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TESTING AND EVALUATION OF ALUMINUM COATED BIPOLAR PLATES OF PEM FUEL CELLS OPERATING AT 70° C

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ABSTRACT

Corrosion resistant metal treated bipolar plates with higher rigidity and electrical conductivity than graphite were developed and tested for PEM fuel cell applications. Six replicas of single cells were fabricated; two of graphite composites bipolar plates and the other four plates were coated aluminum. Two different high corrosion resistant coatings were used in this study and were applied to each pair of the metallic plates. An E-TEK Series 14-W MEA with carbon cloth GDL, thickness of Nafion <50 microns, <1mg/cm^2 total platinum content (anode & cathode) and 6.45 cm^2 active electrode areas, was fitted to each cell and operated under identical conditions. The obtained data from the two graphite cells were averaged and plotted and the other aluminum cells' data were similarly treated and plotted on the same graph for comparison. Generally, the metallic treated bipolar plate provided at least a 22% savings in hydrogen consumption in comparison to graphite. This is attributed to the lower bulk and surface contact resistance of the coated aluminum plates used in this study in relation to graphite. The results of the lifetime testing conducted at temperature of 70^o C under loading condition ranging from 0 to 0.6 W that showed no indication of power degradation due to metal corrosion for at least 60 hours.

INTRODUCTION

The economics of the proton exchange membrane (PEM) fuel cell, similar to many other energy producing systems, relies heavily on the fixed and running costs of the unit. Clearly, the efficiency of any power generating system directly affects its running costs. One of the major advantages of the PEM fuel cell is that it can attain high efficiency since it is not limited by the Carnot cycle. On average, the efficiency of the PEM fuel cell is about 20–30% higher than that of fossil fuels such as oil, natural gas and coal [1]. The efficiency of the fuel cell power system is a product of the efficiencies of its main energy parasite components such as air/oxygen compressor, temperature and humidity control system, etc. [2].

The cost of fuel cell components' price and durability are important issues that need to be dealt with, especially when we compare the cost of electricity generated by PEM fuel cells with that generated by conventional power plants using fossil fuels. In addition, for PEM fuel cells to be able to compete with the currently available power systems fuel cell cost must be reduced, at least, five fold. On the other hand, the cost of hydrogen currently ranges between US$10 and 20/GJ [3], which is not as competitive as fossil fuel in the energy market. However, the cost of hydrogen is expected to decrease in the near future as the research and development efforts focus on the production, storage and transportation of hydrogen at a more economical rate [4][5]. Meanwhile, the cost of conventional fossil fuel is steadily escalating due to the instability in the Middle East, future expected scarcity and additional environmental taxes imposed. Taking these expectations into account, the costs of both hydrogen and fossil fuel are predicted to merge by the year 2030 at a rate of US$6.2/GJ. Then, these costs are expected to diverge with a further decrease in the hydrogen cost and a further increase in the fossil fuel cost [6].

A literature review on fuel cell efficiency indicates that most studies have dealt with energy analysis of PEM fuel cell systems with varying degrees of co-generation [7-12]. Some other articles have focused on the economic aspects of the fuel cell used in various applications [13-17]. Barbir and Gomez [18] described the interrelation of the fuel cell economics with its operating efficiency. They analyzed the efficiency and economics of a 10 kW DC power PEM fuel cell with an active area of 780 cm^2 developed by Energy Partners Inc. in terms of various load profiles and cost scenarios [19]. However, they found that it is extremely important to determine an operating efficiency range where the fuel cell is technically and economically viable. In other words, there is a fuel cell efficiency range where the annual fuel cost and the electricity cost will not be significantly affected by any major variations in the fuel cell efficiency. Therefore, the current study focused on a comparison between the effects of coated aluminum and graphite bipolar plates on hydrogen consumption, fuel cell efficiency and durability over wide range of power density output.

EXPERIMENTAL WORK

The experimental set-up consisted of six fuel cells encompassed in a hydrogen safety enclosure with a negative pressure test station connected to data acquisition system (DASYLab 5.6 software) as shown in Fig. (1). All fuel cells output and operating parameters like current, voltage, and power as well as temperature and reactant gases volume flow rate were recorded by the data acquisition system. The test station provided the reactants (Hydrogen and air) and controlled the electric load while the data acquisition system measured and recorded the information. Both air and hydrogen are regulated by mass flow meters (Type FMA-A2300, Omega). The fuel cells are connected to a programmable electronic load (MCL488 DYNALoad) that was used in increments of constant current mode.

Electrode membrane assemblies, with 6.45 cm^2 active electrode area were loaded into six replicas of single fuel cells. Two of which were fabricated of graphite composites bipolar plates, and the other four cells were made of coated aluminum plates. Two different corrosion resistant coatings were tested in this study. Each coating was applied to a pair of aluminum plates.

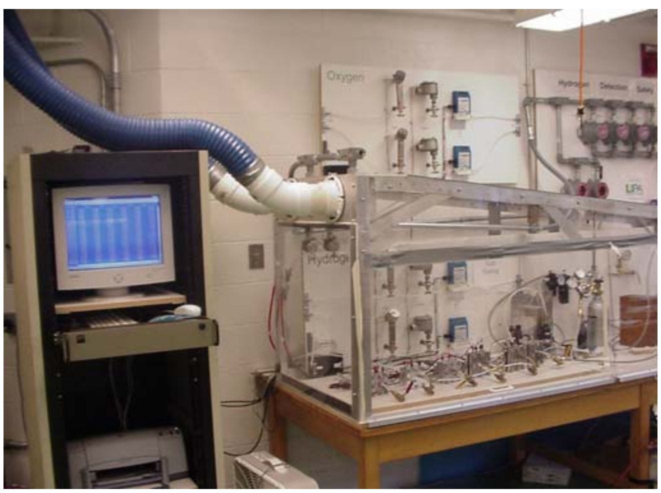

Fig. (1) Fuel Cell Testing Station

All cells were operated under identical conditions of controlled temperature at 70^o C (158^o F), relative humidity at 95%, airflow rate of 470 SCCM (8 SCFH) with back pressure of 0.52 Bars (7.5 psig), and hydrogen pressure of 0.69 Bars (10 psig). The hydrogen was dead-ended at the exhaust manifold for all cells. The obtained data from the two graphite cells were averaged and plotted and other four metal cells data were similarly treated and plotted on the same graph for comparison. Each single cell text fixture consisted of two bipolar plates that contained a serpentine of rib channel patterns to allow the passage of hydrogen and air to the anode and cathode, respectively. The Electrode Membrane Assemblies (MEAs) were acquired from (E-TEK, DeNora.), with double-sided Electrodes, Series 14-W MEA with carbon cloth GDL, thickness of Nafion <50 microns, <1mg/cm^2 total platinum content (anode & cathode) and 6.45 cm^2 active electrode areas was used in this study. The fuel cell operated with ambient air obtained from an industrial compressor and dry industrial grade hydrogen supplied by a metal hydride storage tank.

RESULTS AND DISCUSSION

The experimental results obtained from the two graphite plates were averaged and plotted in one single plot and labeled "graphite" as shown in the following figures. Also, each pair of aluminum bipolar plates, similarly coated, were averaged, plotted, and labeled as Metal 1 and Metal 2.

Figure 2 shows the average polarization and power density curves for each of the two pairs of single aluminum fuel cells. Each pair of the aluminum bipolar plates was coated with a similar material. Also, the results obtained from the third pair of single fuel cells made of composite graphite were averaged and plotted. The results exhibited better performance of the aluminum coated bipolar plate in comparison with the graphite. For example, at a 200 mA/cm^2 current density the cell voltage outputs were 0.70 and 0.55 volt for treated metal and composite graphite bipolar plate, respectively. Also, Figure 2 depicts that the maximum average output power density was 0.32 and 0.14 W/cm^2 for treated metal and composite graphite, respectively. This is attributed to the lower bulk and contact resistances of metal bipolar plate compared to graphite. Moreover, it was found that the graphite cell resistance is approximately 2.5 times higher then the metallic cell under the same operating conditions.

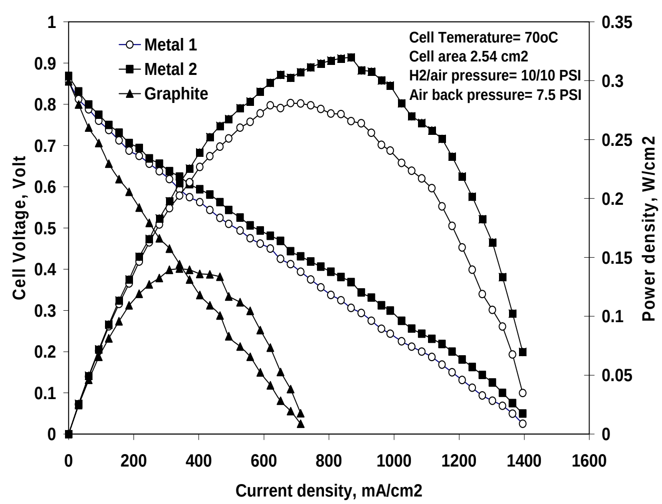

Fig. (2) Polarization Curve and Power Curves - After 30 hours of operation at 70^o C

Figure 3 exhibits the distribution of power density and hydrogen consumption per watt vs. current density for both coated metal and composite graphite bipolar plates. The results showed that the hydrogen consumption per watt using metal bipolar plate is lower than graphite. For example, the hydrogen consumption per watt at a current density of 200 mA/cm^2; was

10.4 and 13.1 SCCM/W when coated metal and composite graphite were used as bipolar plates respectively.

Preliminary experimental results measured at IRTT showed at least 22 % savings in hydrogen consumption because of the lower bulk and contact resistance of metal than graphite. A simple cost analysis of electric energy losses as heat due to the bulk resistance of aluminum and graphite showed that aluminum bipolar plates save electric energy from converting to heat in the amount of $1,060 per year for a 500 kW unit.

The power density and fuel cell average efficiency distributions for comparing metal and graphite bipolar plate performances at different levels of current density are depicted in Fig. 4. The figure shows that the efficiency of the fuel cell using treated aluminum is higher than graphite. For example, the efficiency of fuel cell at 200 mA/cm2 was 58% and 45 % when using metal and composite graphite as bipolar plate, respectively.

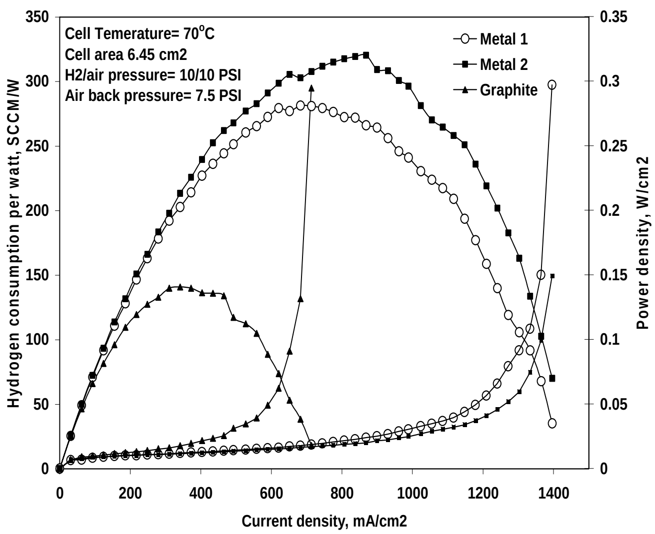

Fig. (3) Hydrogen consumption and Power Curves - After 30 hours of operation at 70o C

The six fuel cells were tested under the same operating conditions and each cell powered the exact variable loading. The metallic bipolar plates performed at 70o C for approximately 60 hrs without a sign of power degradation due to corrosion. The average output power of each pair of aluminum fuel cells with similar corrosion resistant coating were averaged and plotted in Fig 6. Similarly, the other two graphite fuel cells were average and statistically treated and plotted on the same graph for comparison.

The parallel and very similar performance trends of graphite and coated aluminum provide a clear proof that no power degradation was caused by metal corrosion. Graphite is known to be non-corrosive and therefore it can be used as a reference of comparison.

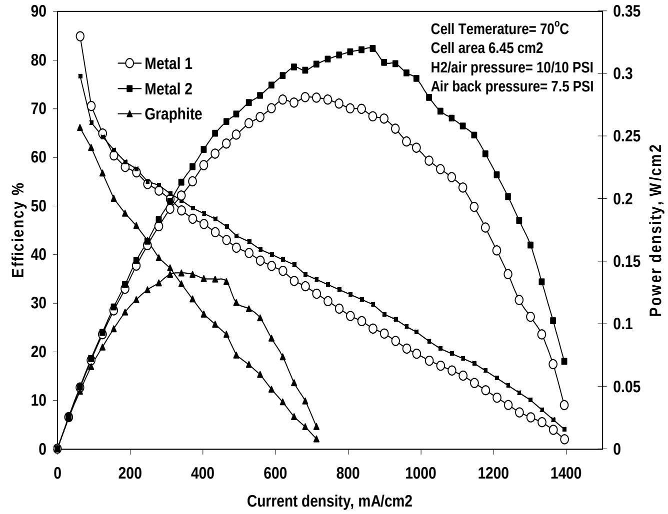

Fig. (4) Efficiency and Power Curves - After 30 hours of operation at 70o C

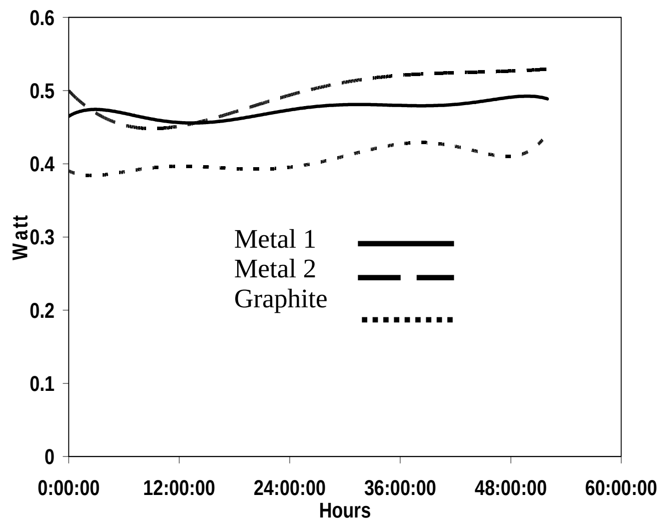

Fig. (5) Life time test of two coated aluminum bipolar plates with corrosion resistant coatings 1&2 and one graphite bipolar plate operated under cyclic loading at 70° C

In this study, industrial hydrogen and oxidant air were used. Air was provided by industrial compressors. Oil, particles and impurities were not effectively filtered from the industrial compressors and hydrogen tanks before feeding the fuel cells. This did not cause any fouling of the MEA or any power degradation as could be observed in Figure 5. Also there is no sign of corrosion on the metallic bipolar plate after 60 hours operation as depicted in Figure 6.

CONCLUSIONS

The results shown above indicate that treated metal bipolar plates can be used in PEM fuel cells because they have a higher performance than graphite. Aluminum coated bipolar plates showed a 22% saving in hydrogen consumption, higher efficiency and durability in relation to graphite. The coated aluminum bipolar plates performed for approximately 60 hrs at 70o C without any sign of power degradation due to corrosion.

However, accelerated corrosion testing needs to be conducted and longer duration for the lifetime testing is required to confirm the durability and efficiency of both MEA and bipolar plates.

In addition, metallic bipolar plates are noted for their ductility and lack of brittleness that plagues the graphite plates and causes cracking and mechanical failure under the stack tightening force. Accordingly, metallic plates are deemed safer, more robust and more reliable than the graphite plates.

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REFERENCES

[1] Gillet, 1999, “From water to water. Hydrogen as a renewable energy vector for the future.” In: World Renewable Energy Congress ’99; Malaysia, pp. 513–517.

[2] Barbir, 2000, “Recent progress and remaining technical issues in PEM fuel cell development.” In: Proceedings of 13th World Hydrogen Energy Conference; Beijing, People’s Republic of China, pp. 173–180.

[3] Ayoub, 2002, “A novel approach on the determination of the minimal operating efficiency of a PEM fuel cell,” Renewable Energy, Vol. 26, pp. 479–488.

[4] Abdallah et al, 1999, “Solar–hydrogen energy system for Egypt.” Int J Hydrogen Energy, **24**, pp. 505–517.

[5] Bockris, 2002 "The origin of ideas on a Hydrogen Economy and its solution to the decay of the environment,” International Journal of Hydrogen Energy, Vol 27, Issues 7-8, Pages 731-740.

[6] Tawfik, H., " Preparing Technologists for the Hydrogen Economy", ASEE Conference, North Carolina, 2005 (Accepted for Publication)

[7] Rosen and Scott, 1987, “An energy–exergy analysis of the koppers-totzek process for producing hydrogen from coal.” Int J Hydrogen Energy, **12**, pp. 837–845.

[8] Morehouse, 1988, “Thermally regenerative hydrogen/ oxygen fuel cell power cycles.” J Solar Energy Eng, **110**, pp. 107–112.

[9] Oosterkamp et al, 1993, “Review of an energy and energy analysis of a fuel cell system.” J Power Sources, **41**, pp. 239–252.

[10] Barbir, 1996, “Control strategy of a vehicular fuel cell power system.” In: Proceedings of 11th World Hydrogen Energy Conference; Stuttgart, Germany, pp. 1695–1705.

[11] Hung et al, 2004, “Corrosion Resistant, Lightweight, and Inexpensive Metallic Bipolar plates with excellent manufacturability for PEM Fuel Cell power systems”, ASME – RIT 2nd International Conference on Fuel Cell Science, Engineering and Technology, Rochester, NY.

[12] Hung, Y., and Tawfik, H., 2001, “Electrical Conductivity of Bipolar Plate Materials for Proton Exchange Membrane (PEM) Fuel Cells”, The 5th International Conference on Engineering Design & Automation, Las Vegas.

[13] Robertson, 1973, “Optimization of use of surplus night electricity in electrochemical processes.” Electrochem Acta, Vol. 18, pp. 897–906.

[14] Newman, 1979, “Optimization of potential and hydrogen utilization in an acid fuel cell. Electrochem Acta. Vol. 24, pp. 223–229.

[15] Vezirog¡lu, 1990, “Hydrogen energy system: application and economics.” Report from Clean Energy Research Institute, University of Miami, Coral Gables, FL.

[16] Teagan et al, 1998, “Cost reduction of fuel cells for transport applications: fuel processing options.” J Power Sources, **71**, pp. 80–85.

[17] Tawfik, H., 2000, “Proton Exchange Membrane (PEM) Fuel Cell Design and Development a “Capstone” Course Case Study, 4th International Conference on Engineering Design and Automation, The Peabody Hotel, Orlando, Florida.

[18] Barbir and Gomez, 1996, “Efficiency and economics of proton exchange membrane (PEM) fuel cells.” Int J Hydrogen Energy, **21**, pp. 891–901.

[19] Barbir, 1995, “Progress in pem fuel cell system development.” In: Yurum Y. (Ed), Hydrogen energy system, NATO ASI Ser. E., Vol. 295, pp. 203–213.