Performance Evaluation of Design AD System Biogas Purification Filter

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Abstract
Biogas purification which is the removal of impurities so as to improve the efficiency of gas produced, ensure the safety of end users and prolong the life of the equipment cannot be neglected. This paper is focused on the design and performance evaluation of AD system biogas purification filter. Three different conceptual designs were generated from possible design consideration, feasibility study and preliminary test and with the help of decision matrix; the best conceptual design was selected from which the purification filter was fabricated. The selected concept for detail design was a transparent polyethene cylindrical purification filter fitted with local iron sponge containing activated charcoal and local potash. The reagents were arranged in this order; local potash for the removal of water vapour and carbon dioxide followed by activated charcoal which serves as a purifying agent for hydrogen sulphide. The results obtained showed reduction in percentage composition of hydrogen sulphide (H_2S), carbon dioxide, and water vapour. On the other hand, there was an increase in percentage composition of methane (CH_4) which is an indication of improvement in methane production after purification. The outcomes of the results obtained were satisfactory and the combination of local potash and activated charcoal was adequate for biogas purification.

Keywords- AD system, Purification filter, Design, Local reagents, Biogas.

1. Introduction
The Anaerobic Digestion (AD) system is a greenhouse technology which has to deal with the generation of methane rich biogas through the biological degradation of regionally available biomass such as food waste, agricultural waste, wastewater, etc. (Bamgboye, 2012; Ray et al., 2013; Orhorhoro et al., 2016). It is a waste management technique that can be adopted for the treatment and utilization of Municipal Solid Waste (MSW), and it has equally been proven to be a promising method for waste reduction and energy recycling (Zhou et al., 2014). The technology is widely adopted by Germany, Sweden, USA, Denmark etc., which have implemented rigorous waste disposal legislation (Igoni et al., 2008; Bhattacharya et al., 2005). Since 2000, annual power generation reported from AD plants/reactors projects in USA has increased almost 25 fold from 14 million kilowatt-hours (KWh) to an estimated 331 million kWh per year (US EPA, 2003). The technology is yet to yield reasonable results in Nigeria despite her huge biogas potential that is estimated at 25.53 billion m^3 per year (Ngumah et al., 2013). AD system technology is still at the elementary stage in Nigeria as major breakthrough has not been achieved in terms of production, purification, commercialization and availability in comparison to other countries with advance technology of AD system. Countries such Germany, USA, Sweden etc. depend on renewable energy from AD processes. However, various research works on the technology and policy aspects of biogas production has been carried out by various researchers in Nigeria (Sambo, 2005; Akinbami, 2001). One aspect of AD system that requires special attention in Nigeria is the technology for the removal of impurities associated with the production of biogas. Little is known about the effort to develop a local technology for the purification and removal of dangerous

impurities (e.g., Hydrogen sulphide, carbon dioxide, water vapour, siloxane, etc.) associated with biogas produce.

Biogas is a mixture of gases evolved from AD of organic matter by anaerobic bacteria at anaerobic conditions (Adelekan and Bamgboye, 2009). Biogas is mainly composed of methane (CH_4), carbon dioxide (CO_2) and low amount of other gases (Zhou et al., 2014). In percentage by composition, biogas composed 40-70% of CH_4, 30-60% of CO_2, and 5-10% of other gases as shown in Table 1 (Ray et al., 2013). The quality of biogas generated by organic waste materials does not remain constant but varies with the period of digestion (Rabah et al., 2010). The ratio of CH_4 to CO_2 is normally stable in the reactor; any variation in the ratio is due to process imbalance (Qiao et al., 2011). However, CH_4 ratio also depends on substrate composition, temperature, pH and pressure (Liu et al., 2009). Since the dissolution of CO_2 is strongly dependent on pH, fluctuation of pH can also change gas composition (Schomaker et al., 2000). Methane is a powerful greenhouse gas if emitted into the atmosphere directly, but can also represent a valuable renewable energy source, with the potential to reduce greenhouse gas emissions when it is collected and substituted for fossil fuels which have reduced the ozone layer.

Substance	Symbol	Percentages
Methane	CH_4	50-70
Carbon dioxide	CO_2	25-45
Hydrogen	H_2	0-1
Nitrogen	N_2	0-1
Water vapour	H_2O	0-3
Hydrogen sulphide	H_2S	0-3
Ammonia	NH3	0-0.5
Siloxane	$R2SiO_3$	0-5

Table 1. Composition of biogas

Biogas can be used directly to generate power, cook, etc., but the large volume of CO_2 produced with it reduces the heating value of the gas. It also increases compression and transportation costs and limits economic usability (Kim et al., 2004). Purification allows for a wider variety of uses, either for heating and lighting, or as vehicle fuels. For use as a fuel, purification to remove CO_2 and H_2S is required, because H_2S corrodes vital mechanical components within engine if it is not removed (Yuan and Bandosz, 2007). Moreover, removing CO_2 increases the heating value and leads to a consistent gas quality, similar to natural gas (Appels et al., 2008). Although H_2S is present in small quantity, it presence usually prohibits the direct use of the gases because of its toxic properties, and also it leads to the formation of sulphur (iv) oxide (SO_2) upon combustion (acid rain), and the problems it usually gives in downstream processing (Zaouak et al., 2012).

Beside, H_2S is frequently encountered in the field of odour monitoring because of its high odorous power. The type and the amount of pollutants depend upon the biogas source and this determines which cleaning and upgrading techniques are the most suitable for gas purification (Gamba and Pellegrini, 2013). Purified biogas provides reductions in GHG emissions as well as several other environmental benefits when used as a cooking fuel, vehicle fuel, lightening fuel etc. Hence there is need for proper purification of biogas, thus this research work. Also, AD system importance to institution, household and industrial process cannot be neglected. The production of biogas from AD system is of growing interest to many developed countries like Sweden, Germany, Switzerland, USA, Canada, China, Japan, etc. and developing countries like Nigeria, Nepal, Sudan, Ethiopia, Ghana etc., as wood fuel, and fossil-fuel resources decline and their resulting effect on the ozone

layer (Sambo, 2006; ECN, 2008; Igoni et al., 2008; Bruni et al., 2010). The increasing world-wide awareness and concern about the environmental impacts of fossil fuels, wood fuel, and nuclear power, and the danger recorded from it use. For instance, the danger recorded in tsunami, Japan, as a result of the meltdown of a nuclear reactor at Fukushima and this has shifted the attention of the world to renewable energy (Akinbami et al., 2001; NISA 2011). Therefore, a renewable source of energy such as AD system technology will be a welcome development.

2. Design Considerations
These design factors were considered in the design process
  (i)   Availability of materials
 (ii)   Functionality
(iii)   Performance
 (iv)   Ease of use
  (v)   Safety
 (vi)   Cost
(vii)   Reliability

2.1 Availability of Materials
The most important consideration is the availability of the materials locally. The biogas filter is fabricated from local materials that can be obtained in every part of Nigeria. The filter was designed to be reused. The materials used were polyethene cylindrical container, mild steel nipple, iron sponge, and glue, potash, coconuts shell, oven, blender.

2.2 Functionality
Functionality is the ability of the biogas filter to serve a utilitarian purpose; it must be capable of purifying the biogas and at the same time ensuring the safety of the user. The purification filter is designed to serve this purpose.

2.3 Performance
Special consideration was taken to ensure that optimum performance was obtained. In order to achieve this, the purification filter was designed to accommodate many local iron sponges attached with local purifying materials.

2.4 Ease of Use
Ease of use is another essential physical consideration. The purification filter was designed to be user friendly to operators.

2.5 Safety
Biogas is highly inflammable and also lighter than air. Precautionary measures were taken to ensure the safety of end users. Safety is an important consideration in design process, for that reason, precaution was taken to ensure bad design; wrong decision, risk taken etc., to avoid causalities (Kopachevsky et al., 2016).

2.6 Cost
The filter is made with polythene plastic, local sponge, local reagents which are not only cheap but available in all parts of Nigeria, and equally affordable.

2.7 Reliability

Reliability is the ability of purification filter to consistently purify biogas under some stated conditions without failure and this was given special considerations in the design of these filters.

3. Conceptualization

The aim was to fabricate and investigate a cheap AD system biogas purification filter made with local materials. To achieve the said aim, three different concepts were generated from which the best concept was chosen for fabrication.

3.1 Design Concept One

In the first concept, the inlet nipple and outlet nipple are on the same side of the polythene plastic. The components/parts are inlet gas nipple, polyethene cylindrical container, outlet gas nipple and local reagents materials without local iron sponge. Fig. 1 shows design concept one.
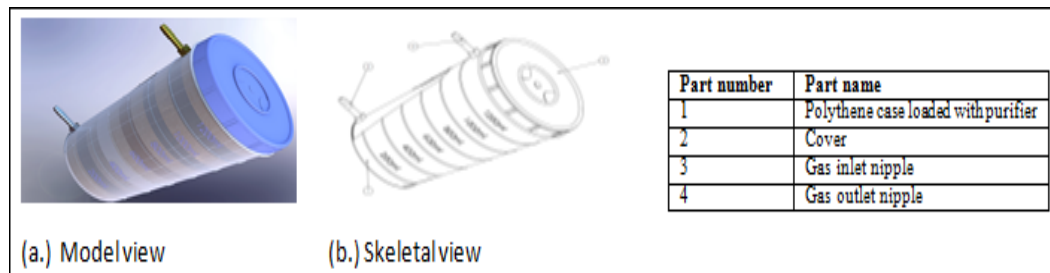

Part number	Part name
1	Polythene case loaded with purifier
2	Cover
3	Gas inlet nipple
4	Gas outlet nipple

(a.) Model view   (b.) Skeletal view

Fig. 1. Design concept one

3.2. Design Concept Two

The second concept is the modification of the first concept. Same component parts as the first concept, except the inlet nipple and outlet nipple are now in opposite side with attachment of local iron sponges and reagents materials. The local reagents were not arranged in a specific order. Fig. 2 shows design concept two.
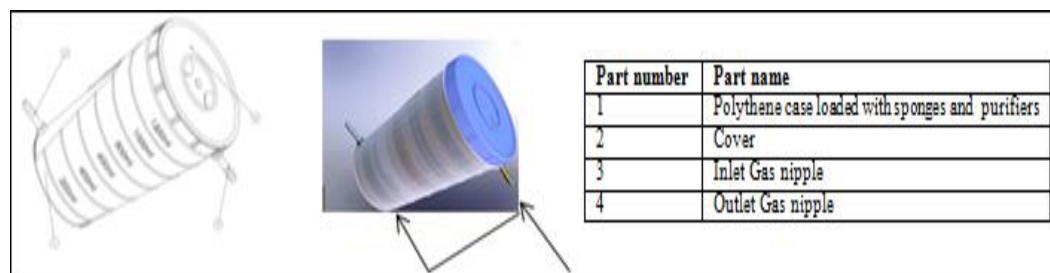

Part number	Part name
1	Polythene case loaded with sponges and purifiers
2	Cover
3	Inlet Gas nipple
4	Outlet Gas nipple

Fig. 2. Design concept two

3.3 Design Concept Three

The third concept was modified from first and second concepts. Concept 3 has the same component parts as the second concept but different from first concept. The inlet nipple and outlet nipple are placed parallel to each other. In this case, the inlet nipple and outlet nipple are positioned on the base and cover of the polyethene plastics loaded with local reagents material and local iron sponges that give the system orientation of biogas movement in the container and as well support the local

materials. Also, the local reagents were arranged in a specific order of removal of water vapour first, followed by carbon dioxide and lastly hydrogen sulphide. Fig. 3 shows design concept three.
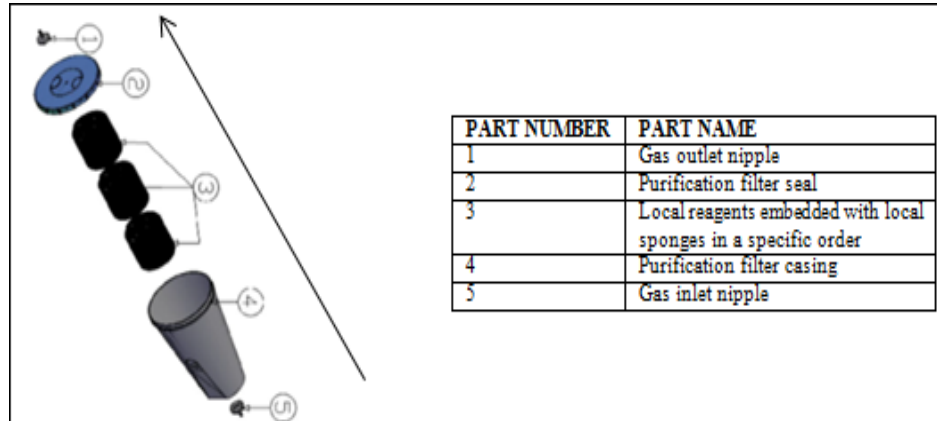
PART NUMBER	PART NAME
1	Gas outlet nipple
2	Purification filter seal
3	Local reagents embedded with local sponges in a specific order
4	Purification filter casing
5	Gas inlet nipple

Fig. 3. Design concept three

3.4 Concept Selection

To ensure the best concept was chosen for fabrication, a decision matrix was drawn based on the following design considerations
  (i)   Functionality
 (ii)   Performance
(iii)   Reliability
 (iv)   Safety
  (v)   Cost.

3.5 Decision Matrix

A decision matrix comprises a list of values in rows and columns (matrix pattern) that can be used for the analysis of a system, rating, and assessing the performance of relationships between sets of values and information. Each category is assigned a weighing factor based on self-belief which measures its relative importance. A detail of the matrix used was shown in Table 2.

	Functionality	Performance	Reliability	Safety	Cost	RANK
Weighting factor	0.30	0.25	0.20	0.20	0.05	1.0
First Concept one	4 / 1.2	2 / 0.5	2 / 0.4	2 / 0.4	7 / 0.35	2.85
Second Concept two	6 / 1.8	5 / 1.25	4 / 0.8	2 / 0.4	6 / 0.3	4.55
Third Concept three	9 / 2.7	8 / 2.0	8 / 1.6	6 / 1.2	6 / 0.3	7.80

Table 2. Decision matrix

Based on the results of the decision matrix, third concept design with the highest cumulative score rank (i.e., 7.80) was selected.

3.6 Basis for the Ranking

In the first concept, functionality is scored low because nothing separates the local reagents and as such, the purification filter will not be effective, performance and reliability ranking were equally low. Also, safety scored is low as well, and this has to do with the fact that the inlet and outlet nipples are positioned by the side of the plastic which is cylindrical. The curved surface will not allow the nipples to lie very well on the plastic unlike flat surface and this can bring about gas leakages during purification process. Finally, cost is scored high because this concept is more cost effective than the other two.

In the second concept, functionality is scored average because the local reagents are not arranged in a specific order that will make the filter to be effective and efficient. This arrangement also makes the performance and reliability score to be within average. This implies that the purification filter will not be able to function optimally.

For the third concept, functionality is scored high, and this is because the local reagents are arranged in a specific order; removal of water vapour first, followed by carbon dioxide and lastly hydrogen sulphide. Based on the arrangement, the performance and reliability score were high. With the positioning of the outlet and inlet nipples, gas leakage is eliminated and the filter is safe for use.

3.7 Purification Filter Dimension

The purification filter is a transparent plastic bottle and is dimension as follow.
  (i)   Diameter = 150mm
  (ii)   Radius =75mm =0.075m
  (iii)   Height = 400mm
  (iv)   Thickness =1.5 mm.
  (v)   Nipple length = 30mm
  (vi)   Nipple thickness = 8mm

Volume of filter $V = \pi r^2 h = \pi \times 0.075^2 \times 0.4 = 7.068^{-3} m^3$
Fig. 4 shows the (a) orthographic projection and (b.) exploded view

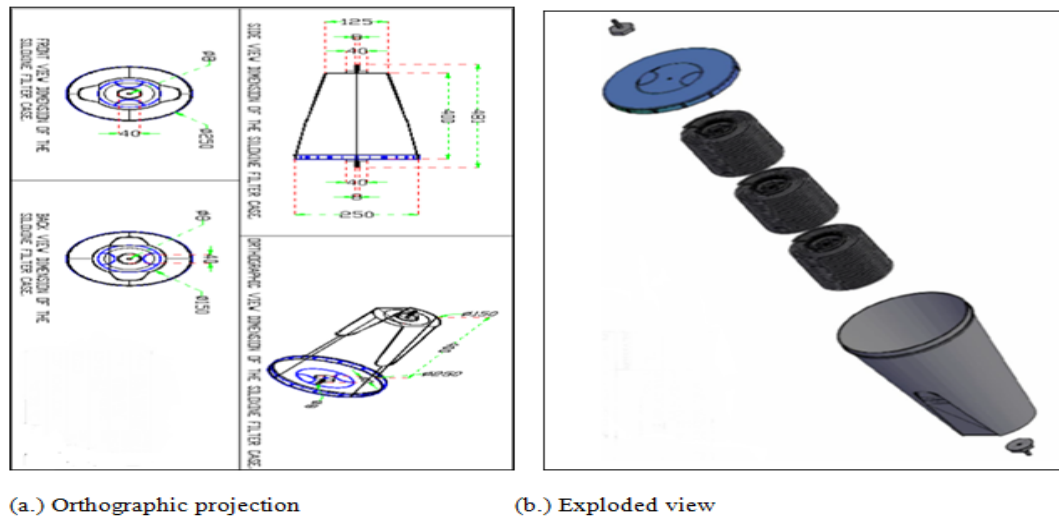(a.) Orthographic projection   (b.) Exploded view

Fig. 4. Orthographic projection and exploded view

Fig. 5 shows (a.) fabricated AD system biogas purification filter while (b.) is the analysis of the gas composition by a gas chromatography.
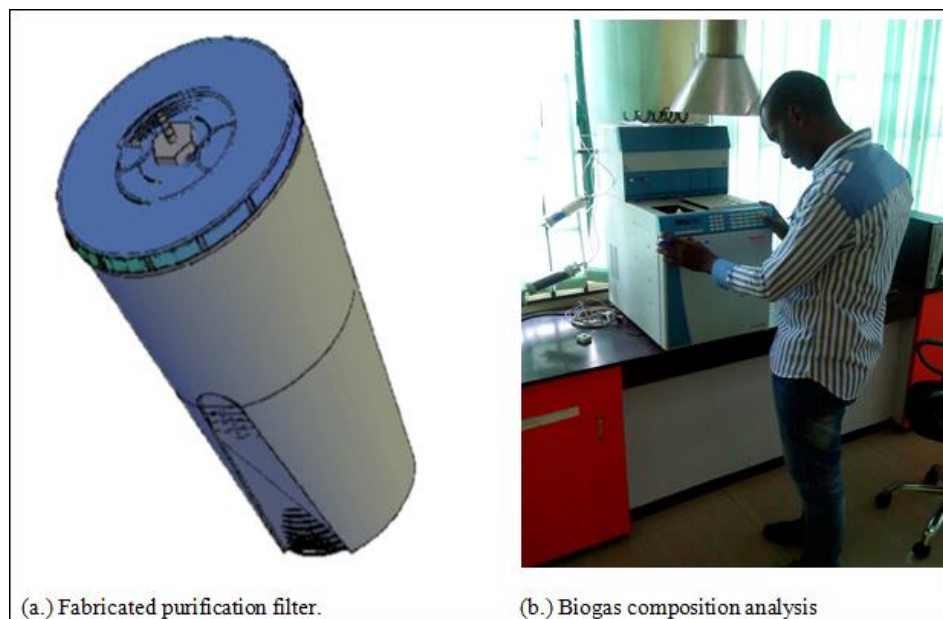

(a.) Fabricated purification filter.   (b.) Biogas composition analysis

Fig. 5. Fabricated purification filter and biogas composition analysis

3.8 Preparation of the Purification Filter

The activated charcoal and potash were impregnated on separate local iron sponge and placed in the cylindrical polyethene container in this order; the iron sponge with potash was inserted first followed with that of the activated charcoal. This is because for dominant adsorption of H_2S with H_2O which could lead to the formation of acid rain. Also, the following conditions must be satisfied.

(i)   Dry
(ii)   Vacuum
(iii)   Low temperature, and
(iv)   Anaerobic

Analysis of the composition of biogas before and after purification was recorded to ascertain the potency of the design filter.

3.8.1 Preparation of Activated Charcoal from Coconut Shell

The coconut shell was washed thoroughly with clean water and allowed to dry completely in order to facilitate combustion. The coconut shell was burned into completely ashes. A standard preparation 250g of calcium chloride ($CaCl_2$) was dissolved in 1000ml of water as chemical activator. The dissolved $CaCl_2$ solution was poured into plastic pail containing the cooled coconut shell ash. The pail was covered and left to cool for one day. During this process, the chemical is impregnated into the ash and it will transform the ash into activated charcoal. The charcoal from the coconut shell was removed from the chemical solution and transferred into a draining tray were it was allowed to drain for about one hour. The charcoal was washed in sterilized water repeatedly to remove chemicals. The charcoal was finally transferred into an oven, with the temperature set at 105^0C for adequate drying. The dried charcoal was crushed with a blender and impregnated with iron sponge mainly to support the tiny particles. Table 3 shows how the purification reagents materials were used.

Reagents	Purification ability
Local potash	To purify water vapour and carbon dioxide
Activated coconut charcoal	To purify hydrogen sulphide

Table 3. Purification ability of the reagent used

4. Results and Discussion

The quantity of impure biogas evacuated for percentage composition analysis was 4kg. This was divided into four different storage containers (1kg each) and four different purification tests were carried out with activated charcoal and potash. The same quantity of activated charcoal and potash each measuring 250g was used. The results of the purification with Activated charcoal and Potash are shown in Table 4

Test	Biogas mass (kg)	Raw Biogas				BIOGAS PURIFIELD WITH Activated Charcoal and Potash			
		CH_4	CO_2	H_2S	H_2O	CH_4	CO_2	H_2S	H_2O
1	1.0	67.50	31.00	0.57	0.93	81.25	18.73	0.01	0.01
2	1.0	67.50	31.00	0.57	0.93	81.20	18.77	0.02	0.01
3	1.0	67.50	31.00	0.57	0.93	81.00	18.95	0.02	0.03
4	1.0	67.50	31.00	0.57	0.93	81.35	18.61	0.02	0.02
Ave.	1.0	67.50	31.00	0.57	0.93	81.20	18.77	0.0175	0.0175

Table 4. Purification results of testing with activated charcoal and potash

The results show that the percentage composition of hydrogen sulphide (H_2S) decreases from 0.57% to 0.01-0.02%, carbon dioxide from 31.00% to 18.61-18.95%, water vapour from 0.93% to 0.01-0.03% and for methane (CH_4), it increases from 67.50% to 81.00-81.35%. The increase in the percentage composition of methane, decrease in the compositions of carbon dioxide, hydrogen sulphide, and water vapour shown the purification filter performance was efficient.

6. Conclusion

This study sets on the design of local AD system biogas purification filter suitable for use in Nigeria shows that biogas purification filter can be design and fabricate locally in Nigeria. Also, impure biogas can be purified with potash, and activated charcoal. The percentage composition analysis of biogas before and after purification with potash and activated charcoal shows improvement of methane. The analysis shows that water vapour (H_2O) in biogas can be removed with potash, while for H_2S that has effect of forming acidic rain if not properly removed from biogas was removed by activated charcoal. Therefore, the possibility of meeting some of our energy needs can be achieved with the help of the low cost locally AD system biogas purification filter for household use in Nigeria.

7. Recommendation

Nigeria biogas potential is estimated at 25.53 billion m^3 per year. With this huge biogas production potential, the department and the government at all levels should take active part in all biogas projects and intensify findings of researches to enhance the production of biogas. Biogas plants should be constructed across Nigeria cities to decrease the volume of domestic wastes that should be disposed and in the process methane liberated into the atmosphere is reduced which has huge negative impact on the greenhouse gas than carbon (IV) oxide. In future research, the filter should be tested several times to know how long it can be reused and with that the life span can be determined.

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