



A Review On Electrode Materials in Microbial Fuel Cell Fabrication

L. Sa'adu¹, N. A. Garba² and M. D. Balarabe²¹Department of Physics, Federal University Gusau, Zamfara State²Department of Biochemistry, Federal University Gusau, Zamfara State

Corresponding Author's Email: lawalsaad@fugusau.edu.ng

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ABSTRACT

Electrical energy needs in Nigeria are expected to continue to rise due to the rise in population. The use of petroleum as a source of energy still dominates till date, although oil reserves in Nigeria are increasingly being depleted. There is therefore the need to develop alternative source of sustainable energy, such as, Microbial Fuel Cell (MFC). Electrode materials are critical for microbial fuel cells (MFC) due to their influence in the construction as well as operational costs. In this study, we reviewed different kinds of electrodes used for the purpose of fabrication of MFC across the globe. The study shows that, most of electrode materials are carbon based perhaps due to their high conductivity, durability, eco-friendliness. While the likes Activated carbon and Biochar are selected for their surface area advantages, Graphenes, Carbon Nanotubes and Some Metals excel in the area of delivering high power density.

Keyword: MFC, Carbon Fibre, CNT, Graphenes, Metals

1. INTRODUCTION

Globally, the need for an alternative energy that is renewable, sustainable and most importantly sustainable cannot be over emphasized as over 80 % (Parkash, 2015) of the world rely on fossil based energy sources, which make them very vulnerable to economic challenges (Du, et. al., 2007; Offei et. al., 2016). Application of microbial fuel cell includes electricity generation, biohydrogen generation, waste water (Ishii et al., 2008) treatment and biosensor (Xu, 2016). A microbial fuel cell (MFC) is a system in which micro-organism produce and electric current while con-currently performing their metabolic processes (Correa Muler, 2016). Microorganisms convert the energy stored in biodegradable organic and inorganic compounds to electrical energy (Groza et al., 2016). Microbes release electrons to the anodes, and then transferred through the load to the cathode, where they combine with protons and electron acceptors, driving a reduction reaction (Li, 2013; Calignan et. al., 2015; Dambatta et.

al., 2017). In comparison with other bioenergy technologies, MFCs offer the advantages of energy production directly from a substrate, high efficiency at room temperature, reliable base load power, waste treatment and low pollution impact (Garba et. al., 2017). The earliest MFC concept was reported in 1910 and electricity was produced from *Saccharomyces* and *Escherichia coli* by using platinum electrodes (Xu, 2016). However, it didn't attract much attention until 1980s when the researchers found that the electricity can be promoted by the addition of electron mediators. Mediators have function of accelerating electricity generation by improving the transfer of electron from microbe to electrode. Common mediators used included methyl blue, neutral red, thionine, methyl viologen, humic acid and etc.; However, the toxicity and instability of the mediators limited their application (Xu, 2016).

To construct an efficient and viable MFC, four basic components are inevitable. These include,

an anode, a cathode, electrode and an external load (Correa Muler, 2016). The electrical performance of a MFC is largely dependent on how well the microorganisms interact with the anode. A prime requirement here is that the biofilm that comprise of the microbes is adhered properly onto the anode (Mahadevan, 2014). Hence, Electrodes do play a vital role in exoelectrogenic biofilm growth and electrochemical reaction and they are equally vital in the efficiency and quality of MFC (Huggins et. al., 2014).

This study intends to review all forms of electrodes used in the fabrication of MFC with a view to suggesting the most viable and efficient ones for future research and industrial activities.

2. ELECTRODE MATERIALS USED MFC FABRICATION

2.1 Carbon Fibre

Schoen (2007) used a dual-chambered microbial fuel cell to harness electricity from *Geobacter*, with carbon fiber as the electrode. *Geobacter* is a typical dissimilatory metal reducing microorganisms, which produce useful energy biologically in the form of ATP during the dissimilatory reduction of metal oxides under anaerobic conditions in soils and sediments (Javalkar and Alam, 2013). However, the peak current measured was 10.7 μA on the day one, and fell to zero within 5 days. But in 2015, Moqsud et al., carried out an experiment to produce green energy (bioelectricity) by using paddy plant microbial fuel cells (PMFCs) in soil and observed the various factors which influenced the bioelectricity generation. The researchers used a total of four buckets filled with the same soil with circular carbon fibre with an electrical resistance of 5ohm as the electrodes for the test. Rice plants were planted in three of the buckets, with the fourth bucket containing only soil and an external resistance of 100 ohms for all cases.

The anode area covers around 125cm² inside the soil of the PMFCs. The carbon fibre used in this study was designated as T-300 with a density of 1.76 g/cm³. The anode was set approximately 5cm below the surface of the

soil, while the cathode was placed immediately above the soil surface, but under the water. These electrodes were connected via epoxy-encapsulated wires, and the circuit was completed using an external resistor of 100 ohms. After the experiments, it was observed that the cells with rice plants and compost showed higher values of voltage of 700 mV and power density with time when a rice plant with 1% compost mixed soil was used, it was however more than 95% less in the case of no rice plant and without compost. When comparing cases with and without compost but with the same number of rice plants, the researchers found out that cases with compost depicted higher voltage to as much as two times. The power density was also three times higher when the compost was used in the paddy PMFCs which indicated the influence of compost on bio-electricity generation (Moqsud et al., 2015).

2.2 Biochar

A biochar is a chocolate-like substance made by burning organic material from agricultural and forestry waste. Huggins et. al., (2014) compressed a milling residue and forestry residue representing a higher lignin ratio waste biomass harvested from beetle-killed pine trees using a high temperature gasification process and with little external energy and then used that as MFC electrodes. The MFC were constructed using two polycarbonate cube – shaped blocks separated by a cation exchange membrane. When comparing the compressed milling residue and forestry residue with that of granular activate carbon and graphite granular, the researchers deduced that both biochars showed specific area higher than that of graphite granular, though, lower than granular activate carbon and power output of 532 mWm⁻² (compressed milling residue) and 457 mWm⁻² (forestry residue) comparable with granular activate carbon (674 mWm⁻²) and graphite granular (566 mWm⁻²).

2.3 Carbon Nanotubes

Carbon Nanotubes (CNTs) have in recent studies act as a promising electrode materials due their high surface area, superior electrical

conductivity, chemical inertness, decreased start-up time and low internal resistance. Functionalizing the CNTs appropriately, may further enhance electron transport (Mahadevan, 2014). Furthermore, Mahadevan, (2014) reported a work in this area where a multi-walled carbon nanotubes (MWCNTs) in combination with a nickel silicide contact area was used as an electrode that produced current density of 197 mA m^{-2} and power density of 392 mW m^{-3} . MWCNTs were said to have increased the anode surface-to volume ratio, which improved the ability of the microbes to couple and transfer electrons to the anode. Nickel silicide were reported to boost the output current by providing a low resistance contact area that allowed efficient shuttling of electrons.

Morozaan et al., (2017) worked on the synthesis of two types of carbon materials, derived from pyrolyzed polymers with ferrocene catalysts. This experiment resulted in the production of a large number of carbon nanotubes. These group of researchers they studied the structural properties of the electrode materials and the resulting electrodes were used in a regular MFC with *Escherichia coli*, glucose and with methylene blue as a mediator.

2.4 Graphene Aerogel

Yang et al., (2016) constructed MFC with porous nitrogen-doped graphene aerogel as bioanode that lead to achieving a low internal resistance of 55.4Ω and a power density of $225 \pm 12 \text{ W m}^{-3}$. This was higher of MFCs with conventional carbon cloth bioanode $16.8 \pm 0.6 \text{ W m}^{-3}$ as well as reduced graphene oxide coated nickel foam bioanode $82.8 \pm 1.3 \text{ W m}^{-3}$ under the similar measurement conditions. Yang et al., further attributed the excellent performance the macroporous structure of the nitrogen-doped graphene aerogel which promotes bacterial colonization on both the exterior and interior surface of the electrode to enhance the utilization efficiency of bioanodes. Also, the enhanced electrical conductivity as a result of nitrogen-doping can facilitate transport of electrons generated by bacteria to

external circuit, thereby, improving the power density.

2.5 Carbon Nanotube/Graphene

In another recent technology, Tsai et al., (2015) investigated the performance of using carbon nanotube(CNT) and graphene – modified carbon-cloth electrodes in a single chamber MFC. Due to coating of CNT and or Graphene, the power density of MFCs improved by applying a carbon-cloth electrode, and the graphene-modified electrode exhibits superior performance by decreasing the internal resistance from $377 \text{ k}\Omega$ for normal electrodes to $5.6 \text{ k}\Omega$ for both electrodes modified by graphene with a cathodic catalyst.

2.6 Graphene

Graphene is one of the promising material used as electrode in fabrication of MFC. In a research conducted by Xiao and co-workers, 2012 investigated the efficiency of two different types of Graphene with different morphologies namely regular (flat sheet of paper) and scramble (scrambled like a rolled ball). Their results revealed that, the scrambled type produced the highest power density of 3.6 W m^{-3} twice that of activated carbon which produces 1.7 W m^{-3} (Xiao et al., 2012).

2.7 Metals

It does not to be carbon or a carbon based material before its being used electrode in MFC fabrication. Baudler, et al., (2015) proof that in their work where they use copper and silver being antimicrobial metals, on whose surface bacteria do not grow. These bacteria readily colonize the surface of these metals, forming a highly active biofilm. The average anodic current densities of 1.1 mA cm^{-2} (silver) and 1.5 mA cm^{-2} (copper) were achieved comparable to that of the benchmark material, graphite used (1.0 mA cm^{-2}). Beside the above metals, the researchers also studied nickel, cobalt, titanium and stainless steel were towards their suitability as anode materials for microbial fuel cells and related bioelectro-chemical systems.

3.0 CONCLUSION

This review reveals that, conventionally, most of the electrodes used in the fabrication of MFC are the graphite - rod, felt, plate and fibre brush, carbon - felt, cloth and paper, and other carbon materials such as activated carbon, carbon aerogels and CNTs. However, some metals such as copper, silver, nickel, cobalt, titanium and stainless steel are also being considered as source of electrode materials in MFC fabrication.

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