Daniel T Vo

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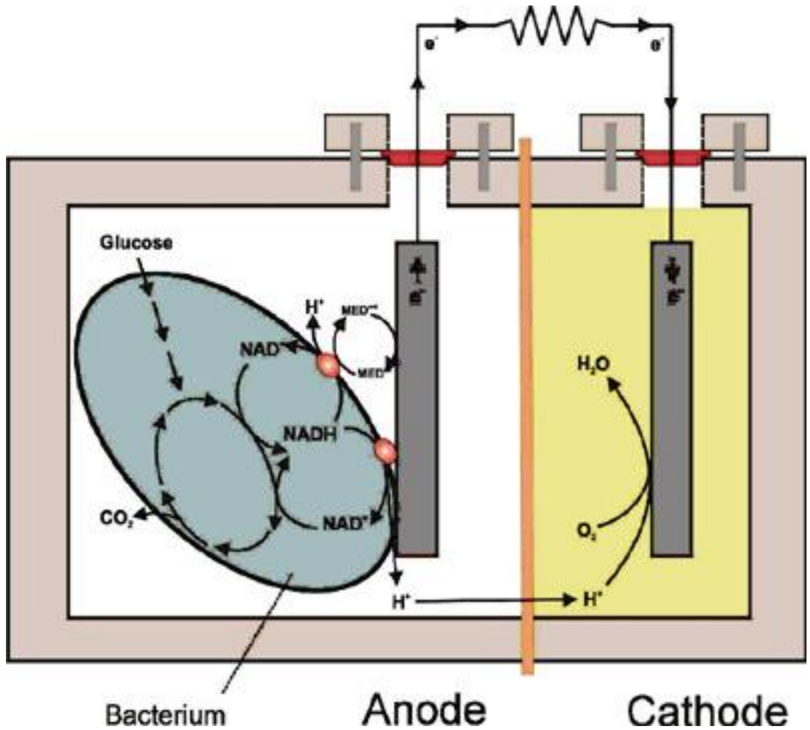
Microbial Fuel Cell

A microbial fuel cell is to be constructed, optimized, and used to demonstrate various aspects of electrical circuits (including Kirchoff's Laws, current, voltage, resistance, etc). Experimentation with the design and materials will allow for the determination of maximum voltage. The voltage attained will attempt to power a low voltage LED light bulb.

A microbial fuel cell (MFC) is a biological fuel cell that utilizes microorganisms such as bacteria and yeast to oxidize organic substrates into various products including $H^+$and e^- (as well as CO_2 and various organic products). A two chambered, mediatorless MFC consists of a cathode and an anode separated by a Cation Exchange Membrane (CEM). An external circuit connects the two chambers. The anode houses the microbes, organic substrate, and an electrode. It is kept anaerobic (no oxygen) as the force the microorganisms to use the electrode as the terminal electron acceptor. [In aerobic respiration, organisms use O_2 as the final electron acceptor]. Through the process of anaerobic respiration (fermentation), hydrogen ions and electrons (as well as various organic products) are produced. H^+ and e^- flow from anode to cathode through the CEM and electrodes (respectively). The Cation Exchange Membrane, a selectively permeable membrane only to cations, allows for the diffusion of H^+ from anode to cathode. The external circuit allows for the flow of electrons (from the anode) into the cathode. The cathode consists of an open aired chamber containing an electrolytic solution and an electrode. The aerobic environment allows for oxygen gas to dissolve into solution. It is in the cathode that electrons, hydrogen ions (from the anode) as well as the (dissolved) oxygen combine to form water. This completes the circuit.



The microbial fuel cell is constructed from two 1-Quart plastic canisters and PVC joined by epoxy and waterproof sealant. The CEM is sealed between the cathode and PVC. The external circuit connecting the two chambers consists of graphite electrodes and titanium wire. The two chambers of the MFC are filled with electrolytic solution. The catholytic solution consists of 5.0 cups of 0.1M Phosphate buffer. The anolytic solution consists of either 1 cup of powerade (for its sugar and electrolyte content) + 4 cups of H_2O or 5 cups of the creek/"swamp" water + 1.0 g of sugar.

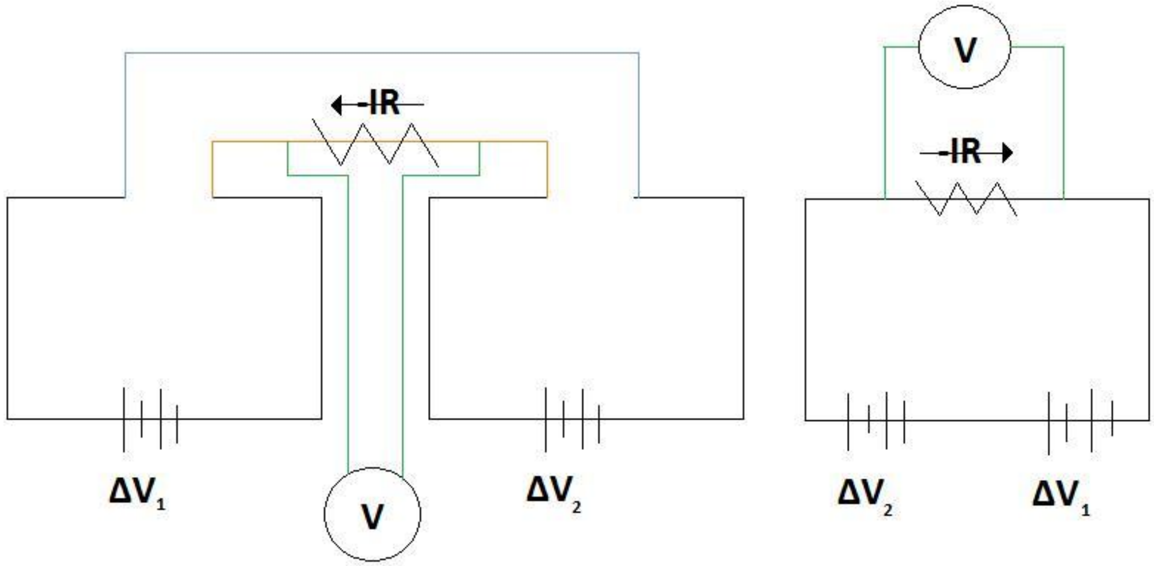
The microbes are inoculated into the anode chamber and are allowed to metabolize the organic substrate. As the oxygen levels decrease, the microorganisms switch from aerobic to anaerobic respiration. As this happens, the voltage steadily increases. Voltage, current and resistance are measured across the electrodes. A 100 ohm resistor is placed in the circuit to allow a small voltage to build up. As the sugar is used up, the voltage will decrease again. This indicates the death of the microbes due to starvation. An additional 1.0 g of sucrose is injected into the anode chamber.

From the experiment, optimal MFC operations involved the creek/ “swamp” water bacteria and Pt/graphite cloth electrode (in the cathode). In earlier experiments, it was also determined that too much powerade (2x) and the addition of a 0.05M Acetate solution (pH = 5) decreased voltage, and thus bacteria health. The results of the experiment are as follows:

Maximum, steady voltage was obtained from the creek/ “swamp” water cell at 200+ mV. In second place (but nowhere near the lead), came the yeast cell at 6 mV, followed by the yogurt cell at 3 mV, creek water cell at 2-3 mV, and the room water and control cells at 0 mV. The addition of the Pt/graphite cloth electrode increased the maximum steady voltage to well over 450 mV.

A microbial fuel cell is similar to a real battery in that as current is depleted, voltage decreases [However, a MFC is a biological fuel cell that can “recharge” when its circuit is disconnected]. A MFC also follows Ohm’s law and Kirchoff’s laws (for DC circuits). Ohm’s law states that “in some cases, the resistance of a material remains constant as the potential difference or current is unchanged” or $\Delta V = IR$, where ΔV is the potential difference, I is the current, and R is the resistance. The resistance of the MFC and circuit can be determined by plotting the potential difference vs. the current. The determined resistance of the MFC was 213.97 ohms. Kirchoff’s laws state that [1] charge is conserved or $\Sigma I_{in} = \Sigma I_{out}$ (junction equation) and [2] the potential difference along a closed loop is zero or $\Sigma \Delta V = 0$ (loop equation).

When a resistor network is connected in series, $\Delta V_1 + \Delta V_2 = \Delta V_s$, $I_1 = I_2 = I_s$, and $R_s = R_1 + R_2$. When connected in parallel, $\Delta V_1 = \Delta V_2 = \Delta V_p$, $I_1 + I_2 = I_{p,}$ and $1/R_p = 1/R_1 + 1/R_2$. Two fuel cells are connected in series (as shown below). Since voltages increase when the network is connected in series, $\Delta V_1 + \Delta V_2 = \Delta V_s = -IR$.



MFCs are a renewable source of energy. They utilize microorganisms to catalytically convert the substrate into energy; both can be replenished when needed. In addition, MFCs can be assembled from relatively cheap, non-toxic materials, as opposed to conventional batteries. However, the drawback is the relatively low voltage that can be achieved by the MFC (compared to a battery). A practical application is to apply MFC technology to waste (sewage, paper, etc) management. MFCs consume organic materials to produce CO_2 (g) and H_2O as products in addition to energy.

Sources

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