Performance Optimization of Direct Methanol Fuel Cell

Abstract

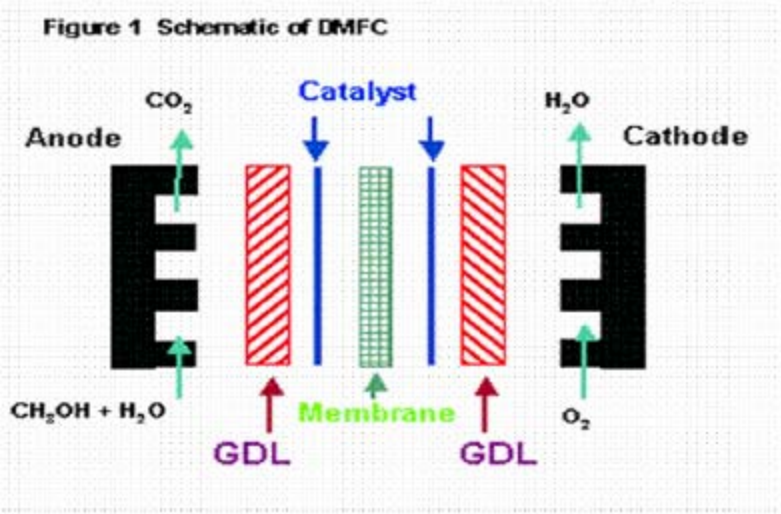
Direct Methanol Fuel Cells (DMFCs) sustain an electrochemical reaction which converts the chemical energy stored in methanol directly into electricity. The main challenge in DMFC technology is that during the reaction, methanol crosses through the nafion membrane, i.e. from the anode to the cathode side, causing losses in electrical potential that leads to lower power output and inefficient fuel consumption. The main goal of the present work is to determine the optimal membrane thickness and operational temperature that will yield the highest current and power densities (CD and PD, respectively). To carry out this experiment, Membrane Electrode Assemblies (MEAs) with similar catalyst loadings and variable nafion membrane thicknesses of N117 (0.177 mm), N115 (0.127 mm) and N212 (0.076 mm) were purchased and utilized. A fuel cell with an active area of 50 cm^2 was assembled and connected to an electronic loading device to record output current, voltage and power. A temperature controlled system was used to set the cell temperature in the range from 20 °C to 70 °C, in 10 °C increments. It was found that at a temperature of 50 °C, MEAs containing N212 and N115 experienced a significant power increase; higher temperatures did provide higher power but were not as significant as the increase from 40 °C to 50 °C. It has also been observed that thinner membranes, at 50 °C and above, provided a greater PD and could achieve higher CD; N212 at 70 °C exceeded the PD and CD of all other tested MEAs. This is an indication that methanol crossover was not the main contributing parameter to power output, as originally thought. The benefits of reaction kinematics at elevated temperatures must have overcome the effects of excess crossover. N212 at 70 °C achieved the highest performance.

Introduction

DMFCs and Hydrogen Fuel Cells (HFC) offer a promising solution to the world's problem of finite energy resources[1-2]. Today's major players in the energy field are petroleum, natural gas, coal and nuclear electric power; renewable energy only accounts for about 7% of the United States energy sources. Possible applications for fuel cells can range from automotive to cellular phones. DMFCs are already being developed to replace lithium batteries as a power source for most handheld and small electronics. Unlike lithium batteries, which take extended time to recharge, a DMFC can be refilled with a water methanol mix to recharge in a relatively short time[3-4]. The design parameters of a fuel cell allow cells to be stacked in series, to achieve the desired current and voltage output. Considering the existing infrastructure for storage and transport of liquid fuel, DMFCs have an advantage over HFCs[5].

Fuel cells are constructed as shown in Fig. 1.
(http://www.eng.wayne.edu/legacy/images/AEImages/DMFC.gif)

On the anode side, the methanol solution is supplied. Air is supplied on the cathode side. The gas diffusion layers (GDLs) are composed of carbon cloth or paper, the MEA consists of a nafion membrane and catalysts on both sides to allow the reaction to occur[6-7].



Many variables affect the DMFCs performance, such as methanol concentration, air and fluid flow rate, temperature and humidity.

It is generally understood that the main issue with DMFCs is the methanol crossover which hinders the FC by creating a mixed potential, which results in lower current and power densities[8-9]. This experiment explores the effects of temperature and membrane thicknesses on power output.

Methods and Materials

A liquid methanol (CH3OH) solution was prepared with a concentration of 5%, diluted with distilled water. Three membranes were purchased, from BCS Fuel Cells, with nafion membrane thicknesses of N117 (0.177 mm), N115 (0.127 mm) and N212 (0.076 mm). These MEAs were installed into a DMFC with an active area of 50 cm^2, graphite bipolar plates and metallic end plates. Air supplied at 15 psi to both the fuel cell and methanol pump, controlled at a rate of 6 SCFH (standard cubic feet per hour) through the FC, as seen in Fig. 2.

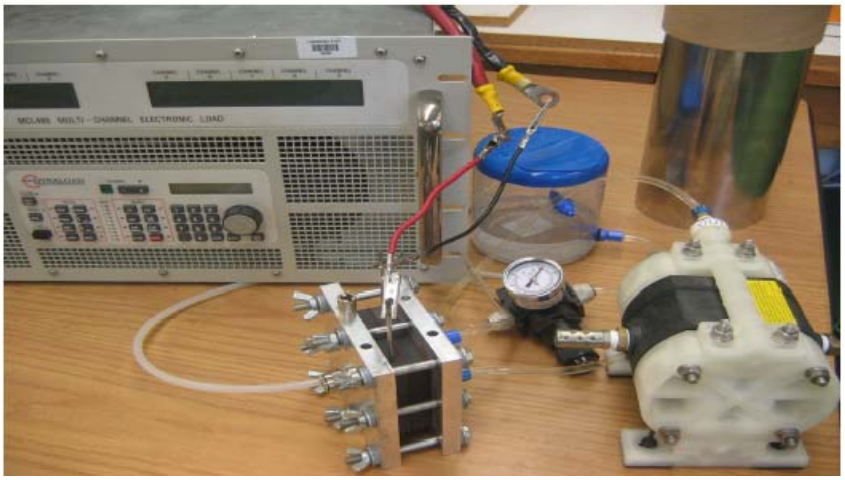


Figure 2 Experimental Setup

The DMFC was connected to an electronic loading device and a temperature control unit. Current loading at 0.2 A increments produced an output voltage that was recorded and plotted in Microsoft Excel. This procedure was repeated until reaching maximum current output. The cell temperature was set at Room Temperature (RT), 30 °C, 40 °C, 50 °C, 60 °C and 70 °C to observe the effects on output power.

Results

Figure 3 shows an overall comparison of Current Density (CD) vs. Power Density (PD) including all membrane thicknesses and temperature variations. Although the N212 membrane exhibited overall the highest PD curve, this was only achieved in the temperature range of 60 °C to 70 °C.

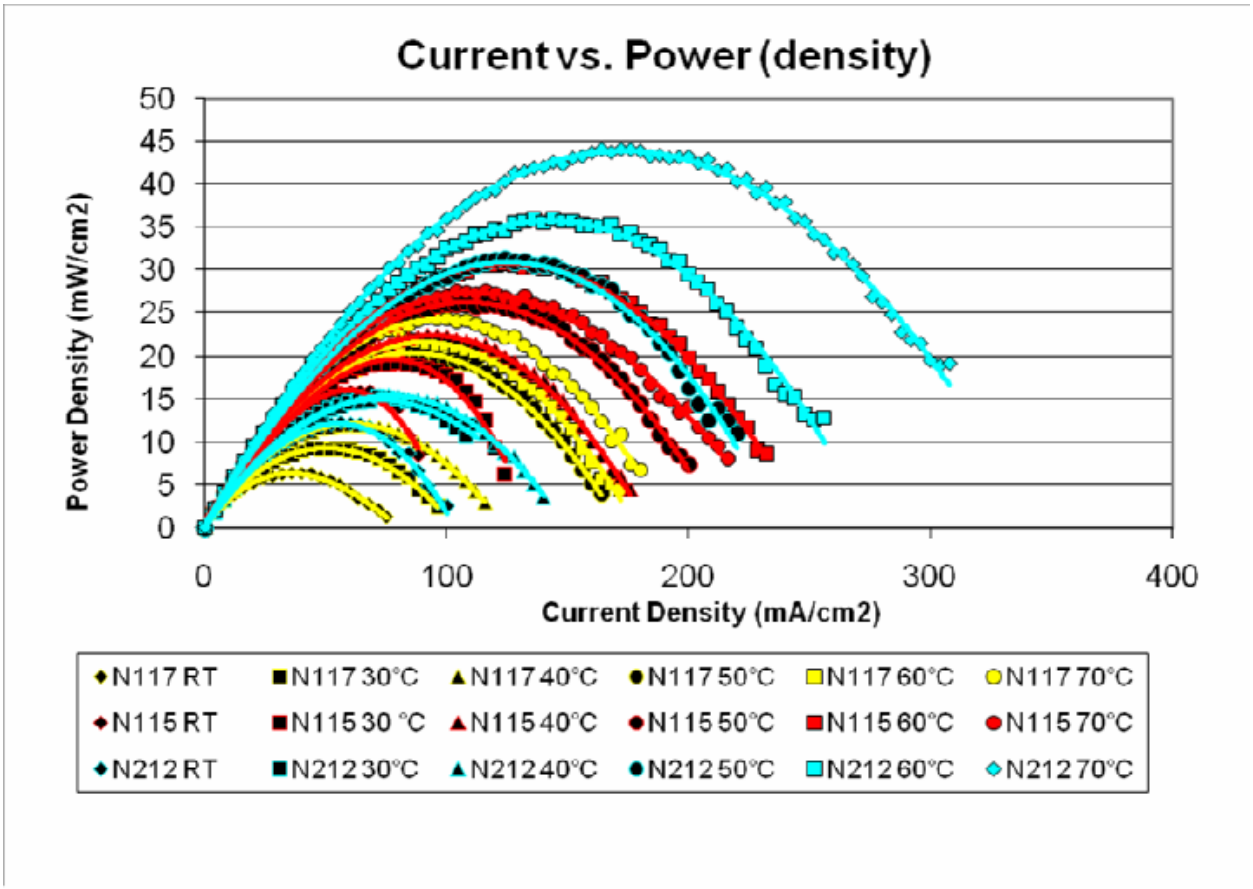


Figure 3 Power Curves at Various Temperatures of Operation and Membrane Thicknesses

Figure 4 shows detailed PD curves at various temperatures, indicating which membrane can produce the highest PD; Figure 4 shows polarization curves at the same temperature levels. From RT to 50 °C, N115 showed the highest power output, however from 60 °C to 70 °C, N212. When observing the highest recorded open circuit voltage, it has been observed that N115 produces 0.8 volts (V) at RT, N117 produces 0.78 V at 50 °C and N212 0.55 V at 70 °C.

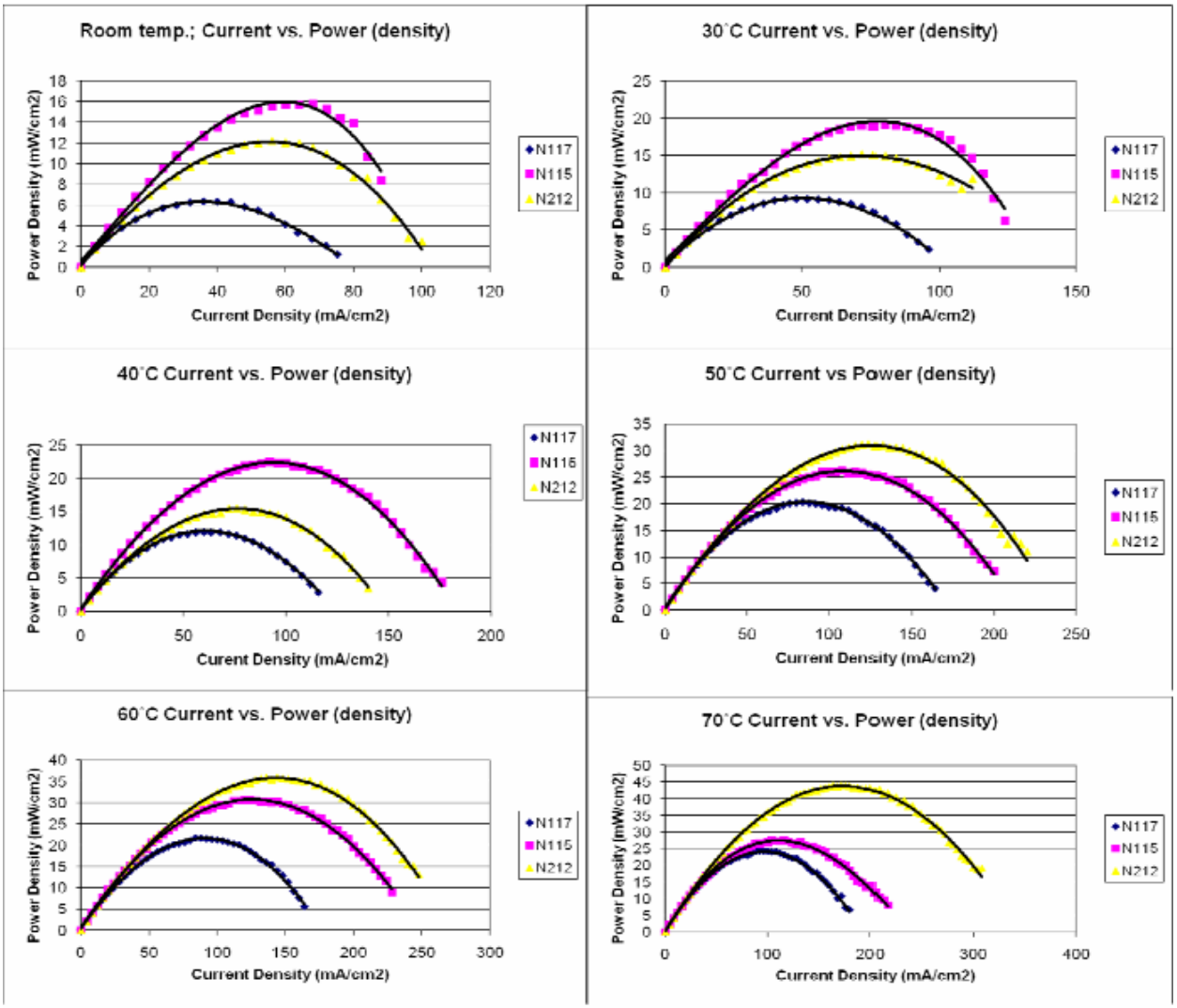


Figure 4 Individual Power Curves at at Different Temperature Levels for Three Different Thicknesses of Membrane

Figure 5 shows the effect of temperature for each membrane thickness, an observed gap in the PD curves is shown between the temperatures of 40 °C and 50 °C. It is also shown that the highest PD is not always supported by temperature; the highest PD from N115 is at a temperature of 60 °C. However N212 and N117 both have their highest PD curves at 70 °C.

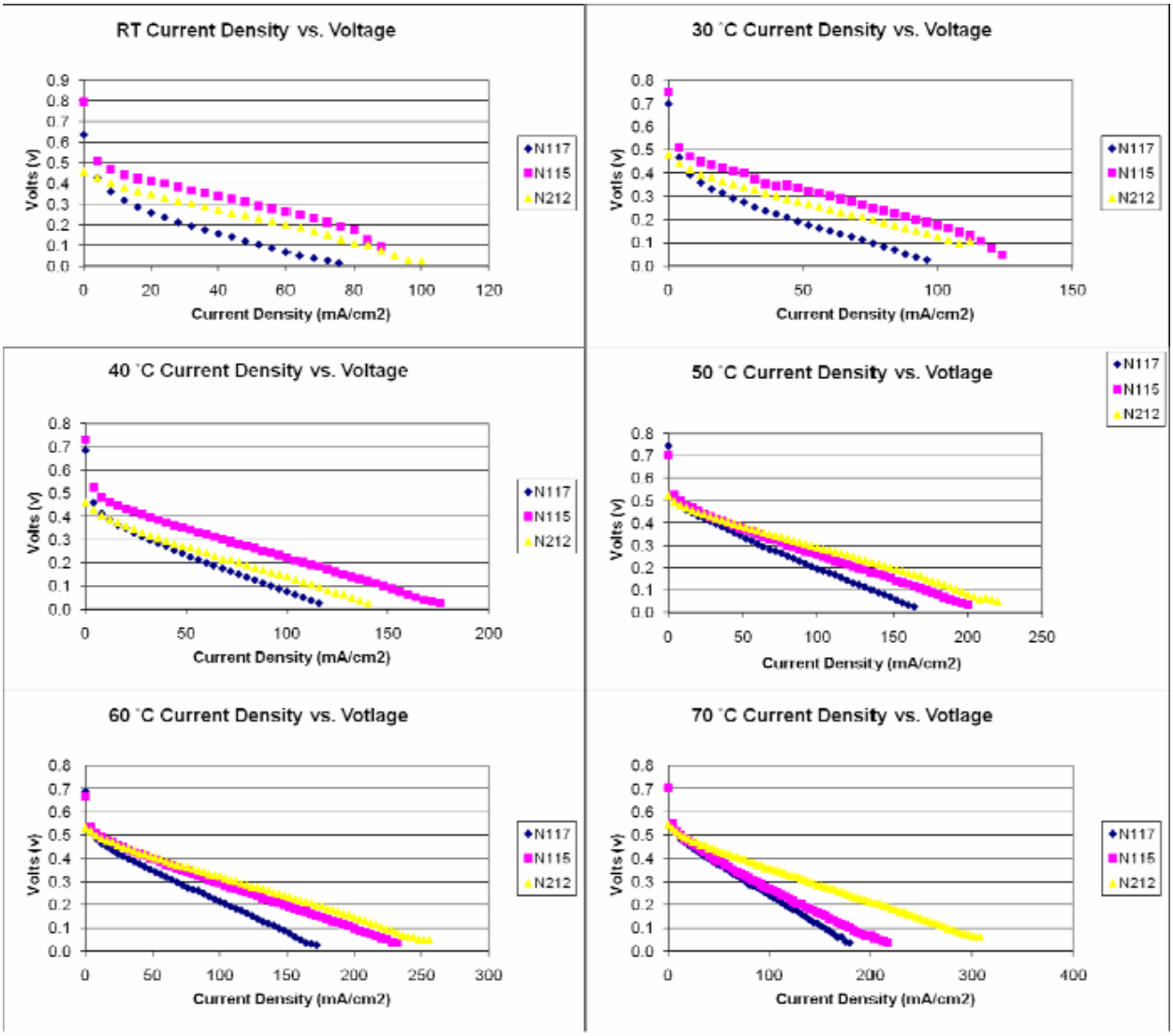


Figure 5 Individual Power Curves at at Different Temperature Levels for Three Different Thicknesses of Membrane

Figure 6 shows an overall comparison of Current Density (CD) vs. voltage, again including all parameters; N212 at 70 °C again achieves superior performance. When observing the highest recorded open circuit voltage, it is seen that N115 produces 0.8 volts (V) at Room Temperature (RT), N117 produces 0.78 V at 50 °C and N212 0.55 V at 70 °C.

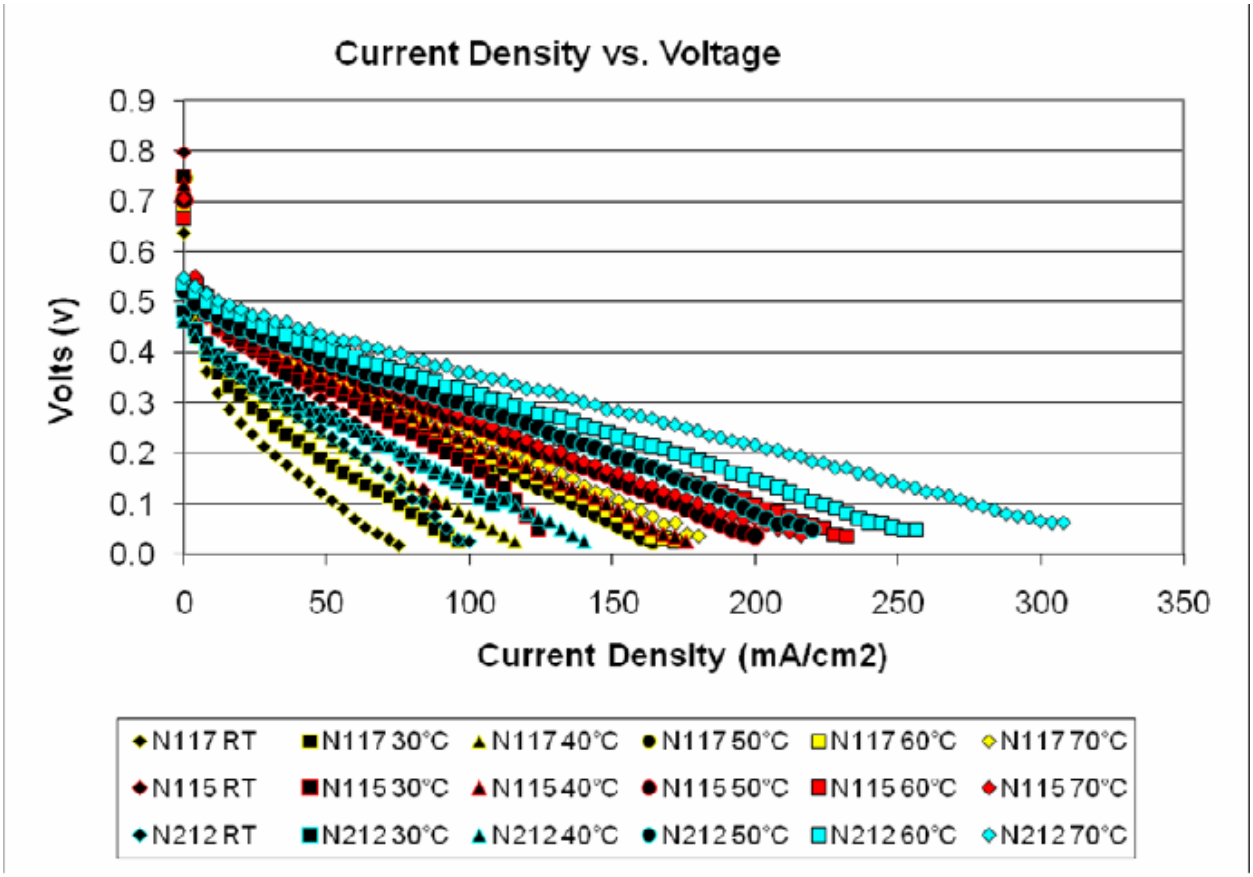


Fig. 6 Polarization Curves at Different Temperature and Membrane Thicknesses

Figure 7 clearly summates all data to graphically present which MEA will produce the highest power at each temperature interval. Trends begin to emerge, with regards to power output and temperature, within the experimental range of this work, and future work will extend beyond.

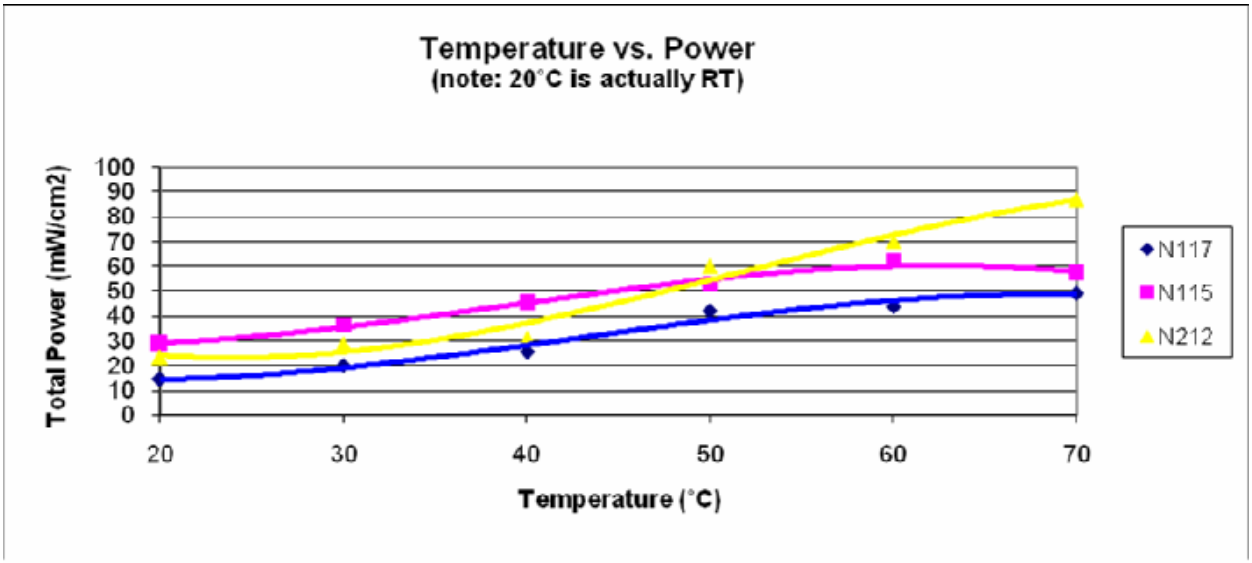


Fig. 7 Temperature and Power Curve

Figure 8 is a comparison of percent differences of total output power at each temperature level, based upon the poorest performing membrane (N117).

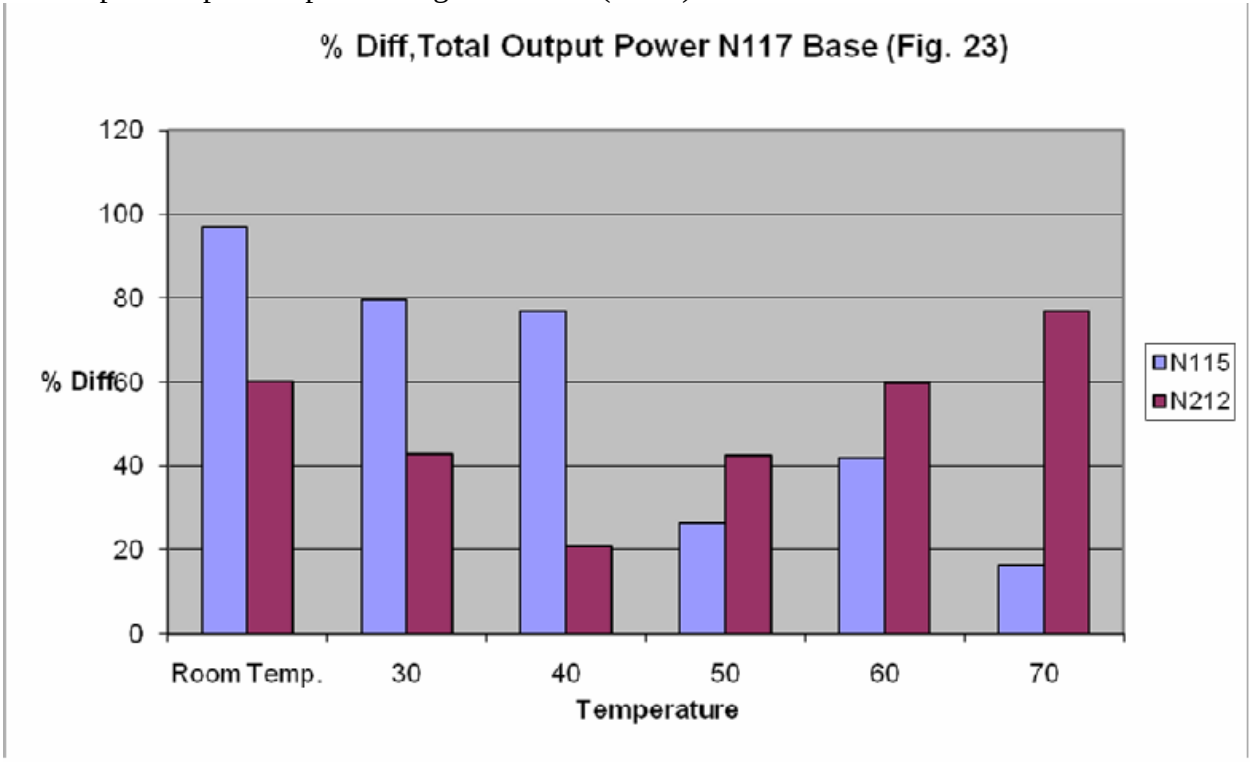


Fig. 8 Percentage Difference Output related to N117 Membrane

Conclusions

1) Temperature increase will have a beneficial outcome on the output power of a DMFC within the experimental range presented in this work (room temperature – 70)

2) Each membrane has a peak performance temperature; N115 at 60 °C, N117 at 70 °C and N212 at 70 °C.

3) Within the temperature range of room temperature to 50 °C a DMFC MEA with a nafion membrane thickness of N115 will produce higher power than N117 and N212, within the range of 60 °C to 70 °C N212 will out perform N115 and N117.

4) N212, the thinnest membrane, produced more power than expected. Membrane permeability should increase at higher temperatures, allowing for excess methanol crossover, and should have had the least amount of power at elevated temperatures. This is an indication that methanol crossover was not as pronounced of a parameter as originally thought; the benefits of reaction kinematics at elevated temperatures must have overcome any hindrance due to excess crossover. Power output optimization was the main focus of this research. To verify why this happened, it would be necessary to fully understand the exact composition of what was being input to, and out from, the DMFC. We understand that the crossover does affect the power output, however we did not monitor or record any data studying this phenomena; which will be included in our future work.

Impact in Engineering Technology Education

Emerging technologies such as those involving alternate forms of energy are expected to play a major role in modern engineering technology curricula. The results presented in this paper involve expertise from multidisciplinary teams in our school of engineering technology; in particular, technology of fuel cells, control systems, fluid mechanics, thermodynamics, and software applications. Major parts of this work were performed as student projects by the first author who is a student in the school of engineering technology. Namely the student was involved in setting up the fuel cell system, developing code for control algorithm and data acquisition, and running the experiments at Brookhaven National Laboratory and Farmingdale State College supported by the Department of Energy (DOE) the Faculty and Student Teams (FaST) Program. It is expected that this lab setup will be used in future undergraduate senior projects for students in the departments of mechanical engineering technology. In addition, interdisciplinary courses in alternate forms of energy, fuel cells, solar energy systems, and control mechanisms could be developed in the future as outgrowth of these experimental setups and activities. Parts of the algorithms developed have also been used as examples in existing courses.

The performance of the fuel cell is influenced by many different parameters. In this paper we analyzed the optimal performance of direct methanol fuel cell. Temperature is an important parameter to the maximize power. We will continuously investigate the relationship between temperature, humidity, time and power. For real life applications, we need to develop a more sophisticated system to consider many parameters in the extended running of direct methanol fuel cells.

Future Work

Both N117 and N212 showed a promising trend with regards to power increase as temperatures elevated, future experimentation should be conducted to find out if this will continue outside of this works experimental range. Also, the reason for why the thinnest membrane outperformed unexpectedly should be examined thoroughly, as this may lead to other DMFC advances.

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