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USE OF EXTERNAL RESISTANCE IN OPERATION OF MICROBAIL FUEL CELLS.

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ABSTRACT

The Microbial Fuel cells that are often used to conduct experiments for research purposes are often made to perform under a constant electrical load. But it is also observed that modifications in strength & quality and the growth and decay of Bio-film growth often results in prominent variations in internal resistance values for the Microbial Fuel cell for set time period. This often ends up with a low output power which is a result of the mis-match of internal and external resistances of the cell. Our research shows the performance study of Microbial Fuel Cell having periodic connection of the electrical load (R_{ext}). Study shows that efficiency of the Fuel Cell is improved as the cells are operated with external resistances, the R_{ext} is fixed such that it is below R_{int}. We have compared the power outputs as well which were found by utilising of either resistances connected of fixed values.

1. INTRODUCTION

Studies have been dedicated towards improvement of microbial fuel cell designs, materials in use. It has also been observed that the amount of knowledge of MFC in increasing and its power output is also rising in magnitude. But There is a whole different side that has been over-looked. We must study and research to find out more ways about harvesting the energy that us produced. The Fuel Cell's power output reaches higher values if an electrical load (external resistance having the correct value) is in connection with MFC is set equal to internal resistance. Microbial Fuel Cells perform with a constant external resistance. Sometimes, while varying the operating conditions and other factors like the process of bio-film growth and decaying of Bio-film which leads to prominent change in internal resistance over time period which often end in a mis-match between the internal and the external resistances. This further results in falling of the total power output.

The resistance mis-match can be solved by manual adjustment of variable external resistor which is in connection with the Microbial Fuel Cell. The process needs knowledge of the Fuel Cell's internal resistance so that it can be found out in polarization experiments. But it is to be kept in mind that the manual adjustment of external resistance would be infrequent maybe weekly or maybe daily. However, the internal resistance value could exclusively alter in a duration of minutes as well. This can result in a major energy loss issue. A method was explored in the recent studies which shows use of an online algorithm for observation purposes used to obtain higher values of the power output. Another method in which approach such as a logic based-control approach was utilised in order to adjust the external resistance. The real time optimization of R_{ext} was provided with the help of these techniques. In order to implement these methods practically, an electrical load was qualified which can be altered as required by us in order to successfully perform the experiment. It is also to be kept in mind that electrical loads cannot be altered and adjusted necessarily.

This research brings forward a concept of Microbial Fuel Cell performance when it is having a connection with an electrical load having R periodic operation and it tries to justify the conclusions obtained which points towards 'making the technique more effecient'.

2. REQUIRED MATERIALS AND TECHNIQUES

2.1 The Microbial Fuel Cell designing and its operations:

As shown in Figure- 01, A no membrane air cathode Microbial Fuel Cell construction is shown made of nylon plates. The dimensions of anode are 5millimeter thickness carbon felt, it measures to around 10 centimetres × 5 centimetres. Cathode is available as a gas diffusing electrode having load of around 0.5 mg/cm^2. Nylon cloth of about 0.5 millimetres thick separates the electrodes. The temp inside the anodic chamber was kept at 20°^{C}. Microbial Fuel Cell was made to feed with solution of acetate and solution which can be used to trace metals. Also, A hydraulic retention time duration of 5 hours in the anode chamber section was being maintained.

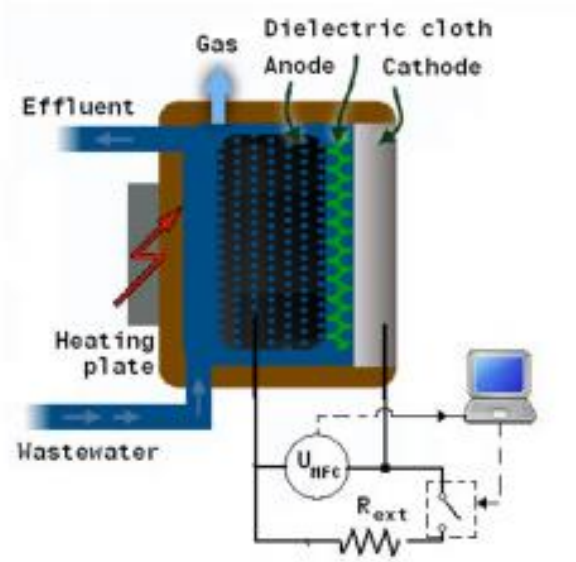


Figure-01: Experimental setup.

The experimental setup having external resistance towards the Microbial fuel Cell terminals was obtained as we added electronic switch at the external circuit part. This switch was controlled via computer using the Lab-jack U-12 DAB (data acquisition board). The DAB was also utilised for recording Fuel Cell's voltage measurements. Its operations with the connection having electrical load calculated through D as:

$$D = \frac{t_{on}}{t_{off} + t_{on}} \quad (1)$$

here D which is the duty cycle can be obtained using equation 1. Here t_{ON} can be described as the on-time associated with every cycle in which the external resistance is connected. T_{OFF} can be described as a disconnection or an off-time. Overall cycle time written as T_{cyc} can be calculated as $T_{cyc} = t_{ON} + t_{OFF}$

The Microbial Fuel Cell performance having variable duty cycle was obtained as we switch through durations off and on, its state are based on voltage estimations and at MFC terminals. An algorithm was put to use. The external resistor was removed from connection, we observed that when the thereshold voltage U_{MFC} was lowered below a fixed minimum voltage threshold U_{min}, while reconnecting the external resistor when U_{MFC} would cross over the fixed maximum voltage threshold U_{max}.

2.2 Electro-chemical calculation and functionality of the cell:

Polarization experiments were conducted so as to find out values for internal resistance of Microbial Fuel Cell. In the trials, the externall resistor was removed from connection for a yime period of around 30 mins after which calculation of the open circuit voltage was done. Similarly, by again connecting the external resistor, after which the resistance was lowered in steps from 1000Ohms to 5 – 15Ohms to obtain around 10 measurements. The cell's Voltage (V) was calculated after an interval of 10 minutes. Obtained voltage and current values were utilised for the construction of the polarization curves in the graph where the internal resistor was used to measure the slope of the linear region.

During the cell performance having being in constant connection with external resistor, the power output was measured using voltage output and a fixed valued external resistor. The cell performance while being in constant connection external resistance, P_{av} was obtained as:

$$P_{av} = 1/T_{cyc} \int_{0}^{Tcyc} (U^2(t)/R_{ext})dt \qquad (2)$$

where P_{av} is the average power output calculated per Duty cucle and the U(t) can be defined as voltage calculated at external resistance value at time (t). Also, total internal capacitance value for surface of electrodes can be measured by analysing cyclic-voltammograms which is found at various sweep-rates. Cyclic voltammetry technique was put into use using an electro-chemical analyser. Where we had used two electrode setups in which "anode" was used as an electrode for working purposes and a "cathode" was used as a counter. The calculations are repeat while having the 'cathode' as a working electrode and 'anode' as a counter and reference electrode. Technique of voltammogram was done around the 'OCV' value at a scan-rate between 1 - 15 mV/s. The Current measured at a voltage level of OCV was graphed having the scan rate vs internal capacitance which is the slope of the linear part in the graph.

2.3 Factorial design test:

An experiment to optimize the factorial design of the Fuel Cell in order to find out the aerage power was conducted by changing the periodic operation threshold voltafe levels (U_{min} and U_{max}) between low-voltage, intermediate-voltage and high-voltage values. The experiment required a total of 05 conductions. we used a 10 Ohms external-load resistance, and we had observed 03 additional mid-points to obtain the measurement respectively.

3. CONCLUSION

3.1 Discussion on the internal resistances & estimation of value of capacitance

Few no. of polarization experiment was done in order to calculate an approx. value of the Microbial Fuel Cell's internal resistances during the cell's performance at a basic OLR of value 4 g/ L_A d which corresponds to 1000 mg/L and at a lower -OLR of 1 g/ L_A d which is 250 mg/L. The concentration of acetate into the anodic chamber was at 170 - 200 mg/ L and 20 - 40 mg/ L, for basic-OLR and lower -OLR. At a basic-OLR, internal resistance value was altered in the range of 19 to 24 Ohms (Shown in Figure- 2A). The figure outcome is obtained when an external resistance range of 18 to 25 Ohms utilised in the Fuel Cell performance, It can be taken to maximum Fuel Cell power output by correct connection of external resistance in the real time. The fuel Cell performance at a minimised OLR resulted into a jump in the internal resistance of 50 to 70 Ohms, same can be vied in the Figure- 2A. It can also be noticed that acetate limitation resulted in a power output fall from 2.1±0.2 milliWatts till 0.8±0.1 milliWatts.

We can conclude that the polarization experiments have shown a deep connection of internal resistance on the concentration of the carbon sources inside chamber where anode is present. Similarly, it is found that there is dependence between MFC and synthetic waste water that is fed to it.

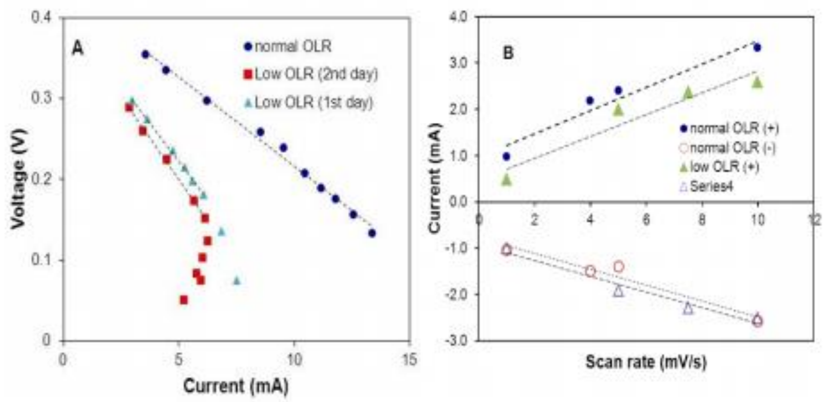


Figure- 02-A shows polarized curve paths and Figure- 02-B shows current versus scan rate graph which was found under basic OLR of 4 g / L_A d and lower OLR of 1 g /L_A d conditions. Internal resistance was set to 22 41 and 38 Ohms in order to find a basic-OLR, lower-OLR "week-01" and lower-OLR "week-02" tests.

We found that the approximate capacitance values lay between 0.20±0.08 Farad and 0.20±0.09 Farad for clear and lower OLR. Estimate of capacitance value of a fuel cell was found using the cyclic-voltammetry technique. Voltammogram was found for uniquw rates, the current in the mid of voltage range is graphed as a function of the sweep rate to find out the slopes, in Figure- 02B. The cyclic voltammograms is found at OLR value of 04 & 1 g / L_A d. Capacitance were estimated to be around 0.20±0.08 Farad and 0.20±0.09 Farad, they are calculated for simple and less OLR. Even though the calculated capacitance was foundby cyclic voltammetry technique, they have a no. of drawbacks and also known for biased, these calculations point to a magnificant internal capacitance of the Microbial Fuel Cell.

3.2 R-periodic Microbial Fuel Cell performance:

Recently, Donovan et al (2008) proposed an Microbial Fuel Cell power managemant system, including a energy-collecting capacitor and a DC - DC converter. Such systems are used by collecting electrical energy in capacitors for some time and releasing it with great force and high powers. This technique was not able to solve the problem for Fuel Cell performance at values of impedance, which is much lower than the value of R_{int} of fuel cells.

Here, we may conclude that maximum internal capacitance of the Microbial Fuel Cells may be utilised to find solutions for resistance mis-match errors and disconnecting the electrical load at very higher frequencies. This technique for Microbial Fuel Cell performance was put to test with value of external resistance as 10Ohms, connect time and the disconnect time are fixed as 5 seconds and 2 seconds respectively. Trials were performed under acetate non limiting condition for OLR of 4 g/L_A d). As shown in the Figure- 03 the The fuel cell voltage was measured at the electrode terminals and the external resistance current was measured as $I_{ext} = U_{ext} / R_{ext}$, where U_{ext} is measured in volts around resistance areas at the terminal points. In each cycle t_{OFF} length, the measured current is nil/zero at the external resistance. In each cycle t_{ON} length, we make connection for the external resistance again. Similarly, the UMFC drops apparently approaches approximately 0.14 Volts in the end. Average power is found out per-cycle using Equation- 2. As per the trial and obtained conclusions in Figure- 03, The average power of 1.73±0.03 milli Watts is observed. Detected values are lower as compared to steady state output value of 2.10 milli Watts found having a constant connection of resistance of 20 Ohms. However, the experiment has shown that by connecting and disconnecting the external resistance from time to time, the Microbial Fuel Cells can be utilised with no significant loss of power output or external resistance value when external resistance value is lower than internal resistance values.

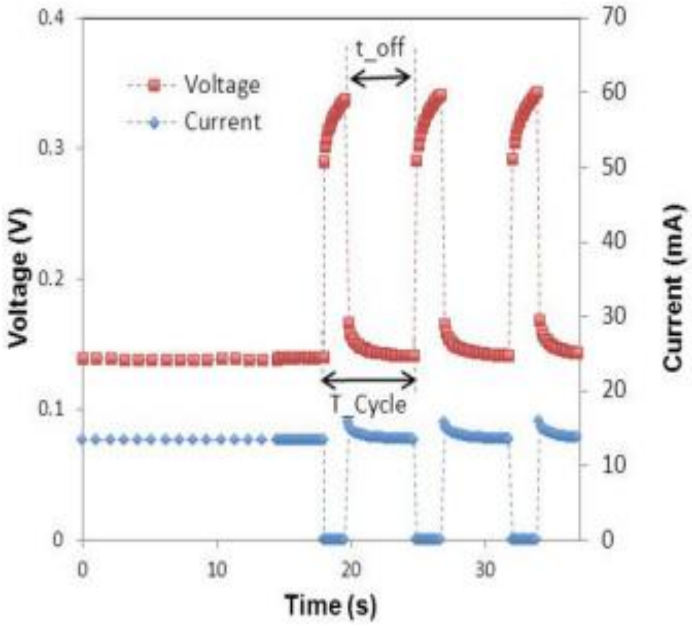


Figure-03. Microbial Fuel Cell operations using intermittant resistance connection (external resistance value of 10 Ohms).

3.3 D curve & factorial design's trial:

The cycle parameter selections for (t_{ON}&t_{OFF}) decide output's power which is found during the Microbial Fuel Cell operation through a periodic external resistance connection. In order to understand the effect of D on the power's output of the fuel cell it was made to operate on multiple D values using an external resistance of 10 Ohms. In this experiment a fixed value of t_{ON} = 3 seconds,value of t_{OFF} was altered so as to find different D values. In Figure- 04 we see D effects on the average power output (per-cycle). All the Datas and point values in figure- 04 are a result of MFC performance on each D-value of 10 hours. The clear outputs was seen for D values in range of 0.75 to 0.95. Pav increased significantly by t_{ON} = 3 seconds and t_{OFF} value of 0.6 seconds. It was found that the average power of 2 milli Watts found in these cycles settings was very near to the 2.1 milli Watts obtained with a 20 Ohms connection of a resistor. We may come to a conclusion that the average power can be improve by an increase in frequencies and using short cycles comparitively, but due to hardware limitation we were not able to perform this trial. At t_{OFF} value lower than 0.2 seconds amount samples for the voltage are not enough to accurately measure the average power.

Additional operation of the Cycle's parameters (t_{ON} & t_{OFF}) is obtained by utilising factorial design test. During the test in each cycle, we switched it inbetween ON&OFF using power measurements rather than using fixed t_{ON} & t_{OFF} lengths. It was observed that the profile decreases in the T_{ON} duration in the test cycle till a steady state value is observed. Therefore, if the voltage is lower than a fixed minimum threshold value then the (t_{ON}) where the resistor is connected ends in the cycle. In order to finish the t_{OFF} length we can decide to use a ficed maximum threshold value when external resistance will ne disconnected.

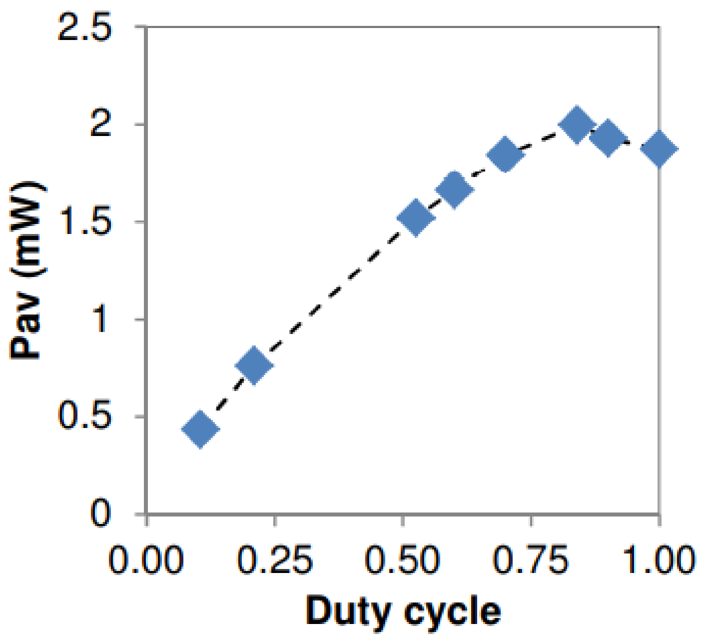


Figure 04. Average power output as a function of the duty cycle at R_{ext}=10.5 Ω.

During the experiment which was performed with values such as external resistance at 10 Ohms & OLR for 4 g / L $_A$ d. Response layer (As shown in Figure- 05) was measured by utilising result, we have come to the knowledge that the shorter the cycles, greater is the energy production.retrieval model of 2[nd] order. The regression coefficient's Statistical analysis concluded that direct interactions of the elements alone must be involved. The emerging model had 02 Radji of 0.87 and p value of 0.94. Suitable working area is available at Maximum threshold voltage of value = 0.32 Volts and minimum threshold voltage of = 0.134 Volts. These values are closer to the lower U_{max} and higher U_{min} limits set, i.e. keeping the Dcycle shorter is acknowledged more.

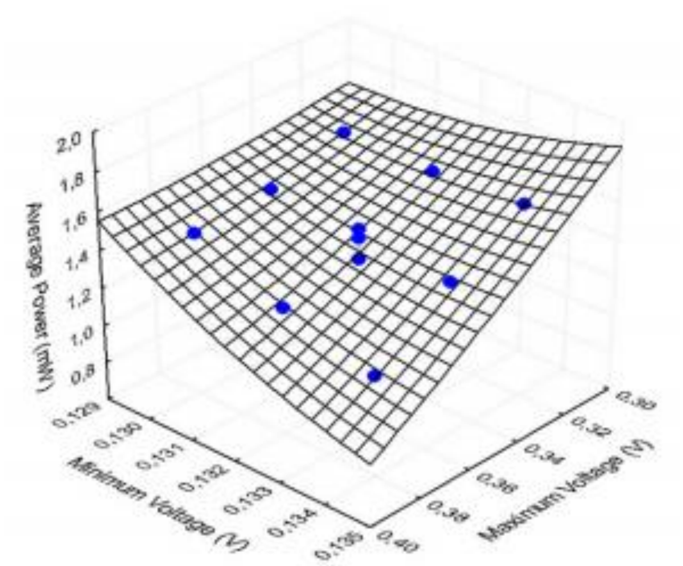
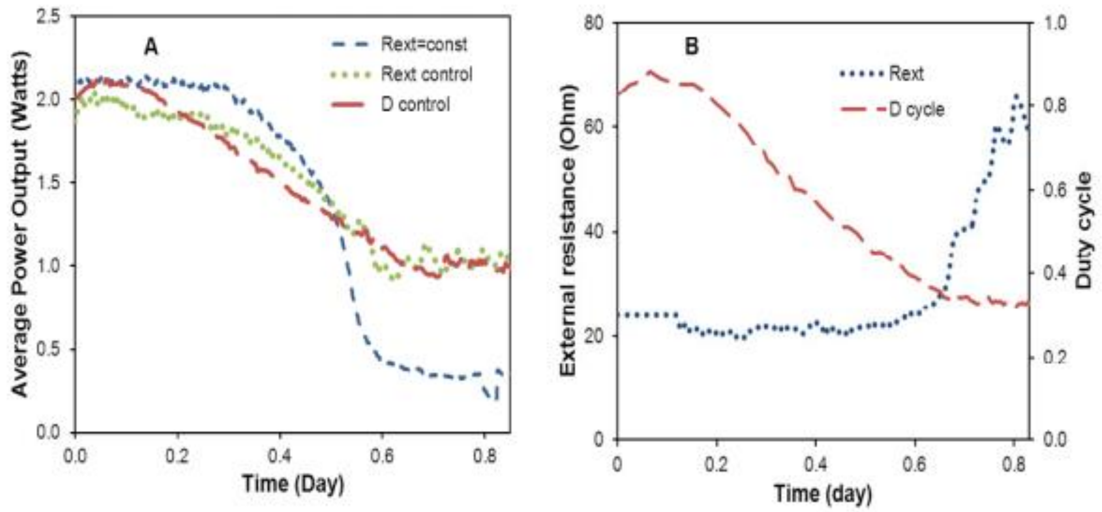


Figure- 05. Display of the Response layer resulting as an outcome of the trial at external resistance value of 10 Ohms.

3.4 R periodic experiments performed with different organic loads:

Values estimated for internal resistances for basic and lower-level OLR's have shown rise in internal resistance under carbon source limited conditions. The difference in internal resistance needs adjustments of electric load such that the Microbial Fuel Cells do not operate at values of external resistances which are lower than the internal resistances, this would result in loosing of the output power. The performance of Microbial Fuel Cells connected to external resistances via poeridic connections make it possible for the cells to operate at external resistance value lower than internal resistance value. It is also observed that the RT algorithm used to obtain a maximum output power of the cell can be controlled according to the voltage measurements in the activity cycle.

The durability of this method was assessed in a Microbial Fuel Cell, initially operated with acetate load of 04 g/ L_A d . Then a transition to 01 g/ L_A d resulting in creation of a unique create carbon source - limiting conditions. These trials were conducted multiple times, everytime utilising a new technique to maintain the external resistance value. During the initial trial, value of external resistance was fixed at 20 Ohms. The selection of external resistance led to an increase and maximum power output was observed at the acetate limiting condition, but there was a decrease in average power value when acetate concentration of anode fluid was rejected (Figure- 06A). In addition, during trial to convert the external resistance value to 10 Ohms in the acetate limiting phase gave a much lower output power (As shown in Figure- 06A, the performance of 10 has been shown by an arrowhead).



As shown in Figure- 06 containing Figure- 06A and Figure- 06B: Graph A indicating the Average output power labelled as A and the external resistance or the value for the duty cycle labelled as B. The Microbial Fuel Cell was in use with a value of constant external resistance of 20 Ohms ow with an P / O algorithm for the control over external resistance of 10 Ohms.

In the 2nd trial, the identical acetate loading profile was put into use, the R_{ext} was under control using a set P / O algorithm. Real time optimisation of value of the external resistor resulted in high power output at lower OLR (As shown in Figure- 06A). The external resistance selected by the P / O algorithm is approximately 20.0 ohms having conditions with non-limited acetate, which was expanded for 50 - 70 Ohms in acetate limitation trial (As shown in Figure- 06B). It was seen that the that the external resistance was required to be modified frequently in the P / O algorithm in order to track any change in internal resistance .Keeping in mind the practical use of a Microbial Fuel Cells, in order to generate adequate power, the voltage must be set to 05 Volts minimum, such that while using an up converter, this method shall result in higher conversion functionality. Even though an up converter can operate at lower input power, its efficiency drops low while the input power drops lower than 100 milli Volts. As a result, in order to improve efficiency, the gas power adjustments must be made correctly in the D-Cycle.

During the 3rd trial, Microbial Fuel Cells were connected periodically with an external resistance of 10 ohms and run. During the trial the V_{TH} was regulated at 0.12 Volts and 0.32 Volts for U minimum and Maximum, progressively. The respective conclusion which caused by average power is shown inFigure- 06A. On occasionally connection of electric load as per electric threshold it was observed that the electrical output potential is increased in both of the cases, acetate non limit and non limit conditions with no changes in the R_{ext}. The homogeneous activity cycle is shown in Figure 06B. It is observed that at lower levels of acetate concentrations, D values rises, external resistance connection is available for a short time in each cycle. Keeping in view that Microbial Fuel Cells are used to generate electricity, voltage levels should be at least 05 Volts, so that cells can be used properly in practical appliances. Even though up - converters are capable of operating at low input power levels, it can be concluded that a decrease efficiency is observed when input power drops below 100 milli Volts. As a result, an improvement in the system efficiency is observed on adjustments in voltage thresholds of the D cycle.

It can be concluded from the experiment that Microbial Fuel Cells can be used in electrical loads below Microbial Fuel Cells internal resistance with no major power loss and suggests an effective way to increase Microbial Fuel Cells power output. The issue with the external resistance and internal resistance mismatch is solved by Microbial Fuel Cells performance by means of periodic resistance, where connect and disconnect period were maintained as per electrical voltage estimations. This method has found a solution to issue faced due to inconsistency of resistance matching which causes modifications in characteristics of the electrical Microbial Fuel Cells due to variability in conditions for its operations.

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