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The Effects of Lignocellulose Reduction Using Steam Explosion Pretreatment Method for Biogas Production

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Abstract

The production of biogas, an alternative source of energy, from Groundnut Shell (GS) and Cow Dung (CD) was investigated in the laboratory scale using the simple locally fabricated digesters labeled A-E of 4,000cm3 working volume. The digesters were fed on a batch basis with the slurry of different mix ratio and operated at ambient temperature (28-40°C) for 30days. The result of chemical analyses shows that Steam Explosion (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 remains barely constant even after SE. 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 recorded toward the end of the retention period. Also, digester A and E containing 100% each of CD and GS being the control for the pre-treated have their highest biogas production around eighteen and twenty first day of retention period respectively and the least are also seen toward the end of the digestion.

Keywords: Biogas, Groundnut Shell, Cow Dung, Methane, Solid Waste

1. Introduction

Lignocellulosic material can be utilized to produce various energy products and other potential products. There are many processes that could be applied to convert lignocelluloses to different energy products such as biofuels and biogases. Such processes include anaerobic digestion, fermentation, incineration, pyrolysis, gasification and others (Galbe et al., 2012) Figure 1.0 presents some of the potential products that could be produced through different processes using lignocellulosic materials as feedstock.

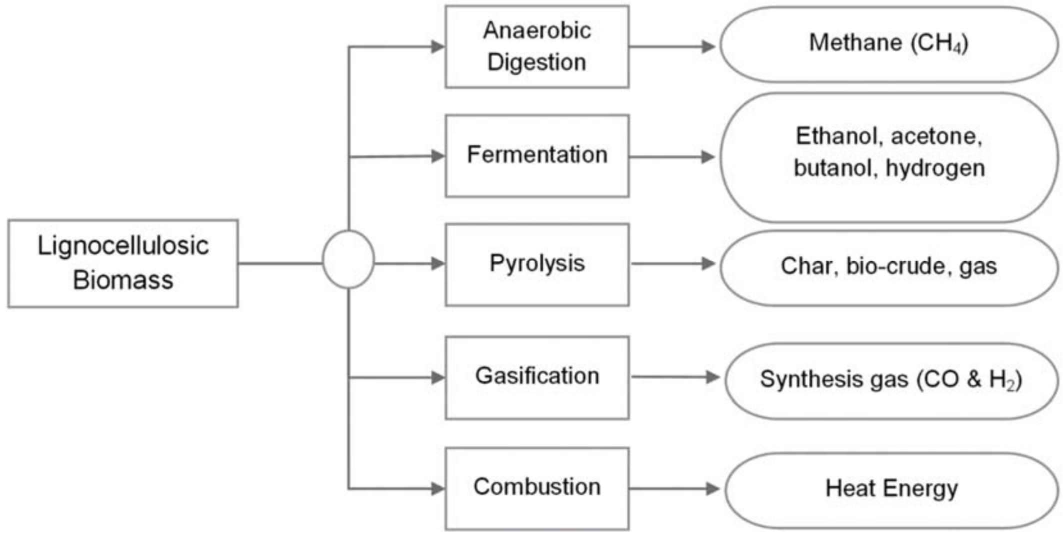

Figure 1.0. Potential products obtained from lignocellulosic materials through various processes.

Pre-treatment of the substrate is needed either for making it easier to handle at the biogas plant or for altering its structure for easy degradation, hence enhancing its methane potential. There are different pre-treatment methods that can be used depending on the types of substrates and the goals of the pre-treatment. The most suitable pre-treatment methods for agricultural, municipal, and industrial solid wastes are discussed in this section. The principal feedstocks used as substrate in the AD process in the work presented herein are lignocellulosic in nature. The bioconversion of lignocellulosic biomass to bio-energy in the form of methane via AD may be limited by its hydrolysis as the digestible cellulose and hemicelluloses are covered by a sheath of insoluble lignin (Weiland, 2010).

However, the complexity and variability of the lignocellulosic structure hinder the biodegradation, particularly the hydrolysis of the complex organic matter to turn into soluble compounds, which is the rate limiting step of the degradation (Cesaro et al., 2012). This structural resistance can be broken by physical, chemical and biological pre-treatment methods (Niemistö et al., 2013) or by their combinations (Li et al., 2013). The purpose of pre-treatment is to change lignin and hemicellulose structures, reduce cellulose crystallinity, and increase the porosity of the materials (Kumar et al., 2009). The physical pre-treatment's include mechanical (grinding, milling, ultrasonic and microwave radiations, gas explosions) and thermal treatment methods (hydrothermal treatment, steam explosion and freezing). There are chemical and biological methods as well (Wei et al., 2013).

Steam Explosion (SE) is one of the most effective methods for the pre-treatment of lignocellulosic biomass. The substrate is put in a vessel and is exposed to steam at high temperature and pressure for normally 5-30minutes which hydrolyzes the glycosidic bonds in the substrate. After that, the steam is released and the substrate is cooled down quickly which makes water in the substrate to "explode", and opens up the structure of the lignocelluloses in the cell wall of the substrate and makes the biomass inside available to the bacteria (Bauer et al., 2009). The biomass undergoes explosive decompression by this swift reduction of pressure (Mood et al., 2013). The high efficiency of the steam explosion treatment is due to the thermo-mechano-chemical destruction applied in the method. The objective of the research is to determine the rate of lignocellulose reduction using steam explosion and biological pre-treatment method.

Fig. 1.2 Steam explosion equipment (Autoclave)

2.0 Material and Method

2.1 Materials

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 equipments 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

2.2 Methods

2.2.1 Pre-treatment Process

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 and biological pre-treatment were used.

2.2.2 Anaerobic Digester Set-Up

A 4,000cm3 plastic container was obtained washed and all stains removed. Two holes were drilled; one at the centre with about 1.25cm diameter, and the other drilled at the side of the container with a diameter of 1.25cm. A reinforced flexible hose pipe of 100cm inserted at the centre hole which served as the gas outlet of the bio digester tight firmly and glued with epoxy resin steel adhesive (arodyte) in order to prevent any form of leakages was connected to 2000cm3 capacity container which served as the water chamber. The 1.25cm diameter side hole was fitted with ⅜ flexible hose pipe, male and female socket and ½inch plug where the sample will be taken for pH. The pH was measured daily using a digital pH meter. The sample to be analyzed were collected into a dry bottle from the digester and then analyzed. The probe of the pH meter was immersed into the samples to be analyzed and the meter was allowed to stabilize before the reading was taken. A hole was drilled at the side of the digester opposite the 1.25cm diameter but of 1.10cm diameter where the thermometer probe was fitted tightly with arodyte adhesive gum. The temperature reading was taken between 2pm and 4pm daily throughout the period of the experiment and also the ambient temperature.

Plate 1.3 The Digester and the Gas Holder

2.2.3 Fermentation Procedures for the Biological and the Physical Pre-treatment

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

h) The fermentation was allowed for a period of 30days under ambient temperature (psychrophilic).

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

Proximate and ultimate composition of the groundnut shell and cow dung were carried out according to the method of AOAC,2010.

3.0 Results and Discussion

3.1 Feedstock Characterisation

The results of the physico-chemical analyses of the substrates prior to anaerobic digestion are shown in tables 1.0a 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. Carbon to nitrogen ratio is one of the factors affecting the anaerobic process; it affects methane yield and production rates. It is often suggested that an optimum C/N ratio should be between 20:1 and 30:1

Table 1.0 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	75.11	86.32
VS/TS ratio	2.76	0.86	1.09
Carbon Content	42.00	62.02	61.90
Nitrogen Content	0.38	0.50	0.70
N/C ratio	0.01	0.01	0.01

3.2 Digesters Temperature during Biogas Production

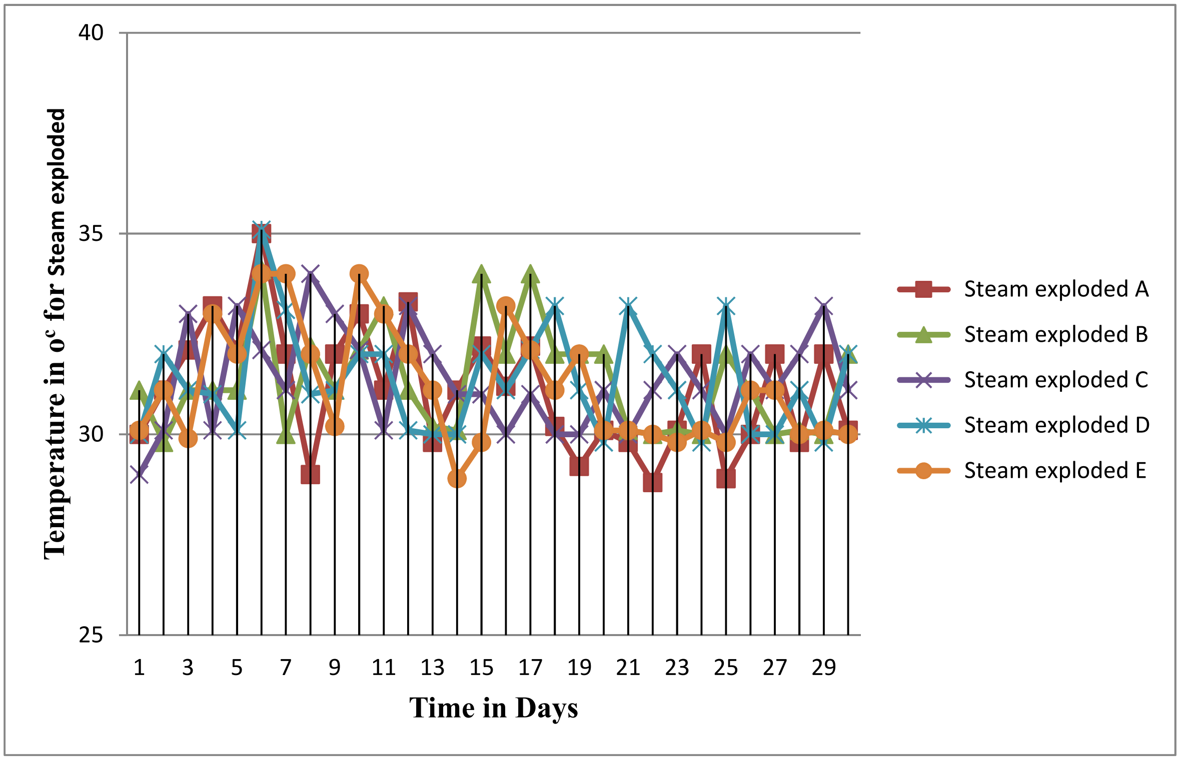

Figure 1.1 Digesters and Ambient Temperature (0C)

Table 1.1 shows that the temperatures in the Five digesters fluctuated optimally between 280C and 400C 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 figure 1.1.

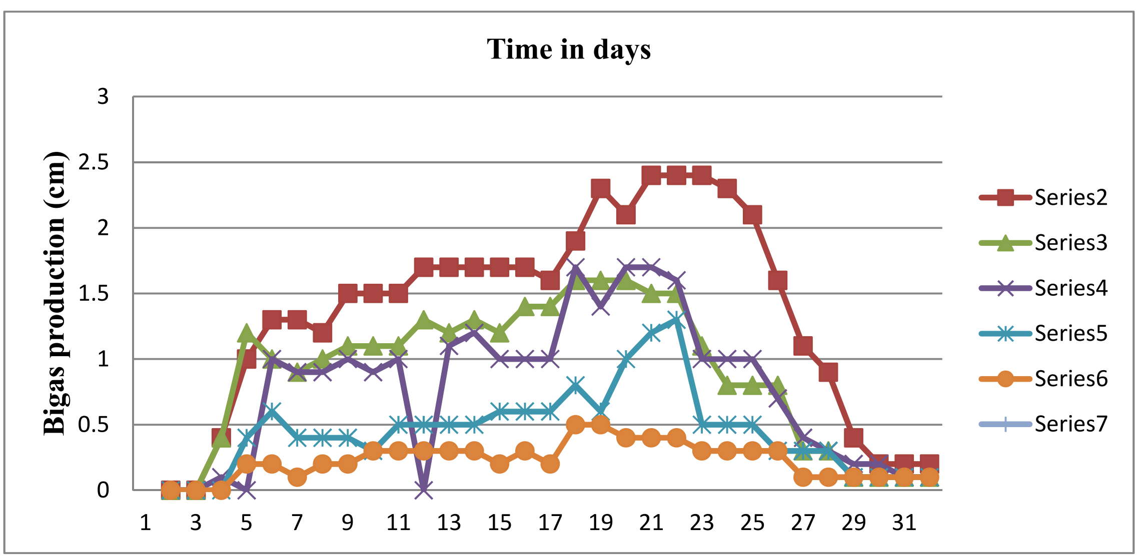

Figure 1.2 Biogas Production (cm)

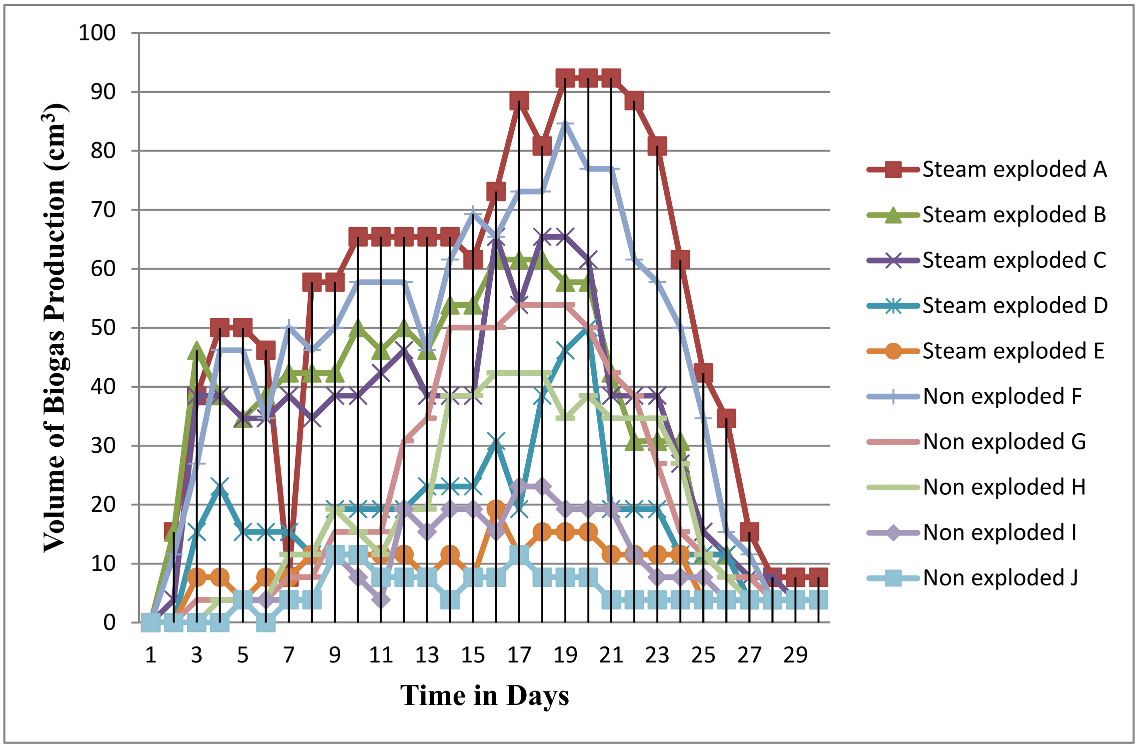

Figure 1.3 Volume of Biogas Production (cm3)

The study of biogas production from co-digestion of groundnut shell and cow dung was conducted in digesters labeled A-E as shown. Biogas production was monitored and measured until biogas production reduced significantly. The modified Gomperzt equation was then used to fit the cumulative daily biogas production which was observed to adequately describe the biogas production from these substrates. Figure 1.2 and Figure1.3 shows the fluctuation in the quantity of gas produced from each substrate possibly due to variation in the ratio of the substrates. Biogas production was very low in the first week of setup in all the digesters. As the feedstock matures over the days, gas production increases. 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 recorded toward the end of the retention period. Also, digester A and E containing 100% each of CD and GS being the control for the pre-treated have their highest biogas production around eighteen and twenty first day of retention period respectively and the least are also seen toward the end of the digestion.

4.0 Conclusion

The utilization of groundnut shell and cow dung as a feedstock in biogas production could help making the maintenance of these agricultural wastes from this region where they are in abundance profitable venture. Steam explosion treatment increases the calorific value of biomass due to the removal of moisture and volatiles and the thermal degradation of hemicelluloses. The carbon content of the biomass increases, oxygen and hydrogen are removed from the biomass. Steam explosion turn biomass from a tenacious flexible material into a brittle rigid material. This behavior is interesting since the mechanical properties of biomass are often limiting its utilization in existing coal fired heat and power plants (CHP-plants). The steam exploded biomass has more “coal like” properties as the untreated biomass and more favorable grinding and combustion characteristics

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