MICRO-CHANNEL METHANOL STEAM REFORMERS FOR FUEL CELLS IN SPACE APPLICATIONS

Sara L. Fong
College of Engineering
University of Hawaiʻi at Mānoa
Honolulu, HI 96822

ABSTRACT

Initial research was performed into methanol and its compatibility with other materials. The information gathered led to the modification of the test section material from copper to 303 Stainless Steel to ensure the compatibility of the test section with the working fluid.

Based upon an estimated volume calculation of the laboratory these experiments will be performed in, the use of methanol in this experiment is well within legal limits and no hazards should be directly posed to individuals in contact with the experiment. However, precautions will be taken to minimize the possibility of hazardous conditions.

Manufacturing the test section of the assembly proved to be time intensive. The test section is comprised of seven different pieces, with the assembly of the pieces being a delicate process.

All material required for the test system has been purchased, and the system may be constructed upon the arrival of components. To date, no testing has been performed.

INTRODUCTION

The current National Aeronautics and Space Administration (NASA) Strategic Plan has established human missions to the moon and Mars as priorities. Of paramount importance to the success of the missions is the availability of efficient and plentiful energy, electrical energy in particular. Existing electricity-generating technologies in space programs include fuel cells and solar panels: fuel cells for short-duration space shuttle missions and solar panels for long-duration robotic exploration and satellites. While advanced energy technologies such as nuclear fission systems are being pursued by NASA as a means to enable long-duration habitats on the moon as well as long and short stays on Mars, fuel cells and solar panels will be the technologies of choice to power short-term lunar exploration. However, their efficiency needs to be further improved so that the overall systems can be both lightweight and compact. The proposed work concerns one important aspect of fuel cell systems in space applications: fuel subsystems.

Fuel cells convert chemical energy in hydrogen fuel directly into electrical energy. In addition to the fuel cell stack where the electrochemical reaction occurs, a complete fuel cell system includes a number of components to support its operation. One of the most important components is fuel subsystem that supplies hydrogen gas to the fuel cell stack. Electrolyzers are commonly used as fuel subsystems in space shuttles, which produce hydrogen gas from water through electrolysis. The main drawback of electrolyzers is their low efficiency: a significant portion of electricity produced by fuel cell stacks is used to electrolyze water.

The recent development of advanced microfabrication technology has led to the emergence of novel micro-channel methanol steam reformers that integrate the various operations for hydrogen production into a flow system composed of micro-channels. Characteristic dimension of these micro-channels ranges from tens to hundreds of micrometers.

Figure 1 shows the concept of micro-channel methanol steam reformer [1]. In micro-channel methanol steam reformers, pure methanol and water in liquid-phase first mix to form a binary liquid mixture and then evaporate to a vapor mixture in micro-channels. The vapor mixture flows into the catalytic reformer section where the two components react to produce hydrogen gas. Utilization of micro-channels renders the reformers unique technical merits of high heat and mass transfer rate and large surface area to volume ratio, which yields high hydrogen productivity per unit volume. In addition, surface tension force becomes dominant and gravity force less significant in micro-channels, which makes micro-channel reformers best suitable for micro-gravity environment. The micro-channel reformers may be a preferable alternative to electrolyzers as fuel subsystem for fuel cells in space applications.

Implementation of micro-channel reformers requires a fundamental understanding of virtually all transport processes in micro-channels.

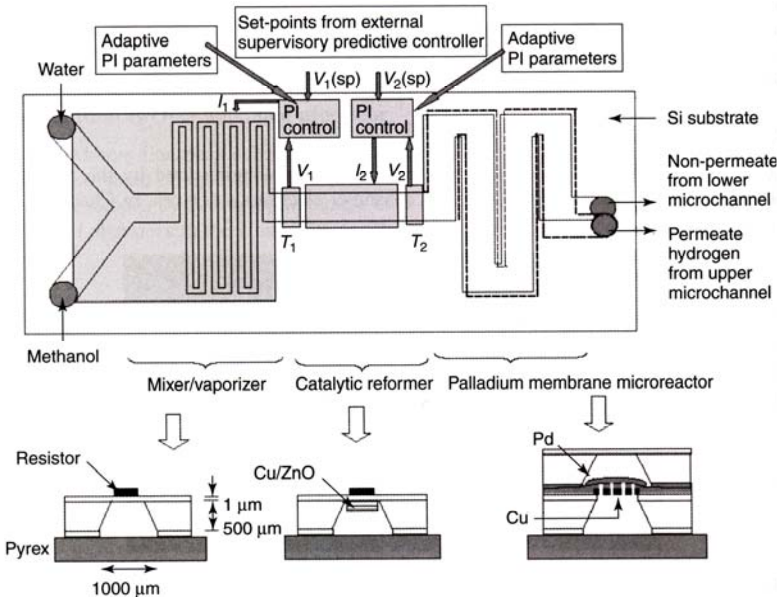

Figure 1. Schematic of micro-channel methanol steam reformer [1].

The main focus of this experiment was to analyze the behavior of the transport processes in micro-channels for methanol water mixtures. To accomplish this, a test system set-up was designed and can be seen in Figure 2.

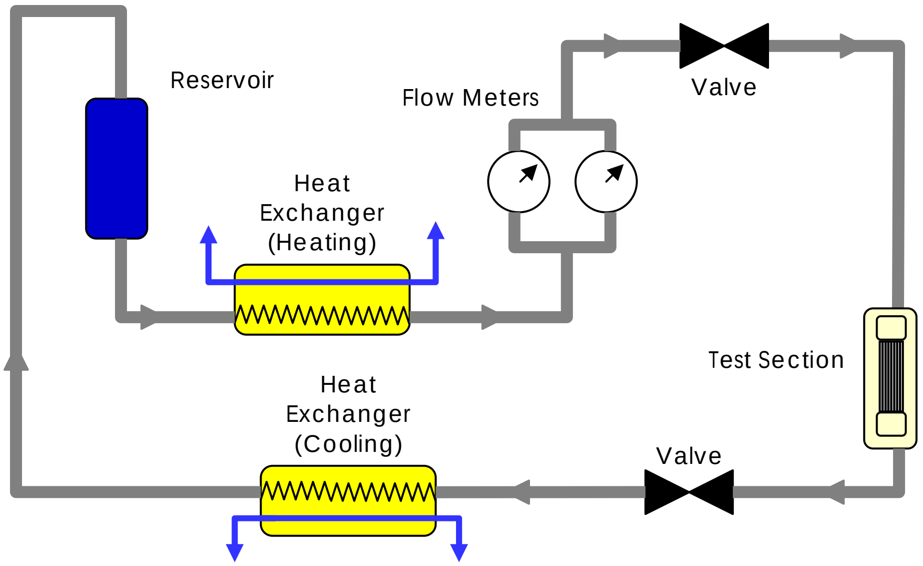

Figure 2: The test system set-up is shown. The working fluid (methanol-water mixture) flows out of the reservoir, through the system, and back to be reused.

The working fluid (methanol-water mixtures) flows out of the reservoir into a heat exchanger (which heats the fluid to a working temperature), through flow meters (which will give necessary flow rate information to analyze data), then a shut-off valve and the test section (where data is obtained), and back through a second shut off valve and heat exchanger (cools the fluid back to a storage temperature). Once the fluid has been cooled, it is returned to the reservoir to be reused in the test system. Note that the system is completely closed, and there should be minimal losses of fluid. This is important as methanol-water mixtures are considered hazardous.

While the data obtained from the experiment was of the most interest, information regarding the use of methanol and construction of the test system were the main priorities. During the duration of the semester, the main focus of the work completed focused on the manufacturing and assembly of the test section.

INITIAL RESEARCH

At the start of this project, not much was known to those on the project about methanol. While the chemical qualities of methanol are desirable for the purpose of this experiment, there are many physical and health hazards associated with working with methanol, as it is a highly flammable and hazardous chemical.

The United States Environmental Protection Agency (EPA) has published data indicating the legal limit of inhaled methanol to be set at 200 ppm for an eight-hour time weighted average [2]. Based upon an estimated volume calculation of the laboratory these experiments will be performed in, our use of methanol is well below the legal limits for inhaled methanol. Other forms of contact with methanol can have varying effects, and proper precautions will be made to ensure the safety of the individuals working with the fluid.

While researching the proper use of methanol, the question of material compatibility arose. Unfortunately, there are many materials which are not compatible with methanol and methanol water mixtures. Materials containing zinc, copper alloys, aluminum, and plastics are listed as "not suitable" for prolonged exposures to methanol. This was a problem, as the main component of our test section was originally designed to be made of copper.

In lieu of this new information, the test section design was changed from copper to stainless steel, the most commonly available material neutral in methanol mixtures. A 303 Stainless Steel (easy-to-machine stainless) was chosen as the material for the main test section piece to ensure machinability as well as compatibility with the working fluid.

The compatibility of methanol with the garolite (a composite material, often used for breadboards due to its insulating properties) and lexan (polycarbonate) pieces of the test section were also in question. A simple test was performed to ensure the compatibility of the lexan with the methanol, by soaking a piece of lexan in denatured alcohol. Although the alcohol is not exactly the same as the methanol, they are similar in the materials that they attack. A picture of the set- up can be seen below in Figure 3.

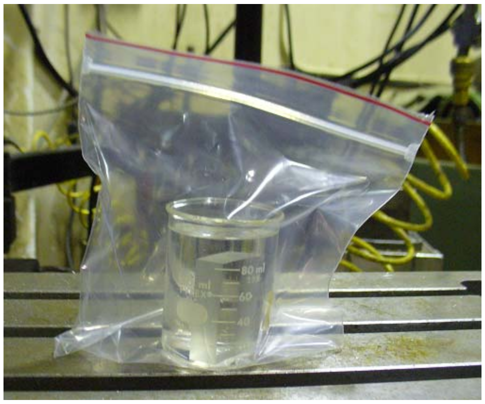

Figure 3. A simple test was constructed to determine the compatibility of lexan with the methanol water mixtures. A piece of lexan was soaked for a week in denatured alcohol with no visible deterioration to the sample.

After a week of being completely immersed in the denatured alcohol, the lexan showed no signs of deterioration. The assumption is this indicates the lexan will be compatible with the methanol water mixtures to be used in the testing phase. The compatibility of the garolite with the methanol was not able to be determined, as there were no extra pieces of garolite for testing.

MANUFACTURING

The test assembly is constructed of seven different pieces: A lexan cover plate, garolite housing, test section, white ceramic insulators, black ceramic insulating base plate, and an aluminum base plate. The assembly was secured together using threaded rod and nuts.

The test section was the most complicated piece of the set-up to manufacture due to the required accuracy of the channels and the material type. The finished channels in the test section were 254 μm wide and 762 μm deep. The details of the piece can be seen in Figure 4.

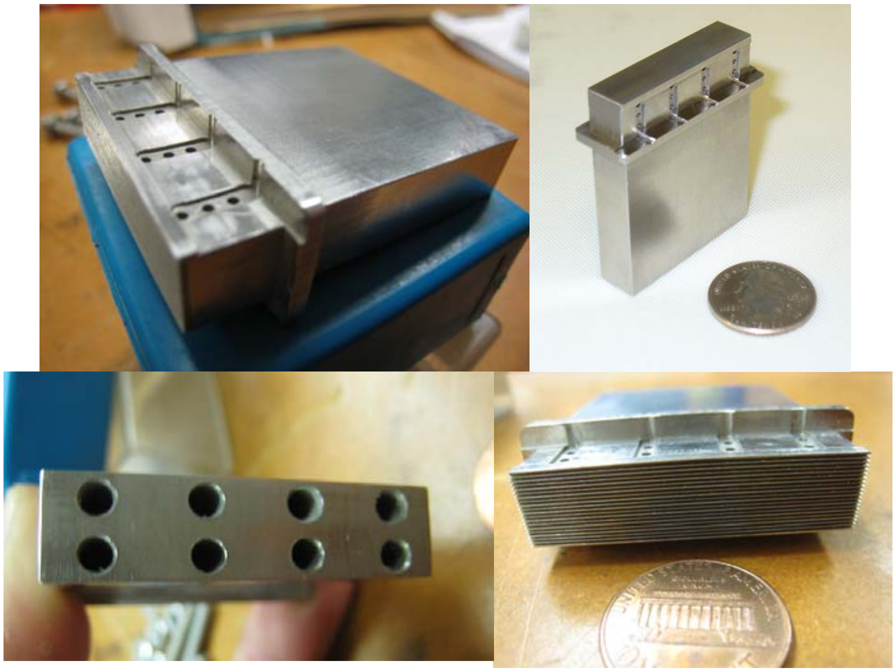

Figure 4. A more detailed picture of the final test section is shown. The coins (U.S. Quarter Dollar and U.S. Penny) are in the pictures for size comparison.

There are many small blind-holes for required for equipment hook-up in the design, which also complicate the manufacturing process. This is the main reason it was the most complicated piece and required many hours to machine. With the in-house capabilities of the College of Engineering Machine Shop, the blank (the test piece without micro-channels) required four work days of machining time on the Computer Numerically Controlled End Mill (CNC Mill).

Two separate test sections were manufactured. In the first test section, cutting the channels caused two end-mill bits to break inside the piece. The bits could not be removed due to their small size. With no way to remove the bits, the piece was scrapped and a second test section was cut. In the second section, a slitting saw was used to cut the channels. The slitting saw provided slightly less accuracy along the length of the channel when compared to the end-mill, but the channels were cut without problem as it is a more robust machining process.

Once the test section had been cut, the other pieces were machined. Although they were comparably easier to cut, they also required time. The ceramic pieces underwent multiple cuts, as the material tended to shatter and chip. Although there are chips in the final ceramic pieces, they should not affect the performance of the test system.

The garolite housing was required to be cut with a diamond saw and end-milled on the CNC Mill. The precision of the garolite housing was also of great importance as the channels needed a complete seal with the lexan cover plate. The height at which the channels sit is directly dictated by the depth of the grooves in the garolite.

Detailed pictures of the ceramic pieces, aluminum base plate, lexan cover, and garolite housing can be seen in Figure 5.

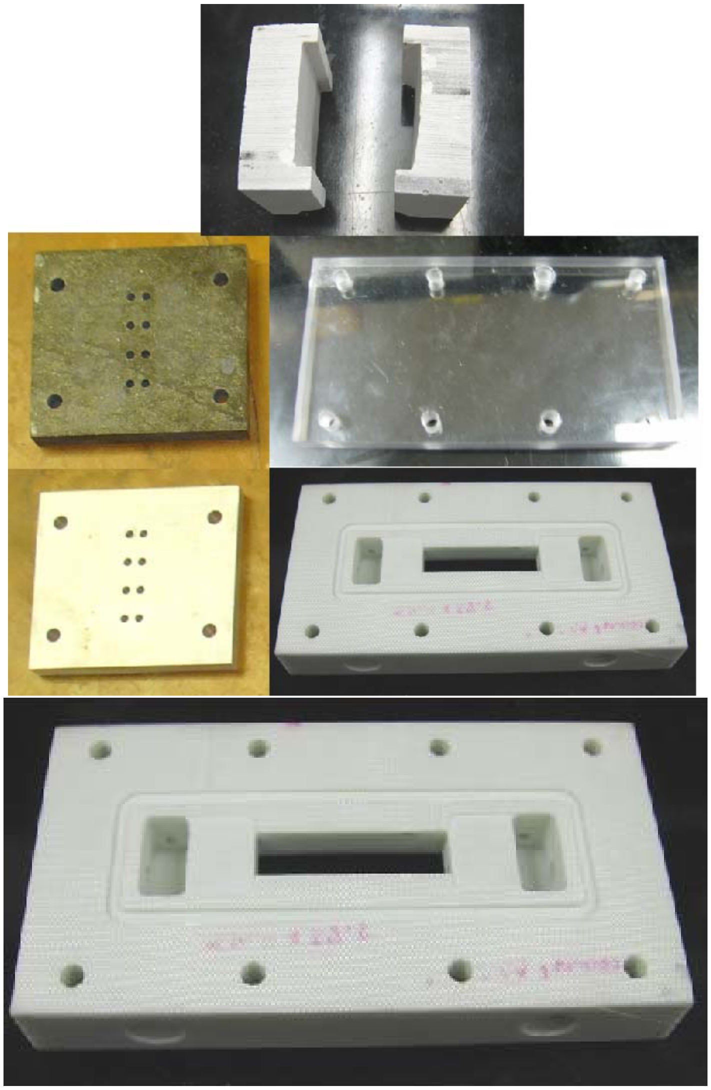

Figure 5. Detailed pictures of the ceramic insulating pieces, aluminum base plate, lexan cover plate, and garolite housing are shown. Top: White ceramic insulating blocks. Second row left to right: Black ceramic insulating base plate, lexan cover plate. Third row left to right: aluminum base plate, garolite housing. Bottom: Detailed picture of garolite housing.

Once all the pieces of the test assembly had been manufactured, the entire section could be assembled. Putting the assembly together was a delicate operation, as many of the ceramic pieces would shatter if dropped, and the channel walls would deform if the test section was dropped.

The required pieces of the test section and its assembly process can be seen in Figure 6.

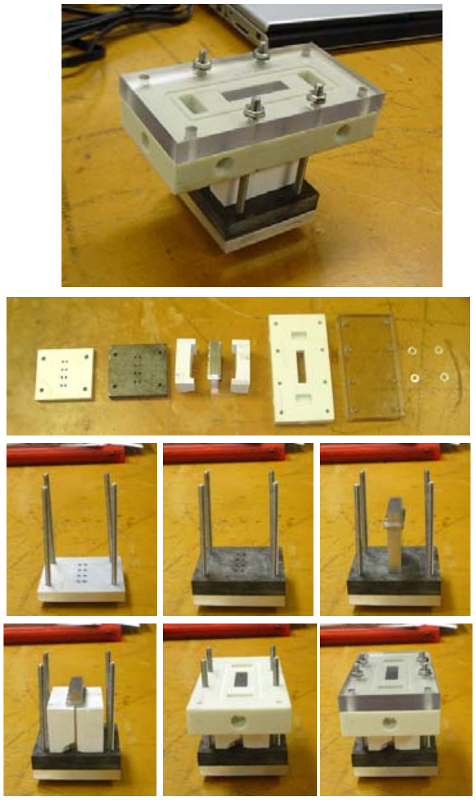

Figure 6: Detailed pictures of the final test assembly and the assembly process are shown above. The top center picture is the final test assembly. The second row is all pieces used in the set-up. The third and fourth rows are progressive assembly pictures, starting at the third row far left, to the fourth row far right.

RESULTS

No experiments were performed with the test section due to time constraints. All materials necessary for the construction of the test set-up (Figure 2) have been purchased, and may be assembled at a later date. Currently, the pump necessary to circulate the fluid through the system is on back order. The manufacturing aspect of the test assembly was the most time intensive part of the system set-up, and has been completed.

CONCLUSION

Research was performed into methanol and its compatibility with other materials. The original design material (copper) was changed to 303 Stainless Steel due to the possibility of the methanol water mixtures attacking and destroying the copper.

Based upon an estimated volume calculation of the laboratory these experiments will be performed in, the use of methanol in this experiment is well within legal limits and no hazards should be directly posed to individuals in contact with the experiment. However, precautions will be taken to minimize the possibility of hazardous conditions.

Manufacturing the test section of the assembly proved to be time intensive. The test section is comprised of seven different pieces, with the assembly of the pieces being a delicate process.

All material required for the test system has been purchased, and the system may be constructed upon the arrival of components. To date, no testing has been performed due to time constraints.

ACKNOWLEDGEMENTS

I would like to first say thank you to my mentor, Dr. Weilin Qu. Your guidance, patience, flexibility, and understanding has allowed me to achieve more than I thought possible. Thank you also to Brian Kodama and Ben Respicio of the College of Engineering Machine Shop for helping me in a crunch and working tirelessly to manufacture the pieces. Without their dedication, this project would never have been completed. Mahalo to my fellows, as their support through this project has been unconditional. And last but not least, thank you very much to the Hawaii Space Grant Consortium for providing me the opportunity to further my own goals. The programs you provide students allow them to follow their own interests and dreams with minimal financial burden.

REFERENCES

[1] Pattekar, A.V., et al. (2001). A microreactor for in-situ hydrogen production by catalytic methanol reforming. Proceedings of the 5th International Conference on Microreaction Technology, 2001.

[2] U.S. Environmental Protection Agency: Office of Pollution Prevention and Toxics. (1994) Chemical Summary for Methanol.