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Biogas Production From Biomass Kitchen Waste Laced With Cow Dung In A Modified Laboratory - Scale Anaerobic Digester

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ABSTRACT

Anaerobic digestion is an effective method for organic pollution reduction and bio-energy production and has increasing applications worldwide. Produced biogas consists mainly of 50–70% methane and 30–50% carbon dioxide. The most common utilization route of biogas is for electricity production, often combined with utilization of the excess heat. This widens up the opportunities to utilize biogas in distant energy consumption locations. The study sort to design, build a laboratory-scale biogas digester and test and optimize the gas production from different types of organic kitchen wastes. Biomass Kitchen waste was collected, as feedstock for a laboratory-scale anaerobic digester (10L capacity) to produce biogas. This was done within a temperature range of 25°C - 35°C and in an alkaline environment maintained by adding a medium of sodium hydroxide. It was set to operate at constant gas pressure. The study has shown that using the displacement of water method in an inverted siphon system, we can sustain high pressure of the stored gas. The same idea can be used to pump this biogas to places far away from the digester for consumption. The biogas produced was then analyzed for its energy potential. The power potential of biogas produced by co-digesting kitchen waste and cow dung was found to be 22,461.77W/m^3. Pure methane has a power potential of 37,258.9W/m^3. Therefore, the methane percentage in the biogas collected in this study was 60.29%. The gas was also taken through gas chromatography to assess its constituents. Cow dung and starch were found to produce a higher percentage of methane. 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 has great domestic and commercial application if exploited.

INTRODUCTION

Kenya's economy mainly depends on the energy resources available. With the advent of the industrial revolution, the use of fossil fuels has been growing and to date, the sources are being depleted. Dependence on this fossil fuel as a primary source of energy has led to global climate change due to the pollution of the environment hence causing human health problems (Budiyano, Widiasa Johari & Sunarso, 2010). With increasing prices of oil and gas, the world looks towards alternative green energy resources. Anaerobic digestion (AD) of biomass to produce biogas offers a very 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 (House & Eng, 2007). AD can successfully treat the organic fraction of biomass (Hill, 1983). Kitchen and animal waste co-digesters seems to offer promising results. Other sources of waste materials considered as a feedstock for anaerobic digestion process are municipal solid wastes (MSW), agricultural animal waste, crop residues, biomass, and energy crops, and wastewater treatment plant sludge (WWTPS).

This study focused on the co-digestion of kitchen waste and cow dung. Co-digestion is the simultaneous digestion of more than one type of waste in the same unit (Nnabuchi et al., 2012). Advantages include better digestibility, enhanced biogas production/methane yield arising from the availability of additional nutrients, as well as more efficient utilization of equipment and cost-sharing (Mshandete & Parawira, 2009). 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 (Ezekoye & Okeke, 2006; Ilori et al., 2007; Adeyanju, 2008; Babel, Sae-Tang & Pecharaply, 2009). Co-digestion of sewage sludge with agricultural wastes or MSW can improve the methane production of anaerobic digestion processes (Georgiadis, 2013). 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. Fixed dome biogas digesters have experienced challenges of fluctuating gas pressure, which poses an even bigger problem of cracks in the walls of the plant hence lowering the efficiency of the plant. Leakages through the cracks are also a great contributor to the failure of some of the plants hence causing an average loss of Ksh. 250,000, the cost of constructing a fixed dome digester of volume 24 m^3, as confirmed by several local masons. This study aimed at designing and building a laboratory-scale anaerobic digester to operate at constant high-pressure cost-effectively and to evaluate the quality and quantity of biogas produced from the co-digestion of organic kitchen waste (OKW) and primary sludge (PS) cow dung, to improve biogas yield. Modifying the system to use water in an inverted siphon system in plastic containers does not only solve the challenge of fluctuating digester pressure but also saves the user the problem of reduced efficiency, due to cracks at a cost lower than half the cost of the traditional fixed dome digesters.

The study sort to design and build a mini-scale biogas digester operated at constant high pressure and test and optimize the biogas production from different types of kitchen wastes as compared with that produced from cow dung. We also assessed the energy and power potential of the biogas produced by co digesting kitchen waste and cow dung.

Figure 1: The setup of the actual laboratory-scale biogas digester designed and built in house by the author

EXPERIMENTAL DESIGN AND PROCESS

Digester Design

Figure1 shows the digester, a plastic container of 10 litres. The sludge inlet and gas outlet were connected carefully so that the digester could not let in air. A water bath was used to keep the digester at a temperature range of 25ºC - 35ºC. The water bath was heated by an improvised electric heater system in which an electric iron box was used to heat water flowing through a coiled copper tube. Other cheap heat sources such as solar energy can be used as well. Heating was meant to provide the optimum temperature for the survival of the mesophilic Bacteria for optimum and fast gas production (Gerardi, 2003).

Figure 1 above shows that the gas holding chamber operated by the displacement method. It was initially filled with water before connecting it using a flexible rubber tube to the digester. An outlet rubber tube was also put in place to let the displaced water out of chamber 2 (the gas reservoir) to chamber 3 (the water reservoir) which held the displaced water. The gasholder and the digester were at the same level while the water reservoir was at a raised point to offer the much-needed pressure on the gas in chamber 2. More gas into chamber 2 displaced water to chamber 3.

Preparation and Incubation of Samples

The desired ratio (90% sample, 10% cow dung) was achieved in a total mixture of 1980g. 300g of each sample (see table 1) were placed in the main digester making a total of 1800g. 180g of cow dung was added and then water to make a substrate mixture of 7000ml. 10ml of 1M Sodium Hydroxide (NaOH) was added to create a slightly alkaline environment that favours the survival of mesophilic bacteria, responsible for methane production. Intense mixing of the substrate mixture was done in order to achieve a homogeneous mixture.

Table 1: The samples used in the experiment

Sample label	Name of sample
S_1	Fruit peelings
S_2	vegetable remains
S_3	Potato peelings
S_4	Raw starch
S_5	Mixture of all kitchen waste
S_6	Cow dung Culture
S_7	Cornmeal / cooked starch

Biogas Energy and Power Potential

A flame test was carried out on the gas collected. The heat energy dissipated was calculated using

equation 1: $E = m_c c_c \Delta\theta + m_w c_w \Delta\theta$

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

The power potential of the biogas produced was determined by dividing the energy arrived at, in *table 3* by the time taken for the said heat energy to heat water. This was made possible using

equation 2: $power = \frac{E}{t}$,

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

RESULTS AND DISCUSSIONS

Overview

The objective of this study was to build a laboratory-scale biogas digester system for kitchen waste at constant gas pressure. To realize this objective, the laboratory-scale biogas digester was built in-house by the author from plastic containers and flexible rubber tubes as shown in *Figure 1* above. The gas in the reservoir (chamber 2) was kept at high pressure by means of a reversed siphon system by connecting it to (Chamber 3) a container in which the displaced water from the gas reservoir was collected. This container was placed in a raised position so that the water column in this position exerted pressure on the gas in the gas reservoir. The water collected in the water reservoir also helped determine the volume of the gas produced in the digester. Given that the water reservoir had a uniform cross-section area, any change in the height of the water level was proportional to the change in the gas volume

The Digester

Figure 1 shows a 10-litre container used as a digester. It held the substrate the entire period of the experiment. The digester was made airtight to provide anaerobic conditions and was placed in a water bath maintained within a temperature range of 25ºC – 35ºC**.** This temperature range is optimum for the survival of the methanogenic bacteria necessary for methane production (Rise-At, 1998). The black digester was chosen to allow for effective absorption of heat from the water bath. To achieve airtight conditions in the digester and the gas reservoir, the tubes were fitted tightly and waterproof glue used at all joints.

The Water Reservoir

This is a 5-litre container connected to the biogas reservoir section by means of a flexible delivery tube full of water to play the role of a reversed siphon system.

Figure 2: Setup showing the height 'h' that sustains high pressure in the biogas reservoir

Displaced water from the gas reservoir was collected in this container due to the increasing pressure of the gas. *Figure 2* shows that the water in the raised container kept the gas in the gas reservoir at high pressure. The difference in the water levels in the two containers 'h' builds up a high gas pressure given by *equation 3* $p_g = h\rho g$

where p_g is the gas pressure, h the height difference in the water levels in the gas reservoir and the water reservoir, $\rho = 1000\ kg/m^3$ the density of freshwater and $g = 10\ N/kg$ is the gravitational field strength. If the raised container was placed at the same level as the gas reservoir, more water flowed back to the water reservoir. See the results in *table 2*. Using *equation 3*, the height of water in the water reservoir, the pressure of the gas in the biogas reservoir can be determined.

Determination of the Volume of Biogas Produced

The ruler was mounted on the container as shown in *Figure 2*, helped determine the volume of the gas collected in the gas reservoir. Biogas collected in the gas reservoir (chamber 2), displaced water equal to its own volume into the water reservoir (chamber 3). The volume of water hence that of the gas that displaced the water was obtained by *equation 4* $V = A \times h_w$ where, *V* is the water volume equal to the gas volume, *A* the cross-section area of the water reservoir and h_w the height of water in the water reservoir.

From *Table 2* we see that for the first three days, no gas was collected. In this period, the population of bacteria in the substrate is still building up. A sample of biogas was realized on the 4th day. The performance improved and was at the peak on the 14th day when over 8000 cm^3 of biogas was collected as shown in table 2 and *figure 3 (d).* At this point, bacteria are at optimal population showing a rapid action on the food substrates and giving larger volumes of biogas; gas production then dropped drastically since no new feed stalk was added to the digester.

Table 2: The results of the collected biogas volume and pressure

	Time (Days)																	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Height of displaced water (cm)	0	0	0	0.5	2	4.2	10	23.1	34.9	45.2	51	65.8	92.7	130.5	144.9	147.4	147.6	148
Height of water displaced (cm) in raised position	0	0	0	0.3	1.7	3.8	9.2	20.4	31.2	40.2	45.9	58.7	81.7	117.9	130.8	133.3	133.4	133.6
Daily volume of biogas collected (cm^3)	0	0	0	110.8	443	930.3	2215	5117	7730	1001	1129	1457	2053	2890	3209	3264	3269	3278
Changes in height (cm) of water displaced	0	0	0	0.2	0.3	0.4	0.8	2.7	3.7	5	5.1	7.1	11	12.6	14.1	14.1	14.2	14.4
Daily changes in the gas pressure (N/m^2)	0	0	0	20	30	40	80	270	370	500	510	710	1100	1260	1410	1410	1420	1440

Figure 3a: Comparison of the Height of Displaced Water

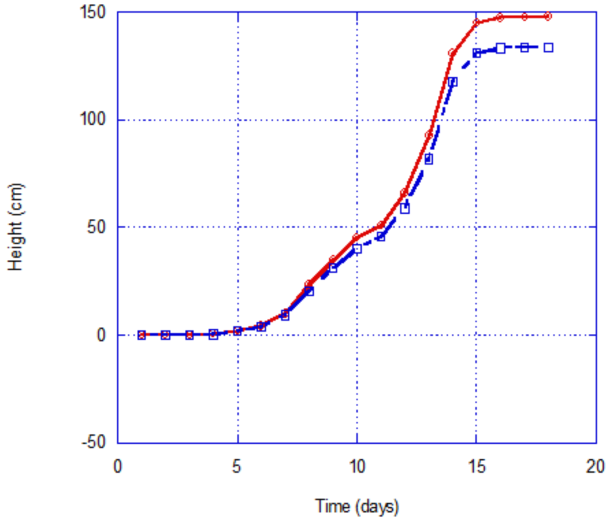


Figure 3(a) shows the variation in the height of displaced water when the water reservoir (chamber 3) is in a raised position (the blue graph) and when at the same level with the gas reservoir (the red graph).

Figure 3b: Cumulative Biogas Volume

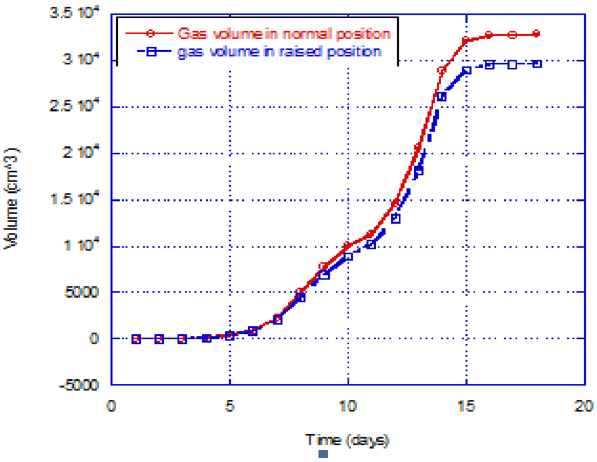


Figure 3(b) represents the daily cumulative volume. A large population of bacteria exhausted the nutrients in the substrate causing a drop in the biogas production and

Figure 3c: Cumulative Biogas Pressure

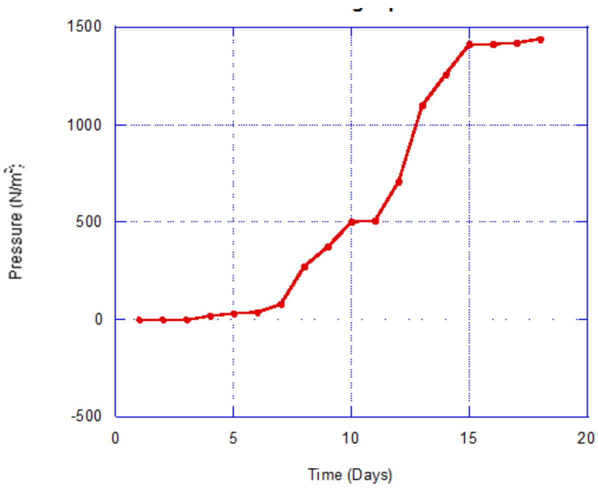


Figure 3(c) analyses the daily changes in the biogas pressure.

Figure 3d: Daily Changes in the Height of Displaced Water

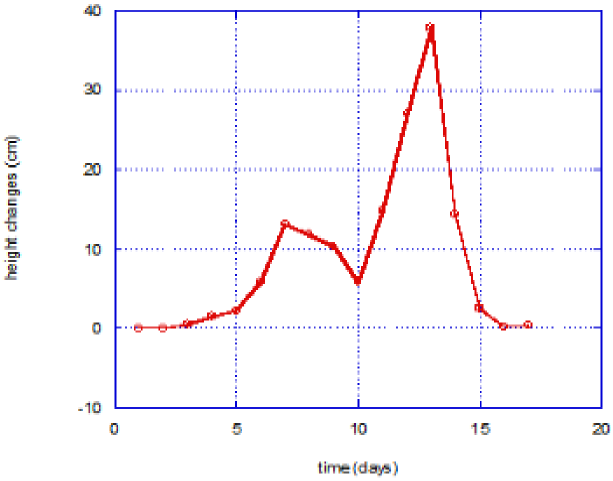


Figure 3(d) shows the daily changes in the height/volume of displaced water. On the 18th day, no further changes in the gas volume were observed. The daily changes in the biogas volume took the same nature of *figure 3(d)*. The figure shows that maximum biogas was produced on the 14th day when 8372.7cm^3 was collected.

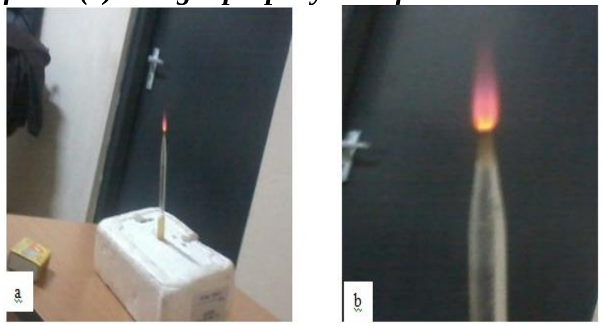
Figure 4: Height h_{w1} of displaced water with the water reservoir in a raised position

Testing for the Presence of Methane in the Gas Sample

The Flame Test

The gas collected in this study was taken through a flame test. *Figures 5* verify that the gas contained methane since it burned. The gas lit and burned with a bright flame. The gas was made to burn continuously by means of a siphon system between the water reservoir, placed at a raised position and the gas reservoir. Water moved back into the gas reservoir displacing biogas and forcing it out through the burner. A steady bright flame was observed.

Figure 5: (a) the gas burns in a bright steady flame (b) a bright purple-yellow flame



Energy and Power Potential

The collected biogas was then used to heat water in a copper calorimeter both of known masses. The temperature change was measured using a thermometer. Using *equation 1* the energy dissipated was determined and tabulated in *table 3*. An average power of 18.87 W realized for an average volume of 840 cm^3 of the gas burned (see results in *table 3*) which was worked using *equation 5*. 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 watts and can cook 3 meals or generate 1.25 kW electricity (Beth & Nate, 2008). 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 1m^3 of biogas we get an estimated value as shown in the calculation below. *Equation 5* is an interpretation of the power potential (equation 2) of biogas collected per unit volume

$$\text{Power } = \frac{18.86789W}{840cm^3} \times 1000cm^3 \rightleftarrows = 22.46177W/Litre.$$

$$power = \frac{22.46177W}{1litre} \times 1000litres/m^3 = 22{,}461.77W/m^3$$

Where 840 cm^3 is the average volume of the gas that was used in the energy evaluation tests.

Table 3: Energy and power potential of the biogas collected

	Volume of gas used (cm^3)	Mass (g)	ΔT(ºC)	E(j)	t(s)	P(watts)
Calorimeter		47.3	15	276.7		
Test 1	1573.0	41.1	15	2866.0	153.26	18.70
Test 2	553.8	33	8	1256.4	63.31	19.84
Test 3	398.7	33	6	942.3	52.17	18.06
Average		**35.7 ± 0.5**	**9.7 ± 0.5**		**89.58± 0.005**	**18.86± 1**

Comparing this with the LPG gas used for cooking which is predominantly butane, we note that 25 m^3 of biogas gives the same energy as 10 m^3 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 (Balat & Balat, 2009). The said amount of biogas can be produced daily from 40 Kg of kitchen waste (Ananthakrishnan, 2013). 1m^3 of methane generates 37,258.9J of energy when pure (Balat & Balat, 2009). This converts to 37,258.9W/m^3. In this study, the results point at a power rating of 22,461.77W/m^3 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.

A Sample of the collected biogas was also taken through gas chromatography to verify the amount of methane and other gases it constituted. Details can be found in our earlier paper (Andati et al., 2017).

CONCLUSION

In this study, the laboratory-scale anaerobic digester was built to work at high pressure, giving a possible solution to the low-pressure challenge of the batch digesters. The power potential for the biogas collected was found to be 22,461.77W/m^3. Comparing this with the Literature value of 37,258.9W/m^3 for pure methane, we found that 60.29% of the biogas sample tested was methane. Biogas production significantly increased when we allowed for co-digestion of kitchen waste with cow dung. A reasonably high biogas yield was realized in the samples maintained in the alkaline environment. This study forms a basis upon which large scale biogas production from kitchen waste can be done for domestic and commercial use.

FUTURE WORK

Based on the research conducted in this study, it is suggested that further analysis be conducted to evaluate the effects of different input materials on the characteristics of biogas. Further analysis of the input materials may uncover new trends related to biogas production efficiency and constituent quality. We suggest that more food substrates mixed with cow dung be studied to get an assortment of substrates that can give a higher yield of biogas. More studies need to be done to refine the gas produced so that it can be used to run engines for the production of electricity and or to power motor vehicles. Waste management in Kakamega county in collaboration with Masinde Muliro University of Science and Technology researchers should consider developing a process of capturing landfill methane and converting it to fuel for its trucks.

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