Utilization of Hydrogen Gas Produced Through Sodium Borohydride

Final Report

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My UROP focused on creating hydrogen gas with the use of sodium borohydride and integrating it into a larger fuel cell system. Hydrogen fuel cells hold extreme potential to be a renewable fuel source while being environmentally friendly. There are two major restrictions in using hydrogen as a fuel. The hydrogen is difficult to acquire in both an energy efficient and environmentally friendly method. Hydrogen is also very difficult to store. Sodium borohydride ($NaBH_4$) provides an opportunity to produce large quantities of hydrogen with low impact on the environment without needing to store Hydrogen. In this report I will review the origin of this project, an overview of what my work consisted of, as well as my findings, future projections for this project and my assessment of the UROP.

Origin

Current industrial methods of producing hydrogen gas are effective at producing large quantities while having large drawbacks. Three current methods of production are steam reforming of natural gas, coal gasification and electrolysis of water. Steam reforming of gas and coal gasification produce greenhouse gasses that are unwanted byproducts, while electrolysis requires more energy to create the hydrogen than can be later utilized; both results are detrimental to the overall goal of a fuel that is clean and renewable. $NaBH_4$ has the opportunity to resolve both issues.

Using $NaBH_4$ to produce hydrogen is a fairly simple process. The reaction is a hydrolysis reaction in which $NaBH_4$ reacts with water to form hydrogen gas and sodium metaborate. Sodium metaborate is a desirable byproduct because it is recyclable and is not hazardous in water supplies. The reaction is spontaneous and exothermic at standard temperature and pressure. However, an accelerant is required for this reaction to be successful.

The goal of the project was to combine already known chemistry along with new advancements in technology. The plan was to use what was already known about the $NaBH_4$ reaction and a commercially available fuel cell and integrate it into one system. The system consists of several key components that result in clean energy that will ultimately be portable.

Project Overview

The project began with safety training. Before any work was started I was directed to the research safety officer, my first few days were spent in training. After becoming safety certified I began learning how to use Lab View.

Lab View is a program that allows the creation of virtual instruments. It controls sensors for basic data, such as temperature and pressure. It also allows the use of valves and other controls. It can be programmed to run autonomously using data it has collected. This is an important feature because the fuel cell system ultimately needs to be able to be started up and left alone, while constantly creating power until the reactants run out. After becoming familiarized with Lab View I began to work on the actual project.

When I began working on the project it had already started. The research team I joined consisted on Kevin Chung, Ayotunde James Olatunbosun and myself. Dr. Steven Sternberg oversaw our team and provided aid whenever it was needed.

The first task that needed to be accomplished was to determine the proper solvents and accelerant. $NaBH_4$ best dissociated in a solution of diethylene glycol dimethyl ether (diglyme). Acetic acid was first used as the accelerant; it caused the reaction to proceed at an uncontrollable rate. When it was decided that it could not be used tartaric acid was substituted.

This proved to be very effective, it allowed the reaction to proceed at a rate that the hydrogen could be utilized by the fuel cell without having to activate the purge stream and thus less hydrogen was wasted.

After the accelerant and solvent were chosen we proceeded to reactor design. The initial reactor prototype consisted of a PVC pipe with PVC end caps, sealed using silicone based sealant. PVC was chosen because it tends to be an inert substance. The pipe's dimensions were six inches in diameter, two feet long and with an approximate volume of two and a half gallons. One of the end caps had five holes drilled into it in order to attach various lines. There were two reactant lines that fed in, a line that fed hydrogen gas to the fuel cell, another line that allowed gas re-uptake into the reactant tanks, and a pressure sensor. This first reactor was large, difficult to make, difficult to operate and had gas leaks. Due to these issues it was determined that a redesign was needed.

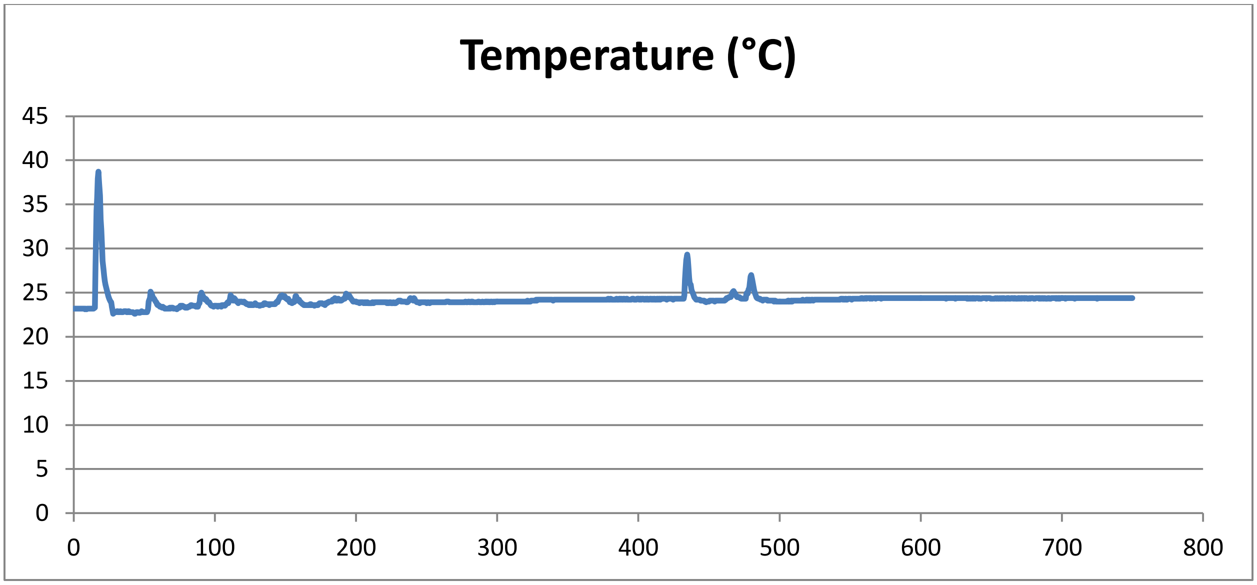
Several different reactors were built to accommodate the reaction, this proved difficult because hydrogen is a very small molecule and easily leaks. After several redesigns a reactor was built that could contain the hydrogen with minimal leakage and is modular so components are easily interchangeable for cleaning and maintenance. The smaller size of the reactor was initially done to ease the process of making the reactors, with the intention of increasing the size once a successful prototype was created. However, with the design changes to the body of the reactor became more modular. It was easier to remove and change parts. The initial amount of space needed to hold a week's worth of waste within the reactor was no longer necessary because it was possible to quickly change the body of the reactor. It was then planned to have two reactor bodies that could easily be interchanged. While one was being used for the reaction the other would be cleaned and serviced for when it would be replaced into the system.

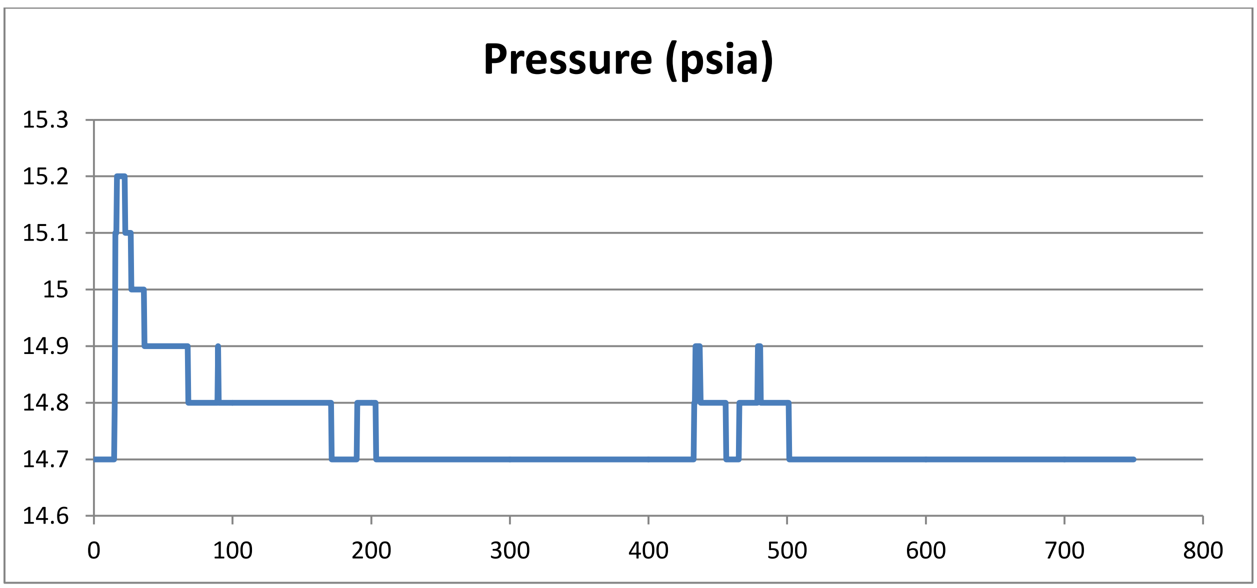
The reactor is part of a larger system that includes feeds, the reactor, a hydrogen fuel cell, a battery and a computer. The reactor is the centerpiece of the system with every component connected to it, with the exception of the battery. There are five inlets and outlets on the cap of the reactor. Two are for reactant inlets. The feed is set up to use gravity to allow the flow of reactant into the reactor. The decision was made to not use any pumps, the system is self-powered and a pump would draw too much power away from the other components of the system. Initially there were problems with the feeds, the reactor developed a higher pressure than was inside of the feed tanks. This pressure differential caused hydrogen gas to push against the reactants inside of the feed lines which prevented them from entering the reactor. This was counteracted by the installation of a gas reuptake. An inlet hole was drilled into the reactor cap with a line that went through a T-valve and then to the tops of the reactant tanks. This allows the pressure in the tanks to be equal to that of the reactor. The equal pressure allows gravity to move the liquid down the lines. The gas reuptake line has no liquids flowing through it so another T-valve was installed so sensors could be snaked down the line and into the reactor. The fourth inlet allows the pressure sensor to be installed. The fifth outlet allows hydrogen gas to vent into the hydrogen fuel cell. The fuel cell is connected to a battery which powers all the sensors and valves.

Once the system was assembled it began to undergo testing. The relationship between amount of reactant and how long the system runs for needed to be determined. After testing, it appears that approximately fifty milliliters of two molar $NaBH_4$ solution runs for about twenty minutes. Another aspect that had to be tested was the frequency of how often reactants were added.

The reactor does not have a constant feed of reactants, it is a semi-batch process. A predetermined amount of reactants are fed in. This causes a reaction to take place very quickly and creates a large amount of hydrogen gas which stays within the reactor. The gas then vents into the fuel cell until there is no longer a pressure differential. The fuel cell is a sensitive piece of equipment. It requires a minimum amount of hydrogen to keep it running, any less and it will automatically shut off. If too much hydrogen is fed in, it will activate a purge stream. Any purged hydrogen is wasted hydrogen, which will increase the cost of running the fuel cell. A balance needed to be found in how much and how often reactants needed to be fed in.

During testing, the semi-batch nature of the system was discovered. There would be flare-ups of temperature and pressure whenever reactants were introduced. They would drop gradually over time. The fuel cell generated approximately twenty volts, however it decreased as there was less hydrogen being fed in. This can be seen in fig. 1.1-1.3.


Temperature (°C)
45
40
35
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
Fig. 1.1


Pressure (psia)
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15.2
15.1
15
14.9
14.8
14.7
14.6
0
100
200
300
400
500
600
700
800
Fig. 1.2

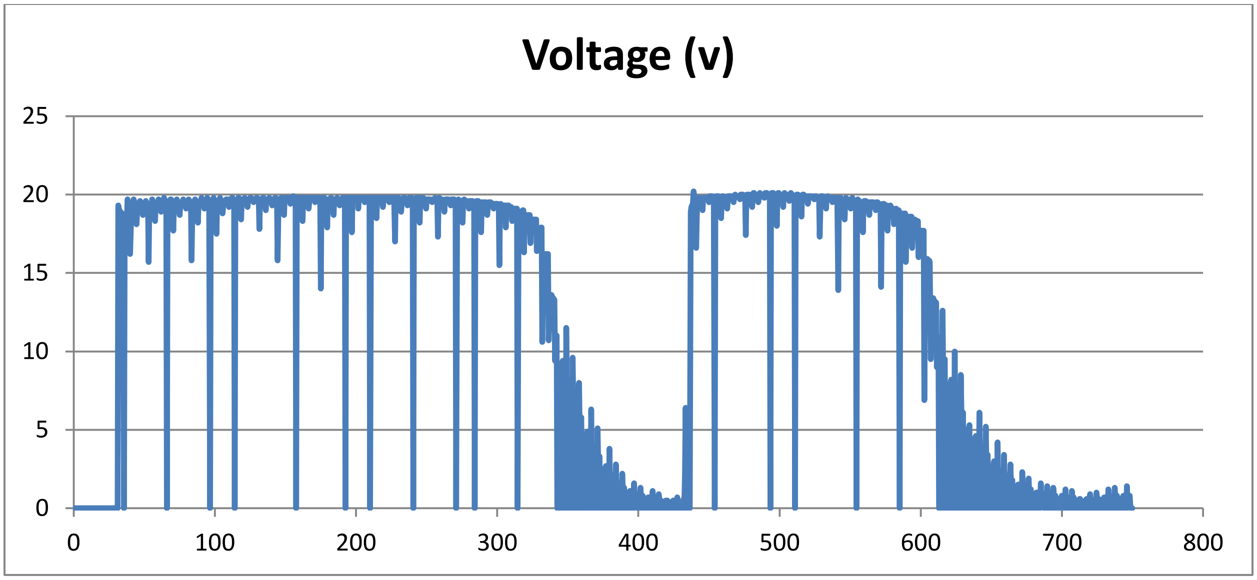

Fig. 1.3

After a month of testing the reactor body suffered a major problem. It was noticed that leaks had begun to arise and there were lower pressure numbers and voltage numbers. It was speculated that the seals on the fixtures had begun to degrade and needed to be changed. The system was disassembled to clean the reactor and then change the fittings. Upon opening the reactor, it was discovered that the entire reactor body had undergone massive amounts of degradation. It was assumed that one of the reactants or waste products had reacted with the PVC walls. A new reactor needed to be made with a new material.

Material testing proved difficult and also highly insightful. Different materials were tested, such as PVC, polycarbonate, hard nylon, Polytetrafluoroethylene (Teflon) and Biaxially-oriented polyethylene terephthalate (BoPET) were tested. PVC was tested to determine what happened to it. It did not undergo a reaction. The diglyme proved to be too powerful a solvent, it began to dissolve the reactor as well as causing swelling. During the material testing two different materials were selected, Teflon and BoPET. Teflon was determined to be the better material, however it could not be used by our research team. It was too expensive to order in the specifications that were needed, as well as being unable to apply to a more cost effective material. BoPET was then chosen to make a bladder or liner within the predesigned PVC reactor.

After the bladder material had been selected the projected shifted from focusing each individual component to integration into one large unit. A steel cabinet was insulated with holes cut into the fixed shelving units to seat the reactor tanks. Holes were also cut in the exterior of the cabinet to allow cables to be run into and out of the cabinet. Each component was added into the cabinet and secured. After securing the hardware components the wiring for all the sensors and valves were done.

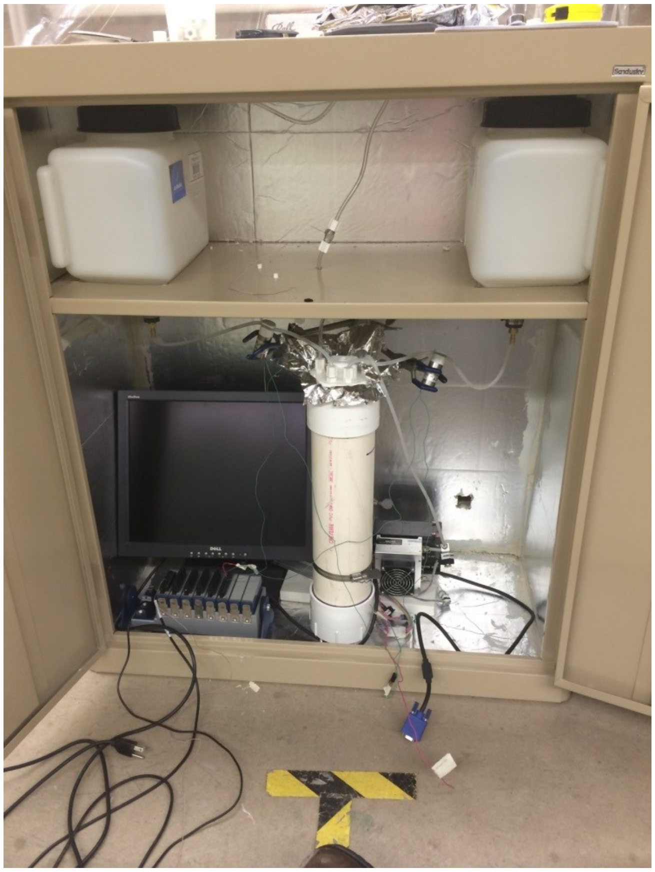

Fig. 1.4

After all the system was assembled testing was to resume. At this point we had equipment difficulties with our valves. We were not able to remotely control our valves to release the reactants. Prior to this point the reactants were manually added in. Without automated valve control the project could not proceed and the remainder of the UROP was spent attempting to fix this problem.

Findings

Over the course of this UROP my goal was to develop a self-powered hydrogen fuel cell system. To an extent I did accomplish my goal. A system was created that worked for a short duration. During this period much information about the operation of the system was learned. Such information learned was the relationship between pressure, temperature and how much power was being generated. This relationship is planned to be used in the programming of when to active the valves. Also learned were the materials that could and could not be used in the creation of the reactor. Unfortunately I did not come to the point of optimizing the process, and reducing the size of the system to make it portable.

UROP Assessment

My assessment of the UROP program is that it is a great opportunity. From the application to this final assessment it has proven very helpful to me. During the application process I had to fill out an application. This provided me with an honest assessment of my own accomplishments and qualifications to that point. The proposal spurred me to do research and gave me an opportunity to write a scientific proposal.

Working in the lab provided me safety training that I would otherwise have not gone through. It taught me to work independently as well as working in a group. We would each have tasks that we accomplished by certain points and then combine the work as a group. I learned to work without much oversight or direction, we assessed everything ourselves and the only solutions we had are the ones we came up with.

The most valuable aspect of my UROP to me was it taught me how to work when things go wrong. When our reactor failed we had to work on a project that we did not originally plan on doing. It introduced me to failure and allowed me to overcome it. Lastly, this final report aided in my reflection of the entire project. Overall, I think the UROP program is an excellent program that should be continued and expanded.