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Optimising Consistency of Voltage Output Using 3D Printed MFC

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Abstract: A microbial fuel cell (MFC) exhibiting a higher peak voltage and more consistent voltage output has been cheaply constructed using 3D printing. MFCs are renewable sources of energy. Although they have a high voltage output, it is inconsistent. The orientation of the cell and interaction between electrodes and solution prevent high energy output from Bennetto's cell (Kim, Chang, & Gadd, 2007) and the aim of this research is therefore to optimise the consistency of voltage output from MFCs by changing its size and orientation. MFCs with different dimensions allowing more interaction between the electrodes and solutions have been designed. The volume of solution the MFC can hold was increased and the cell was placed both horizontally and vertically to check whether reduced density differences within the solutions will affect its voltage output. The redesigned cells were 3D printed and the voltage for both redesigned and Bennetto's cells were recorded by data loggers. Runs were conducted to compare voltage output of an original Bennetto cell and a printed Bennetto cell, a printed cell with same volume but different dimensions and a printed cell with maximised volume. The runs show that the voltage of the maximised cell indeed exceeded the Bennetto cell by 5.35%.

Key words: microbial fuel cell, 3D printing, renewable energy

1. Introduction

Rapid depletion of fossil fuels and other non-renewable energy sources has led to an increased need for the development of alternative renewable energy sources such as solar, wind, and hydropower. Microbial fuel cells (MFCs) can act as a possible renewable energy source and provide a promising alternative to depleting

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sources of fossil fuels (Du, Li, & Gu, 2007). As MFCs are able to harness energy from micro-organisms which are abundant and renewable and can be deployed to areas lacking proper electricity sources. MFCs provide a promising alternative to depleting sources of fossil fuels (Du, Li, & Gu, 2007). As MFCs harness energy from micro-organisms which are abundant and renewable, electricity can readily be generated over a long period of time. In order to enable microbial fuel cells (MFCs) to be an alternative energy source, 3D printing was used to vary the dimensions of a MFC. The current microbial fuel cells (MFCs) are able to achieve a high but inconsistent voltage. Bennetto's cell is such an example. A Bennetto's cell has a theoretical maximum voltage output of 1.1V (B. Logan, B. Hamelers, R. Rozendal et al.) whereas a normal AA/AAA battery has a nominal voltage output of 1.5V. Hence, maximising the voltage output is not an issue, it is improving the consistency of voltage output of the MFC that proves difficult. By optimising the voltage output of the MFC, it would be possible to make the MFC a feasible alternative energy source that generates electricity through renewable sources and solve the problem of the diminishing fossil fuels. Thus, our aim is to optimise the consistency of a MFC. A MFC is made up of a cathode and an anode. In the cathode, the yeast feeds on glucose, which causes H+ ions and electrons to be released. The electrons, mediated by mediator molecules (eg. methylene blue), flow to the anode. They then flow through the voltage sensor and into the cathode. The flow of electrons through the voltage sensor generates a voltage that can be used to do work. During the flow of electrons, the H+ ions flow through the semipermeable membrane (placed between the cathode and the anode) to the cathode. This process is driven by the electro-chemical gradient resulting from the high concentration of H+ ions in the cathode. The H+ ions react with dissolved oxygen in the anode to form H_2O. This paper seeks to investigate the effects of changes in dimensions and orientation on the voltage output of a microbial fuel cell.

All the following diagrams, graphs and tables are self-drawn. All photos are self-taken.

2. Materials and Methods

2.1 Assembly of Microbial Fuel Cells

Redesigned cells

Different components of the redesigned cell were printed using a 3D printer. Rubber gaskets and silicone sealant were used to prevent leakage of solutions injected into the MFC. A carbon electrode was placed in each printed half cell. Silicone sealant was spread over the surface of the printed cell to smoothen the rough surface. The tissue (J-cloth) and rubber gasket were then placed on it. This was done for both half cells. The membrane was then placed in between these half cells. The visking tubing membrane is inserted in between the two half cells and are being held together by binder clips.

Bennetto's cell

The parts of the cell are held together with the membrane between the electrodes, and a piece of paper tissue between the anode and cathode. Rubber gaskets were placed between the parts of the MFC to prevent leakage of the injected solutions. The cell is held together by screws.

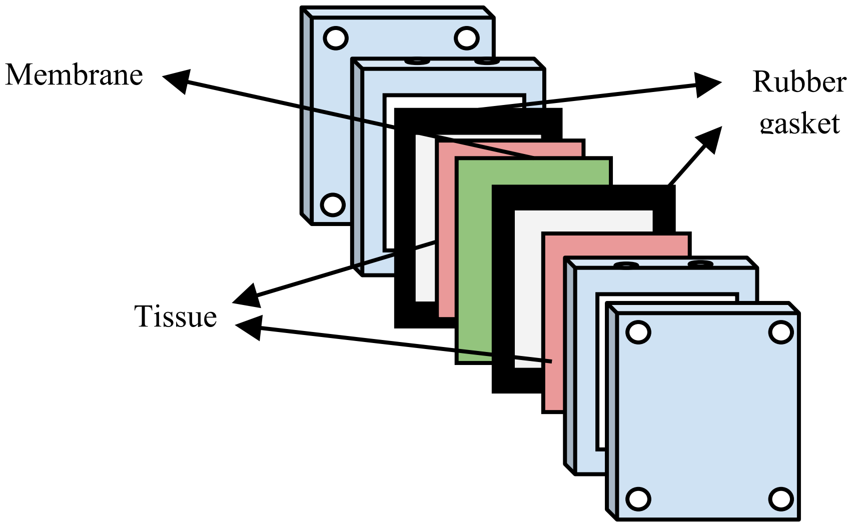

Fig. 1: Assembly of a Bennetto MFC

2.2 Preparation of Solutions

Methylene blue, glucose and potassium permanganate were mixed with phosphate buffer each in a 1:1 ratio. 20ml of phosphate buffer was used for every 3g of yeast. The potassium permanganate solution was then injected into the cathode of the MFC. Methylene blue, glucose and yeast were injected into the anode respectively.

2.3 Recording of Data and Data Analysis

The redesigned cell and Bennetto's cell were connected to a data logger, which was set to detect changes in electrical currents up to ±1 volt. To ensure proper analysis and recording of data, the data logger was made to start recording before the substrates were injected into the cells. The set-up was then left to run for 10 hours. Recorded data was saved in a SD card and exported to an Excel file to be analysed and charted into a graph, which enabled comparison of the efficiency of cells. Maximising the consistency of voltage output of the MFC would be successful if the trend of graph of our designed cell shows that it is able to obtain a higher and more consistent voltage output than Bennetto's cell.

3. Results and Discussion

Dimensions for microbial fuel cells (printed and original) are given in the format length by breadth by height.

3.1.1 Overview of First Experiment

The first experiment was to compare the voltage output of a printed Bennetto cell with that of an original Bennetto cell. The dimensions for the printed cell (3cm by 4cm by 0.8cm) were the same as the original Bennettocell's. The aim of this experiment is to find out if printing a Bennetto cell will cause it to have a higher or lower voltage output compared to the original non-printed Bennetto cell.

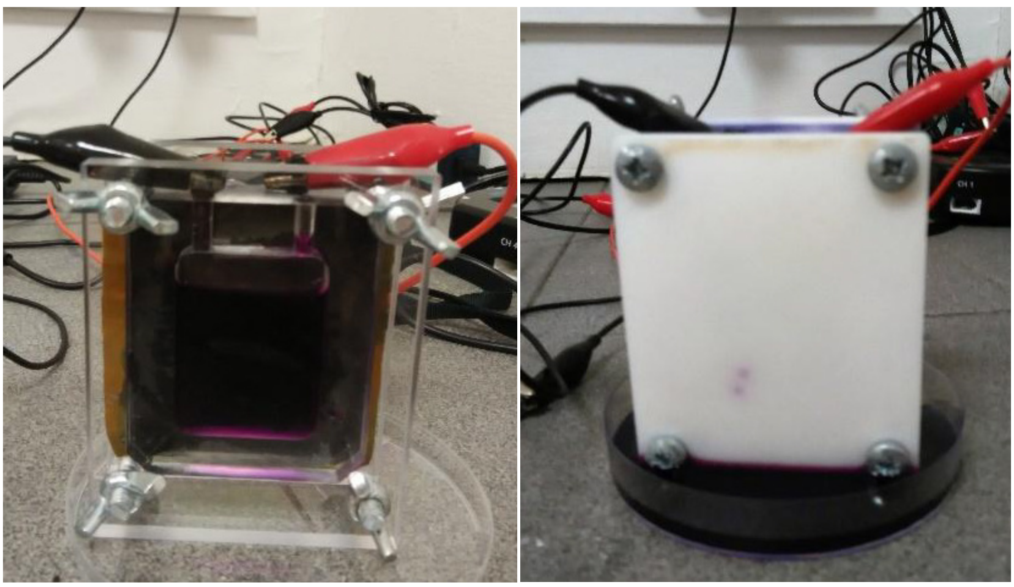

Fig. 2: Bennetto's cell (left), redesigned cell (right)

3.1.2 Results (printed Bennetto cell versus original Bennetto cell)

Fig. 5.1 and 5.2 are the results of voltage output from our printed Bennetto cell and original Bennetto cell. Fig. 3.1 shows the peak voltage, time taken to reach peak voltage, range of voltage and time taken for voltage to drop to the lowest from its peak.

Results								
	Original Bennetto Cell				Printed Bennetto Cell			
Run	Peak Voltage/ volts (peak voltage-lowest voltage)	Time taken to reach peak/ min	Range of Voltage/ volts	Time taken for voltage to drop to its lowest from peak/ min	Peak Voltage/ volts	Time taken to reach peak/ min	Range of Voltage/ volts	Time taken for voltage to drop to its lowest from peak/ min
1st (Fig 5.1)	0.86	375	0.06	599	0.77	20.0	0.36	596
2nd (Fig 5.2)	0.91	72.0	0.13	516	0.67	11.0	0.69	538

Fig. 3.1: Table of the peak voltage, time taken to reach peak voltage, range of voltage and time taken for voltage to drop to the lowest from its peak

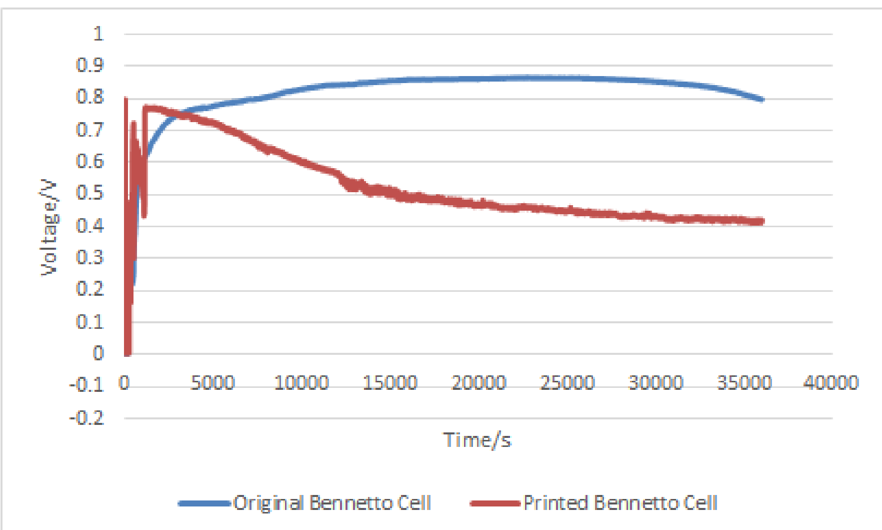

Fig. 3.2: First run

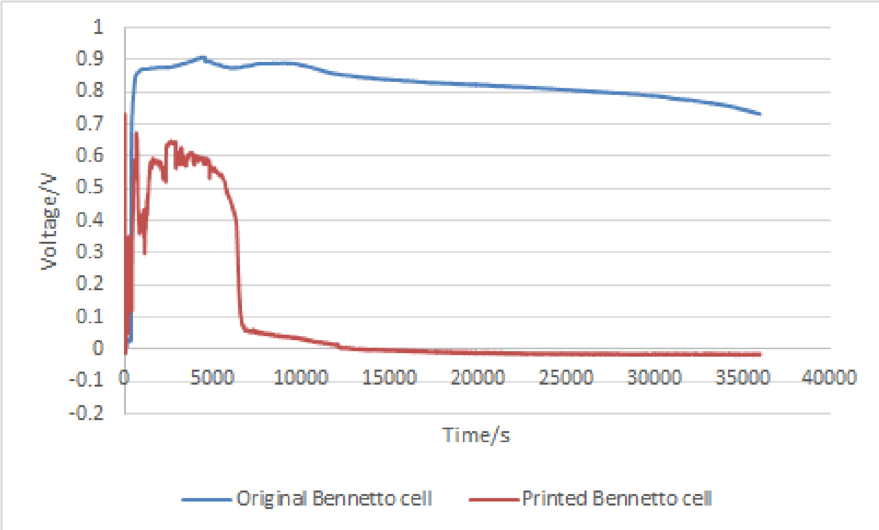

Fig. 3.3: Second run

3.1.3 Results Analysis (printed cell versus original Bennetto cell)

1st Run (Fig. 3.2): The original Bennetto cell has a higher voltage output than the printed Bennetto cell, and also has a more consistent voltage output. There was no leakage of solutions. During the early stages of the run for the printed Bennetto cell, there were frequent fluctuations. After a while, however, the voltage output for the printed Bennetto cell evened out and decreased more consistently. The sudden spike in voltage output is most likely caused by the adding of yeast. When yeast was added, the speed of the redox reaction increased, resulting in the spike.

2nd Run (Fig. 3.3): The original Bennetto cell is both of higher peak voltage output and more consistent voltage output as compared to the printed Bennetto cell. There was substantial leakage of solutions from the printed Bennetto cell, and frequent fluctuations at the start of the experiment. The voltage output for the original Bennetto cell increased steadily and no fluctuations were observed. Near the start of the run, a sudden drop in voltage was observed. The sudden drop could be due to the solutions within the cells being completely used up.

Overall: The original Bennetto cell constantly had a higher voltage peak than the printed Bennetto cell. This is likely due to the vast leakage of solutions from the printed Bennetto cell. It can also be noticed from the graphs of results that the printed Bennetto cell always hits the peak voltage early in the run, meaning that it is a viable setup of a MFC cell. However, further improvements have to be made to reduce the leakage of solutions and improve consistency and peak voltage. The voltage output of the printed Bennetto cell was high at the start but declined rapidly towards the end and reached a final voltage output of close to 0 volts for both runs. This can also be attributed to the leakage of solutions. With decreased solutions, there is lesser yeast, glucose and other substances to generate electricity. At the end of the runs, it was not uncommon for the printed Bennetto cells to be empty, whereas the original Bennetto cells still contained a fraction of the original solutions.

3.2.1 Overview of Second Experiment

The second experiment was to compare the voltage output of an original Bennetto cell and a printed cell of different dimensions (8cm by 2cm by 0.6cm) but same volume as a Bennetto cell. This experiment will show that a longer design and increased surface area of electrode will allow increased voltage output.

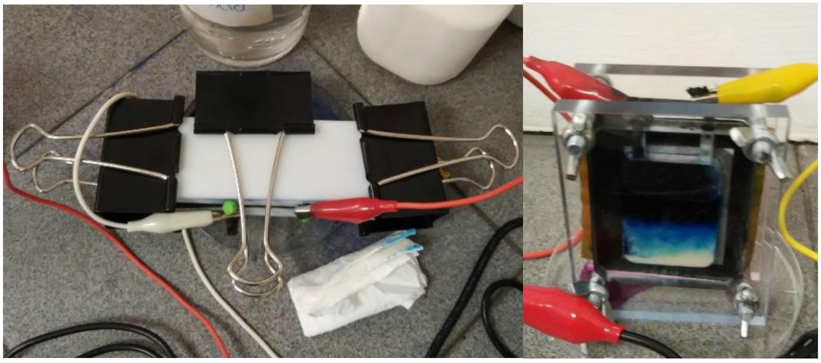

Fig. 4: 3D printed cell with different dimensions (left), Bennetto's cell (right)

3.2.2 Results (printed cell with same volume, different dimensions versus original Bennetto cell)

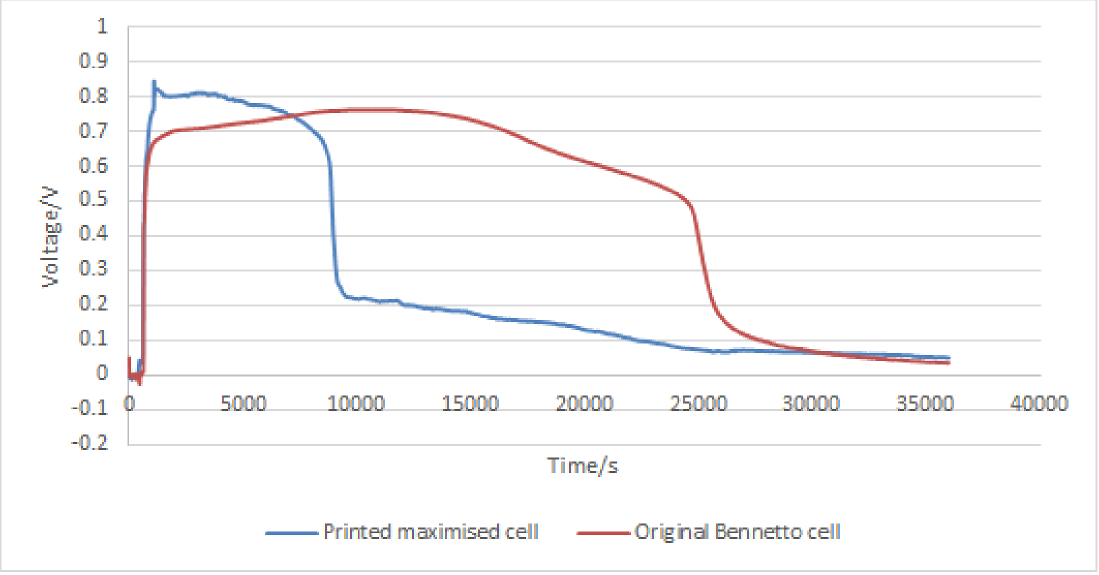

Fig. 5: Run for same volume, different dimensions printed cell versus original Bennetto cell

3.2.3 Results Analysis

The different dimensions printed cell has exceeded the peak voltage of the original Bennetto cell and from where the printed cell exceeded the voltage output of the original Bennetto cell at the last 100 minutes, it can be seen that the printed cell is able to last longer at a consistent voltage. The larger surface area of the different dimensions printed cell enabled a larger volume of solutions to be in contact with the carbon electrode. More electrons flowed through the voltage sensor every 10 seconds. Thus a higher voltage was recorded at the starting. Further into the run, the solutions were used up more quickly than the printed cell due to the greater surface area of contact, thus resulting in a drop in voltage output.

3.3.1 Overview of Third Experiment

The third experiment conducted is to compare voltage output between printed cells with larger dimensions but different orientations (8.5cm by 5.0cm by 0.6cm) and an original Bennetto cell. The printed cells had a maximised volume.

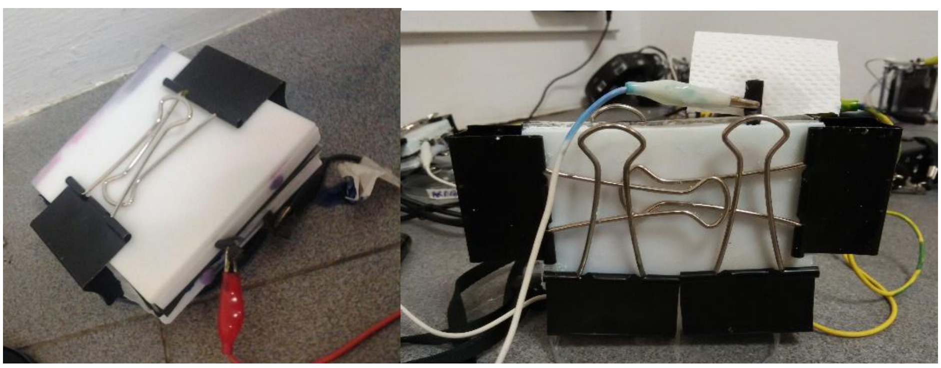

Fig. 6: horizontal maximised volume cell (left), vertical maximised volume cell (right)

3.3.2 Results (printed maximized cell versus original Bennetto cells

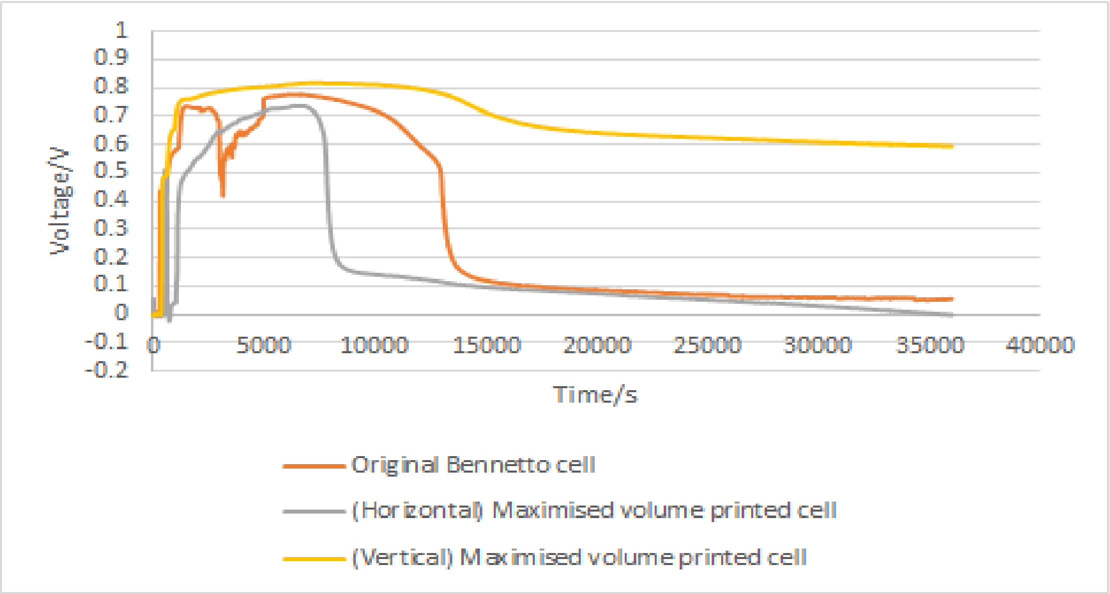

Fig.7: Run for maximised volume, vertical orientation printed cell versus maximised volume, horizontal orientation printed cell versus original Bennetto cell

3.3.3 Results Analysis

As can be seen from the graph, our printed maximised cell in the vertical orientation obtained the highest and most consistent voltage with a peak voltage of 0.818 while the Bennetto's cell had greater fluctuations with a peak voltage of 0.776. However, the printed maximised cell in the horizontal orientation had the lowest peak voltage of 0.737 volts, and was the first to experience a sudden drop in voltage. The drop in voltage of the printed cell in the horizontal orientation may be due to the reduced contact between the membrane and the solutions since the MFC is not completely filled with solutions which results in the gap between the solution and membrane when the MFC is tilted to its side. There was lesser surface area of the yeast at the bottom of the cell in contact with the solution. This results in the solutions being used up more slowly than the cell in the horizontal orientation.

4. Conclusion

From the 4 experiment runs, we can conclude that 3D printed cells are functional and a larger surface area of a MFC and greater volume cell, placed vertically, will increase the peak voltage and also allow the cell to last longer at a more consistent voltage output. Our experiments have shown that 3D printed maximised cells are more effective than conventional Bennetto MFC cells and 3D printed maximised cells can provide a cheap alternative to the conventional microbial fuel cell and hence can be used to solve the problem of depleting fossil fuels. The toughest problem that needs to be solved in order to increase the consistency and maximise the voltage output of the 3D printed MFC is to ensure no leakage of printed MFCs. A better method needs to be undertaken to eliminate leakage of printed MFCs. These methods can include sanding and usage of a better substance to smoothen the rough surface of the printed cell instead of silicone sealant. Once there is little to no leakage, it can become an improved cheaper alternative to conventional MFCs. Microbial desalination cells (MDCs) are constructed by modifying MFCs -- by placing two membranes between the anode and cathode, creating a middle chamber for water desalination between the membranes. An anion exchange membrane is placed next to the anode, and a cation exchange membrane adjacent to the cathode. Since current desalination methods are expensive or energy intensive, MDCs are an excellent alternative option to desalinate water cheaply. Increasing the effectiveness of MFCs would likewise increase the efficiency of MDCs.

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