Original Research Article

ENERGY EVALUATION AND QUALITATIVE ANALYSIS OF BIOGAS PRODUCED FROM CO-DIGESTING KITCHEN WASTE AND COW DUNG

5 ABSTRACT

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Daily, large amounts of kitchen waste are disposed of in homes and institutions posing environmental pollution. The waste can be utilized for biogas production. Biogas production requires anaerobic digestion of organic matter. In this study biomass Kitchen waste was collected, as feedstock for a homemade laboratory-scale anaerobic digester (10L capacity) to produce biogas in the Masinde Muliro University of Science and Technology (MMUST) Physics laboratory for 27 days. The study investigated the energy and quality of biogas produced from co-digesting a mixture of kitchen waste and cow dung. This was done at a temperature range of $25 \,^{\circ}$ C - $35 \,^{\circ}$ C and in an alkaline environment maintained by adding a medium of sodium hydroxide. The biogas produced was analyzed for its power potential. The power potential of biogas produced from this study was found to be 22,461.77W/m³. Comparing this with the Literature value of 37,258.9W/m³ for pure methane. 60.29%. of the biogas sample tested was methane. Gas chromatogram on five gas samples collected from individual kitchen waste substrates showed slightly higher percentage of methane content in the biogas collected from starch and pure cow dung in relation to other tested samples. Biogas production significantly increased when we allowed for co-digestion of kitchen waste mixed with cow dung. Maintaining each substrate within a slight alkaline environment led to a high production of biogas. It is envisaged that the gas generated and the process' friendly cost, will be a perfect alternative source of cleaner, safer and cheaper energy source as compared to the expensive and environmentally unfriendly traditional sources such as firewood, charcoal and petroleum products. This study forms a basis upon which large scale biogas production from kitchen waste can be done for domestic and commercial use.

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Key words: Anaerobic co-digestion, Kitchen waste, Biogas, Gas Analysis

10 **1. INTRODUCTION**

11 The Kenya's economy mainly depends on the energy resources available. With the advent of industrial 12 revolution use of fossil fuels has been growing and to date the sources are being depleted. Dependence on this fossil fuel as primary energy source has led to global climate change due to the pollution of the 13 environment causing human health problems^[1]. With increasing prices of oil and gas the world looks towards 14 alternative green energy resources. Anaerobic digestion (AD) of biomass to produce biogas offers a very 15 attractive route to utilize certain categories of biomass for meeting partial energy needs. Biogas comprises of 55% - 70% methane gas, 30% - 45% carbon dioxide and tress gases ^[2]. AD can successfully treat the 16 17 organic fraction of biomass^[3]. Kitchen and animal waste co-digesters seems to offer promising results. Other 18 19 sources of waste materials considered as a feedstock for anaerobic digestion process are: (i) municipal 20 solid waste (MSW), (ii) agricultural animal waste, (iii) crop residues, biomass, and energy crops, and (iv) 21 waste water treatment plant sludge (WWTPS). This study focused on the co-digestion of kitchen waste 22 and cow dung.

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Co-digestion is the simultaneous digestion of more than one type of waste in the same unit ^[4]. Advantages include better digestibility, enhanced biogas production/methane yield arising from availability of additional nutrients, as well as a more efficient utilization of equipment and cost sharing ^[5]. Studies have shown that co-digestion of several substrates, for example, banana, spent grains and rice husk, pig waste and cassava peels, sewage and brewery sludge, among many others, have resulted in improved methane yield by as much as 60% compared to that obtained from single substrates ^{[6][7][8][9]}. Co-digestion of sewage sludge with agricultural wastes or MSW can improve the methane production of anaerobic digestion processes. Primary sludge is rich in anaerobic bacteria and is abundantly available nearby. This study sought to evaluate co-digestion of kitchen and primary sludge (PS) cow dung, to improve biogas yield in a laboratory - scale digester build to work at constant high pressure. Given that, kitchen waste can be found in every home, it is most suited for the supply of biogas to homesteads as compared to cow dung. With kitchen waste, even those staying in town places can still run digesters to get biogas.

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To the best of our knowledge not much work has been done to investigate the quantity and quality of biogas produced from mixing domestic kitchen waste with cow dung. Hence there is insufficient information on the outcome of co-digesting kitchen waste with cow dung. There is great need for such details to aid the house holds that want to exploit biogas energy as a way of managing waste and cutting down on energy costs.

The main objectives of this research were, to assess the energy and power potential of the biogas produced by co-digesting kitchen waste and cow dung and to establish the quantitative and qualitative analysis of Methane, Nitrogen dioxide and carbon dioxide in the biogas produced in. This study sought to evaluate co-digestion of kitchen and primary sludge (PS) cow dung, to improve biogas yield in a laboratory-scale digester built in-house by the author, to work at constant high pressure. This problem was studied experimentally. Gas chromatography was used to investigate the gas quality.

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49 2. MATERIAL AND METHODS

50 2.1 Materials

51 Samples which included cow dung slurry and biomass kitchen waste (KW) (organic fraction of the 52 household waste) were collected from the Masinde Muliro University of Science and Technology 53 (MMUST) farm and catering unit respectively. Approximately 5 kg of each fraction were collected in 54 plastic cans. The following common kitchen waste samples were collected: Fruit peelings, vegetable 55 remains, Potato peelings, raw starch, Mixture of all kitchen waste above in equal proportions, Cow dung 56 Culture and corn meal / cooked starch. The preparation of the culture took place before the experiments 57 started by collecting slurry from an already operating biogas plant on a farm at Sichirai (an estate in 58 Kakamega town along the Kakamega - Navakholo road). The kitchen waste (KW) samples were 59 prepared individually by crushing them using a fruit blander, to increase their surface area and the volume ration. Samples of the crushed KW were then taken through the evaluation of the total solid (TS) and 60 61 volatile solid (VS). The remaining samples were used as feedstock for the anaerobic digester which was 62 built by the author in-house, in the Physics Laboratory at MMUST.

The digester design chosen was the batch digester semi mixed by shaking and operated at the mesophilic temperature (25°C - 35°C). The batch digester was preferred to the continuous flow digester since we were assessing the given batch of substrate till no more gas is produced. It was also cheaper and easier to assemble and run.

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68 The experimental set up was assembled in the MMUST physics laboratory for a period of 30 days. Two parallel experiments were run concurrently. The laboratory-scale digester and a set of 21 specific 69 70 laboratory experiments for the production and determination of the methane potential of different kitchen 71 waste substrates. The 21 set ups were assessed in three different conditions. Seven were in the pure 72 state, seven were mixed with cow dung and in seven, 1M sodium hydroxide was added to create an 73 alkaline environment. The laboratory-scale digester set up was put up to assess the overall biogas 74 production from a mixture of kitchen waste and cow dung. The volume of biogas produced by each set up 75 was measured and its quality assessed. Analysis of the quality of the biogas collected was done in the 76 Maseno University Chemistry Laboratory using a gas Chromatograph machine while the gas energy 77 potential was assessed in the MMUST Physics Laboratory.

79 In the laboratory experiments the following equipment were used: Four 10 litre plastic cans for the 80 collection of the samples. One 10 litre plastic container was used as the main digester, Eight 5 litre 81 containers one was the gas holder. One 5 litre container used to hold water that offered high pressure on 82 the gas reservoir in a reversed siphon system and also used to measure volume of biogas by the 83 displacement method. Four 5 litre plastic cans for mixing the samples with cow dung, 21 - 500 ml plastic 84 bottles fitted with air tight corks, twenty 50 ml syringe for holding the gas and measuring of the gas 85 volume, rubber tubes for gas delivery, plastic tubes to be used as inlets for feedstock and outlets for the 86 digestate / slurry.

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To facilitate the experimental process, the following tools were used: Porcelain cups for drying the samples, An oven was used to dry the samples at 105°C for the calculation of the dry matter / total solids (TS) and to ash the samples at 550°C for the calculation of the volatile solids (VS), One weighing scale for measuring the mass of the samples, One gas chromatograph machine for determining the gas composition, Thermometers, One 30cm ruler, An electric iron box to provide to heat the water bath (instead of the improvised solar heater).

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The main digester was designed and built by the author in-house as shown below in fig 1. The biogas system was installed with a heating system.

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99 Figure 1: Designed Laboratory- scale biogas system with the digester in a water bath

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101 The laboratory-scale biogas system, fig 1, comprised of: the digester (1), the gas storage chamber (2), 102 the pressure sustaining chamber (3) and digester heating system (4).

103 2.2 Sample preparation

Experiments for the methane potential estimation of the samples were carried out in 500 ml plastic
 bottles. Three parallels for each sample were assessed. They were labeled as shown in table 1 as S1 –
 S7, which was further subdivided into S1a...1c, S2a...2c, S3a...3c up to S7a...7c.

S/No.	Sample label	Name of sample		
1	S ₁	Fruit peelings		
2	S ₂	vegetable remains		
3	S ₃	Potato peelings		
4	S ₄	Raw starch		
5	S ₅	Mixture of all kitchen waste		
6	S ₆	Cow dung Culture		
7	S ₇	Corn meal / cooked starch		

107Table 1:The samples used in the experiment

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109 For each of the 'a' samples, 100g of the substrate were mixed with water to a volume of 350 ml (100% v/v). For the 'b' samples, 100g of the substrate were mixed with water to a volume of 315ml (90% v/v) and 110 111 a volume of 35ml (10% v/v) of cow dung (made by mixing 5g of cow dung and water to make the mixture of 35ml) added to make the total working volume to be 350 ml. The 'c' samples were as the 'a' samples 112 with an addition of 5ml of 1 molar sodium hydroxide to create a basic environment. S_{6a} was pure cow 113 114 dung, S_{6b} clean water and S_{6c} was cow dung in a basic environment. The three parallels served as controls and corrections of the amount of biogas produced from the substrates under study. A total of 115 twenty-one bottle bio-digesters were prepared. The bio-digesters were sealed with rubber corks with 116 117 openings through them. Syringes were connected to these bottle digesters by means of glass tubes and 118 rubber tubes (see fig 2 and 3). The digesters were maintained at a room temperature and shaken 119 periodically.

To keep the ratio of the feedstock to the cow dung constant, the samples were not diluted any further to maintain the total solid (TS) and volatile solid (VS) per litre of sample .TS and VS gram/litre. The mixed sample of the feedstock and cow dung was followed for comparative reasons until day 27. The pH was held constant by adding 1M NaOH in a set of the samples.



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Figure 2: 125 The experimental set up for each sample of kitchen waste

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Figure 3: 128 The two experimental set ups on adjacent tables in the research room

129 Figure 3 shows the laboratory -scale digester, a plastic container of 10 litres connected, by means of 130 rubber tubes, to a gas reservoir (chamber 2) and then a water reservoir (chamber 3 placed in a raised position). The sludge inlet and gas outlet were connected carefully to create anaerobic environment. A 131 132 water bath (heated by an electric iron box) was used to keep the digester at a temperature range of 25°C 133 - 35°C. Cold water from the lower section of the water bath moved down to the heat source while warm 134 water rose to the water bath by Convection.

135 The figure also shows the 21 set ups that were put up to assess the biogas potential for individual kitchen waste substrates. Biogas was collected and held in 60ml syringes connected to the 500ml plastic bottle 136

137 digesters by flexible rubber tubes

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2.3 The Gas Chromatography (GC) analysis 139

A GC analysis was done using a GC machine of serial number N9235. Model 8610C (manufactured on 140 141 14th Sep, 2012). This was done in the Maseno University Chemistry Laboratory. We used nitrogen gas as our carrier gas and the rate of flow was 27ml/minute. The detectors used were Flame Ionization Detector 142 (FID) current 350 for CH₄, CO₂ and Electron Capture Detector (ECD) current 350 for NO₂. GC involves 143 144 three steps: Injection of the sample into the GC at the inlet. Separating of the sample into individual compounds which took place in the column in the oven of a gas chromatograph machine and detection of 145 146 gas constituents in the sample. As each compound entered the detector an electrical signal proportional 147 to the amount of the compound detected was generated. The signal was generally sent to a data analysis 148 system - such as Agilent Chem Station where it showed up as peaks on the chromatogram and 149 displayed on a computer display system. We have several detectors and one is chosen based on the type 150 of analysis required ^[10].

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152 2.4 Total solid (TS) and Volatile solid (VS) determination

Total solids (TS) and volatile solids (VS) were determined using standard methods ^[11]. 50g of each fresh 153

sample was put in a porcelain cup and weighed on a weighing scale. Afterwards the samples were left to 154 dry for six hours at 105±5 °C in the incubator. The dried samples were then weighed again. The dry 155

157 ,
$$TS\% = \frac{W_d}{W} \times 100$$
 (1)

158 where, W_d is Dried sample weight and W is the sample weight ^{[12] [11]}.

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160 The dried samples were placed in smaller porcelain cup and the same procedure was followed. The 161 porcelain cups were first weighed empty and then with the dried samples. Afterwards they were put in the 162 oven at 550°C and then weighed again. The volatile solids were calculated using equation 2:

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$$VS = \frac{W_c - W_i}{W_d} \times 100$$
 (2)

164 where: W_c is the Cup and the dried sample weight and W_i is the cup and incinerated sample weight ^{[12] [11]}.

165 2.5 Conversion of substrate mass to biogas

From literature we learn that the volume of biogas to be collected from a given mass of substrate can be expressed using equation 3.

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$$Volume = 0.056m^3 / kg \times m_s \times 1000l / m^3$$
, (3)

169 where, $0.056m^3/kg$ is the optimum conversion rate of kitchen waste substrates, m_s is the mass of the 170 substrate that was used in this set up and $1000l/m^3$ is the volume conversion. [13].

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172 2.6 Biogas energy

- 173 The flame was found to heat water and appreciable heat energy as calculated using equation 4:
- 174 , $E = m_c c_c \Delta \theta + m_w c_w \Delta \theta$ (4)

where '*E*' is the heat energy dissipated, ' m_c ' the mass of calorimeter, c_c (390 Jkg⁻¹K⁻¹) specific heat capacity of copper, m_w the mass of water, c_w (4200 Jkg⁻¹K⁻¹) the specific heat capacity of water and $\Delta\theta$ the change in temperature.

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179 2.7 Biogas power potential

The power potential of the biogas produced was determined by dividing the energy arrived at, in the table
4 above, by the time taken for the said heat energy to heat water. This was made possible using equation
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$$power = \frac{E}{t}$$
(5)

184 where, E is the heat energy calculated in equation 3 and t is the time taken for the energy to be 185 dissipated.

187 3. RESULTS AND DISCUSSION

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189 **3.1 The total solid and the volatile solid**

The total solid and volatile solid for the substrates under study were assessed (table 2). Cooked starch, raw starch and fruit remain presented higher percentages of volatile solids pointing at their good gas production potential. This clearly shows that mixing the primary sludge with kitchen waste rich in starch (co-digestion) was a promising biogas source. Kitchen waste is rich in nutritive value and mixing it with cow dung rich in biogas forming bacteria, gives a high gas yield as obtained in the results of the tests done on individual feedstock.

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Table 2:Assessment of the total solid and Volatile Solid in the sample substrates

Substrate	Sample	Sample	Dry	TS%	Ash weight	VS %
	ID	weight	weight		W _a (g)	
		W(g)	W _d (g)			
Fruit remains	S ₁	29.4	2.9	9.86	0.5	82.75
vegetables	S ₂	20.3	1.6	7.88	0.3	81.25
Potato peelings	S ₃	38.7	11.6	29.97	3.4	70.68
Raw starch	S ₄	11.3	9.6	84.95	1.7	82.29
A mixture of all	S ₅	20.3	6.4	31.53	1.7	73.44
substrates						
Cow dung	S ₆	20.0	4.1	20.50	3.2	78.04
Cooked starch	S ₇	21.6	8.5	39.35	1.1	87.06

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The results in tables 2 compare closely with results of other research experiments done elsewhere ^[13]. In this study, we notice that 1980g or 1.98kg of a mixture of substrate in the digester produced 32,872cm³ or 0.032872m³ of biogas. This translates to a biogas yield in cubic metres per kilogram of substrate as 0.016602m³/kg. Considering that there were experimental errors, the worked conversion rate is competitive and viable. Without errors, results obtained from equation 3 shows a conversion rate that predicts that a gas volume of 110.88 litres could have been produced from the substrate mass of 1.98kg 210 that was used.

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212 3.2 Assessment of energy and power

213 **3.2.1 The flame test**

- The gas was taken through a flame test, as shown in fig 4, to verify its ability to burn.
- 215



218 Figure 4: Biogas burning with a bright flame

The collected biogas was then used to heat water in a copper calorimeter both of known masses as shown in figure 5. The temperature change was measured using a thermometer. The results were tabulated and the energy dissipated calculated using equation 4. It was clear that the gas produced in the digester contained methane which is a fuel since it burned with a bright flame.



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Figure 5: Biogas is used to heat water in a copper calorimeter

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228 3.2.2 Energy calculation for the biogas produced

The combustion of pure methane produces a blue flame and a great amount of heat. One cubic meter of biogas, produces 6-7 hours of 60 watt and can cook 3 meals or Generate 1.25 kW electricity ^[14].Water and a copper calorimeter of known masses were heated and the temperature change measured using a thermometer, see fig 5. Using equation 4 the energy dissipated was determined and tabulated in table 3 below.

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Table 3:Energy and power rating of the biogas collected on burning

	Volume	Masses of		Heat energy	Time	Power
	of gas	water and	Change in	E(J) gained by	taken	dissipated
	used	calorimeter		water and	t(s)	P (watts)
	(cm ³)	(g)	ΔΤ(C)	calorimeter		
Calorimeter		47.3				
4 + 4	1570	44.4	45	0000 00	150.00	10.70
test	1573	41.1	15	2866.00	153.26	18.70
test 2	553.8	33.0	8	1256.37	63.31	19.84
test 3	398.7	33.0	6	942.28	52.17	18.06
Average power				18.86		

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249 **3.2.3 Calculation of the power potential**

An average power of 18.87 W realized for an average volume of 840cm³ of the gas burned as shown in table 4 worked using equation 5. In this study it was assumed that no heat was lost to the environment. However, the actual value for the power generated in ideal conditions is more than what was realized in this study. Working out the power potential of 1m³ of biogas we get an estimate value as shown in the calculation below. Equation 6 (a), (b), (c) and (d) is an interpretation of the power potential (equation 5) of biogas collected per unit volume

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Power =
$$\frac{18.86789W}{840cm^3} \times 1000cm^3$$

Power = 22.46177W / Litre.
or ,(6 a, b, c, d)
power = $\frac{22.46177W}{1litre} \times 1000litres / m^3$
Power = 22,461.77W / m³

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where, 840cm³ is the average volume of the gas that was used in the energy evaluation tests.

Comparing this with the LPG gas used for cooking which is predominantly butane, we note that 25m³ of biogas gives the same energy as 10m³ of LPG gas. Meaning that, taking the ratio of the fuel value of LPG to the fuel value of pure methane, we get 5:2 ^[15]. The said amount of biogas can be produced daily from 40kg of kitchen waste. ^[16]. 1m³ of methane generates 37,258.9J of energy when pure ^[15]. This converts to 37,258.9W/m³. In this study, the results point at a power rating of 22,461.77W/m³ translating to 60.29% of the expected power rating of pure methane. This proves that only 60.29% of the biogas collected is methane. The rest of the gas is carbon dioxide and trace gases.

269 **3.3 Analysis of biogas by Gas Chromatograph**

Chromatography is the separation of a mixture of compounds into individual compounds ^[10]. Gas Chromatography (GC or GLC) is a commonly used analytic technique in many research and industrial laboratories for quality control as well as identification of compounds in a mixture. GC is also a frequently used technique in many environmental and forensic laboratories because it allows for the detection of very small quantities. A broad variety of samples can be analyzed as long as the compounds are sufficiently thermally stable and reasonably volatile.

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Figure 6: (a) The gas Chromatograph machine connected to a display computer (b) Gas being injected into the GC system (c) GC system connected to a display computer

281 3.3.1 Gas chromatography Analysis of Extracted Biogas

Biogas samples from selected substrates were studied to establish the chemical constituents of the collected gas. This was done using a gas chromatograph machine shown in fig 6 (a), (b) and (c) The gas samples were stored using syringes with tightly fitted rubber tubes and clips to prevent the gas from escaping. Fig7 shows the syringes holding stored biogas.





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289Figure 7:Biogas stored in Syringes ready for testing

290 **3.3.2 Qualitative analysis of biogas samples using Retention Times**

291 Using the gas chromatograph, the gas samples were taken through separation process subject to retention times to establish methane prevalence and other gases. Gas chromatography is known to be 292 the optimal analytical tool for quantifying the components of biogas including methane, carbon dioxide, hydrogen sulfide, nitrogen dioxide and siloxanes ^[17]. Baseline separation of Methane, CO₂ and NO₂ gas 293 294 295 were obtained and their retention times tabulated as shown in Tables 4 and Fig 8(a), for the selected samples. From Table 4 and Fig 8(a) it was possible to use the standards as the marker compounds, 296 297 hence detect the presence of the main gases. The gases were separated based on the different strengths 298 of interaction with the stationary phase ("like-dissolves-like"-rule). Methane interacted fairly faster after 299 NO₂ due to its less polarity as compared to CO₂.

Table 4:

This enabled us to confirm the existence of the methane in the biogas samples obtained from kitchen waste. Literature has established GC analysis as immediate tool in analyzing the above in waste, however, less has been done on mixtures of cow dung and kitchen wastes. This is a confirmation of the isolation of methane that has been detected previously from waste material as the main compound ^[18].

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Retention Amount Retention time Retention time Sample ID time (min) Unit injected (min) CH₄ (min) CO₂ NO₂ Std (carrier 5ml 1.756 3.456 2.733 ppm gas) 3.473 2.743 S1c 5ml 1.766 ppm 1.756 2.733 S4a 5ml 3.463 ppm S5b 1.766 3.473 2.743 5ml ppm S6a 5ml 1.733 3.463 2.733 ppm 1.79 2.730 S7a 5ml 3.46 ppm

Retention time for Methane CH₄, Nitrogen dioxide NO₂ and Carbon dioxide CO₂

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Figure 8: (a) Comparison of Retention time and (b) peak height for the tested gas samples

311 **3.3.3 Quantitative analysis of Biogas samples using peak areas**

To establish the percentage constituents in the biogas samples tested, peak areas of the gas profiles 312 313 were used as shown in table 5 and fig 9. It is clear that the gas samples collected from S_6 (cow dung) and 314 S_7 (cooked starch) had a higher percentage of methane as compared to the other samples. Similar results were established by Harold, 2007, when he tested biogas samples from cow dung and energy 315 crops such as corn which have a high percentage of starch. The biogas from cow dung is known to contain 65% methane and the cooked starch releases 62% ^[18]. S₆ had a higher peak area of 7738.2116 316 317 ppm out of the 5ml of the gas tested comprising of CO₂ as shown in table 5 and fig 9. However, it also 318 319 had the highest peak area (53250.4331 ppm) for methane, an indication that the sample had more 320 nutrients needed by the microbes for the production of methane.

The other samples that were tested had significant amounts of methane though the amount of carbon dioxide collected was notably large. This indicates that though the samples could be good candidates for biogas production, precautions need to be taken to eliminate large amounts of CO_2 . In the previous investigations, this elimination was done using Absorption and Adsorption^[19]. Biogas consists principally of methane and carbon dioxide but can also contain small amounts of a wide range of other compounds including NO_2 ^{[20] [18]}. Some of them don't contribute to the energy content, and may be corrosive, poisonous or be responsive for releasing bad smells in the neighbourhood or during the burning process.

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Table 5: Peak area for Methane CH₄, Nitrogen dioxide NO₂ and Carbon dioxide CO₂

Peak Peak Peak area CO₂ Sample Amount area CH₄ area NO₂ % of % of % of Totals ID injected (ppm) (ppm) (ppm) CH₄ NO₂ CO_2 Std 5ml 36.2154 801.9786 3628.455 4466.649 0.811 17.95 81.23 $S_{1c} \\$ 5ml 50.3645 1100.93 6861.205 8012.499 0.629 13.74 85.63 S_{4a} 5ml 44.2785 947.9118 5550.316 6542.506 0.677 14.49 84.83 951.4714 5353.829 S_{5b} 5ml 1190.59 7495.893 15.88 12.69 71.42 S_{6a} 5ml 53250.4 952.0428 7738.212 61940.69 85.97 1.537 12.49 S_{7a} 5ml 32618.3 939.2674 4770.065 38327.6 85.1 2.451 12.45

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Knowledge about biogas content is thus valuable, to establish the extent of pollution to the environment and give precautions ^[17]. There are minimal amounts of CO_2 and NO_2 in S_{6a} and S_{7a} as shown in figure 10. This advantages the use of biogas from the two sources, with high prevalence of methane (85.97% and 85.1%, respectively).

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340 **Figure 9**:

Peak area for the gas samples collected

341342 4. CONCLUSION

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The study has shown that 1.98kg of kitchen waste mixed with cow dung produced 0.032872m³ of biogas. 344 345 At a conversion rate of 0.056m3/kg we see a prediction of a gas volume of 110.88 litres (from the mass 346 of substrate digested) could be generated in a more efficient digester. The power potential of the biogas produced by co-digesting kitchen waste and cow dung was assessed. It was found to be 347 22,461.77W/m³. From literature it is established that pure methane has a power potential of 348 349 37,258.9W/m³. These points at the methane percentage in the biogas collected in this study to be 350 60.29%. From the chromatograph peak area results of this study, we see that of the tested kitchen 351 waste, the following had the highest methane content: raw starch (S_{5a}) 15.88%, pure cow dung (S_{6a}) 352 85.97% and cooked starch (S_{7a}) 85.1%. The study has demonstrated that the various food wastes in the kitchen have a great biogas potential and can be exploited for both domestic and even commercial use 353 354 especially when co-digested with cow dung. The study has revealed vital details that will guide in the 355 establishment of an eco-friendly biogas system that each household will want to put in place for the 356 supply of the much needed clean and affordable energy.

357 358 **CONSENT**

359 Not applicable

360361 ETHICAL APPROVAL

362 No ethical considerations were made. There were no animals used in the laboratory work

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415	DEFINI	TIONS, ACRONYMS, ABBREVIATIONS			
416	MMUST	MasindeMuliro University of Science and Technology			
417	AD	Anaerobic Digestion			
418	FID	Flame Ionization Detector			
419	ECD	Electron Capture Detector			
420	GC	Gas Chromatography			
421	WWIP	Waste water treatment plant			
422	15	I OTAL SOLIDS (% Of Wet weight			
423	vS	volatile solids (% of total solids or % of wet weight)			
424 495		אות			
420	AFFEN				



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Fig-10

The setup of the laboratory scale biogas digester system