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Landfill Leachate: A Promising Substrate for Microbial Fuel Cells

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***Abstract*—**Landfill leachate emerges as a promising feedstock for microbial fuel cells (MFCs). In the present investigation, direct air-breathing cathode-based MFCs are fabricated to investigate the potential of landfill leachate. Three MFCs that have different cathode areas are fabricated and investigated for 17 days under open circuit conditions. The maximum open circuit voltage (OCV) is observed to be as high as 1.29 V. The maximum cathode area specific power density achieved in the reactor is 1513 mW m^{-2}. Further studies are under progress to understand the origin of high OCV obtained from landfill leachate-based MFCs.

***Keywords*—**Microbial fuel cells, landfill leachate, air-breathing cathode, performance study.

I. Introduction

THE energy requirement of the world has increased to such an extent that the conventional energy resources have started depleting at a higher rate-increasing the need for an alternative renewable energy resource. Recently, MFCs have grabbed attention due to their potential to produce electrical power from a wide variety of wastewater (WW) along with partial treatment. MFCs are based on the oxidation of organic materials in WW by micro-organisms. The micro-organisms adhere to the surface of the anode creating a biofilm which further helps in the transfer of electrons. Various substrates such as domestic WW [1]-[4], distillery WW [5]-[8], brewery WW [9], farm manure [10], chocolate industry WW [11], food processing WW [12], metal processing WW [13], paper recycling WW [14], landfill leachate [15]-[19] are being explored in MFCs. Landfill leachate is a liquid that either percolates through the landfill system or is composed by the waste within the system. In order to protect the surrounding environment, landfill leachate is accumulated and manipulated.

It can also be re-cycled in an operating landfill to deal with the leachate as well as to build up the biodegradation of waste within the landfill. In this way, landfill gas production is also increased. Leachate contains many organic constituents which can be processed through the biotic treatment within the landfill, but ammonia is one of those many constituents that can accumulate and resist the treatment. Ammonia can be noxious to bacteria and other organisms as it inhibits accelerated biodegradation that can be happened via recirculation [20]. Landfill leachate is strongly polluted WW that contains various heavy metals and a wide range of organic and inorganic nutrients [21]. Landfill leachate is characterized based on COD, BOD, pH, heavy metals, ammonium-nitrogen, and suspended solids. The pH of landfill leachate is in the range of 5.8-8.5 depending on the biological activity; the COD/BOD ratio decreases from 0.7 to 0.04 with aging [22]. Landfill leachate affects the quality of ground water due to percolation of leachate into the ground water, in sites near the landfill [23]. Since landfill leachate has a high content of organic and inorganic nutrients, it can be used in MFCs for power generation; this also, simultaneously, treats the WW [15]-[18]. Table I summarizes the maximum OCV achieved from landfill leachate.

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In this paper, landfill leachate is explored in a single-chamber, air-breathing MFC with a flexible graphite sheet as the anode. A peak OCV of 1.23 V was obtained without addition of extra nutrients. To the best of the author's knowledge, this is the highest OCV ever reported in an MFC system. Further studies are in progress to understand the origin of high voltage in landfill-based MFCs.

TABLE I
MAXIMUM OCV ACHIEVED FROM LANDFILL LEACHATE

Vol. of reactor (mL)	Anode	Cathode	Max. Voltage (V)	Reference
343	Graphite granules	Air cathode	0.398	[17]
275	Metal oxide titanium	Metal oxide titanium	0.077	[18]
125	Activated carbon	Graphite rod	0.500	[23]
400	Graphite plate	Graphite plate	0.450	[24]

II. Materials and Methods

In this present work, three identical reactors are fabricated by using clear acrylic sheets to study of the effect of cathode area on power generation in identical MFCs, keeping all other factors identical. The internal dimensions of each reactor are 7 cm x 7 cm x 7 cm, leaving an empty bed volume of 343 mL. All the reactors are closed at all the five faces, and one face is left opened to accommodate the air-breathing $cathode_{(Pt)}$, as shown in Fig. 1 (a). Each cathode is sandwiched between an acrylic mesh with external dimensions of 7 cm x 7 cm, carved into square-shaped openings for Membrane Electrode Assembly (MEA) reinforcement. The effective open area for each face is 36 cm^2. The meshes are connected to the frame using SS nut-bolts and a 2-mm nitrile rubber gasket to prevent leakage. The assembly uses silicon tubing for influent feeding and effluent withdrawal. The top face has a hole of that is 1.5 cm in diameter for insertion of the reference electrode.

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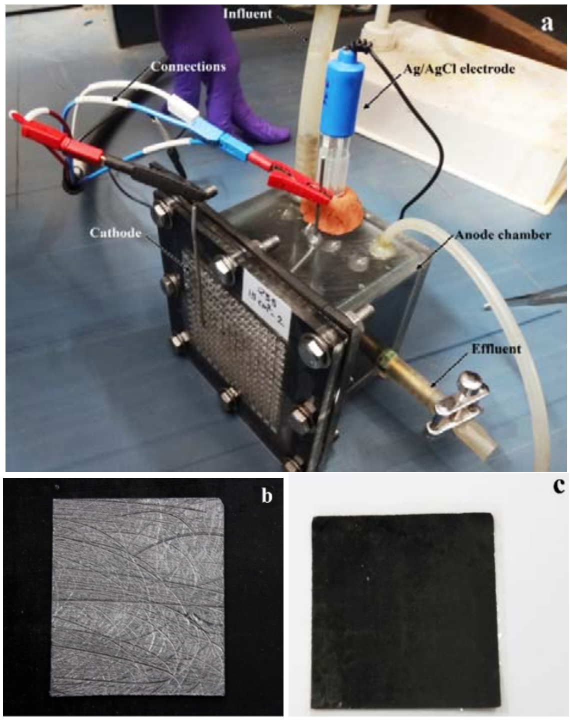

Fig. 1 Schematic design of the MFC (a) complete assembly; (b) details of anode; and (c) air-breathing cathode attached to the membrane

The assembly consists of an anode fabricated using a flexible expanded graphite sheet of thickness 1.5 mm, as shown in Fig. 1 (b). The experimental setups are equipped with a single sided MEA (cathode$_{pt}$) of dimensions 36 cm^2, 5 cm^2, and 1 cm^2. In order to estimate the half-cell voltage that is generated from the anode, a reference electrode of Ag/AgCl is inserted into each of the reactors. The air-breathing cathode is placed between the reinforcing acrylic mesh at the open face of the assembly. Cathode electrodes are fabricated, as described by [8]. Flexible carbon paper (Toray Carbon Paper TGP-H-060) is coated with fine platinised carbon powder (Pt content 20%; Vulcan) to fabricate the cathode electrode. The electrode is loaded with 0.5 mg cm^{-2} of platinum using a perfluorosulfonic acid (Nafion, 5%) solution as a binder. Subsequently, the electrode is hot-pressed at 140 °C for 2 min on one side of a solid polymer electrolyte membrane (50 µm, Nafion NRE-212) under a pressure of one ton to fabricate the air-breathing cathode, as shown in Fig. 1 (c).

The performance of each MFC is monitored continuously using a data acquisition system and captured at time intervals of 30 min. Anode voltage of each cell is measured with respect to the reference electrode and air-cathode of each cell.

MFCs are operated under ambient conditions during the first cycle using landfill leachate collected from a local leachate site, and the OCV is continuously monitored. The polarisation behaviours of the reactors are obtained under the constant resistor (CR) mode during the second cycle. Initially, landfill leachate is sparged with nitrogen for 30 mins to ensure an anaerobic condition in the anode chamber.

The polarisation curve is obtained by varying the resistance across the cell from 10 Ω to 100 kΩ using electronic load. Area-specific current density is estimated based on the cathode area.

III. Results and Discussion

The reactors are operated at a stagnant mode and the landfill leachate is fed into the reactor in batches. During the entire study, the MFCs are operated at ambient temperatures that fluctuate between 24 to 27 ºC. Mesophilic bacteria, mainly responsible for the electro-chemical performances in MFCs, exhibits excellent performance in this temperature range. During the first cycle of the operation, the reactors are operated continuously for 17 days at open circuit conditions. The OCV is recorded at a time interval of 30 minutes using a data acquisition system. The captured data is averaged for 6 hours, and the variations in the OCVs with time depict three distinct phases, as shown in Fig. 2.

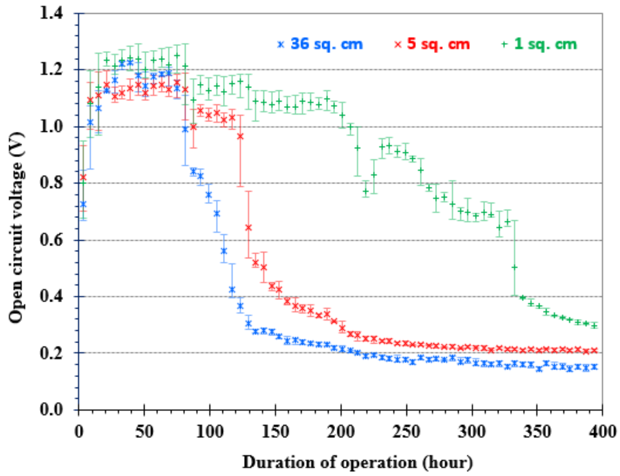

Fig. 2 Variation in the electrode potential under open circuit condition with time during first cycle (a) overall OCV

The variations in the overall OCVs arise mainly from variations in the anode performance, as shown in Fig. 3. The upsurge during the initial phase of the operation indicates the formation of the microbial community. This is followed by a relatively steady phase where the microbial growth saturates, and maximum OCVs are attained in all the three reactors. The maximum OCV of 1.23 V, 1.2 V and 1.29 V, are obtained from the reactors with a cathode area of 36 cm^2, 5 cm^2, 1 cm^2, respectively, during this phase of operation. The final phase illustrates the declination in the performance, which indicates a substantial decrease in the concentration of nutrients in the feed. If the nutrients are completely depleted, then a negative phase develops. During this phase, the bacteria begin to die due to the exhaustion of nutrients.

The reactors are allowed to settle for 15 min at every step before recording the voltage. The area-specific power density and the volumetric power density are given in Fig. 5.

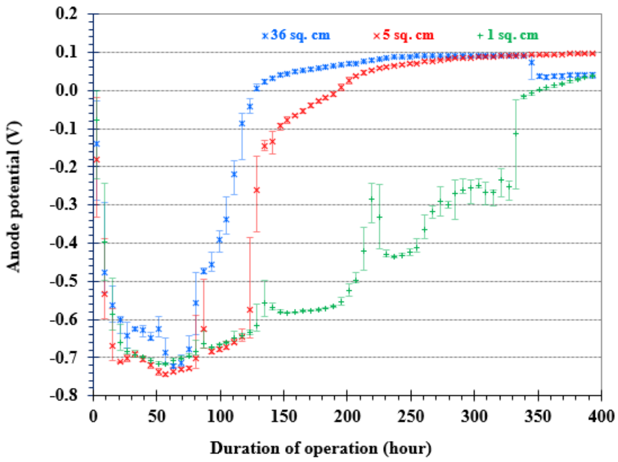

Fig. 3 Variation in the electrode potential under open circuit condition with time during first cycle (b) anode potential with respect to standard electrode (Ag/AgCl)

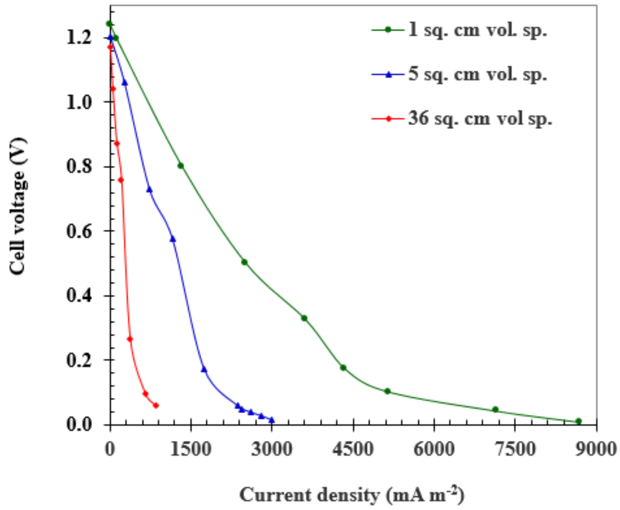

Fig. 4 Polarisation behaviour of MFCs with different electrode area

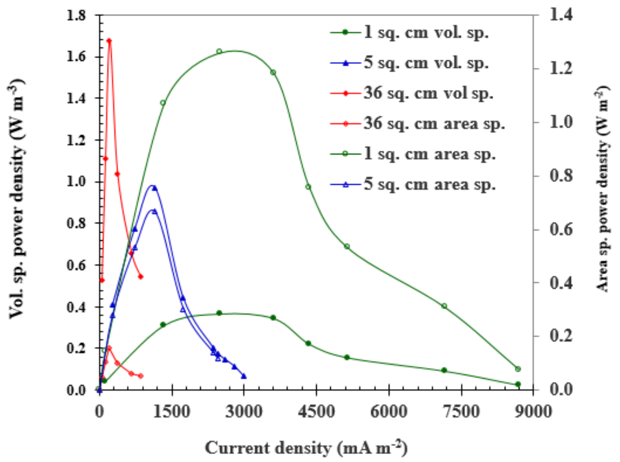

Fig. 5 Variation in the volumetric and area-specific power densities achieved in different MFCs

It is observed that reactors with a smaller cathode offer maximum area-specific power density and minimum volumetric power density. The area-specific power density is found to be 867 mW m^{-2}, 666 mW m^{-2}, and 1513 mW m^{-2} for 36 cm^2, 5cm^2, and 1cm^2, respectively. However, the volumetric power density is observed to be 1.7 W m^{-3}, 0.84 mW m^{-3}, and 0.36 mW m^{-3} for 36 cm^2, 5 cm^2, and 1 cm^2, respectively.

After the first cycle of operation, the reactor is fed with fresh landfill leachate to investigate the current-voltage characteristics. Polarisation behaviour is studied under the constant resistance (CR) mode, as shown in Fig. 4.

IV. Conclusion

In the present investigation, the potential of the landfill leachate as feedstock in MFC is studied. For this, three MFC reactors with different cathode effective areas are fabricated to study the electro-chemical performances using landfill leachate. All the reactors exhibit a very high OCV of around 1.3 V, which is one of the highest potentials ever reported in the literature. Further investigation is in progress in order to understand the root of the high OCV generation in landfill leachate-based fuel cells. The volumetric power densities of the reactors increase with increase in the electrode area, whereas area-specific power density exhibits an improvement with decrease in the electrode area.

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