HYDROGEN FUEL CELL

ME 309 – Mechanical Engineering Individual Project

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Declaration

I declare that this report does not incorporate, without acknowledgement, any material previously submitted for any other Degree or Diploma to the best of my knowledge and belief, it does not contain any material previously published or written by another person or myself except where due references are made. It has not been accepted for any other course and is not being concurrently submitted to any other person.

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ABSTRACT

Fuel cells generate electricity by an electrochemical reaction in which oxygen and a hydrogen-rich fuel combine to form water. It’s an electro-chemical energy conversion device that produces electricity, water, and heat. Existing fuel cells use hydrogen that stored in a separate pressurized tank. This occupies some additional space. Furthermore when delivering hydrogen through an expansion valve its pressure drops. Due to the pressure drop the efficiency of the cell is reduced. In this project the goal is to develop a fuel cell that sores hydrogen in the cell itself. The report consists of experimental methodology that were followed to fabricate and test the conceptual design.

CONTENTS

1 INTRODUCTION

1.1 Background

A fuel cell produces electricity through a chemical reaction, but without combustion. It converts hydrogen and oxygen into water and electricity is also generated in the process. It's an electro-chemical energy conversion device that produces electricity, water, and heat.

Fuel cells operates much like a battery, but they don't require electrical recharging. A battery stores all of its chemicals inside and coverts the chemicals into electricity. Once those chemicals run out, the battery dies. A fuel cell, on the other hand, receives the chemicals it uses from the outside. Therefore, it won't run out. Fuel cells can generate power almost indefinitely, as long as they have fuel to use.

The reactions that produce electricity happen at the electrodes. Every fuel cell has two electrodes, one positive, called the anode, and one negative, called the cathode. These are separated by an electrolyte barrier. Fuel goes to the anode side, while oxygen (or just air) goes to the cathode side. When both of these chemicals hit the electrolyte barrier, they react, split off their electrons, and create an electric current. A chemical catalyst speeds up the reactions here.

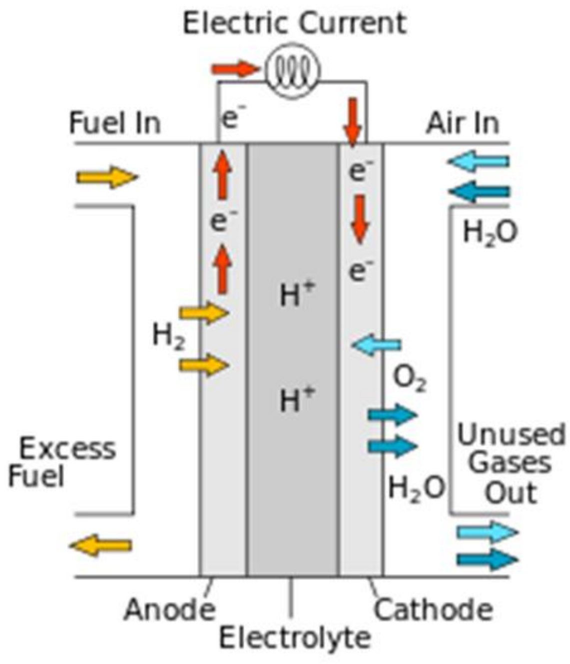

Figure 1.1 : Schematic diagram of fuel cell

1.2 Problem

Existing fuel cells use hydrogen that stored in a separate pressurized tank. This occupies some additional space. Furthermore when delivering hydrogen through an expansion valve its pressure drops. Due to the pressure drop the efficiency of the cell is reduced. Since conventional hydrogen fuel cells use a proton exchange membrane, the cell cannot work under high pressures.

1.3 Solution

If a fuel cell design is developed to store hydrogen in the fuel cell, the efficiency can be improved while reducing its size and complexity. The solution is to generate hydrogen via electrolysis and store it in the cell for later use. The idea is to use a separate stainless steel electrode for electrolysis and another electrode with a platinum coating to draw the current from the cell. Reaction of hydrogen is catalyzed by the platinum coating. Separate stainless steel electrode is used to withstand high charging currents. These kind of cells have a longer life and less maintenance is required. However the voltage of the cell depends on the pressure inside the cell. Therefore the cell must have an ideal working pressure. Another drawback is that, this cell uses a platinum electrode as a catalyst.

1.4 Objectives

1. To develop a hydrogen fuel cell without a separate hydrogen tank.
2. To identify pressure vs voltage characteristics of the cell.
3. To compare the energy density with lithium polymer batteries.
4. To find the ideal working pressure of the cell.
5. To find substitute electrode for platinum.

2 METHODOLOGY

2.1 Concept

At the start of the project the concept has to be tested before modeling and fabrication. To test the concept a simple apparatus was built and initial tests were carried out. Various types of electrolytes and electrodes were tested using this apparatus.

2.2 3D Modelling

All 3D modeling in this project were done using Solidworks 2016 software package. Solidworks was selected since it is more user friendly than other 3D modeling packages. First, parts of the design were modeled and they were assembled using the software.

2.3 Fabrication

Fabrication was done using Acrylic plates. The plates were cut according to the design and a silicon glue was used to seal the container. Iron brackets were used for reinforcements

2.4 Testing.

First the cell has to be charged. During charging electrode behavior under various electrolytes were observed. After charging was completed, voltage readings and the duration of the charge were obtained.

3 TESTING THE CONCEPT

3.1 Apparatus

A simple apparatus was built to test the concept of this project. This apparatus consists of two chambers to collect hydrogen and oxygen and one container to hold the electrolyte. Platinum wires were used as electrodes.

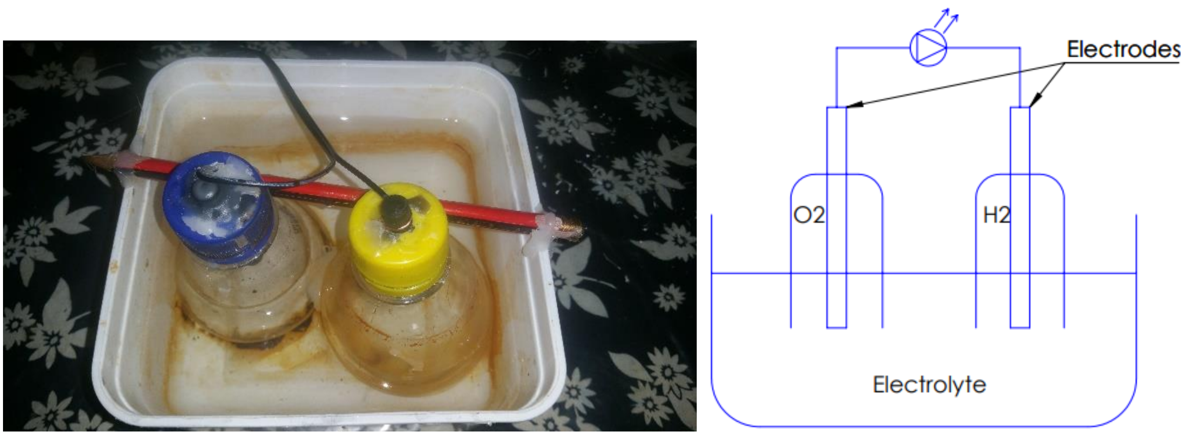

Figure 3.1 : Apparatus to test the concept

3.2 Procedure

First the whole container was filled with water. It was made sure that there were no air bubbles in gas collecting chambers. Then electrolyte salts were added to the container. After adding salts the electrolysis was done using a 24v DC power supply. After sufficient amount of gas was collected, the discharging voltage was measured. Then a small LED bulb was connected and the duration of the charge was measured by observing the LED.

3.3 Results

Using this apparatus the behavior of various electrodes and electrolytes were observed.

3.3.1 Electrolytes

- Water.
    - Since the conductivity is very low electrolysis was slow. Hence gas production was insufficient.
- Salt water
    - Chlorine gas was produced from the anode due to the presence of Chloride ions.
    - Has a high conductivity and a high rate of electrolysis.
    - Metal electrode corrodes during charging.
- Sodium Hydroxide solution.
    - Oxygen was produced from the anode instead of chlorine.
    - Has a high conductivity and a high rate of electrolysis.
    - Metal electrodes were stable during charging.

3.3.2 Electrodes

- Carbon
    - Not stable under high charging currents. Carbon chunks get removed if the rate of electrolysis is higher.
    - Carbon electrode is stable in any electrolyte.
    - No catalytic action was observed during discharge.
- Stainless steel
    - Can withstand high charging currents.
    - Electrode was corroded when salt water was the electrolyte but the electrode was stable when sodium hydroxide solution was used as the electrolyte.
    - Did not discharge a current.
- Platinum
    - Very stable in any electrolyte.
    - Better discharge rate and duration due to catalytic action.

Table 1 : Summery of the results

ELECTRODE	VOLTAGE	DURATION	REMARKS
Carbon	1.21v	15 minutes	• No gas diffusion. • Not stable under high currents.
Stainless steel	-	-	• Cannot be used for discharge.
Platinum	1.21v	2 days	• Acts as catalyst. • Very stable.

3.4 Discussion

According to the results most suitable electrode is platinum and the most suitable electrolyte is sodium hydroxide solution. Platinum act as a catalyst to convert H_2 molecules to H^+ ions and O_2 molecules to OH^- ions.

$$\textit{Anode Half-Reaction} \quad 2H_2 \longrightarrow 4H^+ + 4e^-$$

$$\textit{Cathode Half-Reaction} \quad O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$$

Figure 3.1 Half reactions at electrodes.

Electrons released by H_2 molecules at anode travels through the LED to the cathode creating an electric current. Platinum acts as a catalyst to this reaction by reducing the activation energy of the reaction.

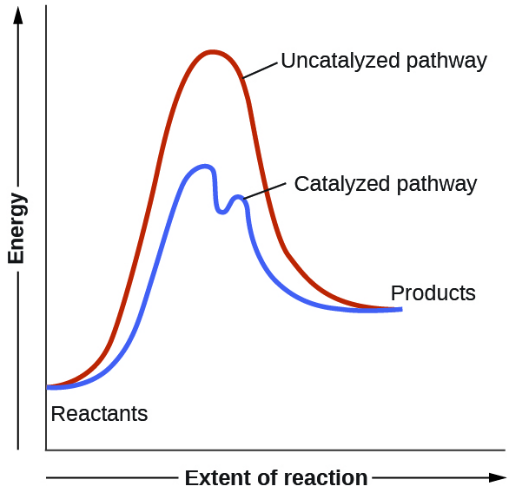

Figure 3.2 Catalytic action of platinum

Gas molecules were adsorbed on to the surface of platinum by van der waals forces. On the surface molecules were broken down to ions giving away electrons. Due to this action when using platinum electrodes, amount of gas inside the chambers were reduced during discharging (Lifting the water column up against the gravity). This phenomenon could not be observed when using other electrodes. The discharging current was small due to the low surface area of the platinum wire. Although the platinum is the most suitable catalyst it is very expensive and rare. Nickel can be used as a substitute catalyst.

4 DESIGN OF THE INITIAL MODEL AND FABRICATION

4.1 Introduction

Apparatus used to test the concept cannot store gases above the atmospheric pressure. Therefore the energy it can store is limited. Due to these reasons a cell has to be designed that can withstand higher pressures thus storing a larger amount of energy. The design was completed using Solidworks software package.

4.2 Design specifications

In the design there were two separate chambers to collect hydrogen and oxygen. Hydrogen chamber is twice as large as the oxygen chamber because hydrogen is produced twice as fast as oxygen. Making the hydrogen chamber larger helps maintain equal gas pressures at two chambers while keeping the electrolyte level equal. In this design two separate sets of electrodes were used for charging and discharging. Stainless steel electrodes were used for charging and Platinum electrodes were used for discharging. This helps protect the platinum electrode and prolong the life time of the cell.

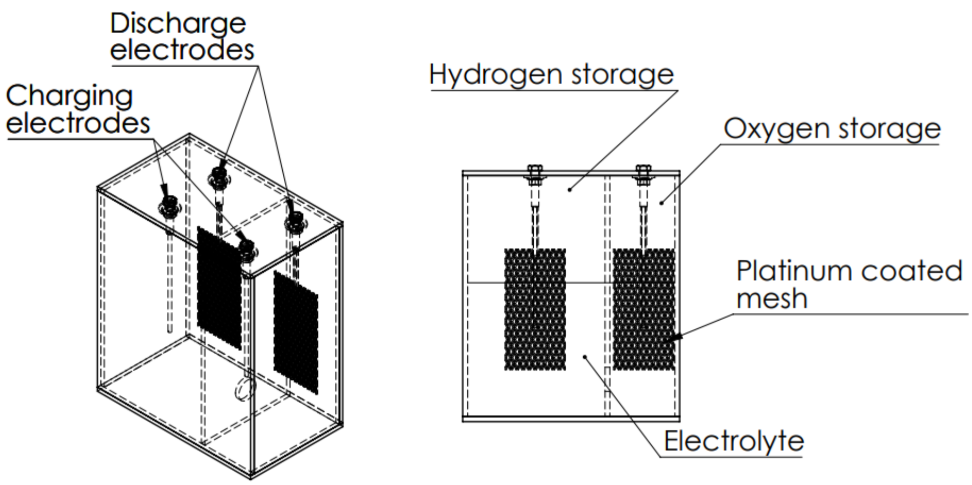

Figure 4.1 Basic design of the cell

4.3 Fabrication

Fabrication of the cell was done using 4mm thick acrylic plates. Plates were modeled using solidworks and part files were converted in to drawing files. Drawing files were uploaded in to a laser cutter and plates were cut according to the design. Plates were glued together using a silicon glue except the top plate. A pressure gauge and electrode connectors were fixed on the top plate. Rubber and brass washers were used to seal the connectors.

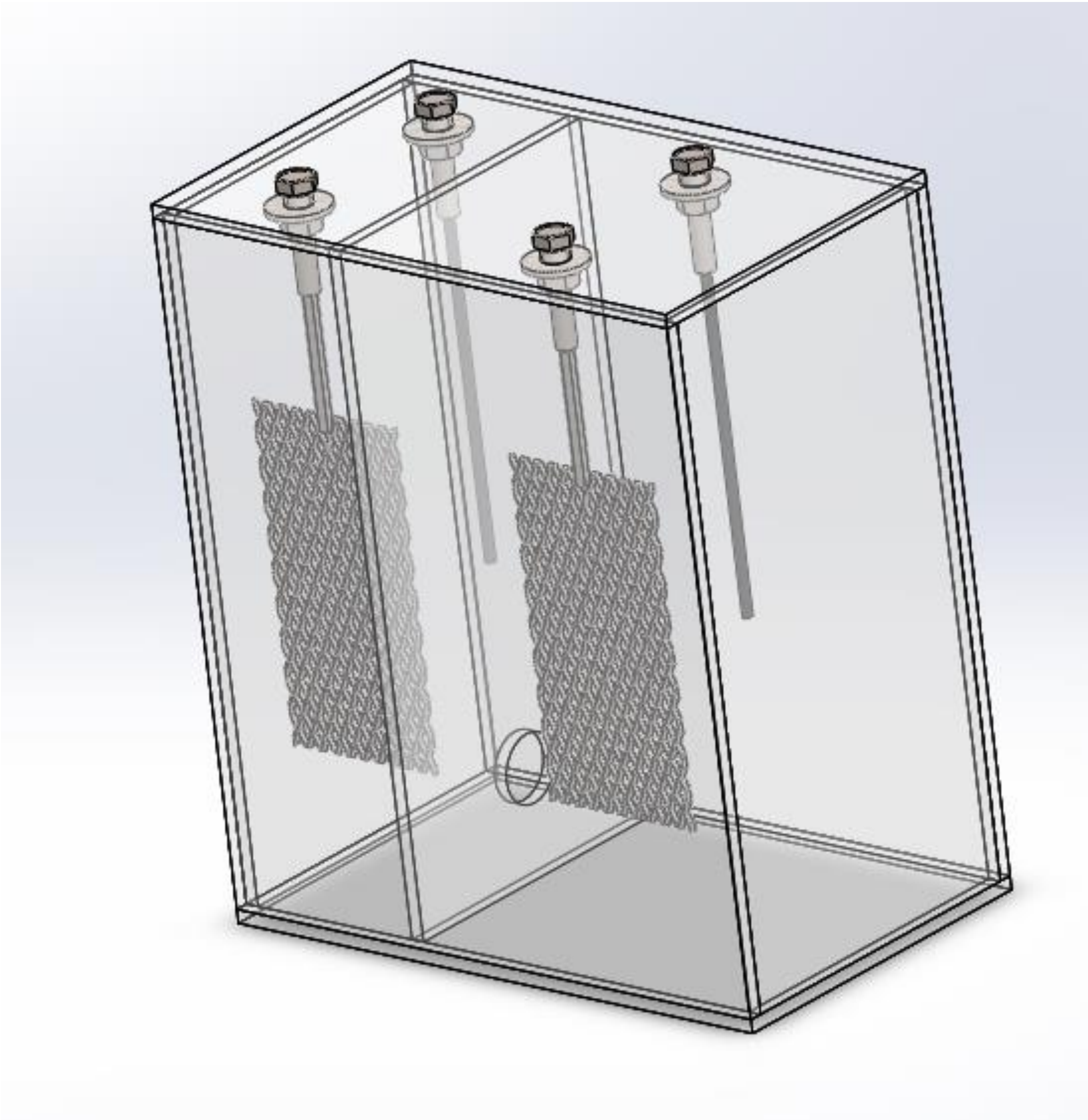

Figure 4.2 : 3D model of the cell

Silicon glue alone cannot hold the plates against the pressure. Extra reinforcement was needed to hold the plates together. Therefore set of iron brackets were fix around the cell as reinforcements. These brackets also help tighten the seal of the top plate. There was a rubber sheet which ensured the seal between the top plate and the gas chambers.

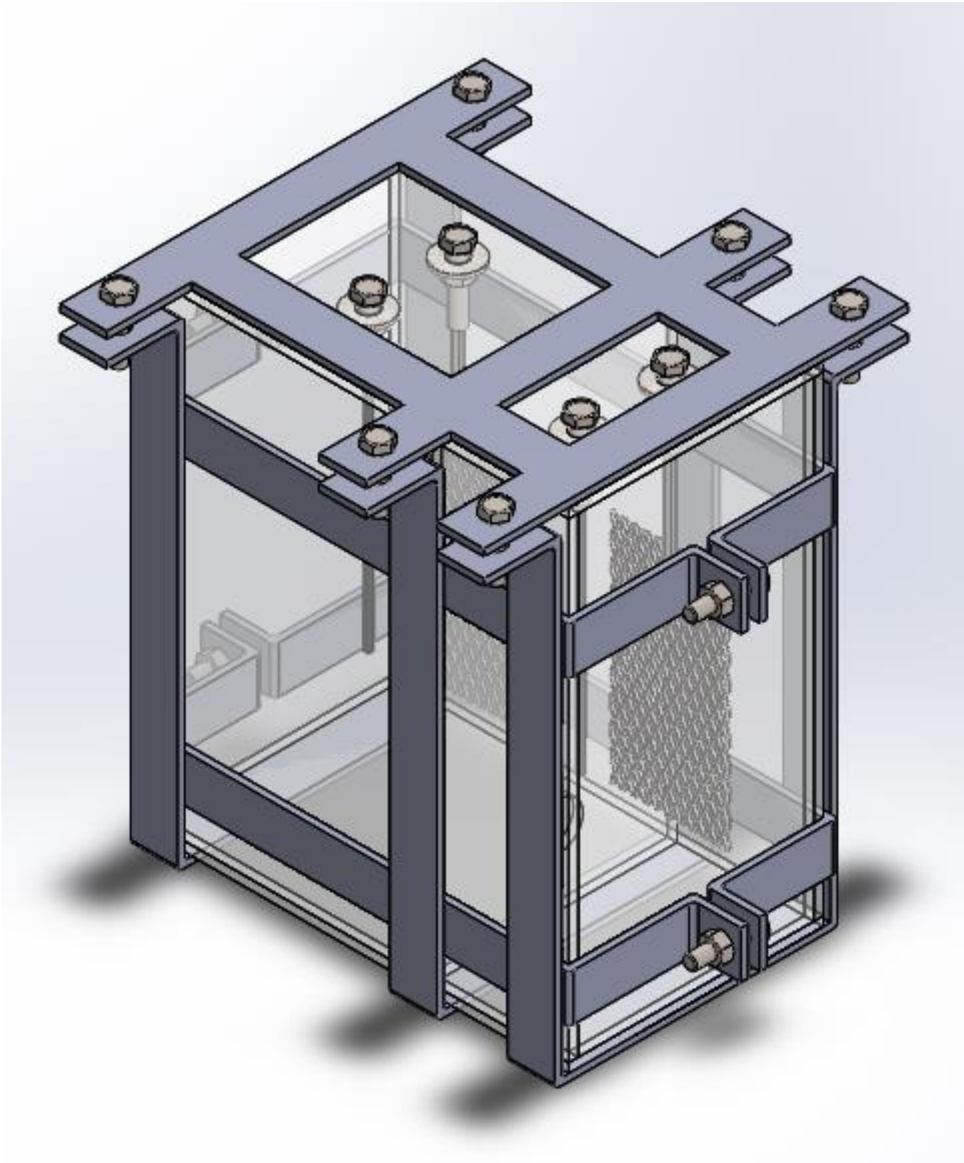

Figure 4.3 : 3D model of the cell with reinforcements.

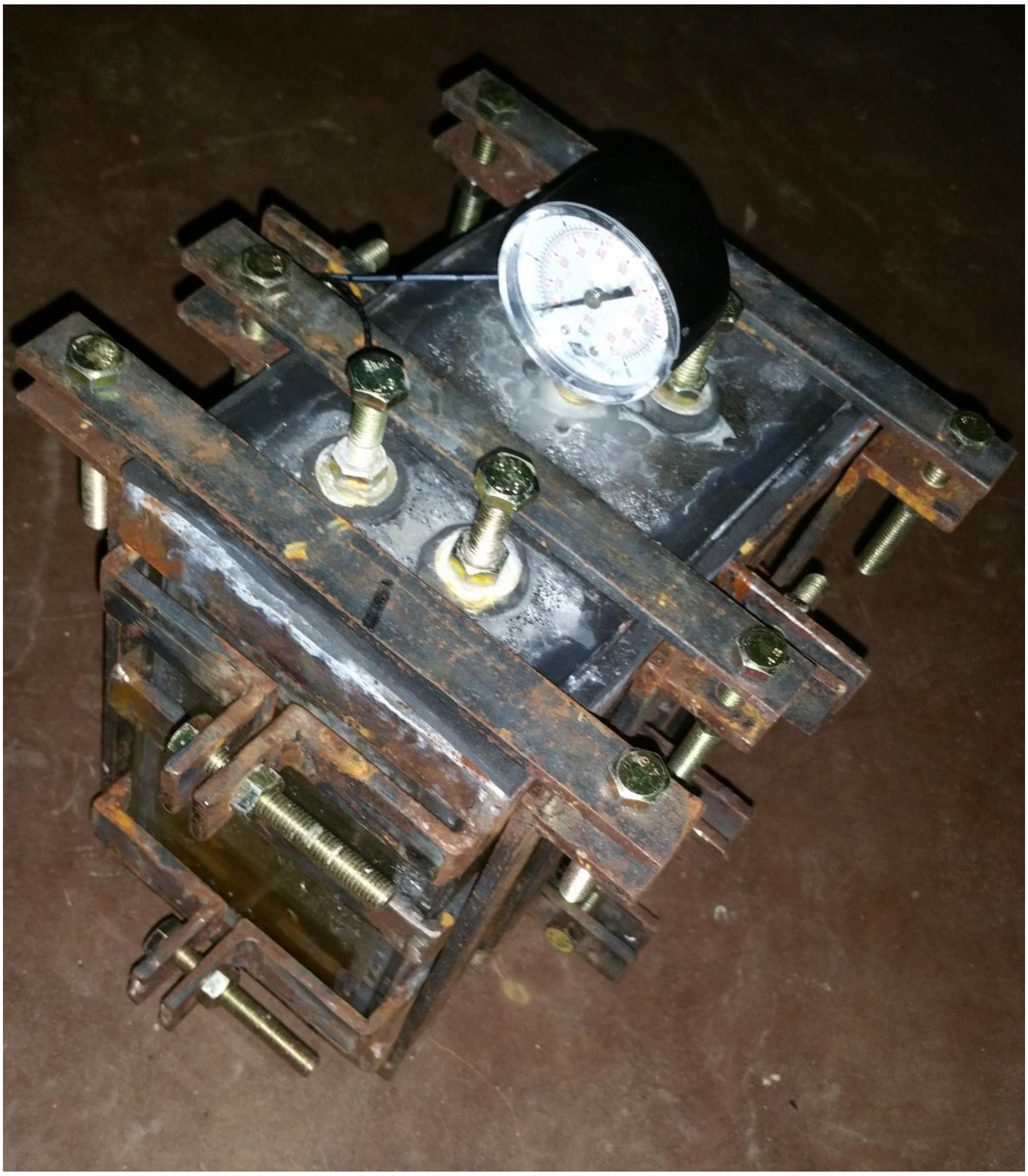

Figure 4.4: Final assembly with reinforcements

5 MODEL TESTING

5.1 Initial tests

Tests were done for platinum electrode as well as nickel electrode. The charging electrodes was stainless steel for both tests and electrolyte was sodium hydroxide solution. At first stages 24v DC power supply was used. But the electrolysis rate was not enough to build up a pressure inside the cell. Therefore 230v domestic supply was rectified and used for electrolysis.

Frist the cell was filled with sufficient amount of water and sodium hydroxide crystals were added until the rate of electrolysis was favorable. Then the top plate was placed and tightened using steel brackets. Then the power supply was connected and kept until the pressure builds up. First set of tests were done for platinum electrode and similar tests were done for the nickel electrode.

5.2 Problems encountered and solutions

5.2.1 Low charging current

When using 24v DC power supply for charging the electrolysis rate were very low. Therefore there was no pressure built up in the cell. As a solution a full wave rectifier bridge was made to increase the charging voltage thus increasing the rate of electrolysis. 1N4007 diodes was used for this rectifier. 1N4007 can withstand 230v, but the current carrying capacity is low. As the circuit was connected to the cell, diodes in the circuit failed due to high currents.

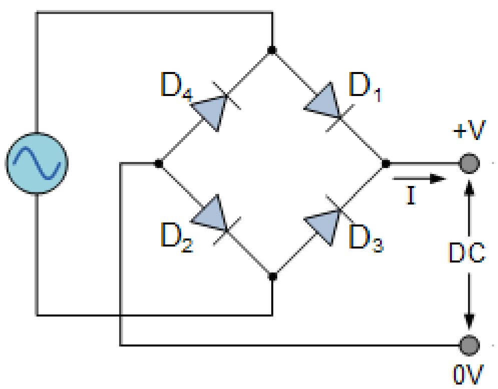

Figure 5.1 : Full wave rectifier

A half wave rectifier was made by connecting 8 diodes in a parallel configuration to avoid failure due to high currents. Due to parallel connection, current going through one diode was reduced and overall current carrying capacity was increased. Due to this configuration the circuit was able to withstand charging currents of 1A. But the average charging voltage dropped to 97v due to half wave rectification.

5.2.2 Deformation due to heat

The electrolyte gets heated when using high charging currents. As a result there was a temperature difference between inside and the outside which deformed plates of the cell. Due to the deformation the seal between the walls were broken and the electrolyte was leaked. An extra set of brackets were made and fixed to hold the deformation

Figure 5.2 : After fixing extra reinforcements

5.2.3 Preparation of the nickel electrode

To prepare the nickel electrode a steel mesh has to be plated with nickel. A mesh was selected to increase the surface area of the catalyst. Nickel cannot be plated directly on to steel. Therefore the steel mesh was first plated with copper and then with nickel. For nickel plating a nickel anode and bright nickel salt was used and to plate copper, a copper anode and copper cyanide salt was used. 5v DC power supply was used for plating.

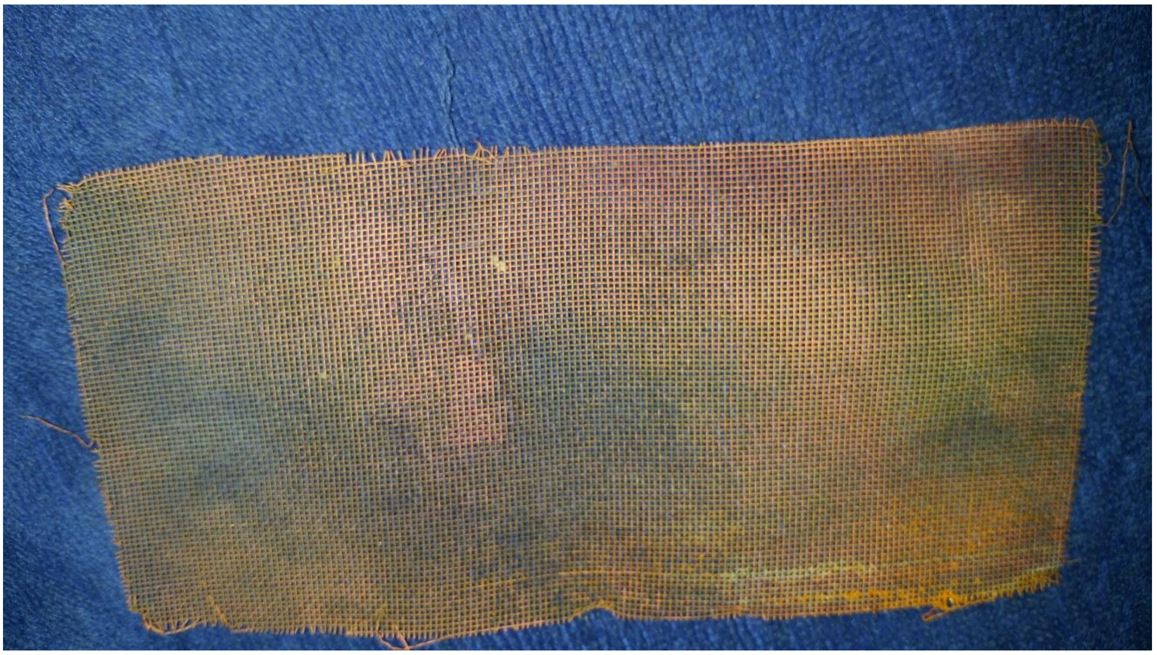

Figure 5.3 Copper plated steel mesh

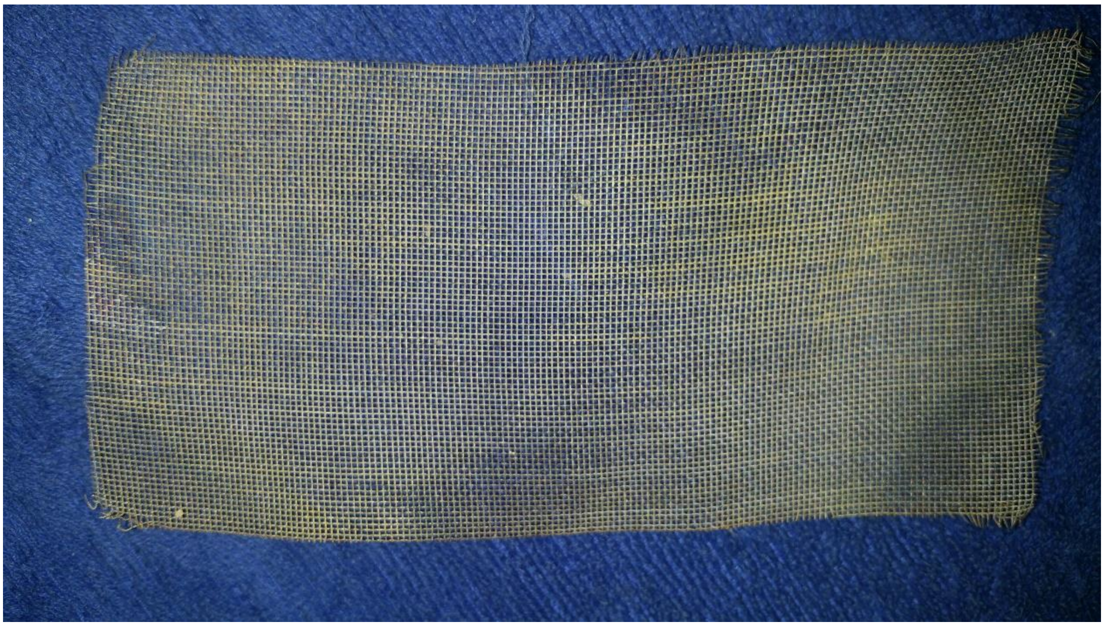

Figure 5.4 Nickel plated mesh

5.2.4 Gas leaks

During charging it was observed that the electrolyte levels were uneven. Therefore a gas leak was suspected. Soap water was used to find leaks. Soap water was sprayed on edges of the cell. Gas leaks were identified as bubbles started to rise. It was observed that the gas started to leak when the pressure is above 2psi. These leaks were sealed using a glue and further charging was done.

Figure 5.5 Identification of gas leaks using soap water

5.3 Results

5.3.1 Platinum electrode

Charging current - 0.612 A

Charging voltage - 97 v

Stainless steel electrode was used for charging and the platinum electrode was used for discharging. The output voltage was measured from time to time by 10 minute intervals. At the same time the pressure gauge reading was also noted. Initially the output voltage was 0 v.

Table 5.1 : Observations

Time/(min)	**Output voltage/v**	**Pressure gauge reading/(psi)**
0	0	0
10	0.975	0
20	1.231	0
30	1.645	2

When the pressure was 2 psi, gases started to leak. Therefore further readings could not be taken. A LED was lit when the voltage was 1.645. But it slowly faded away due to leakage of gases.

5.3.2 Nickel electrode

When using the nickel electrode the nickel electrode started to corrode. When the power supply was connected nickel electrode was oxidized by giving away Ni^{+2} ions to the solution. This made the solution green in colour.

DISCUSSION

According to observations the output voltage was increased with pressure. This confirms the concept is right. In conventional fuel cells the pressure is reduced when hydrogen is supplied to the cell. From this design, the pressure energy of the gases can be recovered as the increased electric potential, which increases the efficiency of the cell. In this design there is no need for a compressor to compress gases. As a result energy wastage during compression can be eliminated. The temperature of the electrolyte was increased during charging. This can be minimized by controlling the charging voltage. The energy density of the cell could not be measured due to gas leaks.

Since nickel is not an inert electrode, it started to decay when the power supply was connected. When there is a voltage difference nickel started to oxidize. Therefore an output from the nickel electrode could not be taken. A separate design was required to test the nickel electrode.

If enough pressure is developed in the chamber these cells can store enough energy to do day to activities. Energy harvested using renewable forms can be stored in these cell. Unlike Lithium polymer batteries fuel cell do not pollute the environment.

Acknowledgments

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