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Evaluating the performance of microbial fuel cells powering electronic devices

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ABSTRACT

A microbial fuel cell (MFC) is capable of powering an electronic device if we store the energy in an external storage device, such as a capacitor, and dispense that energy intermittently in bursts of high-power when needed. Therefore its performance needs to be evaluated using an energy-storing device such as a capacitor which can be charged and discharged rather than other evaluation techniques, such as continuous energy dissipation through a resistor. In this study, we develop a method of testing microbial fuel cell performance based on storing energy in a capacitor. When a capacitor is connected to a MFC it acts like a variable resistor and stores energy from the MFC at a variable rate. In practice the application of this method to testing microbial fuel cells is very challenging and time consuming; therefore we have custom-designed a microbial fuel cell tester (MFCT). The MFCT evaluates the performance of a MFC as a power source. It uses a capacitor as an energy storing device and waits until a desired amount of energy is stored then discharges the capacitor. The entire process is controlled using an analog-to-digital converter (ADC) board controlled by a custom-written computer program. The utility of our method and the MFCT is demonstrated using a laboratory microbial fuel cell (LMFC) and a sediment microbial fuel cell (SMFC). We determine (1) how frequently a MFC can charge a capacitor, (2) which electrode is current-limiting, (3) what capacitor value will allow the maximum harvested energy from a MFC, which is called the "optimum charging capacitor value," and (4) what capacitor charging potential will harvest the maximum energy from a MFC, which is called the "optimum charging potential." Using a LMFC we find that (1) the time needed to charge a 3-F capacitor from 0 to 500 mV is 108 min, (2) the optimum charging capacitor value is 3 F, and (3) the optimum charging potential is 300 mV. Using a SMFC we find that (1) the time needed to charge a 3-F capacitor from 0 to 500 mV is 5 min, (2) the optimum charging capacitor value is 3 F, and (3) the optimum charging potential is 500 mV. Our results demonstrate that the developed method and the MFCT can be used to evaluate and optimize energy harvesting when a MFC is used with a capacitor to power wireless sensors monitoring the environment.

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1. Introduction

It has been demonstrated that microbial fuel cells (MFCs) can generate energy in the laboratory or in the field [1–5]. The power generated in MFCs is limited and not enough to power any high-power-consuming electronic device continuously. To generate sufficient power for operating electronic devices directly, researchers have tried to build larger MFCs [6,7]. Building larger MFCs does not improve power production significantly, due to scaling-up issues of MFCs: power density does not remain constant when electrode size is increased [8]. To meet the power requirements of electronic devices, capacitors have been used to store energy from MFCs and then deliver it in short bursts of high-power [9,10]. The use of a capacitor does not produce higher power continuously, but it does allow the delivery of higher power intermittently. This is acceptable, especially when we use MFCs to power sensors for environmental monitoring [11,12] which requires monitoring the selected parameters at various time intervals rather than continuously.

As an example of this intermittent powering scheme, recently we powered a wireless sensor requiring 11 mW using a sediment microbial fuel cell producing continuous power between 1 and 4 mW (in the winter and summer, respectively) [9]. The power requirement of the wireless sensor (11 mW) was greater than the power production of the MFC, but we were able to power the wireless sensor by storing the energy in a capacitor and using it intermittently. The wireless sensor was powered when the capacitor potential reached 320 mV (Fig. 1), the "charging potential." It continued powering until the capacitor potential dropped below 52 mV, the "discharging potential." The wireless sensor was shut down when the capacitor potential reached 320 mV again, as shown in Fig. 1. It took 18 min to charge the capacitor, and the stored

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Nomenclature

ADC	analog-to-digital converter
A_{in}	analog input
D_{out}	digital output
C	capacitance (F)
GUI	graphical user interface
MFC	microbial fuel cell
MFCT	microbial fuel cell tester
MOSFET	metal oxide semiconductor field effect transistor
P_{avg}	average power (W)
SMFC	sediment microbial fuel cell
SCE	saturated calomel electrode
t_d	time when capacitor is at the discharging potential (s)
t_c	time when capacitor is at the charging potential (s)
V	capacitor potential (V)
V_c	charging potential (V)
V_d	discharging potential (V)
W_c	energy stored in capacitor (J)

energy in the capacitor was enough to operate the wireless sensor for 2 min (Fig. 1). In this previous work [9], the charging and discharging potentials and capacitor value (capacitance) were selected manually by trial and error within the operable range. Also, the frequency of powering the sensor was not known until the sensor was actually powered. This practical application demonstrates that before we power a sensor we need to know: (1) how often we can charge a capacitor to a desired charging potential, (2) which electrode is current-limiting, (3) what capacitor value will allow the maximum harvested energy from a MFC, the "optimum charging capacitor value," and (4) what capacitor charging potential will harvest the maximum energy from a MFC, the "optimum charging potential." Having this information allows us to find the optimum energy-efficient operating conditions for the MFC or modify the design of the electrodes if necessary.

The traditional method of evaluating the performance of a MFC is not capable of obtaining these information. In the traditional method, a resistor is connected between the anode and the cathode and the power generation is monitored over time [3,13]. The power generation observed in this method is the amount of power a MFC can produce continuously. The resistor simulates the electronic device to be powered, and the electrical energy generated by the MFC is dissipated as heat. Using a resistor simplifies the computations: the power delivered by the MFC is the product of the current and the potential drop across the resistor. However, the evaluation of power using a resistor does not give any information on the practical use of the MFC, such as how frequently the proposed sensor can be powered. Moreover, using the resistor method we cannot determine the optimum capacitor value or the optimum charging potential to be used to make sure that the maximum power generation capability of the MFC is utilized. Therefore, a new method of evaluating the performance of a microbial fuel cell is needed. Based on our preliminary results, we find that a series of experiments of charging and discharging a capacitor using different capacitor values and charging and discharging potentials is adequate to obtain the information needed. In our preliminary work the capacitor was charged and discharged manually by connecting it to a MFC, disconnecting it, and then discharging it. For many reasons manual evaluation and optimization of energy efficiency are not practical if we need to operate the MFCs for more than several days. Therefore a device which can perform these tests automatically is needed.

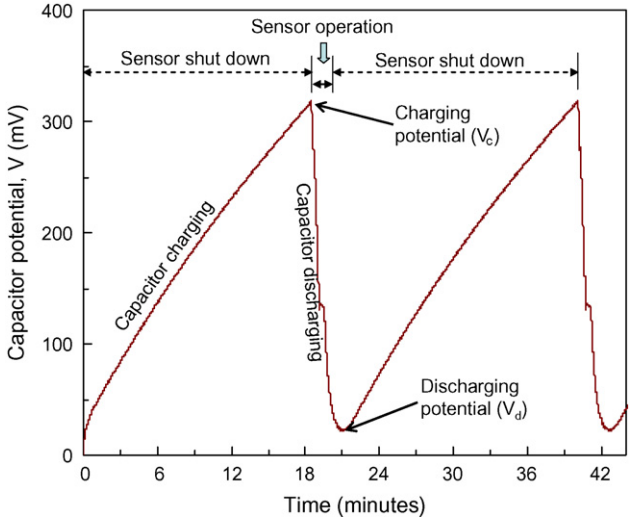

Fig. 1. Cyclic charging and discharging of the capacitor while it powered a wireless sensor using a SMFC as reported by Donovan et al. [9]. The capacitor charge/discharge patterns can be measured automatically for different capacitor values and charge/discharge potentials to estimate the performance of the MFC and to optimize it.

The goals of this study are to (1) develop a method based on capacitor charging and discharging that will allow us to determine or optimize the parameters required to power a sensor, and (2) develop an electronic microbial fuel cell tester (MFCT) that can perform the capacitor charging and discharging experiment automatically by setting the capacitor connected to a MFC to selected potentials while monitoring the anode and cathode potentials. The utility of the method and the custom-designed MFCT was demonstrated using a laboratory microbial fuel cell (LMFC) and sediment microbial fuel cells (SMFC). In the laboratory, we used a two-compartment microbial fuel cell. *Shewanella oneidensis* (MR-1) was grown in the anode with lactate as the electron donor. Oxygen was used as ultimate electron acceptor in the cathode. The SMFC, deployed in the Palouse River, Pullman, WA, had a graphite anode buried under the sediment and a stainless steel cathode placed in the water. Both systems were individually tested (1) to determine how often we can charge a capacitor to a desired charging potential, (2) to identify the current-limiting electrode, (3) to find the optimum charging capacitor, and (4) to determine the optimum charging potential.

2. Materials and methods

2.1. Laboratory microbial fuel cell

The laboratory microbial fuel cell consisted of two compartments made of polycarbonate, each with a volume of 250 mL. The compartments were separated by a cation exchange membrane, ESC-7000 (Electrolytica Corporation). A schematic diagram of the LMFC is shown in Fig. 2A. A similar design was used in our previous study, where a detailed description of the construction of the LMFC is given along with the startup and operating procedures [14]. The anode was made of graphite plate (Graphitestore.com), and the cathode was made of manganese-based catalyzed carbon paste bonded in platinum wire mesh (Electric Fuel Ltd.). The projected surface areas of the anode and the cathode were 0.0068 and 0.013 m^2, respectively. The electrodes were placed against the cation exchange membrane in parallel to each other. The distance between the electrodes was 1 cm. *S. oneidensis* MR-1 was grown in the anodic compartment with lactate as the electron donor. The growth medium used for *S. oneidensis* MR-1 was 0.1 g L^{-1} PIPES buffer, 0.78 g L^{-1} KH_2PO_4, 0.47 g L^{-1} Na_2HPO_4, 1.5 g L^{-1} NH_4Cl,

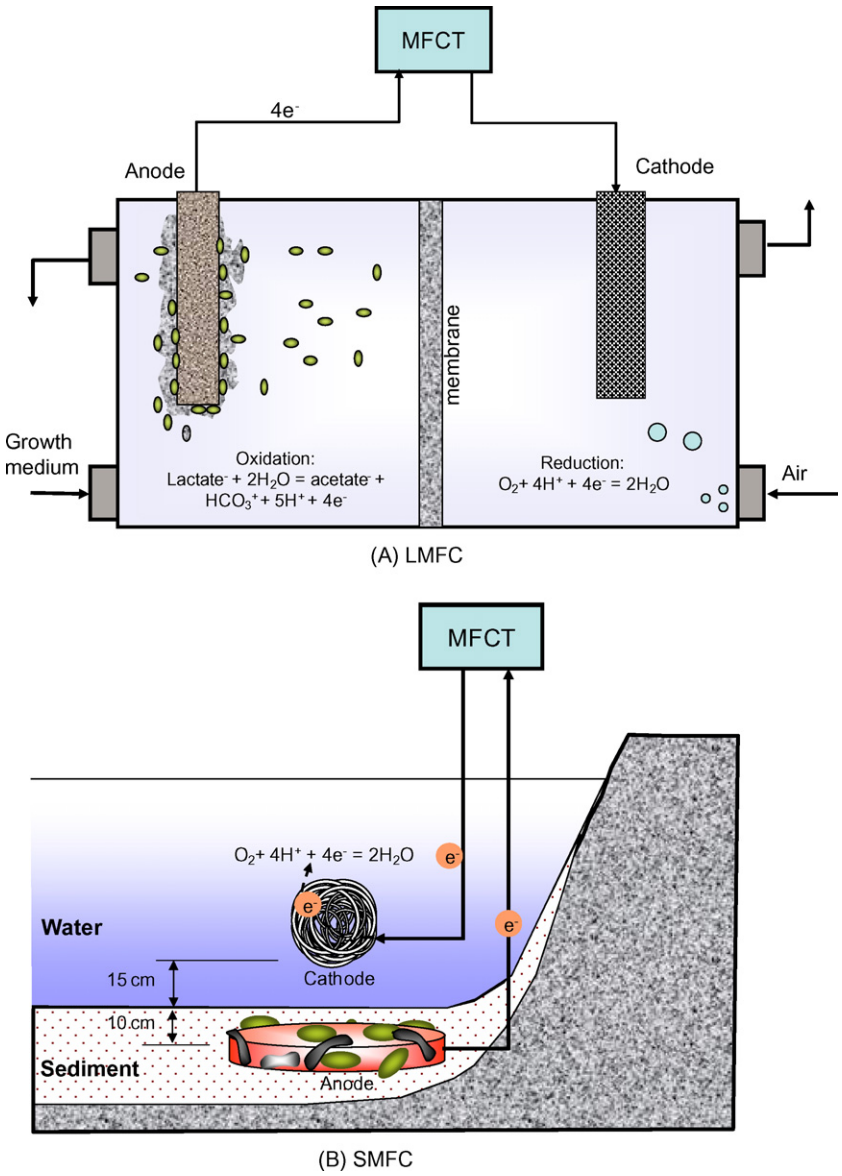

Fig. 2. Schematic diagram of the (A) laboratory microbial fuel cell, and (B) sediment microbial fuel cell connected to MFCT.

0.1 g L^{-1} KCl, 1.75 g L^{-1} NaCl, 11.23 g L^{-1} Na-lactate, 10 mL L^{-1} mineral solution (100×), 1 g L^{-1} yeast extract, 0.05 g L^{-1} ferric NTA solution, and 10 mL L^{-1} amino acid solution (100×) as described by Gorby et al. [15]. The pH of the growth medium was adjusted to 7 using 1 M NaOH or 1 M HCl solution. The solution in the cathodic compartment was a phosphate buffer with 1.825 g L^{-1} Na_2HPO_4, 0.35 g L^{-1} KH_2PO_4 with pH 7.

2.2. Sediment microbial fuel cell

The SMFC was deployed in the Palouse River, Pullman, WA. A schematic diagram of the SMFC is shown in Fig. 2B. The anode was made of graphite plate (GraphiteStore.com, Inc.), its dimensions were 30.48 cm × 30.48 cm × 5.08 cm, and its projected surface area was 0.201 m^2. For the electrical connection with the graphite plate, we used insulated copper wire which was glued to the graphite using conductive epoxy (CW2400, CircuitWorks). To prevent water–copper wire/conductive epoxy contact, the graphite plate and copper wire joints were covered with silicon rubber.

The cathode was made of stainless steel wires (316L, J.W. Harris brand) coiled on a wooden frame in a spherical geometry (Fig. 2B). The projected surface area of the cathode was 2.1 m^2. The electrical connection with the stainless steel cathode was made using insulated copper wire. The electrical cables from the anode and cathode were connected to the MFCT placed by the bank of the river using TREX-ONICS® 16/3 male/female coil cord (4–20′, TPC Wire & Cable). The anode was buried 10 cm below the water–sediment interface, and the cathode was placed 15 cm above the water–sediment interface.

2.3. Microbial fuel cell tester

The microbial fuel cell tester consisted of a custom-designed electronic circuit, a capacitor, an analog-to-digital converter (ADC) board (1608 FS, Measurement Computing™) and custom software written in LabVIEW® (www.ni.com/labview) (Fig. 3). The MFCT was implemented on a printed circuit board (PCB), and an external capacitor was connected which was easily interchangeable. The ADC board was used to (1) power the circuit, (2) monitor capacitor potential, and (3) monitor anode and cathode potentials against a reference electrode. The custom-written program used LabVIEW® with a graphical user interface (GUI), allowing us to select the capac-

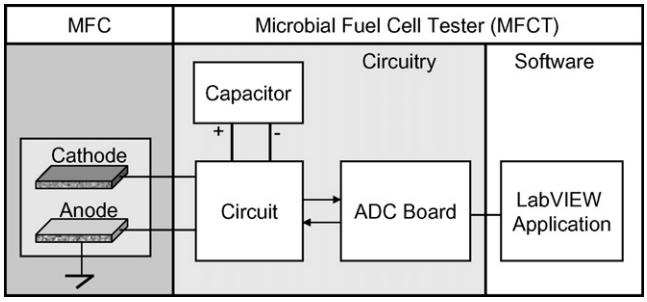

Fig. 3. Block diagram of MFC, MFCT circuitry, and custom-written software in LabVIEW®.

itor charging (V_c) and discharging potentials (V_d), and recorded the data (date/time stamped) to the hard drive of the computer.

The custom-designed circuit was controlled by the ADC board through two digital output (D_{out}) ports (Fig. 4). Both of these output ports were connected to the gate of an n-channel metal-oxide–semiconductor field-effect transistor (MOSFET). These MOSFETs acted as switches, allowing charge to flow from the MFC to the capacitor during charging. During discharging, the switches isolated the MFC from the circuit and discharged the capacitor. The charging time depended on the energy generation capability of the MFC, the capacitor value (capacitance), V_c and V_d. The discharging time depended on the characteristics of the MOSFET, capacitor value, V_c and V_d. The charging and discharging potentials were controlled by the custom-written software. The ADC board had analog input (A_{in}) ports that monitored the capacitor, anode and cathode potentials over time. Note that while charging, the capacitor and the MFC potentials were nearly equal since they were connected in parallel with a low-resistance switch (MOSFET) in between.

A state diagram of the custom-written software is shown in Fig. 5. The software controlled the ADC board and also contained the graphical user interface (GUI) for selecting V_c, V_d and the interval of data collection. Initially, the MFCT started charging the capacitor. During charging a 5-V bias potential was applied to the gate of MOSFET 1 so that it acted as a closed switch. A 0-V bias potential was applied to the gate of MOSFET 2 so that it acted as an open switch. After each sample was taken, the MFCT compared the capacitor potential against the desired charging potential (V_c). If the capacitor potential had reached the charging potential (V_c), the MFCT switched state. In this case, a 5-V bias potential was applied to the gate of MOSFET 2, a 0-V bias potential was applied to MOSFET 1, which isolated the MFC from the circuit, and the capacitor charge was dissipated through MOSFET 2. The MFCT remained in this state until the capacitor potential dropped below the discharging potential (V_d), which caused the MFCT to go back to the

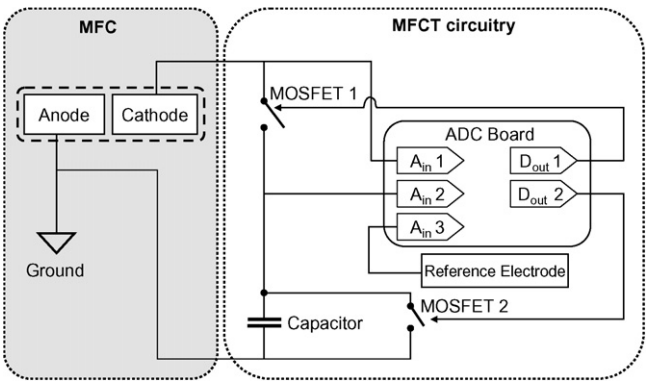

Fig. 4. Block diagram of the MFCT circuitry and MFC. The basic components of the MFCT circuitry are the ADC board, n-channel MOSFETs and a capacitor.

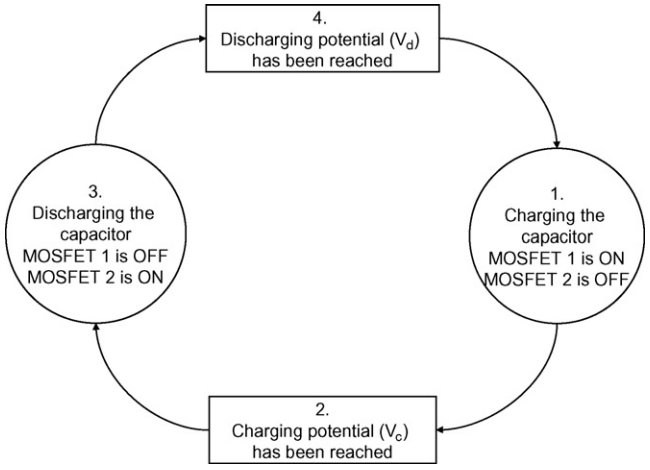

Fig. 5. State diagram of the MFCT controlled by the LabVIEW® software.

original state, in which the MFCs charge the capacitor (charging the capacitor, Fig. 5).

2.4. Calculation of the energy stored in the capacitor and average power generation by the capacitor

When a capacitor was charged from V_d to V_c, the energy (W_c) stored in the capacitor was calculated using Eq. (1) [16].

$$W_c = \frac{1}{2}C(V_c{}^2 - V_d^2) \quad (1)$$

The average power (P_{avg}) generation in a single charging cycle was calculated by dividing the total energy stored in the capacitor by the charging time, as shown in Eq. (2). The charging time ($t_c - t_d$) was calculated by subtracting the time when the capacitor was discharged (t_d) from the time when the capacitor was charged (t_c).

$$P_{avg} = \frac{W_c}{t_c - t_d} = \frac{1}{2}\frac{C(V_c^2 - V_d^2)}{t_c - t_d} \quad (2)$$

Power density was calculated by dividing the total power by the anode surface area.

2.5. Measuring the frequency of the charging cycle

The frequency of the charging cycle is defined as the capacitor charging time per cycle. As an example of this measurement, a 3-F capacitor was used for both LMFC and SMFC. The charging potentials were selected to be 500 and 350 mV, respectively, and the discharging potentials were selected to be 0 V and 50 mV, respectively. We selected these charging and discharging potentials because we operated several sensors at these potentials. We selected the zero discharging potential because it is the minimum possible discharging potential, equivalent to short-circuiting the capacitor. If we know the characteristics of the device to be powered, V_d can be selected to be a specific potential, such as 52 mV, which was the discharging potential used by Donovan et al. [9]. These charging potentials and discharging potentials can easily be changed if desired. The charging time was calculated by averaging at least five reproducible cycles for the LMFC and three reproducible cycles for the SMFC.

2.6. Identifying the current-limiting electrode

If the potential of the electrode remains constant during capacitor charging it is considered to be the non-limiting electrode. The

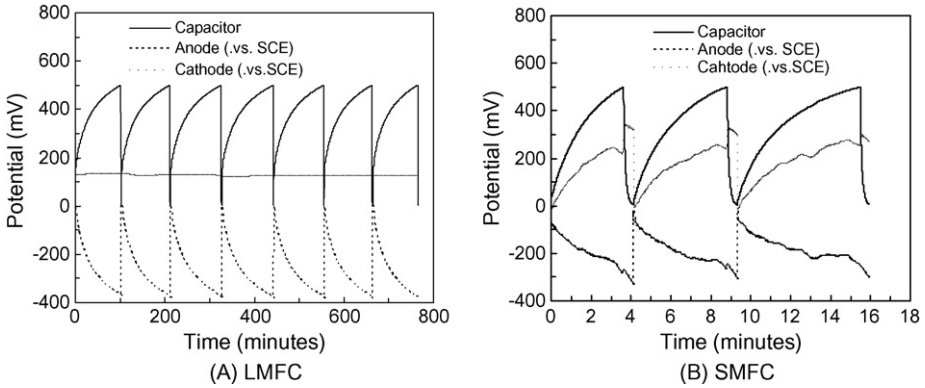

Fig. 6. The capacitor charging and discharging curves and electrode potentials for: (A) the LMFC and (B) the SMFC. A 3-F capacitor was charged from 0 to 500 mV and discharged back to 0 V in both cases.

electrode which has varying potential during capacitor charging is the limiting electrode [10]. If the potentials of both electrodes vary during capacitor charging, both electrodes are limiting. A 3-F capacitor was charged from 0 to 500 mV and discharged back to 0 mV for a LMFC and a SMFC to determine the current-limiting electrodes. The electrode potentials were measured automatically by the MFCT against a saturated calomel electrode (SCE).

2.7. Determining the optimum charging capacitor value: capacitance

The optimum charging capacitor value was defined as the capacitance at which a MFC generates the maximum power with a particular charging potential. To determine the optimum charging capacitor value, capacitor values of 1, 2, 3, 4, 5, and 6 F were used. The capacitors were charged and discharged from 0 to 350 mV, respectively. For each capacitor value, the capacitors were charged and discharged at least five times. The total power generation was calculated using Eq. (2). The optimum charging capacitor was determined graphically using a plot of power density versus capacitor value.

2.8. Determining the optimum charging potential

The optimum charging potential was defined as the charging potential at which the MFC can produce maximum power with a particular capacitor value. To determine the optimum charging potential a 3-F capacitor was charged and discharged for selected charging potentials. For LMFC the charging potentials were 100, 200, 300, 400, and 500 mV, and for SMFC the charging potentials were 100, 200, 300, 400, 500, 600, and 700 mV. For all charging potentials the discharging potential was 0 V. The MFCs were allowed to reach the open circuit potential before being charged for each charging potential. The power generation was calculated using Eq. (2). The optimum charging potential was determined graphically from a chart of power density versus capacitor charging potentials.

3. Results and discussions

Using the developed MFCT we (1) determined the frequency of the charging cycle, (2) identified the current-limiting electrode, (3) determined the optimum charging capacitor values for given charging and discharging potentials, and (4) found the optimum charging potentials for given discharge potentials and capacitor values for a SMFC and a LMFC. The results shown here are representative results of repeated experiments.

3.1. Frequency of charging cycle

Figs. 6 and 7 show the charging and discharging of a 3-F capacitor using the LMFC and the SMFC when the charging potentials were 500 and 350 mV, respectively, and the discharging potentials were 0 and 50 mV, respectively.

When a 3-F capacitor was charged to 500 mV and discharged to 0 mV, the average capacitor charging time was 108 (±5) min for the LMFC (Fig. 6A) and 5 (±1) min for the SMFC (Fig. 6B). The SMFC charged the capacitor faster because its electrodes were larger than those of the LMFC and the operating conditions were different. However, we believe the charging time should not be the only crite-

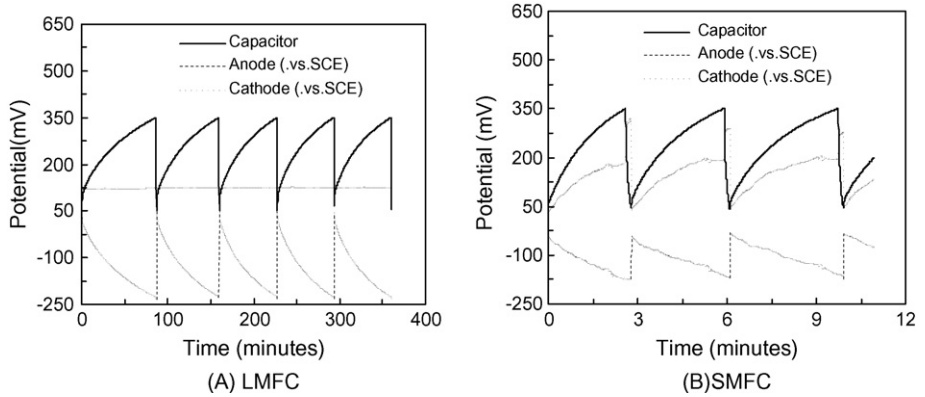

Fig. 7. The capacitor charging and discharging curves and electrode potentials for: (A) the LMFC and (B) the SMFC. A 3-F capacitor was charged from 50 to 350 mV and discharged back to 50 mV in both cases.

rion for comparing the performance of microbial fuel cells because the optimum charging potential will determine the potential at which the microbial fuel cell will be operated.

When the same capacitor (3-F) was charged from 50 to 350 mV the charging time was 76 (±10) min using the LMFC (Fig. 7A) and 3.1 (±0.5) min using the SMFC (Fig. 7B), which are less than the times required when the charging and discharging potentials were 0 and 500 mV, respectively. When the difference between the charging and discharging potentials was reduced the frequency of the charging cycles increased.

Charging the capacitor to 350 mV and discharging it to 50 mV simulates the operation of wireless sensors which was described in our previous study [9]. In that study a 10-F capacitor was charged to 320 mV, which stored a total energy of 0.51 J (calculated using Eq. (1)). Instead of discharging, we used this stored energy to operate a wireless sensor until the capacitor potential dropped to 52 mV. The sensor transmitted three data in each cycle, consuming ~0.17 J in each transmission. The frequency of each cycle was 21 min. For the tested SMFC, using a 3-F capacitor we collected ~0.37 J in each cycle, which was enough for two data transmissions in every 3.1 min. When a higher frequency of data transmission is needed the capacitor value can be decreased. The use of MFCT allows us to glean this information without operating the sensors from the MFC and allows us to calculate the frequency of data transmission.

3.2. The current-limiting electrode

During charging cycles the cathode potential of the LMFC remained constant (Figs. 6A and 7A) but the anode potential varied, demonstrating that the anode was the limiting electrode. However, during the charging cycles the cathode and anode potentials varied for the SMFC, demonstrating that both electrodes can be the limiting electrode. The cathode of the laboratory microbial fuel cell was made of manganese-based catalyzed carbon paste bonded to platinum wire mesh (Electric Fuel Ltd.), and the cathode of the SMFC was made of stainless steel wires. The surface areas of the cathodes of the LMFC and the SMFC were 1.9 times and 10 times larger than the respective anode surface areas. The cathode used in the laboratory is very expensive and has a significantly higher cathodic current density (or oxygen reducing capacity) than the cathodes (stainless steel wires) used in the SMFC. We believe that the cathode was not limiting in the LMFC because of the better-performing cathodes. We note that cathode limitations of the SMFC have also been observed in other literature studies. For example, Nielsen et al. [17] used a two times larger surface area for the cathode in a SMFC deployed in ocean sediment (Nielsen et al. [17]). Oh et al. [18] used a Pt-carbon cathode to overcome the cathode limitation in a LMFC (Oh et al. [18]). Using expensive but better-performing cathodes may not be feasible for practical applications.

Knowledge of the current-limiting electrode is important when we want to improve the performance of a MFC. For example, for the LMFC shown in Fig. 6A, if we increased the cathode surface area the power of the MFC would not increase since the cathode is not limiting. To increase the power we would need to increase the surface area of the anode or improve the operating conditions in the anode (i.e. deliver a larger number of electron donors). However, for the SMFC, an improvement in cathode performance would be needed since the surface area of the cathode is already 10 times larger than that of the anode.

3.3. Optimum charging capacitor value: capacitance

For both the LMFC and the SMFC the power density increased when the capacitor value increased. The power reached a maximum when a 3-F capacitor was used (Fig. 8); then the power decreased as the capacitor value increased beyond the optimum charging potential. Knowledge of optimum capacitor value is required to design the power management system to operate the sensor utilizing the maximum possible energy generation by the MFC.

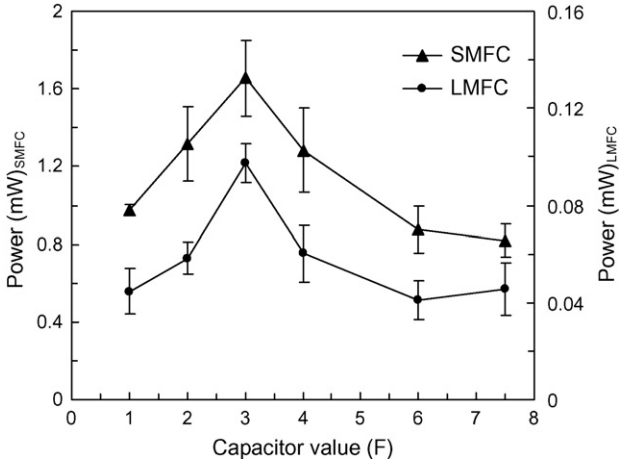

Fig. 8. Power versus capacitor values for the LMFC and the SMFC. The surface areas of the anodes were 0.0068 and 0.201 m^2 for the LMFC and the SMFC, respectively. The error bars indicates the variation of power among repeated experiments.

3.4. Optimum charging potential

As shown in Fig. 9, the optimum charging potentials were ~300 mV for the LMFC and ~500 mV for the SMFC. The optimum charging potential of the LMFC indicates that if a sensor is powered by the LMFC it is best to operate the sensor at 300 mV. Note that DC/DC converters which can use energy from MFCs generally operate more efficiently at larger input potentials [9], so a system level analysis should be performed before determining the optimum operating potential for the sensors. Operating the sensor at 300 mV would utilize the maximum energy generation capability of the LMFC. The difference in optimum charging potential between the LMFC and the SMFC may be due to electron transfer mechanisms in the two different environments; this requires detailed further research. These results demonstrate that depending on MFC design or on environmental conditions the sensor may need to be operated at different potentials.

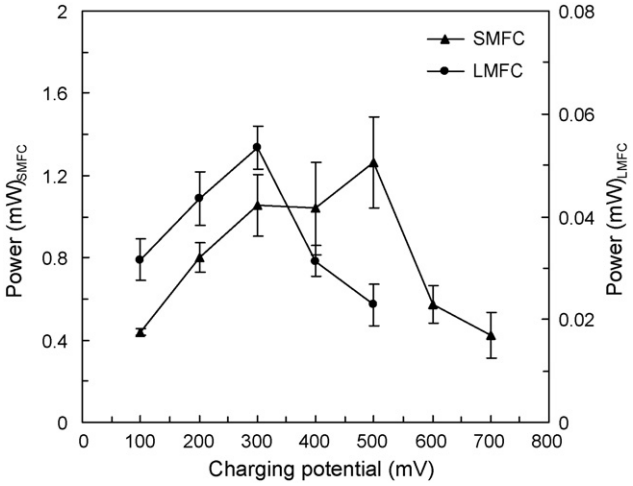

Fig. 9. Power density versus charging potential for the LMFC and the SMFC. The surface areas of the anodes were 0.0068 and 0.201 m^2 for the LMFC and the SMFC, respectively. The error bars indicates the variation of power density among repeated experiments.

We should note that the SMFC and the LMFC showed different characteristics. The power for the SMFC was almost constant when the capacitor was charged to a potential between 300 and 400 mV. This may be due to a mass transfer limitation of electron donors to the microorganisms deposited on the anode surface. However, the LMFC showed peak power when the capacitor was charged to 300 mV. These different characteristics show the importance of determining the optimum charging potential for the MFC before connecting and powering an electronic device.

We believe the optimum capacitor value and the optimum charging potential are functions of the electron transfer processes and mechanisms in each electrode. The electron transfer processes in the anode and cathode are controlled by many factors. Among these are the pH, temperature, concentrations of electron donors and electron acceptors, microbial reaction rates, mass transfer limitations, and internal resistance of the MFC. The factors controlling the optimum capacitor values and charging potentials can be determined by operating microbial fuel cells under well-controlled conditions while changing the values of the variables listed above and testing the effect of each variable on the optimum capacitor value and the charging potential.

4. Practical use of the MFCT

There is a need for a new method to test the performance of microbial fuel cells which power electronic devices such as wireless sensors. Wireless sensors or electronic devices which can be connected to a MFC generally need higher power than a MFC can produce. For example, electrochemical sensors require 50 mW; laser diodes, 225 mW; light-emitting diodes, 30 mW; and temperature sensors, 11 mW [10,11]. These higher power requirements can be accomplished by storing energy in a capacitor. Current testing methods only employ a constant load (which is a resistor) and cannot provide information about the practical use of MFCs. To overcome these challenges and to determine the optimum energy-efficient operating conditions for the MFCs and the sensor, we developed a method and a device, the microbial fuel cell tester, and demonstrated their utility using LMFC and SMFC.

The optimization of energy harvesting from MFCs is needed to increase the power of MFCs. This optimization requires determining the optimum charge/discharge potentials and capacitor sizes. The frequency of charging and the limiting electrode are also critical design parameters. These optimized design parameters can be automatically calculated for a MFC using the MFCT developed in this research. For example, the optimum discharge potential is as important as the charging potential and is expected to be different for different sensors. Moreover, the utility of MFCT can be extended to determining the optimum size of the electrodes required for powering a particular sensor before the MFC is deployed for a long duration. The electrode size can be optimized by running charging and discharging experiments for various sizes of electrodes using our MFCT, which can be a future application of MFCT.

5. Conclusions

We developed a new method to test the performance of microbial fuel cells. This method uses a capacitor to collect microbial energy and then discharges the capacitor. The time needed to charge the capacitor is used to calculate the power of the MFC. The power is optimized by varying the capacitor value and the charging and discharging potentials. To perform these tests automatically we designed an electronic device called the microbial fuel cell tester.

Using a laboratory microbial fuel cell we found that (1) the time needed to charge a 3-F capacitor from 0 to 500 mV was 108 min, (2) the optimum charging capacitor value was 3 F, and (3) the optimum charging potential was 300 mV. Using a sediment microbial fuel cell we found that (1) the time needed to charge a 3-F capacitor from 0 to 500 mV was 5 min, (2) the optimum charging capacitor was 3 F, and (3) the optimum charging potential was 500 mV.

The results demonstrated that our method can be used to evaluate and optimize energy harvesting when a microbial fuel cell is used with a capacitor to power sensors monitoring the environment. These tests can be performed automatically using the microbial fuel cell tester.

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