FuelCell2008-65142

A NOVEL REACTANT DELIVERY SYSTEM FOR PEM FUEL CELLS

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ABSTRACT

This paper deals with the use of microjets as a reactant delivery method for a PEM fuel cell. The flow physics of this technique have been adapted such that an even distribution of reactants over the membrane is achieved. A single cell based on this microjet delivery method has been built and tested using the fuel cell test station at SESEC. Polarization curves were obtained for a number of different operating conditions in which the relative humidity and supply pressure of the air supply were varied. Similar operating conditions were used to obtain polarization curves for a similarly sized commercially available fuel cell that utilizes commonly used serpentine flow channels for reactant delivery. Comparison of the polarization curves at similar operating conditions revealed that the microjet-based fuel cell was relatively unaffected by the changes in relative humidity and and positively affected by an increase in supply pressure, which was in stark contrast to what was observed for the commercial fuel cell.

INTRODUCTION

This paper deals with a low cost polymer electrolyte membrane (PEM) fuel cell that is under development at the Sustainable Energy Science & Engineering Center (SESEC) at the Florida State University (FSU). Much of the current research involving PEM fuel cells is focused on improving the cell membranes and refining the collector/bipolar plate design, which currently accounts for a vast majority of the fuel cell cost [1]. While progress has been made in this area [2,3], a cursory examination of the state-of-the-art in fuel cells led us to the realization that there is significant room for improvement in the reactant delivery mechanism, as well as the manner in which the temperature in the fuel cell is maintained. As such, a new delivery mechanism has been developed and tested for addressing both of these issues. Prior to the discussion of this delivery method, it is first prudent to discuss the more conventional methods for delivering the reactants to the fuel cell membrane electrode assembly (MEA).

The reactants in a PEM fuel cell are typically hydrogen and oxygen (in the form of air) and they are supplied to the fuel cell MEA through the use of flow paths that are set into each of the cell's collector plates, which are typically graphite or a graphite composite. In the event that pure graphite is used, these flow paths are machined into the surface of the collector plates, which significantly increases the cost associated with the electrodes of a PEM fuel cell. The use of the graphite composite allows for the flow paths to be molded into the surface but the conductivity of these electrodes is extremely low, which can significantly reduce the efficiency of the fuel cell. A serpentine pattern is one of the simplest and most commonly used flow paths, but it suffers from the fact that the reactant must follow the flow path over the cell MEA. This results in an uneven distribution over the MEA, which further results in uneven catalyst degradation in the MEA. Complex flow path designs are employed in an attempt to evenly distribute the reactants over the membrane but they can significantly increase the cost of the collector plate due to the costs

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associated with fabrication. An additional problem with the flow paths that is seldom discussed is the fact that the flow through them must remain turbulence-free, or laminar, in order to maintain constant reactant flow through the cell. As such, cells that employ these flow paths typically have a maximum supply to back pressure ratio at which they can operate. Also of note is the fact that the reactant flow is in a direction that is parallel to the MEA. As such, the flow must overcome its directional momentum in order to interact with the MEA.

Instead of the typically used flow paths, the delivery mechanism discussed here employs well known physics related to jet flow studies to address the reactant delivery issue. In this approach, the reactants are fed to stagnation chambers on opposing sides of the fuel cell. A plate with an array of small holes, referred to here as the microjet plate, allows the reactants to escape from their respective stagnation chambers in the direction normal to the MEA, as illustrated in Figure 1. The small holes, of diameter d, serve as converging nozzles and they are arranged to provide even distribution over the MEA. The reactant flows exiting the holes are accelerated such that miniature jets, or microjets, are formed. At a supply to back pressure ratio of 1.89 the microjets that form are sonic and above this pressure ratio the microjets are underexpanded and the resulting flow becomes supersonic as it moves away from the nozzle exit. After exiting the plate, the microjets travel a short distance, $h/d = 7$, before impinging on their respective collector plate, where they lose a significant amount of their energy to heat transfer. The width, $w/d = 28$, of the impingement site on the current collector was chosen to maximize the heat transfer due to the impinging jet. The impingement also acts to significantly slow down the accelerated reactant flow before it flows past the plate, through the slots shown in Figure 1, to interact with the MEA. Of note is the fact that the flow will have a momentum towards the MEA as it flows past the plate. It should also be noted that an increase in the supply pressure of either flow, above the ratio of 1.89, will increase the mass flow into the cell without drastically affecting the gas dynamics of the system. A result of this approach is that the limiting factor in the cell becomes the rate at which the MEA can react the reactants, as well as adequate management of the heat that is generated when utilizing these high mass flows. The initial intent was to employ this approach for both reactant flows into the cell. However, it was realized that almost all of the chemical reactions would be occurring at the cathode. As such, it was decided that the anode side of the fuel cell would be kept at stagnation conditions (i.e. no flow) while the air side would employ this microjet delivery method, as shown in Figure 2.

Aside from allowing higher cell operating pressures and even reactant distribution, the proposed approach will also provide cooling to the PEM fuel cell. Cooling is currently achieved by some active means or by cutting back on the flow of reactants to the cell, thus reducing the power output. As mentioned above, a significant amount of the energy of the microjets is lost
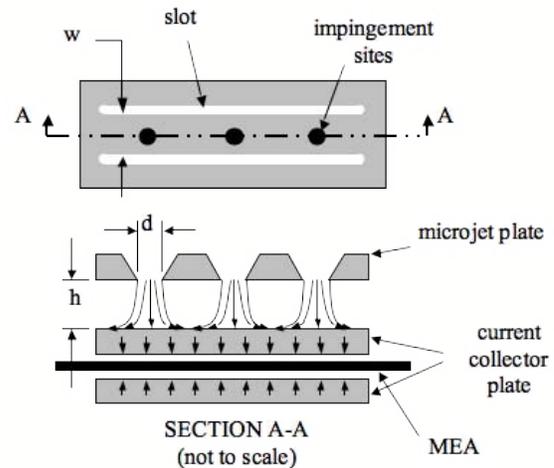

Figure 1. Schematic illustrating the delivery mechanism discussed here.
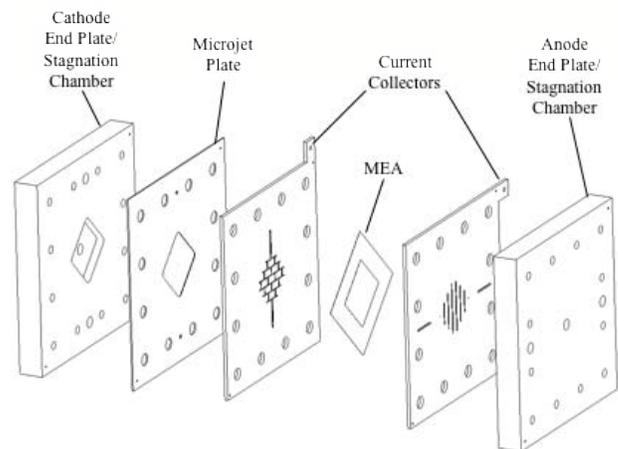

Figure 2. Exploded view of the component parts of the microjet-based fuel cell discussed here.

to heat transfer when they impinge on the collector plate. During this process, the portion of the plate that is impinged upon is brought to the recovery temperature of the microjet, which is very close to the stagnation temperature of the flow. This effect is best characterized by the Nusselt number, Nu, which is a ratio of the conductive and convective properties of a moving fluid. The benefit to this approach becomes significant when the stagnation temperature is much lower than the stack temperature.

Presented in this paper are the experimental results obtained using a single prototype fuel cell that was designed and fabricated based on the microjet-based delivery method put forth
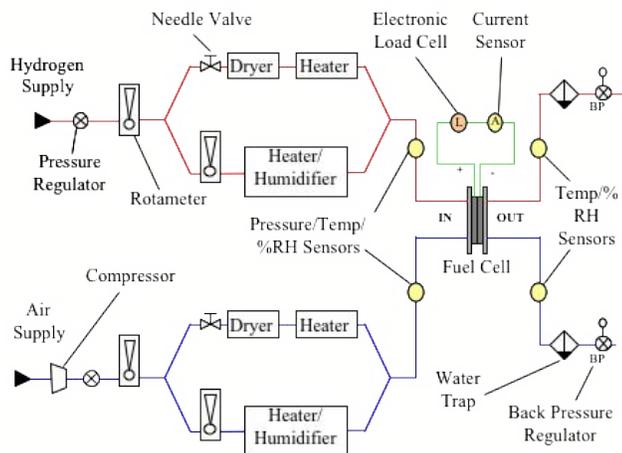
Figure 3. Schematic of the reactant gas flow through the fuel cell test station at SESEC.

above. The temperature, relative humidity and back pressure of the supply air were varied so as to characterize the properties of this cell. These results were compared to those obtained using similar operating conditions with a commercially available fuel cell that utilized serpentine flow paths.

EXPERIMENTAL APPARATUS & PROCEDURE

The experiments discussed here were conducted using the fuel cell test station that was built in-house at SESEC. This test station is capable of handling a single fuel cell and it allows the user to control the pressure, mass flow, and conditions (i.e. temperature, and relative humidity) of the reactant gasses as they are fed to the fuel cell, as illustrated by Figure 3. It also allows for monitoring of the voltage and current generated by the fuel cell at various loads, as well as the conditions of the reactant gases as they exit the fuel cell. A brief discussion of the features of this test station will be presented here but an in-depth discussion can be found in Reference [4].

Paramount to the accurate testing of PEM fuel cells is the ability to control the temperature and relative humidity of the reactant gases. The test station discussed here controls these two parameters using a divided flow humidifier arrangement, as shown in Figure 3. In this arrangement, the flow is divided into two streams; one of which is dried through the use of silica gel and Zeolite molecular sieves and the the other of which is fully humidified through the use of a purified water bubbler. The two streams are then recombined and mixed to achieve the desired relative humidity. Controlling the proportion of dry to humidified gas allows for precise control of the final relative humidity that will be supplied to the fuel cell. Within the divided flow humidifier, both the dry and humidified streams are heated in order

to achieve the desired temperature. Sensors are set up to monitor the temperature, relative humidity, and pressure of each reactant gas as it enters and exits the fuel cell. Worthy of note is that the temperature of the reactant streams in the test station was limited to $40\,^\circ C$ due to the relative humidity sensors that were in use.

The test station is equipped with a custom-built 100W electronic load that is capable of handling currents up to 10A. This electronic load can operate in either constant current or constant voltage mode, but for the experiments discussed here it was only operated in constant current mode. The load current was set using an analog input signal, which was varied in order to obtain the polarization curve of the fuel cell. The actual current flowing through the load was measured through use of a Hall effect current sensor.

The commercial fuel cell that was utilized for comparison purposes was the EcoFC-1AM, which has a nominal peak power of 3.2W at 0.6V. The reactants in this single cell flow through the double serpentine flow path that is set in each of the polymer-graphite composite monopolar plates. The MEA for this fuel cell consists of a Nafion N-212 membrane that has a platinum catalyst loading of about 0.8 mg/cm^2 on the cathode side and about 0.5 mg/cm^2 on the anode side. A carbon cloth gas diffusion layer completes the MEA. The active area of the MEA is about 14.5 cm^2 while the total area of the membrane is about 36 cm^2. Since the primary goal of the experiments discussed here was to determine the effectiveness of the microjet delivery method, as compared to the more conventional approach, the microjet-based fuel cell was designed based on using an MEA similar to the one employed by the EcoFC-1AM.

RESULTS

The first generation fuel cell that was designed and built based on the microjet delivery appeared to have lower activation losses than the commercial serpentine unit. However, it exhibited significantly higher ohmic losses that were attributed to the manner in which the current collectors were placed in contact with the membrane, as well as the choice of collector material and external connections. These factors were taken into consideration during the design of the second generation cell. The results discussed here are those that have been obtained through the use of the second generation microjet delivery fuel cell.

Shown in Figure 4 are the results that were obtained when the supply to back pressure ratio, relative humidity and reactant flow rates through the microjet-based fuel cell (MJFC) were set equivalent to the optimal values used for the EcoFC-1AM fuel cell (EcoFC). For the air flow these values were 1.03, 85% and 650 sccm, respectively, and for the hydrogen flow they were 1.00, 85% and 80 sccm, respectively. Included in the figure are the results obtained for the EcoFC at these conditions. The successive tests in the figure are indicative of the results that were obtained as the testing progressed. At the conclusion of these tests the
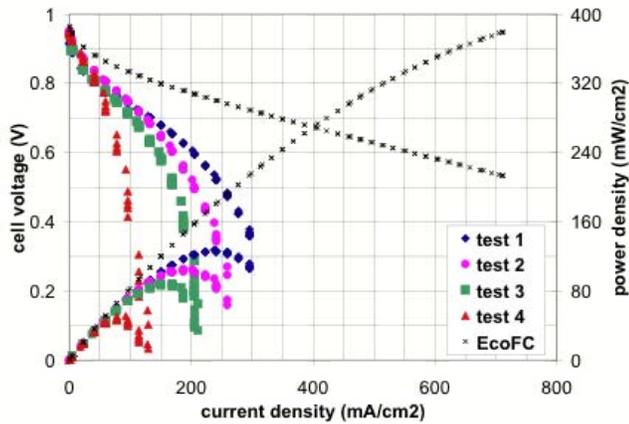
Figure 4. Performance of the MJFC operating at the same reactant flow rates as the EcoFC.
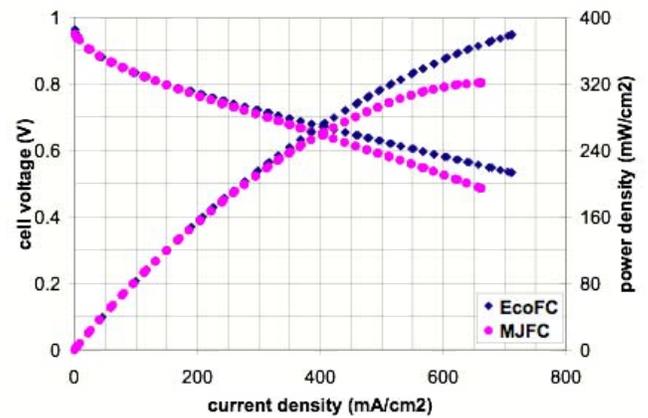

Figure 5. Comparison of the performance of the MJFC and EcoFC operating at optimal supply to back pressure ratio and relative humidity conditions. The stack temperature for both fuel cells varied from 34-38 $^\circ C$.

MJFC was disassembled and it was discovered that water had formed at the contact points between the MEA and the anode and cathode, thus providing an explanation for the increasing ohmic and concentration losses.

While the results shown in Figure 4 are less than favorable for the MJFC, it is important to note that this fuel cell was designed to operate at higher air supply pressures. Shown in Figure 5 are the results that were obtained when the supply to back pressure ratio of the air flow was increased from 1.03 to 4.94 for the MJFC, thus increasing the flow rate to 11.1 slpm, while the hydrogen flow rate was stagnated. Also, the relative humidity for both of the reactant gases was set at 85% for the EcoFC and it was set at 18% for the MJFC. Here it can be seen that the peak power density of the MJFC is about 320 mW/cm^2, which is less than that observed for the EcoFC (380 mW/cm^2). In this case neither of the reactant gases was heated prior to flowing into either of the fuel cells and the stack temperature, taken as the air output temperature, for both of the fuel cells varied from 34-38 $^\circ C$. This lower than usual temperature is attributed to the fact that each of the fuel cells serves as a large thermal mass relative to the small active area of the MEA. Heating the flow would help to counteract this effect but, due to the facility limitations discussed above, the maximum attainable supply temperature was 40 $^\circ C$ and although an increase in performance was observed, it was considered to be negligible for the purposes of presentation here.

The results shown in Figure 5 illustrate that the MJFC has higher ohmic losses than the EcoFC above a current density of 200 mA/cm^2. This suggests that there is still room for improvement in the MJFC regarding the manner in which the current collector is placed in contact with the MEA. Also, the lower activation losses mentioned above for the MJFC can be seen in Figure 6, which corresponds to the range from 0 to 100 mA/cm^2
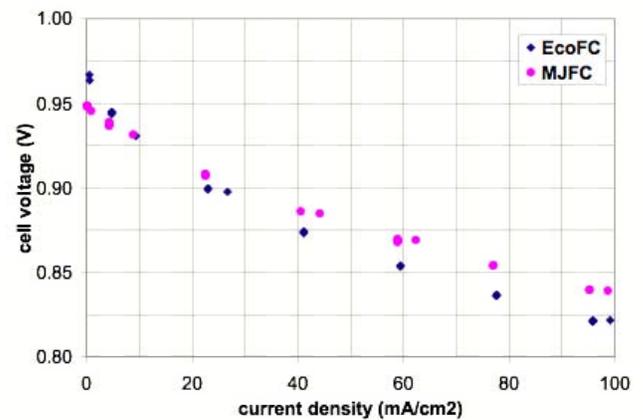

Figure 6. The activation losses for the results shown in Figure 5.

in Figure 5.

Of significance to the operation of a PEM fuel cell is the effect of varying the relative humidity of the air that is supplied to the fuel cells. For these experiments the reactant gases were again unheated so that a stack temperature of 34-38 $^\circ C$ was obtained for both fuel cells. For comparison purposes, both fuel cells were operated at an increased air supply to back pressure ratio of 3.72, resulting in an air flow rate of 13.9 slpm for the EcoFC and 8.1 slpm for the MJFC. The hydrogen flow for both fuel cells was humidified to 18% and subsequently stagnated in each fuel cell. Shown in Figure 7 are the results that were obtained for the EcoFC at two extreme relative humidities. The observed effect of increasing performance with increasing relative humidity is what one would typically expect to observe for
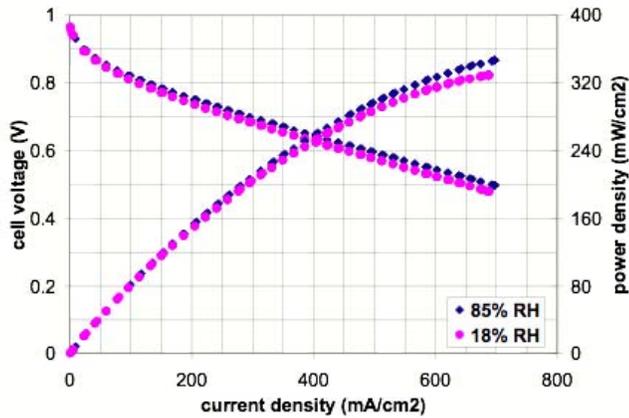
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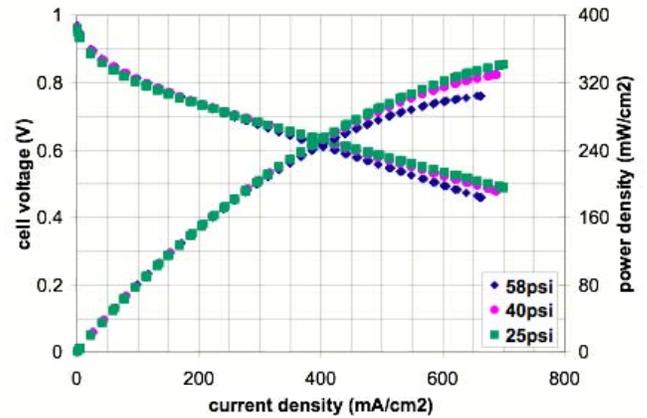Figure 7. The effects of the air supply relative humidity on the performance of the EcoFC.

Figure 9. The effects of varying the supply pressure of the air on the performance of the EcoFC.
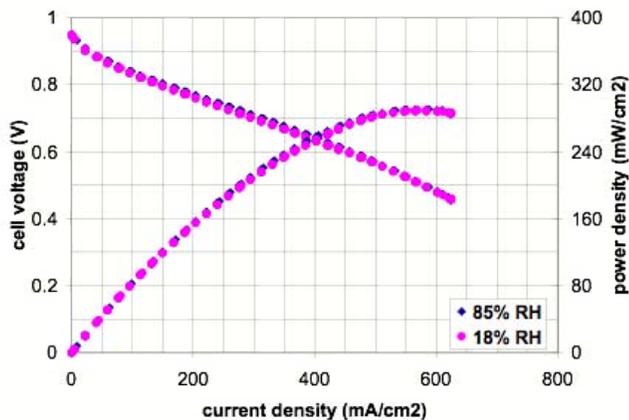

Figure 8. The effects of the air supply relative humidity on the performance of the MJFC.

a PEM fuel cell. The results for the MJFC, at similar relative humidities, can be found in Figure 8. Here it can be seen that the performance of the fuel cell appears to be independent of the relative humidity. These results suggest that the MJFC is capable of operating in environmental conditions where typical PEM fuel cells underperform.

The final parameter discussed here is the effect that varying the inlet pressure of the air has on the performance of each of the fuel cells. It may seem more appropriate to discuss the effects of varying the back pressure but the MJFC is unaffected by back pressure above an inlet to back pressure ratio of 1.89. As such, it was decided that a more appropriate approach would be to maintain the back pressure at atmospheric pressure and subsequently increase the supply pressure. The increased air supply

pressures resulted in air flow rates ranging from 9.2 - 20 slpm for the EcoFC and 5.0 - 11.1 slpm for the MJFC. The operating conditions for these experiments involved a stack temperature that varied from 34-38 $^\circ C$ and relative humidity values of 18% for both of the reactant flows in both of the fuel cells. Figure 9 are the effects that were observed for the EcoFC. The loss of performance with the increase in supply pressure is expected due to the fact that the increased pressure means that the air entering the flow path will be highly turbulent and it will also spend less time in the flow path, thusly it will have less time to react on the MEA. Figure 10 illustrates that the increase in supply pressure has a positive effect on the MJFC. This can be attributed to the fact that, although the flow is choked at sonic conditions, more mass flow is being provided to the MEA as it is a function of the supply pressure.

CONCLUSIONS

In this paper, we have presented a microjet-based reactant delivery method for PEM fuel cells. Based on this delivery method, a prototype fuel cell was built and tested. A comparably sized commercial fuel cell, which utilized the commonly used serpentine flow path reactant delivery method, was procured and used to obtain results for comparison purposes. Based on the results presented here, it appears that, unlike the conventional fuel cell, the microjet-based fuel cell is relatively unaffected by the relative humidity of the air stream and it is positively affected by an increase in the supply pressure. This suggests that this delivery method may be amenable for use in a low cost PEM fuel cell. Of note is that these results were obtained through the use of a prototype for which there has been only one design revision. Based on these results, it is anticipated that future design revisions will result in improved performance.
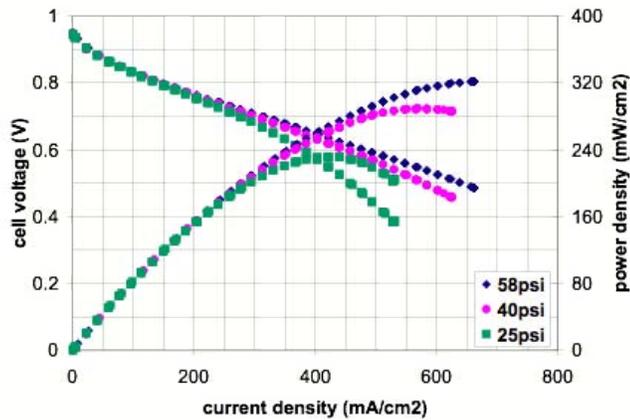
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Figure 10. The effects of varying the supply pressure of the air on the performance of the MJFC.

REFERENCES

[1] Steele, B., and Heinzel, A., 2001. "Materials for fuel-cell technologies". *Nature,* **414**, pp. 345–352.

[2] Murphy, O., Cisar, A., and Clarke, E., 1998. "Low-cost light weight high power density PEM fuel cell stack". *Electrochimica Acta,* **43**, pp. 3829–3840.

[3] Wind, J., Spah, R., Kaiser, W., and Bohm, G., 2002. "Metallic bipolar plates for PEM fuel cells". *Journal of Power Sources,* **105**, pp. 256–260.

[4] DeRoche, P., 2008. "A microjet-based reactant delivery method for PEM fuel cells". Master's thesis, Florida State University.