ASSESSMENT OF THE POTENTIAL UTILIZATION OF SUGARCANE DERIVED PRESS MUD FOR ELECTRICITY GENERATION IN SOUTH NYANZA SUGAR ZONES, KENYA

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Assessment of the Potential Utilization of Sugarcane Derived Press Mud for Electricity Generation in South Nyanza Sugar Zones, Kenya

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DECLARATION

This thesis is my original work and has not been presented for the award of degree in any other University.

Signature_____ Date _____

Evans Ochieng Nyonje

This thesis has been submitted for examination with our approval as University Supervisors.

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DEDICATION

This thesis is especially dedicated to my loving family for the love and care you have given me throughout the period of my studies. The support and endurance they have shown, making this thesis much easier to be completed cannot pass unmentioned. Our journey together has not only given me success in this work but has also strengthened my love for all of you. Thank you and the Almighty God repay your generosity abundantly.

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LIST OF ABBREVIATIONS AND ACRONYMS

AD	Anaerobic Digestion
CH_4	Methane
CO_2	Carbon Dioxide
CV	Calorific Value
GC	Gas Chromatography
MoE	Ministry of Energy
JKUAT	Jomo Kenyatta University of Agriculture and Technology
LPG	Liquefied Petroleum Gas
PVC	Polyvinyl chloride
TS	Total Solid
VS	Volatile Solid
SONY	South Nyanza Sugar Company
KESREF	Kenya Sugar Research Foundation
IEET	Institute of Energy and Environmental Technology
C/N	Carbon to Nitrogen ratio
SDPM	Sugar Derived Press Mud
CHP	Combined Heat and Power
OLR	Organic Loading Rate

ABSTRACT

Sugarcane derived press mud (SDPM) is among the 3 major by-products found in the process of raw sugar production; these are Bagasse, Press Mud and Molasses. A precipitate, which is called press mud weighs about 4-5% of the cane weight. The aim of this study was to assess the potential for utilization of sugarcane derived press mud as a renewable energy resource for biogas production and generation of electricity. Sugar derived press mud samples were collected from South Nyanza Sugar zones (SONY, Sukari industries and Transmara Sugar Companies). Chemical treatment and characterization analysis of its parameters were carried out at Kenya Sugar Research Foundation laboratories in Kisumu City. Production of biogas and biogas composition analysis was carried at JKUAT. Samples taken to JKUAT were blended with cow dung at a ratio of 3:1 as inoculum. The gas compositions, upgrading and gas yields were studied. The result of the compositional analysis of the sugarcane press mud from the three sugar factories had variations of ($p \leq 0.05$) in all parameters analysed. Average values were: Moisture content 63.1 ±1.0%, ash content 16.1 ±1.0%, C/N ratio 19.6 ±1.0% and pH 7.3-7.6. Biogas was found to contain 40% - 52% methane (CH_4), 30% - 32% carbon dioxide (CO_2), 13% - 15% nitrogen (N_2) and 1%-2% hydrogen sulphide (H_2S).The raw biogas was upgraded using solid adsorbents and wet scrubbers increasing the methane content up to 70% - 71% this was good concentration compared to the upgraded biogas from water hyacinth of 70%-76%. From theoretical calculations using Buswell equation, it was found that for every 1kg of mixed SDPM and cow Dung (inoculant) we can generate 72.0 kWh. When a small generator was used to produce electric power with the clean biogas $1M^3$ produced 3.54kWh. And when the annual potential of SDPM biogas converted to electric power it was found that it could produce 453.5MWh per annum. The study concludes that sugarcane press mud is a potential feedstock for biogas production. For 1kg of SDPM produced 2.341/kg and the annual potential of SDPM biogas converted to electric power was approximated at 453.5MWh per annum

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The ever increasing global energy demand has necessitated research in new renewable energy technologies that aim at producing clean power. Biogas being a clean, cheap and environmentally friendly fuel stands out as one of them. For Kenya to achieve its target of becoming industrialized nation by 2030, a reliable supply of quality energy is crucial (GOK, 2008). Interest in bio-fuels has been increasing, motivated on one hand by the need for reducing greenhouse gases (GHG) emission and on the other hand by the desire to improve energy security by reducing dependence on largely imported fossil fuels. The government has enacted a policy (GOK, 2004) and legislation (GOK, 2006) which seeks to ensure sufficient biomass supplies to meet demand on a sustainable basis while minimizing the associated impacts. Majority of people living in the rural areas use biomass, mainly "wood-derived-fuel" as the source of energy for cooking and lighting. However, the potential of biogas has not been effectively utilized in the provision of energy. Continued over-dependence on the unsustainable "wood-derived-fuel" and other forms of biomass to meet household energy needs has contributed to deforestation with negative impacts on the environment.

From the 19thcentury, the main reason for growing sugarcane in different countries in the world was for production of sugar (Rolz *et al*, 2010). Due to energy crises, scientists and researchers have realized the value of sugarcane, it-s by-products (bagasse, sugar press mud and Molases) and co-products (fibre and Ethanol). Sugarcane is processed to sugar and biomass. This biomass contains many components like lignin, fibre, pith and pentosans, which have plenty of applications in biochemical and microbial field (Yadav & Solomon, 2006).

Horecky and Saska (2004) reports that the sugar industry produces a number of by-products during the process of sugar production including bagasse, mill mud or filter cake, ash, mill effluent, and trash. Most of these wastes contain biodegradable matter.

This could be potentially resourceful for biotechnology processes, which can produce extra by-products for the sugar industry. One possibility is using anaerobic technology for biogas production.

1.1.1 Sugar Production Process

During the process of raw sugar juice clarification, dissolved and suspended solid substances are removed to get the clear juice, a precipitate settles at the bottom of the clarifier which is called sugar cane press mud, also known as filter cake or filter mud. In sugar factories, during sugarcane juice clarification, press mud is produced as a by-product, and weighs about 4-5% of the cane weight (Jadhav, 2011). Figure 1.1 shows the flow chart of Sugar Industry processing to produce Sugarcane Derived press Mud

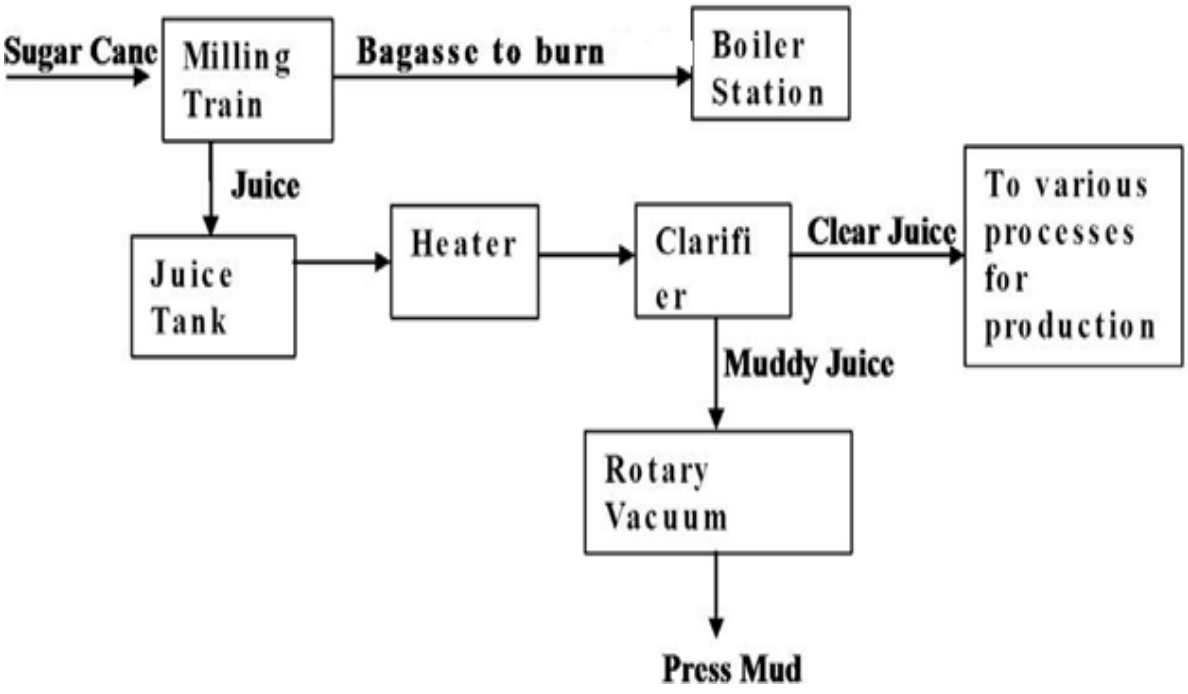


Figure 1.1: A schematic diagram of formation of press mud waste in sugar

(Source: Neha *et al*. 2011)

Sugar derived-press mud also known as filter-cake which is rich in organic matter, is the major source of biogas. The organic matter in the press mud can be tapped through the anaerobic digestion technology and be used as a source of biogas energy. Currently, this press-mud is usually dumped as garbage. Some sugar industries make use of it by converting it into compost. But this compost, along with its advantages,

has some disadvantages too: it increases the wax content in the soil. The increase in wax reduces the porosity of the soil causing reduced penetration and permeability which is not desirable (Rouf *et al*., 2010).

Plate 1.1 and 1.2 represent fresh sugar press mud in the conveyer belt and when the sugar press mud still on the rotary vacuum pan respectively.

Plate 1.1: Collected press mud

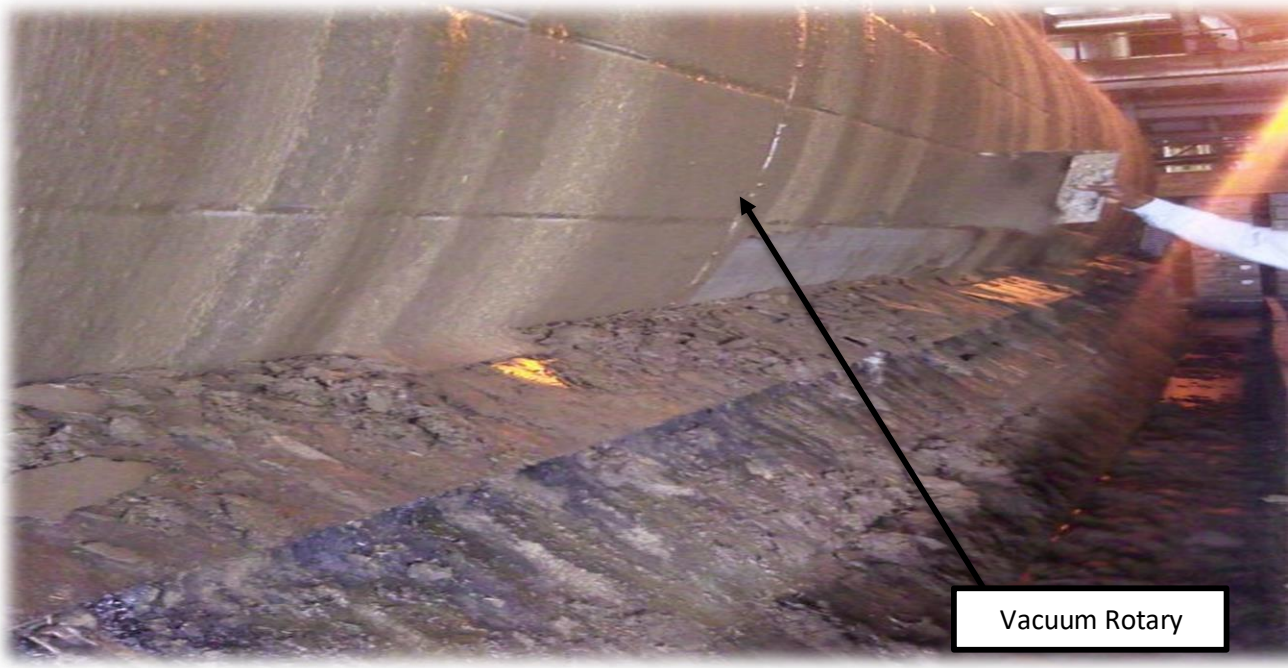


Plate 1.2: Press mud from the vacuum rotary

Much work has been carried out in obtaining biogas from various sources such as kitchen wastes, human wastes, animal wastes and agricultural wastes. The plants constructed for these purpose are working successfully too. Such biogas plants are presently used by many people locally for obtaining biogas. As biogas is a non-polluting with less greenhouse gas emission and renewable energy resource, it is efficiently replacing the liquefy petroleum gas (Karan *et al.*, 2011)

GTZ-HERA (2010), reported that theoretically, biogas can be converted directly into electricity using a fuel cell. However, very clean gas and expensive fuel cells are necessary for this process. This is therefore currently not a practical option. In most cases, biogas is used as fuel for internal combustion engines, which convert it to mechanical energy for powering an electric generator to produce electricity.

The work in this thesis was to obtain biogas, from sugarcane derived press-mud which was anaerobically digested to produce biogas. Biogas produced was used as fuel for generation of electricity.

1.2 Problem Statement

According to Rouf *et al.*, (2010), press-mud is usually dumped as garbage. Some sugar industries make use of it by converting it into compost. But this compost, along with its disadvantages, that is: it increases the wax content in the soil, the increase in wax reduces the porosity of the soil causing clogging which is not desirable. This does not in any way benefit the factories economically.

Therefore, making use of sugarcane press-mud for the production of biogas through the anaerobic digestion is a better option for the benefits of both farmers and Sugar companies. The biogas obtained can be used for many purposes like fuel in kitchen to complement liquefy petroleum gas and save the factories in the electricity used by employees in cooking in their kitchen and also the production of electricity which can be used in the process. The sludge remaining after production of biogas from press-mud can be used as a fertilizer as well. This will save the company in its power expenses and energy balancing.

1.3 Objectives of the Study

1.3.1 Main objective

The main objective of this study was to assess the potential for utilization of sugarcane derived press mud for electricity production in South Nyanza Sugar zone, Kenya.

1.3.2 Specific objectives

I. To determine Moisture %, Solids %, Volatile matters, Ash %, Fibre %, Sugar %, C/N ratio and pH value of Sugar Derived Press Mud from South Nyanza sugar zone.

II. To produce, analyse and compare the composition of raw biogas from the sugarcane derived press mud.

III. To upgrade biogas using locally available material and study electricity production using biogas.

1.4 Hypothesis

H_0- Biogas produced from Sugar cane derived press mud has no difference from cow dung derived biogas.

1.5 Justification

Kenya's current effective electricity supply is predominantly sourced from hydro and fossil fuel (thermal) sources. MoE, 2011, reported that generation energy mix comprises 52.1% from hydro, 32.5% from fossil fuels, 13.2% from geothermal, 1.8% from bagasse cogeneration and 0.4% from wind, respectively. Current electricity demand is 1,191 MW and is projected to grow to about 15,000 MW by 2030. To meet this demand, Kenya's installed capacity should increase gradually to 19,200 MW by 2030.

For the government of Kenya to achieve 19,200 MW by 2030, more energy resources have to be earnest (MoE, 2011). Biomass is renewable energy resource that is abundant, less environmental pollution and locally available, can be used to gap the energy scarcity level in Kenya

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

During sugar processing the cane is crushed and juice is separated, bagasse is removed and sugar press mud which is the solid material left after clarification of cane juice. These by-products may be used as source of energy but also as a source of nutrients and as soil ameliorates. The re-use of mill by-products has been mutually beneficial to the farming community and the milling sectors as well as supporting the industry's endeavours (Barry *et al.*, 2000). Sugar mills generate between 20 and 60 kg of mud per ton of cane crushed (Chapman, 1996). Harvesting conditions affect the extraneous matter and soil content of the cane supply, which, in turn, affects the quantity of mud. In Kenya, there are presently 8 sugar mills crushing 20,000 tonnes of cane per day generating 400 tonnes of sugar press mud, which average about 50 tonnes per mill (www.kenyasugar.co.ke).

2.1.1 Press mud in sugar industry

Sugarcane press mud is among the 3 major by-products (bagasse, press mud and molasses) found in the process of raw sugar production process. It is the second by-product removed as a residue of the filtration of sugarcane juice. The clarification process separates the juice into a clear juice that rises to the top and goes for manufacture of sugar and mud that collects at the bottom. The mud is then filtered to separate the suspended matter, which includes insoluble salts and fine bagasse. There are 3 types of filters: the press filters (used in carbonation factories), mechanical filters and rotary vacuum filters (Hugot, 1986).

Karan (2011), reports that, press mud contains 77% volatile solids, lignin, lipids, cellulose, hemicelluloses, which favours biogas production. It also has good proportion of nitrogen. This makes it a very good material for generation of bioenergy (methane) by anaerobic bio-methanation. The advantage of using press mud is that the sludge coming out from the digester is a good fertilizer and press mud can be used in combination with other raw materials such as molasses and bagasse to increase the

efficiency. Other advantages are:-it is pollution free, waste reduction, flexible use of biogas etc.

Biogas can be used for all applications designed for natural gas, subject to some further upgrading, as not all gas appliances require gas of the same quality standards (www.novaenergie.ch/iea-bioenergy-task37). Biogas can be used for heating using boilers; the heat has many applications such as being used in the plant or producing water vapour for sugar processes. Boilers do not have a high gas quality requirement. Biogas is also used in Combined Heat and Power (CHP) units. CHP units are a good way to produce efficiently both electricity and heat for the Anaerobic Digester (AD) plant.

The sugar industry will benefit financially through installing biogas generators, as the economic analysis reveals that the production of biogas and bio-fertilizer from press mud is economically feasible. Furthermore, there is triple benefit associated with the waste bio-methanation as we get clean fuel biogas, enriched manure bio-fertilizer and also hygienic environment. (Rouf *et al., 2013*)

The plate 2:1 shows a rotary vacuum during recovery and drying of sugarcane derived press mud at Transmara Sugar Company.

Plate 2.1: A rotary vacuum filter for removal of press mud in Transmara Sugar Factory

Source: www.transmarasugar.co.ke (2014).

2.1.2 Gas yield from press mud and other waste

The biogas gas yield from sugarcane derived press mud only and when mixed with other waste is as presented in Table 2:1 below.

Table 2.1 Gas yield from press mud

Substrate	*Gas yield (L/g)*
Press mud	0.241
Press Mud: cow dung (2:1)	0.202
Press mud: cow dung (1:1)	0.167
Press mud: bagasse (2:1)	0.263
Press mud: bagasse (1:1)	0.273
Press mud: cane pith (2:1)	0.290
Press mud: cane pith (1:1)	0.381

(Source: Rouf *et al.*, 2010)

2.1.3 Composition of the sugar press mud

Karan *et al* (2011), reports that press mud is mainly used as manure in India and other raw sugar producing countries. It is a soft, spongy, lightweight, amorphous, dark brown to black coloured material. It generally contains 60-85% moisture; the chemical composition depends on cane variety, soil condition, nutrients applied in the field, process of clarification adopted and other environmental factors (Rouf *et al*, 2010). Press mud from sugar factory typically contains 71% moisture, 9% ash, 20% volatile solids, with 74-75% organic matter on solids (Karan *et al* 2011).

The general characteristics of press mud are presented in Table 2.2. The moisture content in the samples varied from 74.9 to 78.7% (averaging 76.3%). The press mud used for generation of biogas contained about 77% volatile solids. The C/N ratio was ~14. The organic matter present in the press mud consisted mainly of cellulose 11.4%, hemicellulose 10%, lignin 9.3%, protein 15.1%, wax 8.4% and sugar 5.7% (Rouf *et al*, 2010). It also contained various micronutrients. The chemical oxygen demand and pH of 6% press mud slurry usually reported are 50.6 g/L and 7.1 respectively. In fact, the chemical composition of press mud depends on the cane variety, soil conditions, nutrients applied in the field, process of clarification adopted and other environmental factors.

Table 2.2: **Characteristics of the sugar press mud**

S/r No.	Parameter	Average values
1	Moisture (%)	76.3
2	Solids (%)	23.8
3	Volatile Matter (%)	76.6
4	Ash (%)	22.4
5	Wet Bulk Density	0.76

6	Fibre (%)	23.6
7	Sugars (%)	6.4
8	Wax (%)	7.2
9	Protein (%)	15.8
10	Calorific Value (kcal/kg)	3861
11	C/N Ratio	14.0
12	pH of 10% solids	7.5
13	COD of 10% solids (g/L)	86.9

Source: www.banglajol.info (2014)

2.1.4 Current use of sugar press mud

In Kenya, this industrial waste is mainly used as soil fertilizer in the sugarcane plantation in nuclear estate and out-grower. Other industrial applications are reported (cement and paint manufacturing, foaming agent, composting aid for bagasse etc.) and it has been used as human food in poor families. In animal production, it has been used as feed ingredient, notably in ruminants, for its sugar and mineral content, and as a compacting agent for ensiling (Van der Poel *et al.*, 1998).

This has saved the sugarcane farmers in time when cost of chemical fertilizer is skyrocketing and not affordable by farmers. Press mud has been used as a source of plant nutrient and as medium for raising sugarcane seedlings and leguminous inoculants. The advantages of using sugarcane press mud for soil application is its low cost, slower release of nutrients, presence of trace element, high water holding capacity and mulching properties (Bhosale *et al*, 2012).

2.1.5 Environmental impacts

The present methods used by sugar factories in Kenya for disposal of press mud are not economical and pollute the environment (Rouf *et al*, 2010). Because of the

presence of sugar and other organic constituents, the press mud emits obnoxious smell to environment.

2.2 Anaerobic digestion process

Anaerobic digestion is a naturally occurring process of decomposition and decay, by which organic matter is broken down to simpler chemicals components under anaerobic conditions. Anaerobic microorganisms digest the organic materials, in the absence of oxygen, to produce methane and carbon dioxide as end-products under ideal conditions. The biogas produced in AD-plant usually contains small amount of hydrogen sulphide (H_2S) and ammonia (NH_3), as well as trace amounts of other gases (Fabien, 2003).

The processes underlying AD can be complex and the process is best understood if split into the three main stages: hydrolysis, acidogenesis and methanogenesis.

2.2.1 Hydrolysis

During hydrolysis, the fermentative bacteria convert the insoluble complex organic matter, such as cellulose, into soluble molecules such as fatty acids, amino acids and sugars. The complex polymeric matter is hydrolysed to monomers, e.g. cellulose to sugars or alcohols. The hydrolytic activity is of significant importance in wastes with high organic content and may become rate limiting. Chemicals can be added during this step in order to decrease the digestion time and provide a higher methane yield.

2.2.2 Acidogenesis

In the second stage, acetogenic bacteria, also known as acid formers, convert the products from the first stage into simple organic acids, carbon dioxide and hydrogen. The principal acids produced are acetic acid, butyric acid, propionic acid and ethanol.

2.2.3Methanogenesis

Finally, methane is produced during methanogenesis by bacteria called methane formers in two ways: by means of cleavage of two acetic acid molecules to generate carbon dioxide and methane, or by reduction of carbon dioxide with hydrogen. The acetate reaction is the primary producer of methane because of the limited amount of hydrogen available (Fabien, 2003).

2.3 Important AD operating parameters

There are several conditions and variables that must be applied in order to obtain a proper breakdown of the organic compounds. The operating parameters of the digester must be controlled so as to enhance the microbial activity and thus increase the AD efficiency.

2.3.1 Total Solid content

There are three different ranges of solid content: low solid (LS) AD systems contain less than 10% Total Solid (TS), medium solid (MS) from 15-20% and high solid systems (HS) range from 22-40%. When increasing the total solid content, the volume of the digester decreases, due to lower water requirements (Fabien, 2003).

2.3.2 Temperature

Anaerobic digestion can occur under three main temperature ranges:

- Psychrophilic condition, between 5-15°C, usually 12°C.
- Mesophilic conditions, between 20-45°C, usually 35°C.
- Thermophilic conditions, between 50-65° C, usually 55°C.

The optimum temperature of digestion may vary depending on feedstock composition and type of digester, but in most AD processes it should be maintained relatively constant to sustain the gas production rate.

Thermophilic digesters are more efficient in terms of retention time, loading rate and nominally gas production, but they need a higher heat input and have a greater sensitivity to operating and environmental variables, which make the process more problematic than mesophilic digestion.

The sterilization of the waste is also linked to the temperature. The higher it is the more effective it is in eliminating pathogens, viruses and seeds (Fabien, 2003).

2.3.3 Retention time

Retention time is the time needed to achieve the complete degradation of the organic matter. The retention time varies with process parameters, such as process temperature and waste composition. The retention time for waste treated in a mesophilic digester

ranges from 15 to 30 days and 12-14 days for thermophilic digester (www.britishbiogen.co.uk, 2011).

2.3.4 pH

The optimal pH values for the acidogenesis and methanogenesis stages are different. During acidogenesis, acetic, lactic and propionic acids are formed and, thus the pH falls. Low pH can inhibit acidogenesis and pH below 6.4 can be toxic for methane-forming bacteria (the optimal range for methanogenesis is between 6.6 and 7). An optimal pH range is between 6.4 and 7.2 (http://www.biogasworks.com).

2.3.5 Carbon to Nitrogen ratio (C: N)

The relationship between the amount of carbon and nitrogen present in organic materials is represented by the C/N ratio. Optimum C/N ratios in anaerobic digesters are between 20 and 30. A high C/N ration is an indication of a rapid consumption of nitrogen by the methanogens and results in a lower gas production. On the other hand, a lower C/N ratio causes ammonia accumulation and pH values exceeding 8.5, which is toxic to methanogenic bacteria. Optimum C/N ratio of the feedstock materials can be achieved by mixing waste of low and high C/N ratio, such as organic solid waste mixed with sewage or animal manure (Fabien, 2003).

2.3.6 Organic loading rate (OLR)/ Volatile Solids (VS)

OLR is a measure of the biological conversion capacity of the AD system. Feeding the system above its sustainable OLR, results in low biogas yield due to accumulation of inhibiting substances in the digester slurry (i.e. fatty acids). Under such circumstances, the feeding rate of the system must be reduced. OLR is a particularly important control parameter in continuous systems. Many plants have reported system failure due to overloading. OLR is expressed in kg Chemical Oxygen Demand (COD) or Volatile Solids (VS) per cubic meter of reactor. It is linked with retention time for any particular feedstock and anaerobic reactor volume (http://www.biogasworks.com)

Volatile Solids (VS) represents the organic matter in a sample which is measured as solid content minus ash content, as obtained by complete combustion of the feed

wastes. VS comprise the biodegradable VS (BVS) fraction and the refractory VS (RVS). High VS content with low RVS is more suitable for AD.

2.4 Chemistry of Biogas

Biogas is a gaseous mixture generated during anaerobic digestion processes using waste water, solid waste (e.g. at landfills), organic waste, e.g. animal manure, and other sources of biomass (Welink *et al.*, 2007). In the absence of oxygen, anaerobic bacteria will ferment biodegradable matter into methane (40-70%), carbon dioxide (30-60%), hydrogen (0-2%) and hydrogen sulphide (0-3%), a mixture called biogas (Fabien, 2003). Biogas is formed solely through the activity of bacteria. Although the process itself generates heat, additional heat is required to maintain the ideal process temperature of at least 35°C. In comparison, the methane component of natural gas could amount to over 80%. In nature, biogas is generated at the bottom of stagnated ponds, lakes, swamps or in the digestive system of animals (Jepma & Nakicenovic, 2006).

The composition of biogas is different from the one of natural biogas but it is quite similar to landfill gas. Landfill gas often contains significant amounts of halogenated compounds and occasionally the oxygen content is high when too much air is suck during the collection on the landfill. The calorific value is 36.14 MJ/m^3 for natural gas and 21.48 MJ/m^3 for biogas. The composition of biogas is naturally linked to the waste composition and can thus vary (Fabien, 2003).

Biogas can be used for all applications designed for natural gas, subject to some further upgrading, as not all gas appliances require gas of with the same quality standards (http://www.novaenergie.ch/iea-bioenergytask 2014).

Biogas can be used for heating using boilers. The heat has many applications such as being used in the plant or producing water vapour for industrial processes. Boilers do not have a high gas quality requirement. It is preferable to remove the hydrogen sulphide because it forms sulphurous acid in the condensate which is highly corrosive. It is also recommended to condense the water vapour in the raw gas. Water vapour can cause problems in the gas nozzles. Removal of water will also remove a large proportion of H_2S.

Biogas is also used in Combined Heat and Power (CHP) units. Gas engines do have the same quality requirements as boilers, except that the H_2S content should be lower. In biogas engines the NO_x emissions are usually low because of the CO_2 in the gas. CO concentration is often more a problem. However, from an environmental point of view, CO is less of an issue than NOx because it is rapidly oxidized to CO_2. CHP units are a good way to produce efficiently both electricity and heat for the AD plant. For instance, heating of the digester and sterilization of the digestate can be done using this heat. The remaining electricity can be sold to the national grid. This is actually the most popular way of using the landfill gas in the UK (Fabien, 2003).

2.5 Biogas quality

Biogas is mainly composed of methane (CH_4), carbon dioxide (CO_2) and low amount of other gases (Yadava & Hcssc, 1981). GTZ, (1999) reports that, biogas is a mixture of gases that is composed chiefly of methane 40-70 vol.%, carbon dioxide 30-60 vol.% and other gases 1-5 vol.% including hydrogen (H_2) 0-1 vol.% and hydrogen sulphide (H_2S) 0-3 vol.%. (Tjalfe, 2003) reported the same per cent of methane and carbon dioxide while the other gases 0 - 3 vol. %.

The quality of biogas generated by organic waste materials does not remain constant but varies with the period of digestion (Khandewal & Mahdi, 1986). The ratio of CH_4 to CO_2 is normally stable in the reactor and a change of the ratio can be due to process imbalance. However, the methane ratio also depends on substrate composition, temperature, pH and pressure (Liu, 2003). Since the dissolution of CO_2 is strongly dependent on pH, fluctuation of pH can also change gas composition.

The quality of biogas depends mainly on the presence of methane in it. A good quality of biogas has high percentage of methane. The percentage of methane in biogas is generally determined by the Orsat apparatus, gaschromatograph etc. (Holman, 1995). Savery and Cruzon (1972) suggested that, the three agents KOH, NaOH and $Ca(OH)_2$ can be used in chemical scrubbing of biogas. The absorption of CO_2 in alkaline solution is assisted by agitation. The turbulence in the liquid aids to diffusion of the molecule in the body of liquid and extends the contact time between the liquid and gas. Another factor governing the rate of absorption is concentration of the solution.

A solution of potassium hydroxide (KOH), sodium hydroxide (NaOH) and water has enhanced scrubbing capabilities for CO_2 removal because the physical absorption capacity of the water is increased by the chemical reaction of the KOH and NaOH. Konstandt (1976) mentioned that the percentage of methane CH_4 can be estimated through recognition of CO_2 percentage from this equation:

$$CH_4 = 100\% - [CO_2\% + 0.2\% H_2S] \text{ vol.}$$

2.6 Biogas upgrading

According to Hansson *et al* (2002) and Liu (2003), the corrosive nature of H_2S alone is enough to destroy the internals of a plant. The solution is the use of biogas upgrading or purification processes whereby contaminants in the raw biogas stream are absorbed or scrubbed, leaving more methane per unit volume of gas.

2.6.1 Water washing/wet scrubbing

The main method of biogas upgrading includes water washing. The most prevalent method is water washing where high pressure gas flows into a column where the carbon dioxide and other trace elements are scrubbed by cascading water running counter-flow to the gas. This arrangement could deliver 98% methane with manufacturers guaranteeing maximum 2% methane loss in the system. It takes roughly between 3-6% of the total energy output in gas to run a biogas upgrading system. Removal of sulphur can be carried out using wet scrubbers. Plate 2.2 present the cross sectional diagram for the wet scrubber from the end elevation view.

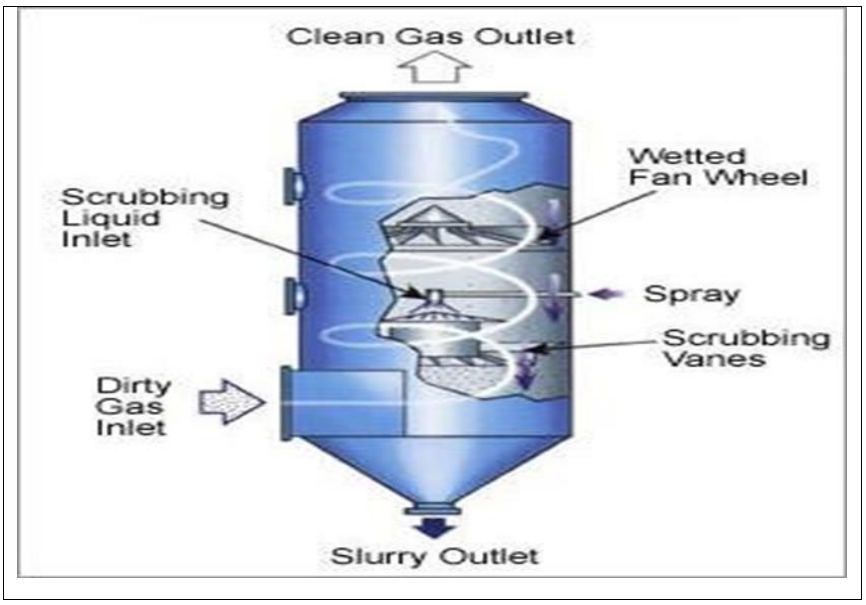


Plate 2.2: Wet scrubber

Source: http:/www.mikropul.com/products/ wscrubber/mikrovane.html.

2.6.2 Pressure swing adsorption

Carbon dioxide can be removed from the biogas by adsorption on a surface, normally activated carbon, molecular sieves or zeolites. In pressure swing adsorption, adsorption takes place at elevated pressure of light vacuum. However, this process requires a pre-treatment step in order to remove water vapour and hydrogen sulphide present in the inlet stream i.e. biogas. Hydrogen sulphide pose a severe operation problem during adsorption at elevated pressure as its adsorption is irreversible in these types of materials. The presence of water can destroy the structure of the adsorbent. In order to solve this, a pre-treatment step, normally adsorption onto impregnated active carbon followed by an increase in the temperature between 60 °C and 90 °C can easily remove gas-phase hydrogen sulphide from biogas. After desulphurization step, water is removed by condensation (Schulte-Schulze Berndt 2005).

2.6.3 Absorption

In absorption techniques for biogas purification, the raw gas is put in contact with a non-volatile liquid phase, the purpose being the mass transfer of the contaminant from the gas-phase to the liquid phase (Kennes & Viega 2001). The main idea of cleaning biogas through absorption is to transfer carbon dioxide from the gas phase to the stationary liquid phase, for example water, in which that pollutant is more soluble than

methane. The different absorption technologies use different types of absorbents like water scrubbing, organic physical scrubbing and chemical scrubbing.

2.6.4 Cryogenic Technique

Cryogenic technique is based on the differences of boiling and sublimation points between methane and its impurities, particularly for the separation of carbon dioxide and methane. Methane has a boiling point of -160°C at atmospheric pressure whereas carbon dioxide has a boiling point of -78°C (Persson *et al.*, 2006). This implies that carbon dioxide can be separated from the biogas as liquid by cooling the gas mixture at elevated pressure. Methane can be taken out in gas or liquid phase, depending on the system configuration. The basis of cryogenic separation techniques is that biogas is compressed and then cooled followed by some expansion steps. These phenomena make the carbon dioxide be removed as a liquid, the gas can be cooled further to condensate the methane. The separated carbon dioxide is clean and can be used elsewhere or sold.

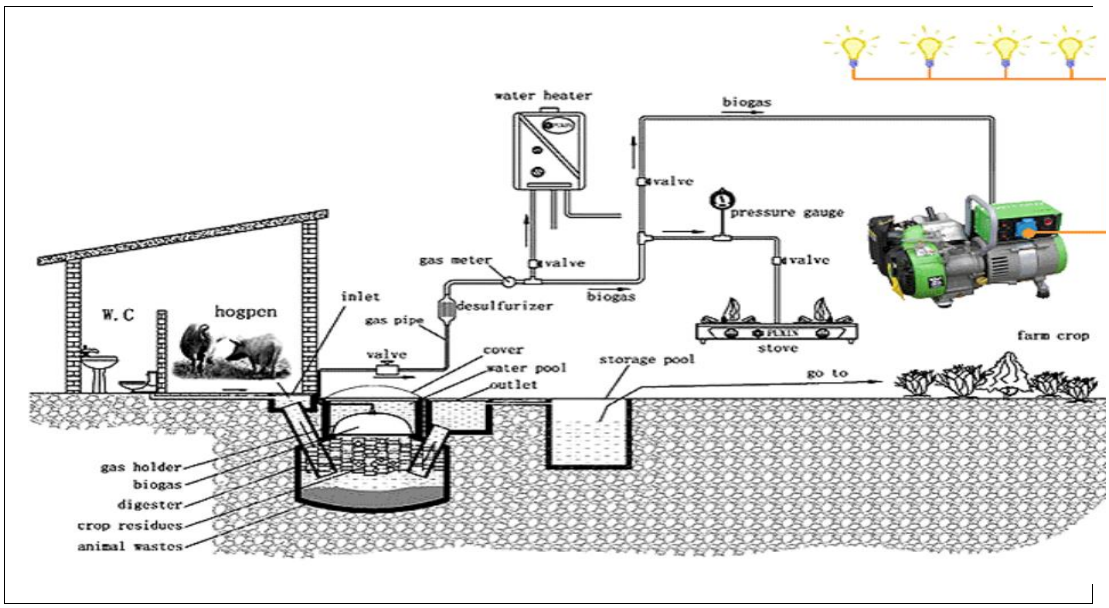
To avoid freezing and other problems during the cryogenic compression expansion process, water and hydrogen sulphide need to be removed from the raw biogas. Water and siloxanes are also removed during cooling of the gas. Cooling usually takes place in several steps in order to remove the different gases in the biogas individually and to optimize the energy recovery.

Cryogenization is an emerging technique and is still under experimentation. De Hullu *et al.*, 2008 reported simulated data from Aspen plus software package, operating at -90°C and 40 bars. The simulation showed removal efficiencies of 91%.

2.7 Conversion of Biogas to Electricity

Theoretically, biogas can be converted directly into electricity using a fuel cell. However, very clean gas and expensive fuel cells are necessary for this process. This is therefore currently not a practical option.

Figure 2.1 below present a simple diagram on how pig droppings can be used to produce biogas for cooking and electricity generation through anaerobic digestion method.



Source*: www.Greenpower.cn (2014).*

Figure 2.1: Schematic of a biogas plant used for power generation.

In most cases, biogas is used as fuel for combustion engines, which convert it to mechanical energy, powering an electric generator to produce electricity.
Appropriate electric generators are available in virtually all countries and in all sizes. The technology is well known and maintenance is simple. In most cases, even universally available 3-phase electric motors can be converted into generators.

Technologically far more challenging is the first stage of the generator set: the combustion engine using the biogas as fuel. In theory, biogas can be used as fuel in nearly all types of combustion engines, such as gas engines (Otto motor), diesel engines, gas turbines and Stirling motors etc.

GTZ (2010), reports that gas turbines are occasionally used as biogas engines, especially in the US. They are very small and can meet strict exhaust emissions requirements. Small biogas turbines with power outputs of 30-75 kW are available on the market, but are rarely used for small scale applications in developing countries as they are expensive. Furthermore, due to their spinning at very high speeds and the high operating temperatures, the design and manufacturing of gas turbines is challenging and maintenance requires specific skills.

External combustion engines such as Stirling motors have the advantage of being tolerant of fuel composition and quality. They are, however, relatively expensive and characterized by low efficiency. Their use is therefore limited to a number of very specific applications.

In most commercially run biogas power plants today, internal combustion motors have become the standard technology either as gas or diesel motors (GTZ, 2010).

CHAPTER THREE

MATERIALS AND METHODS

3.0 Introduction

This chapter describes and explains the research instruments that were used in the study. Which included the experimental design, area of the study, feed stock characterization, production and analysis of SDPM biogas and data management.

3.1 Experimental design

The study was divided into steps areas namely;

I. Feed stock characterization,
II. Production and analysis composition of raw biogas
III. Comparison of composition analysis of biogas production from sugarcane derived press mud with biogas from cow dung.
IV. Upgrade of raw sugar press mud biogas using locally available material and study electricity production using biogas.

3.2 Area of the Study

The study was carried in three different regions in Kenya: three sugar factories (SONY sugar, Transmara sugar and Sukari International) in Kenya from same sugarcane ecological zones, Kenya Sugar Research Foundation and Jommo Kenyatta University of Agriculture and Technology. The press mud samples were collected from South Nyanza Sugar, Transmara Sugar and Sukari International Sugar Companies as selected area of study.

The composition analysis was done at Kenya Sugar Research Foundation situated at Kibos, Kisumu. The sugar derived press mud was then transported from the South Nyanza sugar zone to Jommo Kenyatta University of Agriculture and Technology (JKUAT). A biogas digester bag was repaired and made at JKUAT, IEET site and the small digester was then set up. Feeding of feedstock (sugar derived press mud) was done and biogas was collected. The biogas analysis was carried out at Food science laboratory JKUAT.

Figure 3.1 shows sampling areas and table 3.1 shows the GPS coordinates for the sites as generated from Google Earth. From the figure, the yellow markings represent the sugar factories where samplings of sugar press mud were collected. The main economic activity in the region is sugarcane growing supplemented by maize and tobacco.

Table 3.1: **GPS coordinates**

Sugar Company	GPS Coordinates	
	Latitude	Longitude
Sukari Industries Ltd	0°49'16.71"S	34°23'5.89"E
Sony Sugar Company	0°53'28.84"S	34°31'45.93"E
Transmara Sugar Company	1° 1'6.14"S	34°44'16.46"E

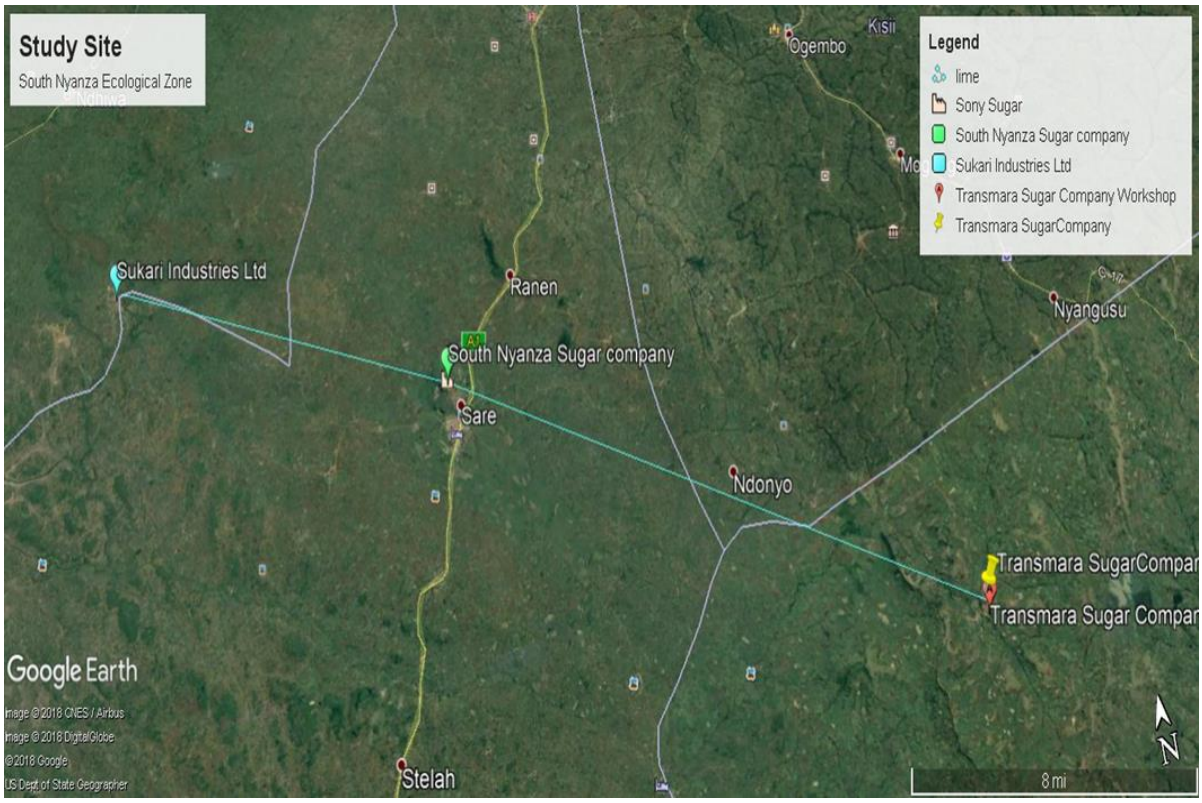


Figure 3.1: Map of the Research Study (Google Earth 18/5/2018)

3.3 Step 1: Feed stock Characterization

During the characterization of the sugar-derived press mud, the following aspects were investigated: Moisture (%), Solids (%), Volatile Matter (%), Ash (%), Sugars (%),Organic Carbon, fibre content, Nitrogen, C/N Ratio, and pH of 10% solids of dry sugar-derived press mud.

3.3.1 Organic Carbon

Organic Carbon was determined by the loss-on-ignition (LOI) method which involved the heating destruction of all organic matter in the soil or sediment. Triplicate of 5g weight of sample were placed in a ceramic crucible which was then heated to 400°C overnight (Blume *et al*., 1990, Nelson & Sommers 1996, ASTM. 2000). The sample was then cooled in a desiccator and weighed. Plate 3.1 illustrates heating of the SDPM inside a furnace in the KESREF laboratory.

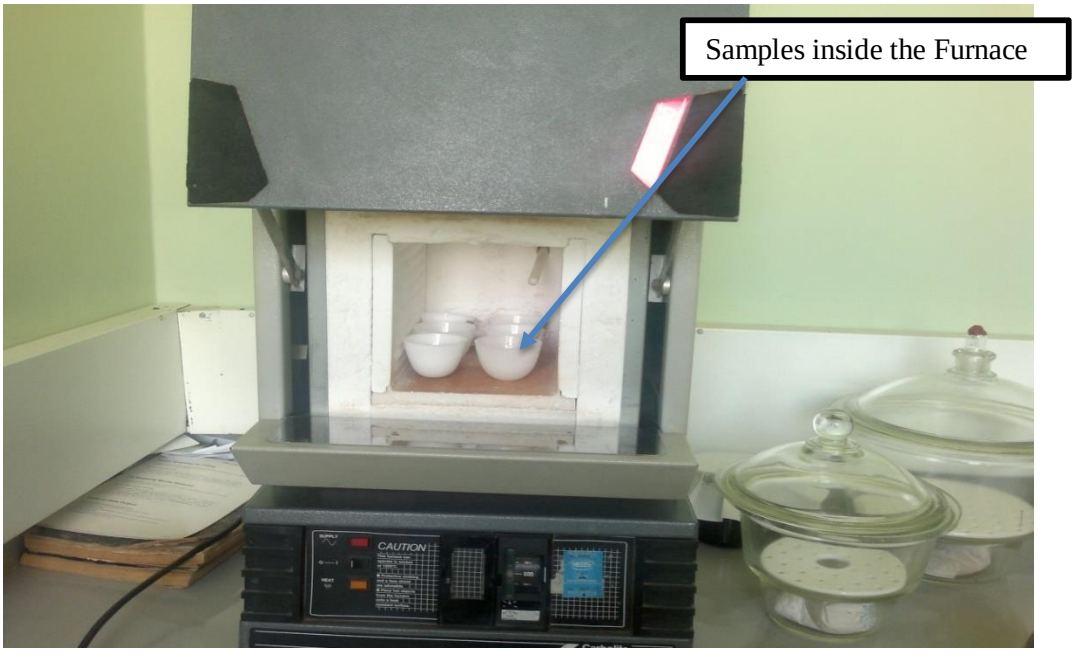


Plate 3.1: Laboratory Furnace

3.3.2 Moisture and Ash Content

Moisture and ash contents were estimated by gravimetric methods by drying at 105^{o}C overnight and by complete combustion at 800^{o}C in the laboratory furnace for 15minutes, respectively.3 portions of 5g of SDPM were weighed, put in crucibles and heated inside the Furnace until temperatures of 800°C attained and then left for 15

minutes. The samples were then transferred to a desiccator for cooling before reweighing was done (Skoog, D *et al.*, 1996). Weight loss was used to express VM and remaining weight was used to calculate the Ash content. The picture in plate 3.2 shows the samples being dry in the oven and during weighing in the laboratory

a) Laboratory oven	b) Weighing Machine
	

Plate 3.2: Laboratory Oven and Weighing Machine

3.3.3 Fibre Content

To determine fibre content for SDPM, 5gms of press mud was weighed accurately and washed over a tarred 100 mesh sieve until the water run clear. Excess water was drained off and the sieve along with its contents was dried in an oven at 105^{o}C to constant weight. Fibre content was calculated from the increase in weight of the tarred sieve (Mathur, 1997).

3.3.4 Sugar content (Pol.)

Sugar content (pol/sucrose) in the press mud sample was determined by measuring the optical rotation in a Polarimeter machine where 10g of the samples were weighed in triplicates in plastic beakers, water was then added up to 50g, $Pb(NO_3)_2$ was added and stirred. The solution was filtered and the clear solution injected in the Saccharimeter/polarimeter machine and the sucrose values read. Plate 3.3 gives an illustration of the process of pol analysis and use of polarimeter machine.

a. Filtration processes	b. Saccharimeter machine
	

Plate 3.3: Samples for Pol analysis and Sccharimeter machine

3.3.5 Nitrogen Determination

Nitrogen was analysed through Kjeldahl method. Where 5g of the samples were weighed and 1g $CuSO_4$, 10g K_2SO_4 and 30 mL Con. H_2SO_4 and then digested in Kjeldahl until a green colour appeared. The solutions were decanted and 40% NaOH solution was added and afterwards titrated against HCl. From titrate, multi equivalence of acid for NH_3 absorbed was calculated and used to get nitrogen % present in the sugar press mud. (Jackson, 1956; Jaber *et al* 2009).

The above method is illustrated in the form of diagram in plate 3.4 below, showing the titration and digestion processes in progress at the Kenya Sugar Research foundation lab.

a. **Loading of the samples in the Kjeldahl**

b. **During titration process**

c. **Kjeldalh Machine**

d. **Titration in progress**

Plate 3.4: Analysis of Nitrogen by use of Kjeldahl instrument and Titration

3.3.5 pH value

pH value was determined by weighing 10g of sample and was toped up with water up to 50g, shaken for 10 minutes in laboratory shaker and then reading were done using pH meter (ASTM, 2000). The plate 3.5 below present the equipment used in taking the pH values of the samples in the lab.

a. **pH meter**	**b. pH reading in progress**
	

Plate 3.5: pH Analysis

3.3.6 Total Organic Carbon

Organic Carbon was determined by the loss-on-ignition (LOI) method for the determination of organic matter which involved the heating destruction of all organic matter in the SDPM. 5g weight of samples were placed in a crucible which were then heated to 400°C overnight (Blume *et al*., 1990; Nelson & Sommers, 1996; ASTM, 2000).The sample were then be cooled in a desiccator and weighed. The procedure was repeated 3 times. Organic matter content was calculated as the difference between the initial and final sample weights divided by the initial sample weight times 100%. The ratio was calculated by dividing total organic carbon with the Nitrogen all present in the samples.

$$\text{C/N ratio} = \frac{Total\ Organic\ Carbon}{Nitrogen}$$

3.4 Step 2: Production and analysis of raw biogas

3.4.1 Design of the biogas digester

The design of the digester was made to allow continues gas production by having an inlet and outlet for feedstock and sludge respectively. The design also included the

water trap part to remove water vapour, saw dust for removal of the Hydrogen sulphide and Concentrated Sodium Hydroxide as in the figure 3.2 below

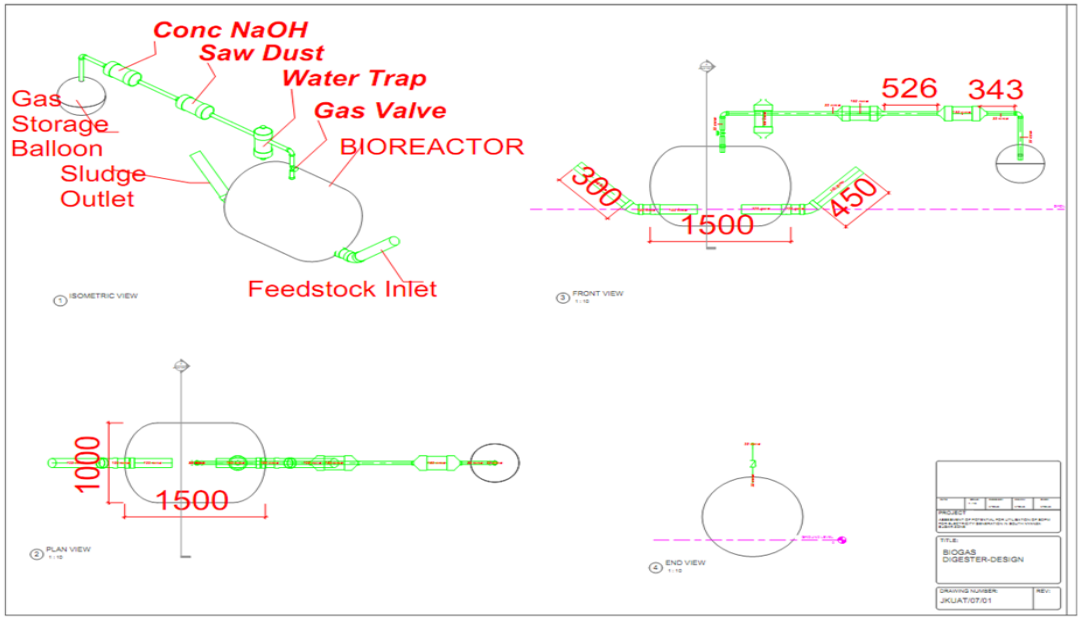


Figure 3.2: Design of the bioreactor

3.4.2 Fabrication of the biogas digester

The digester was made from gas balloon which had been used and abandoned. The gas balloon was of 3 M^3 of capacity and was reduced to 1.18 M^3 capacity. The sizing of the digester was done with the help of the tent makers and a plumber within Juja community.

The digester was made in such that the inlet was 0.45m with 45° elbow and outlet was about 0.3m both of 0.1m pipe and connecting beds and biogas gasholder valve of PVC pipe of diameter 0.032m for gas collection. The below Plate 3.6 illustrate fabrication of the digester from the gas balloon.

a. During fabrication	b. Inflated Bioreactor
	

Plate 3.6: Fabrication process

3.4.3 Setting up of the digester

The fabricated digester was set up in JKUAT, IEET site. Digging was done to about 300mm deep to create a good bed to lay the digester. The digester was then laid on the bed carefully ready for loading with the feed stalk (Sugar Derived press mud). Plate 3.7 show the installation process of the bioreactor on the ground.

a. Laying of the digester	b. Fixing of Gas valve
	

Plate 3.7: setting up of digester

3.4.4 Loading/feeding of the digester

a) Weighing of feeding stalk

Sugar press mud collected from the three Sugar Company was weighed using a beam balance scale of accuracy of ±1kg. The beam balance maximum weight was 10kg so the weighing was done in beats. 60 kg of sugar press mud was weighed and transferred into a big bucket of larger capacity ready for mixing with water. Plate 3.8 is an illustration on how the SDPM was weighed ready for mixing with cow dung in the ration of 3:1 respectively (Rouf *et al*., 2010).

a. **Weighing of SDPM on balance**	**b. Weighing of Press Water**
	

Plate 3.8: Weighing of the raw material

b) Water addition and mixing

Equal amount of water to sugar press mud was also weighed using the beam balance 60kg and mixing was done in mixing bucket which acted as mixing tank before loading. Mixing was done thoroughly all the press mud uniformly dissolved to form mud solution. This was done as presented below in the plate 3.9.

a. **Addition of water**

b. During mixing

Plate 3.9: Mixing of feed stock

c) Inoculation

During clarification of sugar juice to remove sugar press mud, juice being subjected to high temperatures of 132℃ (Hugot E. 1986), and at that temperature bacteria presence are minimal. This called for inoculation to be done. Cow dung was used as an inoculant in the ratio of 1:3 only on the first feeding to provide bacteria. Cow dung weight was 20 kg to arrive at mixing ratio of 1:3:3 for cow dung, sugar press mud and water respectively (Njogu *et al*, 2015).

d) Loading

After mixing of the three components, manual load/feeding of the digester was in portions. Second loading was done after 20 days when the production rate of the gas had reduced. Plate 3.10 shows the loading of the bioreactor.

a. **During Feeding**

b. **After Feeding**

Plate 3.10: Loading of bioreactor (plate a.)

3.4.5 Production Biogas

Biogas yield realisation started on the third day after feed. This was seen as the swelling of the digester began. The production rate was captured through connection to a biogas flow meter which was calibrated in Litres. The flow meter was read every day for 3 weeks and the new volumes were recorded to help in determination of the flow rate of the gas and also to calculate the production rate compared to mass loaded.

The gas after passing through the flow meter was collected in a balloon which was locally modelled as a biogas collector. The excess gas was burnt in air to avoid air pollution and emission.

Biogas collection was done at two points. One collection point was at next to the digester before cleaning and two after passing through cleaning process. The collected biogas was taken to the laboratory for analysis. Plate 3.11 show different process during biogas production as illustrated in individual plates.

a. Biogas in the digesture

b. **Release of gas**

c. Biogas meter for Daily readings

d. **Burning of biogas produced**

Plate 3.11: Biogas production plate a and b, meter reading plate c. and burner d.

3.5 Step 3: Biogas composition analysis

The raw biogas was analysed using gas chromatography analyser (GC-8A Shimadzu model) under operating conditions. The gas was sampled using gas sampling balloons and injected into the detector without any pre-treatment. The samples were run in

triplicates for raw biogas and upgraded gas. The peak areas were determined and gas composition derived in percentages.

3.5.1 Determination of CH_4, CO_2, N_2 and H_2S

The GC-8A (Shimadzu) Gas Chromatograph in the Food Science Laboratory at JKUAT was used to perform the biogas chromatography in the sample raw biogas. The main components of the GC included: carrier gas, flow controls, sample inlet and sampling devices, columns, controlled temperature zone or ovens, detectors and data acquisition systems.

The GC was equipped with a thermal conductivity detector (TCD) and measured the difference in the thermal conductivity of each of the compound in the biogas. The carrier gas used in this application was helium. The output stream of the carrier gas was regulated at 2 bar pressure into the GC. In order to detect CH_4 and CO_2 gases the GC was calibrated with 99.999% standard of the two gases at the start of the study.

The biogas stream for GC analysis was supplied from the digester plants using plastic storage bags. A sample containing 0.2 ml of this gas was sucked from the bags using a syringe and injected into the GC. The separated components were recorded as peaks on the data processor. The operating parameters used for the GC-8A are given in Table 3.1

Table 3.2: GC Operating Parameters

Parameter	**Value**
Detector temperature	150°C
Oven temperature	150°C
Carrier gas	Helium
Carrier gas pressure	2.2kg/cm^2
TCD amplifier	100mA
Column type	Stainless steel/Porapak porous polymer
Column length	3m or 10ft

a. **During filling of compressed gas into balloons**

b. **Collection of the gas after Upgrade in the storage ballon**

c. **Filled balloons with Biogas for lab analysis**

d. **Biogas filled balloons in the lab**

e. **Injection of biogas in GC machine**

f. **Gas chromatography machine**

Plate 3.12: Show the process of gas collection and lab analysis process

3.5.2 Retention time

Retention time of the feedstock (sugar derived press mud) was determined by rate of production of gas in a graph.

3.6 Step 4: Biogas Upgrading and Electricity generation

3.6.1 Biogas cleaning /Upgrade

Apart from methane and carbon dioxide, biogas can also contain water, hydrogen sulphide, nitrogen, oxygen, ammonia, siloxanes and particles. The concentrations of these impurities are dependent on the composition of the substrate from which the gas was produced.

Cleaning/upgrading of the gas was done using saw dust as active carbon for the removal of hydrogen Sulphide and carbon dioxide. To activate the carbon in saw dust, the saw dust undergone pyrolysis in a burning furnace at JKUAT energy workshop at a temperature of 400℃ for half an hours. The char produced was mixed with water and used as an active carbon

3.6.2 Electricity generation

This was done using two Methods: Theoretical Methods and Combustion through small biogas turbine

3.6.2.1 Theoretical Methods

Since the volume of gas produced was little to run the generator for full quantification, we decided to theoretically quantify the electricity that can be produced using the equation below.

A formula to predict on theoretical yields of component products from digestion based on chemical composition by use of Buswell and Boyle scientific formula describing the composition of biogas developed in 1952 (Mark, 2009).

$$Input = output$$

$$C_c H_h O_o N_n S_s + ¼ (4c - h - 2o + 3n + 2s)H_2O \rightarrow 1/8 (4c - h + 2o + 3n + 2s) CO_2 + 1/8 (4c + h - 2o - 3n - 2s) CH_4 + n NH_3 + s H_2S$$

Energy value of methane:

$$1\,m^3\,methane\;=\;36MJ$$

$$1\;kWh\;=\;3.6\;MJ$$

$$1\quad m^3\,methane\;=\;10\;kWh$$

3.6.2.2 Combustion through small biogas turbine

A small generator of rating 50kVA and of power factor 0.8. The generator was used to run on the SDPM biogas as in the Plate 3.13

a. **Genset Rating**

b. Gensent during Burning

Plate 3.13: Electricity generation

3.7 Data management and analysis

Statistical analysis of data was done using analysis of variance (ANOVA)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Feed stock characterization

Characteristics of press mud are given in Table 4.1 which shows the averages of parameters from the three sugar industries where the samples were collected.

Table 4.1: Characteristics of the sugar press mud (source: Author)

Parameter	*Sony sugar company*	*Transmara sugar company*	*Sukari industry*	*Mean ±SD*
Moisture (%)	67.7	63.7	60.1	63.1±3.1
Solids (%)	32.3	36.3	39.9	36.2±3.1
Volatile Matter (%)	87.0	83.2	79.9	83.4±2.9
Ash (%)	13.0	16.8	20.1	16.6±2.9
Fibre (%)	15.5	23	18.7	19.0±3.8
Sugars (%)	5.4	6.7	6.8	6.3±0.61
Nitrogen (%)	4.8	3.7	4.3	4.3±0.3
Organic Carbon (%)	85.8	83.0	82.2	83.7±1.9
C/N Ratio	17.8	22.4	19.1	19.8±2.4
pH of 10% solids	7.4	7.6	7.5	7.5±0.01

N=3 (triplicate sampling tests)

From the test statistic, the two tailed test was ±0.49 this showed that no major significant differences as the deviation was ±5% from the mean as seen from all the three sugar industries parameters. This meant that the weather conditions, cane variety planted, soil content and milling methods are almost/similar in South Nyanza sugar zone. See appendix for more data.

4.1.1 Moisture Content

The moisture content in the samples varied from 60.1 to 67.1% ($\bar{x}\pm SD = 63.1\% \pm 3.1\%$) which is within the range of 60-85% by Desdin *et al*. (1995). However, the moisture contents of press mud from some South African sugar mills in the range of 60-69.6% and from an American sugar mill 57.6% (Dasgupta and Nemerow, 1988) have been reported. This shows a variation ($P \leq 0.05$) compared to other countries. This showed that sugar derived press mud moisture content is within the range conforming to the literature

4.1.2 pH Value

For Biogas generation from press mud, pH values of 6.5-8.5 and maximum in the pH range of 7.0-7.5 is required for high production yield. The samples mean pH value was 7.5 which are good because it falls within the required range of 6.5-8.5. From the literature, pH varies during the processes of biodegradation, having a neutral value was a good indicator.

4.1.3 C/N Ratio

The C/N ratio of the press mud sample varied from 17.8 to 22.4 and the average C/N ratio was found to be19.8±2.4. The value of C/N ratio reported by other investigators was at 17 (Dasgupta and Nemerow 1988) which is just below the research value.

The C/N ratio of the substrate is another important parameter for the biogas production. On the one hand, biodegradation of nitrogenous compounds contributes to the neutral pH stability. The nitrogen is also important for bacterial cell growth, which is an important phenomenon in the whole process of bio-methanation. At low C/N ratio, carbon addition stimulates methane production by reducing ammonia inhibition.

At high C/N ratio, carbon addition decreases the methane yield as nitrogen becomes a limiting nutrient and bacteria suffer a nutrient deficiency. The methane content of biogas also depends on the C/N ratio. At higher C/N ratio, the percentage of methane decreases in the biogas.

4.1.4 Volatile Solids

The press mud used for characterization contained about 79.9-87.0% volatile solids of average 83.4%. VS of cow dung and other feed stocks in the literature was about 80-89% which qualified the samples from the three sugar industries.

4.1.5 Organic Matter

The organic matter present in the press mud consisted mainly of organic carbon (82.2-85.8%), Nitrogen which was between 3.7-4.8%. Sugar which was found to be of average 6.3±0.61%sucrose content showed potentiality as high sucrose content leads to high biodegradation. This is because the chemical composition of press mud depends on the cane variety, soil conditions, nutrients applied in the field, process of clarification adopted and other environmental factors.

The three sugar Companies (SONY, Transmara and Sukari Industiries) where samples were collected from had very minimal variations on the parameters since the cane variety type, soil conditions and climate in the regions where they are located are similar and categorized as one sugar zone.

4.2 Design and Fabrication of laboratory scale bioreactor

The laboratory bioreactor which was fabricated is represented in the Plate 4.1. The reactor was sized in such a form to be cylindrical. The bioreactor had a diameter of 1m and a height of 1.5m. These parameters were used to calculate the volume of the bioreactor as below.

Formula for find the area of a cylinder

$$V = A \times H$$

And $A = \pi R^2$

So the volume will = $\pi R^2 h$

$$V = 3.142 \times 0.5 \times 0.5 \times 1.5$$

$$V = 1.18m^3$$

The capacity of the bioreactor was $1.18M^3$

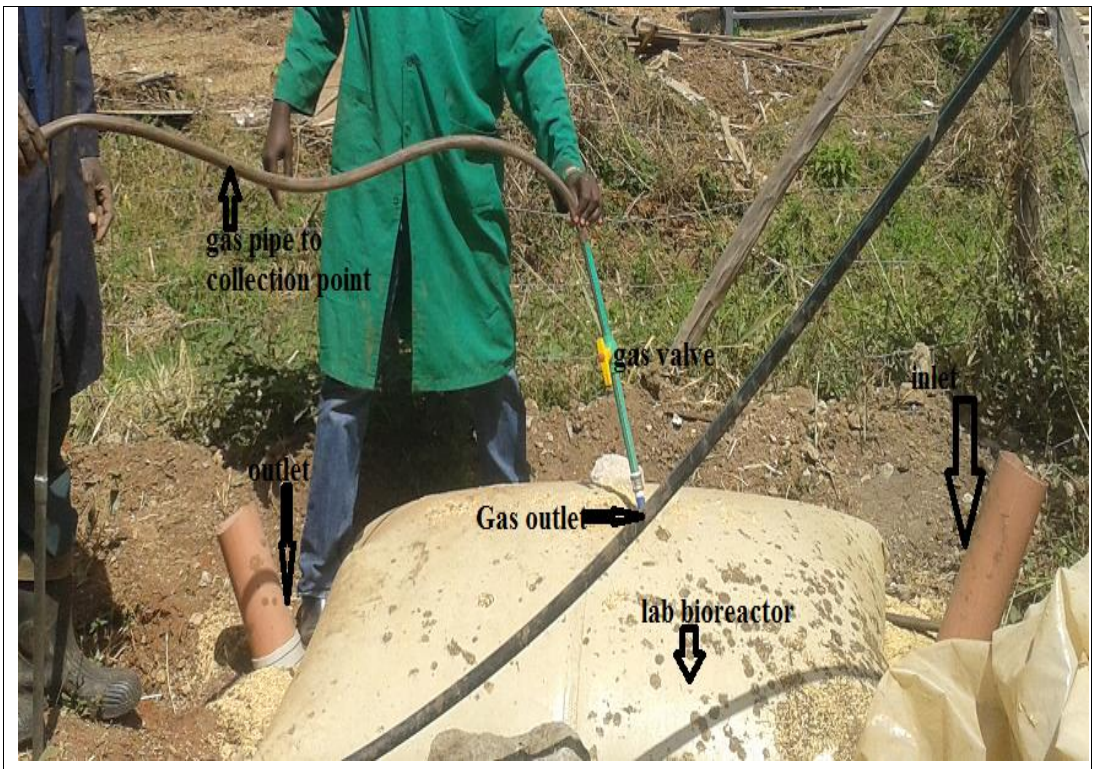


Plate 4.1 : Bioreactor set up

From the bioreactor, the connecting pipe was channelled to the filters and connected to gas collecting balloon which was designed for storage purposes.

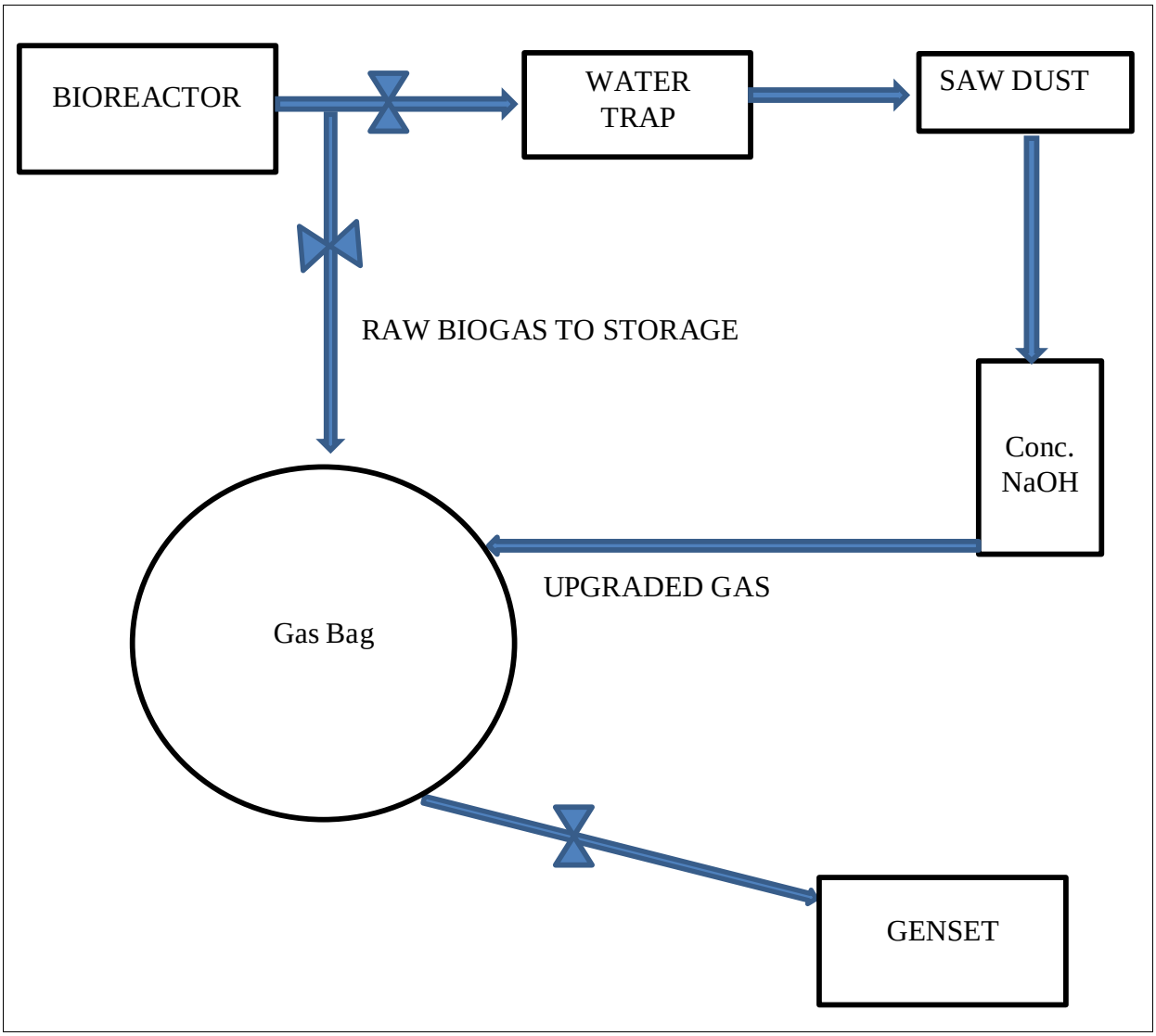
4.3 Biogas production and Process Study

The anaerobic digester plant system used for the production of biogas consisted of digester, vapour collecting bottle with water inside, gas transport pipes, control valves, biogas flow meter, saw dust adsorbent, gas burner, gas storage balloon and coarse and fine fabric filters as represented in Figure 4.1.

Figure 4.1: The schematic diagram represents the whole production process of Biogas

4.3.1 Daily Gas Production

The figure 4.2 represents the volumes of daily gas present on graph and it shows a cone shape trend. It was observed that gas generation started on the 3rd day of feeding



the digesters with the slurry. The rate of gas generation gradually increased with increasing the digestion period. The graph also indicates that during the digestion period, most of the daily gas production range was 1-33 liters of volume. In this reactor, the peak gas production of 33 liters was observed on the 8th day. It was observed that gas production rate declined after 13th day.

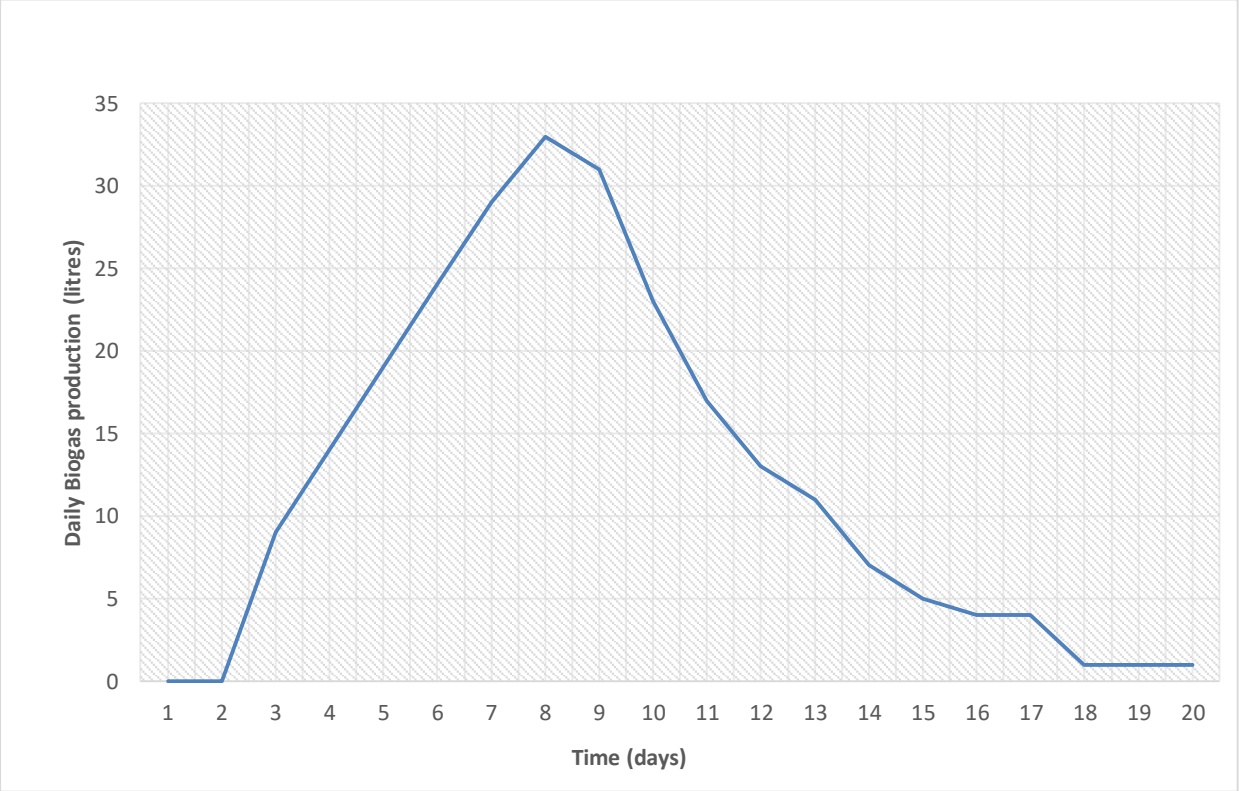


Figure 4.2: Biogas production against Time

This peak production day was established to be related to the growth of bacteria within the digester and after that the bacteria start to starve and competition for food lead to elimination of the bacteria. The reduction in population of the microbes lead to a significant drop in gas production. This can be adjusted by constant production of gas through periodic loading of the digester with fresh feedstock.

4.3.2 Cumulative Gas Production

The cumulative gas production from the test reactor operating in the laboratory shows that the lag phase prevailed up to 2 to 6 days of digestion period (Figure 4.3). This was due to microbe limiting at the initial stage of fermentation. The longer the lag phase, the longer the time delay of peak gas generation. After the lag period, the cumulative volume of biogas increased sharply and continued up to 20th day of fermentation period. After which the rate of gas generation decreased and declination continued until the biogas production appeared to be zero.

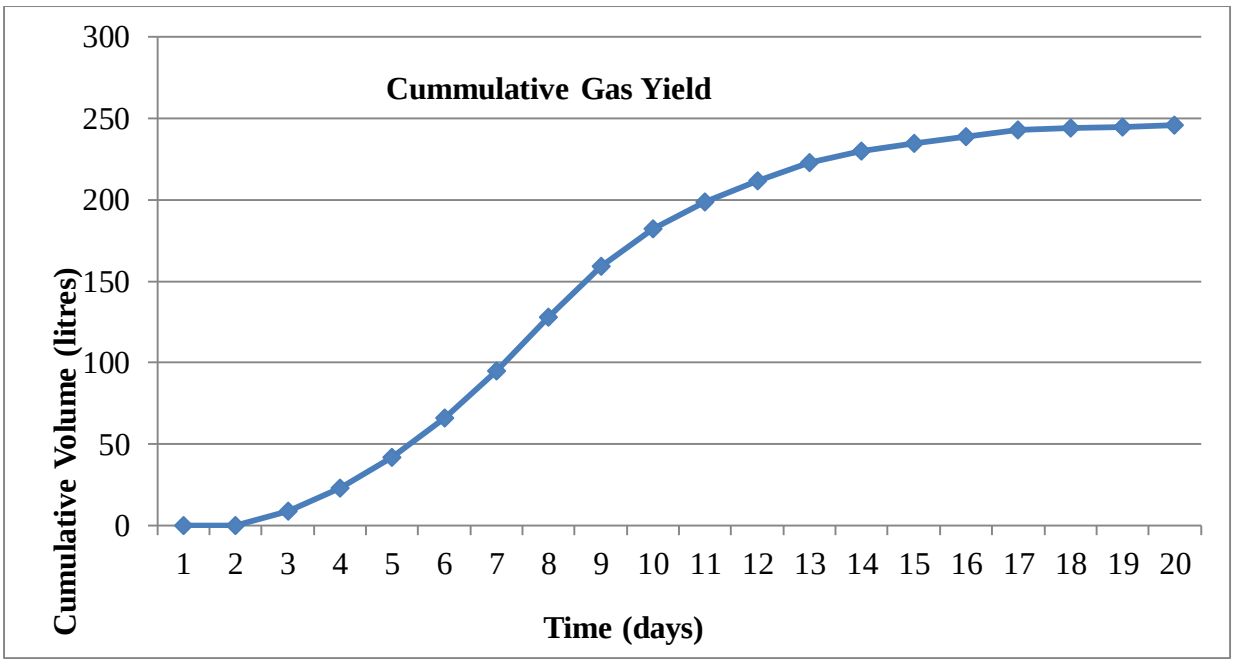


Figure 4.3: Cumulative biogas Volume against Time

When biogas generated from SDPM was compared with other feed stocks such as cow dung and water hyacinth values as reported by Njogu *et al*, (2015), the results were as presented in the figure 4.4.

The cow dung feedstock was found to produce biogas from the 4th day rising to gradually up to 8th day and remained constant reaching maximum between the 28 - 36th days.

The biogas production from the water hyacinth/cow dung mixture showed a different trend; biogas production remained low than that from cow dung between the fourth and the 18th day but rose steadily to reach a maximum at the 32nd day and increased steadily from 32nd to 36th day due to new feeding.

When sugar derived press mud was mixed with cow dung, the production of biogas started in the 4th day increasing rapidly compared to the other two above and quickly reached at the 32nd day.

The trends show a rather similar trend but the delay during the first few days for water hyacinth/cow dung mixture could be attributed to the low bacteria population or dominant activities in the matrix. And for the fast production in the sugar derived

press mud and cow dung showed high rate of bacteria multiplication in the early days of degradation. The study shows a greater yield of biogas from the hyacinth/cow dung mixture compared to cow dung and sugar derived press mud being the least.

The results of the study findings was similar with those reported by other researchers using Sugar press mud as a feed stock (Rouf *et al.*, 2013)

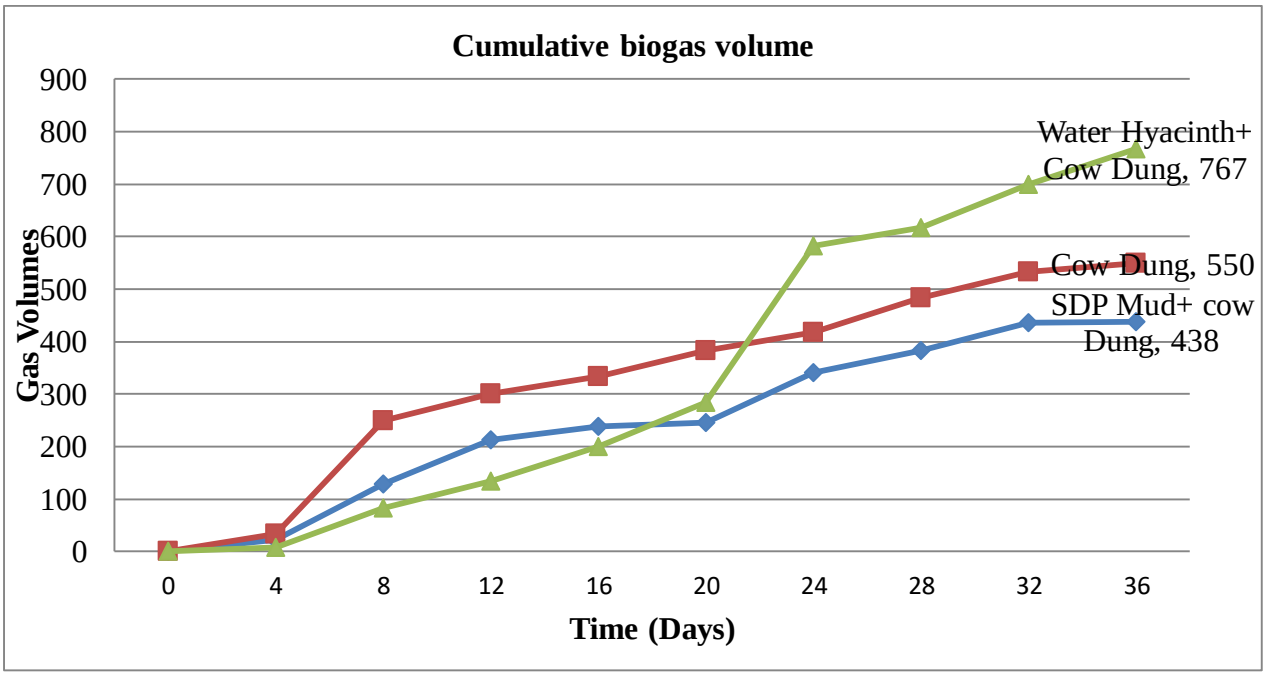


Figure 4.4: Comparative cumulative gas yield from different feedstock

4.3.3Retention time

Retention time is the time needed to achieve the complete degradation of the organic matter. The retention time varies with process parameters, such as process temperature and waste composition. The retention time for waste treated in a mesophilic digester ranges from 15 to 30 days and 12-14 days for thermophilic digester (Fabien, 2003)

The retention time for the set up was between 30 to 33 days where there were no gas being produced and degradation of the feedstock was estimated to be completely done.

4.3.4 Weather conditions during the production Period

The table below show the conditions during the production period.

Table 4.2: Weather conditions

Day	Description	High / Low	Precipitation	Wind	Humidity
Wed AUG 15	Partly Cloudy	78˚54˚	10%	SE 10mph	55%
Thu AUG 16	Partly Cloudy	78˚55˚	10%	SSE 9mph	57%
Fri AUG 17	Partly Cloudy	77˚56˚	10%	SSE 8mph	60%
Sat AUG 18	Cloudy	77˚57˚	10%	SSE 9mph	63%
Sun AUG 19	Cloudy	77˚58˚	10%	SSE 8mph	61%
Mon AUG 20	Mostly Cloudy	77˚58˚	10%	SSE 9mph	59%
Tue AUG 21	Cloudy	77˚58˚	10%	SSE 9mph	60%
Wed AUG 22	Mostly Cloudy	77˚58˚	20%	SSE 8mph	60%
Thu AUG 23	Mostly Cloudy	77˚58˚	10%	SSE 8mph	61%
Fri AUG 24	Mostly Cloudy	77˚59˚	20%	SE 8 mph	62%
Sat AUG 25	Partly Cloudy	78˚59˚	20%	SE 8 mph	61%
Sun AUG 26	Partly Cloudy	79˚59˚	20%	SE 8 mph	58%
Mon AUG 27	Mostly Cloudy	79˚58˚	20%	SE 8 mph	59%
Tue AUG 28	Partly Cloudy	80˚58˚	20%	SE 8 mph	56%
Wed AUG 29	Partly Cloudy	80˚59˚	20%	SE 8 mph	54%

Source: Weather Channel.

https://weather.com/weather/tenday/l/Juja+Kenya+KEXX1743:1:KE

4.4 Biogas composition analysis

4.4.1 Composition of raw biogas

Biogas produced during anaerobic digestion is primarily composed of methane (CH_4) and carbon dioxide (CO_2), with smaller amounts of hydrogen sulphide (H_2S) and ammonia (NH_3) (Fabien, 2003).

Compositional data analysed from GC machine for the SDPM raw biogas was as presented in Table 4.2. The gas was found to contain a mixture of gases. On average

range, Methane (CH_4) 50- 52%, 30-32% Carbon dioxide (CO_2), Nitrogen (N) 13-15% and traces of Hydrogen Sulphide (H_2S) 1-4%.

Table 4.3: **Composition Data for SDPM Raw biogas**

Gas	Retention Time (Seconds)	Percentage composition (%)
Carbon dioxide	0.812	30-32
Nitrogen	1.006	13-15
Methane	1.304	50-52
Hydrogen sulphide	4.688	1-4

Njogu *et al*, (2015) and Chege, (2015) reported that the composition of the biogas depend on the feed stock used. Table 4.3 shows composition of raw biogas from water hyacinth inoculated with cow dung and from cow dung as the only raw material.

Table 4.4: **Composition analysis for raw biogas from other feed stock**

Element	Water Hyacinth+ Cow Dung (Njogu et al, 2015) in %	Cow Dung (Chege, 2015) in %
Carbon dioxide	21-29	25-36
Nitrogen	17-19	15-18
Methane	49-53	46-53

From the above results, there was a deviation of ±4% of biogas composition from different feedstock used. These results show that there is not much difference among the digesters regarding the CH_4 and CO_2 content. However the difference in the feedstock explains that some materials are more easily degradable breaks fast in comparison with complex materials and this being the reason for the slight variations of the composition percentages. The findings also showed that the comparisons of

CH_4 yields reported in the introduction cannot be precise because of possible differences in the feedstock and the experimental conditions.

The data obtained from the GC analysis in terms of the composition agreed with the literature review although the concentration of the CH_4 is low while that of CO_2 is high this might have been as a result of feedstock composition.

4.4.2 Composition of cleaned biogas

Compositional data for the cleaned biogas was presented in Table 4.4. The gas was found to contain a mixture of gases. The average range are Methane (CH_4) 70- 72%, 6-9% Carbon dioxide (CO_2), Nitrogen (N_2) 15-19% and traces of Hydrogen Sulphide (H_2S) 1-2%.

Table 4.5: **Composition Analysis for cleaned SDPM biogas**

Element	Time	Percentage composition
Carbon dioxide	0.812	6-9
Nitrogen	1.006	15-19
Methane	1.304	70-72
Hydrogen sulphide	4.688	1-2

According to Njogu *et al* 2015, below is result of the composition analysis for the biogas after upgrading from the feed stock water hyacinth plus cow dung as in Table 4.5.

Table 4.6 : **Composition analysis for clean biogas from water hyacinth**

Element	Time	Percentage composition
Carbon dioxide	1.62	4-8
Nitrogen	1.02	19-27
Methane	1.12	65-73

From the above results, it depicted that although different feedstock were used and methods of cleaning biogas were employed. The deviation was ±4% when compared with other upgraded biogas composition.

When the results for raw SDPM biogas on Table 4.2 and upgraded SDPM biogas on Table 4.4 were compared, there was increase in the percentages of Methane (CH_4) and Nitrogen N_2. This may be because their volumes were not interfered during cleaning of the biogas process hence their concentration in the composition increase. For the values of hydrogen sulphide (H_2S) and Carbon (IV) Oxide (CO_2) decreased significantly by a bigger margin. This shows that the aim of cleaning process was to efficient enough to clean other unwanted gas compounds in the mixture.

4.5 Electricity Generation using SDPM biogas

This was done using theoretical formula and small turbine wo methods:

4.5.1 Theoretical Electricity Generation

Buswell and Boyle scientific formula describing the composition of biogas developed in 1952 was used to calculate theoretical electricity yields of component products from digestion based on chemical composition.

$$Input = output$$

$$C_c H_h O_o N_n S_s + ¼ (4c - h - 2o + 3n + 2s) H_2O \rightarrow 1/8 (4c - h + 2o + 3n + 2s) CO_2 + 1/8 (4c + h - 2o - 3n - 2s) CH_4 + n NH_3 + s H_2S$$

Gas composition based on percentage of elements by weight:

$$(C_c H_h O_o N_n S_s): C_c = (12 * 4.17), \quad H_h = (1 * 7.90), \quad O_o = (16 * 2.44), \quad N_n = (14 * 0.44), S_s = (32 * 0.04)$$

$$[¼ (4c - h - 2o + 3n + 2s) H_2O] = 1.32$$

Table 4.7: Gas elemental composition based on percentage of elements by weight

Input elemental composition	Atomic weight	Empirical formula	Percentage input elemental composition
C	12	4.17	50.4
H	1	7.9	7.9
O	16	2.44	39.4
N	14	0.44	6.16
S	32	0.04	1.28
H_2O			1.32

Output percentage composition from Buswell equation:

$$1/8\,(4c - h + 2o + 3n + 2s)\,CO_2 + 1/8\,(4c + h - 2o - 3n - 2s)\,CH_4 + n\,NH_3 + s\,H_2S$$

$$1/8\{\,(4 * 4.17) - (7.90) + (2 * 2.44) + (3 * 0.44) + (2 * 0.04) = 1.88\,CO_2$$

$$1/8\{\,(4 * 4.17) + (7.90) - (2 * 2.44) - (3 * 0.44) - (2 * 0.04) = 2.29\,CH_4$$

$$0.44\,NH_3$$

$$0.04\,H_2S$$

Table 4.8: Output percentage composition of Biogas

Output	Empirical formula	Gas composition based on % of elements by weight	Percentage composition for CO_2 and CH_4 only
CO_2	1.88	40.5	45.1
CH_4	2.29	49.3	54.9
NH_3	0.44	9.5	
H_2S	0.04	0.8	

From Buswell equation, 45% is CO_2 and 55% is CH_4. Therefore to estimate the biogas and energy yield:

- Calculate the carbon content of the wet boiwaste.

140 kg of bio-waste:
Solid content =80 kg (57.14%)
Water content = 60 kg (42.86%)
Organic Dry Matter (ODM) = 23.2 kg (16.59%)
Residue non degradable solids = 4.76 kg (3.40 %)
Residue organic solids = 23.2*60/100 = 13.92 kg
Thus the digester solids will be 4.76 kg + 13.92 kg = 18.68 kg

From Buswell and Boyle's equation: ODM in 23.2 kg wet boiwaste has 50.4 % carbon content

$$(23.2 * 50.4/100) = 11.69 kg\ C$$

If carbon (C) biodegraded is 60%, then

$$(60/100 * 11.69) = 7.01\ kg\ C$$ Was converted to biogas

Form Buswell equation, 55% is CH_4 and 45 % is CO_2
Thus the weight of methane-carbon:

$$(CH_4 - C) = (7.01 * 55/100) = 3.86\ kg\ C$$

Weight of methane (CH_4)

$$(3.86\ kg * 16/12) = 5.144\ kg\ CH_4$$

Energy equivalents:

$1\ mol\ gas\ at\ STP$
$= 22.4\ liters$

$$16\ g\ CH_4 = 22.4\ liters$$

$$\text{Thus: } 5143.6\ g\ CH_4\ =\ 5143.6/16\ moles$$
$$=\ 321.475\ moles\ CH_4$$

$$321.475\ *22.4\ =\ 7201.04\ liters\ CH_4$$
$$=7.20\ m^3\ \ CH_4$$

Therefore:

140 kg biowaste of Sugarcane derive press mud and cow dung produced:

$$7.20\ m^3\ CH_4\ +\ 5.89\ m^3\ CO_2\ =\ 13.09\ m^3\ biogas$$

Energy value of methane:

$$1\ m^3\ methane\ =\ 36MJ$$
$$1\ kWh\ =\ 3.6\ MJ$$
$$1\ m^3\ methane\ =\ 10\ kWh$$

$$Thus: 140\ kg\ wet\ biowaste\ energy\ value$$
$$=\ 7.20\ m^3\ \ CH_4\ *\ 10\ kWh\ /\ m^3\ CH_4$$

$$=\ \mathbf{72.0\ kWh}$$

4.5.2 Use of Small Turbine for Combustion

4.5.2.1 Clean Biogas Produced

From page 48 Figure 4.4 from the mixing ratio of SDPM to Cow dung 3:1 (140kgs) stored biogas 438 litres of biogas. When cleaning was done 25% of Carbon Dioxide and other gases was lost.

Therefore the remaining gas volume was**:** $\boldsymbol{V = 438l \times (100\% - 25\%) = 328.5}$

In the mixture of SDPM and Cow dung of 140kgs produced 328.5litres of clean biogas. Hence 1kg for the mixture: $= \frac{1 \times 328.5}{140}$**=2.34l/kg**

Gas yield per ton from the above equation is:

$$= 1000kg \times 2.34l/kg$$

= 2340L

From the literature review, SDPM is produced in Kenyan Sugar Factory per day is averagely 50 tons (www.kenyasugar.co.ke) and from the South Nyanza Sugar Zone having three Sugar factories of a total capacity 150tons/day.

So when all the SDPM were all converted to biogas, the potential of the gas would be:

$$2340l \times 150 = 351000l \approx 351M^3$$**Per day.**

For the annual potential of SDPM = Volume produced per day multiplied by 365 day in a year.

$$351M^3 \times 365 = 128115M^3/annum$$

4.5.2.2 Power Generation from the Generator

The rating of the small biogas generator used for combustion had the following ratings:

Rated Output: 2.8kW

Maximum Output: 3.1kW

Power factor: 1.0

kW=kilowatt.

The Genset burns 0.9M^3 of Biogas in 1 hour

438 liters volume of the biogas used to run the small biogas generator. From the rating of the generator, the gas of 0.438M^3 run the generator for 30 minutes. Therefore power produced against time is

kWh= kW X h

= 3.1 X .5

= 1.55kWh

So 438L = 0.438 m^3 of produced 1.55kWh

Therefore **1 m^3 = 1.55/0.438**

=3.54 kWh

So, the potential per annum for the power produced within the South Nyanza Sugar Zone would be:

Volume produced Per annum= $\boldsymbol{128115M^3}$

So power which can be generated from SDPM per year

$$= \mathbf{128115}\boldsymbol{M^3}\boldsymbol{X}\ \mathbf{3.54}\boldsymbol{kWh/M^3}$$

$$= \mathbf{453527}\boldsymbol{kWh} \approx \mathbf{453.5}\boldsymbol{MWh}$$

a. Voltmeter during electricity Gen

b. Ac/dc slots

Figure 4.5: Voltage Levels during electricity conversion

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study aimed at assessment of the sugar derived press mud potential to produce biogas which can be used in production of electricity.

The characterization of sugar derived press mud done, showed that SDPM met the thresh hold values for the biogas production and qualified as a feedstock in biogas production. This also answered the research hypothesis question: does biogas produced from Sugar cane derived press mud has no difference from cow dung derived biogas.

Compositional data for the raw biogas on average was; Methane (CH_4) 50- 52%, 30-32% Carbon dioxide (CO_2), Nitrogen (N) 13-15% and traces of Hydrogen Sulphide (H_2S) 1-4%. And when upgraded/cleaned, the average range were Methane (CH_4) 70-72%, 6-9% Carbon dioxide (CO_2), Nitrogen (N_2) 15-19% and traces of Hydrogen Sulphide (H_2S) 1-2%. This improved the concentration of methane to high level suitable for heating and fuel for electricity generation.

From theoretical calculations using Buswell equation, it was found that for every 1 kg of mixed SDPM and cow Dung (inoculant) we can generate 72.0 kWh. When a small generator was used to convert the clean biogas of $1M^3$, 3.54kWh was produced. And when the annual potential of SDPM biogas converted to electric power it was found that it could produce 453.5MWh per annum. These results have proven to be one of the feedstock which can be used well in production of biogas and electricity as the production profiles compares well with those of conventional feed stocks such as cow dung and water hyacinth.

The present methods for disposal of sugar press mud from sugar industry are not environmentally sound. Its disposal is a problem and creates environmental nuisance. But generation of biogas from the substrate will reduce environmental problem.

5.2 Recommendations

Sugar industry is one of the heavy electricity power consumer in the country and by producing the power will reduce their expenditure in power hence low cost of production.

The sugar industry will financially benefit from installation biogas generators, as the economic analysis reveals that the production of biogas and bio-fertilizer from press mud is economically feasible. Furthermore, there is triple benefit associated with the waste bio-methanation as we get clean fuel biogas, enriched manure bio-fertilizer and also hygienic environment.

5.3 Further research is recommended in the following areas:

I. Doing analysis on the characterization of sludge as the degradation and digestion takes place to check and compare with the sugar derived press mud before loading.

II. Production of biogas on large scale by sugar industry and other uses a part from production of electricity.

III. Doing an assessment on the impact of using sugar press mud in production of the biogas to farmers before utilization as fertilizer and how that impact cane yields in their farms and the economic analysis.

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APPENDICES

Appendix 1: Published paper and Proceedings

Paper

Nyonje E.O, Njogu P and Kinyua R. (2015): "Assessment of the potential for utilization of sugarcane derived press mud for Biogas generation in South Nyanza sugarcane zones, Kenya". *Journal of Sustainable Research in Engineering* 1(4) 2014, 30-33. http://www.jkuat-sri.com/ojs/index.php/sri/issue/view/13

Proceedings

Nyonje E. O, Njogu P. and Kinyua R. (2014) Assessment of the potential for utilization of sugarcane derived press mud for Biogas generation in South Nyanza sugarcane zones, Kenya. *Proceedings of 2014 International Conference on Sustainable Research and Innovation*, Volume 5, 7th-9th May 2014.

Nyonje E. O, Njogu P. and Kinyua R. (2014) Characterization and Utilization of Sugarcane derived press mud for Electricity generation in Sugar industries, Kenya. *Proceedings of 2014 International Conference on Sustainable Research and Innovation*, Volume 9, 13th-9th November 2014.

Appendix 2: Individual Sugar industry SDPM results

SUGAR INDUSTRY	CRUCIBLE WEIGHT (g)	SAMPLE + CRUCIBLE(g)		SAMPLE (g)	ASH +CRUICIBLE(g)	ASH(g)	ASH %(g)	
SUKARI 1	42.4933	45.0617		2.5684	42.8625	0.3692	12.9747070799	
SUKARI 2	36.335	39.1483		2.8133	36.7028	0.3678	13.073614 62	
TRANSMARA 1	45.6644	49.1979		3.5335	46.3229	0.6585	18.635913 4	
TRANSMARA 2	34.9465	38.0946		3.1481	35.5392	0.5927	18.827229 12	
SONY 1	36.8908	39.0357		2.1449	37.3317	0.4409	20.555736 86	
SONY 2	41.5832	44.24383		2.66063	42.2784	0.6952	20.129149 86	

SUGAR INDUSTRY	POL %	AVERAGE						
SUKARI 1	6.82	6.875						
SUKARI 2	6.93							
TRANSMARA 1	6.69	6.69						
TRANSMARA 2	6.79							
SONY 1	5.68	5.425						
SONY 2	5.27							
SUGAR INDUSTRY	DISH + LID	DISH+LID+SAMPLE	SAMPLE	DISH+LID+SAMPLE (AFTER)	MOISTURE	MOISTURE %		
SUKARI 1	28.2958	40.0025	11.7067	32.0356	7.9669	68.0541919		

SUKARI 2	38.015	49.1164	11.1014	41.6308	7.4856	67.429333 24		
TRANSMARA 1	35.442	46.7067	11.2647	39.5635	7.1432	63.412252 43		
TRANSMARA 2	38.4477	49.7242	11.2765	42.5126	7.2116	63.952467 52		
SONY 1	35.1409	46.01	10.8691	39.5036	6.5064	59.861442 07		
SONY 2	37.4088	48.1342	10.7254	41.657	6.4772	60.391220 84		
SUGAR INDUSTRY	CRUCIBLE WEIGHT	SAMPLE + CRUCIBLE	SAMPLE	ASH +CRUICIBLE (AFTER HEATING)	ORGARNIC CARBON	O C %		
SUKARI 1	38.2921	43.4449	5.1528	39.0189	4.426	85.895047 35		

SUKARI 2	39.114	44.2605	5.1465	39.849	4.4115	85.718449 43		
TRANSMARA 1	47.026	52.4756	5.4496	47.9895	4.4861	82.319803 29		
TRANSMARA 2	46.5763	51.6116	5.0353	47.3957	4.2159	83.726888 17		
SONY 1	48.1076	53.1247	5.0171	49.1753	3.9494	78.718781 77		
SONY 2	42.7068	47.7419	5.0351	43.432	4.3099	85.597108 3		
ASH +CRUICIBLE (AFTER HEATING)								
SUGAR INDUSTRY	CRUCIBLE WEIGHT	SAMPLE + CRUCIBLE	SAMPLE	AFTER HEATING	VOLATILE MATTER	VM %		
SUKARI 1	38.2921	43.4449	5.1528	39.0089	4.436	86.089116 6		

SUKARI 2	39.114	44.2605	5.1465	39.7314	4.5291	88.003497 52		
TRANSMARA 1	47.026	52.4756	5.4496	47.9773	4.4983	82.543672 93		
TRANSMARA 2	46.5763	51.6116	5.0353	47.3877	4.2239	83.885766 49		
SONY 1	48.1076	53.1247	5.0171	49.143	3.9817	79.362579 98		
SONY 2	42.7068	47.7419	5.0351	43.6965	4.0454	80.343985 22		
PROTEIN								
SUGAR INDUSTRY	FINAL VOLUME	INITIAL VOLUME	VOLUME USED	AVERAGE	%NITROGEN			
BLANK	0.7	0	0.7	0.7				
SUKARI 1	6.8	0.7	6.1	5.55	48.50776			

SUKARI 2	11.8	6.8	5					
TRANSMARA 1	14.3	11.8	2.5	2.7	3.700432			
TRANSMARA 2	17.2	14.3	2.9					
SONY 1	21.2	17.2	4	4.3	43.00688			
SONY 2	25.8	21.2	4.6					
C.O.D								
SUGAR INDUSTRY								
Ferrous Ammonium Sulphate used= 0.1M								
SAMPLE 10%(0.5mls)	**START MLS**	**END MLS**	**TITRE MLS**	**BLANK TITRE**	**Molarity of FAS**	**mls Sample used**	**COD as mg O2/L**	

BLANK 1	3.1	7	3.9	3.9	0.1	0.5	0	
BLANK 2	0	3.9	3.9	3.9	0.1	0.5	0	
SUKARI 1	0	3.1	3.1	3.9	0.1	0.5	1280	
SUKARI 2	3.1	4.1	3	3.9	0.1	0.5	1440	
TRANSMARA 1	4.1	6.4	2.3	3.9	0.1	0.5	2560	
TRANSMARA 2	6.4	8.9	2.5	3.9	0.1	0.5	2240	
SONY 1	8.9	12	3.1	3.9	0.1	0.5	1280	
SONY 2	12	15.1	3.1	3.9	0.1	0.5	1280	
FIBRE % (100GM SAMPLE)								
SUGAR INDUSTRY	WEIGHT OF THE SIEVE	WEIGHT SIEVE PLUS SAMPLE		WEIGHT OF DRY SAMPLE PLUS SIEVE		WEIGHT OF DRY SAMPLE		FIBRE %

SUKARI	174.73	274.73		190.23		15.5		15.5
SONY	174.66	274.66		197.63		22.97		22.97
TRASMARA	174.68	274.68		193.33		18.65		18.65

PH ANALYSIS

SUGAR COMPANIES	SAMLPE 1	SAMPLE 2	AVERAGES
TRANSMARA	7.58	7.77	7.675
SONY	7.67	7.03	7.35
SUKARI	7.61	7.57	7.34