PERFORMANCE OF MUNICIPAL SOLID WASTE AS FUEL IN A BINARY DIRECT CARBON FUEL CELL.

AJAW A. R., ADENIYI O. D., ADENIYI M.I. AND OLUTOYE M. A.

Department of Chemical Engineering, Federal University of Technology, PMB.65, Minna, Niger State, Nigeria.

Abstract

A variety of abundant carbonaceous fuels such as municipal solid waste (MSW) and biochar from biomass carbonization can be utilized to generate electricity in a direct carbon fuel cell (DCFC) system.In this paper, characterized municipal solid waste of different fractions of sawdust, sugarcane bagasse and orange peel were characterized. The proximate and ultimate analysis employed to determine the High heating value (HHV). The result shows that the HHV of municipal solid waste of the different fractions of sawdust, sugarcane bagasse and orange peel were 6.79, 9.78, 7.68 and its combination which makes up the municipal solid waste to be 11.00 MJ/kg respectively. The calorific values were evaluated to be 7.0, 6.7, 5.8 and 7.9 MJ respectively .The XRD and SEM/EDX reveals that amorphous carbon were present in the analysis. It shows the possibility utilizing municipal solid waste (MSW) as fuel in a direct carbon fuel cell(DCFC) for power generation.

Keywords: Municipal solid waste, Energy, Biochar, DCFC.

Introduction

Population growth, migration from rural to urban areas, as well industrial growth have recently escalated, resulting in substantial increases in waste generation that is of socio-economic and environmental global concern (Omisore, 2018). The management of Municipal Solid Waste (MSW) is a challenging ideal that can potentially provide use-able commodities such as recycled materials and energy. The world economy is driven by consumer-based lifestyles, which generate a high quantity of waste (Axon 2017). MSW are classified into either inorganic or organic and they are further categorized in accordance with hazardousness for resource recovery. In general, some of these MSW are organic matter, paper, wood, glass, plastic, metals, rubber, fiber, medical waste and

batteries (Hamad *et al.,* 2014). The composition of MSW differs from one country to another, depending on their socio-economic and cultural status. The low income countries generate the highest amount of organic waste while the high income countries produce the highest proportion of inorganic waste (Aleluia and Ferrão 2016).

Currently, the worldwide is clamoring towards less dependence on fossil fuels, due to the emission of greenhouse gases and energy security issues, has led to the strong interest in using biomass energy. As an alternative, renewable energy source, biomass absorbs the same amount of carbon dioxide (CO_2) during plant growth, contributing less to global warming. The only remaining issue, however, is how to produce energy from biomass without competing with food supply over the use of arable lands. As such, utilization of waste biomass byproducts, especially from the organic and inorganic materials is key to solving this problem (Bishoge *et al.,* 2019).

The Direct Carbon Fuel Cell (DCFC) have attracted growing attention nowadays as an efficient generator of electrical power. It has the advantages of a near 100% thermodynamic efficiency and a practical efficiency of about 80 % far higher than hydrogen fuel cell technologies and coal fired generator. The overall process of generating electricity by a DCFC system is relatively compared to other fuel cell technologies and does not require expensive preparation of any gaseous fuel, as well as accepts a variety of carbon-rich materials (coal, graphite, carbon black, coke, active carbon, etc.) as potential fuels. This cell is an interesting system because it offers the possibility to use, as fuel source, available and abundant raw materials with only minor pretreatment (Elleuch *et al.,* 2015).

MSW, as a significant feed-stock of biomass fuel, possesses truly high potential as the fuel feed-stock for DCFCs due to its easy availability, low cost, and high energy content (19,800 kJ/kg), especially for the MSW after pyrolysis or compaction . The energy content of pyrolysed MSW is competitive to that of coals (30,200 kJ/kg). Waste materials in terms of weight, account for nearly half composition of the MSW, and possesses the above mentioned properties of MSW. It is highly expected that waste materials would be suitable feed-stock for DCFC. Therefore, it is well worthy to study the feasibility of municipal solid waste.

Materials and methods

Raw materials-municipal solid waste (MSW)

Municipal solid waste collected mainly from households consists of plastics, paper, metals, textiles. organic waste, leather, rubber, metals, glass, ceramics, soil materials

and miscellaneous other materials. Typical household waste contains a wide range of materials that vary significantly in composition depending on the type of community and its consumers' incomes and lifestyles, and its degree of industrialization, institutionalization and commercialism. In general, the highest waste generation is correlated with the highest income. Moreover, even the season of year or the number of persons living in a household influence the amount and composition of waste. For example, more food waste and less paper is generated during summer. Additionally, the larger the community, the more garbage is produced per capita (Pichtel,2014). This work is being motivated by the availability of solid waste found in abundant in most part of Nigeria(Adeniyi,*et al* 2014).As a renewable energy source. The problem of instability can be resolved by using the fuel cell technology which offers a great deal of efficiency and low emissions in the production of electricity it is portable and easy to handle with level of stability at a constant fuel oxygen supply. In an attempt to investigate the electrochemical performance of the fuel cell the efficiency is obtained and it gives us an idea of the quantity of electricity that can be generated. The direct carbon fuel cell uses waste materials as its fuel source making it economically-viable for waste management and reduction of greenhouse effect.

Experimental apparatus and procedure of bio char preparation

This paper investigate the potential of selected municipal solid waste biochar as carbon fuel in DCFC.

Solid waste sample is collected at three(3) different dump site from Kaduna. The collected solid wastes was sorted into biodegradable and non-biodegradable waste. The biodegradable samples of the waste, which were sugarcane bagasse ,sawdust and orange peel. The sorted solid waste was sun dried. Particle size reduction was carried out by pounding in a mortar. The pounded sample was sieved with a 500µm (0.5mm) sieve.

Pyrolysis of the Sieved Sample

The sieved sample was pyrolysed in other to obtain the bio char. A crucible containing Nitrogen gas in its cylinder was used to hold the dry sample and later was inserted into a muffler furnace Carbolite RHF 600 at high temperature. The sample was prepared for pyrolysis. The sample pyrolysed was carried out in a muffler furnace at 500^{o}C for 30 minutes for the MSW. The nitrogen gas in the cylinder was used to purge the crucible from Oxygen so as to remain only the solid carbon for DCFC Performance. The muffler furnace was heated at an increasing rate of 10^{o}C/min to 500^{o}C for 30 minutes to

complete the pyrolysis process (Adeniyi,*et al* 2014). At the end, the biochar was sieved using a 250 µm size mesh to obtain fine carbon particles.

Characterization of the Bio char

Proximate Analysis.

The proximate analysis of the biocher is given in terms of four constituents namely.Moisture Content Analysis.Ash Content Analysis.Volatile Content Analysis.Fixed Carbon Analysis.

Ultimate Analysis.

The elemental components of the biochar sample was detected by elemental analyzer. The elemental component includes carbon, hydrogen, oxygen, nitrogen and sulphur.

X-Ray Diffraction (XRD) Analysis.

X-ray diffraction analysis was carried out to determine the structure of the various biochar obtained from the solid waste.

Scanning Electron Microscope (SEM).

SEM was carried out to determine the texture, chemical composition and crystalline structure (Raju et al, 2014)

Calorific Value.

The calorific value was carried out to determine the amount of chemical energy in a given waste sample.

Proximate Analysis of Biomass

The proximate analysis of the biomass is key to determining the chemical compositions of the biomass and to provide their various combustion characteristics of the biomass. The proximate analysis of biomass composition (by mass) is given in terms of four constituents, namely: moisture content, fixed carbon, volatile matter (the gases emitted during thermal decomposition of the biomass in an inert atmosphere) and ash (inorganic matter left after combustion). The fixed carbon is estimated by difference.

Moisture Content Analysis

The moisture content was carried out on the individual samples in order to ascertain the level of moisture (water) in the samples. An empty crucible of known weight was put in

a drying oven for 30minutes at 105°C to eliminate any trace of moisture. The crucible was put in a desiccator to cool down and then was reweighed, the weight was noted. Then 1g of the sample was measured out. The sample and the crucible were put in a drying oven set at 105°C and left for 1hr. The crucible and its contents was removed and put in a desiccator, allowed to cool to room temperature and reweighed. This was repeated until the weight after cooling was constant within 0.3mg and was recorded as the final weight.

$$\text{Moisture Content (\%)} = 100\frac{(W2-W1)-(W3-W1)}{(W2-W1)}X\,100 \quad (1)$$

Where, W_1 = weight of clean, dry crucible (g), W_2 = weight crucible + wet sample (g), W_3= Weight of Crucible + Dried Sample (g)

Ash Content Analysis

1.0g of the dried test samples each was measured and heated in a furnace at 750°C for 30 minutes by following the previous weighing procedures and heating was carried out in a muffler furnace known as Carbolite RHF 1600 and left in a desicator to cool down to room temperature, and weighed. This was repeated for 1hr interval until the weight was constant. This weight each was recorded as the final weight of the ash by using Equation (2) in grams (g).

$$\text{Ash Content (\%)} = \frac{\text{(Weight of ash)}}{\text{(Initial weight of dried sample)}}\ X\ 100 \quad (2)$$

Volatiles Content Analysis

The volatile matter of the sample was determined using the Meynell method. 1.0g of the residual dry sample each from moisture content determination was placed (spread evenly) on an empty crucible, after weighing the empty crucible and was then covered and place in a furnace preheated at 950°C for 30 minutes to drive off the volatile. The resulting sample was further heated at 800°C for 5minutes (just before the materials turns black, that is, before it ashed), placed in a desiccator and allowed to cool and then calculated using the equation below:

Volatile Matter = Weight of residual dry sample before heating – weight of dry sample after heating

$$\text{Volatile Matter (\%)} = \frac{\text{Loss in weight due to removal of volatile matter}}{\text{weight of sample taken}}\ X\ 100 \quad (3)$$

Fixed Carbon Analysis

The fixed carbon analysis gives a measure of what is left of the biomass when moisture, volatile and ash have been removed. The fixed carbon content of the samples was calculated using the following relation:

Fixed carbon content (%) $= 100 - (\text{moisture content} + \text{volatile matter} + \text{Ash content})$ (4)

Ultimate Analysis

Elemental components of the fuel samples were placed in a platinum crucible and detected by an elemental analyser. A given weight (1 mg) of sample was burned at a raised temperature (°C) in an oxygen atmosphere, so the Carbon was converted into CO_2, Hydrogen in H_2O, Sulfur into SO_2 and the Nitrogen in N_2. The first three compounds were detected quantitatively by an IR detector, while N_2 was determined by a thermal conductivity detector.

Carbon and Hydrogen Contents

Big-Pregle Method was used actually to determine the Carbon and Hydrogen determination. To determine the Carbon and hydrogen content: 1g of the biomass sample was placed in quartz tube and burnt off through the absorbent Magnesium percolate to absorb water and Sodium Hydroxide to absorb Carbon Dioxide. The amount of water and carbon dioxide were determined from the difference between the weigh before and after absorption of water. The Hydrogen and Carbon (%) were evaluated thus as:

$$\%C = \frac{a(0.2727)}{g} \times 100\% \quad (5)$$

While for Hydrogen content we have

$$\%H = \frac{b(0.2727)}{g} \times 100\% \quad (6)$$

Calorific Value (CV) Determination

The calorific value of a given biomass is the heat released by the biomass when it is completely burnt at standard pressure (1 bar) and reference temperature (298 K). The higher the calorific value of a given biomass, the greater the heat released. The sample was analysed using a Bomb Calorimeter. The equation used to calculate the calorific value is given as:

$$\text{Calorific Value} = \frac{(\text{Rise in Temperature of Sample}) \times (\text{Water Equivalent})}{\text{weight of Sample}} \quad (7)$$

X-Ray Diffraction (XRD) Analysis

XRD is the technique for analyzing crystalline phase in solid materials. XRD can be used as a tool for measuring carbonization, as material reactivity is influenced its phase composition. The total intensity of diffracted beam from crystalline part is the remaining area under curve above background.

The powdered samples were pelletized and sieved to 0.074mm. which were later placed in an aluminium alloy grid (35 mm x 50 mm) on a flat glass plate and enclosed with a paper. Wearing hand gloves, the samples were gently compressed with the hand. Each sample was run through the Rigaku D/Max-lllC X-ray diffractometer developed by the Rigaku Int. Corp. Tokyo, Japan and set to make diffractions at scanning rate of 2^0/min in the 2 to 50^0 at room temperature with a CuKa radiation set at 40kV and 20mA.

The diffraction information (d value and relative intensity) obtained was compared to that of the standard data of minerals from the mineral powder diffraction file, ICDD which contained and includes the standard data of more than 3000 minerals. Similar diffraction information means the same minerals to standard minerals which exist in the soil sample.

SEM/EDX Analysis

Scanning Electron Microscope were taken on a JOEL-JSM 7600F with a 6587 EDS (energy dispersion X-rays spectrometer) detector, using an accelerating voltage of 15KV. The Samples are coated with platinum coating of electrically conducting material, deposited on the sample either by low-vacuum sputter coating or by high-vacuum evaporation, the samples were deposited on a sample holder with an adhesive carbon foil and sputter with gold.

Design and Assembling of the Direct Carbon Fuel Cell (DCFC)

The design arrangement in this research work is similar to the work of Cooper *et al*, 2004, experimented also by Adeniyi,*et al* 2014. which employed Direct Carbon Molten Carbonate Fuel Cell. There are similarities in the shape, size, and configuration but with a modified design similar to that of Kacprzak *et al*., 2015 and the design is advantageous in terms of cost and availability of materials, and with ease of fabrication.

The cell has a corrugated flow channels (two gas pipes) attached at both ends of the cell which serves as inlet and outlet of purging gas (anode) and oxidizing gas or air (cathode)

passage, the anode and the cathode were made from steel pipes with considerations of operating temperature and melting point(2600°F or 1427°C) of steel, as the cell operates at high temperature.

A molten binary mixture of NaOH or KOH was used as the electrolyte. While copper wires were used as current collectors on the electrode (anode and cathode). The copper wire which was to transmit the generated power was insulated with crystal beads which are also resistant to high temperature. The anode was made up of a porous alumina mesh of area 2.5 cm^2 and about 40 % void, which provided the conductive surface for effective carbonate ions transportation.

Preparation of Carbonate Electrolyte Using a Mesh Wire

The electrolyte was prepared using molten hydroxide of Sodium and Potassium as suggested by Adeniyi*et a*l (2014). 9.5g of NaOH and 15.5g of KOH (i.e. 38 mol% of NaOH and 62 mol% of KOH) were measured and mixed together and later transferred to a stainless steel (Copper *et al.*, 2007). The stainless steel was then place on a hot plate where it was been prepared. The mixture was immediately stirred continuously to ensured homogeneous mixture. Molten started at a temperature of 130^0C and at 159^0C the molten hydroxide has completely formed. The 25mm Aluminium wire mesh was saturated with the melted molten hydroxide and upon cooling, the molten hydroxide stick to the aluminum wire mesh and it was used as the electrolyte.

Preparation of Carbon Fuel Particles

The carbon fuel particles used for The carbon fuel particles used for the electrochemical reaction as suggested by Copper (2008) was mixed with the mixed hydroxide salt (15 wt% of Biomass, 46.6 wt% of NaOH and 53.4 wt% of KOH. The Sodium Hydroxide (13.98 g) and Potassium Hydroxide (16.02 g) were mixed together and later mixed with 4.5 g of the biomass carbon particle to form the fuel for the DCFC (Adeniyi,et al 2014)

Result and Discussion

Thermo-Gravimetric Analysis of MSW

The result of the Thermo-Gravimetric analysis involves the Proximate and Ultimate Analysis and it is represented in Tables 1 and 2;

Table 1: Proximate analysis of MSW(sawdust, sugarcane bagasse, orange peel)

Sample	Moisture Content (wt%)	Ash Content (wt%)	Volatile Matter (wt%)	Fixed Carbon (wt%)
MSW	1.36	3.57	65.10	29.97

Table 2: Ultimate Analysis of MSW(sawdust, sugarcane bagasse, orange peel)

Sample	C (wt%)	H (wt%)	O (wt%)	N (wt%)	S (wt%)
MSW	58.40	6.60	34.00	0.72	0.28

From Table 1, The result of the Thermo-gravimetric analysis carried out on the samples indicates the properties of the fuel source and which invariable is an important check for the a suitable fuel for use in the Direct Carbon Fuel Cell. The moisture content, ash content and volatile matter of the MSW are 1.36 wt%, 3.57 wt%, 65.10 wt% compared to the result gotten by Omari 2015. of 8.41 wt% 4.18 wt% respectively. The difference can be attributed to the different drying temperature and procedure being that for this research, the sample was sun dried for a week as against 60°C for Omari 2015.While having a fixed carbon content of 29.97wt% ,which makes it a suitable fuel with high carbon content.

From Tables 1 and 2 the moisture content, ash content, volatile matter, carbon (C) content, hydrogen content and sulphur content obtained are 1.36 wt%, 3.57 wt%, 65.10 wt%, 29.97 wt% 6.60 wt% and 0.28 wt% respectively for the combined fuel. Higher volatile matter, hydrogen (H) content and low moisture content are suitable for short term use as substrate in the DCFC but for long term a high carbon content and low sulphur (S) content is better (Andrzej *et.al*, 2017).

Calorific Value

This is an important characteristic in the setup of DCFC as it determines the amount of heat released during burning a unit quantity of fuel, the higher and lower heating values was determined with the help of the calorific value. The calorific values of the proposed fuel obtained are:

Table: 3.3: Calorific value of MSW(sawdust, sugarcane bagasse, orange peel)

Sample	Calorific Value (MJ/Kg)	LHV (MJ/Kg)	HHV (MJ/Kg)
MSW(sawdust, sugarcane bagasse, orange peel)	7.9	9.54	11.00

X-ray Diffraction (XRD) Pattern

The X-ray diffraction (XRD) analysis was carried out to investigate the phase composition, crystalline structure and the degree of disorderliness of the carbon fuel. This was done for the pyrolysis of the MSW sample at 500°C. The result from the XRD pattern is presented in Figure 3.1. The pattern constitute the basis for comparison for the carbonized MSW to

be used in the fuel cell. It has been agreed by several researchers that less crystalline carbon contains more edges sites and defects which are considered reactive sites for carbon oxidation in DCFC (Xiangling, 2016).

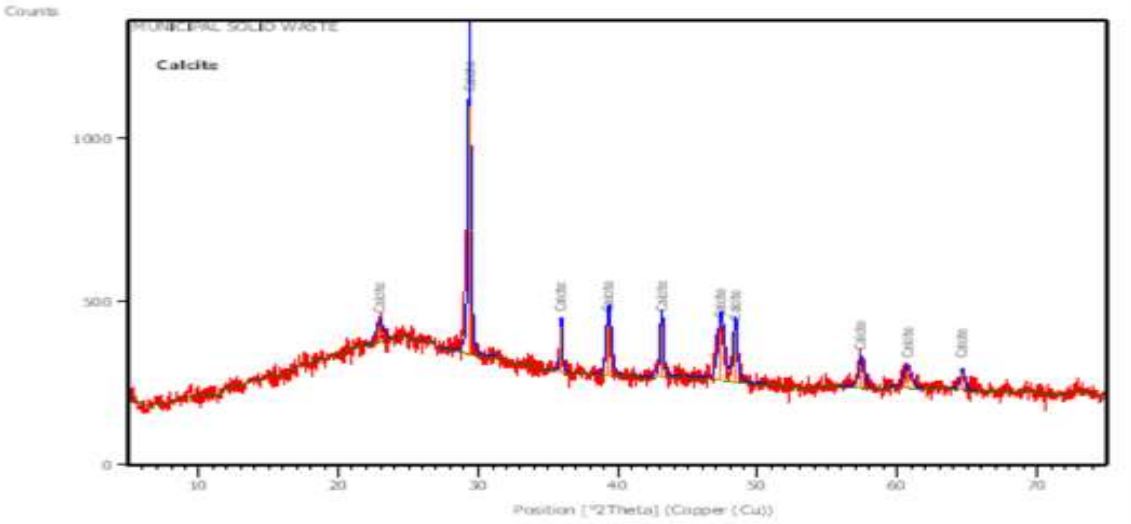

Figure 1: X-ray diffraction pattern for MSW(sawdust, sugarcane bagasse, orange peel)

The XRD pattern for MSW is in Figure .1. The crystallographic parameter are crystal system calcite(rhombohedral) with space group of R-3C and space group number of 167.The sample exhibits four prominent peaks at (2 θ) value of 24^0,29.5^0, and 58.5^0.peak 58.5^0 is in amorphous area and the remaining are in crystal area.

SEM/EDX Analysis

The SEM uses a focused beam of high energy electrons to generate a variety of signals at the surface of the solid sample.The signals that derive from electron sample interaction reveal information about the sample including texture, chemical composition and crystalline structure.The EDX shows the elemental composition of the fuel samples.

The Morphological analysis of carbonized MSW.

The carbon Biochar were subjected to scanning electron microscope (SEM) to obtain more understanding on the structures and size distributions of the carbon sample. Figures 2 show the SEM structure for the biomass carbon obtained after pyrolysis. The **morphology of the samples was determined by Scanning Electron Microscope (SEM) and** then the graded composition was analysed by energy dispersive X-ray dispersion (EDX).

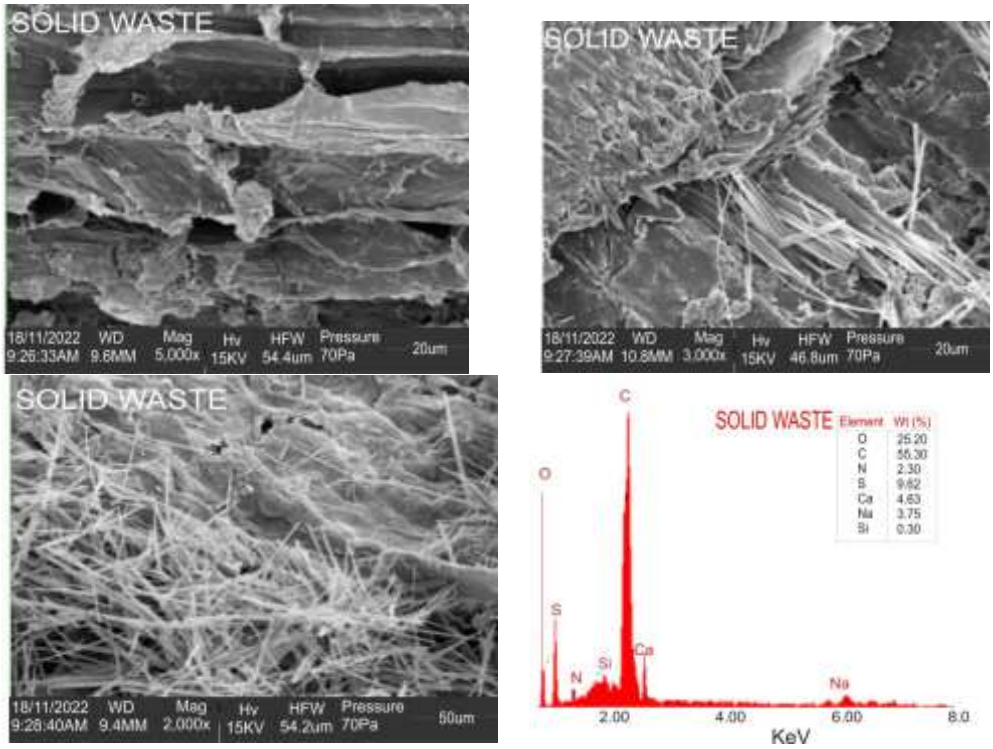

Figure 2 SEM/EDX of MSW carbon at 5000_x, 3000_x and 2000_x magnification.

Figure 2 gives the morphological structure of carbonized sawdust at 500°c under 5000,3000 and 2000 times magnification.The SEM micro-graph indicate that MSW is very rich in fine particles with non uniform but well developed pore structure.These features could be as a result of surface area because when the porosity increases the surface area also increase. The EDX shows the elemental composition of the fuel sample. The sawdust consist of C, O,N,S,Ca, Na and Si with a corresponding weight percent of 55.30%,25.20%,2.30 %, 9.62%,4.63%,3.75%,0.30%.

Conclusion

Municipal solid waste biochar were prepared using using a pyrolyzer at around 500 ^{0}c. the proximate and ultimate analysis was done. SEM/ EDX and XRD analysis was performed for the pyrolysed carbon which served as fuel in the DCFC. **The scanning electron micrograph and X-ray diffraction reveals that the carbon fuels contain large sized particles with the highest peak of 29.6° with corresponding d-spacing of 3.42 Å.** The composition of MSW shows that there is possibility of utilizing municipal solid waste as fuel in direct carbon fuel cell(DCFC) due to having carbon content of 55.30 wt(%). The XRD and SEM/EDX results shows that these materials can be used in direct carbon fuel cell for conversion of the electrochemical properties to power generation due to amorphous carbon present. This

work will prevent environmental degradation and contribute to renewable energy sustainability

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