Co-Digestion of Sweet Sorghum Bagasse with Scientific and Crude Glycerols for Electricity Generation

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Abstract—With the global fossil fuel supplies dwindling and the alarming increase of carbon dioxide in the atmosphere, the need for alternative, clean energies, from carbon neutral sources is pressing. This impetus advanced research on microbial fuel cells to increase the current produced during the bioelectrochemical process. The beneficiation of abundant biomass such as sweet sorghum bagasse, and crude glycerol could contribute to maintain high level of power in the MFC. The influence of pretreatment and co-digestion on the utilisation of sweet sorghum bagasse in the MFC was investigated in this study. The results showed that pretreatment allowed the release of simple carbohydrates and improved the utilisation of sweet sorghum bagasse in the MFC; maximum power density (11 mW/m²) was achieved from the co-digestion of pretreated bagasse and crude glycerol at relatively lower concentrations. Co-digestion of adequate amounts of pretreated sweet sorghum bagasse and crude glycerol improve the power output in the MFC.

Keywords—Microbial Fuel Cell, co-digestion, waste beneficiation, electricity generation, crude glycerol, sweet sorghum bagasse

I. INTRODUCTION

Approximately 15% of South Africans do not have access to electricity, a situation likely to worsen in the next 20 years as it is expected that electricity’s demand will double [1]. The country relies mostly on coal combustion for electricity generation; however the South African coal reserve is estimated to last for only 50 years; without alternative source of energy the company responsible of electricity supply (ESKOM) will struggle to meet the demand.

Bioelectrochemical systems, typically microbial fuel cells (MFCs), have emerged as promising technologies for energy generation. In the microbial fuel cells or MFC, the substrate is broken down to carbon dioxide and water while continuously producing electricity as useable by-products [2]. MFC could therefore be considered as a reliable source for domestic energy, since it relies on the degradation of substrate by microorganisms for electricity generation. Currently, substantial energy is being lost from waste or in treatment processes; microbial fuel cells can utilize these lost energies [3].

The unique way in which microbial fuel cells function, gives them distinct functional advantages over other conventional technologies used for generating energy from organic matter. The way in which microbial fuel cells directly convert substrate energy into useable electrical energy enables for a high conversion efficiency. Microbial fuel cells have the ability to operate at ambient or even at low temperatures, which is a major advantage over conventional bio-energy processes [4].

Minimization of the cost involved in the process is very important for its sustainability. Hence the need to maximize the beneficiation of waste byproducts in such systems. Crude glycerol is a byproduct from the biodiesel plant while sweet sorghum bagasse is a waste generated from the agricultural sector. Sweet sorghum bagasse being a lignocellulosic biomass, could not be easily digested by microorganisms, hence the consideration of two approaches to facilitate oxidation of the bagasse in the system: the use of crude glycerol and scientific glycerol to stimulate the activity of microorganisms or the pretreatment of the bagasse to get rid of the lignin.

The objective of this study is to investigate the beneficiation of sweet sorghum bagasse through co-digestion with scientific and crude glycerol in sewage wastewater for electricity generation.

II. METHODOLOGY

A. Substrates and Materials

Sweet Sorghum Bagasse
Sweet sorghum bagasse grown, harvested and pressed at the Potchefstroom College of Agriculture (26°43′40.2″S 27°04′53.2″E) was collected and exposed to the sun to allow
for drying. The bagasse was then milled as soon as it was sufficiently dried. A rotary hammer mill was used to mill the bagasse to sizes of 3 mm or less. Once the milling was completed the bagasse was stored in a breathable bag for later use at a room temperature of 22°C.

**Pre-treatment of Bagasse**

The milled and dried bagasse was transferred into a 2 litre container up to the 1200 ml mark. For the pre-treatment with slacked lime, 1 gram of slacked lime was added for each ten grams of bagasse, requiring 27.1 g of slacked lime for the 270.8 g of the bagasse in the container. Then the 2 litre container was filled to the 2000 ml mark with de-ionized water.

The container was then closed and the contents shaken to distribute the slacked lime throughout the container. The container was thereafter placed in a pot of boiling water. Once boiling started, the mixture was left for two hours and stirred occasionally.

Once the boiling of the mixture was completed the container was left to cool for 18 hours followed by neutralization of the mixture with a diluted 98% sulphuric acid mixture. Thereafter the container was closed and stored in a refrigerator for later use.

**Scientific Glycerol**

The scientific glycerol used during the experiment was purchased from Associated Chemical Enterprises (ACE, SA) batch number 29267.

**Crude Glycerol**

The crude glycerol used during the experiment was collected from the Pukki Diesel Plant (S26°41’26” E27°05’36””) on the engineering campus of the NWU Potchefstroom Campus. Once collected the crude glycerol was left open overnight for the residual methanol to evaporate.

**Inoculum**

The inoculum chosen for this experiment was the sewage. The sewage was harvested from the Potchefstroom Sewage Treatment Plant (S26°43’40.2” E27°04’53.2””). The sample was taken at the weir of the primary clarifier. This site of sampling ensures no biological treatment took place, with only physical treatment occurring. Samples (2 l) were collected early the morning prior to the experiment to minimize changes resulting from microbial activities.

**B. Microbial Fuel Cells Setup**

**Proton Exchange Membrane**

For the experiment a CMI-7000S Cation exchange membrane was used. The membrane was obtained from Membranes International (USA). For optimal fitment and leak free operation the membrane was cut into circles with a diameter of 23 mm before each run.

**Microbial Fuel Cell Glassware and Membrane Fitting**

A double chamber microbial fuel cell was used in this study. The glassware was made to the desired specification (Instrumentation Department, NWU Potchefstroom). To ensure leak free operation marine silicone has used as a sealant. Both sides of the microbial fuel cell flanges were coated with a thin layer of silicone and the membrane placed between them. The flanges were then pressed together to allow for a sufficient seal. The flanges where subsequently bolted together using two U-clamps to ensure no movement or distortion of the seal. Once the assembly was completed the glassware was left for 24 hours to dry.

**Electrode Preparation**

The electrode material chosen for this experiment was 200GSM Plain Weave carbon fibre cloth obtained from AMT Composites (SA). The carbon fibre cloth was cut into squares, the edges were subsequently covered with duct tape to ensure no unravelling of the fibre occurs during setup or operation. Both the anode and cathode electrodes consisted of the same materials with the same operational area.

Once the electrodes were prepared the wires were weaved through the cloth, ensuring adequate contact for electron transfer.

**Wiring of Microbial Fuel Cell**

The wire used to connect the two electrodes is standard communications cable purchased from the NWU Potchefstroom electrical store. The resistors used are 1k ohm multi-turn trim-pot or trimming potentiometers, also purchased from the electrical store. The multi-meters used to measure the voltage drop over the resistors are UNI-T DMM 3D5 units. Figure 1 shows the wiring diagram of the microbial fuel cell. The resistors where wired in series with the wire passing through a switch. The multi-meters were wired in parallel across the resistor. This allowed the resistor to be set to the correct resistance while the circuit was broken and the microbial fuel cell to function normally while the circuit is closed.

![Fig. 1 Schematic representation of wiring diagram](Image)

**Gas Capture Setup**

To gage the activity of the microbial fuel cells a quantitative measurement of the gas was required. This entailed capturing the gas formed in the anode compartment. The gas captured was routed, via 5 mm flexible tubing, to a 1 litre Erlenmeyer flask filled to the top with water and a pressure relief line routed from the bottom of the flask to allow the water to escape. Any gas given off by the microbial process increases the pressure in the flask forcing the water to be expelled from the flask. This setup allows airtight
operation while being able to estimate the activity of the microorganism.

To ensure no gas escapes the system the bottle caps on the anode side were sealed around the gas capture line and the electrical wire.

Anode and Cathode filling

1) Cathode Electrolyte and Filling

For the microbial fuel cell to function correctly the cathode compartment has to be able to transmit electrons. This is done by adding an electrolyte. Rather than using tap water, which could lead to membrane fouling, de-ionized water was used and an electrolyte added to facilitate the electron transfer.

2) Anode Filling

The anode compartment was filled with various combinations and concentrations of substrate. One of the microbial fuel cells was always run as a baseline, being filled only with sewage inoculum. The control microbial fuel cell consisted of 300 ml of sewage.

The remaining five microbial fuel cells where filled with given volumes of sewage and biomass. The volume of the biomass was varied to investigate the effect on the power output. The substrates varied in this study included: untreated bagasse, pre-treated bagasse, crude glycerol and scientific glycerol, the effect of their concentrations was also investigated. The anode was purge with nitrogen prior to the start of the experiment to create an anaerobic compartment.

C. Data Capture

The pH of the anodic chamber was recorded before each run was started and once it was completed. The baseline voltage was recorded at the start, subsequent readings of both the voltage and gas displacement occurred at 24 hours intervals for 5 days with the resistor kept at 900 Ω for the duration of the run.

D. Calculation of Current and Power Density

The voltage (V) was measured using the multimeters and the resistance (R) set to 900 Ω, the current (I) could be calculated using Ohm’s law, given as:

\[ I = \frac{V}{R} \]  

The current density could also be calculated using the equation below:

\[ I_d = \frac{V}{\alpha R} \]  

Where \( \alpha \) is the surface area of the anode.

Once the current is known it is possible to calculate the power (P) generated using the following equation:

\[ P = I \times V \]  

III. RESULTS AND DISCUSSION

A. Composition of pretreated bagasse juice

The abundance of natural carbohydrates such as herbal biomasses makes them suitable substrates for the MFC; they constitute waste materials from agricultural and industrial activities and readily available in the environment. However, they include mainly cellulose and starch which are complex carbohydrates that can be utilised by only few specific microorganisms with the right enzymatic system. The main idea in this study is to find a way to facilitate the digestion of sweet sorghum biomass in the MFC. One of the major steps consisted to pretreat the bagasse and liberate the sugars from the complex structure of lignocellulose. The compositional analysis of the liquid juice from the pretreated bagasse revealed an abundance of Sucrose (40.92%) and Fructose (23.44%); these were equivalent to the concentrations 2.420 g/l and 1.418 g/l respectively as calculated using the areas obtained from GC-HPLC analysis fitted with a SHODEX column. No traces of the following elements were found: Xylan, Cellulbiose, Glucose, Xylose, Galactose, Arabinose, Ethanol and Mannose; however, sucrose and fructose are simple carbohydrates likely to be used by several microorganisms.

B. Effect of pretreatment on the substrate utilization in the MFC

Figure 2 shows the power density in the MFC with sewage as inoculum and supplemented with pretreated or untreated bagasse as substrates. As it can be seen, the power generation in both cases stabilized at a low level in the first few days and peaks up in the unit containing pretreated bagasse on the third day to reach a maximum of 0.425 mW/m² on the fourth day and then decreases on the fifth day to around 0.15 mW/m²; while the power density remain relatively stable (~0.1 mW/m²) in the unit containing the untreated bagasse during the whole period. This observation clearly translates to the fact that the pretreatment made available simple carbohydrate easily converted to electricity by the microbial community in the MFC. According to [5], lignocellulosic biomass cannot be directly utilized by microorganisms in MFCs and therefore has to be converted to low-molecular-weight compounds. The stability of the power density in the first two days in the unit containing pretreated bagasse corresponds to the adaptation time required by microorganisms to reorganize the metabolic system for the use of new substrates; the significant peak identified in the same unit has been ascribed in previous study [6] to acidogenic metabolism which results in acidification of the medium and decrease of the activities of microorganisms. The drop of pH was recorded in the unit containing pretreated bagasse (pH 8 to pH 5.5) and in the unit with untreated bagasse (pH 7.97 to pH 3.74).
**C. Co-digestion with glycerol and impact on biogasse utilisation**

*Effect of glycerol type on co-digestion*

Abbad-Andaloussi et al. [7] have reported the simultaneous glucose-glycerol consumption by C. butyricum when grown on glucose-glycerol mixture. It was expected in this study that addition of glycerol in the MFC will enable a value generation and beneficiation of crude glycerol produced in excess in the biodiesel industry; on the other glycerol could maintain the activity of microorganisms while allowing adaptation to the utilisation of bagasse. Using crude and scientific glycerols to co-digest biogasse, it was observed (Figures 3a and b) that the crude glycerol had better enhancement of the utilisation of pretreated bagasse than the scientific glycerol; this was likely due to the fact that the trace elements and mainly chlorine, present in the scientific glycerol could have contributed to the inhibition of microorganisms.

Furthermore, lower power density was generated in presence of higher concentration of pretreated bagasse and glycerol, to elaborate on this the influence of the concentration was further investigated.

*Effect of substrate load on co-digestion*

Keeping constant the concentration of crude glycerol (the rest of the investigation was carried out with crude glycerol as it exhibited better performance), the concentration of pretreated bagasse was increased and the effect on power output is shown in Figures 4a and b; it can be observed that for the tested loads (2.75 ml, 8.25 ml and 21 ml) the higher power density (~11 mW/m²) was achieved at a load of 8.25 ml of pretreated bagasse, this clearly shows the importance of an adaptation period during which microorganisms need enough of lower-molecular-weight substrates (e.g. glycerol) to survive prior to the use of sucrose and fructose. At high concentration of pretreated bagasse there is little sewage substrates and microorganisms leading to failure of adaptation, while at lower concentration of pretreated bagasse the substrates are quickly exhausted after adaptation.
**Effect of glycerol load on co-digestion**

Using crude glycerol as substrate or co-substrate in anaerobic digestion, previous authors [8] have suggested the dilution of glycerol to avoid problems of inhibition due to the presence of inorganic salts of chloride and sulfate as well as possible metabolites accumulation. It was therefore imperative to use an adequate load of crude glycerol to minimize the inhibitory effect. Figure 5 shows that higher power density was achieved with 0.63 ml of crude glycerol than with 6 ml. This implies that at 6 ml of crude glycerol microbial inhibition was perceptible. The two peaks of power density observed at lower concentration of crude glycerol, are said to correspond to the acidogenic metabolism and solventogenic metabolism for the first and second peaks respectively [6].

**REFERENCES**


Dr Elvis Fosso-Kankeu has been the recipient of several merit awards.