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COMPOSITIONAL ANALYSIS OF BIOGAS PRODUCED FROM FAECAL SLUDGE CO-DIGESTED WITH ORGANIC FEEDSTOCKS

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ABSTRACT
The objective of this study was to determine the composition and cooking of biogas generated from faecal sludge co-digested with three organic feedstock materials. The feedstock materials (cow dung, cow intestinal waste and mixed organic waste) were fed into the digester to mix with faecal sludge for biogas production. Temperature and pH of the digester contents during decomposition were taken at four days interval. The biogas produced was analyzed using multi-gas analyzer to determine the concentrations of CO, CO_2, CH_4 and H_2S while the efficiency of the biogas produced was determined by comparing the cooking time of a 200 g of rice using kerosene, Liquid petroleum gas (LPG) and biogas produced simultaneously and the time taken recorded accordingly. The result of the ANOVA showed that feedstock materials had significant ($P \leq 0.05$) effect on the temperature and pH. Population distribution of the microflora showed aerobic and anaerobic bacteria (*Bacillus spp*, *Clostridium spp*, *klebsiellaspp)* and a methanogen of the genera methanococcus. Methane formed major component of the biogas produced by all the substrates (40-70%) followed by carbon dioxide (20-30%) and H_2S (8-10%). The result of comparison of cooking time (minutes) was in the order of kerosene (40.00 min$\pm$1.00) > liquefied petroleum gas (27.33 min$\pm$0.58) > biogas (25.67 min$\pm$0.58). The study showed that faecal sludge co-digested with Cow dung, Cow Intestinal Waste and Mixed organic waste demonstrated a potential for biogas generation.

Keywords: Biogas, Faecal-sludge, Kerosene, Micro-flora, Anaerobic bacteria.

INTRODUCTION

Nigeria is a country blessed with several energy resources including both renewable and non-renewable. Over the years, the non-renewable resources have been the center of energy mix contributing to gross domestic product of the country while creating employment. Petroleum production dominated Nigeria on non-renewable resources. In the current situation, the petroleum products which have been largely reported as the main cause of greenhouse gases leading to global warming is depleting in reserve. The renewable energy resources include biomass, hydropower, solar, wind etc. The biomass has a substantial advantage over other renewable resources due to their ability to mitigate carbon dioxide emissions through the mechanism of photosynthesis and providing energy without any interruption. In developing countries like Nigeria, several feedstocks have emerged as having potential for energy production. These feedstocks include cassava, sugar cane, sweet sorghum and oil palm.

Biogas is a clean renewable energy produced from organic wastes using anaerobic digestion as a method. The anaerobic digestion is a biological degradation of organic matter by bacteriological flora in anaerobic mode [1]. The products of the digestion are biogas and residue. Biogas is a mixture of methane (CH_4) with percentage over than 65% and carbon dioxide (CO_2). CH_4 is the highest component of natural gas. The digestate is the liquid residue containing non-degraded materials. The biogas produced from the anaerobic digestion is flammable and can be used such as: heating, cooking, power generation, lighting and as a biofuel. The biogas production will normally be in the range of 0.3 - 0.45 m^3 of biogas per kg of solid substances for a well-functioning process with a typical retention time of 20-30 days [2].

Biogas plant has a self-consumption of energy to keep the sludge warm. This is typically 20% of the energy production for a well-designed biogas plant. For example if the biogas is used for power and co-generation, the available electricity will be 30-40% of the energy in the biogas, the heat will be 40-50% and the remaining 20% will be said self consumption. The objective of this study is to determine the composition and efficiency of the biogas generated from faecal sludge co-digested with three organic feedstock materials.

Materials and Methods

The feed stock materials; cow dung (CD), Cow intestinal waste (CIW) and mixed organic waste (MOW) were used for co-digestion with faecal sludge for biogas production in the digester. The Cow dung was sourced from Federal University of Agriculture, Abeokuta (FUNAAB) Cattle cooperative farm and Cow intestinal waste was sourced from Ifesowapo Asejere abattoir, Agbeloba, Abeokuta while mixed organic waste was sourced from the households and Panseke market, Abeokuta. Each of the feedstock was replaced at the end of the retention time (time between the commencement of gas production and termination of the experiment) which is average of 30 days for each feedstock material. Each feedstock was fed into a locally fabricated 2 m^3 capacity digester and the readings taken accordingly until the retention time is reached before the next feedstock was loaded. Proper stirring of the content inside the digester was carried out to ensure uniform decomposition, using a specially fabricated stirrer improvised with the digester. Digital gas detector was also used to analyze the composition of the biogas and assess methane generating potential of the feed stock materials.

Monitoring of Temperature and pH of Digester Contents

Temperature and pH of the digester contents during decomposition were taken after each agitation at four days interval. Thermometer model (ts 005110510) and a digital pH meter (Rapidest made by LuserLenf. Products Inc., China) were used throughout.

Microbial Populations Isolation and Assessment

The microbial species in the digester were enumerated by standard plate count technique using 0.1ml aliquots of appropriate dilution pour onto Nutrients agar, MacConkey, Eosin methylene Blue agar and Fastidious Anaerobic agar for bacteria. Potato Dextrose Agar (PDA) plus chloramphenicol was used for fungi isolation and enumeration. Nutrient agar, MacConkey and EMB agar plants were incubated at 37 ^{0}C for 24-48 hours, Potato Dextrose Agar plates were incubated at room temperature for 3-5 days while Fastidious Anaerobic agar plates were incubated in an anaerobic jar (Oxoid) containing a moistened pack of gas generating kit (Bio-oxoid) at 37 ^{0}C for 7 days. Individual colonies were purified and indentified by morphological and biochemical techniques [3,4] for the fungi isolates, the microscopic and macroscopic features of the hyphal mass, morphology of cells and spores, nature of the fruiting bodies, among other criteria were used for identification [5].

Determination of Biogas Composition and Volume

Biogas produced was analyzed using EXIBD-1 Multi-Gas Analyzer. The gas detector was used to determine the concentrations of CO, CO_2, CH_4, and H_2S in the biogas. Also, volume of biogas produced was measured using intermittent measurements with syringe method according to Pham *et al.*,[6], while gas pressure was monitored by OGOTEX pressure gauge meter that was -mounted along the outlet pipe

The efficiency of the biogas produced was determined by comparing the cooking time of a cup (200 g) of rice using kerosene, Liquid petroleum gas (LPG) and biogas produced simultaneously. The time taken to cook 200 g of rice was measured with stop-watch and recorded accordingly.

RESULTS AND DISCUSSION

Temperature monitoring in the digester

The result of the ANOVA showed that feedstock materials had significant ($P \leq 0.05$) effect on the temperature and pH.

The values obtained from changes in temperature and pH of Faecal Sludge only and faecal sludge mixed with the feedstock materials during period of biogas production super-imposed on one another (Figures 1 and 2). At the beginning of the digestion, the temperature rose gradually and sharply declined at day 20. Although, all the materials exhibited the same trend of inconsistent temperature rise and fall, the slope was sharper in the mixture of faecal sludge and mixed organic waste. This could probably be attributed to high nitrogen content in the material. The internal temperature of the digester fluctuated between 22 ^{0}C and 30.5 ^{0}C.

The pHmonitoring in the digester

The pH value of the digester mixtures started at 7 and 7.5 for mixtures of faecal sludge with cow dung and cow intestinal waste respectively. At day 20, pH of faecal sludge + CIW rose up to alkaline position of 8.0 and then fell to a neutral pH of 7 throughout the period of gas production while it dropped to 6.5 for other mixtures. All the mixtures showed rise and fall pattern in pH.

Temperature has been observed by most researchers to be quite critical for anaerobic digestion, since methane-producing bacteria operate most efficiently at temperatures 30-40^{0}C or 50-60^{0}C [7]. In this work, the temperature of the digester remained constant at mesophillic range (22^{0}C-30.5^{0}C) throughout the digestion period. This result agreed with the works of Ojikutu, *et al.*,[8] who reported a fluctuated internal temperature of digester during evaluation of biogas production from food waste to be 27 ^{0}C and 31 ^{0}C; while Dahunsi and Oranusi, [4] recorded a temperature range of 22 ^{0}C – 30.5 ^{0}C during co-digestion of food waste and human excreta for biogas production.

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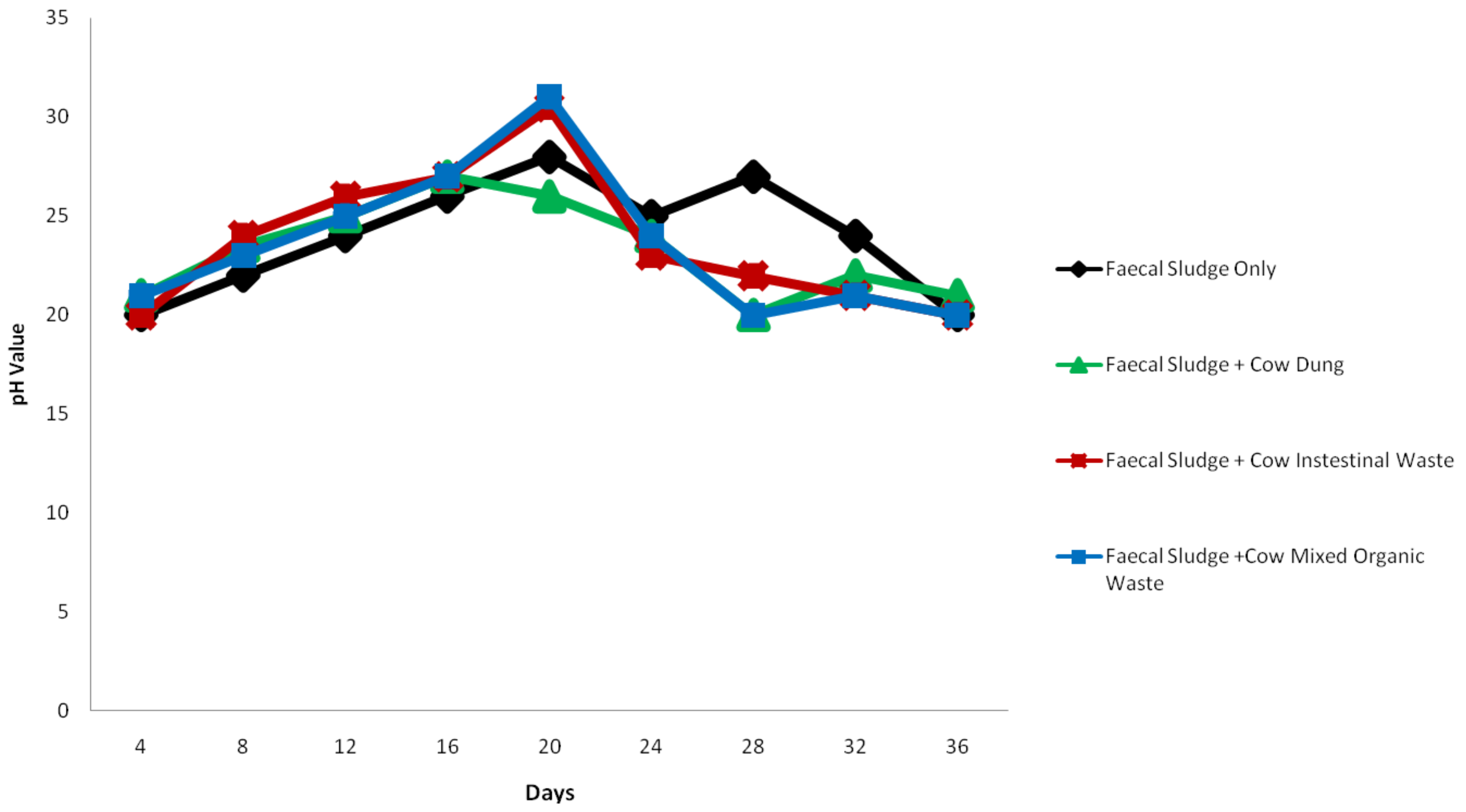

Figure 1: Temperature Variation of the digester mixture

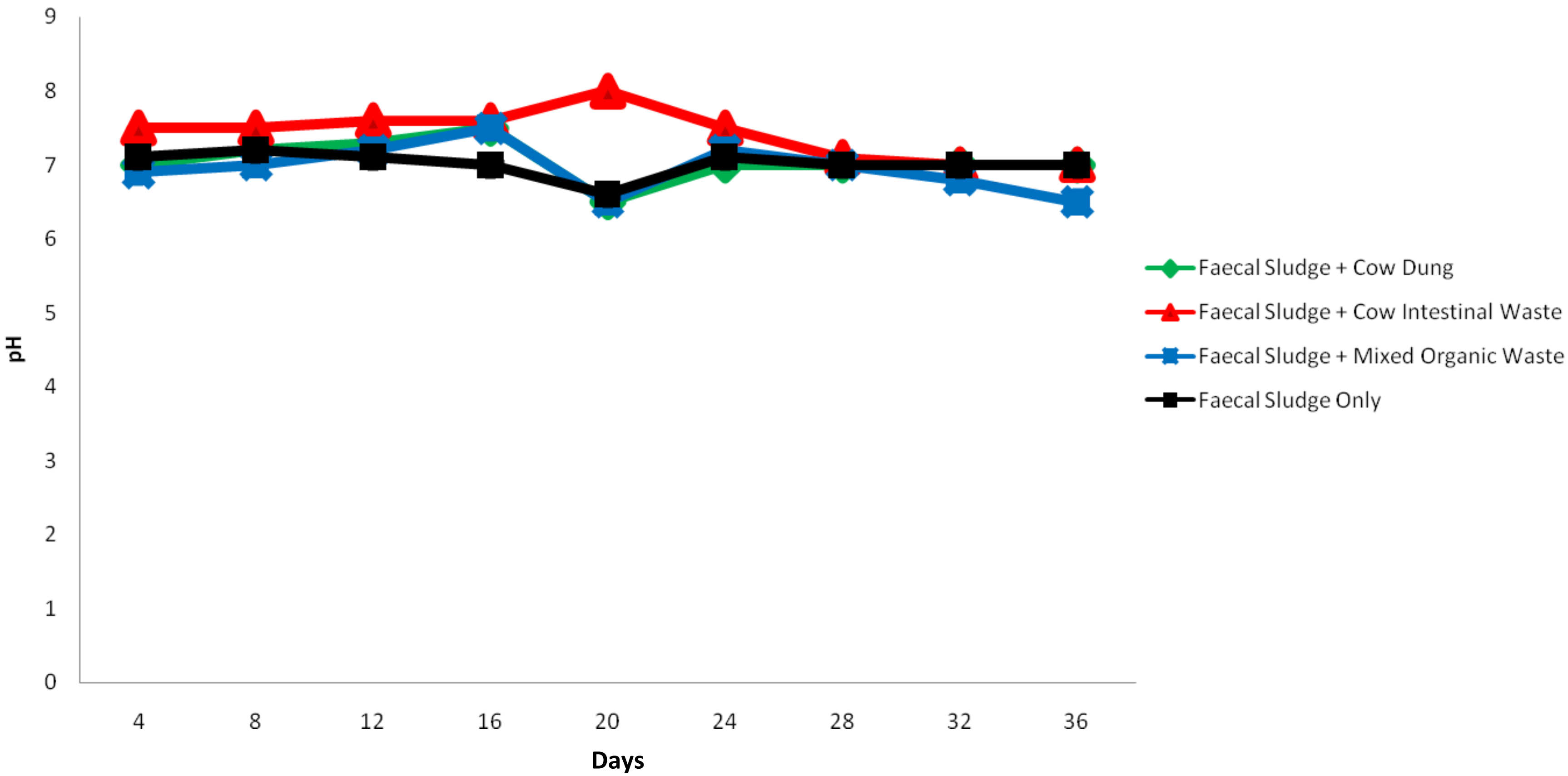

Figure 2: pH Variation of the digester mixture

In this study, temperature seems not to have any significant effect on the amount of gas produced daily, as the daily gas production did not follow a specific pattern and which is indicative of the fact that other parameters apart from temperature could be responsible for the quantity of biogas generated daily. This was similar to the report of Ilori *et al.* [7] and Dahunsi and Oranusi, [4] that the recovery time for biogas production as well as the quality and quantity of biogas produced from organic materials are functions of nature and composition of the digester feedstock.

The pH values of all the feedstock materials showed a rise and fall pattern. This could be attributed to the biodegradation of the organic acids, mineralization of organic compounds and the consequent release of volatile NH_3 [9]. The pH between 6.0 and 8.0 attained during the biodegradation process indicated a successful and fully developed process [10]. The pH of faecal sludge from septic tanks was normally in the range of 6.5 to 8.0 [11,12], but can vary greatly from 1.5 to 12.6. APHA [13] also submitted that a pH outside the range of 6 to 9 indicates an upset in the biological process that will inhibit anaerobic digestion and methane production. It could also result from a change in the hydraulic loadings, the presence of toxic substances, a large increase in organic loading, or that the systems are receiving industrial or commercial wastewater [11]. Similarly, variation has also been observed in previous degradation. The initial drop in pH from 8 to stable 7.0 throughout the period of gas production is important since activities of aerobes and facultative aerobes are essential to produce relevant acidic metabolites, which are acted on by methanogenic bacteria to produce methane. Methanogenesis occur best within a pH range of about 6.5 and 7.1 as seen in this study which was in agreement with the findings of Gungor and Karthikeyan, [14, Farrel *et al.*, [15] and Laskri and Nedjah [16], where the highest biogas yields were observed at digester pH 8. The observed pH in this study were in agreement with pH of 6.65-7.81 obtained by Abubakar and Ismail [17] during anaerobic digestion of cow dung for biogas production.

Volume and composition of biogas produced from the digester

The results of ANOVA showed that feedstock materials did not have significant ($P>0.05$) effect on the volume of biogas production.

Figure 3 shows the daily gas production super-imposed on one another. The gas production started on the fourth day for Faecal Sludge + Cow Intestinal Waste (40 cm^3**)** while for Faecal Sludge + Cow Dung it was on the fifth day (32 cm^3**).** For Faecal Sludge Only, the highest gas volume production of 105 $cm^3$was recorded on nineteenth day, Faecal Sludge + Cow Dung recorded highest gas volume of 108 cm^3 on nineteenth day of the experiment. The Faecal Sludge + Cow Intestinal Waste produced its highest gas volume of 175 cm^3 on the twenty second day. Gradual fall in volume of gas production was noticed among all the feedstock materials and faecal sludge substrate. No gas was recorded on the last day of the experiment. However, Faecal Sludge Only produced the least volume of gas (105 cm^3) while Faecal Sludge + Cow Intestinal Waste produced the highest volume (175 cm^3) within 32 days of monitoring of gas production in digester for each of the substrates. This could be attributed to its high content of total volatile organics.

In terms of gas composition, methane formed the largest component of the biogas produced by all the substrates (Figure 4). There was no hydrogen sulphide in the gas produced by Faecal Sludge + Cow Intestinal Waste. The highest percentage of methane was found in Faecal Sludge + Cow Intestinal Waste produced biogas while Faecal Sludge Only produced the gas with the least percentage of methane and highest percentages of CO_2 and CO.

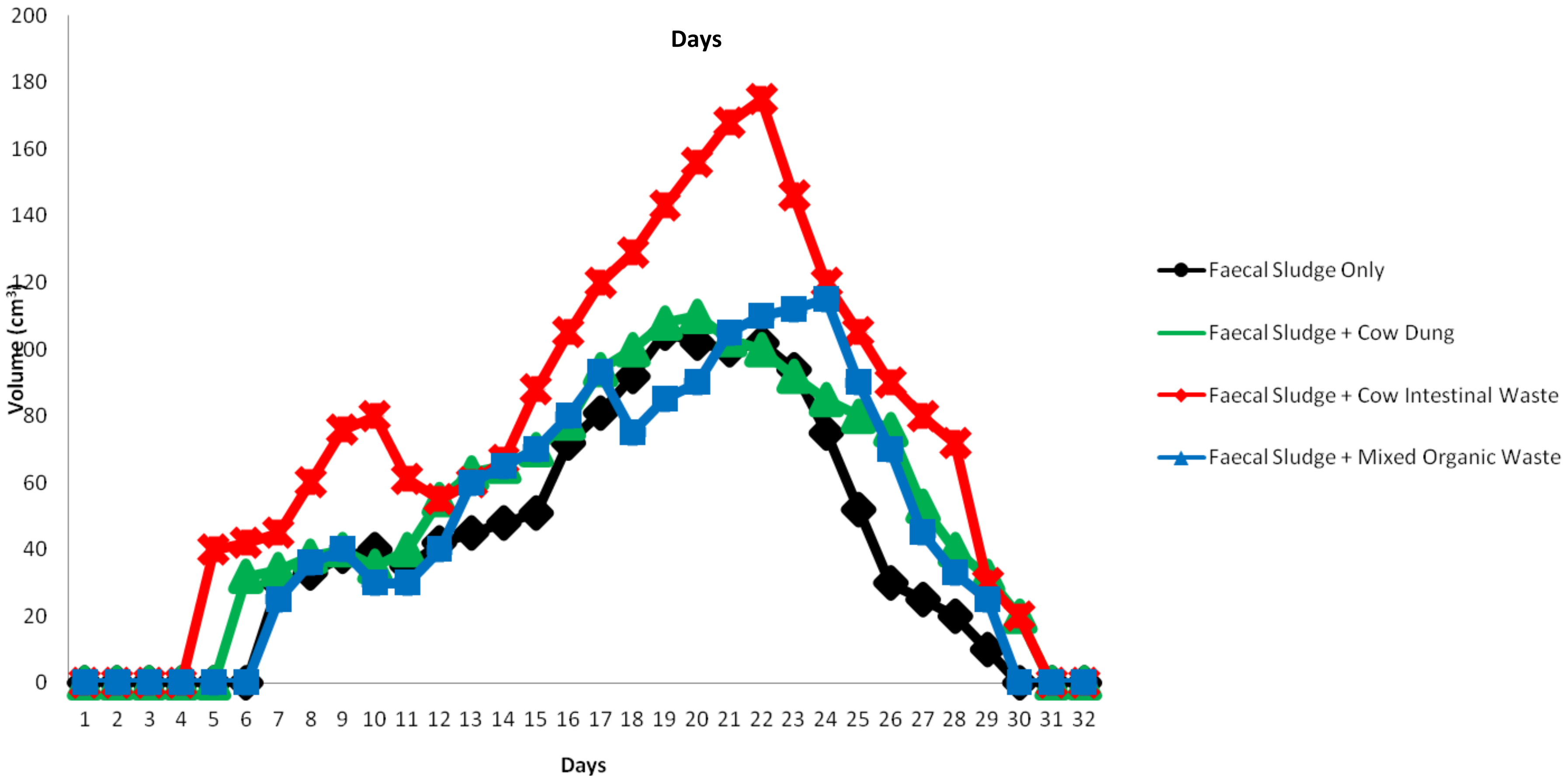

Figure 3: Volume of gas produced

According to Sridhar *et al.*[18] biogas is chiefly methane (60-70 %) and carbon dioxide (30-40 %). Occasionally, other gases such as hydrogen (5-10 %), nitrogen (1-2 %), and hydrogen sulphide (<1%) may be found depending on the nature of raw materials and operating conditions. The level of methane obtained in this study (70 %) was quite a good indication that the mixture of faeces, vegetable waste, faeces and cow dung forms suitable recipe for biogas generation. The level of methane was similar to 70.6 % of methane evolved from the mixture of pig dung and selected crop waste in a study conducted by Okareh *et al.*[19]. Good performance of the digester in terms of methane generation could be explained by air tight condition of the digester that was ensured during the construction. The composition of methane gas generated from the mixture was higher than 58 % CH_4 and 24% CO_2 obtained by Laskri and Nedjah [16]. It was also higher than the levels found in other previous studies: Smith [20] (CH_4:55-70% and CO_2: 30-45%), Mathias [21 (CH_4:65-70%, and CO_2:42%) and Lawbuary [22] (CH_4: 58 % and CO_2: 15-35%).

Isolation of bacteria and fungi species in the digester

Table 1 shows the different bacteria and fungi species present in the digester during the digestion process. Eight species of bacteria including Citrobracter, Klebsiella, Bacillus, Pseudomonas, Escherichia, Clostridium, Bacteriodes and Methanococcus were isolated and identified while four species of fungi including Mucor, penicillium, Rhizopus and Aspergillus were identified.

Table 1: Species of bacteria and fungi in the digester

Methanogen	Aerobes	Anaerobes	Fungi
Methanococcus	*EscherichiaColi*	*Clostridium botulinum*	*Rhizopus*
	Citrobacter	*C.Chavoie*	*Penicillium*
	Klebsiella	Bacteroides	Mucor
	Baccilus		*Aspergillus*
	Pseudomonas		

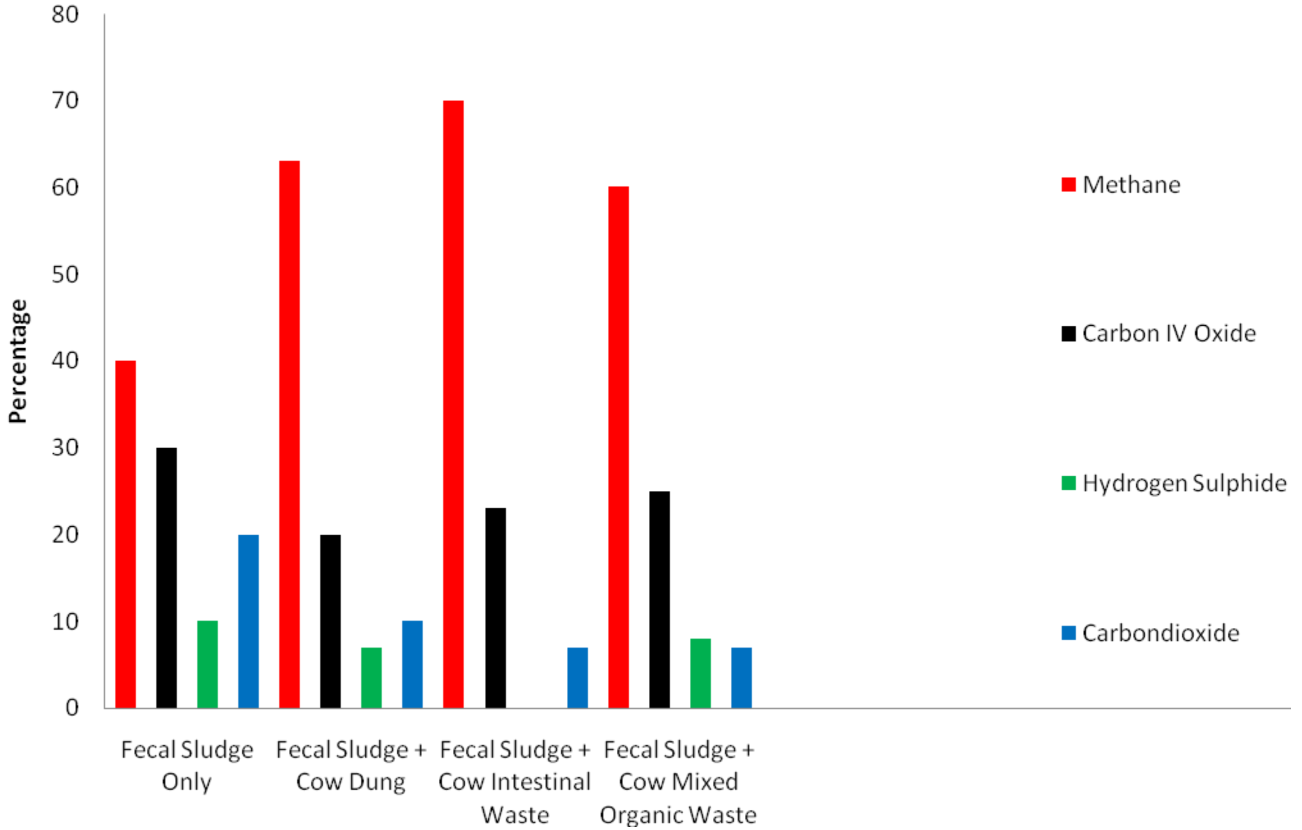

Figure 4: Composition of biogas generated from the digester

Some of which are acid-formers and a methane former methanococcus species. The correct balance between these two groups of microorganism determines the successful operation of anaerobic digesters for biogas production. The methane formers however multiply at a slower rate than acid formers and are very sensitive to environmental changes [23]. The fungal isolates includes; mucor, *penicillium*, *rhizopus* and *aspergillus* whose source could be feedstock materials. This finding showed similarities with the work of Pritchard *et al. [24]* who reported *E.coli, Aspergillus, Clostridium botulinum, C. chavoie* and others as isolated from water contaminated by human excreta in Malawi. It also agreed with the work of Rabah *et al.*[23] who reported *Bacillus*, *E.coli*, *Clostridium*, *Klebsiella*, *Proteus* and bacteriodes as bacteria isolates and *Aspergillus*, *Rhizopus*, *Pencillium* and Mucor as fungi isolates in the digester during gas production of food waste and human excreta. Similarly, it also corroborated with Nwankwo, [25] who isolated *E.coli*, *S. aureus*, *Candida albicans*, *Clostridium perfringes* and *Streptococcus* species during production of biogas from paper waste blended with cow dung.

Determination of efficiency (Cooking time) of biogas produced, LPG and Kerosene

Table 2 shows the time taken to cook a cup (200g) of rice using biogas produced from the study, LPG and kerosene. The mean time taken (minutes) for the three energy sources are; 25.67±0.58, 27.33±0.58 and 40.00±1.00 respectively. Biogas had lowest cooking time, followed by LPG while kerosene had highest. The result of the ANOVA showed that there was significant difference ($p<0.05$) in the cooking times of the three energy sources.

Table 2 :Stove Value of the biogas Compared with other energy sources

Energy	**Cooking Time (minutes)**			**Mean ± SD**
	1st	2nd	3rd	
Biogas	26	26	25	25.67 ± 0.58
LPG	27	27	28	27.33 ± 0.58
Kerosene	39	40	41	40.00 ± 1.00

The main influencing factors in using biogas as a combustible gas are gas / air mixing rate, flame speed, ignition temperature and gas pressure. Compared to LPG, biogas needs less air per cubic meter for combustion [26]. This study revealed that biogas had lowest cooking time of 26 minutes followed by LPG (27 minutes) and kerosene (39 minutes) for cooking a cup (200g) of rice. This result agreed with the work of Ovueni, [27] who reported a significant difference between the heating capacity of biogas and LPG. Joshi *et al.*[28] reported the nominal combustion efficiency of biogas and LPG to be 99.4 % and 97.7 % respectively. Similarly, Shrestha, [29] also reported efficiency measurement of biogas, kerosene and LPG stoves as 45 %, 40 % and 43 % respectively. He then concluded that the efficiency of stove depends upon the following conditions; environmental conditions (such as wind, temperature, pressure); shape, specific heat capacity and weight of vessel; burner size of stove and size of bottom face of cooking vessel; energy content of fuel and quality of fuel.

Conclusion: The biogas generated from faecal sludge co-digested with the three organic feedstock materialswas highly rich in methane and more efficient than liquefied petroleum gas and kerosene in terms of cooking time comparison.

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