

A Gas Distributor Design for Proton-Exchange-Membrane Fuel Cells

Trung V. Nguyen*

Department of Chemical and Petroleum Engineering, University of Kansas, Lawrence, Kansas 66045, USA

ABSTRACT

A nonconventional gas distribution design has been developed to improve the mass-transport rates of the reactants from the flow channels to the inner catalyst layers of the porous electrodes and to reduce the electrode water flooding problem in the cathode of proton-exchange-membrane fuel cells. Preliminary results validate the effectiveness of the design in achieving the above goals.

A conventional proton-exchange-membrane (PEM) fuel cell consists of a membrane/electrode (M/E) assembly sandwiched between two flow fields. The M/E consists of a membrane that is hot pressed between two porous electrodes. The electrodes consist of two layers, the catalyst layer and the gas-diffusion layer to which Teflon[®] is often added to make it hydrophobic.

During operation, the reactant gas flows down the channels that were machined into the flow fields. From the channels, the reactant gases diffuse into the electrodes, through the diffusion layers, to the catalyst interfaces. Figure 1 shows a scheme of a PEM half-cell with a conventional flow-field plate. At high current densities, the reaction rate becomes mass-transfer limited by the transport rate of the reactant/product gases from/to the electrode and channel interface to/from the catalyst interface.¹ At the anode, the rate is limited by the transport rates of hydrogen and water vapor from the channels to the catalyst sites. Water vapor transport is needed to keep the membrane hydrated. At the cathode, the rate is limited by the transport of oxygen from the channel to the catalyst sites and water vapor from the catalyst sites to the channel. In addition to the gas-transport limitation, the cathode faces another problem called electrode flooding. The water generation rate at the cathode by reaction and electro-osmotic drag at high current densities often exceeds its removal rate from the inner porous electrode layers in the form of water vapor, resulting in condensation. This liquid, when accumulated in the porous layers, results in an additional barrier to the transport of the reactant gas to the catalyst surface.

The water flooding problem in the cathode can be described as follows. Assuming that oxygen (air) coming into the cell is not saturated, the difference between the partial pressures of water vapor inside the electrode and in the flow channels causes water that is created at the catalyst sites to be transported out of the porous electrode. However, as the gas traverses the channels, at some point it becomes saturated. Beyond this point there is no longer a driving force to remove water from the inner layers of the electrode. As a result the cathode becomes partially flooded and under utilized. We have found that at high current densities due to electrode flooding about a third of the electrode surface area was often not fully utilized. Furthermore, one can see that the addition of Teflon to the diffusion layer will only exacerbate the flooding problem by making it more difficult for the liquid water to be transported out of the diffusion layer.

To solve this problem a new flow field design was developed. See scheme in Fig. 2. By making the inlet and outlet flow channels dead-ended, the reactant gases are now forced to flow into the porous electrodes in order to exit. This design in effect has converted the transport of the reactant/product gases to/from the catalyst layers from a diffusion mechanism to a convection mechanism with a much reduced gas-diffusion layer over the catalyst sites. Since convection is much faster than diffusion, the reaction rates at the catalyst sites can be significantly enhanced. Furthermore, the shear force of this gas flow helps remove most of the liquid water that is entrapped in the inner layers of the electrodes, thereby significantly reducing the electrode flooding prob-

* Electrochemical Society Active Member.

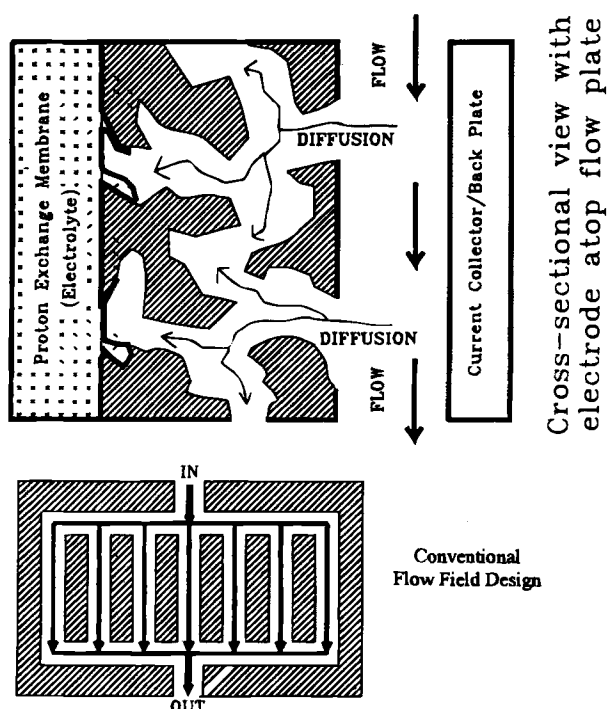


Fig. 1. Scheme of a PEM half-cell with a conventional flow field.

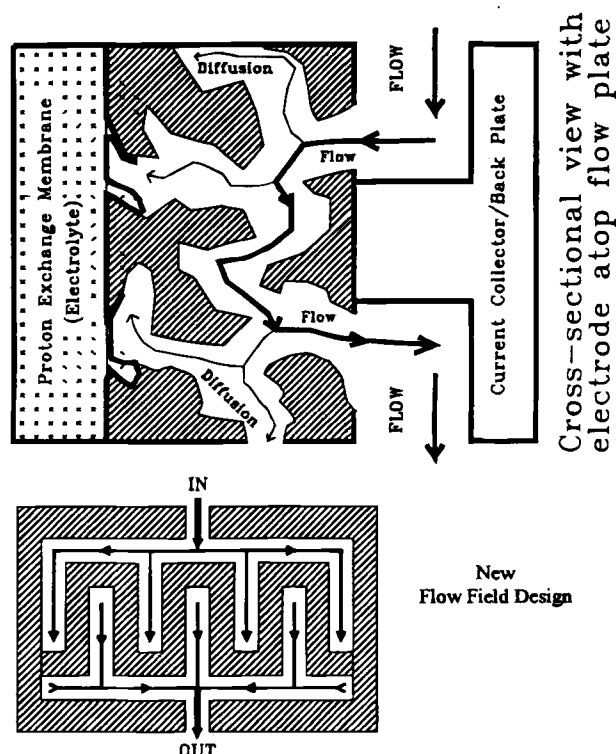


Fig. 2. Scheme of a PEM half-cell with the new field flow.

lem. Test runs with the new flow-field design have shown less water accumulation in the M/E (determined from the difference in the M/E weights measured at the beginning and the end of the runs). It is necessary to point out here that Wilson *et al.* from the Los Alamos National Laboratory have arrived at the same design from their work on the use of macroporous materials as an alternative backing material for the membrane-electrode assembly, and the design was recently published.² Their published results on air operation showed great improvement in the performance when a fuel cell using an M/E with standard backings and serpentine flow fields was compared to another fuel cell using an M/E with much thinner backing diffusion layers and dead-ended flow fields. However, the improvement that can be attributed to the new flow field is hard to quantify because of the differences in the M/E's construction. Very recently, one of the reviewers of this work helped us locate an earlier work by Ledjeff *et al.*³ that showed similar improvement of air operation with a similar flow-field design.

This paper shows the improvement that was achieved with this new flow-field design for a PEM fuel cell using an M/E with standard backing materials from GlobeTech (College Station, TX) operating under both H_2/O_2 and H_2 /air conditions. Figures 3 and 4 show the H_2/O_2 performance of a PEM fuel cell using conventional flow fields for both electrodes vs. the new flow-field design for the cathode. Cell potentials are not corrected for IR losses. Fuel-cell specifications are: 100 cm^2 electrode area, pure hydrogen saturated with water and dry oxygen, gas flows maintained continuously at 0.9 A/cm^2 equivalent rate for hydrogen and 1.05 A/cm^2 equivalent rate for oxygen for both designs (*i.e.*, ~ 1.3 and ~ 1.5 times the stoichiometric flow rates at maximum current for hydrogen and oxygen, respectively), 22°C, ambient pressure, Nafion® 115, and 2 mg Pt/ cm^2 .

As shown in Fig. 3, the mass-transport-limited region has been significantly extended. At the maximum current shown in the figure,

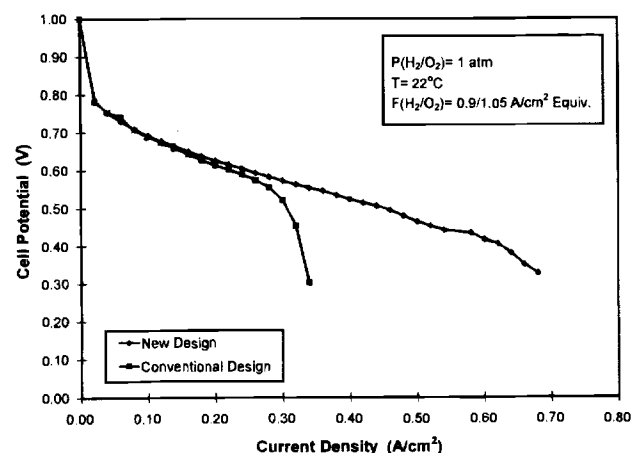


Fig. 3. Effect of the new flow field on the pure oxygen performance.

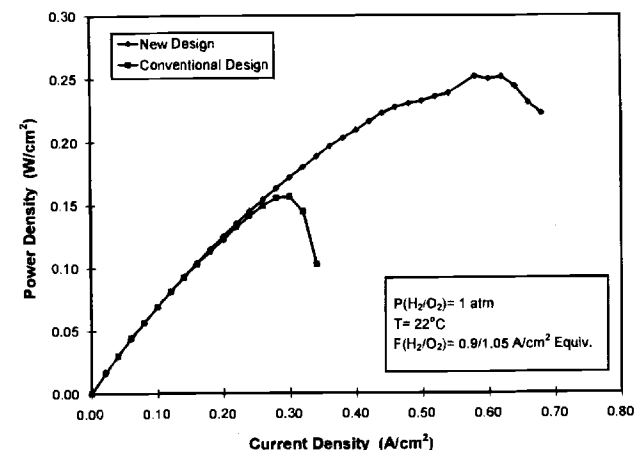


Fig. 4. Power density enhancement of pure oxygen performance by the new flow field.

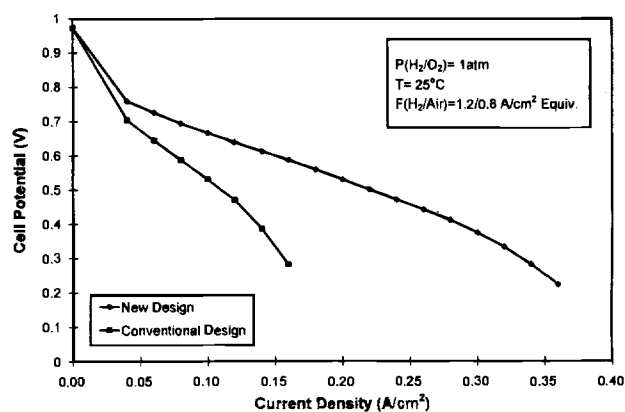


Fig. 5. Effect of the new flow field on the air performance.

a mass-transport-limited region is still not observed. Figure 4 shows that the peak power increased from 0.16 W/cm^2 with the conventional flow field to 0.25 W/cm^2 with the new flow field, a 60% improvement in performance. Other observations with the new flow-field design include no water accumulation in the channels with the new design as compared with excessive water accumulation observed with the conventional design and no performance hysteresis. That is, the cell potential at a given current does not depend on the direction in which the current is varied. The pressure drop over a 1 mm shoulder width was measured to be 2.4 kPa for the H_2 side and 1.4 kPa for the O_2 side. No degradation of the electrodes was observed at these flow rates and pressure drops. Last, this flow field allows us to use the liquid water injection system⁴ for anode humidification and simultaneous heat removal with minimal electrode flooding effect.

Figures 5 and 6 show similar enhancement with the new flow-field design for H_2 /air operation. Continuous hydrogen saturated with water at 1.2 A/cm^2 equivalent and dry air at 0.8 A/cm^2 equivalent flow rates were used. Pressure was at 1 atm, and temperature was maintained at 25°C. As with pure oxygen operation, cell potentials were not corrected for IR losses. With similar flow and operating conditions for both designs, the new flow field resulted in current and power densities increases of better than 100% over most of the potential range. The higher increase observed with air operation can be explained as follows. With pure oxygen, oxygen transport into the porous structures in a conventional flow-field design is by convection as created by the depletion of the oxygen at the reactive sites. At low current densities where the reaction rates are not transport limited, switching from convection by reactant depletion to forced convection does not yield any noticeable increase in the reaction rates. The increase in pure oxygen performance observed at higher current densities with the new flow field can be attributed to both the enhanced convective flow and the water removal from the porous structures effect, with the water removal being most significant.

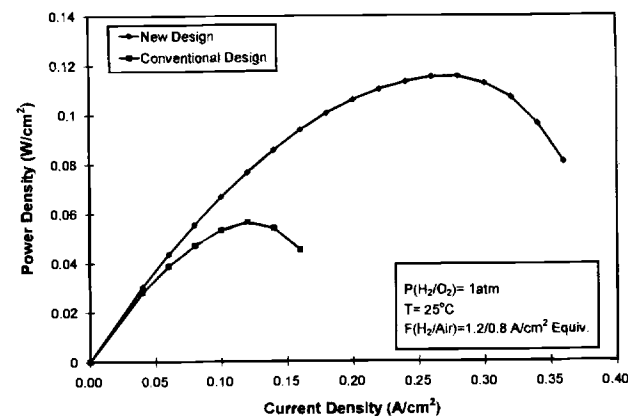


Fig. 6. Power density enhancement of air performance by the new flow field.

In air operation, the transport of oxygen to the reactive sites in the porous electrode is totally by diffusion with a conventional flow field. Consequently, even at low current densities the reaction rates can be strongly affected by the reactant-mass-transport rate. By switching from a diffusion-driven to a convection-driven mass-transport process, the cathode reaction rates can be significantly enhanced. This effect is clearly illustrated by the improvement in the current and power densities at all potentials with air operation as shown in Fig. 5 and 6.

We are in the process of getting data at other temperatures, pressures, and flow rates for both oxygen and air operation and trying to determine the optimal gas-diffusion-layer thickness and the flow-pattern dimensions. Results will be presented in a future paper.

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