	31.1	30.1	31.0	30.0	28.9	31.0	30.0	28.9	30.0	28.9	32.5

15	32.2	34.0	31.0	32.0	29.8	30.1	32.0	31.1	29.8	30.1	34.6
16	31.2	32.0	30.0	31.1	33.2	29.8	30.1	32.0	30.0	31.1	33.0
17	32.2	34.0	31.0	32.1	32.1	32.0	30.0	33.2	29.8	30.1	35.0
18	30.2	32.0	30.0	33.2	31.1	30.0	31.1	30.1	32.0	31.1	34.0
19	29.2	32.0	30.0	31.1	32.0	30.0	31.1	32.0	30.0	31.1	33.0
20	30.1	32.0	31.1	29.8	30.1	30.0	33.2	32.0	30.0	33.2	33.0
21	29.8	30.1	30.0	33.2	30.1	32.0	31.1	32.0	30.0	31.1	34.0
22	28.8	30.0	31.1	32.0	30.0	33.2	32.0	30.0	31.1	28.6	33.2
23	30.1	30.1	32.0	31.1	29.8	30.1	30.0	31.1	30.0	31.1	32.0
24	32.0	30.0	31.1	29.8	30.1	30.0	31.1	32.0	30.0	33.2	34.0
25	28.9	32.0	30.0	33.2	29.8	30.1	30.0	31.1	29.8	30.1	32.0
26	30.0	31.1	32.0	30.0	31.1	32.0	30.0	33.2	30.1	32.0	33.9
27	32.0	30.0	31.1	30.0	31.1	30.1	32.0	31.1	30.0	31.1	33.2
28	29.8	30.1	32.0	31.1	30.0	31.1	32.0	30.0	31.1	30.2	32.0
29	32.0	30.0	33.2	29.8	30.1	30.0	31.1	30.1	32.0	31.1	34.0
30	30.1	32.0	31.1	32.0	30.0	33.2	32.0	30.0	33.2	28.2	35.0

Table 3 shows that the temperatures in the Ten digesters fluctuated optimally between 28^0C and 40^0C which conforms to the mesophilic range. The temperatures were recorded one time daily using a thermometer that was fitted to the digester. The foregoing show that the digesters operated within the mesophilic temperature range; and that it is possible to install digesters that will operate within this range in Minna and environs. This agrees with the findings of previous studies (Igboro, 2011 and Alfa, 2013). Since all the digesters were operated simultaneously, the temperature across them were the same as shown in table 3.

Table 4 Volume of Biogas Production (cm^3)

Time (Days)	Steam exploded					Non exploded				
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	15.39	15.39	3.85	0.0	0.0	11.54	0.0	0.0	0.0	0.0
3	38.48	46.18	38.48	15.39	7.70	26.94	3.85	0.0	0.0	0.0
4	50.02	38.48	38.48	23.09	7.70	46.18	3.85	3.85	0.0	0.0
5	50.02	34.63	34.63	15.39	3.85	46.18	3.85	3.85	3.85	3.85
6	46.18	38.48	34.63	15.39	7.70	34.63	3.85	3.85	3.85	0.00
7	7.72	42.33	38.48	15.39	7.70	50.02	7.70	11.54	3.85	3.85
8	57.72	42.33	34.63	11.54	11.54	46.18	7.70	11.54	3.85	3.85
9	57.72	42.33	38.48	19.24	11.54	50.02	15.39	19.24	11.54	11.54
10	65.42	50.02	38.48	19.24	11.54	57.72	15.39	15.39	7.70	11.54
11	65.42	46.18	42.33	19.24	11.54	57.72	15.39	11.54	3.85	7.70
12	65.42	50.02	46.18	19.24	11.54	57.72	30.78	19.24	19.24	7.70
13	65.42	46.18	38.48	23.09	7.70	46.18	34.63	19.24	15.39	7.70
14	65.42	53.87	38.48	23.09	11.54	61.57	50.02	38.48	19.24	3.85
15	61.57	53.87	38.48	23.09	7.70	69.26	50.02	38.48	19.24	7.70
16	73.11	61.57	65.42	30.78	19.24	65.42	50.02	42.33	15.39	7.70
17	88.50	61.57	53.87	19.24	11.54	73.11	53.87	42.33	23.09	11.54
18	80.81	61.57	65.42	38.48	15.39	73.11	53.87	42.33	23.09	7.70
19	92.35	57.72	65.42	46.18	15.39	84.66	53.87	34.63	19.24	7.70
20	92.35	57.72	61.57	50.02	15.39	76.96	50.02	38.48	19.24	7.70
21	92.35	42.33	38.48	19.24	11.54	76.96	42.33	34.63	19.24	3.85
22	88.50	30.78	38.48	19.24	11.54	61.57	38.48	34.63	11.54	3.85
23	80.81	30.78	38.48	19.24	11.54	57.72	26.94	34.63	7.70	3.85
24	61.57	30.78	26.94	11.54	11.54	50.02	15.39	26.94	7.70	3.85
25	42.33	11.54	15.39	11.54	3.85	34.63	11.54	11.54	7.70	3.85
26	34.63	11.54	11.54	11.54	3.85	15.39	7.70	7.70	3.85	3.85

27	15.39	3.85	7.70	3.85	3.85	11.54	7.70	3.85	3.85	3.85
28	7.70	3.85	7.70	3.85	3.85	3.85	3.85	3.85	3.85	3.85
29	7.70	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85
30	7.70	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85

i.e from eqn 19

Table 4 shows the fluctuation in the quantity of gas produced from each substrate possibly due to variation in the ratio of the substrates. The co-digestion of 25%CD-75%GS, 50%CD-50%GS, and 75%CD-25%GS have their highest gas production around sixteen and twenty-first day of retention period respectively while their least were also recorded toward the end of the retention period. Also, digester A and E containing 100% each of CD and GS have their highest biogas production around eighteen and twenty first day of retention period respectively and the least is also seen in toward the end of the digestion.

From the results it was observed that digester A and F containing 100%CD each produced the highest biogas and this could be attributed to multiplication of microbial organism within the methanogenesis stage, the digester E and J containing 100% each of GS digested alone produce the least biogas. So, pre-treatment of groundnut shell before digestion enhance gas production.

9.0 CONCLUSIONS

From the results of the study conducted, the following conclusions can be made:

1. 4,000cm^3 biogas digester were designed modifying the Ajoy Karki's Biogas model (Karki, 2002), fabricated using locally available materials and tested under the existing weather condition in Minna.

2. The biogas digesters constructed in this study were used for the anaerobic digestion of cow dung, groundnut shell as well as co-digestion of cow dung and groundnut shell respectively. The study has shown that biogas can be produced from cow dung and groundnut shell (as observed in previous studies).

3 The pH values recorded before and after digestion indicates that the digesters operated well. The temperatures inside the digesters were stable fluctuating around 28°C to 40°C which is within the mesophilic range.

9.2 RECOMMENDATIONS

1. The work done herein can be used to produce good quality biogas for use locally and internationally.

2. This technology should be encouraged in the rural areas where our forest resources are stretched due to over dependency on wood.

3. The technology again can play a major role in achieving the United Nations Sustainable Development Goal of climate action.

REFERENCES

Alfa M. I. (2014). Comparative Production and Utilization of Biogas for Cooking, Using Cow Dung, Chicken Droppings, *Cymbopogon citratus* (lemon grass), MSc Thesis Presented to the Department of Water Resources and Environmental Engineering, Ahmadu Bello University, Zaria Nigeria.

Igboro, S. B. (2011). Production of Biogas and Compost from Cow Dung in Zaria, Nigeria, unpublished PhD Dissertation Presented to the Department of Water Resources and Environmental Engineering, Ahmadu Bello University, Zaria Nigeria.

Ilochi E. E and Nwachukwu A (1989). Proc. Int. Symposium Biotechnology for Energy. Dec 1621.

Karki A. B., Shrestha N. J., and Bajgain S. (2005). Biogas as Renewable Energy Source in Nepal: Theory and Development. Nepal, BSP. Obtainable on www.snvworld.org

Matthew P. (1982). Gas production from animal wastes and its prospects in Nigeria. *Nigeria Journal of Solar Energ*y, 2(98): 103.

Massé D.I., Talbot G. and Gibert Y. (2011). In farm biogas production: A method to reduce GHG emissions and develop more sustainable livestock operations, *Animal Feed Sci. and Techn.*, 166: 436-445.

Sadaa, B.H., Amarteyb Y.D. and Bako S. (2013). An investigation into the use of groundnut shell as fine aggregate replacement. *Nigerian Journal ofTechnology (NIJOTECH)*Vol. 32 (1), pp. 54–60

Ubalua A.O. (2008). Cassava wastes: Treatment options and value addition alternatives. *Africa Journal of Biotechn*ology 6: 2065-2073.