BUILDING A MICROBIAL FUEL CELL

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Galvanic or Voltaic Cell

- An electrochemical cell produces electrical energy from spontaneous oxidation-reduction (redox) reactions.
- The cell consists of two different solid metals in the metal’s salt solution connected by a salt bridge.
- A redox reaction is a chemical reaction that transfers electrons between two species.
- Reduction is the gain of electrons and Oxidation is the loss of electrons by a molecule, atom, or ion.

\[
\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu} \\
\text{Zn} \rightarrow \text{Zn}^{2+} + 2e^-
\]
Galvanic Cells

- $\text{Zn} \rightarrow \text{Zn}^{2+} + 2e^-$ (Anode)
- $\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu}$ (Cathode)
- One $\frac{1}{2}$ cell reaction occurs in each container
- A salt bridge allows for charge neutrality in the solutions
- Current will not flow without the salt bridge to shuttle ions
Build One – Materials

- 0.1 M \( \text{ZnCl}_2 \) solution
- 0.1 M \( \text{CuSO}_4 \) solution
- 0.1 M \( \text{NaCl} \) solution (for salt bridge)
- At least 3 dixie cups
- Copper wire (14G +)
- Galvanized (zinc-coated) nail
- Filter paper (for salt bridge)
- Voltmeter with alligator leads
Build One – Procedure

- Pour ~ 20ml of ZnCl₂ solution in a dixie cup and add the galvanized nail so its head sticks out of the cup
- Pour ~ 20ml of CuSO₄ solution in a dixie cup and add the copper wire so its end sticks out of the cup
- Clip one voltmeter lead to the nail and the other lead to the wire – Is there a voltage?
- Soak filter paper in NaCl solution and then roll the soaked paper into a tube shape
- Place one end of the NaCl soaked filter paper tube in the ZnCl₂ solution and the other end in the CuSO₄ solution – Is there a voltage?
The theoretical voltage generated by the Zn/Cu galvanic cell is +1.1V under standard conditions, i.e.
- T = 25°C and P = 1 bar for gases,
- Solids and liquids are pure, and
- Solutions are 1 M in all species.

Real voltage will vary
- Has equilibrium been reached & maintained
- Concentrations change over time
- Temperature dependence
Microbial Fuel Cell

Soil acts as salt bridge

Electron flow

Oxygen Rich Zone

Anoxic Zone

Taken from “Advanced Intro to MFC’s”, keegotech.com (2011)
Microbial Fuel Cell—Alternate Anode

Oxygen Rich Zone
- Soil acts as salt bridge
- Electron flow
- \( \frac{3}{4} \text{O}_2 \rightarrow \frac{3}{4} \text{H}_2 \text{O} \)
- \( \frac{1}{4} \text{O}_2 \)

Anoxic Zone
- Anode = steel wool
- \( \text{Fe} \rightarrow \text{Fe}^{2+} \)

Taken from “Advanced Intro to MFC’s”, keegotech.com (2011)
Theoretical Voltages

Double-Biofilm Cell

Anode: \( \text{CH}_3\text{COOH} + 2\text{H}_2\text{O} \rightarrow 2\text{CO}_2 + 8\text{H}^+ + 8\text{e}^- \) \( E^o = -0.097 \text{ V} \)
Cathode: \( 2\text{O}_2 + 8\text{H}^+ + 8\text{e}^- \rightarrow 4\text{H}_2\text{O} \) \( E^o = +1.33 \)
NET: \( \text{CH}_3\text{COOH} + 2\text{O}_2 + \rightarrow 2\text{CO}_2 + 2\text{H}_2\text{O} \) \( E^o = +1.23 \text{ V} \)

Steel Wool at Anode

Anode: \( \text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^- \) \( E^o = -0.44 \text{ V} \)
Cathode: \( 2\text{O}_2 + 8\text{H}^+ + 8\text{e}^- \rightarrow 4\text{H}_2\text{O} \) \( E^o = +1.33 \)
NET: \( \text{CH}_3\text{COOH} + 2\text{O}_2 + \rightarrow 2\text{CO}_2 + 2\text{H}_2\text{O} \) \( E^o = +1.77 \text{ V} \)
Potential MFC Construction Pitfalls

- Moisture content of soil
  - Maintain moisture with lid

- Electrical circuit considerations
  - Ensure top cathode contact with soil
  - Avoid short circuits between electrodes
  - Optimal load resistance

- Soil/microbial nutrients and additives
  - Sugary foods drinks can increase voltage, but beware of noxious-smelling byproducts

- Maintaining anoxic and oxygen-rich zones
  - Avoid air pockets during assembly
  - Iron (steel wool/nails) is good oxygen scavenger
In 1780, Luigi Galvani contracts frog leg muscles with two different metals
In 1799, Alessandro Volta invents a non-biological cell similar to the galvanic cell
Later, Carlo Matteucci constructs a battery entirely out of biological material
These discoveries paved the way for electrical batteries and Volta's cell is an IEEE Milestone (1999)
Practical Applications of MFC’s

- UN Sustainable Development Goals

6. Clean Water and Sanitation

7. Affordable and Clean Energy
Wastewater Treatment

- MFC’s used in wastewater treatment can
  - effectively remove organic waste
  - generate electrical power
- 1.5% of electricity produced in US is used for wastewater treatment (15 GW)
- Successful pilot programs treated municipal wastewater in
  - Bottrop, Germany
  - Harbin, China
Recharging portable devices in the developing world

- MFC’s built with local materials costing 10 to 20 US dollars have the demonstrated ability to
- Power LED lamps
- Recharge cell phones