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# AN IMPROVED CATHODE DESIGN

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## Field of the Invention

The present invention relates to the manufacture and use of a fuel cell and having particular application to microbial fuel cells. Specifically the invention relates to an arrangement and construction of a Cathode for such a fuel cell.

## Background of the Invention

The shift toward a more sustainable society has increased the need for renewable energy. A particular source of renewable energy is obtained from biomass produced from the biological treatment of wastewater or organic solid waste. The recovery of renewable energy can be achieved by anaerobic conversion of waste biomass or organic solid waste to produce biogas, which is currently a well-established technology. However, this technology presents some limits, such as the need for high strength wastewater or organic solid waste and heat requirement. In addition, the treatment of biogas prior to its combustion and conversion into electricity is costly and the conversion step itself occurs at a low efficiency.

Microbial fuel cells (MFCs) have recently been considered as an alternative and promising way for the direct conversion of the biochemical energy bound to wastewater into electricity without any intermediate step.

A MFC is fundamentally an anaerobic process where bacteria grow in the absence of oxygen in a chamber containing an anode and form a biofilm that covers the anode. To generate electricity, bacteria in the anode chamber degrade organic matter (the influent/fuel) and transfer the electrons to the anode. These electrons pass through an external circuit producing current. The digestion of organic matters occurs in anaerobic environment so that the electrons are not consumed by electron acceptors such as oxygen. The transfer of these electrons occurs via bacterial respiratory enzymes. Protons, created at the anode to maintain a charge balance, migrate through the solution to a cathode where they combine with oxygen and the electrons produced at the anode to form water. Hence, the cathode has to be maintained under aerobic conditions.

MFC can be of two types: 1) a two-chambered MFC, where the anode chamber is anaerobic and the cathode chamber is aerobic (Figure 1A), or 2) a single-chambered MFC where both electrodes are placed in an anaerobic chamber, with one face of the cathode exposed to the air (Figure 1B). A proton exchange membrane (PEM), aiming at facilitating the transfer of protons, usually separates the anode from the cathode. The potential difference between the respiratory enzyme and oxygen results in electricity generation.

Summary of the Invention

In a first aspect the invention provides a cathode for a microbial fuel cell comprising; a backing layer mounted to an aperture in a fuel chamber of said microbial fuel cell; wherein said catalyst layer mounted to the backing layer on a face opposed to the aperture, so as to be in fluid communication with atmospheric oxygen

In one embodiment, the cathode may include a piece of conductive material, such as but not limited to carbon paper, conductive plastic polymers, steel, graphite granules, graphite fibers, reticulated vitreous carbon, or any non conductive material coated with a conductive paint, on which are applied the catalyst layer

In a second aspect, the invention provides a method for generating electricity, said method including the steps of: providing a microbial fuel cell (MFC) having a cathode, said cathode including a catalyst layer and a backing layer mounted to an aperture in a fuel chamber of said microbial fuel cell; said catalyst layer mounted to the backing layer on a face opposed to the aperture, so as to be in fluid communication with atmospheric oxygen; providing fuel to an anode of said MFC; generating electrons passing through said anode to an external circuit coupling the anode and cathode; communicating resulting protons to said cathode.

In general, the present invention provides a new type of cathode for single-chambered air-cathode MFC wherein the catalyst layer is applied to the side of the cathode exposed to the air on top of a backing layer. The catalyst layer can then be protected by one or more gas diffusion layers. By providing a catalyst layer that is facing the air, the arrangement may become more efficient through closer and better contact with the atmospheric oxygen, leading to better performance. Further, by separating the catalyst from the biomass/influent/fuel, the catalyst remains uncontaminated, also increasing performance and functional life of the MFC.

The invention provides for an arrangement whereby the carbon cloth and/or backing layer isolates the catalyst layer from contamination by the fuel/biomass within the anode chamber of the microbial fuel cell.

The backing layer provides support for the catalyst layer and allows the diffusion of protons to the catalyst. Such a backing layer may seal an aperture in the anode chamber of the MFC so as to prevent the flow of biomass, such as wastewater from the chamber. The backing layer may also provide mechanical support for the catalyst layer. It may be made of Nafion or polytetrafluoroethylene (PTFE) which may also be mixed with carbon black.

An advantage provided by embodiments of the present invention may include higher electricity generation while achieving biological treatment of an

influent/fuel using the MFC technology. The influent/fuel may include (i) biofuel (defined as a substrate derived from the biomass), (ii) wastewater (low strength, such as domestic wastewater or high strength, such as industrial wastewater), (iii) organic solid waste mixed with liquid (such as wastewater) to become liquid waste, and (iv) pretreated forms of items (i) to (iii).

The present invention may also use any organics dissolved in solution as the influent for the purpose of generating electricity using the MFC technology.

Possible applications of the present invention may include (i) wastewater treatment plants, (ii) power plants for electricity generation from any solutions that contain organics (intentionally or unintentionally produced) and (iii) any locations where wastewater or waste are generated and required to be treated.

The gas diffusion layer (GDL) may provide pathways for reaction between atmospheric $O_2$ and water. This GDL may be made of polytetrafluoroethylene (PTFE) mixed with carbon black. Deposition methods may include brushing, air brushing, sputtering. Additional GDLs made of pure PTFE may be added on top of the first GDL.

The catalyst layer is where the reaction takes place. The nature of the catalyst may include Cobalt, Platinum and alloys thereof. Deposition methods may include but are not limited to brushing, air brushing, sputtering.

Brief Description Of Drawings

It will be convenient to further describe the present invention with respect to the accompanying drawings that illustrate possible arrangements of the invention. Other arrangements of the invention are possible and consequently, the particularity of the accompanying drawings is not to be understood as superseding the generality of the preceding description of the invention.

Figure 1A is a schematic of a two chamber microbial fuel cell according to the prior art;

Figure 1B is a schematic view of a single chamber microbial fuel cell having the catalyst facing the biomass within the chamber, according to the prior art;

Figure 2 is a schematic view of a microbial fuel cell according to one embodiment of the present invention;

Figure 3 is a graphical representation of the performance of a microbial fuel cell according to the present invention as compared to the prior art and;

Figure 4 is a graphical representation of the performance of a microbial fuel cell according to the present invention as compared to the prior art.

Detailed Description Of The Preferred Embodiment

Figures 1A and 1B show different microbial fuel cells (MFC) according to the prior art.

With respect to Figure 1A, shown is a two chamber MFC 5 having an anode chamber 10 and cathode chamber 20. The anode chamber 10 is characterized by being anaerobic so as to prevent released electrons being consumed by oxygen feeding into the chamber 20. Within the chamber is a supply of biomass, such as wastewater, within the chamber 10. The organic material within the wastewater then forms a biofilm 40 on the anode 15 which on degradation of the influent/fuel 45 produces electrons. The anode 15 is connected to an external circuit 35 through which the consequential current flows to the cathode 25 within the cathode chamber 20. Thus, the fuel 45 supplied to the anode chamber 10 is oxidized 50 producing a flow of protons 55 through a proton exchange membrane (PEM) 30 whereby the protons combine with oxygen 57 within the cathode chamber 20 to form water 58.

Figure 1B shows an alternative arrangement of an MFC 60 whereby a single chamber 70 exists being the anode chamber 70, again being anaerobic to prevent oxygen entering the chamber. The cathode chamber of Figure 1A is replaced by an external cathode 65, having a catalyst layer attached to the MFC, and so facing the biomass within the chamber 70. The protons 75 combine at the site of the cathode 65 with atmospheric oxygen 80 to produce

water 85. Again a PEM 90 is provided to separate the cathode 65 from the anode chamber 70.

The present invention provides an alternative arrangement of the above single chamber MFC. As shown in Figure 2, in one embodiment of the present invention, the cathode 110 includes a sheet of carbon cloth 115 situated at the wastewater / air interface 141 of a single-chambered MFC 100. In the following example, the cathode working surface area equaled 64 $cm^2$. In this case, the carbon cloth acts as a separation layer isolating the catalyst layer from the influent/fuel. Accordingly, the catalyst layer is directed in a direction away from the aperture. For clarity, this will be called an air-facing catalyst, as compared to a influent/fuel, or water, facing catalyst, as shown in Figure 1B.

The fabrication of the cathode 110 includes the following successive steps:

Teflonization by soaking carbon cloth 115 in 30wt% PTFE suspension in water. The carbon cloth 115 is dried in oven at 100°C and then weighed to determine the Teflon content 115 so as to achieve a target 115 in the range of 15-20 wt%. The teflonized carbon cloth 115 is then transferred to an oven and heated to 350 °C at 4.5 °C/min to gradually remove the dispersant agent present in PTFE and to melt the PTFE particles at 350°C for 30 minutes.

Next is provided an application of a backing Layer (BL) 120 made of Nafion and carbon black (VXC72-R) and Nafion particles. The weight ratio of the carbon

black to Nafion is 2:1. Carbon black is mixed with distilled water and ethanol (1:1 v/v). Nafion solution (5%) is added to the carbon black ink and stirred to make a homogeneous dispersion. The mixture is ultrasonicated for 30 min. The diffusion ink is applied to one side of the carbon cloth 115 using an air brush. The gas diffusion electrodes are baked in oven at 130°C for 30 min. Typical loading of the diffusion ink is around 3.6mg/cm$^2$.

Application of the catalyst layer 125 includes Cobalt being applied at a load of 0.1 mg cm$^2$ by sputter-deposition using a Denton Vacuum Discovery TM 18 Deposition System.

Application of a GDL 130 made of PTFE on top of the catalyst layer 125. The GDL 130 for the electrodes comprises carbon black (VXC72-R) and PTFE particles. The weight ratio of the carbon black to PTFE is 3:2. The carbon black is treated in an ultrasonicator in a mixture of distilled water and ethanol (1:2 vol. ratio) and the PTFE is stirred in distilled water. The PTFE solution is added to the carbon black ink and the mixture is ultrasonicated for 30 min. The diffusion ink is applied to one side of the carbon electrode using an air brush. Typical loading of the diffusion ink is around 3.6mg/cm$^2$. The gas diffusion electrode is dried in oven at 100°C. The gas diffusion electrode is sintered at 350°C under the same conditions as the heat treatment of the Teflonized carbon electrodes. The sheet of carbon cloth is then ready to be incorporated in a single-chambered MFC for test.

The MFC 100 used for tests and illustrated in Figure 2, had dimensions 120×120×30 mm and the working volume of the MFC 100 was 85 mL. It was incorporated with channels that provided a serpentine pathway for the wastewater. The flow channels were sandwiched between a sheet of anode and a sheet of cathode and the distance between the anode and cathode was set to 2 cm. Anode and cathode surface areas were similar and each equaled 64 $cm^2$. The anode was made of non-wet-proofed plain carbon cloth and was applied against a piece of acrylic to ensure anaerobic conditions.

Inoculation was done using bacteria naturally present in domestic wastewater. This inoculation step was performed in a batch-mode, the MFC being refilled with fresh domestic wastewater when the voltage dropped below 50 mV. The inoculation step was considered achieved when the profiles of voltage generation showed similar pattern for at least three consecutive batches. The MFC 100 operation was then switched to continuous mode using sodium acetate as substrate. Sodium acetate was pumped continuously using a peristaltic pump at a flow rate of 0.3 mL $min^{-1}$ into the bottom of the MFC and was allowed to flow through channels directly between an anode and a cathode in an upflow mode. The loading rate was 16 Kg acetate $m^{-3}$ $d^{-1}$ and the hydraulic retention time equaled 4.7 hrs.

Comparison of performance obtained with the new type of cathode 145 and with a conventional cathode 150 built in the same way except that the catalyst layer

faces the wastewater is displayed in Figure 3. Cell potential is in average higher with the present invention by 40 mV (i.e. an increase of ≈15%)

These improved results are confirmed by polarization curves obtained at different external resistances by using a resistance box and displayed in Figure 4 for the new type of cathode 115 and the conventional cathode 150.

The level of teflonization of the carbon cloth can be modified.

The carbon cloth 115 can be replaced by any other type of conductive material, such as but not limited to carbon paper, conductive plastic polymers, steel, graphite granules, graphite fibers, reticulated vitreous carbon, or any non conductive material coated with a conductive paint.

The nature of the BL and GDL may be changed to other materials (e.g. PTFE, Nafion, others).

Additional GDLs can be added on top of the catalyst layer to increase cathode hydrophobicity and prevent leakage. Such GDLs can be made typically but not only of pure PTFE.

The nature and the load of the catalyst on the cathode can be changed (e.g. Pt, Co, Alloys, others).

In further embodiments of the present invention, the cathode 110 may omit the BL 120 and GDL 130 so as to have the catalyst layer 125 applied directly to the carbon cloth 115. A key feature of the present invention is ensuring the catalyst layer is not contaminated by the waste water within the anode chamber and hence, the separation by the BL 120. The omission of a PEM allows higher power output. This is due to reduced internal resistance of the MFC and higher cathode potential. The omission of a PEM adds further advantage through the omission of a construction step and so saving materials and costs.

The embodiment shown in Figure 2 has further advantage in replacing the platinum catalyst with a cobalt alloy which combined with the less complex construction of the MFC 100 which may provide significant savings in construction costs at little or no sacrifice as compared to more complex and expensive construction. Further, advantages of such an air facing cathode compared to having the catalyst layer facing the waste water, is demonstrated by the performance shown in Figures 3 and 4.

Claims

1. A cathode for a microbial fuel cell comprising

a catalyst layer;

a backing layer mounted to an aperture in a fuel chamber of said microbial fuel cell;

wherein said catalyst layer is mounted to the backing layer on a face opposed to the aperture, so as to be in fluid communication with atmospheric oxygen.

2. The cathode according to claim 1 or 2 wherein said backing layer arranged to communicate protons from the chamber to the catalyst layer and preventing contamination of the catalyst layer by fuel within the chamber.

3. The cathode according to any one of the preceding claims further including an external gas diffusion layer mounted to the catalyst layer on a face in an opposed direction to the aperture.

4. The cathode according to any one of the preceding claims wherein the backing layer includes Nafion™ particles.

5. The cathode according to any one of claims 2 to 6 wherein the backing layer and gas diffusion layer, or layers, includes PTFE.

6. The cathode according to any one of the preceding claims wherein the catalyst layer includes cobalt, platinum or alloys thereof.

7. A microbial fuel cell having a cathode according to any one of claims 1 to 6.