Construction and Preliminary Testing of a Direct Water Methanol Fuel Cell

Dawson Plummer
Department of Civil & Mechanical Engineering
United States Military Academy
West point, New York

ARL Sponsor: Dr. Deryn Chu and Rungzung Chung
Research Scientist
U.S. Army Research Laboratory
Adelphi, Maryland

1 Executive Summary

Direct Water Methanol Fuel Cell technology is a hydrogen fuel cell which utilizes the chemical reactions between methanol, water, platinum, and ruthenium to create electricity. The recent advances in fuel cell technology and the increasing need for alternative power have attracted interests at the national level. Research in conceptual designs and applications of using fuel cell technology in vehicles, generators, and power plants has increased over the past 10 years. As ideas for different kinds of fuel cell applications increase, so does the types of fuel cells. Although there are many types of fuel cells, the three most popular are: alkaline fuel cells which are primarily used for space applications, solid oxide fuel cells which are primarily used for large scale power plants, and proton exchange membrane (PEM) hydrogen fuel cells which are primarily used for medium to small scale generators as well as automotive applications. The purpose of this study is to explain how to construct a water methanol fuel cell, graphically display the output parameters, and discuss some of the possible present and future applications.

2 Introduction

A Direct water methanol fuel cell is a type of PEM hydrogen fuel cell that can generate electro-chemical energy by some very basic chemical reactions within the membrane of the cell. The basic components of the methanol fuel cell consist of an outer casing that can be configured for a water tight seal, perforated titanium plates with a Teflon coating around the edges, a membrane consisting of an anode and cathode, and electrical wire that is connected to each titanium plate that covers the anode and cathode sides.

2.1 Chemical Reactions

Methanol is a carbonaceous fuel which, at low temperatures, can quickly provide a large amount of electrochemical reactions when mixed with oxygen. The products at the completion of this chemical reaction are water, carbon dioxide, direct voltage (D.C.), and current. Due to the corrosiveness of methanol, non-corrosive materials such as titanium, Teflon, and polymers were used in the construction of the fuel cell and storage of the methanol. The chemical reactions utilizing oxygen and methanol when introduced to the fuel cell are:

Anode: $$CH_3OH + H_2O \longrightarrow CO_2 + 6H^+ + 6e^- \quad (2.1)$$

Cathode: $$3/2\ O_2 + 6H^+ + 6e^- \longrightarrow 3H_2O \quad (2.2)$$

Overall Reaction: $$CH_3OH + 3/2\ O_2 \longrightarrow CO_2 + 2H_2O \quad (2.3)$$

Direct hydrogen PEM fuel cells are slightly similar to the methanol fuel cell. Although both fuel cells use oxygen as an oxidant and involve hydrogen, only the direct hydrogen fuel cell can take pure hydrogen in its gaseous state and convert it to electrochemical energy. The chemical reactions are:

Anode: $$H_2 \longrightarrow 2H^+ + 2e^- \quad (2.4)$$

Cathode: $$1/2\ O_2 + 2H^+ + 2e^- \longrightarrow H_2O \quad (2.5)$$

Overall Reaction: $$H_2 + 1/2\ O_2 \longrightarrow H_2O \quad (2.6)$$

3 Construction

The most common assembly at the research lab is the two cell stack; however, four cell and six cell arrangements have been constructed upon request. Currently the United States Military Academy Fuel Cell Lab is capable of constructing the direct water methanol fuel cell excluding the membrane electrode assembly (MEA).

3.1 Process

The fuel used in this particular type of fuel cell is water and methanol. The percentage of water versus methanol can range from 90% water and 10% methanol to 80% water and 20% methanol by volume. The equipment and materials needed for fuel cell construction are:

1. Teflon paper
2. Nafion polymer
3. Platinum
4. Ruthenium
5. Alcohol
6. Carbon gas diffusion material
7. Distilled water
8. Temperature regulated press
9. Temperature regulated vacuum
10. Plexiglas
11. Titanium mesh or Graphite mesh

The construction of the MEA begins by cutting two 3cm by 3cm pieces of Teflon paper. This is the working surface of the platinum (Pt) and platinum ruthenium (PT-Ru) which are the primary elements that make up the MEA. The platinum and platinum ruthenium solutions are created by mixing with distilled water, a nafion polymer dissolved in alcohol and then mixed with approximately 93% platinum or 95% platinum ruthenium. We recommend that the following steps be performed in the order exactly as stated:

1. Weigh and record each Teflon square and set them on top of a heating element which is less than 100°F.
2. Coat one Teflon square with platinum black ink solution (Pt) until the Teflon surface can no longer be seen.
3. Coat the second Teflon square with platinum ruthenium black ink solution (PT-Ru) until the Teflon surface can no longer be seen.
4. After the solutions dry on the Teflon, both Teflon squares should be at least 4 milligrams heavier.
5. Cut one 10 x 10 cm nafion (117) polymer square and dry it for 40 minutes in a temperature controlled vacuum press at 60°C.
6. Place the two Teflon squares on each side of the nafion polymer(coated sides are face down on polymer) and immediately place under a heated press until the temperature and pressure increase to 257°F and 500psi, wait one minute and remove.
7. Pull the Teflon squares slowly away from the nafion, the platinum and platinum ruthenium sides should stay on the nafion. Immediately immerse into distilled water then remove.
8. Label the Platinum side of the MEA as O_2 then cut two 3x3cm sections of a carbon gas diffusion layer material, cover each coated side of the MEA and place under the heated pressing machine until the temperature and pressure increase to 257°F and 500psi, wait one minute and remove.
9. MEA construct is now complete; non corrosive materials such as titanium or graphite can be used to secure the MEA in the cell housing and is the medium that will transmit the D.C. voltage created by the chemical reactions around the membrane.
10. Fabricate the cell housing by using plexiglas, glass, or any non corrosive water impermeable material.
11. Test the fuel cell by using 10-20% methanol water solutions.

If the methanol solution is greater than 20% then the chemical reactions will not increase and large quantities of methanol would cross over to the oxidation side and damage the nafion polymer within the MEA.

4 Results and Conclusion

Although preliminary testing was performed at the Army Research Lab in Adelphi Maryland, the majority of resistance, current, and voltage testing were performed at the United States Military Academy's Department of Civil and Mechanical Engineering Fuel Cell Lab. Results are as follows:

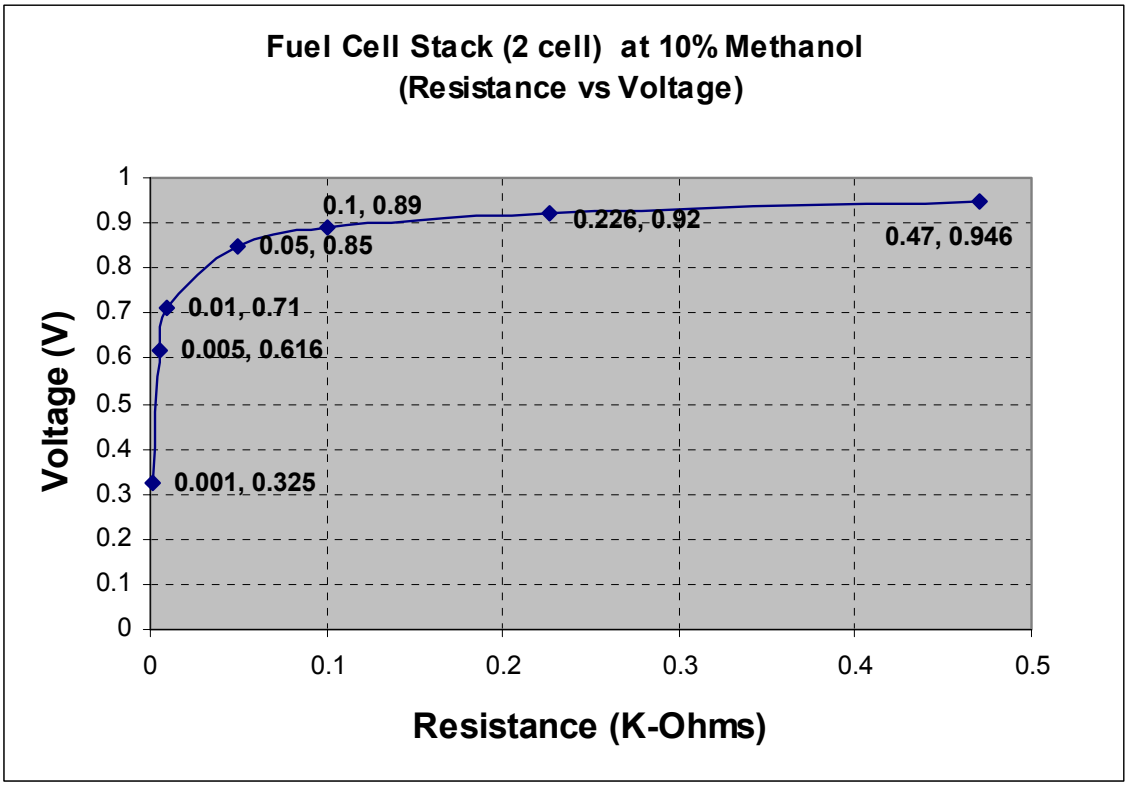

Figure 1. Two Cell Stack utilizing 10% water methanol solution as a fuel

Figure 1 is the primary configuration of this study in which the ideal fuel source of 10% methanol is used and the output voltage measured while varying resistance. These results indicate that this particular cell can produce nearly 1 volt DC at 470 ohms and 1 amp at 0.33 volts DC.

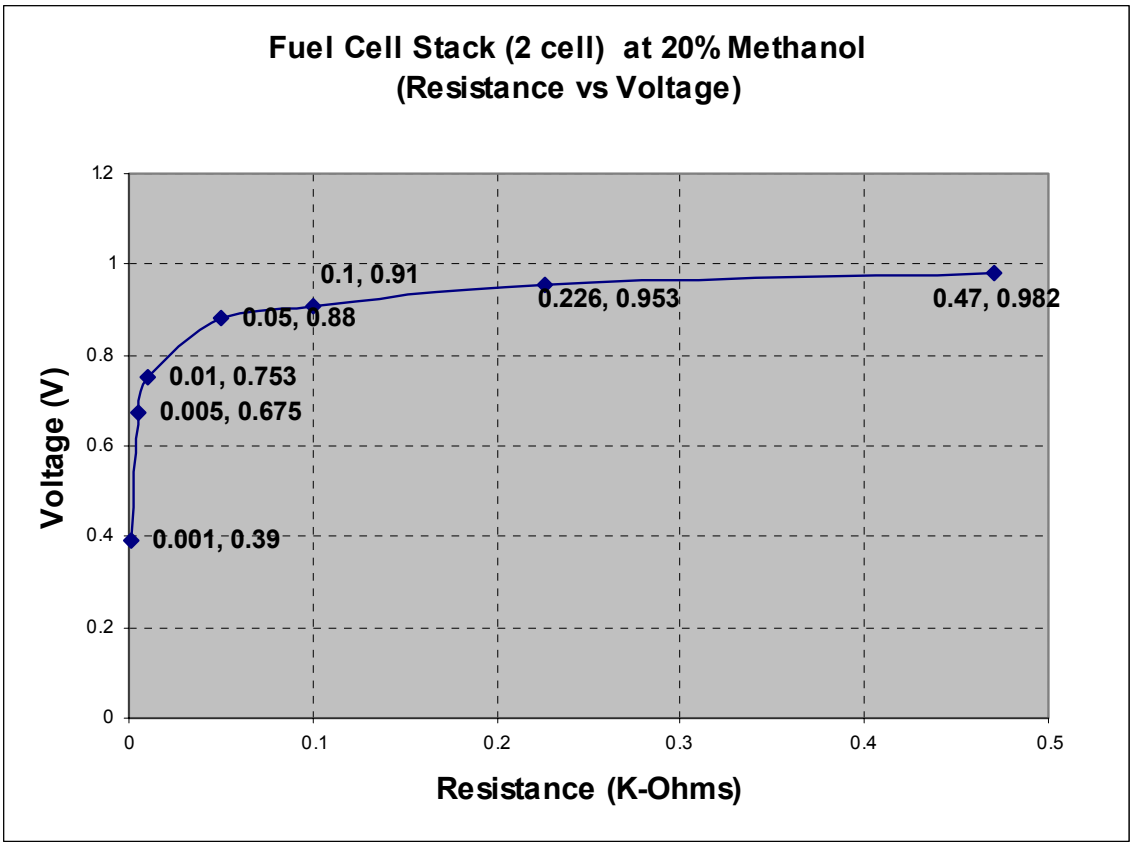

Figure 2. Two Cell Stack utilizing 20% water methanol solution as a fuel

Figure 2 is the same configuration as figure 1, but the ideal fuel source of 20% methanol is used. These results indicate that this particular cell can produce nearly 1 volt DC at 470 ohms and 1 amp at nearly 0.4 volts DC. The 20% methanol solution results in approximately a 3% increase in voltage and power as compared with the 10% methanol solution.

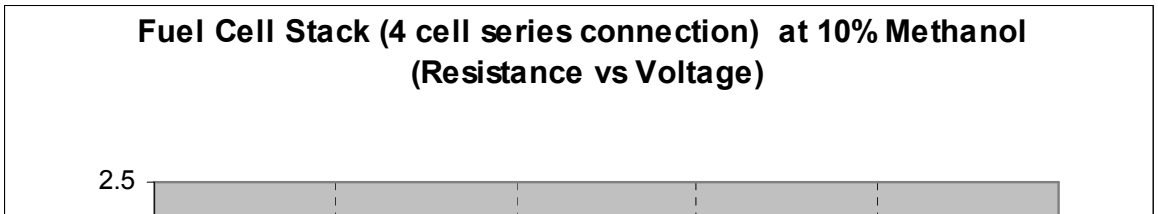

Figure 3. Four Cell Stack in series connection utilizing 10% water methanol solution as a fuel

Figure 3 exhibit the same trend as the results in to figure 1. The peak output is nearly double that of the two cell systems. At a 1 ohm resistance the fuel cell begins to become slightly unstable, causing the water methanol solution to heat and bubble up. This instability causes the membrane to continually clear itself of the ions created and will eventually damage the cell if left for an extended period of time. Initial perceptions were that in a series connection, more current can be produced; however, the increase was not as expected due to the chemical reactions within the fuel cell. The upper values of figure 3 are very close to a "AA" up to a "D" size battery and can be utilized in nearly the same capacity.

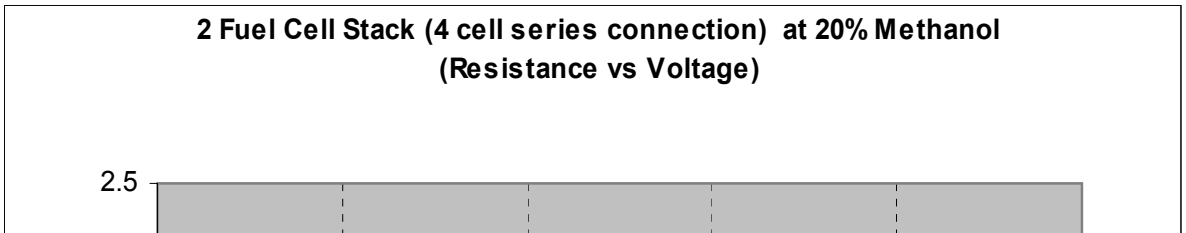

Figure 4. Four Cell Stack in series connection utilizing 20% water methanol solution as a fuel

Figure 4 exhibit the same trend as the results in to figure 2. The peak output is nearly double that of the two cell systems. These results were similar to the comparison made with figures 1 and 3. The fuel cell instability also occurred at 1 ohm in which case the MEA continually cleared itself of the ions created. Also the middle values of figure 4 are also very close to a "AA" up to a "D" size battery and can be utilized in nearly the same capacity. In addition the 20% methanol had 3% greater outputs than the 10% solution. Parallel connections were also performed with the above configuration at 10 and 20% water methanol solutions and yielded similar results.

In conclusion, direct water methanol fuel cell application can currently be used in small scale DC electrical components; however, further studies must be conducted to find a way to counteract either the methanol crossover occurrence with solutions higher than 20% and the chemical reaction that occurs when the heating and bubbling occur at 1 ohm resistance. More studies are needed in construction and configuration in order to power higher current and voltage products which are used today.

References

[1] Boettner, Modeling of PEM Fuel Cell Systems Including Controls and Reforming Effects for Hybrid Automotive Applications, Ohio State University, 2001

[2] Plummer, Wepfer, and Haynes, Investigating the *i*ntegration of a Solid Oxide Fuel Cell and a Gas Turbine System with Coal Gasification Technologies. American Society of Mechanical Engineers Heat Transfer Conference, July 2003.