Clean Fuel Cell Energy.com

Clean Fuel Cell Energy.com Fuel Cell Idea Booklet

"A Brief Synopsis of Fuel Cell Technology and Ideas"

Introduction

A PEM fuel cell consists of a negatively charged electrode (cathode), a positively charged electrode (anode) and an electrolyte membrane. Hydrogen is oxidized on the anode and oxygen is reduced on the cathode. Protons are transported from the anode to the cathode through the electrolyte membrane and the electrons are carried to the cathode over the external circuit. On the cathode, oxygen reacts with protons and electrons forming water and producing heat. Both the anode and cathode contain a catalyst to speed up the electrochemical processes. Figure 1 shows a schematic of a single fuel cell.

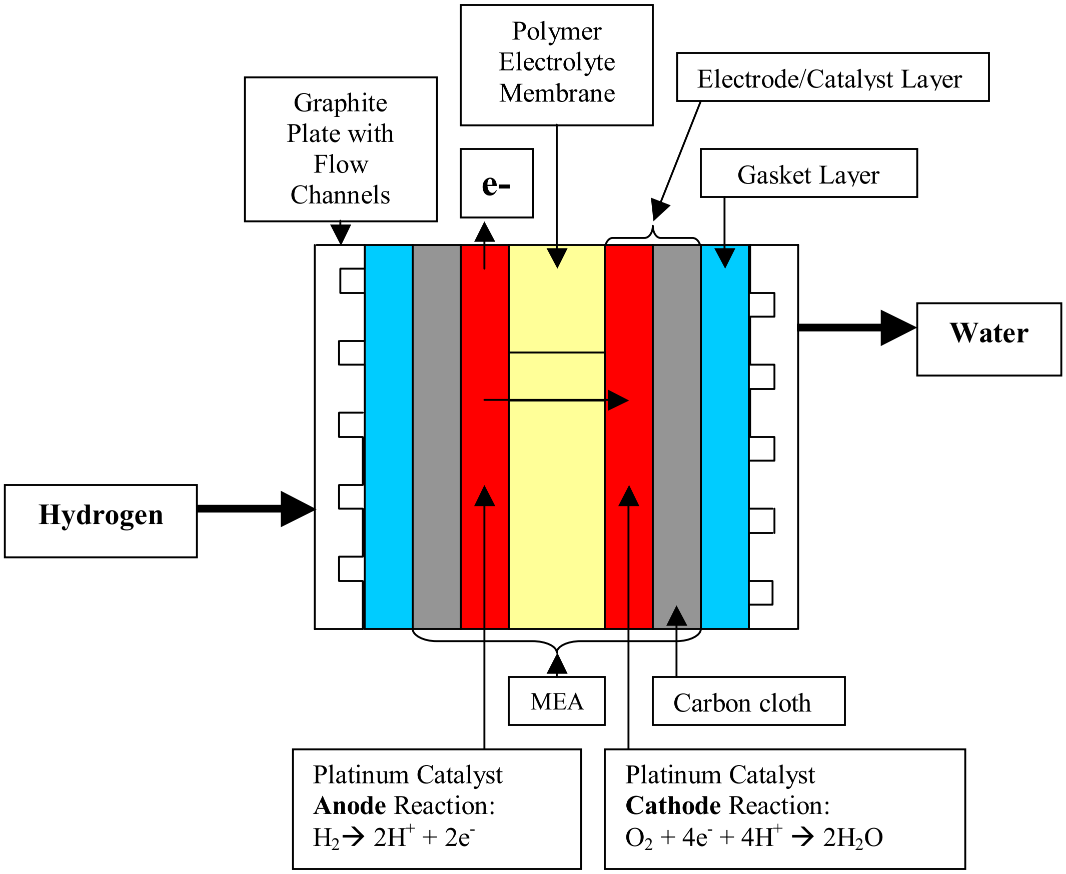


Figure 1: Generalized Schematic of a Single Fuel Cell

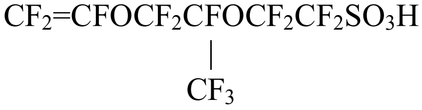
Reactants are transported by diffusion and/or convection to the catalyzed electrode surfaces where the electrochemical reactions take place. Transport to the electrode takes place through an electrically conductive carbon paper or carbon cloth-backing layer, which covers the electrolyte on both sides. These backing layers typically have a porosity of 0.3 to 0.8, and serve the purpose of transporting the reactants and products to and from the bipolar plates to the reaction site. An electrochemical oxidation reaction at the anode produces electrons that flow through the graphite plate/cell interconnect to the external circuit, while the ions pass through the electrolyte to the opposing electrode. The electrons return from the external circuit to participate in the electrochemical reduction reaction at the cathode.

Parts of a Fuel Cell

Polymer Electrolyte Membrane

The standard electrolyte material presently used in PEM fuel cells is a fully fluorinated Teflon-based material produced by duPont for space application 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, which are fully fluorinated polymers, exhibit exceptionally high chemical and thermal stability. They are stable against chemical attack in strong bases, strong oxidizing and reducing acids, H_2O_2, Cl_2, H_2, and O_2 at temperatures up to 125 °C.

The proton-conducting membrane usually consists of a PTFE-based polymer backbone, to which sulfonic acid groups are attached. The chemical formula for Nafion® 117 is:



$$CF_2{=}CFOCF_2\underset{\underset{\displaystyle CF_3}{|}}{CF}OCF_2CF_2SO_3H$$

The proton conducting membrane works well for fuel cell applications because the H^+ jumps from SO_3 site to SO_3 site throughout the material. The H^+ emerges on the other side of the membrane. The membrane must remain hydrated to be proton-conductive. This limits the operating temperature of PEM fuel cells to under the boiling point of water, and makes water management a key issue in PEM fuel cell development.

The Electrodes

The electrodes are usually made of a porous mixture of carbon supported platinum and ionomer. In order to catalyze reactions, catalyst particles must have contact to both protonic and electronic conductors. Furthermore, there must be passages for reactants to reach catalyst sites and for reaction products to exit. The contacting point of the reactants, catalyst, and electrolyte is conventionally referred to as the three-phase interface. 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. Therefore, the electrodes are made porous to form a three-dimensional network, in which the three-phase interfaces are located.

Most PEM fuel cell developers have chosen the thin-film approach, in which the electrodes are manufactured directly on the membrane surface. The benefits of thin-film electrodes include lower price, better use of catalyst and improved mass transport. The thickness of a thin-film electrode is typically 5 – 15 microns, and the catalyst loading is between 0.1 to 0.3 mg/cm^2.

Gas Diffusion Backings

In a PEM Fuel cell, the MEA is sandwiched between flow field plates. On each side of the MEA, between the electrode and flow field plate, there are gas diffusion backings. They provide electrical contact between electrodes and the bipolar plates, and distribute reactants to the electrodes. They also allow reaction product water to exit the electrode surface and permit passage of water between the electrodes and the flow channels.

Gas diffusion backings are made of a porous, electrically conductive material (usually carbon cloth or carbon paper). The substrate can be treated with a fluoropolymer and carbon black to improve water management and electrical properties.

Bipolar Plates

In a fuel cell stack, bipolar plates separate the reactant gases of adjacent cells, connect the cells electrically and act as a support structure. Bipolar 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 bipolar plate.

Flow channel geometry has an effect on reactant flow velocities and mass transfer and thus on fuel cell performance. Bipolar plate materials must have high conductivity and be impermeable to gases. Due to the presence of reactant gases and catalyst, the material should be corrosion resistant and chemically inert.

Most PEMFC bipolar plates are made of resin-impregnated graphite. Solid graphite is highly conductive, chemically inert and resistant to corrosion, but expensive and costly to manufacture. Flow channels are machines or electrochemically etched to the graphite or stainless steel bipolar plate surfaces. These methods are not suitable for mass production and therefore new bipolar materials are being researched.

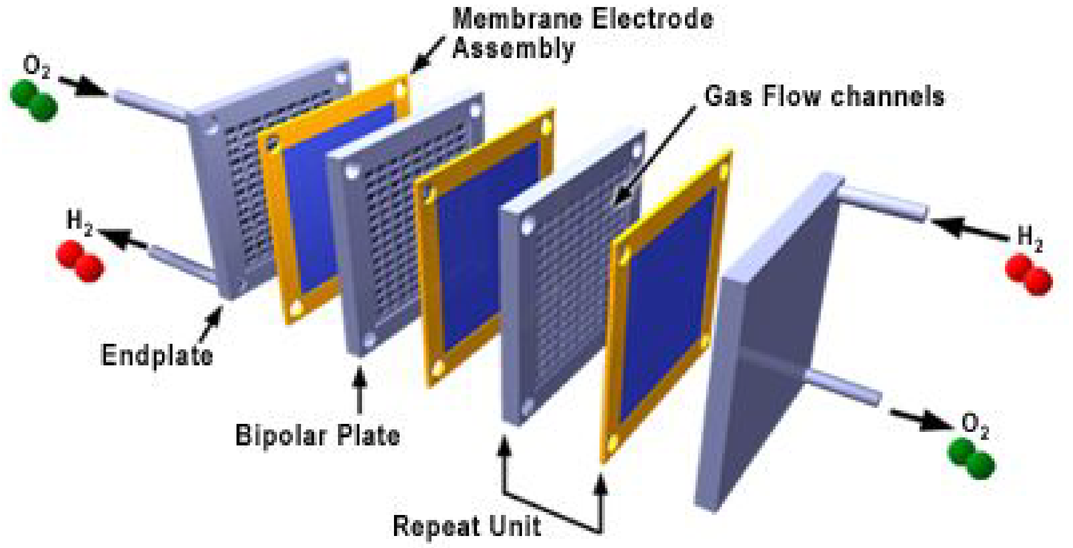


Figure 2: An Exploded View of a PEMFC stack. (Picture: 3M[1])

Figure 2 shows an exploded view of a PEMFC stack. The stack is made of repeating cells of MEAs and bipolar plates. Increasing the number of cells in the stack increases the voltage, while increasing the surface area increases the current.

Flowfield Design

In PEM fuel cells, the flowfield should be designed to minimize pressure drop (reducing parasitic pump requirements), while providing adequate and evenly distributed mass transfer through the carbon

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[1] 3M Corporation. http://www.3m.com/us/mfg_industrial/fuelcells/overview/pemfc.jhtml

diffusion layer to the catalyst surface for reaction. The three most popular channel configurations for PEM fuel cells are: 1) serpentine, 2) parallel, and 3) interdigitated flow. Serpentine and parallel flow channels are shown in Figures 3 and 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.

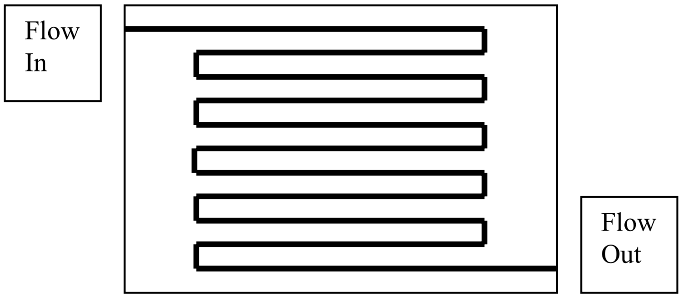

Figure 3: Serpentine Flow Field Design

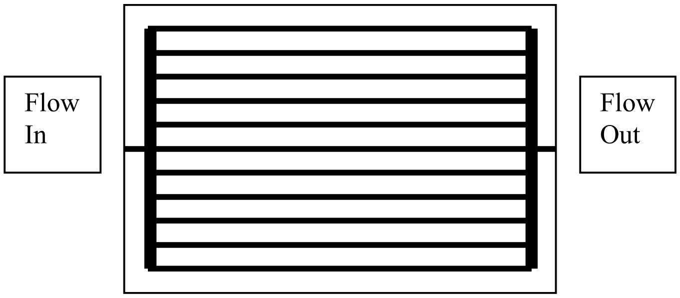

Figure 4: Parallel Flow Field Design

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 polarization 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.

Since the hydrogen reaction is not rate limiting, and water blockage in the humidified anode can occur, a serpentine arrangement is typically used for the anode in smaller PEM fuel cells.

Building a Fuel Cell

A single cell can be made to achieve whatever current and power 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 insure that the system temperature remains below Nafion® perfluorinated membrane material glass transition temperature of approximately 130 °C.

To make an 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) catalyst, which is usually platinum, (5) graphite or other type of flowfield plates, (6) gasket material to seal the gases into the flowfield area, (7) metal electrode material, (8) end plates, (9) clamping device or nuts and bolts, (10) hydrogen source, (11) 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 held the PEM film for one hour in sequence.

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

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.

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 (membrane electrode assembly) 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 (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, mechanical deposition, etc.

Hot-Pressing the MEA

The two catalyst layers and polymer electrolyte membrane need to be fused together by temperature and pressure for proper mass transfer. The catalyst pieces are first coated with liquid Nafion® solution, and it is only applied 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 heating plates are coated with graphite to make a release and contamination layer. The three layers (catalyst-PEM-catalyst) are then set on top of the lower heating plate. The upper heating plate was placed on top of the layers. The three layers are heated to 90 °C (194 °F) 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 flowfields next to the electrode/diffusion layers to create a seal to prevent gas leakage. These pieces should be cut and made to fit around the MEA and flowfields.

Finishing the Stack

1. The MEA is placed in the center of a piece of Mylar or other material 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. Ensure that the metal electrodes are not near the MEA.

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 minimally a multimeter or voltmeter for testing. If available, an oscilloscope would also be helpful.

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:

4. Apply the catalyst layers directly to the membrane (instead of on carbon cloth).

5. Create mechanical flow channels to carry the H+ from the anode to the cathode (this method only works with MEMS Fuel Cells because of the properties of fluids on the microscale).

Ideas to improve Fuel Cell Geometry:

6. Consider circular fuel cell designs and/or different methods of inputting hydrogen into the stack. For example, design the stack and the flowfields to accept hydrogen from the center of the stack.

7. To create thinner and lighter fuel cell designs, consider other carbon-based or metal materials to create conductive fuel cell plates from. Metal plates can be coated to prevent corrosion over time.

For additional technical questions, information about fuel cells, or information about our products, please email us at info@cleanfuelcellenergy.com. We are updating our information, site and products frequently, so please check back often.

Bibliography

Appleby, A and F. Foulkes. (1989) Fuel Cell Handbook, Van Nostrand Reinhold, New York, New York, pp.1-762.

Bard, A.J., and Faulkner, L.R. (1980) Electrochemical Methods, John Wiley and Sons, New York, New York, pp.101.

Halliday, David, Robert Resnik, Jearl Walker (1997). Fundamentals of Physics. Fifth Edition. John Wiley & Sons, Inc, New York. pp. 470.

Hirschenhofer, J.H., D.B. Stauffer, R.R. Engleman, and M.G. Klett (1998). The Fuel Cell Handbook. Fourth Edition. Parsons Corporation. Reading, PA.

L.E. Unnewehr, S.A. Nasar. (1982). Electric Vehicle Technology. John Wiley & Sons, Inc. pp.52

Mench, Matthew M., Cao-Yang Wang, and Stephan T. Tynell. “An Introduction to Fuel Cells and Related Transport Phenomena.” Department of Mechanical and Nuclear Engineering, The Pennsylvania State University.

Mikkola, Mikko. (2001) “Experimental Studies on Polymer Electrolyte Membrane Fuel Cell Stacks”, Helsinki University of Technology, Department of Engineering Physics and Mathematics, Masters Thesis.

Pyle, Walt, Alan Spivak, Reynaldo Cortez, and Jim Healy. (1993) “Making Electricity with Hydrogen”. Home Power #35. June/July 1993, pp. 42-48.

Ren, X., and Gottesfeld, S. (2001) Electro-osmotic Drag of Water in Poly(perfluorosulfonic acid) Membranes, Journal of Electrochemical Society, Vol 148, No. 1, pp. A87-A93.