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Fuel Cell Locomotive

Single Cell Group
Department of Chemical Engineering

Spring Quarter Final Report
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Abstract:

The activities of the single cell research group over the course of the Spring Quarter 1997 are presented. Our research has provided direction for next year's single cell group and our final results should inspire some optimism. In addition, modification made to the testing apparatus should allow more realistic and meaningful performance tests to be made in our laboratory. However, we were not able to meet the project goals for this year (cell power output between 0.5 and 0.7 watts per square centimeter of membrane surface area).

Spring Quarter Activities:

The majority of the quarter was spent addressing an issue that is crucial to the success of the project: safe handling of hydrogen. For about half of the quarter, we researched hydrogen safety and various methods of hydrogen disposal. The results of this research are presented in Appendix A. Overall, we find that hydrogen is a very unique gas that deserves a high level of respect. It can be handled safely but care must be taken to ensure that a dangerous situation does not arise.

Once we understood the safety issues surrounding the use of hydrogen, our next step was to use this knowledge to redesign our testing apparatus. We wanted to increase the safety of our gas delivery and disposal system. In addition, other modifications were made for various reasons. These modifications provide better control over the system as well as relevant data that can be used to quantify the operating conditions of the cell. This work is summarized in Appendix B. This appendix also contains a standard operating procedure for both the new test cell and the new test stand.

The above pursuits consumed the majority of the quarter. However, toward the end of the quarter, we were able to perform a few membrane performance tests. These tests, while not conclusive, are promising. They show that the power output of our cell increases consistently as the cell is run. However, we were not able to run the cell for an extended length of time and observe a maxima in the power output. Thus, the results are inconclusive (we do not know where the power maxima will occur). The information gained from these tests is presented in Appendix C.

Another test was run in order to determine the water content of our Nafion membrane at the time that it is placed in service. The results of this test, which indicate that our membranes contain a sufficient amount of water, are also contained in Appendix C.

Since we were unable to produce the desired amount of power, we feel that it is very important for next year's single cell team to get started on the project quickly. To aid them in this regard, we have included a number of specific observations and recommendations in Appendix D. We recognize that our approach to the problem over the course of this year may not be the best (as evidenced by our failure to meet project goals), and we hope that next year's students will keep this in mind. Our recommendations should be used only as a guide, recognizing that another course of action may be more appropriate. However, we do feel that the included recommendations will speed the orientation of next year's team members and provide them with some useful insights. Diagram of the single cell test unit can also be found at the end of Appendix D.

A summary of work performed by Karen Fukuda in constructing a web page for the project is included in Appendix E. This appendix summarizes the purpose of the work and furture direction for this aspect of the project.

Finally, we have included a list of materials that need to be purchased (per Professor Stuve's request) in Appendix F. We feel that it would be most beneficial if these materials can be obtained over the course of the summer so that the single cell team will not waste time waiting for things to arrive once school starts.

Appendix A: Hydrogen Safety

Hydrogen is the best solution to the twin problems of environmental pollution and energy crisis. Unfortunately, few of its unique properties set it apart from other conventional fuels and require special handling to avoid an accident. Hydrogen has been classified by the National Fire Protection Association (NFPA) in its most hazardous group of flammable liquids, gases, and volatile solids (Das 619). As undergraduate research students working with hydrogen on the Fuel Cell Locomotive project, we all should be knowledgeable of hydrogen's properties to achieve best results without even a smallest accident. The table below lists hydrogen's "must known" properties as compared to natural gas methane.

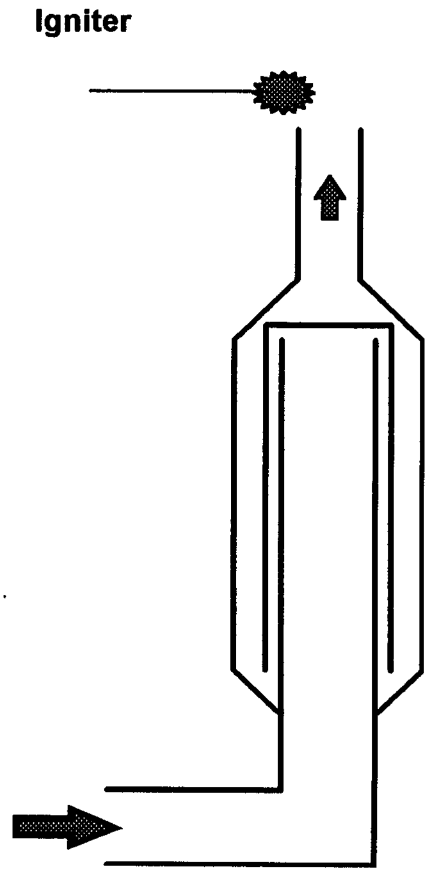
Property	Hydrogen	Methane
Combustion Range (vol % in air)	4-94	5.3-17
Detonation Range (vol % in air)	20-65	6.3-13.5
Minimum Ignition Energy (mJ)	0.02	0.3
Ignition Temperature (K)	847	813
Flame Velocity (cm/s)	265-325	37-45
Flame Temperature (K)	2323	2148
Quenching Distance at 1atm (cm)	0.06	0.203
Normalized Flame Emissivity 2000 °K, 1 atm	1	1.7
Solubility in water (vol/vol)	0.019	
Diffusion Coefficient in air (cm^2/s)	0.63	0.2

Properties that are frequently mentioned as making hydrogen hazardous are the low as well as wide combustion and detonation range. The very low lower limit of these ranges (4 volume % in air) illustrates the fact that only a small amount of hydrogen is needed for combustion and detonation. The wide range of combustion of 4-94% volume leads us to rule of thumb: never allow hydrogen-air mixtures, both within the handling equipment and external to this equipment. To avoid the formation of hydrogen-air mixtures, any hydrogen leak needs to be detected early.

The third property of hydrogen is the incredibly low minimum ignition energy, which is defined as the energy needed for ignition to occur. Because the minimum ignition energy is only 0.2 mJ, one order of magnitude lower than that of methane, all ignition sources must be avoided. This poses difficulty since all experiments with hydrogen require the use of electrical or electronic equipment which can be ignition sources. We learned this well after the explosion last winter quarter. Sometimes, the discharge or static electricity is found to be unidentified initiator of hydrogen fires. – reference for this?

The next property is actually favorable, especially for our research purpose. Hydrogen has a an ignition temperature as high as 847 °K. Our cell needs to be operated at only 373 °K. An overtemperature rise wouldn't present a problem in this aspect, assuming everything else is kept in check.

Flame velocity is defined as the rate of burning with respect to the flame front. – UNCL Hydrogen burns nine times as fast as methane, at a rate of 265-325 cm/s. The high flame velocity of hydrogen causes overpressure rise in a closed system incredibly fast. A normal Bunsen burner is not adequate for the purpose of flaring excess hydrogen because the flame can burn backward inside the burner and melt it. One method of flaring makes use of a flare stack incorporating a molecular seal? as shown below. The narrow channels allows a small but fast flow to exclude the atmosphere from entering the interior of the stack. reference?



Hydrogen Flare Stack

what makes the seal a "molecular seal"?

Another distinguished property of hydrogen is the quenching distance. Quenching distance is the distance between parallel walls which just permits a flame to pass. A hydrogen flame can pass through an opening with a diameter of 0.06 cm. Flames of other hydrocarbons requires a diameter four times as large to pass through. This is the reason why flame arrestor designed for a hydrocarbon flame will not be able to suppress a hydrogen flame. The quenching distance depends on the pressure. As the pressure increases, the quenching distance also increases.

The low flame emissivity of hydrogen can be very ambiguous in safety considerations. It is beneficial in the sense that the energy radiated decreases rapidly with distance and thus reducing the likelihood of causing burn to operators at a given distance from the flame. On the other hand, the flame envelop is invisible, and thus presents additional hazards to someone inadvertently entering the flame.

The next to last property is the solubility of hydrogen in water. This is very useful to us when we calculate the heating energy and humidification required to saturate the hydrogen gas with water.

Finally, large diffusivity in air can make hydrogen either more or less hazardous. In confined spaces, hydrogen will mix faster and reach all parts of the space more rapidly. However, it will also dissipate faster with the result that, for a given hydrogen release, at any one time only a small portion of the hydrogen may exist in concentrations within the combustibility limits. It is for this reason that the total energy emitted from a hydrogen explosion is usually only a few percent of the total energy available.

In summary, hydrogen is the most versatile fuel of the modern age. However, it can be best utilized only once we are knowledgeable of its properties. A few properties which require special treatment to reduce the risk of accidents are the broad combustion and detonation range, the low minimum ignition energy, and the rapid rate of diffusion.

Works Cited.

Das, L.M. "Safety Aspects of a Hydrogen-Fuelled Engine System Development." Journal of International Association for Hydrogen Energy 16.9 (1991): 619-624.

Cox and Williamson. Hydrogen: Its Technology and Implications. CRC Press, 1979.

Appendix B: Testing Apparatus

Based on the information that we obtained while learning about hydrogen safety, we felt that our test stand needed major renovation. We must be able to flow hydrogen and oxygen gases across the surface of the Nafion membrane in order to ensure the correct level of cell hydration. Thus, we cannot simply dead-end the gases at the membrane as has been done in the past.

However, flowing the gases presents numerous challenges. How do we move them and what do we do with them? For oxygen, the answer is easy. It is not flammable or dangerous and can therefore be vented to atmosphere.

Hydrogen is a different story. During Winter Quarter, we tried to simply flow hydrogen through our test cell and then burn the excess. This proved to be disastrous due to the dangers associated with burning hydrogen. If a fume hood were available, the obvious answer would be to vent the hydrogen. We feel that this is the safest and most desirable alternative. However, a hood is not available to the single cell research group at this time.

Finally, we settled on hydrogen recirculation. To accomplish this task, a stainless steel bellows pump was obtained from Roger Pick. Using this pump, we were able to construct the recirculating hydrogen supply system that is shown in Figure B-2. This system does allow us to flow hydrogen; however, the capacity of the pump is limited. A larger pump is needed.

A number of other modifications were also made to the test stand. These were done to provide ease of use, information regarding gas flow rates, gas hydration, and safety. Figure B-2 shows these modification as well. At this point, we will note a number of the test stand's features:

1) Heating and humidification of feed gases is accomplished by sparging them through heated water vessels. Water, and thus feed gas, temperature is controlled using VariACs connected to the water vessels' heating bands.

2) Pressure relief is provided by two adjustable, stainless steel safety valves. Both are currently set to relieve at approximately 60 psig, which should be well below the pressure rating of any of the other system hardware (plastic components are rated to 100 psig).

3) Oxygen and hydrogen feed rates are monitored by two inline rotameters. The oxygen rotameter provides real-time flow readings and the factory calibration is relatively accurate. The hydrogen rotameter provides a measure of hydrogen leak rate from the closed-loop recirculation system. It should be calibrated. Both meters measure flow rate prior to humidification. need to explain what this means

4) Hydrogen delivery is accomplished using a closed-loop recirculation system. This system is most easily understood by referencing Figure B-2. Note that hydrogen is recirculated through the humidification vessel on each pass. Thus, water demands are minimized and heating efficiency is improved.

5) All connections to the cell itself are accomplished using polypropylene quick connects. This allows for fast and easy cell connection.

6) The humidity and temperature of both feed streams are measured just before the gases enter the cell.

7) Cell heating/cooling is accomplished through the use of a water jacket within the cell and a water heating/circulation loop as shown in Figure B-2.

8) An inert purge (nitrogen gas) is available to both sides of the gas delivery system. This makes operation much safer, allowing the system to be purged of reactive gases at any time.

To clarify operation, Figure B-3 is included. This figure is a representation of the front of the test stand. It labels the various hardware components present and references them to Figure B-2. Good to distinguish between a schematic and a system layout.

Finally, we have included a standard operating procedure for both the test cell and the stand. These procedures should be strictly followed when performing tests until the operator is familiar with the testing apparatus.

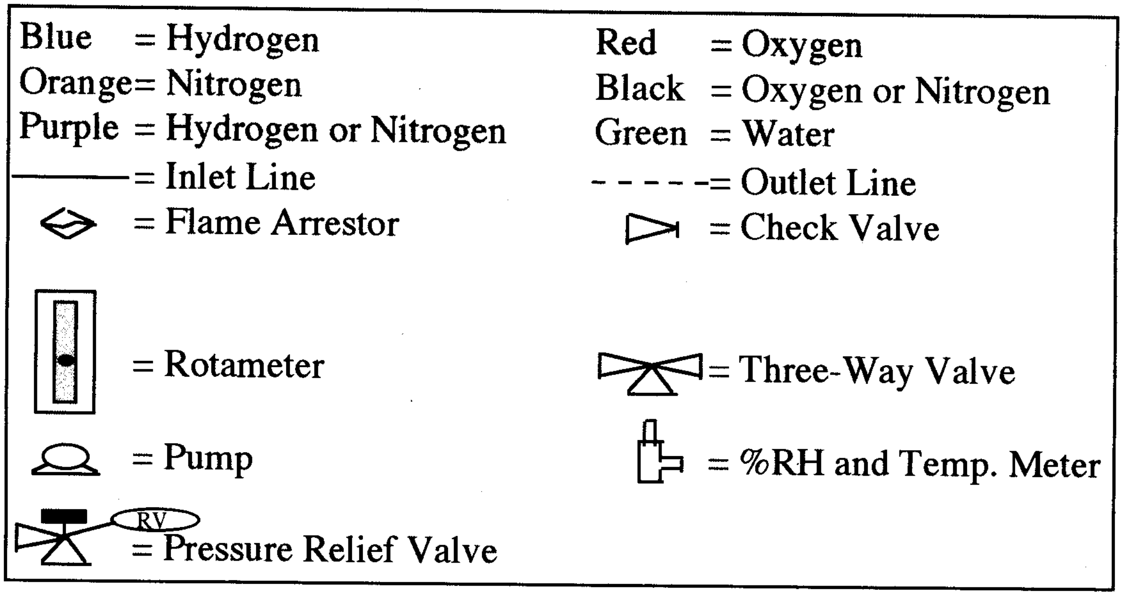


Figure B-1: Legend for Figures B-2 and B-3

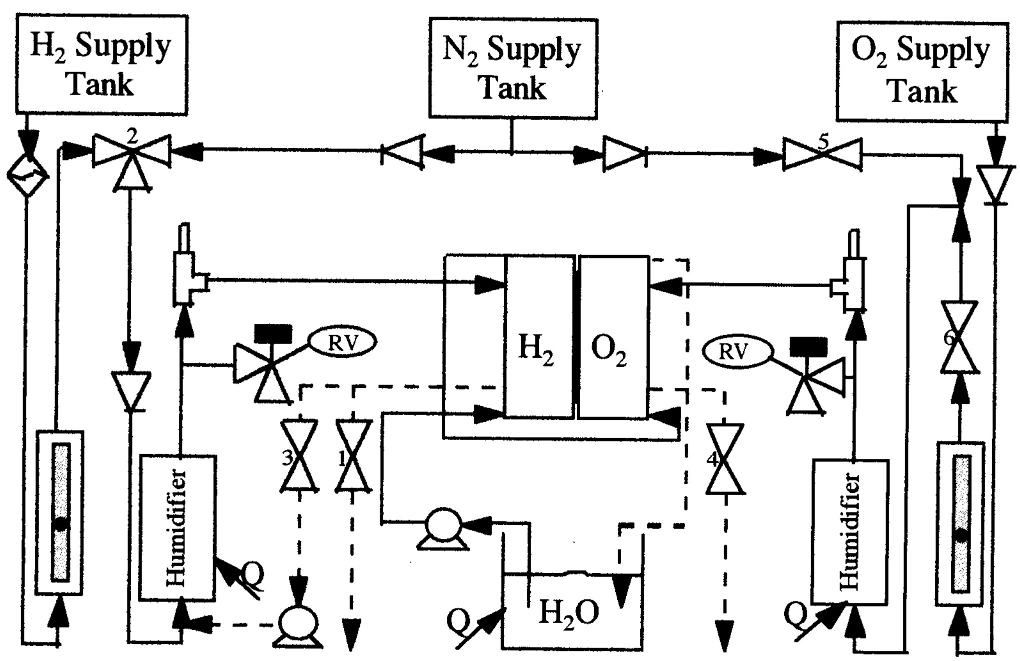


Figure B-2: Block Diagram of Fuel Cell Test Stand

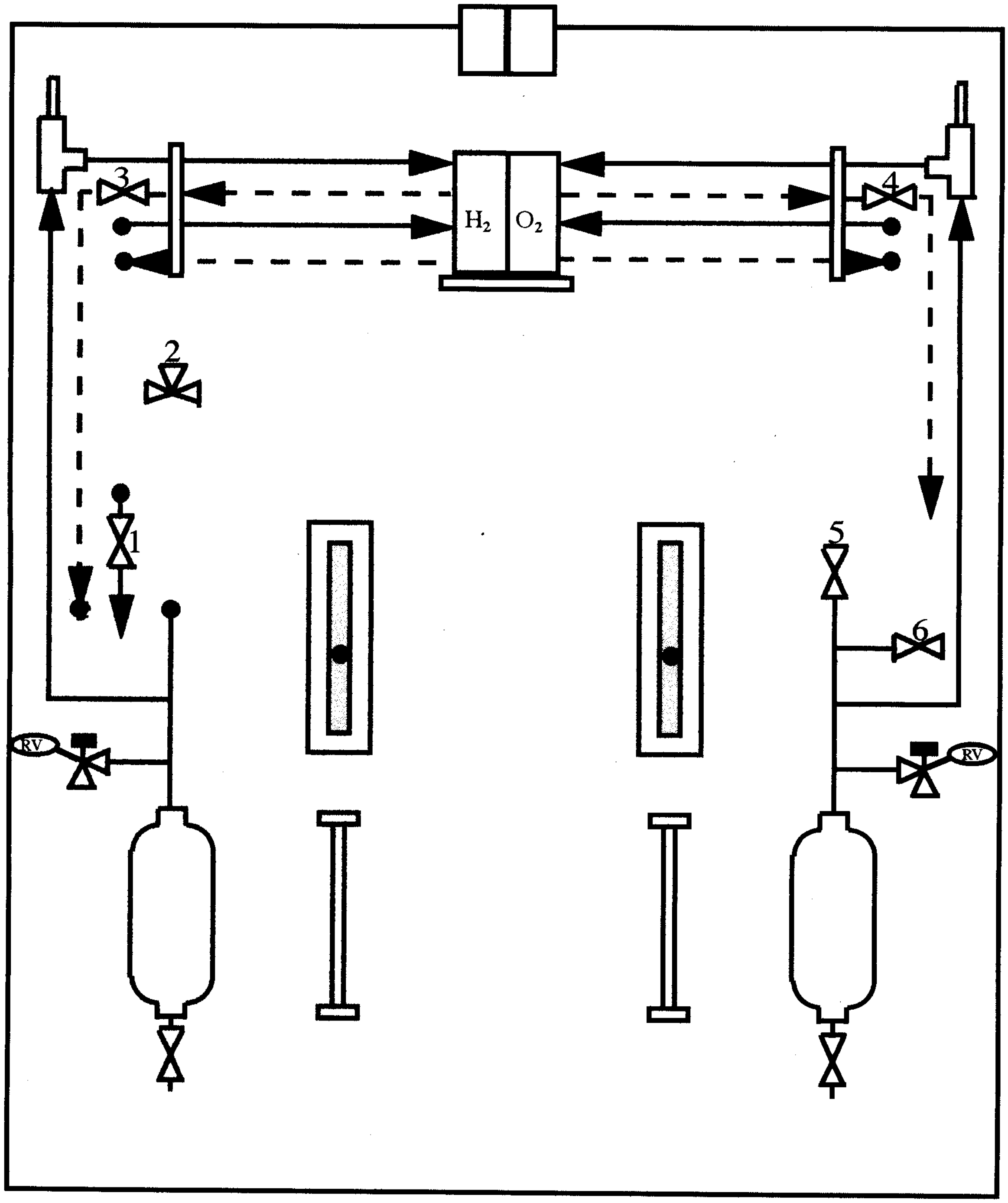


Figure B-3: Front of the Test Stand
Valve 1 = hydrogen purge; valve 2 = three-way hydrogen/nitrogen selection valve; valve 3 = hydrogen flow control valve; valve 4 = oxygen flow control valve; valve 5 = nitrogen feed for oxygen side; valve 6 = oxygen feed

Standard Operating Procedure for Test Cell and Stand

0. Emergency Shutdown Method => we need a one-step procedure for this
   - 0.1 Runaway cell, immediately turn off main hydrogen and oxygen cylinder valves, making sure you cannot be burned from this action. If this is not possible, turn off gases with small valves on front of apparatus. — label valves
   - 0.2 Flood both sides of gas delivery system with nitrogen gas.
   - 0.3 Disconnect electrical power supply to band heaters and water supply system.
   - 0.4 NOTE: Under no circumstance are hydrogen and oxygen gases to contact one another while at elevated temperatures or in the presence of the platinum catalyst.

perhaps should do this first?

1. Test Cell Assembly
   - 1.1 Cell halves should be coated with electrodag (procedure for this?) and be in good condition. If either has been dropped or severely scratched, it should be checked to ensure that it can still function properly and then repaired.
   - 1.2 O-rings are installed in each half, each should be retained in the gland even when inverted.
   - 1.3 A cut piece of Teflon coated carbon paper is placed in the recess in one of the halves, which has been suspended with the flow field facing up (the corner of a box works well for this). (should refer to sketch)
   - 1.4 A prepared membrane is then placed over the carbon paper, centering the electrode as well as possible on the flow area.
   - 1.5 An identical piece of carbon paper is placed on top of the membrane, again centering as well as possible.
   - 1.6 The second half of the cell is then brought down on this sandwich of parts. As it is brought down, it is imperative that the carbon paper find its way into and remain in the recesses above the flow fields. IF IT IS SUSPECTED THAT THE CARBON PAPER IS NOT SEATED, DO NOT CONTINUE!!! PROCEEDING WITH THIS MISASSEMBLY WILL RESULT IN MEMBRANE DAMAGE AND A VERY DANGEROUS CONDITION.
   - 1.7 After it has been made certain that the carbon papers are seated and the Nafion is making contact all around with the O-rings, bolt up can now be done. Using the nylon bolts, insert them all finger tight, then use the deep socket only to tighten then in a circular pattern. Tighten to about 4 foot-pounds each (not very

tight). Never use a wrench other than a box type or socket, as the nylon could be easily damaged.

1.8 After bolt up, unit is placed on the shelf of the test stand and all connections are made.

1.8.1 Attach feed gas tubes (these must connect to one of the center ports on the test cell.

1.8.2 Attach purge gas tubes to the other center ports.

1.8.3 Attach water feed and discharge lines to the outer ports on the test cell.

1.8.4 Connect resistive load to the cell.

1.8.5 Connect voltmeter to the cell.

2. Start Up of the System

2.1 Leak testing must first be performed.

2.1.1 With all valves closed, open main nitrogen cylinder valve 1/4 turn. Regulator pressure should not exceed 45 psi.

2.1.2 SLOWLY crack the valves feeding into the water bottles, one side of the cell at a time. This will charge the system through the cell. After charging, leave this valve open 1-2 turns.

2.1.3 Crack each exit valve for about 5 seconds to bleed air and charge entire system with feed gas. Then close these valves securely.

2.1.4 Close main cylinder valves tightly. A leak is now evidenced by a falling pressure reading on the high pressure gauge. If this pressure is falling faster than 100 psi/min, a substantial leak is present, and should be located/corrected. Correct the situation before continuing.

2.2 Disconnect gas supply to the test cell

2.2.1 Release gas pressure to both sides of the cell using the purge valves

2.2.2 Disconnect the gas supply lines to the cell

number? 2.2 Start heating

2.2.1 Start water bath for heating of the cell, and turn on bottle heater VariACs to a setting of '60 V'. It may take up to 1/2 hour for substantial temperature rise.

2.2.2 Flow nitrogen gas through the system to heat the gas delivery lines (nitrogen will be vented to atmosphere at the cell gas supply lines).

2.3 When gas delivery lines reach the desired temperature and the nitrogen gas venting from the lines appears humid, cell testing can begin.

3. Testing

3.1 Reconnect gas supply lines to the test cell and disconnect the exit lines from the cell.

3.2 Start heating/cooling water flow to the cell.

3.3 Allow the test cell to come up to the desired temperature while nitrogen gas flow continues.

3.4 NOTE: The membrane must remain humidified. Do not heat the cell to a higher temperature than that of the humidified feed gas!

3.5 Reconnect the exit gas lines to the cell.

3.6 Be sure that valve #3 is at least partially open and start the hydrogen recirculation pump.

3.7 Open the main valves on the hydrogen and oxygen supply tanks.

3.7.1 Adjust the pressure regulators to the desired pressure (less than 45 psig!)

3.7.2 BE SURE that the pressure on the nitrogen regulator is higher than that on the hydrogen or oxygen regulators. This ensures that there is no cross-flow of these gases through the nitrogen supply system.

3.7.3 Perform a second leak test as described previously. — I think this means check for leaks with H_2/O_2 gases instead of N_2. Nope! I'm confused

(onfusing

3.8 Purge the nitrogen from both sides of the system using the two vent valves.

3.9 The cell should now be operational

3.10 Select different loads (resistance) to put the cell through. Voltages are measured, and the resultant voltage versus current graph produced.

3.11 NOTE: Make sure water level and temperature in humidifier tanks is high enough to maintain good operation. This is one of the major problems with long term operation of the cell.

4. Shut Down of the system

4.1 Turn off hydrogen main cylinder valve, allow system hydrogen pressure to come to atmospheric. ⇒ by venting ?

4.2 Turn off oxygen main cylinder valve, allow system to come to atmospheric. venting ?

4.3 Turn off heating units, water bath and bottle heaters.

4.4 Purge both sides of the system with nitrogen

4.5 Turn off volt meter.

4.6 Allow unit to cool sufficiently before handling

4.7 Disassemble cell, inspect components as desired. This high performance unit should provide years of trouble free operation, if used in the correct manner with good membranes!

5. Storage of the Test Cell

5.1 Unit should be stored disassembled with membrane faces secure from any form of damage. Any dents or scratched must be repaired, or it may not go together again correctly and leak.

5.2 Over time, the electrodag coating may need to be replaced. This should be done with all components removed from the blocks, save the plugs in the water jacket. Follow the procedure appearing in previous works. ⇒ refer to them by name

5.3 Membranes should be stored under deionized water in labeled containers. If it is necessary to store more than one in the same container, then they should all be discernible in some way. A suggested method is to cut very small notches into the periphery of the membrane, the part falling outside the sealing area. } good point

5.4 Dry membranes should not be placed into the test cell. When put into use the membrane will swell. Only fully saturated membranes should be installed.

6. Other Notes

6.1 Carbon papers are cut using cookie cutter and nylon block in the press. Only run the press to 1500 psi, this is sufficient to cut through the paper. In the future, a new cutter will be made from a more suitable material (steel) once the correct size is known.

6.2 Nafion discs are cut from DRY stock with cutter an nylon block in press. This time around 2000 psi should be used. Don't worry if they appear small, upon saturation with water it will grow to the appropriate size.

6.3 It is unknown at this point the actual longevity of this cell. The electrodag coating is supposed to render the areas treated quite inert to this type of environment, but it is unknown whether or not sufficient coating is being achieved.

Appendix C: Test Results

As stated in the introduction, the majority of the quarter was consumed with research on hydrogen safety and test stand modifications. However, we were able to perform a couple of promising tests during the last week of the quarter.

The first experiment involved performing a standard power output test. The difference between this test and previously performed tests was that we were able to make use of our test stand modifications and maintain water saturation of the feed gases as well as operate the cell at approximately 80 °C. It has been suggested by numerous sources that both of these conditions are necessary if high power output is to be expected. The results of our tests are summarized in Figures C-1 and C-2 below.

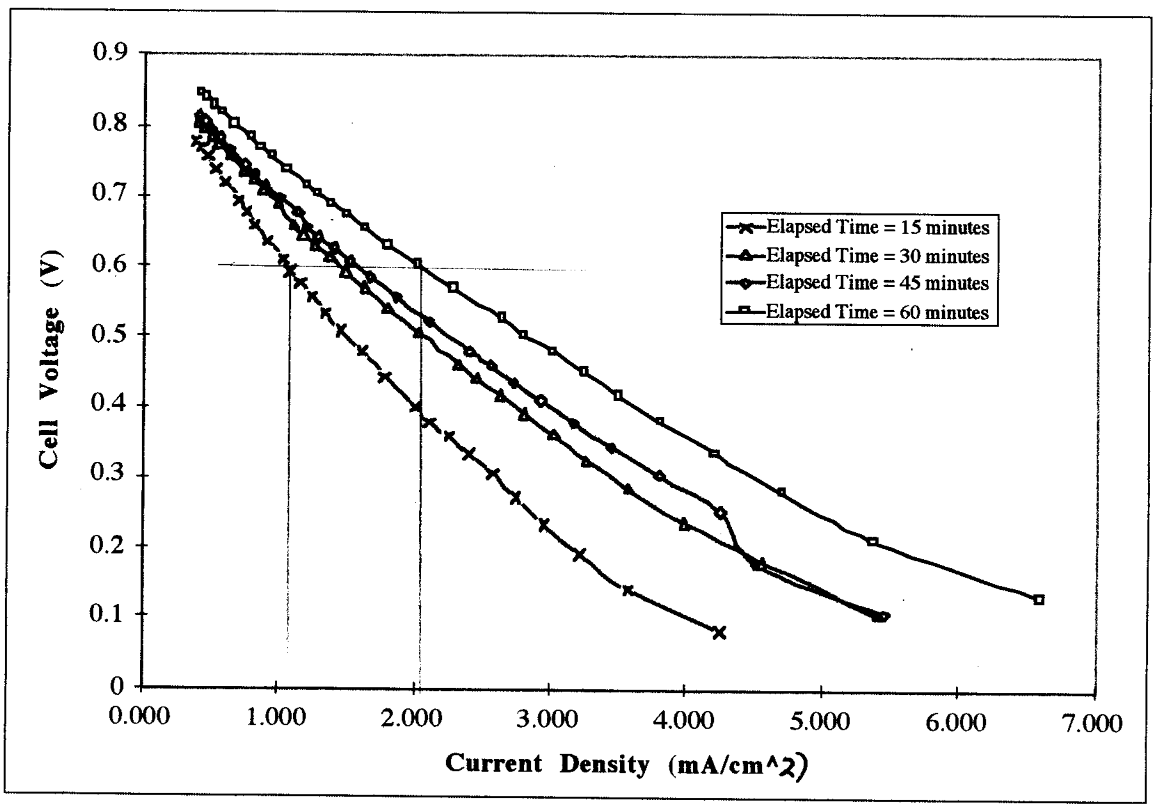


Figure C-1: Cell Voltage vs. Current Density

Current density at 0.6 V doubles after 1 hour ... excellent!

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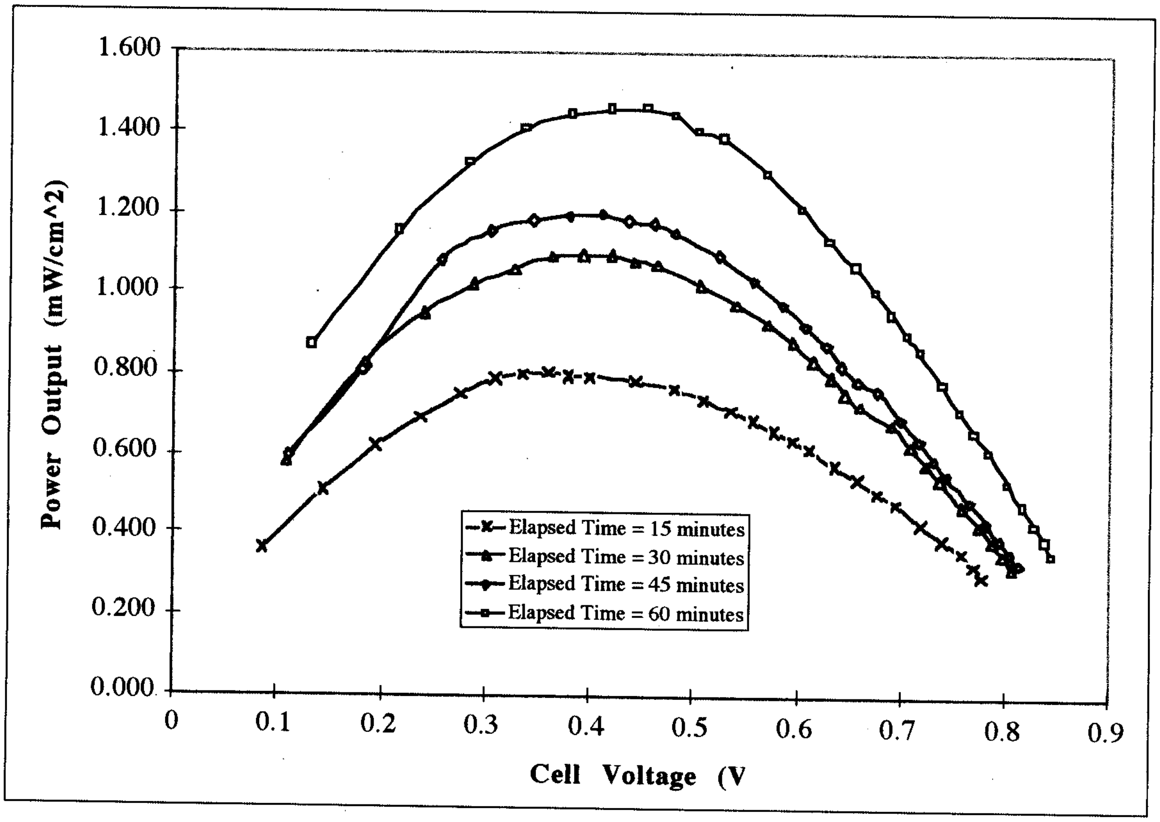


Figure C-2: Cell Power Density vs. Voltage

Both of these figures show a very promising trend, and one that has been reported in the literature. We see that the power output of our cell increases quite steadily as time passes. cite reference

Due to time constraints, we were unable to run the cell for more than an hour. Thus, we did not observe a leveling out of this trend and do not know how long it will continue. However, it is definitely worthy of further investigation.

The second test which we performed involved measuring the water content of our membranes. The test was performed on a fully processed membrane that had been soaking in room temperature deionized water for a couple of weeks. The results of this test are given in Table C-1. From this table, we see that the water to Nafion ratio in our membranes is about 23:1 at the time that they are placed in the test cell. This value compares very well with the literature, which reports a maximum ratio between 22:1 and

cite reference

17

25:1. Thus, we can assume that our membranes are well hydrated when they are placed in the test apparatus.

Table C-1: Membrane Hydration Data

Membrane State	Soaked in D.I.	Dry, Room Temp 2 hrs	100 degrees, 5 min	100 degrees, 10 min
Weight (g)	1.350	1.041	0.974	0.976
Water Content (g)	0.374	0.065	-0.002	0.000
Molecules Nafion	5.34E+20	5.34E+20	5.34E+20	5.34E+20
Molecules Water	1.25E+22	2.17E+21	-6.69E+19	0.00E+00
Molec. Water/Molec. Nafion	23.418	4.070	-0.125	0.000
wt% H_2O/dry Nafion	38.3	0.7	0	0

It would be interesting to run drying curves of this in the 437 UO Lab.

Appendix D: Recommendations

The past year has been mostly dead ends as far as the single cell group was concerned. Many different methods were attempted to at least reproduce existing results of other membranes in the field, all of which were met with little success. This being discouraging, we pressed on, and at the end have created possibly the most complex fuel cell test stand known to exist! For future work, this year's group is making the following proposals for future work, mainly intended for those working on the project next year.

The Year in Review-

To begin, a short review of what was done and/or attempted this year, and how they may be improved on in the future:

The original cell, constructed from 1 1/2" stainless vacuum system parts, has been scrapped. It is still possible to make a membrane for it and run it, but many improvements have been made so that this system is not used for testing procedures anymore.

The new single cell test unit was completed at the end of winter quarter 1997. Incorporating many improvements since the stainless cell, this one is constructed of T6061 aluminum, with the Electrodag coating on all active exposed parts. The cell is designed for delivering feed gasses dynamically over the membrane surface through two parallel running flow channels per side. This allows, *theoretically*, for many different configurations for feed gas through each side. It has been observed that this is hardly the case, as the design facilitates the gas to 'short circuit' the membrane and have very little contacting and residence time.

Improvements to this cell may include removing the existing flow channels and making a new *single* channel flow field block from either aluminum or graphite, and pressing this into the existing block. Enclosed shop drawings detail exactly what has been made to this point, and how an addition such as this could be made to the cell. Sealing the Nafion against the aluminum is another consideration, as it was found that the O-ring was not required under operating conditions. As long as the sandwich is allowed to come completely together, the metal to Nafion seal is quite sufficient. If the carbon paper recess is reduced too low, this will not be the case, however.

The test stand has undergone MAJOR changes, as very little of the original system remains. Enclosed schematics detail its current operating characteristics and design intentions, and where certain components are in definite need of improvement. A few of these are explained below.

The humidification bottles are insufficient for this application, as they are two small and it is too hard to deliver heat to them in a controllable manner. Being of stainless steel construction, the external band heaters provide a response time of almost 20 minutes when input current is changed. This makes for very difficult control of the heat delivery rate to the water inside. Perhaps a much larger chamber with more dead space above, with internal heating rods and external insulation, will do the trick here.

but there are safety problems w/ larger vessels

Valves and tubing connections are designed to purge the entire system with nitrogen if desired, and is a suggested activity when starting up and shutting down the system. Hydrogen can either be recirculated with an external pump, or purged to a suitable disposal device. This is one of the major concerns with the system as it sits now in Benson 215, as this room has no windows that open and no viable ventilation system, much less an exhaust hood! It is almost mandatory that a decent facility be obtained to run the test stand, as it is impractical to think it will not leak anywhere, and is fairly dangerous to boot as demonstrated at 1620 PST on March 6, 1997....

Recommended Course(s) of Action Starting Next Year-

One of the first things that should occur is the group should concentrate on existing literature pertaining to our specific research intent, and fire up the test stand a few times according to the enclosed procedure. Spend about one month at maximum doing this, formulating questions along the way as to why this thing just doesn't work.

While getting familiar with the concept of fuel cell operation and our dysfunctional system, close two way contact should be established with an organization that runs successful fuel cell programs. This may be in the form of telephone conversations, writing, or maybe indirectly with the research advisor. After the group is familiar with the way things are going, and are near the point where no more can be gained just from messing with the current system, a trip can be made. Go to a location where this does work, and watch--even help--in setting up and running a membrane on an apparatus that performs with practical power output. Maybe even work a ski trip in at the end!

Hopefully this will alleviate the small problems that have been overlooked in past years, and allow the research into the next stages of this project, mass production of the membranes. The Stack is estimated to require at least 700 individual cells to provide the desired operating voltage (~400 V). The large number is required due to the maximum operating voltage per cell of about 0.7 volts, and this number may be a bit high. Putting multiple cell patches on a single membranes has been tested, but with inconclusive results as of yet as to any advantages it may offer.

A control system could be incorporated into the testing apparatus, to permit long term operation of the cell at constant conditions. It has been thought that people could watch the device continuously, but the facility is still not in place for this to work anyway. Ventilation is required in the room before this can be done (long term), as small amounts of hydrogen are expected to leak over time. This is a must eventually due to the fact that the locomotive will need some sort of active control system because of changing power load demands in the field.

important

To recirculate the hydrogen gas, a better system must be used in lieu of the existing one. A pump capable of much larger flow rates but still certified for use with a wet hydrogen stream at low pressure is required. The stainless bellows pump currently in use is much to slow, and its longevity is in question, as well as its suitability for hydrogen service.

this turns out to be expensive

Over all, the correct environment for fuel cell operation must be achieved, and for extended periods of time. Water management is the key, and being able to introduce enough water into the hydrogen stream at the right temperature without going over. It is expected that a site visit will shed much light on this problem, as there is currently no method for us to ascertain just what the humidity is within the cell.

For a final suggestion, someone should be responsible for securing another way to provide the required membranes to the group and/or other required apparatus that cannot be constructed in time for the project. Of course we all want to succeed, but we don't want to be stuck with 5mW/cm^2 membranes that wont even produce enough power to move itself (membrane) around the track, much less a one ton railcar! Come up with definite specifications that must be met with any membranes, be it ones made here or purchased from another location.

Closer association with the stack group is now a must. Constant interaction to ensure that any new requirements or discoveries are immediately transferred, so work is not performed to the wrong ends. The membranes made must fit into the stack, and the stack must have the flexibility to accommodate any number of membrane units that are required for the dead set voltage specified by Penn State. Lead-acid is not a way out in this case!

Some things that have been observed over the year that may be of some help:

Power output appears to increase continuously with longer operating times. Running a membrane at constant conditions for a long time (24 hours) may provide fruitful results. This is the key

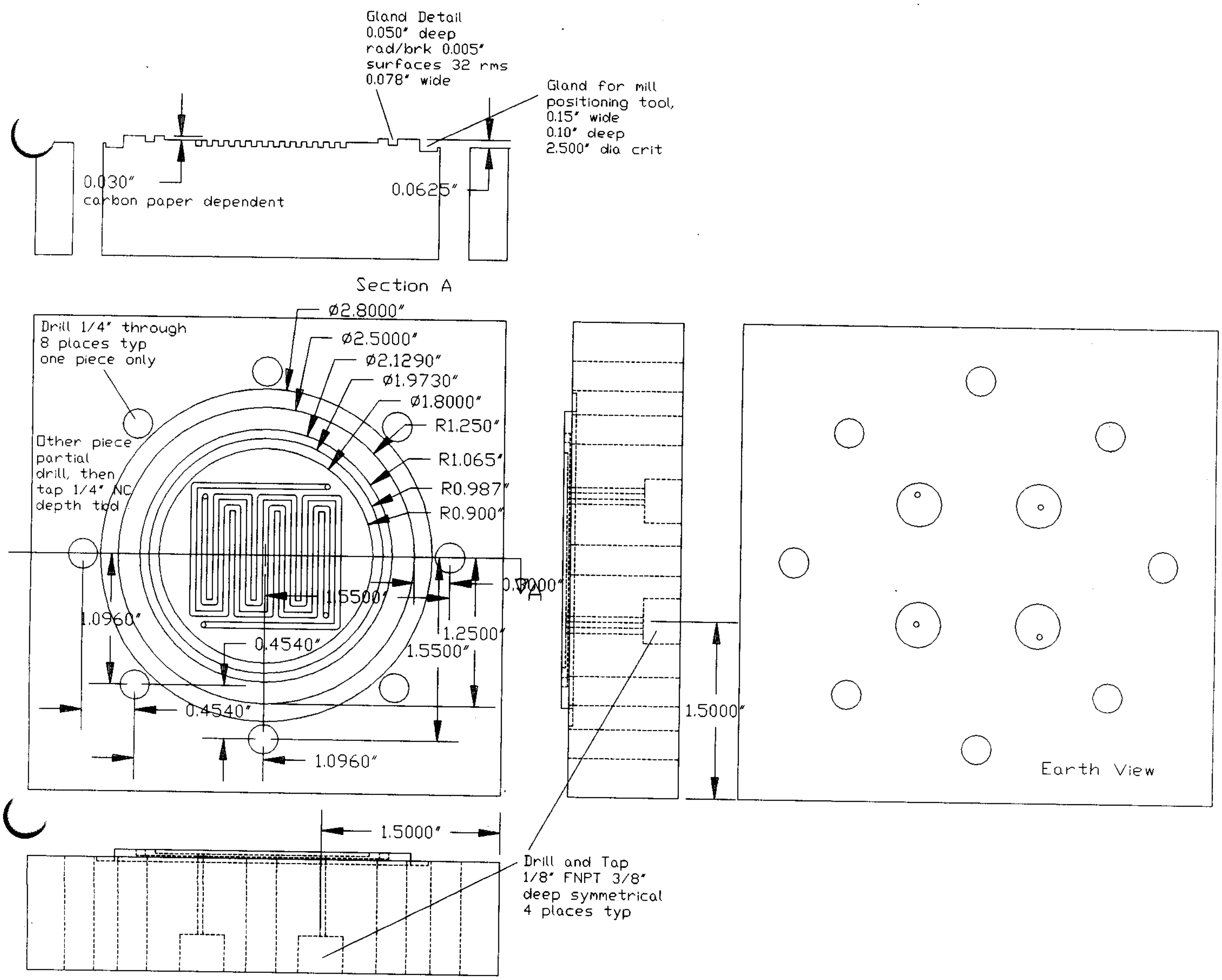
There just may be one little thing that we are overlooking as far as correct operating conditions go; if this can be found it may end all our worries.

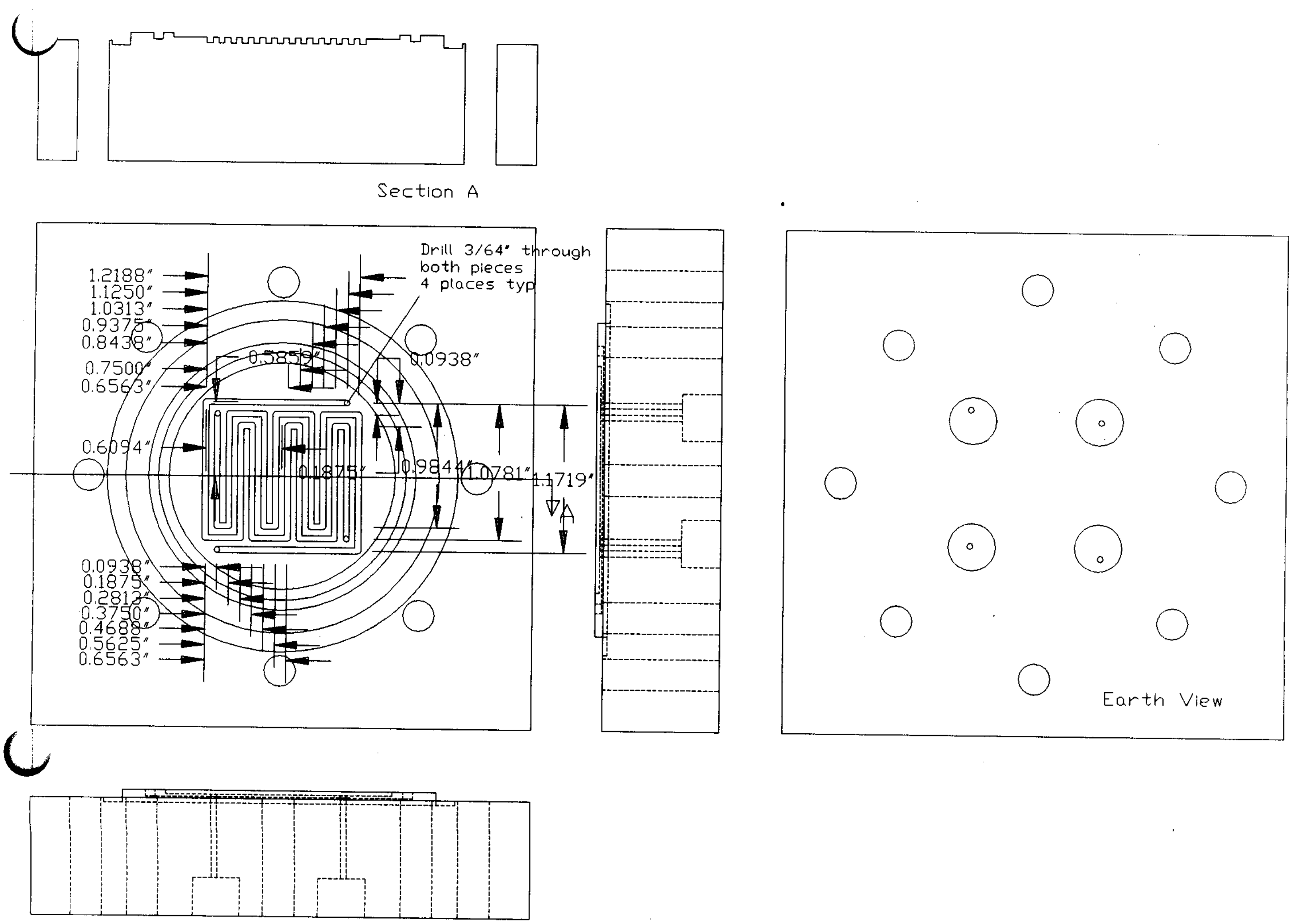
Humidity into the cell is so critical, that a way should be found to measure it inside the cell. Everyone that knows this business says that if the water is at the correct level, everything else falls into place. Our current humidity sensors provide questionable results at best.

This whole project is really going to be something as it comes together. We as a group hope it works out, and are anxious to see it in action next spring at the fair. A short summary of the things that need to happen before this will probably happen are summarized below in tabular format:

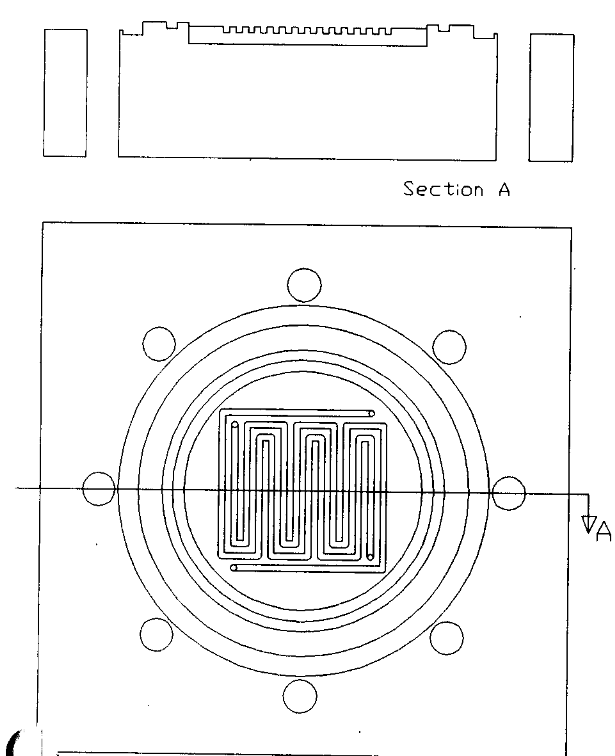
Become familiar with cell operation
Read literature pertaining to cell operating characteristics
Take a trip to a site where these things are actually working
Add an active controls system
Manage water in the feed streams correctly
Work closely with the stack group and all other engineering teams
Ensure a source for membranes is secured for an alternative solution to the main problem
Have fun while working hard
Don't blow up the lab!

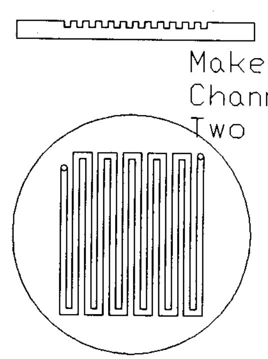
SINGLE CELL TEST UNIT




Section A
Drill 3/64" through
both pieces
4 places typ
1.2188"
1.1250"
1.0313"
0.9375"
0.8438"
0.7500"
0.6563"
0.5859"
0.0938"
0.6094"
0.1875"
0.9844"
1.0781"
1.1719"
A
0.0938"
0.1875"
0.2813"
0.3750"
0.4688"
0.5625"
0.6563"
Earth View

Replace, machine out old stuff.





Make new insert with only ONE
Channel through it, using
Two holes instead of 4

Appendix E: Electronic Website

Introduction

The increasing dependence of internet use for advertising, conducting business and meeting a wide range of other needs is growing at a zealous rate. The internet is a viable means of reaching a diverse audience and can facilitate interaction between the web user and our fuel cell locomotive project. The original goal of this website was to generate interest and promote greater participation between the university's academic resources and industry through financial and or technical support.

Website Development

What was needed before the construction of our website was research on what was currently available on the subject of hydrogen fuel cells on the internet through search engines such as Yahoo, web Crawler, and Alta Vista. Once this was done it became apparent that most sites were giving general information on the subject of hydrogen fuel cells and their applications. The challenge was to find another way to communicate the same type of information as other sites, without seeming redundant in a sea of fuel cell hype. Taking to heart the old adage 'a picture says a thousand words', the task of presenting a visual concept of a hydrogen fuel cell became essential to our web presence.

Many schematics have been drawn of a hydrogen fuel cell accompanied with an explanation of how it works. An original approach was needed so a moving diagram of the chemical process on how our fuel cell would work was created out of 15 frames. When people browse the internet and reach your site their interest must be maintained or the will look elsewhere. The first impression you make on this page needs to make a strong impact. This page needs to communicate the essence of what the user will read later on. A picture of a galaxy courtesy of Mary Edmunds, Coordinator & Student Advisor with the Washington NASA Space Grant Consortium was used for the front page of our website. A picture of a galaxy was used because it was representative of the 'space age' in which we live, it has an abundant source of hydrogen, and it was a powerful image. In my opinion, these three ideas should be connected with our website. The content was the next concern for our website.

Icons and attached content headings where made along side the picture on the front page to help walk the user our website presentation. A list of frequently asked questions were offered to the user as well as what our project was about and a contact information if the user wanted to know any additional information. Problems arose with the direct e-mail segment. There is an internal text issue in which I currently do not know how to fix. Hopefully this will be fixed by the begging to middle of the summer. An important part of the information presented is the section 'who are the participants?' This is a natural place to make quarterly updates with our project.

<u>What's Next?</u>

The advantage of having a website is your ability to change it, as you feel necessary. The site is dynamic, so it is a future plan to update it quarterly as further progress is made in the project. Overall changes can be incorporated, as the different groups of this project deem necessary. A picture or schematic of our locomotive included in the website will be added.

Appendix F: Materials and Hardware to Obtain or Purchase

The following is a list of materials that we feel are needed before Fall quarter 1997 research can be started in earnest. Due to the time required to order and receive these materials, we feel that it would be beneficial for someone to look into obtaining them over the course of the summer, so that they will be available for use when the single cell research group begins the Fall quarter.

Description	Quantity	Recommended Vendor
Nafion 117	As needed	Electro Chem
Hydrogen Recirculation Pump (variable speed, 5-10 mL/second max flow)	One	Unknown
Humidity Meters (suitable for hydrogen duty as the last meters obtained quit working after a short time, ability to handle 100% RH is desired)	Two	Unknown
Macintosh Computer (minimum of 13" color monitor)	One	See Eric Mehan
Temperature Controllers for Humidification Bottles	Two	Unknown