THE EFFECT OF TEMPERATURE ON THE ELECTRICAL OUTPUT OF A SEDIMENT BATTERY

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ABSTRACT

The purpose of this experiment was to see the effect of temperature on the electrical output of a sediment battery. A sediment battery was constructed using two graphite electrodes, conducting wire, a 500 ohm resistor, conductive and non-conductive epoxy, a clear plastic container and mud and seawater from Nantucket which contains *Geobacter metallireducens*. The sediment battery was put in three different temperatures (6°C, 20°C, 27°C) under controlled conditions and the electrical output was recorded. The sediment battery had a higher electrical output in an environment of 27°C, which was the highest temperature that the sediment battery was tested in. The lowest electrical output was at the lowest temperature, 6°C. Since the electrical output increased at a higher temperature this helps to understand ideal conditions for a sediment battery made with Geobacter. This research may help make sediment batteries (microbial fuel cells) more effective than they have been in the past.

INTRODUCTION

RESEARCH QUESTION

How does temperature affect the electrical output of a sediment battery?

BACKGROUND RESEARCH:

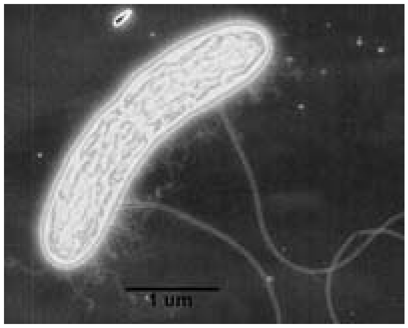
Microbial Fuel Cells: Fuel cells are a way to convert chemical energy to electrical energy. For example, a hydrogen fuel cell converts the energy stored in hydrogen into electrical energy. Microbial fuels are special because they use microorganisms to generate electricity. The way microorganisms generate electricity is by breaking down organic matter (acetate for example) and taking in water. As a by-product of their metabolisms, they release hydrogen, carbon dioxide and electrons.

$$C_2H_4O_2 + 2H_2O \longrightarrow 2CO_2 + 8H^+ + 8e^-$$

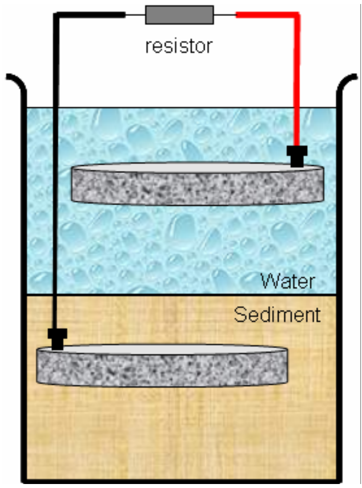
Acetate + Water ⟶ Carbon Dioxide + Hydrogen + electrons

In their natural environment, they would release electrons onto Iron III which reduces it to Iron II. In a microbial fuel cell, the Iron III is replaced with a graphite electrode which serves as the anode (electron acceptor). The electrons deposited on the graphite electrode, create an electrical potential (voltage). This causes the electrons to flow through the wire to another graphite electrode (the cathode). If the electrodes were made of different conductors, an electrical potential would be created because some conductors give electrons more freely than others. Because the electrodes are made of the same material, we know the flow of electrons is due to the presence of the bacteria.

Geobacter metallireducens (Geobacter):



Geobacter is one species of bacteria cultured to be used in a Microbial Fuel Cell. It was discovered in the Potomac River 1987. Geobacter favor living in places where there is a lot of iron and no oxygen (anaerobic). They can be found virtually anywhere that meets their needs of living. Geobacter are 1-2 microns wide and are shaped like a crescent. They have 2 kinds of extremities, pili and flagella. Flagella are long nanowires that help the Geobacter travel and find iron in their environment. Their pili are protein filaments smaller than flagella used to move electrons to iron or other metals. They are capable of reducing uranium in soil and taking gold out of sea water. In the case of Microbial Fuel Cells, they use their pili to transfer electrons to the graphite electrodes. They form a slime like matrix called a biofilm on top of the anode, by using their pili to connect to each other to make a sort of chain towards the graphite electrode. They pass the electrons through each other in order to deposit them onto the anode. The biofilm can grow to 30-100 microns thick of the anode. Genetically engineered Geobacter without pili cannot form the biofilm necessary to transfer electrons onto the graphite electrode, thus proving that the pili are essential for electrical transfer.



Sediment Battery: A Sediment battery is a type of Microbial Fuel Cell. Sediment batteries are usually bigger, bulkier, and less efficient than other kinds of Microbial Fuel Cells. They contain mud (sediment) around the anode which is where the bacteria are located. Above the mud there is water surrounding the cathode. The anode and the cathode are both made up of graphite electrodes. The wire connected to the anode loops out of the sediment battery container and is joined by a resistor to the wire from the cathode. The junction where the two wires are met by the resistor is the place where it is possible to measure the electrical current/voltage of the battery.

Electricity: The formula for measuring electricity is called Ohm's Law- V= I x R. V stands for voltage which is the pressure of electricity in the circuit. I stands for the current at which the electricity is flowing (measured in amps). Lastly, R stands for the resistance to the flow of electricity (measured in ohms). Electricity flows through conductors which have low resistance allowing easy electrical flow. Insulators don't allow electrical flow to pass through them. Static electricity is when electrons build up in one place, while current electricity is when electrons flow through a conductor. To measure electricity, a multimeter/voltmeter is used and it can measure resistance, amps, and volts.

Experiment #1: The Effect of Temperature on the Electrical Output of a Sediment Battery

Hypothesis:

An increase in temperature will speed up the movement of the bacteria found in the mud, thus increasing the electrical output of the bacteria.

Experimental Design:

Independent Variable- Temperature

Temperature	6°C	20°C	*27*°C
Number of Days Measured	3	3	*3*

Dependent Variable: Electrical Output from Sediment Battery (mV)

Constants: Graphite electrodes set up, Amount of Water (500 mL), Amount of Mud (1 kg), Sediment Battery Container, resistor (500 ohm), multimeter, conducting wire

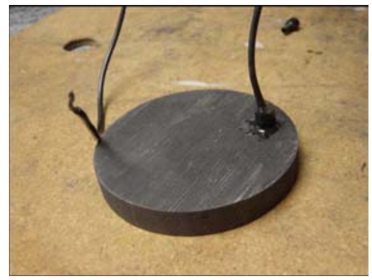
Materials:

1. Graphite electrodes (Grade G-10, 8.9cm diameter x 1.3cm thick) (x2)
2. Insulated Wire (16 Gauge Ancor Marine Wire)
3. Electrically Conductive epoxy (H20E Silver)
4. Non-Electrically Conductive epoxy
5. Resistor (500 Ohm)
6. Voltmeter
7. Wire Cuter
8. Wire Strippers
9. Clear Plastic Bucket
10. Mud from Nantucket
11. Water from Nantucket

Procedure:

Electrode Assembly

1) Cut insulated wire to desired length and strip about 4 mm of insulation from the wire using wire strippers or a razor blade.
2) Drill a small hole in each electrode. This hole may be in the top or side, depending on where the wire will be connected.
This hole SHOULD NOT go through the graphite. It should be only deep enough to cover the exposed part of the newly exposed wire and a few millimeters of the insulation itself (~ 8 mm). The diameter of the hole should be large enough that the insulated wire may fit.



3) Drip enough electrically conductive epoxy in the bottom of the hole to cover the exposed wire. Insert the wire so that the exposed wire is in the epoxy and allow it to dry. After the epoxy has dried, test the electrode to make sure that a good connection exists between the graphite and the free end of the wire. This can be done with a multimeter.
4) After the conductive epoxy has dried, fill the remainder of the hole, generously with non-conductive epoxy. This will protect the electrical connection as well as give some mechanical stability to it. Allow epoxy to dry.
5) When you are finished, the electrode should look similar to the one shown above.
6) Repeat the above steps to make the second electrode.
7) Before assembling the sediment battery, test each electrode for good electrical connections between the graphite and the free end of the wire using a multimeter or other method.

Sediment Battery Assembly

Notes: For best results, mud should be collected from the sediment at the bottom of a body of water, rather than made from a mixture of dry soil and water (although this will work also). The sediment battery should be made in a plastic bucket or glass beaker; metal should not be used.

1) Fill the bucket with a few centimeters of mud (~ 10 cm).
2) Place one of the graphite electrodes on the mud. This will be the “anode” of the sediment battery. Make sure to keep the free end of the wire dry and out of the mud.
3) Add a few more centimeters of mud (~ 5-7 cm) over the anode. The anode should be completely covered with at least a couple centimeters of mud.
4) Carefully pour water (preferably water from the same body of water that the mud was collected) over the mud and anode. Be sure not to uncover the anode or disturb the mud very much. Add water to at least 10 cm deep over the mud. Allow the particles to settle over night.

5) The next day, place or suspend the other electrode in the overlying water above the anode. This electrode is now called the cathode. As with the anode, keep the wires dry.
6) Connect the anode and cathode wires together with the resistor in between.
** 7) The first trial is done in room temperature 20°C measuring a total of 3 times every three days. Using the multimeter or volt meter, measure the voltage. Place the red wire from the multimeter on the cathode side of the resistor and the black wire on the anode side.
**8) Record on data table.
**9) Repeat steps 1-8 but changing the temperature to 27°C and then again to 6°C after the second trial. (Note: The mud should be changed after every new trial).

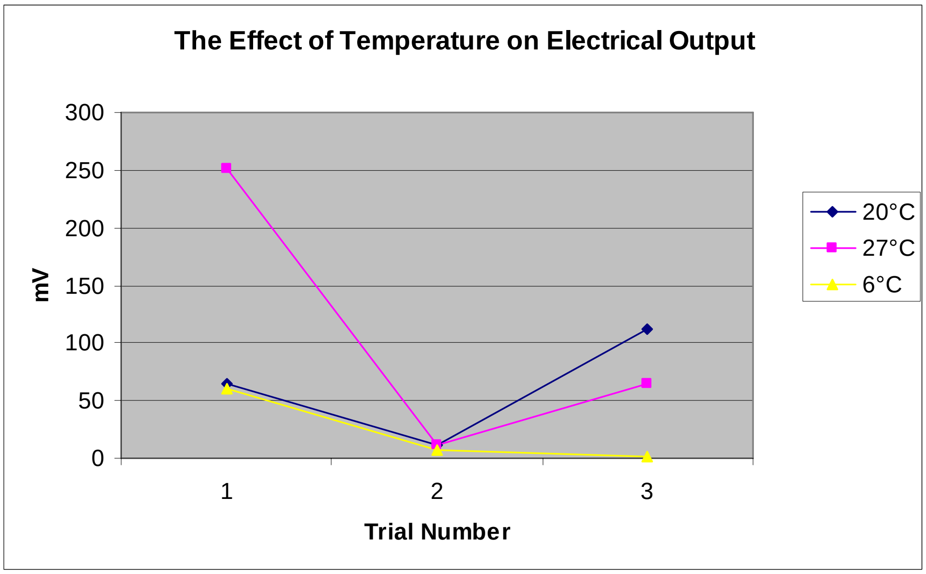
(Procedures above came directly from Professor Derek Lovely's Sediment Battery Preparation website: http://www.geobacter.org/research/microbial/Sediment%20Battery%20Preparation%20copy.pdf)

** These parts of the procedure were added for our specific experiment

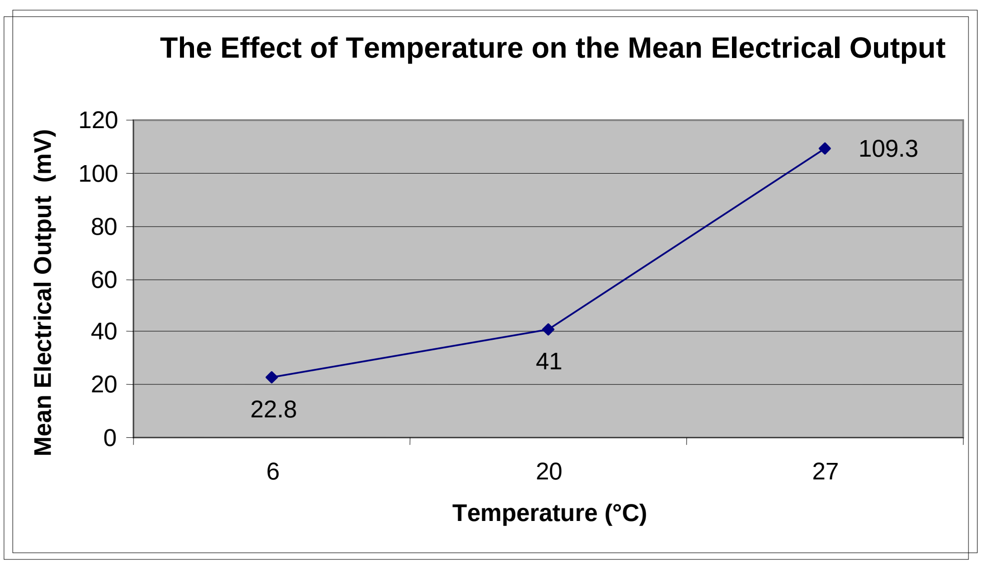
Data Tables

	DV: mV			
IV: Temperature (°C)	**1**	**2**	**3**	**Mean millivolts**
20	**65**	**11**	**112**	**41**
27	**251**	**12**	**65**	**109.3**
6	**60**	**6.5**	**2**	**22.8**

Graphs



The Effect of Temperature on Electrical Output
mV
300
250
200
150
100
50
0
1
2
3
Trial Number
20°C
27°C
6°C



The Effect of Temperature on the Mean Electrical Output
Mean Electrical Output (mV)
120
100
80
60
40
20
0
109.3
41
22.8
6
20
27
Temperature (°C)

Conclusion

Purpose:
The purpose of the experiment was to make a sediment battery more electrically efficient, by finding out what temperature best suits the bacteria in their environment. By finding their ideal temperature, it would increase their electrical output.

Major Findings:
After completing the experiment we found that the bacteria had a higher mean electrical output at a temperature of 27 degrees Celsius, compared to the other temperatures we tested which were 20 and 6 degrees Celsius. The mean electrical output for 27 degrees Celsius was 109.3 mV. This was 68.3 mV higher than the mean electrical output for 20 degrees Celsius which was 41 mV. It was also 86.5 mV higher then the mean electrical output of 6 degrees Celsius which was 22.8 mV.

Support for Hypothesis:
Our hypothesis was supported in the experiment. The greater the temperature the sediment battery was kept in, the greater the mean electrical output was.

Discussion/Explanation:
The reason that the bacteria could have generated more electricity in 27 degrees Celsius is because the heat energy in the bacteria's environment made them more active and able to release more electrons onto the electrode. Since metabolism is a chemical reaction, chemical reactions generally happen faster in an environment with more heat energy.

Sources of Error:
There were some sources of error in the experiment. One of them was the amount of light the sediment batteries were exposed to during the different trials. Also the same pond water was used in each trial which could have affected the data in the experiment. Another source of error was that the mud used in the trials aged while it was in storage to be used. Also the measurement couldn't always be exact. Lastly we used a different way of suspending the anode in water during each trial.

Experimental Improvements:
To improve the experiment for future research we would need to reduce or fix all the sources of error encountered in the experiment.

Ideas for Future Research:
There are also questions for further study which could be experiment on in future experiments. One question is, if we increase the surface area on the anode would that increase the output of electricity? Also, if sugar/acetate was added to the organic matter would the output of electricity increase? Lastly, it would be good to test whether different organic matter would have an impact of the electrical output of the bacteria?

Real-World Application:

Microbial Fuel Cells soon will be coming into our lives. They can be used to power cars, which would eliminate a lot of pollution caused by bad emissions from the cars we have today. Also, they can be used in remote environments, like space and underwater. In fact, NASA is currently interested in Microbial Fuel Cells to be used aboard their spacecrafts. Since MFC's can clean waste, sewage treatment plants are looking into the idea of having MFC's power and clean in their treatment plants. Soon all our electronic devices could be powered by MFC's, making the earth cleaner.

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The pictures in the background research are from the Geobacter Project homepage: http://www.geobacter.org/index.html

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