

## COATED AND LAMINATED FABRICS FOR FUEL CELLS

**Project Team:** Dr. Sabit Adanur, Auburn University, Dept. of Textile Engineering  
Dr. Faissal Abdelhady, Auburn Univ., Dept. of Textile Engineering  
Dr. Ben Choe, Auburn University, Dept. of Mechanical Engineering  
Dr. Bruce Tatarchuk, Auburn University, Dept. of Chemical Eng.  
Dr. Qinguo Fan, Univ. of Massachusetts, Dartmouth  
Dr. Steve Warner, Univ. of Massachusetts, Dartmouth

**Graduate Students:** Ms. Lale Isikel, Auburn University, Dept. of Textile Engineering  
Mr. Vishal V. Narvekar, Univ. of Massachusetts, Dartmouth

### Abstract

The current fuel cell technology is analyzed. Polymeric structures play an important role in fuel cell technology. The current polymer types, surface texture, coating formulations and processing are studied. The benefits of using new or different polymeric structures is investigated. A membrane in a fuel cell should allow proton transfer and prevent the transfer of hydrogen (fuel) and contaminants. A new fuel cell is being manufactured to investigate these issues. Modeling of the polymer electrolyte membrane (PEM) is continued.



**GOAL**

This project deals with the coating and laminating needs of membrane-based fuel cell components. The precise size and shape of the coated area is a concern in fuel cell manufacturing. This research will characterize the fundamentals of coating and laminating the active components in fuel cells with the aim to increase efficiency, reduce cost and further develop and optimize the substrates, recipes and process technology.

**INTRODUCTION**

A fuel cell is a battery that produces heat and electricity via an electrochemical reaction. It does not need recharging so long as hydrogen and oxygen fuel are supplied. A fuel cell is constructed by sandwiching an electrolyte between an anode and a cathode. The fuel, hydrogen, is fed to the anode continuously. A catalyst activates the system; the hydrogen gas is separated into protons and electrons. The electrons are conducted through a wire. The potential difference between fuel and oxygen produces an electrical current. The protons travel through a special proton exchange membrane and combine with oxygen to produce heat and water byproduct, the water being removed as water vapor [1-6]. Figure 1 shows schematic of a fuel cell.

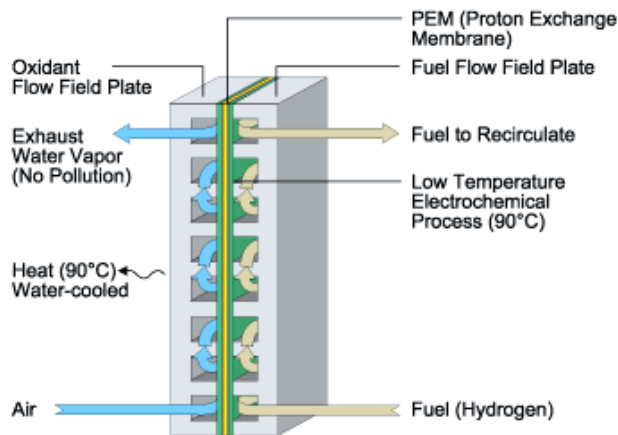


Figure 1 Schematic of a fuel cell (Ballard, Inc.)

Although there are several types of fuel cells, the polymer electrolyte membrane fuel cell (PEMFC) has especially high potential for future. In this fuel cell, a polymer membrane acts as

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the electrolyte to transport electrons from anode to cathode. This work focuses on the polymer electrolyte membrane (PEM) and gas diffusion layer. The current membrane uses a fluorinated Teflon®-based polymer membrane such as Nafion 112-117 from DuPont. The gas diffusion layer can be woven or nonwoven carbon, such as SGL or Lydall paper. The current properties and future goals of the PEMs are given below:

<u>Property</u>	<u>Present</u>	<u>Target</u>
Efficiency	35%	40%
Cost \$/kW	300-500	30-50
Durability	2000 hours	5000 hours
Operating temperature	80°C	-40 to 200° C

Other technical targets set by the U.S. Department of Energy (DOE) for fuel cell stack system by the year 2010 are high, sustained proton conductivity ( $>0.1$  S/cm) at 120°C and 25% RH (automotive), and low oxygen and hydrogen cross-over (2 mA/cm<sup>2</sup>). Fuel cell stacks are made of 100-200 individual fuel cells. Each fuel cell contains a membrane electrode assembly (MEA). The area of each membrane is approximately 25 cm<sup>2</sup>. The membrane separates oxygen and hydrogen in the fuel cell, which should not be mixed; however, a certain amount of moisture in the membrane is necessary for the proton transport. The membrane is 50-180 µm thick.

In order to achieve the targets, the PEM is the most promising approach. However, there are barriers, such as high temperature stability, durability, low humidity application, and cost. Many new materials are being synthesized and evaluated.

### **PROJECT ACTIVITIES**

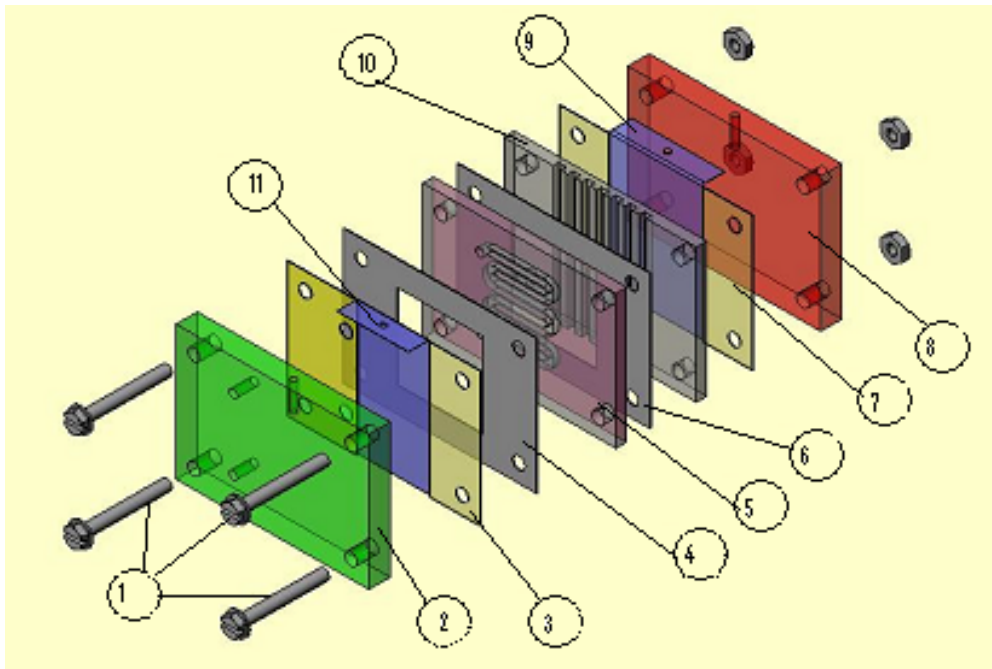
A new student was hired at Auburn University Department of Textile Engineering and another student was hired at the University of Massachusetts Dartmouth, who have been working on the project. A meeting was held between Dr. Adanur and Dr. Fan on 21 March 2005 during the National Textile Center forum in Raleigh, NC. In the meeting, the progress and future directions were discussed.

The literature search has been completed. Using light energy, distilled water was separated into hydrogen and oxygen for a small scale fuel cell car. The car was successfully run with the hydrogen which has been demonstrated to prospective students for the Department of Textile Engineering at Auburn University at various occasions (Figure 2).

Improving the membrane electrode assembly (MEA) structure is the subject of this work.

We

are



developing a fuel cell prototype which will allow us to change the membrane inside the fuel cell easily. This way, new polymeric membranes will be tested and the results will be used to improve the membrane properties. All the components of the fuel cell have been purchased and/or manufactured. Currently, assembling is being done.

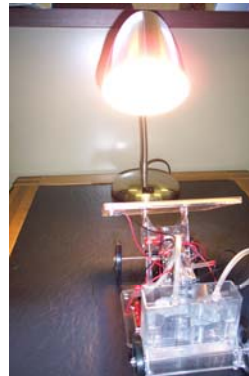


Figure 2. Fuel cell car with solar panel (left); production of hydrogen from distilled water using a lamp and the solar panel.

- |                                 |                                   |                             |
|---------------------------------|-----------------------------------|-----------------------------|
| 1. Assembly bolts gasket        | 2. Hydrogen side end plate        | 3. Silicon rubber strip     |
| 4. Silicon rubber gasket        | 5. Hydrogen flow field plate      | 6. MEA+Mylar gaskets        |
| 7. Silicon rubber strip gaskets | 8. Air side end plate             | 9. Air side metal electrode |
| 10. Air flow field plate        | 11. Hydrogen side metal electrode |                             |

Figure 3 Exploded view of fuel cell being manufactured.

The fuel cell being manufactured will expose the graduate and undergraduate students working on the project to the fundamentals of the fuel cell technology. Manufacturing of the fuel cell is not the objective in itself but it furnishes a custom made fuel cell to test newly developed gas diffusion electrodes (GDE) and compare their performance with present GDEs. The fuel cell being manufactured is simple in design, low cost, and accepts both on-shelf GDE or custom made GDE. Figure 3 shows a perspective view of our fuel cell design with the major components. Figures 4-7 show various components of the fuel cell that have been manufactured.

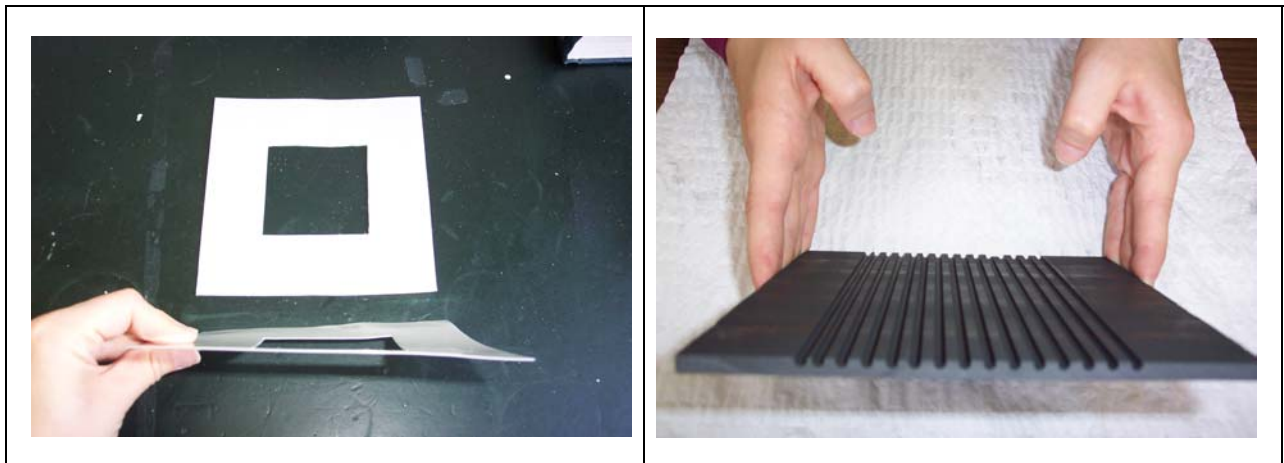




	Figure 5. Air side flow field plate
 <p>Figure 6. Air and hydrogen metal electrodes</p>	 <p>Figure 7. End plate</p>

**Study of the Finite Element Method using FEMLAB:**

The FEMLAB 3.1i software was used to do the modeling of fuel cell. The governing equations used for modeling are:

- Mass balance equation for the gases
- Electronic charge conservation equation
- Stefan - Maxwell equation for multi-species diffusion
- Ohm's law for electrical current conduction
- Darcy's equation for fluid flow in the porous media
- Fick's law for diffusion
- Butler-Volmer equation relating the electric current and potential
- Faraday's law relating the electrical current and consumption of reactants in the electrochemical reaction

Gases and gas mixtures are treated as ideal and are transported through diffusion and convection. The electrodes are assumed to be uniformly porous and permeable. Since gas in the electrodes exists in continuous phase, Darcy's law is applied, which states that the gradient of the pressure, the viscosity of the fluid, and the structure of the porous media determines the velocity vector (**u**):

$$\mathbf{u} = -[1/k_p \cdot \rho](\Delta p)$$

where:  $k_p$  denotes the gas permeability of the electrode ( $\text{mol} \cdot \text{m} \cdot \text{s}^{-1}$ ),

$\rho$  the gas density ( $\text{kg}\cdot\text{m}^{-3}$ )  
 $p$  the pressure ( $\text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-2}$ )

The density is given by:

$$\rho = \sum M_k C_k$$

where  $M_k$  is the mole mass ( $\text{kg mol}^{-1}$ ) for each species and  $C_k$  is the mole fraction ( $\text{mol m}^{-3}$ ) for each species.

The water droplets generated in the anodic layer and transported through the porous membrane are assumed to be of negligible volume. The electrodes are considered as homogeneous media in which the porosity and the permeability are distributed uniformly. The following dependent variables were used for the modeling:

- (1) for anode domain: gas-phase pressure/stress; mass fraction/mole fraction of hydrogen in the gas phase; and current distribution.
- (2) for the membrane: the electrolytic potential, and
- (3) for cathode domain: gas-phase pressure/stress; mass fraction/mole fraction of oxygen in the gas phase; and current distribution.

The constant variables for the hydrogen, oxygen, electrode potentials at the inlets and outlets were added as per the size of the fuel cell. A 2D model of a cross – section from anode to cathode through the membrane was designed for analyzing the fluxes, concentrations, potentials and current distribution in the catalyst layer (anode and cathode layers) and the membrane for any given condition in the channels. The sub-domain settings and boundary settings were done using the modeling package for the cathode, anode and membrane considering the Darcy's law, the Maxwell-Stefan diffusion and convection module and the mass transfer module. Further mesh parameters were set for all the domains.

### **Modeling of Fuel Cell Using Data for the Nafion® 117 Membranes Used in the Industrial Experiments [7,8,9]:**

The experimental operating conditions are as follows:

- hydrogen gas inlet pressure – 10 psi;
- oxygen gas inlet pressure – 10 psi;
- temperatures of experiment – 20 °C, 80 °C and 100 °C

The cell voltage and the current measurements from the load measurement box can give the current density at the anode using the cross-sectional area of the Pt/C electrode fused with the membrane. All the parameters were used in the modeling to study the working of the fuel cell in terms of current distribution, water transport, mass distribution, and thus to determine the optimum requirement for efficient working of the fuel cell.

**Distribution of Current Density**

The current density distribution is governed by the Butler-Volmer equation using the temperature, the diffusion of the protons from anode to cathode through the membrane, prohibiting the water diffusion from cathode to anode which depends on the permeability of the membrane and is governed by the Darcy’s law. The equation takes into account the porosity of the membrane with respect to temperature and humidity and the diffusion coefficient of the membrane with respect to the density of the membrane and bonding in the polymers. The potential at the anode current collector was arbitrarily chosen zero while total cell voltage ( $\phi$ ) was used as boundary condition.

The cell temperature was set to 20°C, 80°C (Figure 8) and 100°C. The mole ratio of oxygen to hydrogen supply was 1:1. The inlet pressure of hydrogen and oxygen was set to 0.01MPa. The remaining boundaries were given either insulation or symmetry conditions, using the boundary settings.

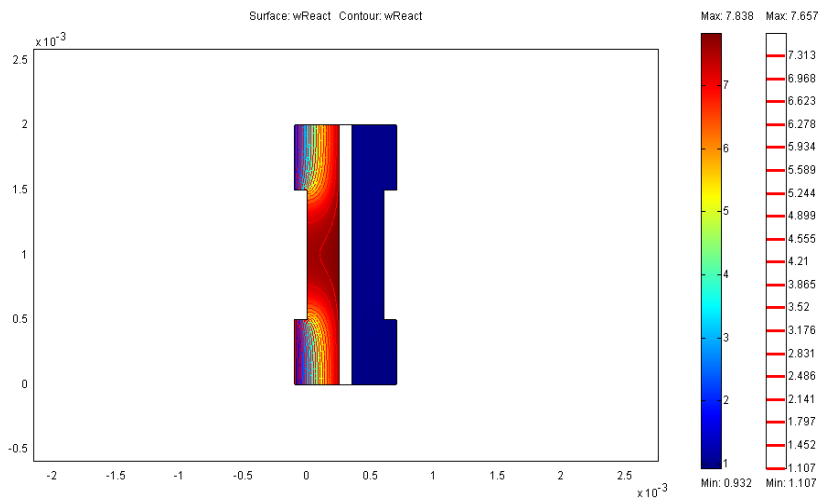


Figure 8 Nafion® 117 – current density distribution at 80 °C

The models showed a very high current density distribution at the current collector and throughout the anode-membrane intersection. This is because the availability of oxygen is higher in this reaction zone. It is observed that once the cell voltage is relaxed, current density shows a drop since the oxygen concentration at the cathode catalyst still remains low due to the higher consumption rate. An increase in oxygen content at the cathode increases the efficiency of proton fusion to form water, thus increasing the proton mobility which leads to an increase in current density at the anode – membrane interface. The humidity (40%) of the membrane is sufficiently high to facilitate the efficient proton transfer from anode to cathode. This study revealed a new possibility to control the lateral current profile.

**Distribution of Mass Fraction**

The mass balance distribution is governed mainly by the Maxwell – Stefan diffusion and convection equation. The potential at the anode current collector was arbitrarily chosen zero while total cell voltage ( $\phi$ ) was used as boundary condition at the cathode current collector, and was set to 0.74V. The temperature of the cell was set to 20°C, 80°C and 100°C (Figure 9). The mole ratio of oxygen to hydrogen supply was 1:1. The inlet pressure of hydrogen and oxygen was set to 0.01MPa. The remaining boundaries were given either insulation or symmetry conditions, using the boundary settings.

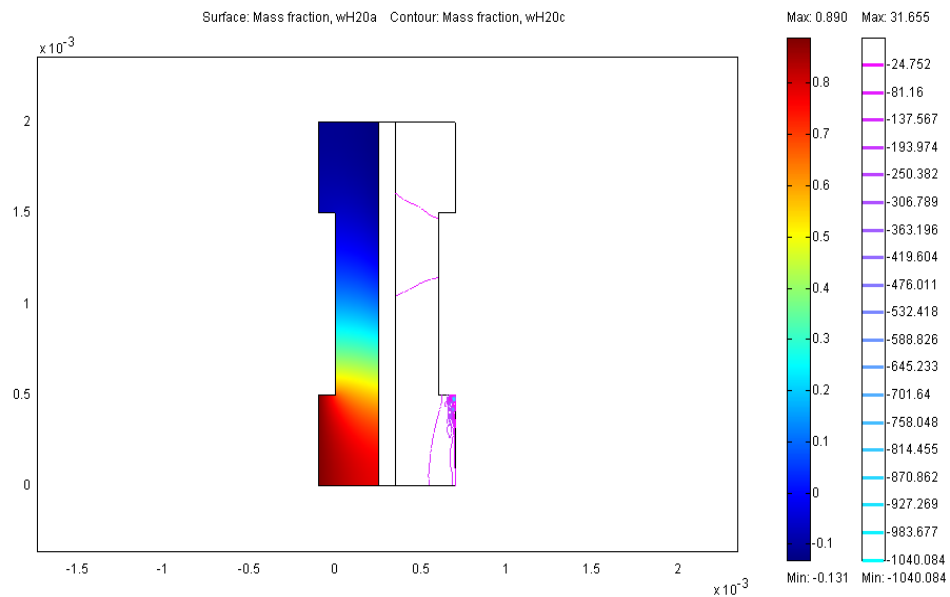


Figure 9 Nafion® 117 – mass fraction at 100°C

The modeling was done considering the mass fractions of the reactants at the anode and the cathode in the fuel cell. The mass distribution in the cell at anode, cathode and proton exchange membrane boundaries with respect to the electrodes were simulated, applying Darcy's law for the membrane from the mass transfer module and Maxwell-Stefan diffusion equation for the electrodes.

It is observed that as hydrogen gas flows, hydrogen fraction decreases, because of the drag induced flux of hydrogen along the membrane – anode inlet channel interface, which is more than the consumption of water and is seen to be lower at the current collector - membrane boundary, and medium at the anode outlet channel – membrane boundary. Thus, at the anode, the mass distribution does not show any variation with the increase in temperature.

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### **Oral Presentations:**

- Adanur, S., "Coated and Laminated Fabrics for Fuel Cells", 2<sup>nd</sup> International Technical Textiles Congress, Istanbul, Turkey, 13-15 July 2005.

### **Poster Sessions:**

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- Adanur, S., Choe, B., Fan, Q., and Warner, S., “Coated and Laminated Fabrics for Fuel Cells”, National Textile Center 13th Annual Forum, March 20-22, 2005, Raleigh, NC.

### **Industrial Contacts:**

- UTC, Ballard, Hawaii Transportation Center, Enova Systems, Hyundai, LG Electronics, Gore Associates, DigiFab Systems, Zimmer Machinery Corporation, Lacom GmbH.

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