Clean Fuel Cell Energy

FREE FUEL CELL INFORMATION BOOKLET

"A brief synopsis of fuel cells"

Thank you for visiting Clean Fuel Cell Energy today. Our mission is to provide you with the most up-to-date and informative fuel cell information and products. Please feel free to contact us with any questions or suggestions. Happy learning!

INTRODUCTION

Fuel cells produce electricity from an electrochemical reaction between reactants such as oxygen and hydrogen, although other fuels besides hydrogen can be used. The reaction produces water and heat as byproducts. Some benefits of fuel cells are that they are much more efficient than the internal combustion engine; they produce more usable energy, and they don't produce pollution (as our current IC engines do).

The typical polymer electrolyte membrane fuel cell, or PEMFC, contains two electrodes: one positively charged, called the anode, and one negatively charged, called the cathode. The anode and cathode are made of an electrically conductive carbon paper or carbon cloth-backing layer, coated with a catalyst layer. Between them is an electrolyte membrane, which is the heart of the fuel cell; it conducts protons from the anode to the cathode. To understand how it works, we need to get down to the molecular level.

When the hydrogen gas enters the anode, it comes into contact with the catalyst, which splits the gas into positive ions (hydrogen protons), and electrons. The electrons traveling to the cathode via an external circuit create the electrical current which runs the vehicle, or whatever device the fuel cell is running. The protons can travel through the membrane to the cathode.

At the same time, oxygen is being fed to the cathode, where a catalyst layer creates oxygen ions. When the hydrogen protons arrive at the cathode side, they bond with these oxygen ions, creating water and heat as the byproduct of the electrochemical reaction.

Since a single fuel cell isn't enough to power most devices, fuel cell manufacturers stack them together in a series, which is why they are called fuel cell stacks. The greater the number of fuel cells in the stack, the higher the voltage. The greater the area of the electrodes, the greater the current. Voltage times current is total power output. Figure 1 shows a schematic of a single fuel cell.

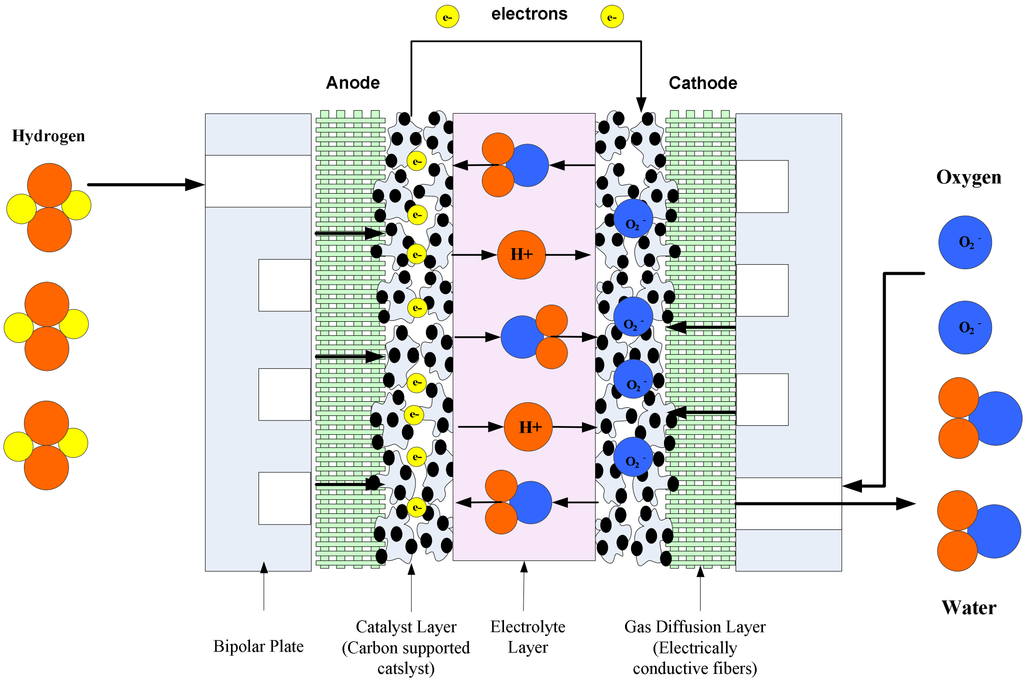

Figure 1. Illustration of a single cell fuel cell

PARTS OF A FUEL CELL

The Polymer Electrolyte Membrane

The standard electrolyte material currently being used in PEM fuel cells is a Teflon-based polymer membrane produced by DuPont for space applications in the 1960s. The DuPont electrolytes have the generic brand name Nafion®, and the specific type used most often is number 117. The Nafion® membranes exhibit exceptionally high chemical and thermal stability. They are stable against chemical attack in strong bases, strong oxidizing and reducing acids, and chlorine, hydrogen and oxygen at temperatures up to 125 °C. The proton-conducting membrane usually consists of a polytetrafluoroethylene, or PTFE-based polymer backbone, to which sulfonic acid groups are attached (this ia a negatively charged group, that “carries” the hydrogen protons through the membanre). The chemical formula for Nafion® 117 is:

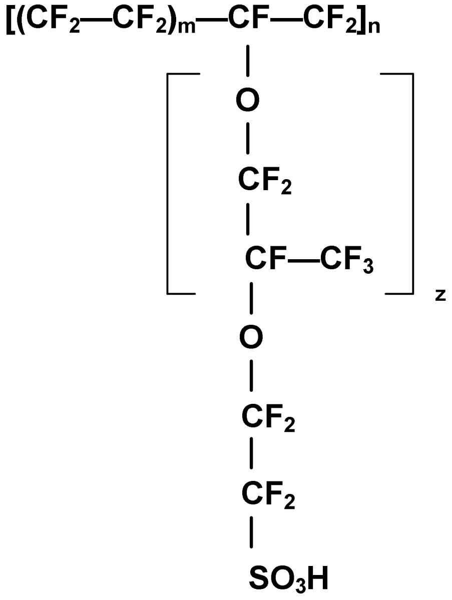

Figure 2. Chemical structure of a Nafion® membrane

The proton-conducting membrane works well for fuel cells because the hydrogen protons jump from SO_3 site to SO_3 site throughout the material, and emerge on the other side of the membrane. However, the membrane must remain hydrated in order to conduct the protons, which limits the operating temperature of PEM fuel cells to under the boiling point of water, and makes water management a key issue in PEMFC development.

The Electrodes

The electrodes are usually made of a porous mixture of carbon-supported platinum and a carbon-based backing layer. In order to catalyze the reactions effectively, the catalyst particles must have contact with both the carbon-based backing layer and the electrolyte (Nafion®) membrane. Furthermore, there must be passages for the reactants (the hydrogen and oxygen) , to reach the catalyst sites and for the reaction products, the water and heat, to exit. The “passages” are usually created by the combination of the porosity of the carbon-backing layer, the porous catalyst layer and the flow field plates. The contacting point of the reactants, catalyst, and electrolyte is usually referred to as the three-phase interface. But in order to achieve acceptable reaction rates, the effective area of active catalyst sites must be several times higher than the geometric area of the electrode, so the electrodes are porous, forming a three-dimensional network in which the three-phase interfaces are located.

Most PEMFC developers have chosen the thin-film approach, in which the electrodes are manufactured directly onto the membrane surface. The benefits of thin-film electrodes include lower price, better use of catalyst and improved mass transport of reactants and reaction products. The thickness of a thin-film electrode is typically 5 - 15 microns, and the catalyst loading is between 0.1 to 1.0 mg/cm^2 per square centimeter of membrane.

Gas Diffusion Backings

In a PEMFC, the membrane electrode assembly, or MEA, is sandwiched between flow field plates. On each side of the MEA, between the electrode and flow field plate, are gas diffusion backings made of a porous, electrically conductive material (usually carbon cloth or carbon paper) that can be treated with a fluoropolymer and carbon black to improve water management and electrical properties. These backings provide electrical contact between the electrodes and the flow field plates, and distribute reactants to the electrodes.

Flow Field Plates

Since a single fuel cell cannot produce much electricity by itself, fuel cells are usually stacked together to form what is known as a fuel cell stack. Flow field plates allow electricity to be conducted between these adjacent individual fuel cells in the stack. The flow field plates separate the reactant gases of adjacent cells, connect the cells electrically, and act as a support structure. Figure 3 shows an exploded view of a PEM fuel cell stack composed of repeating cells of MEAs and flow field plates. Increasing the number of cells in the stack increases the voltage, while increasing the surface area increases the current.

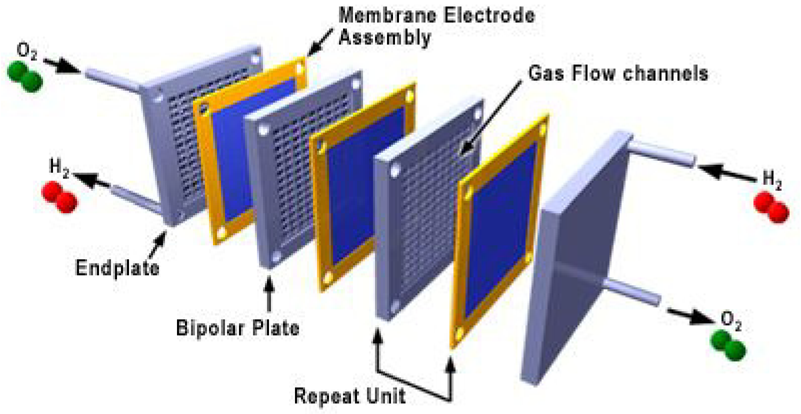

Figure 3. Exploded view of a fuel cell stack (3M)

Flow field plates also have reactant flow channels on both sides, forming the anode and cathode compartments of the unit cells on the opposing sides of the flow field plate. Flow channel geometry has an effect on reactant flow velocities and mass transfer and thus on fuel cell performance. Flow field plate materials must have high conductivity and be impermeable to gases. Also, because of the presence of reactant gases and the catalyst, the material should resist corrosion and be chemically inert.

Most PEMFC flow field plates are made of resin-impregnated graphite. Solid graphite is highly conductive, chemically inert and resistant to corrosion, but it's also expensive and costly to manufacture. The flow channels are machine or electrochemically etched to the flow field plate surfaces. These methods are not suitable for mass production, though, and research for new flow field plate materials is ongoing.

Flow field Design

In PEM fuel cells, the flow field should be designed to ensure that the pressure of the reactants does not drop drastically, while providing adequate and evenly distributed mass transfer through the carbon diffusion layer to the catalyst surface for reaction.

Two popular channel configurations for PEM fuel cells are the serpentine and parallel flow patterns, as shown in Figure 4. Some small-scale fuel cells do not use a flow field to distribute the hydrogen and/or air, but rely on diffusion processes from the environment.

The serpentine flow path is continuous from start to finish. An advantage of the serpentine flow path is that any obstruction in the path will not block all downstream activity of the obstruction. A disadvantage of serpentine flow is the fact that the reactant is depleted through the length of the channel, so that an adequate amount of the gas must be provided to avoid excessive voltage losses.

In the parallel configuration, the flow channels require less mass flow per channel, and provide more uniform gas distribution with a reduced pressure drop. The disadvantage of the parallel flow configuration is that an obstruction in one channel results in flow redistribution among the remaining channels, and a "dead zone" downstream of the blockage.

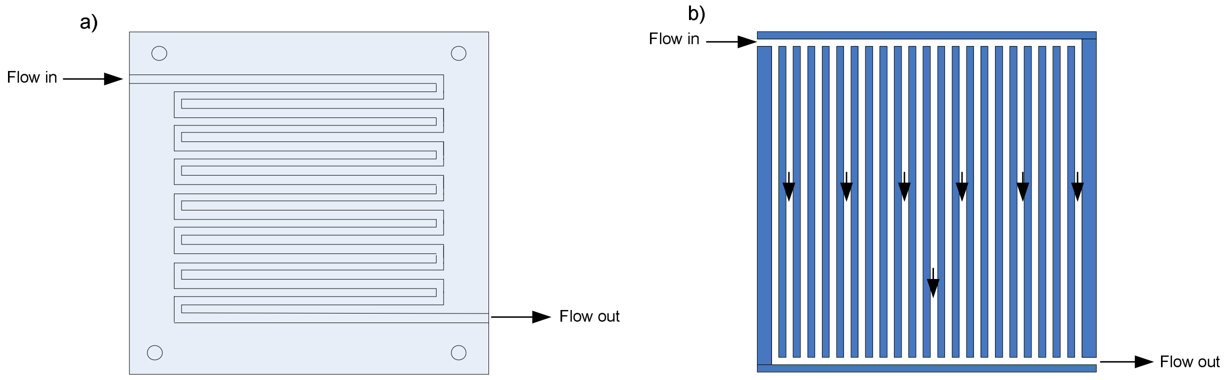

Figure 4. The (a) serpentine and (b) parallel flow field designs

The serpentine flow field design is usually preferred for many types of fuel cells due to better reactant distribution and good water drainage.

BUILDING A FUEL CELL

A single cell can be made that will achieve whatever current and power are required, simply by scaling up the size of the active electrode area. However, the output voltage of a single cell is less than 1 V for realistic operating conditions. Therefore, for most applications and for compact design, a fuel cell stack of several individual cells connected in series is used. Separate humidification and cooling systems are needed for larger stack sizes to ensure that the system temperature remains low enough for the Nafion® perfluorinated membrane to remain hydrated in order to efficently conduct protons.

To make a PEMFC, the following materials are needed: (1) a proton exchange membrane, such as Nafion® 112, 115 or 117; (2) Nafion® solution; (3) carbon fabric or paper; (4) a catalyst, which is usually platinum; (5) graphite or other type of flow field plates; (6) gasket material to seal the gases into the flow field area; (7) metal electrode material; (8) end plates; (9) a clamping device or nuts and bolts; (10) a hydrogen source; (11) a multimeter or voltmeter for testing; and (12) heated plates for pressing the MEA together.

Preparing the Polymer Electrolyte Membrane

The proton exchange membrane should be placed on a clean surface and handled using clean cotton gloves to avoid contaminating the sheet. The appropriate sized PEM pieces should be cut according to your fuel cell design.

The PEM film is then prepared for catalyst application by dipping it in six different heated solutions in glass beakers. The solutions are all held at 80 °C using heating plates. Each beaker holds the PEM film for one hour in sequence, as follows:

1) 100 mL of distilled (DI) water, to hydrate the membrane and dissolve surface contaminants.
2) 100 mL of 3% hydrogen peroxide solution (USP), to remove organic contaminants from the PEM surface.
3) 100 mL of sulfuric acid, to remove metal ion contaminants from the PEM surface and sulfonate the PEM surface.
4) 100 mL DI water, to rinse sulfuric acid from the surface and hydrate the PEM.
5) 100 mL DI water, to rinse and hydrate the PEM again
6) 100 mL DI water, for the final rinse and hydration

While the film is in the beakers, it should remain submerged at all times. A thermocouple or thermometer should be kept in each beaker to make sure the temperature is 80 °C. After the PEM disk is dipped in each of the six beakers for one hour, it should be dried in a clean place.

The Catalyst/Electrode Layer Material

The catalyst/electrode layer is made from a mixture of platinum and carbon powder bonded to a conductive carbon fiber cloth. Each fuel cell MEA requires two pieces of catalyst/electrode material. The carbon fiber cloth is the substrate for a gas diffusion catalyst holder. The cloth is often wet-proofed on one side (that is, coated with Teflon) to help keep the water management in a fuel cell stack under control. The catalyst can be applied by any one of several methods, such as painting, screen-printing, sputter diffusion, electrochemical deposition, electroless deposition, or mechanical deposition.

Hot-Pressing the MEA

The two catalyst layers and polymer electrolyte membrane need to be fused together using temperature and pressure for proper mass transfer. The catalyst pieces are first coated with liquid Nafion® solution, which is applied only to the active side of the catalyst to be bonded to the polymer membrane. The coating can be applied with a brush, and then dried at room temperature in a clean place for one hour.

The three layers (catalyst-PEM-catalyst) are then sandwiched between a set of heating plates, and then heated to 90 °C (194 °F) under pressure for one hour to evaporate the solvents from the liquid Nafion® coating. The temperature is then raised to 130 °C (266 °F) over the next thirty minutes. Once the heating plates and the PEM "sandwich" reach 130 °C, apply additional pressure to the three layers. After two minutes at that temperature and pressure, the temperature is turned off and the plates and MEA are cooled to room temperature.

Gas Gaskets and Spacers

The rubber gasket is usually some type of rubber or silicone material that has enough elasticity to compensate for surface flaws in the graphite. The gasket is placed around the flow field pattern in order to create a seal to prevent gas leakage. These pieces should be cut and made to fit around the MEA.

Finishing the Stack

1) The MEA is placed in the center of a piece of Mylar to hold it in the stack.
2) Metal electrodes made from any type of conductive metal are seated on the graphite plates to collect the electrons.
3) End plates can be made of metal, polymer, or a number of other materials to hold the stack in place when it is clamped together by nuts and bolts or some other clamping device.
4) To test a fuel cell a hydrogen source is needed and, at the minimum, a multimeter or voltmeter for testing. If available, an oscilloscope would also be helpful.

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BASIC IDEAS FOR FUEL CELL IMPROVEMENT

Ideas to improve the catalyst effectiveness

1) Add finely powdered platinum to your catalyst formulation.
2) Mix carbon nanotubes with the platinum to create more catalyst surface area (which creates a greater powder density).
3) Mixtures can be made of carbon black and platinum to use as a catalyst.

Ideas to improve the MEA

1) Apply the catalyst layers directly to the membrane, instead of on the carbon cloth.
2) Create mechanical flow channels to carry the hydrogen protons from the anode to the cathode.

Ideas to improve Fuel Cell Geometry

1) Consider circular fuel cell designs and/or different methods of inputting hydrogen into the stack. For example, design the stack and the flow fields to accept hydrogen from the center of the stack.
2) To create thinner and lighter fuel cell designs, consider other carbon-based or metal materials from which to create conductive fuel cell plates. Metal plates can be coated to prevent corrosion over time.

Thank you for reading the free Clean Fuel Cell Energy fuel cell booklet. For technical questions, information about fuel cells, or information about our products, please e-mail us at info@cleanfuelcellenergy.com. We are updating our information, site and products frequently, so please check back often.

Best Regards,

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