Design for Manufacturing Reliability and Economics

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

Table of Tables

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1.0 Introduction

There are many different shapes, sizes, and applications of a fuel cell that are available. Team 16 has focused on incorporating how a fuel cell works into a fun experimental kit for learning. The fuel cell kit has been designed with the consideration of who the potential targeted consumers may be. The purpose of this kit is to demonstrate from how a fuel cell operates to how a fuel cell can be integrated with other green energy systems. People that would be operating our kit are in the education field from junior high school to college learning levels. Safety, convenience, and affective learning have been the main components in making the final design of the kit. The kit contains all components as well as multiple flow configuration plates to test the importance of flow within a fuel cell. The design of each plate was carefully chosen to show different results when finding the performance curve of each plate. The addition of different flow plates in the kit has been the key component in making this kit different from other fuel cell kits on the market. Multiple operation manuals are inclusive and designed for the different learning levels. Alongside the versatility of the kit, materials were chosen to satisfy low cost budget, safety, and long life use of the cell making the product more appealing to a consumer.

2.0 Design for Manufacturing

In order to assemble the kit for trail, some items need to first be considered and prepared before assembly. To operate a fuel cell, hydrogen gas and oxygen must flow into the cell for functionality. KOH is an electrolyte that is utilized for functionality for an alkaline membrane fuel cell. The membrane enables for the fuel cell to run properly. KOH must be handled with care and therefor it is important to use protective gloves and eye wear. The membrane must be soaked in the KOH solution before the cell can be assembled. It is recommended to soak for long periods of time so the membrane does not dry out too quickly during operation. The Hydrostik pro is a device that uses electrolysis from distilled water to produce the hydrogen gas in the kit. The Hydrostik pro takes about 4 hours to fill the cylinder, therefore this must be considered before operating the cell. The top bath tank of the Hydrostik pro must be filled to the fill line with distilled water while the cylinder is tightly screwed in for fill. The multimeters must carry 9V batteries and it is important that these are working correctly in order to produce accurate readings. Once the cylinder is fully filled, the assembly can be carried out, starting with the fuel cell assembly. Figure 1 below illustrates an exploded view of the fuel cell when it is opened.

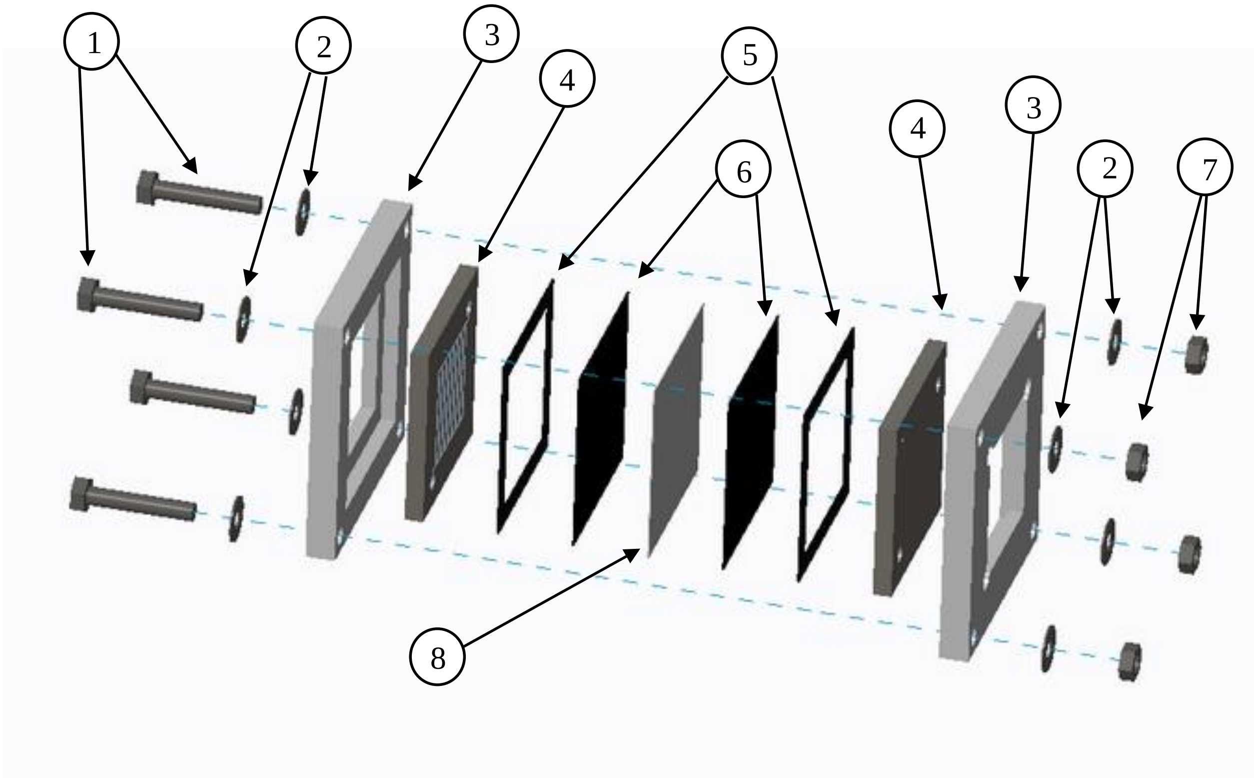

Figure 1: Exploded view of fuel cell

The fuel cell consists of 8 different components. Table 1 below lists out the different components with the amount of parts needed.

Table 1: Bill of materials of fuel cell

Part Name	Part Number	Quantity	Material
Mounting Bolts	1	4	Steel
Washers	2	8	Steel
Mounting Bracket	3	2	Polycarbonate
Cell Plate	4	2	Stainless Steel
Gasket	5	2	Rubber
Electrode Anode/Cathode	6	2	Electrode 40% Carbon Paper
Nut	7	4	Steel
Membrane	8	1	Paper

A mounting bracket (3) is selected and laid flat on the table where a fuel cell plate (4) is inserted in for a tight fit. The rubber sealing, or gasket will fit around the border of the plate so that it does not interfere with the flow configuration. The electrode (6) fits on top of the gasket where it now covers the flow configuration. It is important to note that the electrodes must be cut with a razor blade carefully to the size of the plate. The soaked KOH membrane (8) is then added on top of the electrode, the same procedure of placement is done down to the other plate in the same order (electrode, gasket, plate, bracket). As the cell lays flat on the table, the mounting bolts (1) will be placed in the four available holes where the nut will be screwed in tightly on the other end. The bolts should be torqued down the same weight for each screw, and it is recommended to first hand tight them then tighten them down with a wrench. The filled Hydrostik cylinder is connected to the pressure regulator which can be connected to the tubing. The tubing will lead to one end of the fuel cell and will be the anode. The oxygen pump will be connected from the tubing to the other side of the cell and be the cathode. The bottom remaining holes on both sides of the cell are used for water disposal where extra tubing is used to lead into a sink. The fuel cell is now in operation and the load box must be connected in order to take voltage and current readings. As mentioned, the anode side of the cell will be connected with a red banana clip where there is a plug in the exposed plate. The cathode is done the same way with the black wire where they are inserted into PORT 1 of the load box. The multimeters can be connected into the voltage port and the current port to then start gathering data. The fully assembled fuel cell in operation can be viewed below in Figure 2.

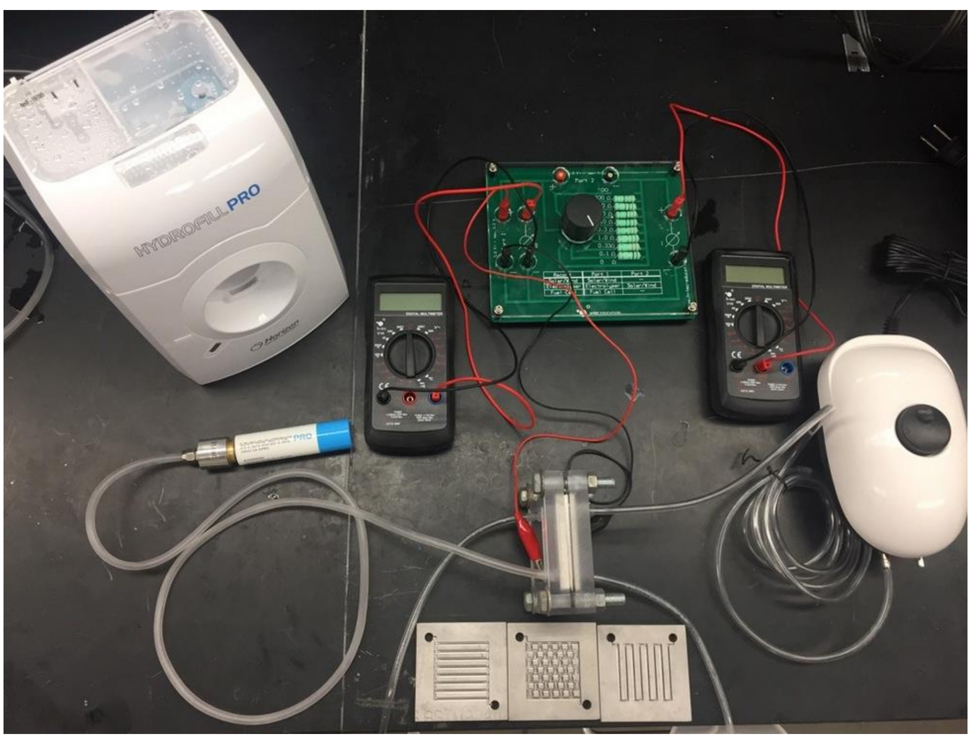

Figure 2: Fully assembled fuel cell in operation

The assembly of the kit as seen in Figure 2 was performed at the center for advanced power systems at FSU. The assembly can take up to 15 min for one person to preform, however preparation can take up to 4 hours. The Hydrostik must be filled and the membrane must be soaked prior to starting the kit. The time it took was about anticipated since the fuel cell is a basic build with only several components. The Hydrostik system takes a sufficient amount of time to prepare for operation, nevertheless assembling of the cell is done simply and quickly.

Overall, there are 25 components within the fuel cell without the connection of fuel and testing tools. The fuel cell requires 4 bolts, 8 washers, and 4 nuts making the number of components relatively high. The bracket design could have been simplified by incorporating another tightening device instead of using bolts since they require a nut and a washer for each bolt. A possible idea of using a skewer, a one component tightening device (used for bike wheels) could be incorporated to limit the components down to 13.

3.0 Design for Reliability

Due to this educational kit being for educational purposes reliability is of upmost concern. The kit will be used in classroom/lab settings where time is a constraint. If the fuel cell does not perform or has issues operating, the effectiveness of the experiment will lose value due to loss of time. The team wants so that the product user can easily hook up and operate the fuel cell with no issues and proceed with the desired experiments that were scheduled for learning during class period. In experiments any accident can happen and therefore the design of the fuel cell has been constructed accordingly. The mounting bracket is made out of polycarbonate material, which demonstrates good material properties such as toughness and thermal qualities. If the cell were to fall on the floor, the brackets would protect the fuel cell internals by having a high impact strength of 16ft-lbs/in. When the fuel cell operates it generates heat, therefore the mounting bracket also holds as an insulator for safety and efficient operation. In order for the fuel cell to operate safely and efficiently there are some precautions that must be addressed to reduce failure. A failure mode effects analysis (FMEA) has been added to the appendix section of this report to see a step by step approach that identifies and solves all possible failures that are associated with operating the fuel cell.

A main concern when operating the fuel cell and that results in safety hazards are the use of compressed gases, handling KOH solution, and the heat of the plates. As observed in the FMEA, insuring that the gas lines are all connected securely is very important so that the cell can operate effectively and safely. It is important to note that when dealing with compressed gasses such as hydrogen, that it is flammable. When hydrogen is ignited it produces a flame that cannot be seen with the eye. KOH or Potassium Hydroxide is a hazardous material that emits fumes that can burn eyes and cause blindness. The cell plates can reach temperatures of 100°C and can burn the skin on impact. Before using the cell, it is important to be knowledgeable on these accidents that could be caused. The fuel cell kit will include procedures that alerts and educates the user on the hazards that are associated with the functionality of the kit to increase safety.

After the possible hazards are addressed, the user will now be aware on what to check before and during operation. When the fuel cell is used there must be associated maintenance to upkeep the safety. The gas lines are connected to the cell with plastic nozzles that are stuck into the lines. They are made out of plastic and after many uses the threading will warp and there will not be a tight fitting. An estimated of 100 uses of screwing in and out of the gas tubes will cause an unsecure connection, or a leak in the cell. As the user, it is important to again acknowledge the associated risks with a gas leak. The kit will include multiple nozzles to replace the gas lines as well as extra tubing in case they rip when new nozzles are applied. After each use of the cell a new membrane is recommended to be replaced before running again. It has been estimated that the cell can run for about 25 min before the membrane dries out and either burns or cracks. By applying a new soaked membrane, the next test will run efficiently and produce credited results. The kit will also include a stack of 500 sheets of membrane paper so that the cell can be ran a high number of times. The gaskets are cut to fit the plates as seen in Figure 1. They are made out of rubber and will last about 100 times during operation before they rip from normal wear and tear of assemble and disassemble of the cell. The kit will also contain a 12in by 12in sheet of gasket rubber that can be cut to size for future use. Stainless steel has been a choice of the cell plates due to the corrosive resistive properties of the metal. The metal will not corrode as long as it has been thoroughly been rinsed and dried off after the experiment has been performed. With correct maintenance, the cell kit should be able to run for about 500 times before new replacement parts need to be ordered.

4.0 Design for Economics

The main objective of this project was to investigate the importance of flow configurations on a fuel cell's performance. Intensive research has been conducted in order to fully understand the importance of the design of a plate configuration on the performance. This project has promoted a high understanding of thermal fluids systems incorporated into a fuel cell. The fuel cell is more than just a chemical reaction and the purpose of this kit will educate the user on these important aspects. As well as a thermal fluids system and understanding how fuel cells can become more efficient, the kit also includes information on green energy systems. For the college experimental procedure, fuel cells are shown in large scale applications. With full understanding of optimization and functionality, users will get more out of this fuel cell kit than just assembling and operating a fuel cell. The importance of these aspects are to compare to other fuel cell kits that are currently on the market. There are many fuel cells kits that can be purchased however, there are no other kits that contain multiple flow configuration plates that can be interchanged and tested to compare performance. This kit can be used for many different age groups, making it available to more than one specific group. Other kits do not show the versatility and high educational promotion as team 16's specific fuel cell kit. An objective of this project was to create the kit and intend to commercialize it. This objective has put the team in an entrepreneurial mind set to create a kit that was different than the current kits on the market.

Due to the kit having more components, it will cost more than a standard fuel cell kit. The team has used a previous constructed fuel cell kit that included one configuration. Team 16 designed new cell plates, included a self-sufficient fuel delivery system, and measuring instruments. The previous kit cost was $205.36, and Team 16's total budget was $1000 which was achieved with a $68 over budget. The fuel delivery components and the stainless steel sheet were the most costly portion of the overall money spent on the project. Figure 3 demonstrates the total budget breakdown of Team 16's addition to the pre-existing kit.

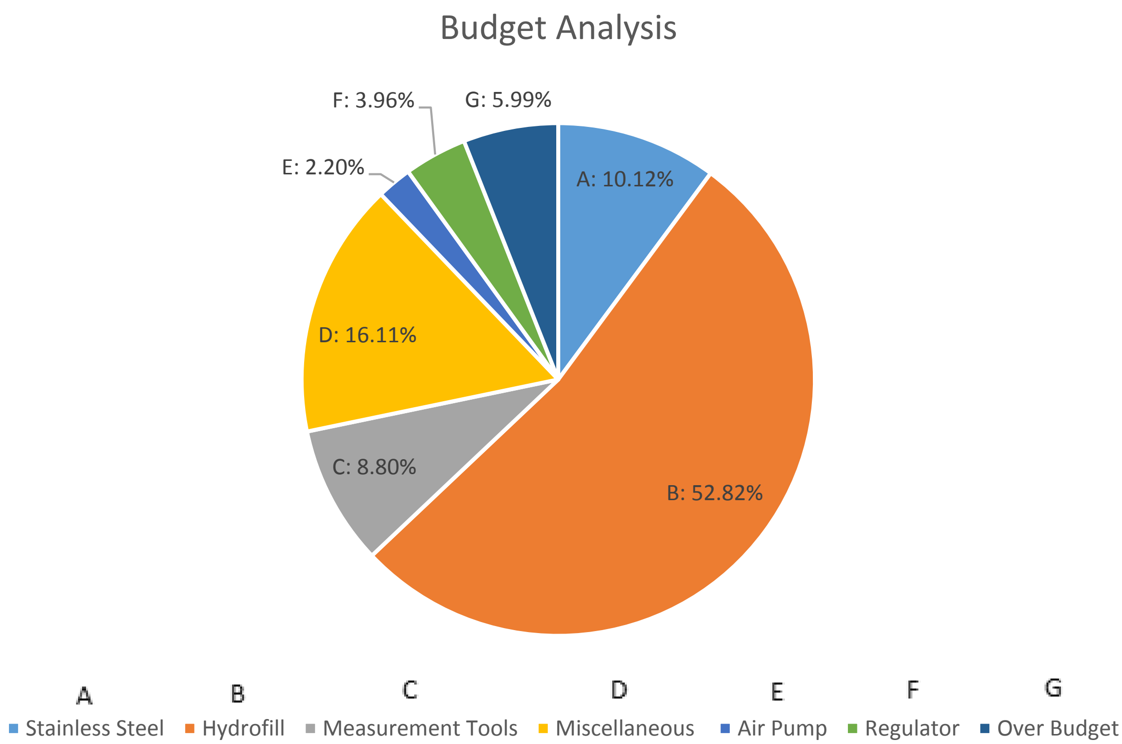

Figure 3: Budget breakdown of fuel cell

Section B is denoted as the Hydrofill, which was the hydrogen delivery for the fuel cell. This component contributed to 52.82% of the overall cost of the spent money of the $1000 budget. In order to make the cell self-sufficient, this device was the solution and was a necessary purchase. As compared to other cells they do not provide effect gas delivery systems, therefore it has been decided that this was the most important purchase. Section C, labeled as measurement tools include the resistor load box and the multimeters. Section D, incorporates all the miscellaneous items that were purchased to make this project possible. Items such as extra tubing, nozzles, paper, and wiring are some miscellaneous purchases that were made and are in this category. Section G is the over budget, the team has considered the $1000 budget and have tried to stay in this range, however all purchases were necessary for a successful product. The 6% over budget was manageable and with proper discussion and explanation the extra $68 were funded.

With the budget considered the total cost of team 16's kit was $1273.36. This number is considerably high when thinking of the total price of a fuel cell. However, as mentioned the extra components and versatility of this cell which is incorporated into a portable kit holds this high cost value. An example of another cell on the market is Dr. FuelCell Science Kit and is shown in Figure 4.

Figure 4: Dr. FuelCell Science Kit

This kit costs a total of $395 plus shipping and handling. The kit includes a gas delivery method, however is not as efficient as team 16's kit. This kit utilizes an electrolyzer that is powered by a solar panel. The gases coming from the electrolyzer is at a very low and unknown pressure. Team 16 has an efficient, consistent, and regulated pressure of the gases that are being fed into the cell. For testing purposes this is an important value when testing the efficiency of a fuel cell. This kit most importantly does not come with other flow configurations and is not meant to be taken apart. Team 16's kit is hands on for fully assemble and disassemble of the fuel cell. For educational purposes this is an extremely important aspect when purchasing a fuel cell kit. Team 16's kit also contains a nice portable case that can be easily transportable, as viewed in Figure 5.

Figure 5: Team 16 educational kit

The material components incorporated in this kit are of better quality than the Dr. FuelCell kit as seen in Figure 4. Team 16's kit is expected to last longer and have an overall higher purpose than the current kits available. Multiple flow configurations, efficient gas delivery, multiple experiments for different ages, replacement components, high quality materials make this kit sit at its higher cost and shows that this price is reasonable to the consumer when purchasing. The table below in Figure 6 shows a price comparison of Team 16's kit with Dr. FuelCell kit and the previous standard kit without gas delivery and multiple flow configurations.

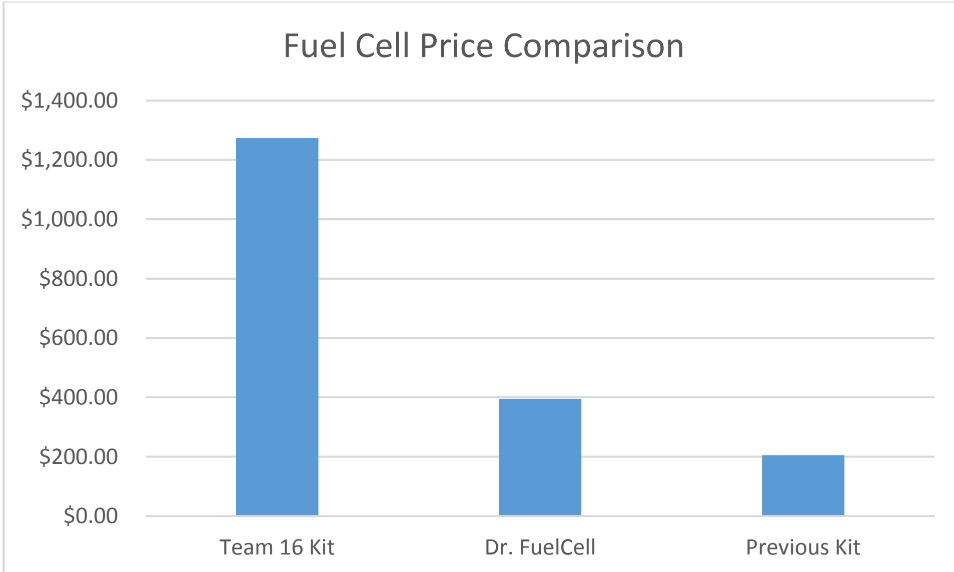

Figure 6: Fuel cell price comparison chart

Since Team 16's kit cannot be directly compared to another available product since it is innovated, the price between the previous kit can be compared. If Team 16 where to produce strictly a working fuel cell on the market (as named previous kit) it would be cheaper to purchase than Dr. FuelCell.

5.0 Conclusion

Team 16 has designed a fuel cell kit for educational purposes to demonstrate more than a functioning fuel cell. The cell has been designed for effectiveness, long life, and safety at a reasonable price for what the consumer is really getting out of the kit. With quality materials that demonstrate good properties the kit will be safe and reliable. A failure analysis has helped reduce the risk of failure or injury that is associated with the use of the kit. Extra components have been added to add to the longevity of the kit to give further reasoning for the higher cost of the overall kit. Team 16's kit is a good investment to the academia field where a costumer would be left nothing but good results. It is hoped that schools will invest in this product to encourage students the importance of alternative energy and open new doors for green energy systems.

Appendix

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended
Preparation	HydroStick empty	No power output	5	Hydrofill out of Water, Not plugged in	8 3	Double Check System	10	400 150	Make sure Hydrofill is working and allow time to charge
Preparation	HydroFill Malfunction	Red Light Indicator on	10	Using non-distilled water	1	Buddy Check, Only use distilled water	4 10	40 100	Pour apple acid into tank to neutralize ions
Preparation	Dry Membrane	Reduced Power Output, Burnt Membrane	5 8	Not sufficiently soaked	4	Make sure properly soaked	6	120 192	Cut out new membrane if necessary
Assembly	Mismatched Parts	No power output, Leaking Fuel	5 10	Human Error	6	Buddy Check, Follow Instructions	10	300 480	Dissasemble and Reassemble Carefully
Assembly	Bolts not tightened	Leaking Fuel	8	Improper Tools, Human Error	4 6	Tighten bolts using correct sized wrench	10	320 480	Tighten bolts using proper wrench
Operation	Leaking Gases	Undesired noise, Fire Hazard	2 10	Damaged tubing, Bolts not Tightend	2 6	Inspect tubing before each use	8	32 480	Replace tubing if cracked, hard, or discolored
Operation	Fuel Cell too Hot	Melted housing, Burnt Membrane	10 10	Unregulated gas flow, High ambient temperature	3 3	Gradually inc. flow rate, operate in A/C if necessary	8	240 240	Housing or membrane may require replacement