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ARTICLE

Utilization of Crop Stubble as Alternate Source of Electricity Generation

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ABSTRACT

The Indian states including Punjab, Haryana, Bihar, Uttar Pradesh, Madhya Pradesh, and Himachal Pradesh follow combine harvesting method followed by burning of crop stubble to prepare the fields for next crop. Crop stubble burning is the reason of annual increment in pollution concentrations which lead to massive winter pollution in the region. However, the state governments have taken several initiatives for proper management of crop stubble through various departments and institutions but still air pollution level is increasing. Instead of burning the crop residue, it can be used in other ways, which are beneficial to humanity. In the direction of rising issues due to burning of the crop stubble, efforts have been carried out to explore the options to utilize the crop stubble rather than burning of it. Present experimental study is an attempt to outline alternative use of crop stubble like utilization of rice straw for electricity generation through microbial fuel cell. In 10 days experimental set up, the MFC produced the maximum voltage of 0.002 V corresponding to the maximum current of 2.5 mA which results in power output of 0.05 mW. The experiments' results of the study accentuate the significance of biomass by utilizing the rice paddy straw for generating the electricity by means of microbial fuel cells. The electricity generated through crop stubble can be used as a sustainable source of energy in the remote areas. It is also focused on suggesting policies to the government so that air pollution can be minimized in affected areas.

1. Introduction

Combine harvesting method requires machines like thresher to separate and clean the grain in one go. But the machine cannot cut close enough to the ground and leaves stubble behind as residue. On the other hand, the farmer remains under pressure to clear the field for timely sowing the next crop to gain a full yield. Therefore, burning the stubble is the fastest and cheapest solution to remove crop residue from the field to sow next seasonal crop. But the burning of crop stubble has become one of the major causes of air pollution. Yang et al. observed that 3.04×10^6 ton/year crop residue was generated during the year 2001 to 2005. Out of which about 43% crop residue was burnt including approximately 82% of wheat straw and 37% of rice straw. During burning, the particulate matter and gaseous pollutants were measured seasonally and found that these pollutants were emitted more in summer (78%) than the autumn season. However, higher concentration level of PM_{10} (0.25 mg/m^3) was observed throughout the summer season [1]. It was estimated

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that one ton of stubble burning produced 3 kg PM, 60 kg CO, 1,460 kg CO_2, 199 kg ash and 2 kg SO_2 [2], also, emission elevates the aerosol, SO_2 and NO_2 levels during the crop stubble burning episode [3]. Addition to this, the smoke was also recognized as toxic due to presence of particulate matter from partially combusted materials forms airborne which may be transported downwind. Worsen air quality was reported in North east part of India due to long range transport of particulate matter during winter season [4]. In a study of Bathinda district of Punjab, the gaseous pollutants such as SO_2, Benzene, Ammonia and Ozone recorded within the National Ambient Air Quality Standards (NAAQS), however the concentration of CO and NO_2 crossed the prescribed limits and the concentrations of PM_{10} & $PM_{2.5}$ were found much beyond the permissible limit [5].

Burning of biomass not only pollutes the air but results in loss of considerable amount of plant essential nutrients [6] and harm the overall sustainability of the combination cropping system [2]. Loss of essential nutrients affects the soil's fertility and also causes serious threat to human health including breathing problems, allergies and asthma attacks. The poor air quality due to the emission from crop residue burning causes sub-acute effect on pulmonary functions of healthy people. Gaseous pollutants like SO_2 and NO_2 have less adverse effects on pulmonary functions than Particulate Matter. A significant decrease in pulmonary function test was recorded with association of 10 $\mu g/m^3$ increase in particulate matter and NO_2 [7]. Biomass burning is one of sources of emission of benzo(a) pyrene (BaP), dibenz (a,h) anthracene (DahA), and fluoranthene (Flu). Approximately 10% of the BaP, DahA, and Flu emissions found correspond to over 80% of all observed human health effects with a significant positive linear relationship with mortality from malignant tumors and the nervous system, heart, and cerebral-vascular diseases as well[8]. The residue generated from the combination cropping system may be utilized as alternate options. Hegde suggested that the residue is separated from the grain and carried out to the field is short in supply by more than 40% for the livestock. Generally, livestock in northern India are fed with wheat straw while paddy straw is preferred in Southern India [9]. In combine harvesting system, huge amount of the residue is left in the fields and burning is the immediate solution to clear the fields. Presently many farmers are adopting zero tillage after crop stubble burning; in fact less than 1% of farmers incorporate the paddy straw due to incorporation requires more tillage operations than after burning the crops. The intensive tillage operation leads to a long rotation period which often results in delay to planting the wheat [10]. Tripathi et al. have also given the alternate solution for managing the crop residue by emerging the systems to plant residue into bailing and eliminating it for utilizing as animal feed, industry etc. These systems may include the machine harvesting which enhance the composition of straw and improve the nutrients in the soil. Another option of utilizing crop stubble is to decompose the crop residue through microbial sprays [10].

It is essential to seek alternative farmer-friendly solution of managing the crop stubble instead of burning it to avoid the emission. The crop residue possesses immense economic value because of the properties of farm animals' feed, energy source and raw material [11]. Therefore, this study was conducted to utilize the crop stubble for electricity generation and to control air pollution by proper utilization of the crop stubble. This study is an effort to generate electricity in a very cost-effective manner by using microbial fuel cell (MFC) technology which will help in two ways- to reduce the air pollution and second the electricity generated from it can be used to light the houses in the rural areas. Microbial fuel cells (MFCs) is a technology in which chemical energy produced by the oxidation of organic/inorganic compounds is converted into ATP by sequential reactions through microbes. Sequential reactions involve the transfer of electrons from a terminal acceptor to produce the electrical current [12, 13]. Till now most of the experiments are carried out by using nafion tube which is quite expensive, and it makes microbial fuel cell very expensive. In this study, we have mainly focused on making MFC cost effective, what we have used is simple ion exchange membrane to allow the protons to transfer into the cathode to produce electric current.

2. Materials and Method

2.1 Crop Stubble

Raw rice paddy straw for the experiment was obtained from a Rice Mill situated in Katni district of Madhya Pradesh of India. The rice paddy straw was composed of 12.6% moisture, 30% cellulose, 12.7 % lignin, and 14.9 % hemicelluloses. The rice paddy straw was cut to 23 cm in length and filtered with clean water to remove impurities. Then this powder was dried in hot air over at 60˚C for 2 hours [13,14]. The powder of rice paddy straw was the carbon source and employ as electron donor for present study.

2.2 Cellulose Degrading Bacteria (CDB) and Medium Nutrient Mineral Buffer (NMB)

Cellulose Degrading Bacteria (CDB) characterized strain named Bacillus subtilis was used as inoculum to extract carbon from rice straw. The genome sequence of B. subtilis sub-strain QB928 includes 4,146,839 DNA base

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pairs and 4,292 genes [15]. The CDB were transported to modified Dubos' salt medium and amended with carboxy methyl cellulose. This CDB culture was incubated at 30 ℃ for 7 days and used as the inoculum in the MFC [16] (Figure 1). Nutrient Mineral Buffer (NMB) was employed as the medium for anode and cathode compartments of the MFCs with the composition of 3.13 g/L $NaHCO_3$, 0.31 g/L NH_4Cl, 0.75 g/L $NaH_2PO_4.H_2O$, 0.13 g/L KCl, 4.22 g/L NaH_2PO_4, 2.75 g/L Na_2HPO_4, trace metal and vitamin solutions [17,18].

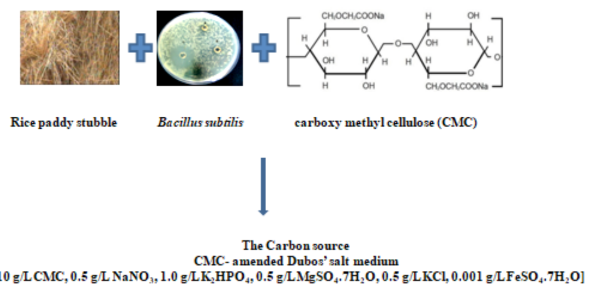

Figure 1. Preparation of carboxy methyl cellulose amended modified Dubos' salt medium

2.3 Microbial Fuel Cells (MFCs)

Microbial Fuel Cell technology involves the transformation of chemical energy of organic compounds into electricity energy through microorganisms. An extensive range of carbon sources may be utilized by using diverse microbes for this purpose [19]. An MFC system consists of two compartments for anode and cathode which are disarticulated by the cationic membrane. The anode compartment produces electron donor by metabolizing the organic compounds through microbes. Electricity generation pathway from crop stubble is shown in Figure 2. The metabolic reactions take place in organic compounds present in crop stubble and produce electrons and protons. The electrons are transported to the anode surface and further moved to cathode from end to end electrical circuit, whereas the protons travel through the electrolyte followed by moving all the way through cationic membrane. The consumption of electrons and protons occurs at the cathode by reducing the soluble electron acceptor like oxygen or hexacyanoferrate and acidic permanganate. A load is placed between two electrode compartments to harness the electrical power [20,21,22]. Protons relocate to the cathode and form water molecule by fusing with O_2 and electrons then discharged through anode. Commonly platinum is used to accelerate the reduction of oxygen at the cathode, because it has tremendous catalytic ability. But platinum is a costly metal, so it has limitations to economic viability and so application. Other cheap metals can also be used as catalyte instead of platinum e.g. MnO_2, Fe^{++}, CO based materials etc. may also enhance reduction rate of oxygen along with cost reduction [22,23,24,25,26]. In this experiment, normal copper wires were used as these are cheap as compared to platinum. Electron exchange can happen either through membrane associated parts, dissolvable electron transports created by particular microbes, or profoundly conductive nanowires. The utilization of piled MFCs in arrangement or in parallel is essential to expand the voltage.

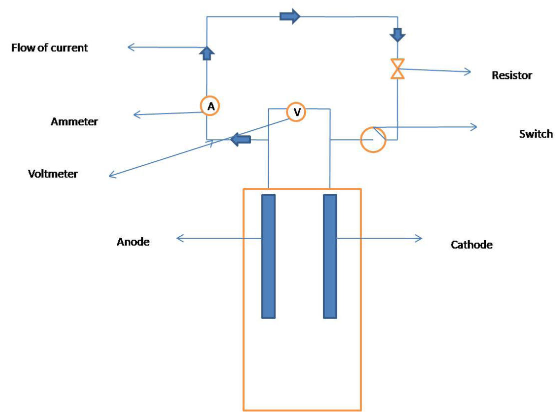

Figure 2. Electricity generation pathway from crop stubble

2.4 Construction of Microbial Fuel Cells (MFCs) and its Operation

The two-chambered MFCs were constructed in H shape. Both of the chambers filled with media bottles, an anaerobic anode chamber and another aerated cathode chamber were joined with an ion exchange membrane tube clamped with the help of rubber gaskets. The electrodes of 10 cm^2 diameter consisting of non-humid proof carbon strips attached to each side of the dialysis membrane. Anode and cathode of the MFC compartments were connected with copper wires and inserted inside fluorinated ethylene propylene tube (Figure 3). The chambers of MFC were filled with 200 mL NMB medium. The anode compartment was inoculated with 2 mL mixed culture of CDB and at the same time 1 g/L rice paddy straw was put in which would act as the electron donor. The anode chamber was sealed with a rubber stopper after swilling out 80% nitrogen gas for five minutes and 50 mM $K_3Fe(CN)_6$ was added as a catholyte to the terminal to accept the electrons. Each time the anode compartment was refilled with fresh NMB medium and rice straw after repeating the cycle for power generation.

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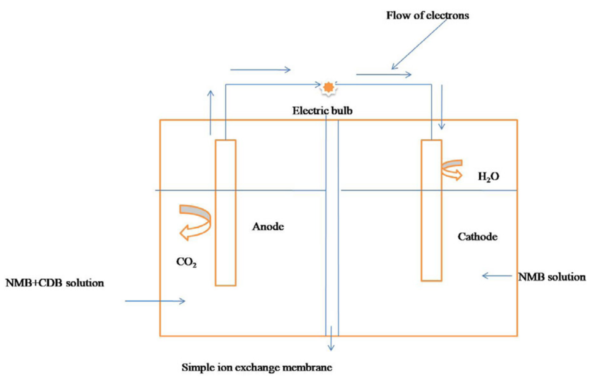

Figure 3. Dual chambered Microbial Fuel Cells (MFCs) Construction and Operation

2.5 Data Analyses

The MFCs system was examined through a precision multi-meter and a data acquisition system. The voltages across the resistors were recorded at the intervals of every 24 hours and continued up to 10 days. The potentials of each electrode were found through a reference electrode of Ag/AgCl (0.195; corrected to Normal Hydrogen Electrode). MFCs were remained in open circuit mode for 30 minutes. All the tests at MFCs were performed at a definitive external resistance (1,000 Ω). The power was normalized according to Oh and Logan at the anode surface area [27]. Current density was calculated as i = I/A, where, I (mA) current through a conductor, A (m^2) the projected surface area of the studied electrode [28].

Power density was calculated according to P = iV where i is current density and voltage is denoted by V[25].

3. Results and Discussion

A slack time of approximately 100 hours was followed after the main immunization of the anode chamber containing mixed culture of CDB and rice paddy straw as the substrate. A quick increment in power was noticed succeeding to 240 hours (Figure 6). The greatest voltage was recorded as 0.002 V at a steady power density of 1.2 mW/m^2 during 10 days experimental set up (Figure 5). The MFC was refilled multiple times with crisp medium containing rice paddy straw (1g/L), what's more, the pinnacle voltage immediately balanced out at 340e350mV without a slack stage for each cycle. Figure 6 shows polarization curve to evaluate the performance of the MFCs and found that the highest value for power was recorded as 0.005 mW with corresponding highest current of 2.5 mA. These outcomes were corroborated with that the voltage achieved an unfaltering state dimension of 300 ± 2 mV at 250 hours by utilizing the rumen microorganisms to create electricity from cellulose through H-type MFCs [29]. The underlying slack stage showed increment at the underlying cogitating, and at that point it evaporated after progressive exchanges of new media. It suggests that the power age generated from rice paddy straw was established because of direct electron exchange by cellulose degrading bacteria at anode which was not required any combination [18]. The highest value of power density was obtained as 1.25 mW/m^2 which corresponds to the highest current density of 625 mA/m^2 with 1 g/L rice paddy straw (Figure 7). For this experimental study, rice paddy straw was chosen as a substrate because it has high amount of cellulose and hemicelluloses caused easy hydrolization into fermentable sugars. This property of rice paddy straw makes it a potential substrate for generating electrical energy through MFCs [30,31,32].

Different investigations likewise have demonstrated comparable outcomes that refilling MFCs with other medium outcomes in prompt control age. The steady time frame for control age with rice paddy straw was regularly extended than other unadulterated substrates, for example, acetic acid derivation, glucose, and xylose [33]. This more drawn out constant period for power age might be because of the distinctive synthesis of lignocellulosic substrates of rice paddy straw. However, the power can be generated from the wheat straw because it hydrolyse as the substrate in MFCs with an extensive steady time of intensity age i.e.123 mW [34].

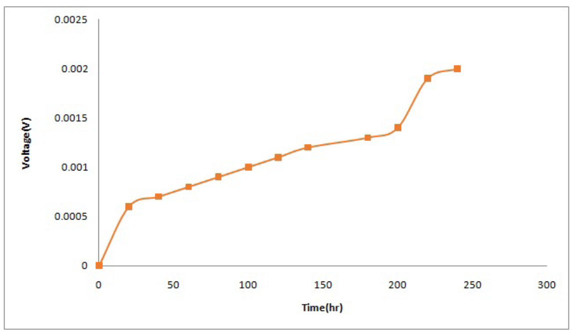

Figure 4. The generation of voltage through rice paddy straw at 1000Ω resistance

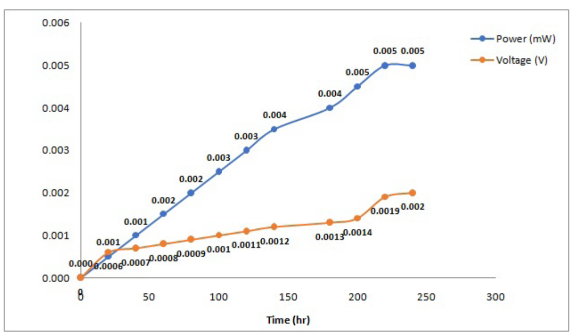

Figure 5. Generation of power corresponded with voltage from rice paddy straw

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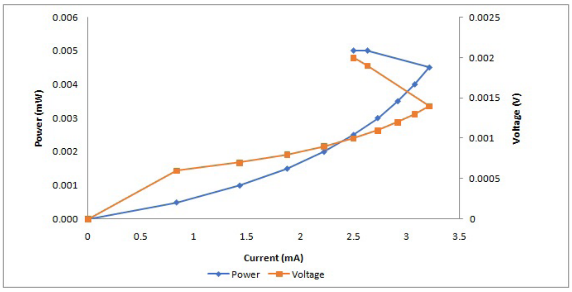

Figure 6. Polarization and power density curves through rice paddy straw

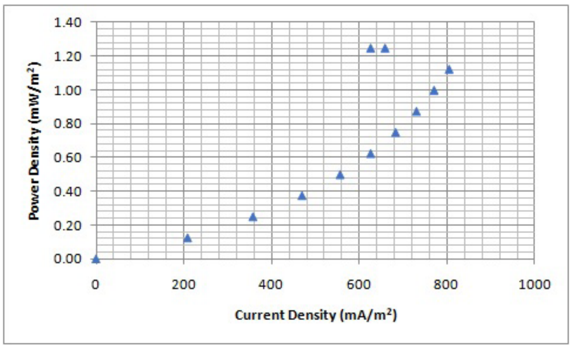

Figure 7: Power density versus Current density through rice paddy straw

4. Conclusion

This experimental study concludes that the mixed culture of cellulose degrading bacteria is capable to utilize the rice paddy straw as a potential substrate for power generation and exchanging the electrons to MFCs cathode exclusive of the support from outside electron transports. Results are indicating that other crop stubble like wheat may also be used for the same purpose because of similar properties. This study corroborates with already detailed examinations that a blended culture of CDB can generate power through MFCs. Crop stubble is the principle rural waste, which is utilized as primary encourage for ruminants, though, this waste of biomass can also be transformed to vitality for meeting the nations' requirements. This investigation exhibited that the steady power may be generated from rice paddy straw. The cost effective MFCs generated the most extreme energy of 0.005 mW relating to the highest current (2.5 mA). While the maximum power density produced by MFCs was 1.25 mW/m^2 which corresponds to the maximum current density is 625 mA/m^2 with 1 g/L rice straw.

Apart from this, rice paddy straw was straight forwardly utilized without pre-treatment as the substrate in the MFCs for this study. The results of this study revealed very less generation of current and power as compared to other studies as the efforts were to build a cost effective microbial cell by using normal ion exchange membrane instead of nafion tube which is highly expensive. Secondly, all the experiments were performed at the lab scale and obviously certain improvements need to be done for taking it to the industrial scale, . However, the results indicate that the power obtained from rice paddy straw can be used for direct utilization and charging the battery.

Benefits Associated

All the materials used in the experiments are pollution free and there is no such emission of harmful gases as in other methods of electricity generation. Secondly, most important raw material i.e. rice straw which is utilized for the experiment is available free or at very nominal cost which makes the electricity generation "cost effective".

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