Needs Assessment

Team 16

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

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ABSTRACT

The goal of the fuel cell project is to investigate the performance of a proposed alkaline fuel cell membrane (AMFC) and optimize it for an education kit for high school and college level laboratory fuel cell functional demonstration. This investigation involves learning from the flaws of the current fuel cell kit and finding new ways of improving the performance of the fuel cell. An understanding of how flow channels affect performance will contribute a key factor in the new design of the fuel and oxidant delivery components. Senior design group 16 members have previously chosen roles, responsibilities and have emerged with a code of conduct that we are diligently going to follow. A lot of background research has been carried out by the group members on how the design will be carried out. A list of goals and objectives were created to achieve optimum success. Design constraints have also been identified and are related to budget, resources available, and process product generation. A methodology for how this design problem will be solved has been outlined and a schedule of how tasks relevant to the described methodology will take place throughout the semester. This needs assessment will serve as a vital foundation for how the design will be at the end of the project.

1. Introduction

Advancements in the development of fuel cells have been slow relative to other power generation systems like combustion engines, wind power, and hydropower. The highly demand of more clean and sustainable power generation brought a new focus in the development of fuel cells. In practical application, fuel cells operate at lower efficiencies than the expected value. Therefore most researchers are dedicated to improving their performance. With the development of computer based software and knowledge in fluid dynamics, a previously developed cellulose-based AMFC prototype will be studied and modified.

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

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.

2.3 Fuel Cell Operation

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]

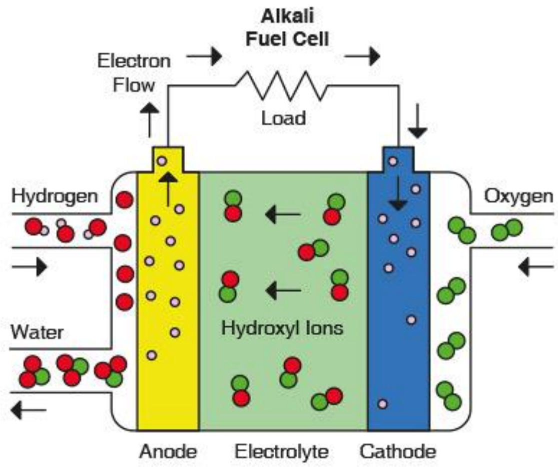

Figure 1: A diagram depicting an alkaline fuel cell [3]

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]

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

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.

2.4 Advantages and Drawbacks

There are several advantages to using alkaline fuel cells. Generally, fuel cells only emit pure water. If contained and managed properly, the fuel cell can also prove to be a source of clean water in addition to providing clean energy. Furthermore, fuel cells are quiet. Also, when compared to other types of fuel cells, alkaline fuel cells offer relatively high current density. This is due to the fact that the alkaline solution allows for quicker chemical reactions than acidic membrane fuel cells. It is also due to the fact that alkaline fuel cells can safely operate at temperatures ranging from 100° to 120°C, which is much higher than other fuel cells. Higher temperatures facilitate faster chemical reactions and increased diffusion rates. [3]

The main drawback to using an alkaline fuel cell is a phenomenon known as carbon dioxide poisoning. This occurs when the fuel being used is not pure. An example would be using air instead of pure oxygen. When carbon dioxide enters the fuel cell, carbonates form. These carbonates block and clog the pores in the anode and cathode. This blocking slows the rate at which diffusion occurs until it eventually stops the process altogether. The chemical reaction which causes this phenomenon at the anode and cathode can be seen below in equations 3 and 4, respectively. [4]

$$CO_2 + 2KOH \rightarrow K_2CO_3 + H_2O \quad (3)$$

$$2OH^- + CO_2 \rightarrow CO_3^{-2} + H_2O \quad (4)$$

The formation of these carbonates, potassium carbonate (K_2CO_3) and carbon trioxide (CO_3^{-2}), create a need for pure hydrogen gas and pure hydrogen gas in order to allow the fuel cell to remain efficient for long periods of time without maintenance. Purifying and collecting these gasses is a relatively complicated and sometimes expensive process. The best way to obtain pure oxygen is to use cryogenics. If air is cooled to -183°C, pure oxygen will liquefy, and it can then be collected and returned to a gaseous state. This method, however, is expensive and complicated. A simpler method to collect pure hydrogen is to use electrolysis in order to separate water into pure hydrogen and pure oxygen. A diagram of this process, as well as the chemical reactions involved, can be found below in figure 2. [6]

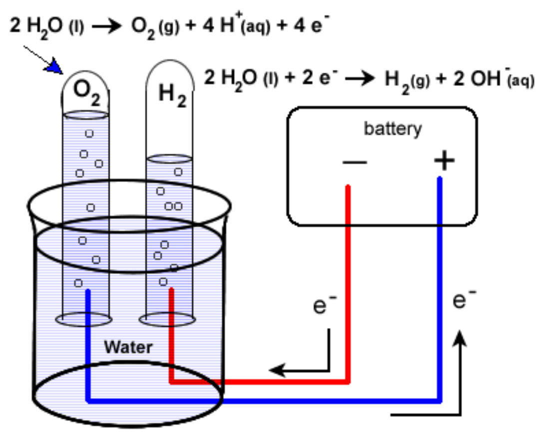

Figure 2: A diagram showing the electrolysis of water into hydrogen gas and oxygen gas [6]

The figure above shows a relatively safe and inexpensive way to produce pure fuel for an alkaline fuel cell. This method is one that could be easily used in order to power an at home fuel cell kit. As seen in the diagram, electrons leaving the battery from the negative terminal create a negative electrode in the water. This causes a reduction reaction (electrons gained) of H_2O, and hydrogen gas escapes where it is collected. The blue wire then becomes an effective positive electrode or cathode, and H_2O is oxidized. This releases pure oxygen gas which can be collected. It is important to note that pure water is a very poor conductor. This is due to the fact that pure water molecules have no free electrons to transfer electrical current. This slows down the process of electrolysis. In order to speed up this process, salt or any other common water soluble electrolytes can be added to the water. [6]

2.5 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."

2.6 Goal Statement and Objectives

"Deliver a 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 model for commercialization of the kit.

2.7 House of Quality

The house of quality is used to gather information and rank what aspects are more important than others. This purpose is helpful when dealing with budget and customer requirements. As a part of this project, the AMFC educational kit system is expected to be commercialized and sold on the market. A house of quality was created to see what aspects are desired from the outcome of the product so the team can lead focus on these aspects. This knowledge gives the team an advantage for the kit to be successful on the market in the future.

Table 1: House of Quality for Fuel Cell Kit

Engineering Characterisitcs							
Improvement Direction		↓	↓	↑	↓	↑	↑
Customer Requirements	Importance Weight Factor	Weight	Leaking Probability	Material Strength	Time to Set up	Accuracy of Volt Meter	Weather Resistance
Contains all Parts	**5**	9	0	1	8	0	0
Five-Year Lifetime	3	2	3	9	2	4	9
Test effects of flow structures	5	0	7	2	0	9	2
Portable	4	9	4	5	5	0	0
Tool-less installation	2	4	7	4	8	0	0
Efficient	4	1	9	7	2	9	0
Raw Score (527)		99	110	98	90	93	37
Relative Weight		18.8	20.9	18.6	17.1	17.6	7.0
Rank Order		2	1	3	5	4	6

From Table 1 above it is possible for team 16 to assess their priorities when pursuing the redesign of the AMFC kit. The engineering characteristics are shown with their corresponding importance scores totaled at the bottom. It can be seen from the rank results that leaking probability was rated with the highest priority when compared to the customer requirements. This tells the team that the kit must not leak so the fuel cell can function properly. From these results the kit will not be a successful product if it has a high leakage probability, therefore the team must ensure that the system will not leak easily in order to ensure functionality.

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2.8 Constraints

By considering the HOQ in Table 1, the project has customer requirements which result in several 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 pure Oxygen and Hydrogen. This method requires an outside power source such as a battery to make the process possible. A customer requirement was to have all components to fit inside the fuel cell kit resulting in a desire of fewer components. Electrolysis method requires more components of the system, resulting in new problems in making storage in the kit more difficult. Size and weight from the HOQ have shown that this is a major constraint due from the need statement to deliver a mobile kit. 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.

3. Methodology

In order to successfully produce an alkaline membrane fuel cell on the market, it is important to set specific objectives. Foremost, the team's goal is to take a pre-existing kit and optimize it in a way that it becomes a better learning tool. In order to do this, it is important to understand the parameters that affect the efficiency of the fuel cell. The noticed constraints and background research has helped the team form certain goals for the project. To optimize the fuel cell, the team will redesign the fuel and oxidant delivery components, or the flow channels. Different flow designs will be incorporated into the kit so during application users can visually see the effects on the voltage produced. A series of demonstration experiments can be done due to the versatility of the kit, allowing users to learn the effects of flow structures on a fuel cell's efficiency. The kit will contain all necessary parts and include a specification sheet which will allow a higher success rate for commercialization to educational institutions on the market. The objectives above have been organized and summarized in Table 2 below.

Table 1: Team 16 Objectives

Research and prototype planning of kit redesign
Flow Channel Designs
Budgeting
Construction-machining and assembly
Testing
Assessing and improvements
Final presentation of results
Commercialize
Sell on Market

4. Conclusion

An alkaline fuel cell is a device that uses a source of fuel, such as hydrogen, and an oxidant to create electricity from an electrochemical process in which its electrolyte is alkaline e.g. potassium hydroxide (KOH). These cells were costly at the beginning stages but different research focusing on their optimization reduced that cost. Alkaline Fuel Cells in the market today have a power output of 300 Watts to 5kW per cell with an efficiency of about 70%. The only by-products are heat and water. They are very stable and can operate for several thousand hours within the temperature range of 90-100 C.

The objective of this project is to improve the design of an alkaline membrane fuel cell (AMFC) educational kit for high school and college level laboratory demonstration, and also to develop a model for commercialization of the kit. One of the major advantages of an alkaline fuel cell is that it doesn't pollute the atmosphere with carbon dioxide as other means of energy like fossil fuels and coal do. The biggest challenge of the fuel cell is cost, it cannot yet compete economically with more traditional energy technologies

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