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Evaluation of sugarcane vinasse and maize stalks for anaerobic digestion

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ABSTRACT: Sugar cane vinasse and maize stalks waste disposal poses serious challenges to the environment. However, anaerobic digestion is an attractive treatment method for these wastes. The current study therefore established the suitability of theses wastes for anaerobic digestion. Specifically, the study aimed at characterizing the substrates and anaerobic digestion of the substrates. The raw materials were collected from Muhoroni Sugar Company and Uasin-Gishu county maize farms, respectively. The pH, moisture content, chemical oxygen demand (COD), total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), total organic carbon (TOC), nitrogen content, and CN ratio were determined based on standard methods. Experiment setups were run depending on batch experiment. The study established that the pH, moisture content, COD,TS, TSS, TDS, TOC, and nitrogen content for vinasse were 4.34, 93.91%, 71.28g/L, 7.05%, 6.04%, 1.01%, 2.23 g/L, and 0.27g/L, respectively. For the maize stalks, the pH, moisture content, TS, TSS, TDS, TOC, and nitrogen content were 7.52, 9.52%, 91.50%, 90.12%, 7.38%, 49.51g/kg, and 1.28g/kg, respectively. The cumulative biogas yield for sugarcane vinasse and maize stalks were 329mL and 385 mL, respectively. In conclusion, this study found that the characteristics of vinasse and maize stalks are suitable for biogas production.

1 INTRODUCTION

High oil prices, increasing population, industrialization, and the decline in energy security have all led to an increase in global interest in biofuels. However, studies on biomass availability have concluded that by 2050, the possible contribution of biomass to global energy supply could vary from 100 EJ/year to 400 EJ/year, which represents 21%–85% of the world‘s current total energy consumption, estimated at 470 EJ.Although biofuels are only a fraction of total biomass, biofuels still have the potential to play a significant role in meeting future global energy demand, if developed through the appropriate channels (Bailis et al. 2015).

Furthermore, the disposal of some biomass waste has proved to be a problem in developing countries. The disposal of vinasse and maize stalks in Kenya poses serious challenges to the environment. Iqbal (2016) stated that vinasse has a dark colour, the concentration of total solid and COD value are very high, and the pH condition of vinasse is 3.25-4.97, while the total solid (TS) value in vinasse is 63,000–79,000 mg/L. If vinasse is discharged directly into the rivers without treatment, water biota will be killed. Dissolved oxygen in the rivers is used by oxidation bacteria to degrade COD and BOD, hence the availability of dissolved oxygen is depleted, so the water biota cannot breath and finally die (Summardiono et al. 2013). The same applies for maize stalks. Here in Uasin-Gishu county maize stalks are abundant since they are left in the farms and even sometimes burned. These disposal methods of maize stalks cause harm to the environment.

Attempts have been made to establish ways to dispose of vinasse with minimum negative effect on the environment. Iqbal (2016) in his review further supported and concluded that it is more effective to degrade organic materials through anaerobic digestion than aerobic treatment. He further stated that anaerobic digestion is a viable option for sugarcane vinasse processing and enables energy recovery as biogas production.Studies have established that maize stalks could be used as a raw material for anaerobic fermentation (Adebayo et al. 2014; Bruni 2010; Zhong et al. 2011). A pretreatment process is required to decompose cellulose to reduce the volume of material and increase production of biogas (Antognoni et al. 2013).

Based on these facts and problems associated with disposal of these wastes, this study evaluated the potential of these wastes (vinasse and maize stalks) as substrates for co-digestion. Co-digestion is the simultaneous digestion of a homogenous mixture of two or more substrates. The most common situation is when a major amount of a main basic substrate (such as manure or sewage sludge) is mixed and digested together with minor amounts of a single, or a variety of additional substrates.

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2 LITREATURE REVIEW

2.1 *Biogas*

High oil prices, increasing population, industrialization, and the decline in energy security have all led to an increase in global interest in biofuels. However, despite this growth, the global market for biofuels is still in its infancy. The future global potential for biofuel production is also difficult to estimate, due to a number of factors including the limits of natural resources and the need for food security above biofuel use. However, studies on biomass availability have concluded that by 2050, the possible contribution of biomass to global energy supply could vary from 100 EJ/year to 400 EJ/year, which represents 21%–85% of the world's current total energy consumption, estimated at 470 EJ.Although biofuels are only a fraction of total biomass, biofuels still have the potential to play a significant role in meeting future global energy demand, if developed through appropriate channels (Bailis et al 2015).

Many developing countries are faced with the dilemma of finding alternative energy sources with reduced environmental impact. Wind energy, hydro, solar, and biofuels energy sources are potential solutions. According to Earley et al. (2015), global ethanol and biodiesel production increased from about 4.8 billion gallons in 2000 to about 21 billion gallons in 2008. The goal of replacing fossil fuels with biofuels has resulted in a high production of ethanol (Gil 2011).

Ethanol is a prominent biofuel because of its advantages; however, there is a challenge in disposing of vinasse, which is the effluent from the distillation columns of ethanol industries (Wilkie et al. 2000). It is said that for each litre of ethanol produced, between 0.8 and 3.0 litres of vinasse are obtained (Asocaña 2011). Vinasse has a dark colour and a low pH (Iqbal S. 2016). The concentration of total solid and COD value are very high. The pH condition of vinasse is 3.25–4.97, while the total solid (TS) value in vinasse is 63,000–79,000 mg/L (Iqbal S. 2016). Budiyonoet al.(2014) reported that vinasse contains COD content of 299,250 mg/L. Wilkie et al.(2000) further stated that vinasse is an organic liquid residue comprising about 93% water, 5% organic matter mainly unfermented sugars and other carbohydrates, and about 2%inorganic dissolved solids. Vinasse contains many kinds of organic compounds, such as acetic acids, lactic acids, glycerol, phenols, polyphenols, and melanoidins (Budiyono et al. 2014).

Vinasse is wastewater that is a by-product of distillation from the production of ethanol by fermentation. Besides containing high COD, vinasse has a strongly acidic character (pH 3.67–4.98) (Lutoslawski et al. 2011; Siles et al. 2011). Vinasse characteristics pose serious challenges to the environment in terms of disposal. The strongly acidic pH of vinasse causes the remobilization of heavy metals in soil (Kafle et al. 2012). The dark colour in vinasse is not good for the environment, being unsightly. Besides that, it also can hamper penetration of sunlight into the rivers, so water plants cannot photosynthesise (Iqbal S. 2016). Soluble salts in vinasse can cause soil salinity and sodicity. It can cause poor soil structure and reduce fertility. Vlyssideset al. (1997) stated that high concentration of P and N nutrients cause eutrophication in water bodies. The temperature of fresh vinasse from a distillation unit is 65–105°C. If vinasse is disposed of in water bodies, without cooling, the temperature of water bodies can increase. It can also disturb fish activity (Siles et al. 2011).

Attempts have been made to establish ways to dispose of vinasse with a minimum negative effect on the environment. In Brazil, vinasse is applied directly to the soil because of its organic matter and nutrient content; potassium, nitrogen and phosphorus make it a good organic fertilizer for sugarcane farms (Ferraz et al. 2015).From an economic perspective, the soil application of vinasse represents the simplest and cheapest solution. However, continuous application of vinasse to the soil results in soil and groundwater contamination, leaching and salinization, and seed germination inhibition (Ferraz et al. 2015).Dávila et al. (2009) evaluated the electro-flotation/oxidation process for vinasse, obtaining reductions in COD of 58%. Similarly, Yavuz (2007) achieved a 90% reduction in total organic carbon in vinasse through electro-coagulation with the use of a supporting electrolyte and the gradual addition of hydrogen peroxide. Goncalves (2006) performed research for the treatment of the vinasse by utilizing coagulation and flocculation. The study evaluated several variables influencing COD removal which was used to develop a model. The model demonstrated that the COD removal varied as a function of the pH and mixing. The best results were achieved when calcium oxide and ferrous sulfate were used, with pH values of 12.4 the removal efficiencies were 52% and 44%, respectively. The study established that the resulting sludge could be used as a fertilizer because it was rich in nutrient content. The major challenge in utilizing sludge as organic fertilizer from vinasse is the high pH of 12.4 which causes soil pollution. Tang et al (2007) and Íñiguez-Covarrubias and Peraza-Luna (2007) found that biological treatment such as active sludge is expensive and it produces poison. According to Satyawali et al. (2007), anaerobic treatment is the most attractive primary treatment of vinasse due to the BOD and COD removal being over 80%, and the energy recovery in the form of biogas. Ribas (2006) stated that the anaerobic reactors are a promising alternative because they accomplish a high rate of organic load removal and produce biogas. Iqbal (2016) in his review concluded that it is more effective to degrade organic materials through anaerobic digestion than aerobic treatment. However, the value of COD removal is not maximal. That is caused bythe presence of phenolic compounds in vinasse. He further stated that anaerobic digestion is a viable option for sugarcane vinasse processing and enables energy recovery as biogas production. To further support and minimize these challenges, the current study will digest vinasse.Wilkie et al (2000) also stated that anaerobic treatment can reduce organic matter to biogas that can be used for heating for an evaporation and distillation unit or can be saved for aerobic–anaerobic treatment.

Studies have established that maize stalks could be used as raw material for anaerobic fermentation (Adebayo et al. 2014; Bruni 2010; Zhong et al. 2011). A pretreatment process is required to decompose cellulose to reduce the volume of material and increase the production of biogas (Antognoni et al. 2013). In Uasin-Gishu county maize stalks are abundant since they are left in the farms and even sometimes burned. These practices cause harm to the environment. When the maize stalks are left or burnt they cause air pollution. The current study will also digest maize stalks.

3 MATERIALS AND METHODS

The test substrates consisted of maize stalks and sugarcane vinasse. Maize stalks was collected from the farms in Uasin-Gishu County (Indany Kipsum farm) during harvesting season and dried. The maize stalks samples were milled and dried at ambient conditions to average equilibrium moisture content of 10% (±1.5).

The vinasse was obtained from Muhoroni Sugar Company, ethanol plant, collected in 20 litre plastic containers and transported to the laboratory.

Table 1. Materials, reagents, and apparatus.

Raw materials	Reagents	Equipment/apparatus	
			Model
Maize	Sodium	Weighing balance –	Ohaus-
stalks	hydroxide	Digital	Scout Pro
Sugarcane	Calcium	Milling machine	Alfa
Vinasse	hydroxide	Digital pH meter	Machines
	Hydrochloric	Thermo balance	HANNA
	acid	Beaker	(HI9812)
	Distilled water	Clamps	HANNA
	$(NH_4)_2SO_4$	Measuring	
	Copper sulfate	cylinders	
	Potassium	Thermometer	
	dichromate	Conical Flask	
	solution	Gas deliveryr tubes	
	$(K_2Cr_2O_7)$	Water bath	
	Silver	Kjeldahlr apparatus	Beckman
	sulfate	& condenser	DU640
	(Ag_2SO_4)	UV-Vis	AGRIPRO
	$HgSO_4$	Spectrometer	605
	Iron sulfate	Moisture analyser	HANNA
	heptahydrate	Photometer	(HI83300)
	Potassium	COD reactor	HANNA
	sulfate		(HI839800)

3.1 *Determination of pH of the substrates*

The pH of vinasse was measured using a Hanna pH-meter directly. The maize stalks were sun-dried for 15 days, and then milled and sieved to obtain different substrate particle sizes: 0.5 mm, 1 mm, and 2 mm (Elely et al. 2018). 5g of crushed (1mm) maize stalks was placed in a glass test tube, 150 Ml of distilled water was added and stirred, after 3 hours the pH readings were taken. The samples were made in three replicates.

3.2 *Determination moisture content*

The moisture content of the substrates was measured using moisture analysers. The moisture content for vinasse was determine using the MAX50 moisture analyser while for maize stalks the AGRIPRO 6095 moisture meter was used. The procedure was done in three replicates

3.3 *Determination of nitrogen*

Nitrogen content for the substrates was determined based on the persulfate standard method—4,500-N_{org} D (LAMNDA 900). The method determines total nitrogen content by oxidation of all nitrogenous compounds to nitrate. Alkaline oxidation at 100–110°C converts organic and inorganic nitrogen to nitrates. The total nitrogen is determined by analysing the nitrate in the digestate. A standard curve was constructed by plotting the standard sample absorbance due to NO_3against strength/concentration. The table below shows the results for absorbance against strength for the standard samples

3.4 *Determination of carbon content*

The carbon content for the substrates was determined from Kenya Agricultural & Livestock's Research Organization (KALRO), Soil laboratory, Nairobi centre.

3.5 *Determination of C/N ratio*

The C/N ratio was determined by dividing the total organic carbon content by the total nitrogen content, according to Xiaojiaoet al. (2014). The carbon content and the nitrogen content of the respective substrates (VN and MS) were determined based on the standard methods highlighted in 3.3 and 3.4 above. The equation used to determine the ratio was as follows;

$$C/N = \frac{W1C1}{W1 \times N1} \quad (1)$$

$$C/N = \frac{(W1 \times C) + (W2 \times C2)}{(W1 \times N1) + (W2 \times N2)} \quad (2)$$

Where W1, W2, and W3 were the TS weight in a single substrate in the mixture; C1, C2, and C3 were the organic carbon content (g kg^{-1}VS) in each substrate; and N1, N2, and N3 were the nitrogen content (g kg^{-1}VS) in each substrate.

3.6 *Determination of COD*

COD was determined based on closed reflux, Colorimetric standard method-5220D. The standard and substrate samples were treated in standard potassium dichromate solution (K_2Cr_2O) and sulfuric acid reagent. The reduction of dichromate absorbance was measured using a UVs spectrometer. The standard samples were prepared using potassium hydrogen phthalate with COD equivalence.

3.7 *Determination of total solids (TS), total suspended solids (TSS), and total dissolved solids (TDS)*

TS, TSS, and TDS for the substrates was determined based on standard methods (2,540B, 2,540C, and 2,540D) for the examination of water and wastewater by Eaton et al. (1995). Vinasse was well mixed and evaporated in a weighed dish and dried to constant weight in an oven at 103 − 105°C, while maize stalks were dried directly. The decrease in weight over that of the empty dish represents the solids. The relationship between TS, TSS, and TDS is given by the following expression;

$$TS = TSS + TDS \tag{3}$$

3.8 *Biogas production*

3.8.1 *Experiment setup*

Biogas production from sugar cane vinasse (SV) and maize stalks (MS) was analysed in a batch anaerobic test at 37.5°C according to Linke and Schelle (2000). A constant mesophilic temperature of 37.5°C was maintained through a water bath. Fresh cow-dung from Moi university farm was used as inocula in this study. 20mL of inocula was mixed with 40mL of vinasse and 40mL of pretreated maize stalks in separate digestion vessels (250mL conical flasks) and labelled runs 1 and 2, respectively. In each run, three conical flasks we rearranged in a way that the first flask contained substrate; the middle contained water and the last was for collecting water that was expelled out of the second container (Budiyono et al 2010a, 2010b). The cocks of all digesters were sealed tightly using clear silicon glue in order to control the entry of air and loss of biogas as indicated in Figure 1. Shaking of digesters was done manually on a daily basis to ensure contact between the substrate molecules and microbial cells.

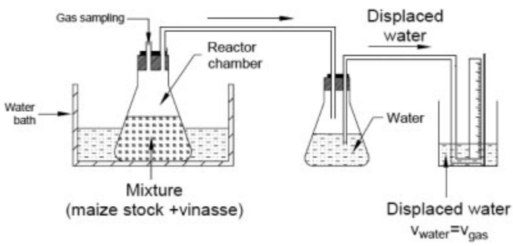

Figure 1. Experiment setup.

4 RESULTS AND DISCUSSION

4.1 *Substrates*

The characteristics of the substrates were analysed before digestion. The pH, moisture %, COD g/L, total solids %, total suspended solids %, total dissolved solids %, carbon content (TOC), nitrogen content, and C/N ration were determined based on standard procedures outlined in the study. The results were recorded in the table below.

Table 2. Composition of various components of maize stalks and vinasse.

Parameters	Maize stalks	Vinasse
pH	7.52	4.34
Moisture %	9.52	93.91
COD g/L	**	71.28
Total solids (%)	91.50	7.05
Total suspended solids %	90.12	6.04
Total dissolved solids %	7.38	1.01
Carbon content (TOC)	49.51g/kg	2.23g/l
Nitrogen content	1.28g/kg	0.27g/l
C/N ratio	38.68	8.25

Key: Number of repetition (n) =3, except for pH and TOC which has n = 1. **Not applicable.

The characteristics of the substrates are suitable for biogas production as supported by the result posted by Kirchgebner(1997) and Mahnert et al. (2002).

4.2 *Biogas production*

The parameter measured was biogas production daily. The tested samples of sugarcane vinasse and maize stalks showed a normal curve of accumulated biogas production. The curves had a steep increase followed by a decrease of biogas production. The maximum biogas yields were obtained in the first 2weeks of digestion experiment (Figures 2 and 3). The two lines represent the two substrates.

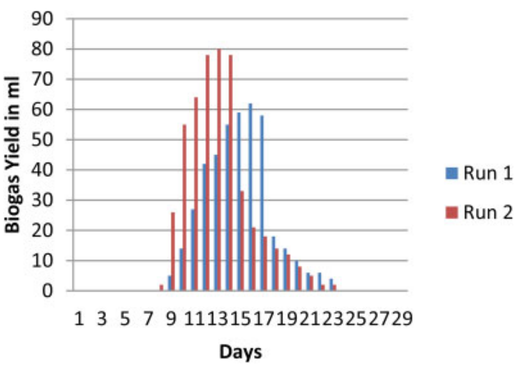

Figure 2. Daily biogas yield (*Run 1, 100% sugarcane vinasse and temperature of* 37.5°*C*; *Run 2, 100% maize stalks and temperature of* 37.5°*C*).

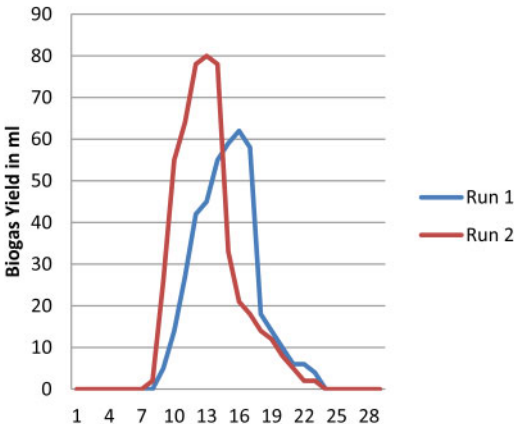

Figure 3. Daily biogas yield (*Run 1, 100% sugarcane vinasse and temperature of 37.5° C*; *Run 2, 100% maize stalks and temperature of* 37.5°*C*).

A maximum production of biogas was produced by 100% maize stalks (Run 2) followed by 100% sugarcane vinasse (Run 1). The cumulative biogas yields for sugarcane vinasse and maize stalks were 8.225mL/g and 38.5mL/g respectively. Some researchers have also worked on various residues for the production of biogas. Anunputtikul and Rodtong (2007) reported a biogas yield of 0.36m^3/kg from 1.00% (w/v) TS when a single stage digester of 5L is used. Similar observations have been recorded by Somayaji and Khanna (1994). Reports have also showed that retention time for biogas production depends on the type of substrate (Ezekoye et al. 2006) Similarly, in this study biogas production from Run 1 (100% sugarcane vinasse) and Run 2 (100% maize stalks)was different, as shown in Figure 2. This could also depend on the amount and growth phase of the added cow-dung (20 mL inocula) that might create a prolonged lag phase of the methanogenic bacteria. According, to Wilkie (2008) the quality and quantity of inocula are critical to the performance, time required, and stability of bio-methanogenesis for the commencement of the anaerobic digester.

5 CONCLUSION AND RECOMMENDATION

The biogas potential of sugarcane vinasse and maize stalks was investigated by batch experiment under mesophilic conditions (37.5°C). It can be concluded that the characteristics of the test substrates (sugarcane vinasse and maize stalks) are suitable for biogas production. These characteristics made favourable conditions for the multiplication of bacteria. The results for anaerobic digestion strongly support the potential of these wastes to produce biogas.

The study recommends further research to be done to determine the optimum conditions for maximum yield (pH, temperature, quality and quantity of inocula used), co-digestion of these wastes, and to analyse the methane content of the biogas.

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