Restated Project Scope and Project Plan

Team 16

Design and development of optimized flow channels for an alkaline membrane fuel cell (AMFC) educational kit

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Table of Contents

Table of Figures and Tables

ABSTRACT

The goal of this project is to design and manufacture a working alkaline fuel cell education kit which contains multiple flow channel configurations. This will allow users of the kit to compare the performances of different configurations, and study the fluid properties which contribute to said performances. The different flow configurations will be tested and optimized to ensure the fuel cell functions, and also assist in the process of designing experiments which can be carried out by users of the kit. The current investigation involves studying and improving from the flaws of the previously designed AMFC educational kit designed in 2015. One modification made was the replacement of the fuel delivery system. The kit originally contained a method for using electrolysis to produce fuel as needed. This method is being replaced by a third party advanced fuel delivery system which will produce and store hydrogen in a compressed cylinder. This will make the fuel cell more reliable and will also reduce the risk of electrical shock present in electrolysis. Another large portion of this project has been devoted to improving the safety of the fuel cell. A stand has been designed in order to increase the stability of the fuel cell during operation to prevent burns or electric shocks. Electrical connections will be replaced with built in banana clips to increase reliability and reduce the need to touch the fuel cell during operation. Additionally, the assembly of the fuel cell is being streamlined by replacing standard nuts and bolts with quick release skewers commonly used to secure bicycle wheels to the frame. This removes the need for tools within the kit. Furthermore, the endplates will be replaced by three newly designed configurations which will be used for experimentation to provide a deeper understanding of fuel cell operation to the user of the kit. The different flow channel configurations will maintain a constant volume to ensure experimental constants. Finally, the newly designed kit will contain the necessary instruments to test the fuel cells performance during operation. A Fluke 116 multimeter will work injunction with a thermocouple and a load box to measure outputted voltage, current, and temperature. Ultimately, the fuel cell kit will be commercialized so that it can be produced and sold at a reasonable cost to institutions and individuals wishing to study fuel cell operation from the ground up.

1. Introduction

A high demand for cleaner, more sustainable energy has fueled the development of methods of power generation which have less of an impact on the climate and the environment than typical fossil fuel methods. Many methods of sustainable power generation such as harnessing wind energy, or collecting solar energy have proven to be an issue for their dependence on specific atmospheric conditions to perform at an optimum level. Fuel cells offer a solution to this issue because they can provide on demand power at any time of day, and in nearly any condition found on Earth. Unfortunately, the development of fuel cell technologies has lagged behind that of other methods of power generation. Additionally, practical applications of fuel cells have proven to operate at less than ideal efficiencies. This project will modify and improve a previously designed AMFC to be included in an educational kit with the usage of computer based software and engineering knowledge specializing in the field of thermal fluids. This project hopes to produce a product which will spark interest and passion for sustainability in students.

2. Project Definition

2.1 Background Research

The fuel cell was invented in 1839 by a British professor William Grove. His fuel was made of a series of cells made with a dilute solution of sulphuric acid and pairs of test tubes of hydrogen and oxygen. Grove observed that the ratio of consumption of the hydrogen to oxygen was 2:1. The volume ratio is an agreement with the simple reaction equation of hydrogen and oxygen to produce water. Since the invention of the first fuel cell, other types of cells has emerged this includes:

1) Proton Exchange Membrane (PEM)
2) Phosphoric Acid Fuel Cell
3) Alkaline Fuel Cell (AFC)
4) Direct Methanol Fuel Cell

2.2 Fuel Cell Application/Operation

Fuel cells have been used for power generation for over two decades and are an attractive alternative source of energy due to their high efficiencies and non-polluting operation. They have been used to power automobiles, spacecrafts, and some power plants. Some portable fuel cells have also been developed for use in powering of electronic devices for camping, yachting, traffic monitoring, medical treatment, and warfare. [1] In general, fuel cells produce electricity and can power any device or equipment that runs on electricity. Once again, the main advantage of fuel cell application is that it does not emit pollutants and other greenhouse gasses that are harmful to the environment.

The purpose of a fuel cell is to convert chemical energy into electrical energy. The fuel cell provides an electrical current to an external circuit, providing on-demand power and requiring no moving parts. This is achieved by taking advantage of oxidation and reduction reactions, which release and capture electrons, respectively. The diagram of a standard alkaline fuel cell can be found below in figure 1. [2]

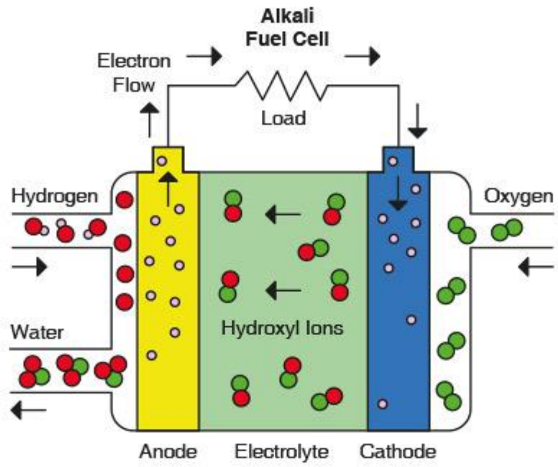

Figure 1: A diagram depicting an alkaline fuel cell [3]

The diagram above shows how the alkaline fuel cell functions. On the left side of figure one, hydrogen gas is supplied into the fuel cell. Once hydrogen gas enters the fuel cell, it begins to diffuse into the anode, which is highlighted in yellow. The anode is an electrical conductor which allows for a flow of electrons. The anode must not only conduct electrons but must also contain a catalyst for the oxidation reaction. The anode in an alkaline fuel cell is usually made of carbon which is coated with either platinum or palladium. These two metal are highly conductive of electricity and act as a catalyst for the oxidation and reduction reactions. This is due to the high porosity of the metals microstructure, which allows for efficient diffusion of hydrogen and oxygen into the microstructure. The faster this diffusion process can take place, the most efficient power generation can occur. To the right of the anode is the electrolyte soaked membrane (seen in green). From this membrane, hydroxyl ions supplied from the electrolyte solution also diffuse into the anode. The hydroxyl ions react with the hydrogen gas. This reaction is the oxidation reaction, and its balanced chemical equation can be found below in equation 1. [4]

$$2H_2 + 4OH^- \rightarrow 4H_2O + 4e^- \quad (1)$$

From equation 1 seen above, we can see the how the first half of the process works. As the hydrogen gas (H_2) diffuses through the anode, the two hydrogen atoms which make up the hydrogen gas, break apart. One of these atoms bonds with one hydroxyl ion. This reaction results in one water molecule and one excess electron. The water is expelled out of the anode, and eventually out of the fuel cell, and the electron flows out of the anode and through the external circuit. This electron flows from the anode to the cathode (seen above in figure 1 in blue) because of electric potential. The anode is electronegative, and the cathode is electropositive. This simply means there is an excess of electrons at the anode, and a shortage of electrons at the cathode. The cathode is constructed the same as the anode, which is described above. Oxygen gas supplied into the fuel cell (which can be seen on the right side of figure 1), diffuses into the cathode, and a reduction reaction occurs. The balanced reduction reaction that occurs at the cathode can be seen below in equation 2. [4]

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \qquad (2)$$

The hydroxyl ions (OH^-) produced in equation 2 then flow through the membrane from the cathode to the anode. Currently, two possible configurations of membranes exist. One is the static electrolyte configuration. In this configuration, the membrane is usually either asbestos or the more complex Alkaline Anion Exchange Membrane (AAEM) which is ammonium based. These membranes are soaked in a highly concentrated electrolyte solution such as potassium hydroxide (KOH). This electrolyte solution is responsible for the flow of ions. In the flowing configuration, the membrane consists of some form of a matrix microstructure which allows the electrolyte to circulate freely. The static configuration is generally safer in vehicular applications. However, these materials tend to be more toxic. More specifically, ammonia cause acute toxicity when inhaled or digested, and asbestos is a well-known carcinogen. Research is still attempting to develop a safe and efficient membrane. One possibility that is still being tested is a cellulose based membrane. [4]

One important aspect governing fuel cell efficiency are the flow channels which provide fuel to the anode and the oxidizer to the cathode. Very little actual research has been done to test the best way to supply these gasses to the fuel cell. Ideally, the flow channels will be designed to produce maximum diffusion of both hydrogen and oxygen through the corresponding electrodes. The flow channels must also be designed to facilitate the removal of water vapor from the surface of the anode, which is the byproduct of the oxidation reaction occurring within the anode.

Theoretically, a perfectly designed flow channel would be able to supply equally concentrated gas over the entire surface of the electrode while having the least amount of pressure drop. If the gas is not equally concentrated over the entire surface of the electrode, the current density will be uneven within the electrode, and will not produce optimal results. One consequence of having an uneven distribution of current within the electrode is uneven heat distribution. This could potentially affect the longevity of certain components in the fuel cell. This could also lead to a poor evacuation of water vapor. Likewise, if the head loss is too significant due to the complexity of the design, diffusion through the electrode will be slowed drastically. High pressure drops caused by head loss could also result in stagnation within the flow channels, which would have similar results as previously mentioned.

3. Need Statement

The project is being sponsored and advised by Florida State Professor Dr. Juan Ordonez. The project will include and demonstrate various experiments of testing different flow diagrams to show students the correlation between flow systems and efficiency in AMFC single cell. The fuel cell and all necessary parts will be in one portable kit that can be easily transportable. A previous educational fuel cell kit has been made and is located at the CAPS lab at Florida State University. This project will take this fuel kit and redesign it with the addition of exchangeable flow channel plates that contain different flow configurations. The team eventually plans to deliver a fully functioning AMFC educational kit that will be commercialized as a marketable product.

"The current AMFC setup does not effectively allow students to test the effects of flow configurations on fuel cell performance."

4. Goal Statement and Objectives

"Deliver a safe functioning educational alkaline membrane fuel cell kit that demonstrates the effects of flow configurations on the fuel cell's performance by the end of spring 2017 semester."

The main objectives that have been addressed from assessing the need statement are listed below.

- Improve the design of an alkaline membrane fuel cell (AMFC) educational kit for high school and college level laboratory demonstration.
- Include multiple flow configurations to test performance
- A standard operation procedure and a product specification sheet included in the kit
- A series of demonstration experiments will be designed and conducted
- Develop a potential model for commercialization of the kit.

5. Methodology

5.1 Project Plan

For the start of the new semester our team decided to update our schedule and methodology due to progress made from last semester. This part will be an update of all the changes and the why behind them.

5.2 Scheduling

To properly keep track of our progress a Gantt chart was used last semester. After satisfying the time frame set from the previous chart an update has been done incorporating the schedule for this semester. This chart is shown in Table 1 below.

Currently the team is researching the ideal ways to optimize the gas delivery system and electrode membrane for a fuel cell of this size. This is a very important step because these are the costly parts of the project. Team members are also making a more detailed design in order to machine the necessary parts without confusion. Purchase orders will also be placed within the week for new stainless steel plates and other important components that we will need to be ready for actual testing of the flow configurations. Developing a safe functioning fuel cell kit with all the different flow configurations is currently the top priority the rearrangement of the case will not be the primary goal until this steps is complete. At the end of this semester we will have a fully functional alkaline fuel cell kit with three different configurations to display their effect on performance and a proposal kit for commercialization.

Task Name	Duration	Start	Finish
Background Research	13 days	Wed 9/21/16	Fri 10/7/16
Discuss Design Ideas	26 days	Wed 9/14/16	Wed 10/19/16
Gain Access to CAPS Laboratory	9 days	Mon 10/10/16	Thu 10/20/16
Communicating with machine shop	26 days	Thu 11/3/16	Thu 12/8/16
Web Design	14 days	Wed 10/19/16	Mon 11/7/16
Begin Testing of Existing Design	13 days	Mon 11/21/16	Wed 12/7/16
Communication with Brazilian Team	60 days	Sun 12/11/16	Thu 3/2/17
Meet with Advisor/Sponsor	2 days	Thu 1/19/17	Fri 1/20/17
Communicate with Machine Shop	1 day	Fri 1/20/17	Fri 1/20/17
Purchase Components	14 days	Sun 1/22/17	Wed 2/8/17
Machine New Flow Channels	7 days	Sun 2/12/17	Mon 2/20/17
Optimize Gas Delivery System	9 days	Tue 2/21/17	Fri 3/3/17
Optimize Electrolyte Membrane	9 days	Tue 2/28/17	Fri 3/10/17
Test Flow Configurations	9 days	Sun 3/12/17	Wed 3/22/17
Conduct Mathematical Analysis	9 days	Sun 3/12/17	Wed 3/22/17
Finalize Kit	10 days	Thu 3/23/17	Wed 4/5/17

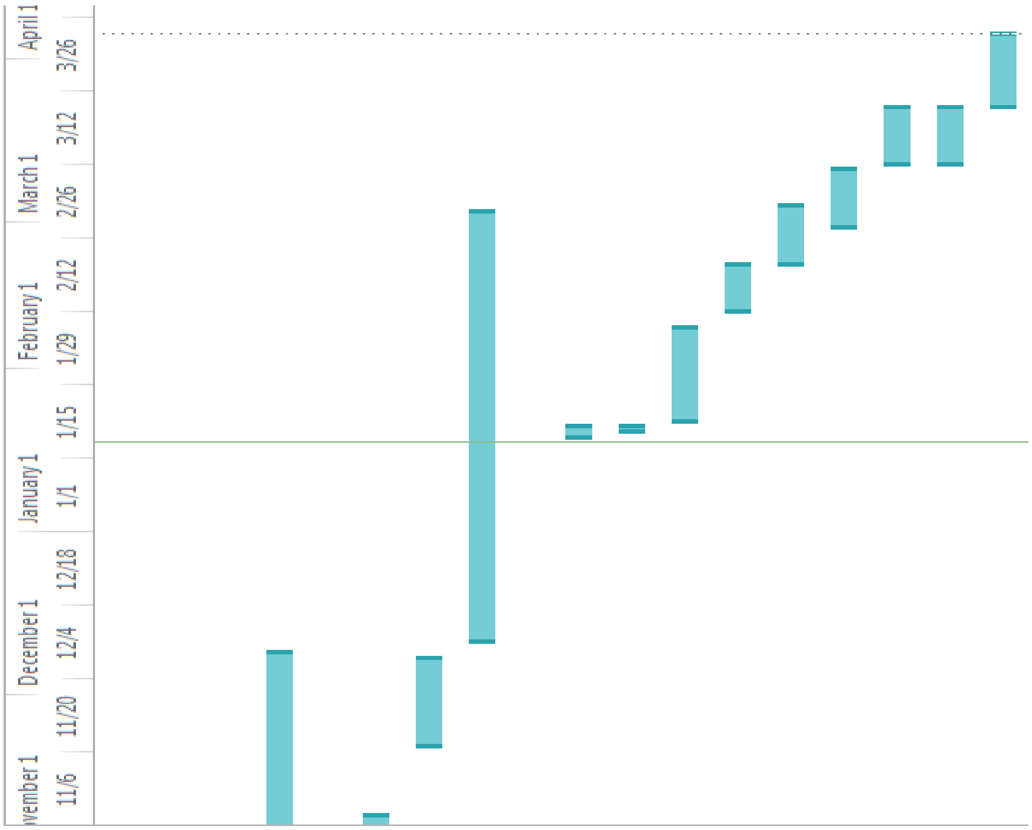

Table 1: Updated Gantt chart for spring semester

6. Progress/Changes Made

The overall progress of the project has been to determine an effective way to carry out the educational kit. Several problems mentioned prior was due to the poor fuel delivery in the system. After communicating with the fuel cell lab in Brazil, it has been decided to use an advanced fuel delivery system. The HyrdoFill mechanism utilizes electrolysis to produce the hydrogen fuel component and will be connected to the system. In order to deliver the fuel component to the cathode, an air pump (Petco 9902) will be used to pressurize air into the system. To prevent carbon dioxide poisoning in the cell, the pressurized air will be filtered through a 30% KOH filter solution. The addition of these fuel components will increase safety of the kit due to the elimination of wires and electronics in water for electrolysis. These components will also regulate flow that will be brought to the system at a consistent rate which can be monitored. The electrolysis set up did not produce enough pressure in order to overcome the thermal fluid energy losses within the configurations. The new delivery system will overcome these losses and create fuel production at a faster rate compared to the old electrolysis set up that was used in the kit.

The team has also decided to make some changes in regarding the design of the configurations that will be included in the kit. The current set up uses a parallel configuration as shown in Figure 2 below.

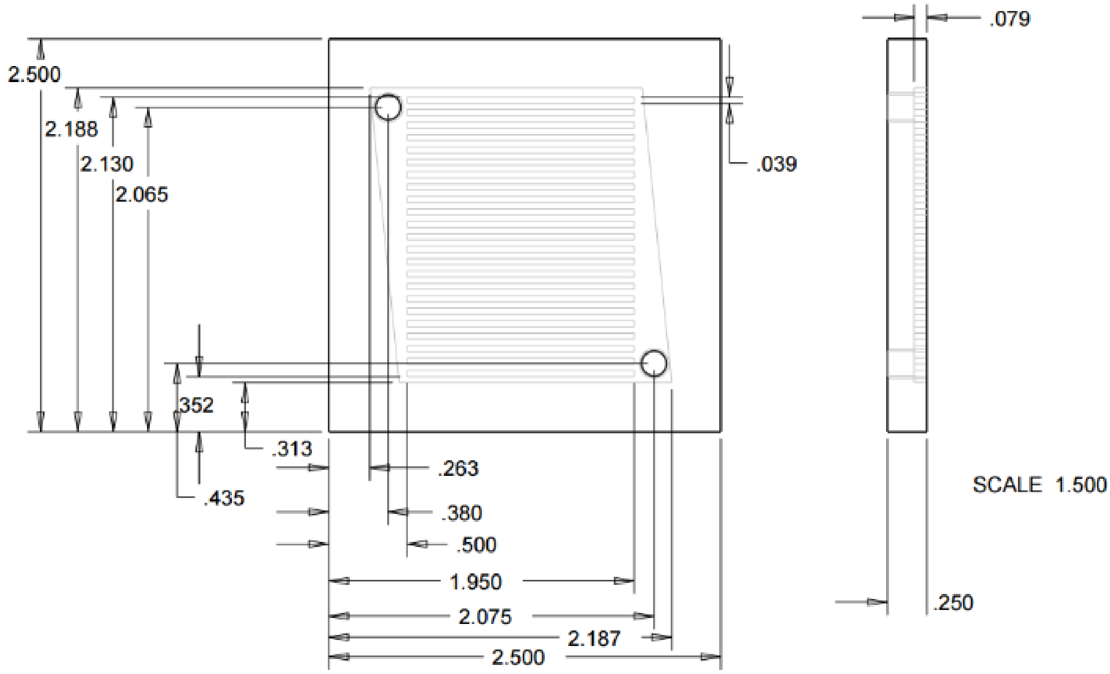

Figure 2- CAD drawing of current parallel plate

The team has decided to not use this plate in the kit due to several reasons. First, the plate is used, resulting in inconsistencies when comparing to the new configurations that the team has developed. The volume and surface area where the fuel flows also must maintain consistencies in order to receive accurate comparison results. As observed in the figure above, the design of this plate is not uniform and is specifically designed for a parallel flow. To create the new configurations such as the serpentine design, the flow must have only one continuous path. This design above was not abdicable for a one path flow due to the extra space in the inlet and outlet regions. Figure 3 below shows a new design of the parallel configuration that the team has developed.

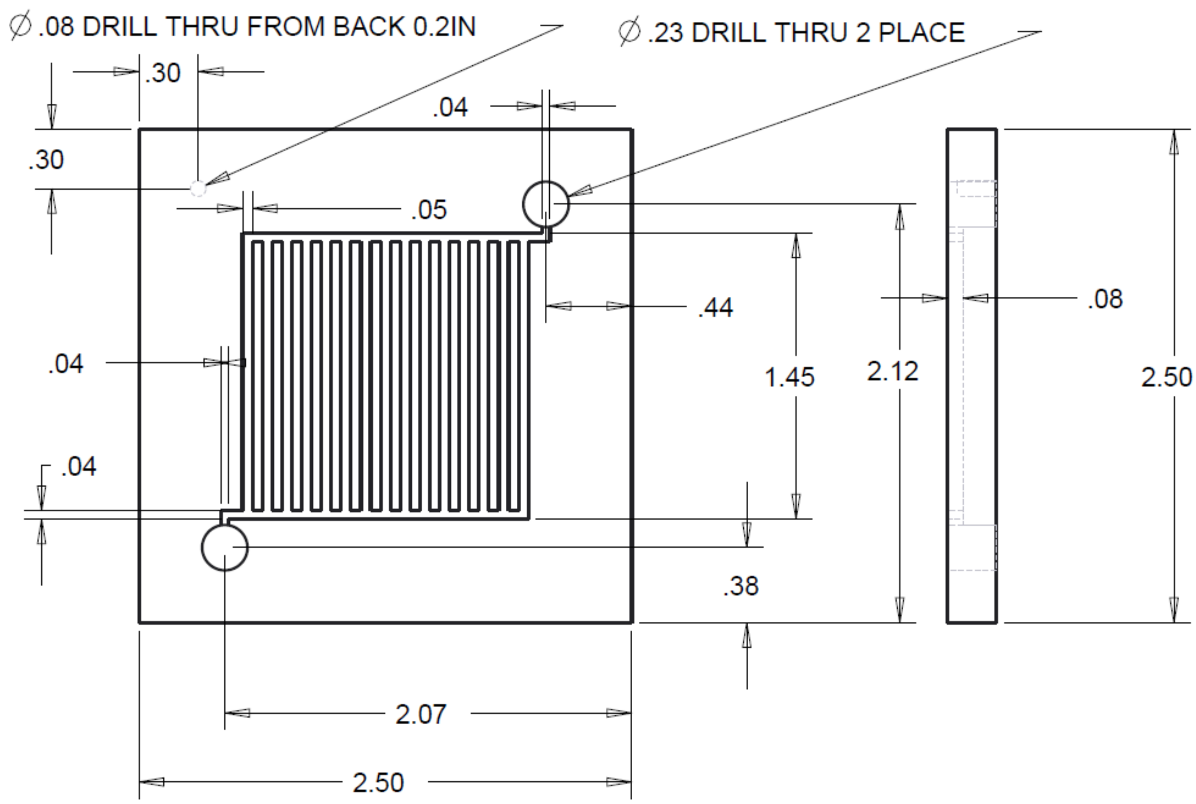

Figure 3- CAD drawing of new parallel design

This design is a cleaner design where the inlet and exit sections start as a one path flow that flows into the multiple path flow of the parallel design. By having the inlet and outlet sections separate from the design of the plate, the serpentine plate can also use this base design and not have inconsistent areas. The prior attempt to create drawings for the serpentine design based off of the old parallel plate has also created machining complications. This base design in Figure X has been used to carry out the other configurations that will be used in the kit. The team has also discussed with the advisor that the interdigitated design would not be included in the kit. The design is very similar to the parallel design and would produce similar results. Due to this kit being for experimental educational use, the team has decided to add a third configuration that is much different to produce drastic performance results. Figure 4 shows the team's box design that has been created.

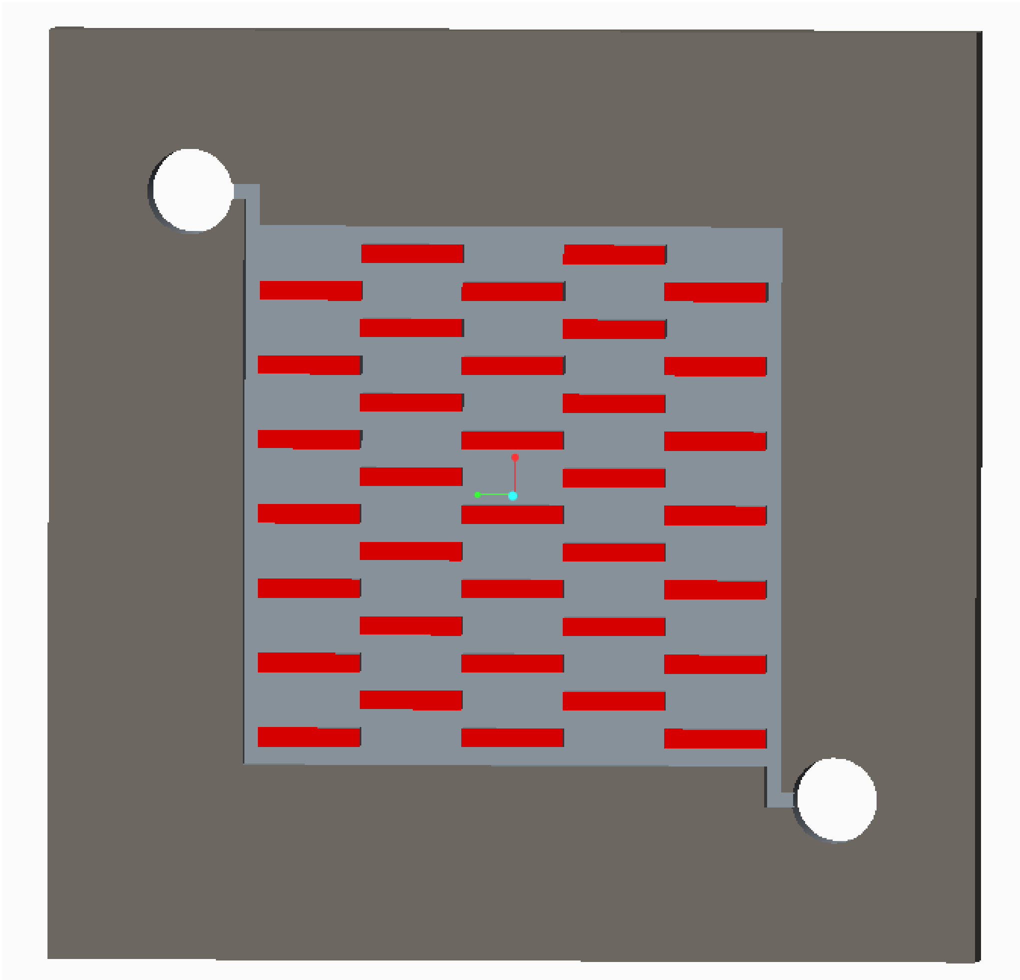

Figure 4- CAD image of box design

The box design has less contact surfaces when compared to the other designs due to the spacing of each bar. The design was taken from the parallel design with new omitted sections in the bars. The less contact surfaces will create less diffusion and therefore a lower performance output. The team is hoping that this produces drastic results that are different from the parallel design in order to show the importance of configurations when undergoing experiments.

Other minor changes and updates have been to incorporate banana plugs in the plates, load box, and a thermocouple adapter. These new components will be useful during the experimental process. The banana plugs will be plugged into the back of the plate to connect the electrical wires to the load box. The plugs will keep the system secure during use and adds a clean look without the use of loose wires. The load box will allow the user to change the resistance going through the circuit. By using the voltmeter, the user can measure the appropriate voltage through the system and then calculate the appropriate current with the corresponding resistance. Power and current plots can then be constructed to see the performance curve of the cell. The thermocouple will allow the user to measure different temperatures on the cell to see where the current density is the highest.

7. Constraints

The proposed functionality of the fuel cell requires multiple components such as delivering pure Oxygen and Hydrogen to the system. As mentioned in the background research a method of electrolysis will be used to create Hydrogen. This method requires the use of an electrolysis machine that produces 99.99% pure Hydrogen called the HydroFill Pro. A customer requirement was to have all components to fit inside the fuel cell kit resulting in a desire of fewer components. Any part of the system that requires extra parts or components will create problems of keeping this desire satisfied.

Safety is another constraint noticed from assessment. The fuel kit product will be used as a learning tool to deliver to students on how fuel cells function and what parameters affect functionality. The system will deal will pressurize gasses and electrical components being used in a classroom setting putting safety at a high priority. This puts constraints on material selection and assembly to ensure that the system is safe during operation. The material selection also impacts the resistance to weather where oxidation or material failure can occur. It is desired for the kit to be durable during its lifespan for safety and practical reasons.

8. Conclusion

Based on the fact that our fuel cell will be for educational use, and safety is most important, a better gas system delivery method was chosen. The hydroStick Pro which uses the principle of electrolysis to supply 99.99% hydrogen was chosen over pure electrolysis complemented with an air pump which supplies oxygen to the system as mentioned in the report. Also, due to the progress made from last semester, a more detailed design was made in order to machine the necessary parts without confusion. Due to the new components we plan to input, we plan to have a new light weight case which will house all the components with a view of potential commercialization of the kit in mind. The plates has also been ordered to make sure we are on the right track to finish the project at the right time based on our schedule. At the end of the semester we hope to deliver a safe and functioning educational alkaline membrane fuel cell kit that demonstrates the effects of flow configurations on the fuel cell's performance for educational use.

References

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