



Preliminary Evaluation of a Biogas Purification Filter Suitable for use in Nigeria

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Abstract Purification is very vital in the production process of biogas; which is the removal of impurities so as to improve the quality of gas produced, ensure the safety of end users and prolong the life of the biogas equipment. The aim of this research work is to show that a simple filter locally fabricated can be used to remove hazardous and unwanted gases (hydrogen sulphide, carbon (IV) oxide, water vapour) associated with production of biogas. The filter was locally produced from coconut shells. The coconut shells were carbonized at activation temperature of 600 °C within a period of 120 minutes. 250g of sodium hydroxide pellets was dissolved in 1000ml of water as chemical activator. The dissolved sodium hydroxide solution was poured into a conical flask containing the cooled carbonized coconut shells and this was covered and left to cool for a period of 24 hours. The activated charcoal was used together with calcium (II) oxide to purify the collected sample of biogas produced from co-digestion of 30kg of biodegradable kitchen waste and cow dung (seeding agent). Evacuated gases were analyzed before and after purification with gas chromatography. The results obtained showed an improvement in average percentage composition of methane yields from 68.6% to 88.62%. Therefore, the biogas filter can be used for purification of raw biogas meant for home use.

Keywords Biogas, purification, filter, kitchen waste, co-digestion, methane

1. Introduction

The lack of commercial production and utilization of biogas has been of major concern in Nigeria due to the high potential demand for sustainable renewable energy [1-4]. Biogas has become a major source of renewable energy in developed countries like United States, Germany, Switzerland, United Kingdom etc. where the technology had been adopted for commercialization [5-7]. However, in third world nations such as Nigeria, Ghana, Kenya, etc. major breakthrough is yet to be recorded in terms of commercialization [8-9] despite their huge biogas potential, thus their dependence on other sources of fuel is deplorable [10-11]. Majority of Nigerians rely on the use of kerosene and fire wood for cooking [12-13]. The rampant use of firewood for domestic heating in Nigeria invariably necessitates the destruction of forests and this is harmful to our environment [14-15]. The use of kerosene also contributes to the amount of greenhouse gas emission in our environment and this can drastically affect the ozone layer, thus aiding global warming [16-17].

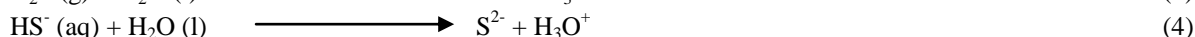
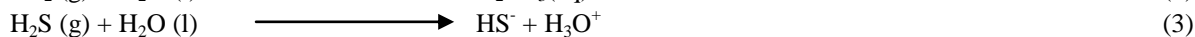
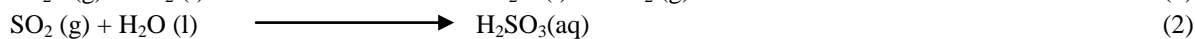
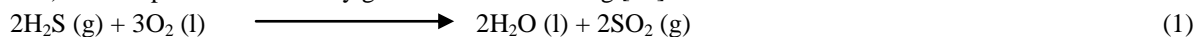
Biogas, that is methane (CH₄), hydrogen sulphide (H₂S), carbon (IV) oxide (CO₂), water vapour (H₂O) and other constituents depending on the substrates used is produced from anaerobic digestion (AD) of organic fraction of municipal solid waste (MSW) and other feedstock such as wastewater [18-21]. The AD system is extensively acceptable as an efficient process for treatment and utilization of organic waste because it has proven to be promising method for waste recycling and energy generation [22-25].

However, the biogas produced from anaerobic digestion of substrates need to be treated prior to its usage, because it contains some basic impurities [26-27]. These impurities include: carbon (IV) oxide (CO₂), hydrogen



sulphide (H₂S), water vapour (H₂O), etc. [31-30]. For biogas to be used as domestic cooking gas, the harmful impurities such as carbon (IV) oxide (CO₂), hydrogen sulphide (H₂S), and water vapour (H₂O) must be removed. The large percentage composition of carbon (IV) oxide (30-40 %) produced along with other gases reduces the heating value of the gas. It also increases compression and transportation costs and limits economic usability [27,31]. On the other hand, removing carbon dioxide (CO₂) increases the heating value and gas quality, to make it similar to natural gas [27-28].

Despite hydrogen sulphide (H₂S) is present in small quantities in biogas, however, its presence prohibits the direct use of the gas due its toxic properties, the formation of sulphur (IV) oxide (SO₂) upon combustion (acid rain) and the problems it usually gives in indoor cooking [29].



Moreover, hydrogen sulphide (H₂S) is frequently encountered in the field of odour monitoring because of its high odorous power that has the smell of rotten egg [33-35]. Purified biogas is odourless and the formation of acid rain resulting from the creation of sulphur (IV) oxide (SO₂) is completely absent [31]. Purified biogas provides reductions in greenhouse gas (GHG) emissions as well as several other environmental benefits when used as a cooking fuel, vehicle fuel, lighting fuel etc. Hence, there is need for proper purification of biogas.

Research had shown that chemical absorption process can be used in purification of biogas [39]. Chemical absorption involves formation of reversible chemical bonds between the solute and the solvent. Chemical solvents generally employ either aqueous solutions of amines (i.e. mono-, di- or tri-ethanolamine) or aqueous solution of alkaline salts (i.e. sodium, potassium and calcium hydroxides) which is used to scrub carbon (IV) oxide. Figure 1 shows a schematic diagram of chemical absorption process [40]. For scrubbing of hydrogen sulphide, iron (II) oxide suspensions are used in absorption treatments for the removal of hydrogen sulphide [41]. Chemical absorption method completely removes hydrogen sulphide and the process is commonly used in industrial applications, including natural gas purification.

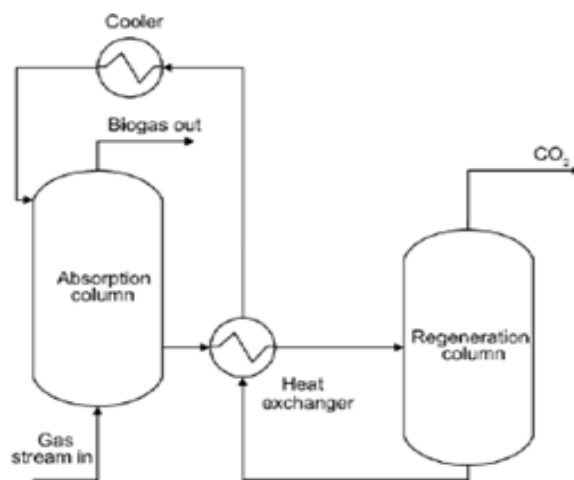


Figure 1: Schematic Diagram of Absorption Process

Although, other local materials such as potash, zeolite, etc. can be used for biogas purification [31] but due to scarcity and cost, it became necessary to sort for alternative materials. In this research work, carbonized coconut shells activated with sodium hydroxide pellets was used to remove hazardous and unwanted gases associated with production of biogas. Coconut tree (*Cocos nucifera*) is a member of the family Arecaceae (palm family) and the only species of the genus *Cocos* [36] which is readily available in Nigeria. The term coconut can refer to the whole coconut palm or the seed, or the fruit, which, botanically, is a drupe, not a seed [37]. Like other fruits, it has three layers: the exocarp, mesocarp and endocarp. The exocarp and mesocarp make up the husk of the coconuts. The mesocarp is composed of a fiber, called coir. The shell has three germination pores (micropyles)



or eyes that are clearly visible on its outer surface once the husk is removed [38]. Figure 2 shows samples of the coconut.



Figure 2: Sample of Coconut

2. Materials and Methods

Table 1 shows the materials used in this research work while figure 3 shows the experimental set up.

Table 1: Materials used in this Research Work

S/N	Materials	Usage
1.	Activated Charcoal	Used for purification of hydrogen sulphide
2.	Calcium Oxide	For purification of carbon dioxide and water vapour
3.	Iron sponge	Act as base support for reagents
4.	Silica gel	Used for water vapour purification
5.	Iron fillings	Used for purification of hydrogen sulphide
6.	Transparent cylindrical polyethene case	Serve as housing for the filters
7.	Laboratory oven	For drying the activated charcoal
8.	Burning sink	For burning the coconut shell
9.	Sodium hydroxide pellets	For activating the charcoal chemically
10.	Draining tray	For removing moisture from the charcoal
11.	Sterilized water	For washing
12.	Digester	For generating biogas

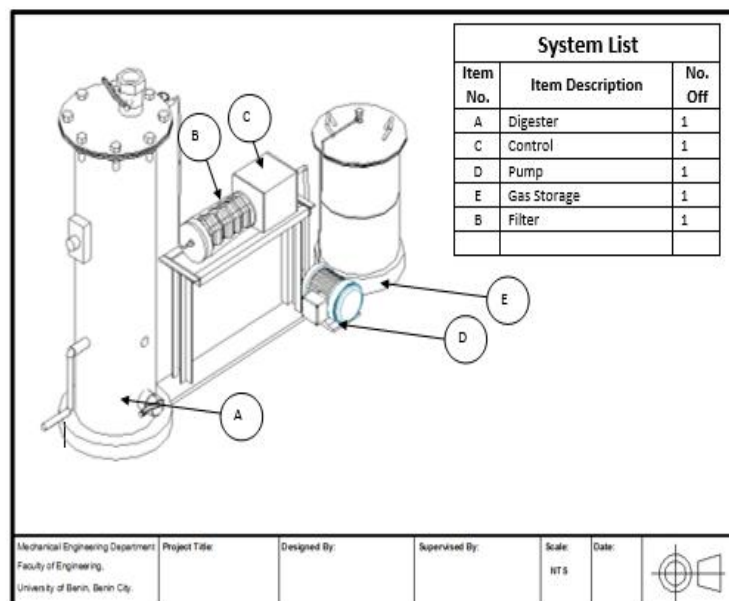


Figure 3: Experimental set up



2.1. Production of Biogas

30kg of feedstock of biodegradable kitchen waste was reduced to smaller particle sizes by grinding since particle sizes enhances hydraulic retention time [20]. This was mixed with water in a ratio of 1:2 and co-digested with cow dung which serves as a seeding agent. The slurry in the digester was stirred and left for anaerobic digestion to take place. The pressure gauge was monitored for the production of biogas and flame test was immediately carried out after the pressure gauge indicated an increase. Formation of blue flame is a confirmation of proper production of biogas. At this stage the biogas produced was evacuated for purification with the test materials and control set up filters. Evacuated gases was analyzed before and after purification with gas chromatography.

2.2. Preparation of Activated Charcoal

Coconut shells were bought from local market in Nigeria. The coconut shells were washed thoroughly with clean water and allowed to dry completely in order to facilitate combustion. The coconut shells were completely carbonized at activation temperature of 600 °C within a period of 120 minutes. A standard preparation 250g of sodium hydroxide was dissolved in 1000ml of water as chemical activator. The dissolved sodium hydroxide solution was poured into a conical flask containing the cooled carbonized coconut shells. The conical flask was covered and left to cool for one day. During this process, the chemicals are impregnated into the carbonized coconut shells were its transformation into activated charcoal took place. The activated charcoal was removed from the chemical solution and transferred into a draining tray and allowed the treated activated charcoal to drain for about 1 hour. The activated charcoal was washed in sterilized water repeatedly to remove chemicals. The activated charcoal was then transferred into a laboratory oven (New Life DHG 9023A), setting the temperature at 105 °C to adequately dry it (Figure 4). After drying, the charcoal from the oven was crushed and ground into powder form. This was used to impregnate the iron sponge in the filter.

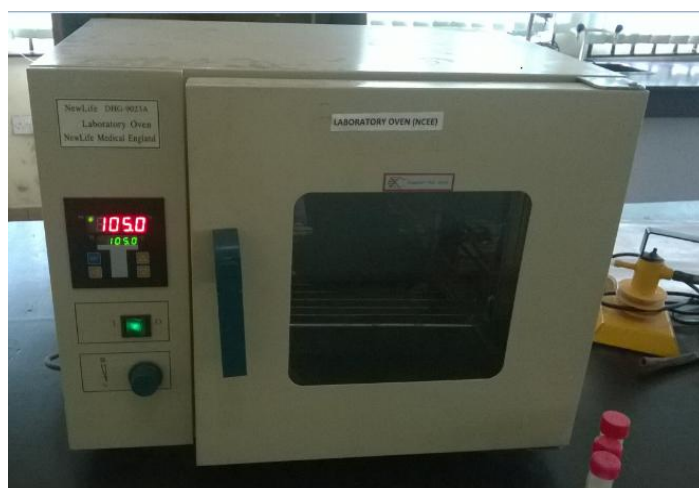


Figure 4: Laboratory Oven

2.3. Preparation and Assembly of the Filter

The activated charcoal and quicklime were impregnated on separate iron sponges and placed in a frustum polythene container in this order; the sponge with quicklime was inserted first followed with that of the activated charcoal. This is because of the effect of water vapour with hydrogen sulphide. So, it became necessary for the removal of water vapour due to the formation of hydrogen trioxsulphate (VI) acid from sulphur (IV) oxide which have the following effects; corneal haze, breathing difficulty, eye irritation, heart failure, etc. Also, the sponge inserted with quicklime will help to purify carbon (IV) oxide. The control set up consists of silica gel, iron fillings and calcium oxide. The biogas evacuated was purified with both test materials filter and control setup filter. Figure 5 shows the filter arrangement for test materials while figure 6 shows the control set up arrangement.



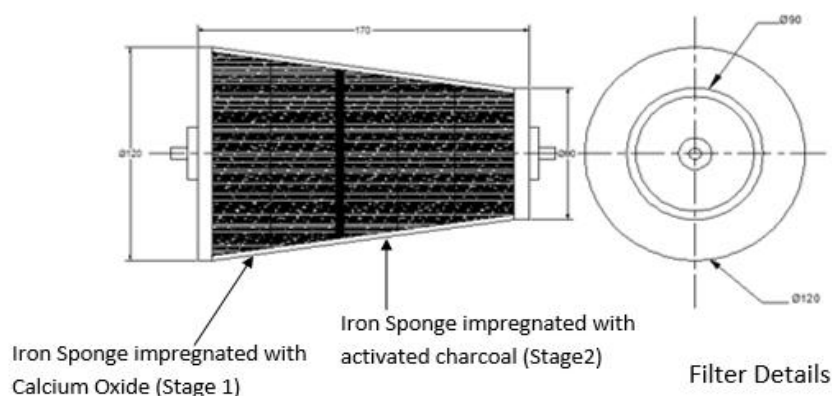


Figure 5: Filter arrangement for Test Materials

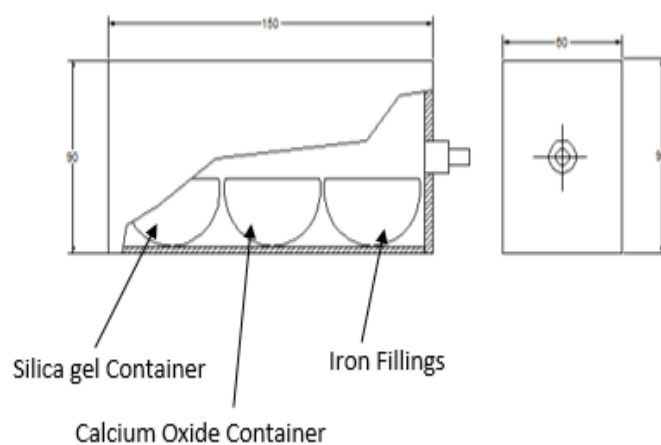
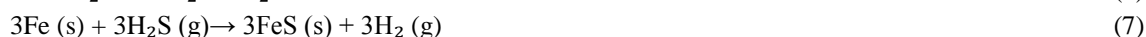


Figure 6: Control Setup Arrangement

2.4. Chemistry of the Process

The chemical equations for the reactions taking place in the filter is detailed below:



3. Results and Discussion

The constituents of impure (raw) biogas, biogas purified with control set up (silica gel and iron fillings) and with test materials (activated charcoal and calcium oxide) as obtained is tabulated in Table 2 and Table 3 respectively. The results show that the composition of biogas obtained comprises of hydrogen sulphide (H_2S), methane (CH_4), carbon (IV) oxide (CO_2), water vapour and other gaseous constituents that was not detected by the GC analyzer. Both the control setup and filter incorporated with activated charcoal and calcium oxide were able to purify the biogas collected within a period of nine evacuations. Furthermore, there was an improvement in average methane yield from 68.06% to 88.62% after purification (Table 3). This was as a result of the removal of carbon dioxide, hydrogen sulphide, water vapour and other gaseous constituents present. The results analysis shows that water vapour (H_2O) and carbon dioxide were successfully purified with calcium oxide in test materials and silica gel in control setup. Correspondingly, the hydrogen sulphide (H_2S) that has health side effect if not properly removed from biogas was properly purified with iron fillings (control setup) and activated charcoal (test materials). Additionally, comparative analysis of purified biogas sample with control setup (silica gel and iron fillings) and test materials (activated charcoal and calcium oxide) proved that the percentage composition of methane after purification was approximately close (Figure 7). This confirm that the filter is effective and can be used for biogas purification.



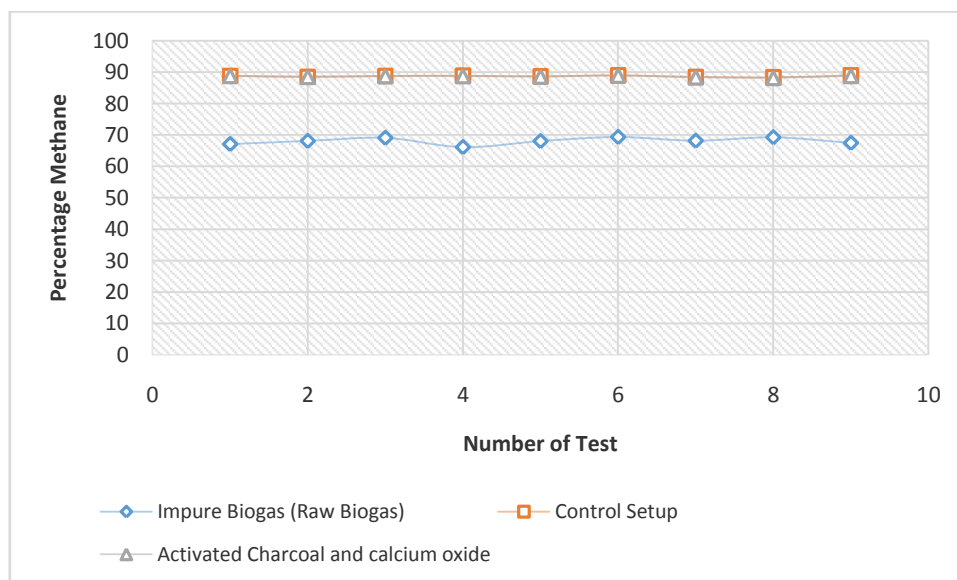
Table 2: Results of Impure (Raw) Biogas

S/N	Biogas Mass (kg)	Raw Biogas				
		CH ₄	CO ₂	H ₂ S	H ₂ O	OG
1.	0.27	67.08	31.15	0.41	0.65	0.71
2.	0.23	68.08	31.03	0.29	0.54	0.06
3.	0.28	69.08	30.01	0.26	0.45	0.20
4.	0.21	66.08	32.05	0.24	0.76	0.87
5.	0.27	68.03	30.96	0.25	0.64	0.12
6.	0.24	69.35	29.85	0.18	0.45	0.17
7.	0.20	68.15	31.02	0.13	0.51	0.19
8.	0.29	69.25	29.95	0.11	0.49	0.20
9.	0.24	67.45	31.23	0.28	0.72	0.32
Ave.		68.06				

*OG-Other gases present, Ave.-Average

Table 3: Purified Biogas with Control Setup and Activated Charcoal with Calcium Oxide

S/N	Biogas Purified with Control Setup					Biogas Purified with Activated Charcoal and Calcium Oxide				
	CH ₄	CO ₂	H ₂ S	H ₂ O	Other Gases	CH ₄	CO ₂	H ₂ S	H ₂ O	Other Gases
1.	88.80	10.89	0.00	0.00	0.31	88.79	10.89	0.00	0.00	0.32
2.	88.50	11.50	0.00	0.00	0.00	88.48	11.51	0.00	0.00	0.01
3.	88.75	11.18	0.00	0.00	0.07	88.75	11.24	0.00	0.00	0.01
4.	88.82	10.77	0.00	0.00	0.41	88.75	10.78	0.06	0.26	0.47
5.	88.63	11.27	0.00	0.00	0.10	88.59	11.29	0.00	0.00	0.12
6.	88.95	10.96	0.00	0.00	0.09	88.90	11.00	0.00	0.00	0.10
7.	88.45	11.45	0.00	0.00	0.10	88.36	11.53	0.00	0.00	0.11
8.	88.32	11.67	0.00	0.00	0.01	88.17	11.73	0.00	0.00	0.10
9.	88.96	11.04	0.00	0.00	0.00	88.79	11.10	0.00	0.00	0.11
Ave.	88.69					88.62				

**Figure 7:** Percentage Composition of Methane after Purification

Moreover, there was no sign of degradation in the control setup till day twenty-seven. After then it was observed that the silica gel started to absorb water and this is an indication of failure. The result obtained is shown in Table 4.



Table 4: Effect of purification on the filter

Day	Time	Temp. °C	Manometer reading	Observation	Control
5	Evening	36	40mm	Blue flame	No change
6	Morning	26	40mm	Blue flame	No change
7	Afternoon	36	40mm	Blue flame	No change
8	Evening	20	40mm	Blue flame	No change
9	Morning	30	40mm	Blue flame	No change
10	Afternoon	36	40mm	Blue flame	No change
11	Morning	28	40mm	Blue flame	No change
12	Afternoon	34	40mm	Blue flame	No change
13	Evening	30	40mm	Blue flame	No change
14	Morning	28	40mm	Blue flame	No change
15	Afternoon	36	40mm	Blue flame	No change
16	Evening	30	40mm	Blue flame	No change
17	Morning	28	40mm	Blue flame	No change
18	Afternoon	34	42mm	Blue flame	No change
19	Evening	27	42mm	Blue flame	No change
20	Morning	28	46mm	Blue flame	No change
21	Evening	26	46mm	Blue flame	No change
22	Morning	26	46mm	Blue flame	No change
23	Afternoon	34	50mm	Blue flame	No change
24	Evening	28	50mm	Blue flame	No change
25	Morning	27	50mm	Blue flame	No change
26	Afternoon	34	50mm	Blue flame	No change
27	Evening	28	50mm	Blue flame	Visible change
28	Morning	26	50mm	Blue flame	Visible change
29	Afternoon	36	56mm	Blue flame	Visible change
30	Evening	28	60mm	Blue flame	Visible change

4. Conclusion

From the abovementioned, the filter was successfully used in purification of impure (raw) biogas. Thus, it can be deduced that complete purification of the biogas for domestic usage is achievable. The technology is simple, safe and cost effective. In Nigeria if the design, testing and production of this filter is optimized, commercialization of biogas can be undertaken. The work will greatly help to reduce the number of Nigeria families and commercial enterprises dependent on kerosene and firewood for cooking. Therefore, the biogas filter can be used for purification of raw biogas meant for home consumption such as in cooking and this will reduce deforestation, thus friendly ecosystem attains.

5. Recommendation

More research work should be carrying on the life span of the filter and this should involve the incorporation of a visible indicator that can determine when the purifying agents are used up.

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