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Comparative GC-MS Analysis of Biogas Produced from Sand Filter Backwash Water Pretreated Biowastes and Un-Pretreated Biowastes

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ABSTRACT

Background: Biogas impurities are major problems in biogas production. Evidence-based locally available methods for reducing biogas impurities is limited. The present study aimed at evaluating the effect of sand filter backwash water (SFBWW) pretreatment on the reduction of impurities in biogas.

Methods: SFBWW was collected from a borehole water purification plant in the University of Africa Toru-Orua (UAT), Bayelsa State, Nigeria. Plantain peels were collected from UAT farm and grinded, while sewage was collected from a septic tank in UAT. Twenty kilograms of grinded plantain peels was mixed with 20 kg of sewage and 10 L of SFBWW. The mixture was fed into a locally fabricated anaerobic biodigester. Two experimental groups were employed: pretreated and control (without SFBWW pretreatment) and two replicates were made for each group. Gas chromatography-mass spectrometry (GC-MS) was used to compare the types and concentrations of gaseous impurities in the biogas produced from pretreated and un-pretreated biowastes as well as the quantity of methane gas produced.

Results: Arranged according to their order of increasing retention times (8.629 - 19.923 minutes), the types of gaseous impurities identified in the biogas produced from both control and pretreated groups were: hydrogen (H_2), methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2), hydrogen sulphide (H_2S), water vapour (H_2O), nitrogen (N_2) and oxygen (O_2). Compared with control, a significant ($p < 0.05$) reduction in the concentration (%/v) of gaseous impurities was found in the biogas from pretreated group [Control: H_2-(2.00±0.01%), CO-(3±0.01%), CO_2-(40±0.00%), H_2S-(3±0.01%), H_2O-(2±0.03%), N_2-(4±0.00%), O_2-(1±0.00%); Pretreated: H_2-(0.4±0.01%), CO-(0.2±0.01%), CO_2-(13±0.00%), H_2S-(0.01±0.00%), H_2O-(0.29±0.00%), N_2-(1±0.01%), O_2–(0.1±0.00%)]. Also, compared with control, a significant ($p < 0.01$) increase in the concentration of methane gas was found in the biogas produced from pretreated group [Control: methane-(45±0.01%); Pretreated: methane-(85±0.00%)]

Conclusion: The present study demonstrates that sand filter backwash water is an effective biowastes pretreatment for the reduction of impurities in biogas and may serve as an alternative to the currently existing biowastes pretreatments.

Keywords: Backwash water, biogas impurities, biowastes, methane, pretreatment

Background

According to a recent report by the International Energy Agency (IEA), the magnitude of renewable energy consumption has seen tremendous increase over the years [1] and just like other renewable energy sources such as solar and wind [2], the production of biogas for sustainable renewable energy has also increased tremendously over the years [3, 4]. Also, studies on the use of biogas effluent as feed for fish and organic fertilizer for plant growth has also gained active research over the years [5, 6, 7]. Various wastes such as cassava peels, plantain peels, palm oil mill effluent, pineapple peels, sewage, cow dung, and cassava mill effluent have been successfully used to produce biogas through anaerobic digestion [8].

Biogas is a complex mixture of gases with methane (CH_4) as the only combustible gas [9]. Methane gas also has the highest percentage composition among all the other gases in biogas [9]. The other gases found in biogas such as carbon dioxide (CO_2), hydrogen sulfide (H_2S), water vapor (H_2O), hydrogen (H_2), nitrogen (N_2), carbon monoxide (CO) are non-combustible and are thus regarded as impurities in biogas. These non-combustible gases in biogas usually occur at low concentrations except for CO_2 that occurs at a fairly high concentration [9 - 10]. Although these impurities occur in trace amount, the presence of these non-combustible gases in biogas results in a low grade biogas [11]. Studies have showed that the presence of these impurities in biogas especially hydrogen sulphide impurity makes biogas toxic to humans because hydrogen sulphide inhibits the oxygen carrying efficiency of haemoglobin in the blood [12]. It also causes corrosion of equipment and inhibition of methanogenesis [11]. The removal of hydrogen sulphide from biogas by post-treatment has been shown to increase the cost of biogas production [13].

Studies on various pretreatments for efficient biogas production have been carried out in the past [14, 15]. The use of calcium hydroxide as pretreatment for the co-digestion of wheat straw and animal manure was reported in a previous study [16]. Another previous study reported the use of sodium hydroxide as pretreatment for the enhancement of biogas production from banana pseudo-stem fiber [17]. Also, another previous study used a combination of three chemical pretreatments; sodium hydroxide, calcium hydroxide and ammonium chloride for fresh and stale cassava peels before biogas production [18]. However, the goal of these previous pretreatment studies [14 – 18] was not primarily on the reduction of impurities in biogas and as such, the levels of the various impurities after pretreatment were not evaluated in these previous studies. Most biogas pretreatments aside from not been locally available, have also been reported to increase the cost of biogas production [19]. Thus, locally available alternative pretreatment for the removal of biogas impurities is needed.

Sand filter backwash water is a liquid waste that is generated from the purification of underground water in borehole water purification plants [20]. It is very rich in iron and manganese [21]. Previous studies have shown that the underground water in Bayelsa State, Nigeria contains a very high concentration of iron [20, 22, 23], which results in a very high concentration of iron in the sand filter backwash water generated in borehole groundwater purification plants in the State [20]. A previous study showed that the residual sludge from sand filter backwash water can be used as an adsorbent for the removal of radium (Ra) from underground water [24].

Research on the feasibility of using sand filter backwash water for the reduction of impurities in biogas, are not available in literature. The present study therefore, aimed at evaluating the effect of sand filter backwash water (SFBWW) pretreatment on the reduction of impurities in biogas.

2.0 Methods

2.1 Study location

The study was carried out in the University of Africa Toru – Orua, Biogas Research Centre, Bayelsa State, Nigeria, a facility where biogas research has been previously reported [25]. The availability of clean and pure water for domestic consumption is a major challenge in Bayelsa State due to the contamination of underground water with a high concentration of iron [26]. Bayelsa State is located on latitude 4.77190N and longitude 6.06990E [27], between Rivers and Delta State [28].

2.2 Collection of sand filter backwash water (SFBWW)

SFBBW was collected from a borehole water purification plant in the University of Africa Toru-Orua, Bayelsa State, Nigeria and brought to the biogas plant in the University.

2.3 Collection and preparation of biowastes

The study employed two co-digested biowastes (plantain peels and sewage). Plantain peels were collected from UAT farm and grinded, while sewage was collected from a septic tank in UAT. Twenty kilograms of grinded plantain peels was mixed with 20 kg of sewage and 10 L of SFBWW pretreatment and stirred thoroughly.

2.4 Anaerobic biodigestion

The present study employed two groups: control and pretreated groups. Anaerobic digestion was carried out as previously described [29]. The mixture was fed into a locally fabricated anaerobic biodigester and a control was set up without SFBWW pretreatment. Each group had two replicates. The anaerobic biodigester was operated at mesophilic temperature [29].

2.5 Gas chromatography–mass spectrometry (GC-MS)

The various gaseous components in the biogas produced from control and pretreated groups were identified and quantified (%/volume) using GC-MS analysis as previously described [30].

2.6 Statistical analysis

SPSS version 27 was used for data analysis. Results were presented in graphs and tables. T-test and one-way ANOVA were used to determine significant differences between means and results were expressed as mean ± standard error of mean. Significant level was set at $p < 0.05$ [31, 32]

3.0 Results

3.1 Comparative identification of the gaseous impurities in the biogas produced from pretreated and un-pretreated biowastes

Figures 1 and 2 show the gaseous impurities in the biogas produced from pretreated biowastes and control (un-pretreated biowastes) as well as their elution order based on their retention times. Arranged according to their order of increasing retention times (8.629 - 19.923 minutes), the types of gaseous impurities identified in the biogas produced from both control and pretreated groups were: hydrogen (H_2), methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2), hydrogen sulphide (H_2S), water vapour (H_2O), nitrogen (N_2) and oxygen (O_2).

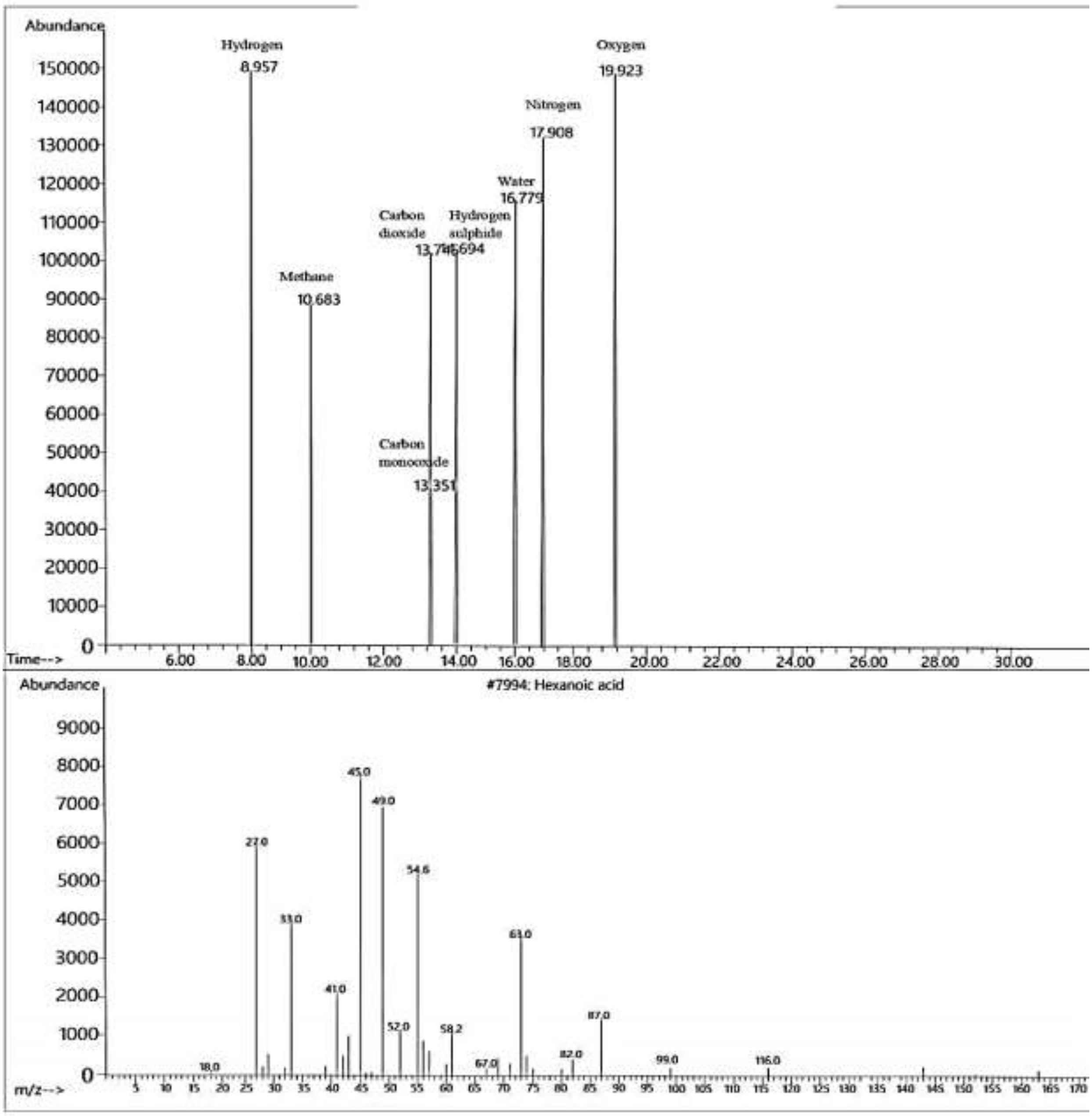

Figure 1. A representative GC-MS graph of the biogas produced from control (un-pretreated biowastes)

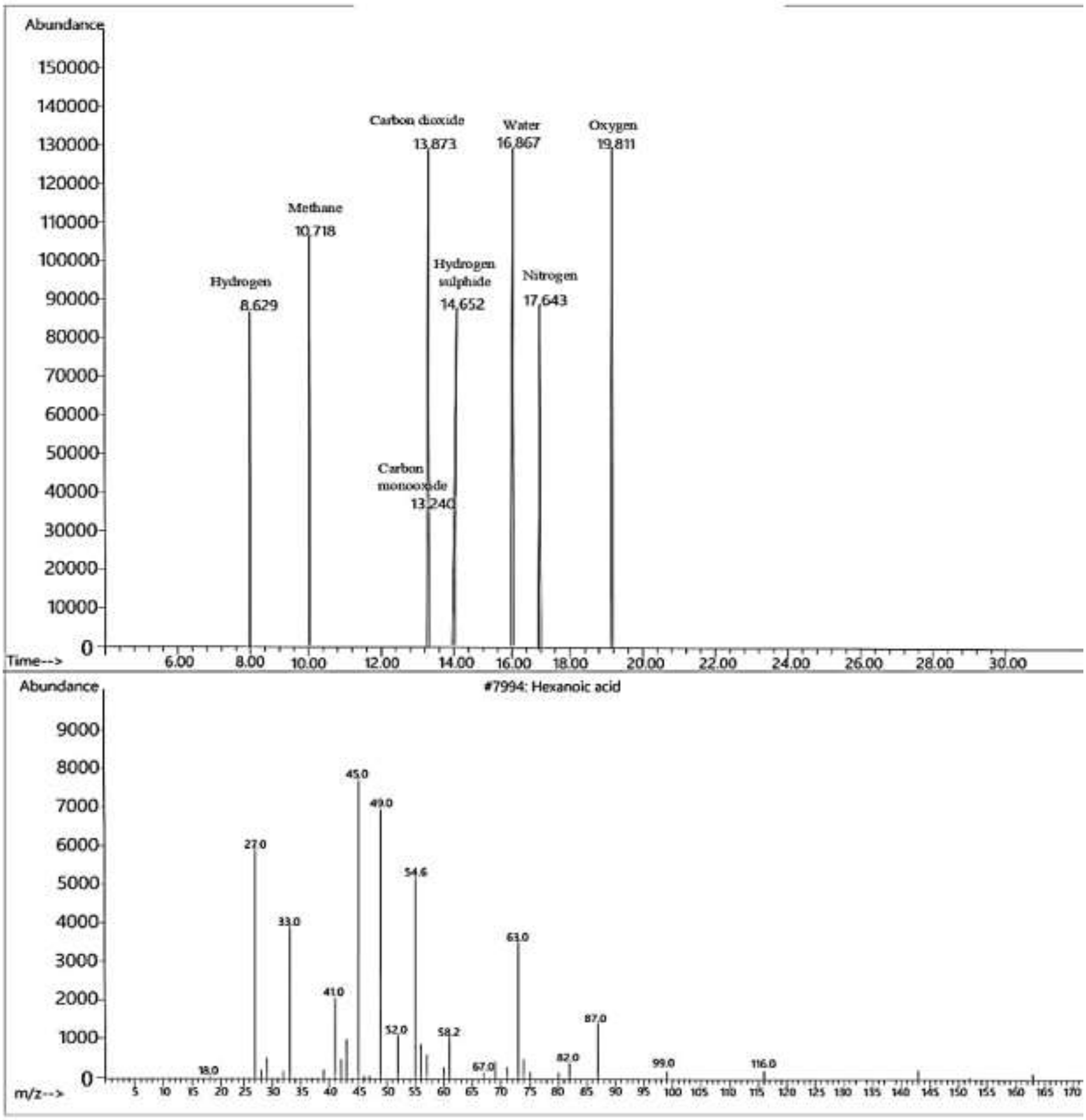

Figure 2 A representative GC-MS graph of the biogas produced from SFBWW pretreated group

3.2 Parameters for the calibration standards used for GC-MS analysis

The parameters for the calibration standards used for GC-MS are presented in Table 1. The Chemical Abstracts Service Registry Number (CAS No or RN) for each of the calibration standard used in the present study are shown in Table 1. This validates the findings of the present study.

Table 1. Parameters of the calibration standards used for GC-MS

Gas	Molecular weight gram/mol	CAS No
Hydrogen	2.016	1333-74-0
Carbon monoxide	28.010	630-08-0
Carbon dioxide	44.010	124-38-9

Hydrogen sulphide	34.100	7783-06-4
Water	18.010	7732-18-5
Nitrogen	14.00	7727-37-9
Oxygen	15.99	7782-44-7

CAS No: Chemical Abstract Service Registry Number

3.3 Comparative quantification of the gaseous impurities in the biogas produced from pretreated and un-pretreated biowastes

The percentage concentrations (%/v) of the gaseous impurities found in the biogas produced from control and pretreated biowastes are presented in Figure 3. As shown in Figure 3, compared with control, the concentrations of all the gaseous impurities were significantly ($p < 0.05$) lower in the biogas produced from SFBWW-pretreated group.

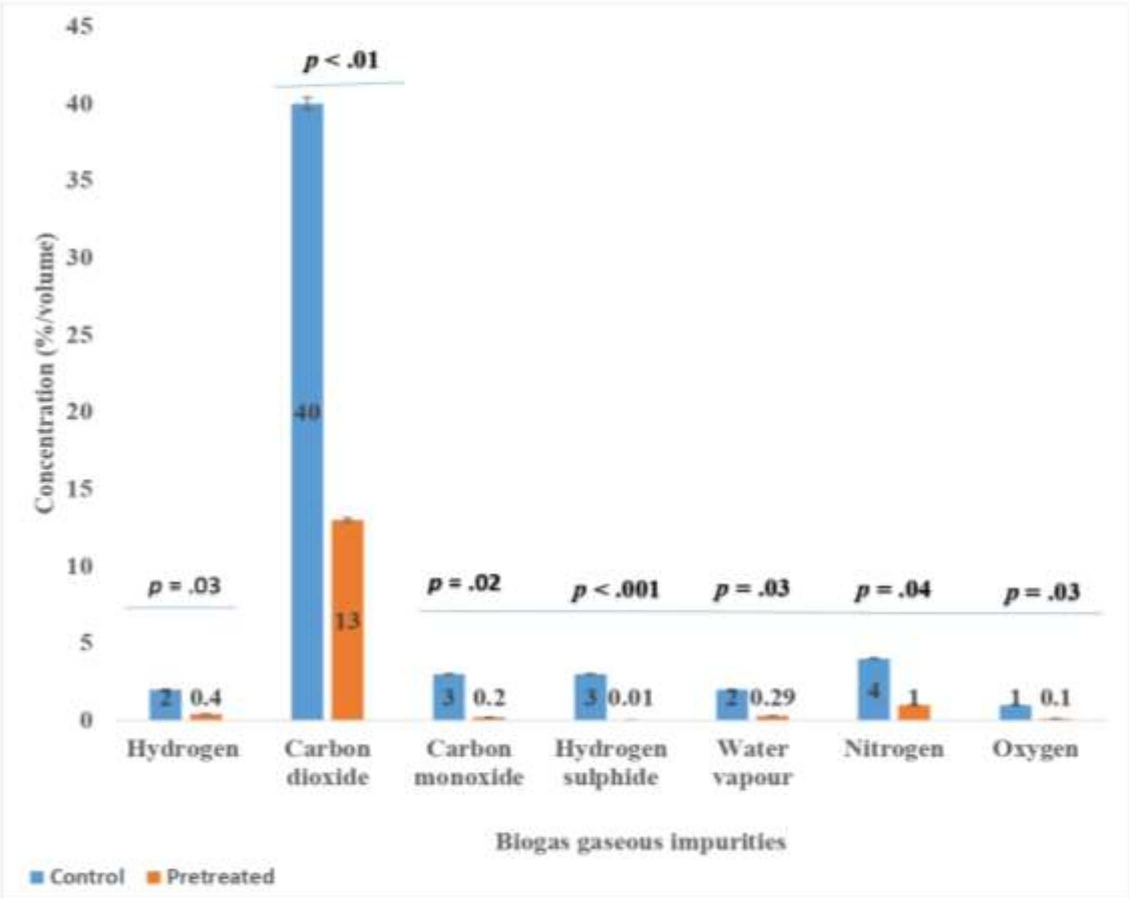

Figure 3. Differences in the concentrations of the gaseous impurities in the biogas produced from pretreated biowastes and control.

Results presented as mean ± standard error of mean. Values inside the blue bars and on top of the red bars represent concentrations, while the p values on top of the horizontal blue lines indicate a significant difference between the concentration of a gaseous impurity in control and pretreated group.

3.4 Comparative quantification of the methane in the biogas produced from pretreated and un-pretreated biowastes

The percentage concentrations (%/v) of methane found in the biogas produced from control (un-pretreated) and pretreated biowastes is presented in Figure 4. As shown in Figure 4, compared with control, the concentration of methane gas was significantly ($p < 0.01$) higher in the biogas produced from SFBWW-pretreated group.

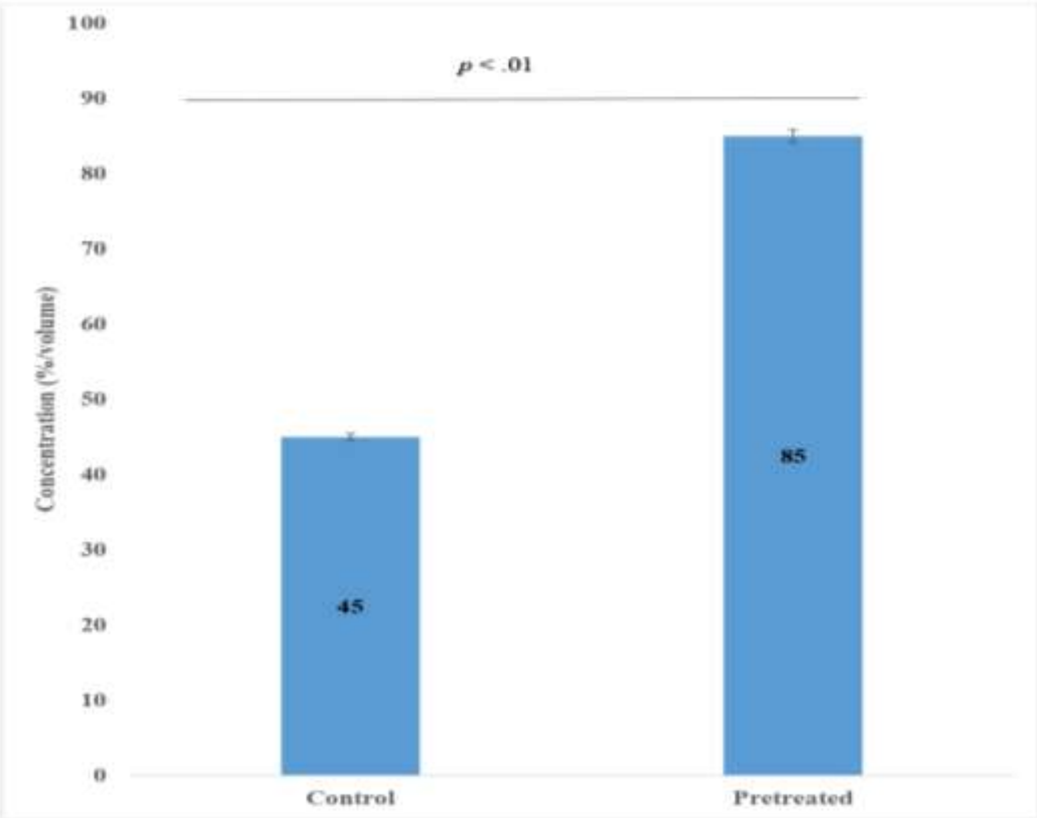

Figure 4. Differences in the concentrations of methane in the biogas produced from pretreated biowastes and control.

Results presented as mean ± standard error of mean. Value inside each bar represent concentration, while the *p*-value represents a significant difference between the concentration of the methane gas from pretreated group and control.

4. Discussion

The present study determined the effectiveness of SFBWW pretreatment on biowastes used for biogas production. The gaseous impurities in the biogas produced from pretreated and un-pretreated biowastes were analyzed using GC-MS. A significant reduction in biogas impurities was found in the present study in the pretreated group. This underscores the effectiveness of sand filter backwash water pretreatment for biogas production. A previous study showed that sand filter backwash water sediment can be used as an adsorbent for the removal of radium from backwash water [24], however, the use of SFBWW as pretreatment for the biowastes used for biogas production has not been previously reported. Thus the present study is novel and has filled a major gap in research.

The biogas impurities found in the present study were lower than the biogas impurities reported in a previous study [33]. This suggests that SFBWW is effective for the reduction of impurities in biogas. The use of GC-MS analysis for the quantification of the concentrations of various biogas components is a widely accepted technique [10]. However, previous studies on biogas used GC-MS to evaluate the levels of siloxanes in biogas originating from landfill, wastewater treatment plants, agriculture biogas plants [34] and mixed organic manure [35]. GC-MS has also been used to determine the composition of biogas produced from pineapple peels [9]. However, the use of GC-MS for the comparative analysis of the level of impurities in biogas produced from SFBWW pretreated and un-pretreated biowastes has not been previously investigated. Thus, the present study has contributed information to the body of knowledge on biogas production.

The percentage of methane gas found in the present study after pretreatment with sand filter backwash water was 85%. This is higher than the findings of a previous study on biogas production from the anaerobic co-digestion of corn-chaff and cow dung digestate where a percentage of 49.81 – 68.15% was found [10]. Also, data from the present study show that the composition of methane gas increased by 40% when sand filter backwash water pretreated biowastes was used for biogas production compared with the un-pretreated biowastes. The percentage increase in methane gas found in the present study after SFBWW pretreatment is higher than the percentage increase found in a previous study where liquid hot water–steam explosion was used as pretreatment for wheat straw [36].

High methane gas yield indicates high biogas combustion value [37]. Thus, the high methane gas yield found in the present study indicates higher combustion energy and heating value for the biogas produced from pretreated biowastes. Further studies on the use of SFBWW pretreatment for pretreating other types of biowastes is recommended.

Bayelsa State is located in the core of the Niger Delta, Nigeria [38], and has a high proportion of unemployed population [39]. The availability of a locally available pretreatment for biogas pretreatment in Bayelsa State groundwater may facilitate biogas production in the State. This may serve as a means of job creation in the State. Given that previous studies have showed that the sand filter backwash water and fresh water in Bayelsa State is rich in iron [20, 22. 23, 40] and other extant studies have showed the positive effect of iron-containing compounds on biogas production [14, 15], thus, the positive effect of SFBWW on biogas production found in the present study might be due to the high concentration of the iron found in SFBWW. However, further research is required to establish this.

5. Conclusion

The present study confirmed that SFBWW pretreatment reduces the impurities in biogas and increases the concentration of methane gas. The present study demonstrates that sand filter backwash is reliable and satisfactory for the pretreatment of biowastes for biogas production and presents an alternative to the currently existing biowastes pretreatment. Future usage of sand filter backwash water for biogas production is highly recommended.

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Conflict of interest

The authors declare no conflict interest.

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