Appendix A

Fuel Cell Stack Progress Report
Fall 1996

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INTRODUCTION

In June of 1996 an interdisciplinary project was started with the purpose of designing a fuel cell stack that would power a locomotive. In Autumn of 1996, a group of studenst began to design a fuel cell stack, capable of delivering a certain power output and meeting size constraints. The specifications, findings and recommendations from first quarter of work follow.

SCOPE

Preliminary research lead the group to investigate the following issues:

A) Fuel Cell System Design Specifications

- System schematic
- Throughput rates of oxygen and hydrogen (stoichiometric and excess)
- Humidification requirements for each gas
- Time between refilling tanks carried on locomotive
- Best guess size of gas and humidification tanks
- Power requirements

B) Fuel Cell Stack Conceptual Design

- Layout of cells
- Materials used
- Cooling water and gas input and output locations
- Seals
- Layout of the stack
- Manufacturing; ease and cost

C) Water Management

- Removal of excess water
- Humidification of H_2
- Humidification of O_2
  1. Humidify at a low temperature, run low excess ratio
  2. Humidify at a high temperature, run large excess ratio

D) Heat Management

- Water requirements for cooling
- Size and type of pump
- Optimal operating temperature

PROCEDURES AND FINDING

Fuel Cell System Design Specifications

The needs of the system were carefully analyzed. It was determined that a cooling system, including a heat exchanger within the stack, a pump, and a radiator outside of the stack are needed. (See Figure 1.) In addition, the tanks containing the gases (H_2 and O_2), used to fuel the locomotive, will be made refillable so the tanks will be able to be carried. Humidification tanks are needed for each each fuel gases. The possibility of recycling the H_2 gas was considered, which would call for a recycling pump.

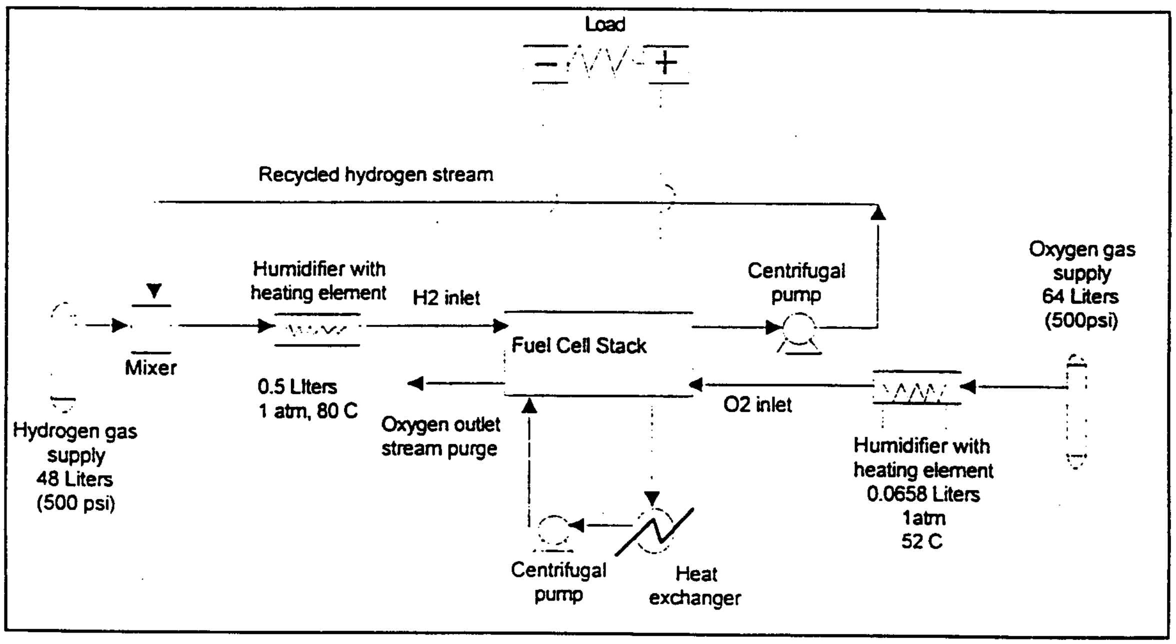


Figure 1. Schematic of Fuel Cell System

The initial working power specification for the power cell as dictated by the locomotive needs, was set at 5 kilowatts. The current density was set at one ampere per square centimeter of reaction area. Determining the throughput of the fuel gases through the system and water produced was the next priority. Stoichiometric requirements and water production were determined by using the current density, power requirements, and predicted efficiencies (See Appendix B).

To keep the cell from flooding, all of the water produced must be removed from the cell. The water can be removed by saturating the inlet oxygen gas, which is below the 100% saturation at 80 ° C, and/or by entrainment using excess inlet oxygen to pull away the produced water. The humidification requirements are based on saturating the inlet oxygen gas. If excess oxygen entrains the produced water, a very large oxygen fuel tank and oxygen humification section are required. If entrainment is used, it would be more feasible to use compressed air than oxygen. Unfortunately, the large portion of nitrogen in air can form a blanket over the membrane, impeding the reaction. For this project, this issue is best avoided by using oxygen.

Volume calculations of the humidification and the feed tanks were done at different saturation levels of the entering oxygen gas. Refilling time required between fuel and humidification tank was also considered. Originally, refilling the tank every hour was considered, but once the calculations were performed, and the tank sizes found to be rather large, the time was reevaluated. The tank sizes for fuel gases at 500 psi and humidification water at STP (standard temperature and pressure) were found based on a thirty minute refill time, predicted uptime of the cell of 50%, and excess oxygen 2.7 times the required to pull away all produced water. The results are as follows:

Volume of O_2 humidification tank (in liters)	Volume of H_2 humidification tank (in liters)	Volume of H_2 fuel tank at 500psi (in liters)	Volume of O_2 fuel tank at 500psi (in liters)
6.58E-02	0.5	48	64

The initial layout of the system involves determining relative size of the stack, and where the cooling system and humidification units should be in relationship to the stack. Based on one of the fuel cell stack designs, an initial layout was devised (See Appendix C).

Fuel Cell Stack Conceptual Design

The initial stack design was based on the Ballard fuel cell stack patents (patent # 5260143.) The membrane is sandwiched between two graphite coated aluminum plates, the cathode and anode. This pattern (the serpentine area), is repeated for 36 ten cm^2 cells, connected in series. In order to meet the initial voltage requirements of 48 volts, two stacks are connected in series.

The fuel cell plate contains two inlets and outlets for each gas and the cooling water. The serpentine represents the catalytic reaction area. See Figure 2.

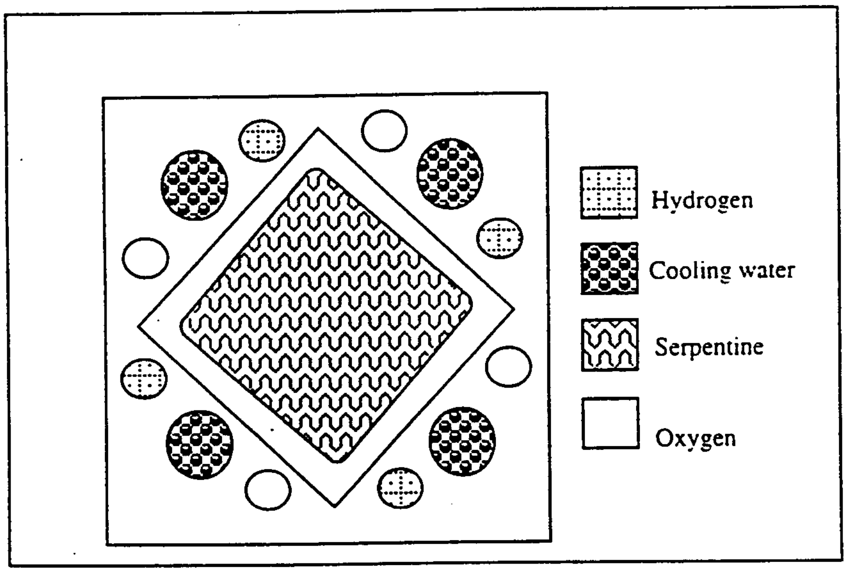


Figure 2. Diagram of fuel cell plate

With this design, seals are required for each plate at every gas or cooling water inlet and outlet, and between each plate. This amounts to an enormous number of seals and an increased probability of leaks.

The Penn State electrical engineering professor requested that the voltage of the fuel cell system be increased to 300-500 volts to meet a standard voltage range used in small motor drives. A minimum of 150 volts is required, which can be converted to approximately 300 volts with a DC-DC converter. To accomplish this the number of cells must be tripled. As a result, the number of seals must be tripled, which increases the probability of leaks. In addition, the cost of the fuel system will increase by one and one-half to three times the original price.

In a response to the increased cost and safety issues, the fuel cell stack design was reevaluated. To achieve a higher voltage with limited seals and lowered cost, a new design was created. With the new design, the cells are placed in strips on a single membrane, assuming 350 volts, 1 $Amps/cm^2$, and an overall power of 4.8 kilowatts. A total of 500 cells are needed to obtain 350 volts, based on nominal voltage of 0.7 volts per cell. The area of each cell will be seven square centimeters. Each strip will contain two rows of 25 cells. According to size considerations, ten 80.5 cm (2.64 feet) by 8.4 cm strips will be stacked together with a one-half centimeter space between them in the long direction, and a one centimeter space in the narrow direction. A conductive surface will protrude from each cell to the edge of the strip, where a metal tab will extend through the outer casing of the strip. Wires outside of the strip casing will connect all of the individual cells in series. This will occur at each side of the strip. (See figure 3)

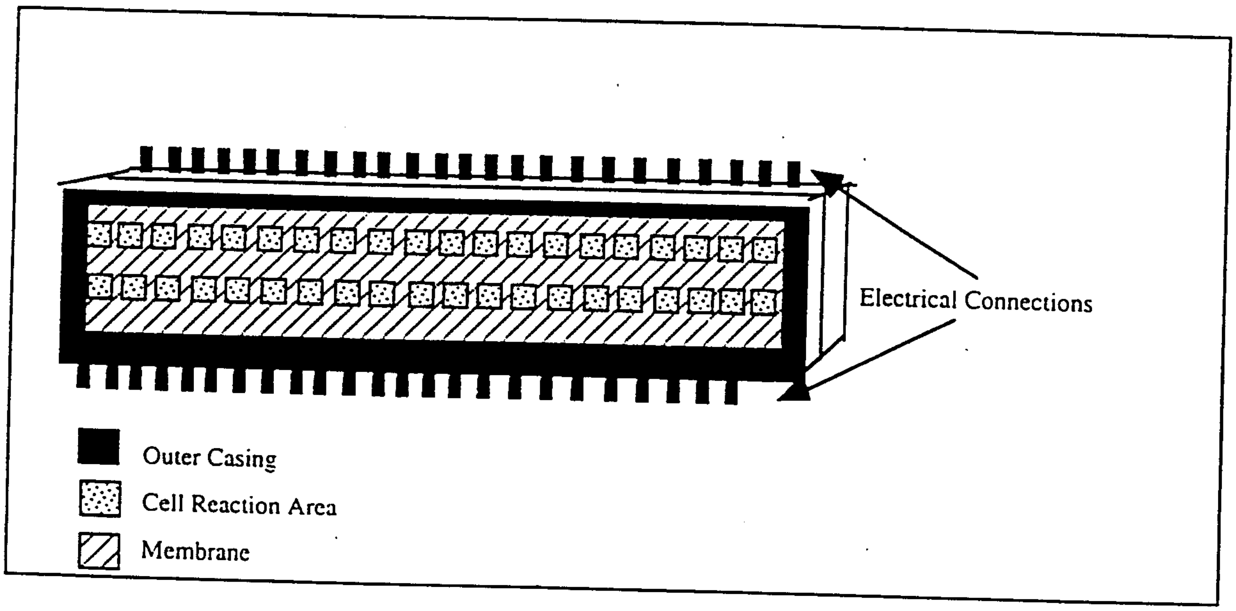


Figure 3. Diagram of "Strip Stack"

The oxygen will enter one side of the fuel cell strip stack, and the hydrogen to the other. The number of seals required are minimized. The casing material will to be a clear polymer. The posts will be epoxied into the case, eliminating the need for complex seals. The casing must be sealed together, and the inlet and outlet gas must be sealed off as well. The cooling water can run on plates on the backside of the strips, never passing into the reaction area. This design may prove to be advantageous for many reasons. Unfortunately, the spacing between cells is unknown, as there may be a problem with current leakage of cells. This is potentially the largest obstacle to successfully using this design.

Water Management

As stated before, all of the water produced must be removed from the cell, but the cell must not dry out. An experiment must be conducted to determine if the above described entrainment, or saturation should be used. To see the designed experiment, please see 'Proposal #1' (Houger.) It is predicted that the hydrogen will be humidified to 90-100% at 80 °C. without excess flow. The oxygen humidification and throughput are yet to be determined.

Heat Management

The estimated optimal operating temperature of the fuel cell is 80 °C, as based on work done by Dr. Gottesfeld at the Los Alamos National Laboratories (Gottesfeld.) This temperature must be achieved by having water flow by the hot faces of the stack. The total heat that must be pulled away based on maximum fuel cell capacity is 106 J/sec. The water required to do this is 93 L/sec, assuming a temperature increase from 60 °C to 80°C. The pump then must move 1.44 gallons/ minute. The required external radiator has not yet been researched.

RECOMMENDATIONS / NEXT QUARTERS WORK

- Improve stack test stand
- Do cost comparison of the two different fuel cell stack designs
- Conduct water management, humidification, and heat management experiments. (as seen in proposal #1), a set of experiments for each type of fuel cell stack design
- Create and implement experiments to test interaction conductivity, and feasibility of new strip fuel cell stack design
- Contact material engineers to look into material choice on strip fuel cell stack design
- Look into various flow field techniques, and method to test efficiency for each stack design
- Research manufacturing and assembly techniques for stacks
- Research corrosivity and reliability of materials used to carry current from reaction area to outside of the casing of the strip stack design
- Research and experiment optimal seal designs, for any potential seals

WORK CITED

Gottesfeld,

Houger, Kevin, Janel Martinsen, Yao Huang; <u>Fuel Cell Proposal. Fall 1996.</u> University of Washington, Professor Eric Stuve, 10/25/96.

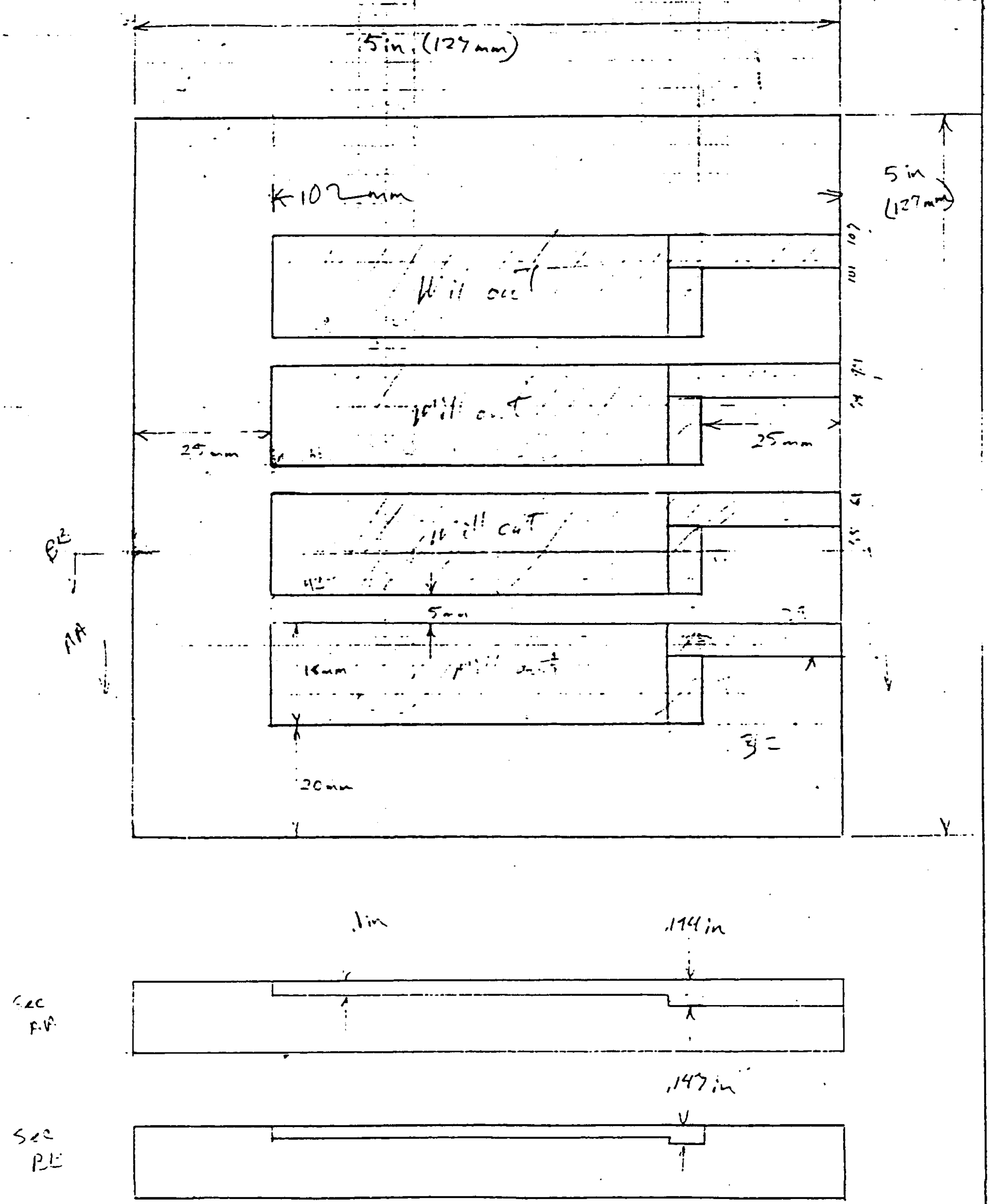
Appendix B

Detailed Milling Instructions

DO NOT COPY

97/03/05-1 | Milling layout | FC stack group Kevin Houger

① start w/ a 1/16 end mill and out line everything at proper depth.
② use 1/4 end mill to remove the rest of the material.



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Appendix C

Sample Calculations

At Max Capacity, 1 cell will produce 100 amps @ 1 amp/cm².

$$2H^+ + \tfrac{1}{2}O_2 + 2e^- \longrightarrow H_2O$$

Max H_2O produced:

$$\left(\frac{100\ amps}{cell}\right)\left(\frac{1\ C/s}{amp}\right)\left(\frac{1e^-}{1.6\times10^{-19}C}\right)\left(\frac{1\ H_2O}{2e^-}\right)\left(\frac{1}{6.023\times10^{23}}\right)\left(\frac{18g}{mol}\right)\left(\frac{1000mg}{g}\right)$$

$$= \boxed{\frac{9.34\ mg\ H_2O}{cell \cdot second}}$$

Max O_2 consumed:

$$\left(\frac{100amps}{cell}\right)\left(\frac{1C/s}{amp}\right)\left(\frac{1e^-}{1.6\times10^{-19}C}\right)\left(\frac{1\ O_2}{4e^-}\right)\left(\frac{1}{6.023\times10^{23}}\right) = \frac{2.59\times10^{-4}\ mol\ O_2}{cell\cdot sec}$$

$Pv = nRT$; Assume run @ 80°C = 353K & 3atm = 3×10^5 Pa

$$v = \frac{nRT}{P} = \frac{(2.59\times10^{-4}\ mol)(8.314\ J/K\cdot mol)(353K)}{3\times10^5\ N/m^2} = \frac{2.54\times10^{-6}m^3}{s\cdot cell}$$

$$= \boxed{\frac{2.54\ cm^3\ (O_2\ consumed)}{cell\cdot sec}} = \frac{9144\ cm^3\ O_2\ consumed}{cell\cdot hr}$$ if refilled every hr.

Max H_2 consumed:

$$\left(\frac{100amp}{cell}\right)\left(\frac{1C/s}{amp}\right)\left(\frac{1e^-}{1.6\times10^{-19}C}\right)\left(\frac{1\ H_2}{2e^-}\right)\left(\frac{1}{6.023\times10^{23}}\right) = \frac{5.19\times10^{-4}\ mol\ H_2}{cell\cdot sec}$$

$Pv = nRT$; Assume 353K & 3×10^5 Pa

$$v = \frac{nRT}{P} = \frac{(5.19\times10^{-3})(8.314)(353)}{3\times10^5} = \frac{5.07\times10^{-6}m^3}{s\cdot cell} = \boxed{\frac{5.07cm^3\ H}{s\cdot cell}}$$

If only refilled every hr,

$$\frac{18{,}280cm^3\ H_2\ consumed}{cell\cdot hr.}$$

each cell = 100cm

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http://weber.u.washington.edu/~fcstack

400 Volts D.C. 4 Amps

Humidity charts w/

3/7/97.

Ideal Gas Law Calculation

$p^*_{H_2O}$ - balance is O_2 or air)

(2) 13 atm.

solve for P → gas law to find volume ... O_2.

$$Hum = \frac{p^*_{wv}/R_{wv}\cdot T}{p^*_{DA}/R_{DA}\cdot T}$$

$$H = \frac{p^*_{wv}}{p^*_{DA}}\left(\frac{M_{wv}}{M_{da}}\right)$$

$P = p^*_{da} + p^*_{wv}$ ∴ $p^*_{DA} = P - p^*_{ww}$

can use just one of the two.

$$H = \frac{p^*_{wv}}{(P - p^*_{ww})}\left(\frac{M_{wv}}{M_{da}}\right) \frac{\text{kg water/mol}}{\text{kg dry air/mol}}$$

$p^*_{ww} = 0.0007x^2 - 0.104x + 4.2332$

page 2

To find Amount of H_2O in w/ H_2

We use the fact that 1.1 to 2 moles of water are needed for each mole of H_2.

Using the spreadsheet & H values we can heat the H_2 gas to 84°C and humidify it.

The H_2O brought in is $\left(\frac{0.1342\,mg}{cm^2 \cdot s}\right)\left(\frac{g}{1000\,mg}\right)\left(\frac{mol}{18\,g}\right)$

$= 7.46 \times 10^{-6} \frac{mol}{cm^2 \cdot s}$

H_2 in $= \left(\frac{0.01038\,mg}{cm^2 \cdot s^2}\right)\left(\frac{g}{1000\,mg}\right)\left(\frac{mol}{2\,g}\right) = 5.19 \times 10^{-6} \frac{mol}{cm^2 \cdot s}$

$\frac{7.46 \times 10^{-6} \frac{mol\ H_2O}{cm^2 \cdot s}}{5.19 \times 10^{-6} \frac{mol\ H_2}{cm^2 \cdot s}} = 1.44 \frac{mol\ H_2O}{mol\ H_2}$ @ this humidification.

Hum(O_2, 80°C) = 0.604

so if X = O_2 flow out

H_2O out = 0.604 X

Balance:

Water in w/ H_2 + Water Produced = Water Out
(O_2 is dry)

Water in H_2 + 0.09324 = 0.604X

Water in w/ H_2 @ 84°C

$H(84°C) = \left(12.96 \frac{mg\ water}{mg\ H_2}\right)\left(0.01038\ mg\ H_2\right) = 0.1345$

0.134 mg water w/ H_2 + 0.09324 mg H_2O produced = 0.604X

X = 0.37622 mg O_2 excess

O_2 required = 0.0803 mg/s²·cm²

Total O_2 in = 0.4565 mg/cm²s

Excess = $\frac{0.4565}{0.0803}$ = 5.7 excess Stichiometric Requirement.

Heat Management

Heat in

$$h(H_2 gas)(\dot{m}_{H_2}) + h(H_2O \text{ in } H_2)(\dot{m}_{H_2O}) + h(O_2)(\dot{m}_{O_2})$$

(84°C, 84°C, 24°C)

$$\left(\frac{5049.7\ J}{g}\right)\left(\frac{1g}{1000mg}\right)\left(\frac{0.01038mg}{cm^2 \cdot s}\right) + \left(\frac{2651.9J}{g}\right)\left(\frac{1g}{1000mg}\right)\left(0.1345mg\ H_2O\right)$$

$$+\left(\frac{322.4\ J}{g}\right)\left(\frac{1g}{1000mg}\right)\left(\frac{0.4595mg}{cm^2 \cdot s}\right) = \boxed{0.5325\ J/cm^2 \cdot s}$$

Heat Out

$$h(O_2 gas\ Excess)(\dot{m}_{O_2 excess}) + h(H_2O\ prod)(\dot{m}_{H_2O prod}) + h(H_2O_{excess})\dot{m}_{H_2O}$$

(80°C, 80°C)

$$= \left(\frac{322.39J}{g}\right)\left(\frac{0.3792mg\ O_2}{cm^2 \cdot s}\right)\left(\frac{g}{1000mg}\right) + \left(\frac{2644.78\ J}{g}\right)\left(\frac{g}{1000mg}\right)\left(0.09324mg\ H_2O\ prod + 0.1350\ mg\ H_2O\right)$$

$$\boxed{= 0.7236\ J/cm^2 \cdot s}$$

Heat Produced

$$\Delta G = -nFE^{\circ}$$

$E_{H_2O} = 1.23V$

$F = 96,486\ C/mole^-$

$n = 2$

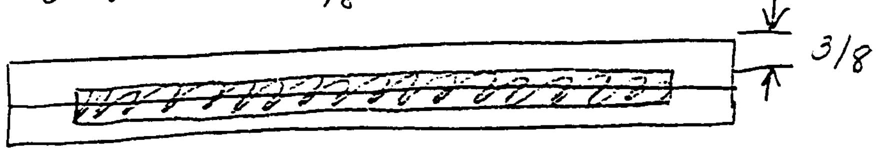
$$\Delta G = (-2\ mol)(96,486C/mole)(1.23V) = 237,355\ J/mole$$

$$\left(237,355J/mole\right)\left(\frac{5.19\times10^{-6}\ mol\ H_2}{cm^2 \cdot s}\right)\left(0.83\ \text{efficiency}\right) = \boxed{1.03\ J/cm^2 \cdot s}$$

Heat Transfer

Thermal Conductivity $1.39 \left(\frac{Btu \cdot in}{hr \cdot ft^2 \cdot F^\circ}\right)$

Assume - no heat transfer through ends
- single cavity 4 in x 4 in (16 in²)
- thickness = 3/8"



$R = \frac{L}{KA}$ $L = 3/8"$ $A = 16\,in^2$ $K = 1.39$

$1.39 \frac{Btu \cdot in}{hr \cdot ft^2 \cdot F} \left(\frac{1\,ft^2}{144\,in^2}\right) = 9.65 \times 10^{-3} \frac{Btu}{hr\ in\ F^\circ}$

$R = \frac{0.375\,in}{9.65 \frac{Btu}{in\,hr\,F}\ 16\,in^2} = .243 \frac{hr\,F}{Btu}$ $\frac{1}{R} = 4.12 \frac{Btu}{hr \cdot F}$

Free Convection, air = 3-25 $\frac{W}{m^2K}$

$R = \frac{1}{h_c A}$ $h_c = \frac{K}{L}$ K air at 330K = 0.287 $\frac{W}{mK}$ $P_r = .69$

$B = 1/T = 1/330$

$\nu = 18.37 \times 10^{-6}\,m^2/s$

Assume Vertical Heated Plate

$Ra_L = \frac{\beta \Delta T g L^3}{\nu^2} P_r = 53787$

$\psi = \left[1 + \left(\frac{.492}{.69}\right)^{9/16}\right]^{-16/9} = .343$

$Ra_L \psi = (0.343)(53787) = 18449.1$ $Nu_L = 0.68 + 0.67(Ra_L \psi^{1/4}) = 8.49$

$h_c = \left(\frac{K}{L}\right) Nu_L = \left(\frac{0.0287}{0.0254}\right) 8.49 = 9.59 \frac{W}{m^2K} = .187 \frac{Btu}{hr\,F}$ c

$\frac{1}{h_c A} + \frac{L}{KA}$ $A = 16\,in^2$ $= \frac{1}{.187} + .243 \frac{hr\,F}{Btu} = 5.6 \frac{hr \cdot F}{Btu}$ $T_i = 80$, $T_o = 24$ } 10

$q = UA\Delta T = \frac{1}{5.6 \frac{hr\,F}{Btu}} (100.8^\circ F) = 18 \frac{Btu}{hr} \left(\frac{.2931\,W}{Btu\ hr}\right) = \underline{5.27\,W}$ loss due to nat

3/7/97

Heat In

Heat Balance

H_2 in + O_2 in + H_2 hum in + O_2 hum in

Heat Out

O_2 out + H_2O prod out + ~~H_2O~~ H_2 hum out + O_2 hum Out

Heat Produced

1.03 J/cm²·s

So

Heat In + Heat Produced = Heat Out.

H_2 in + O_2 in + H_2 hum in + O_2 hum in = 1.03 + O_2 out + H_2 prod. out + H_2 hum out + O_2 hum out.

↳ = 41.7 = W

Water Balance

H_2O prod + H_2O in = H_2O out

H_2O prod = 0.09324 mg

H_2O in = O_2 hum + H_2 hum

H_2O out = ~~H_2O~~ (O_2 * hum)

H2 (mg/s*cm^2)	T H2(C)	T (F)	p water	hum	lb water	h H2(J/g)	H2O (mg/s*cm^2)	h H20 (J/g)	heat H2(J/cm^2*s)	heat H2O (J/cm^2*s)
0.01038	24	75.2	0.3709	0.2330	5.32E-09	4188.1400	0.0024	2545.2552	0.0435	0.0061
H2 (lb/s*cm^2)	28	82.4	0.4164	0.2624	5.99E-09	4245.5800	0.0027	2552.3644	0.0441	0.0069
2.2836E-08	32	89.6	0.5345	0.3396	7.76E-09	4303.0200	0.0035	2559.4736	0.0447	0.0090
	36	96.8	0.7252	0.4670	1.07E-08	4360.4600	0.0048	2566.5828	0.0453	0.0124
	40	104	0.9884	0.6488	1.48E-08	4417.9000	0.0067	2573.6920	0.0459	0.0173
	44	111.2	1.3242	0.8910	2.03E-08	4475.3400	0.0092	2580.8012	0.0465	0.0238
	48	118.4	1.7326	1.2025	2.75E-08	4532.7800	0.0125	2587.9104	0.0471	0.0322
	52	125.6	2.2136	1.5955	3.64E-08	4590.2200	0.0165	2595.0196	0.0476	0.0429
	56	132.8	2.7671	2.0870	4.77E-08	4647.6600	0.0216	2602.1288	0.0482	0.0563
	60	140	3.3932	2.7009	6.17E-08	4705.1000	0.0280	2609.2380	0.0488	0.0730
	64	147.2	4.0919	3.4716	7.93E-08	4762.5400	0.0360	2616.3472	0.0494	0.0941
	68	154.4	4.8632	4.4494	1.02E-07	4819.9800	0.0461	2623.4564	0.0500	0.1209
	72	161.6	5.7070	5.7114	1.30E-07	4877.4200	0.0592	2630.5656	0.0506	0.1556
	76	168.8	6.6234	7.3807	1.69E-07	4934.8600	0.0765	2637.6748	0.0512	0.2017
	80	176	7.6124	9.6664	2.21E-07	4992.3000	0.1001	2644.7840	0.0518	0.2648
	84	**183.2**	**8.6740**	**12.9547**	**2.96E-07**	**5049.7400**	**0.1342**	**2651.8932**	**0.0524**	**0.3559**
	88	190.4	9.8081	18.0448	4.12E-07	5107.1800	0.1869	2659.0024	0.0530	0.4970
	92	197.6	11.0148	26.9007	6.14E-07	5164.6200	0.2786	2666.1116	0.0536	0.7429
	96	204.8	12.2941	45.9905	1.05E-06	5222.0600	0.4764	2673.2208	0.0542	1.2735
	100	212	13.6460	116.5218	2.66E-06	5279.5000	1.2070	2680.3300	0.0548	3.2351

OUTLET STREAMS (T = 80 degree C)

O2 (mg/s*cm^2)	h O2 (J/g)	heat O2 (J/cm^2*s)	H2O prod. (mg/cm^2*s	h H2O (J/g)	heat H2O prod
0.3765	322.3920	0.1214	0.0932	2644.7840	0.2466

heat out	heat in	balance	balance for 16 in^2 area	balance 16 in^2 w/ cavity
0.7236	0.5325	0.8389	46.9768	***41.7068***

PRODUCED STREAM

heat prod. (J/cm^2*s)
1.03

mass balance

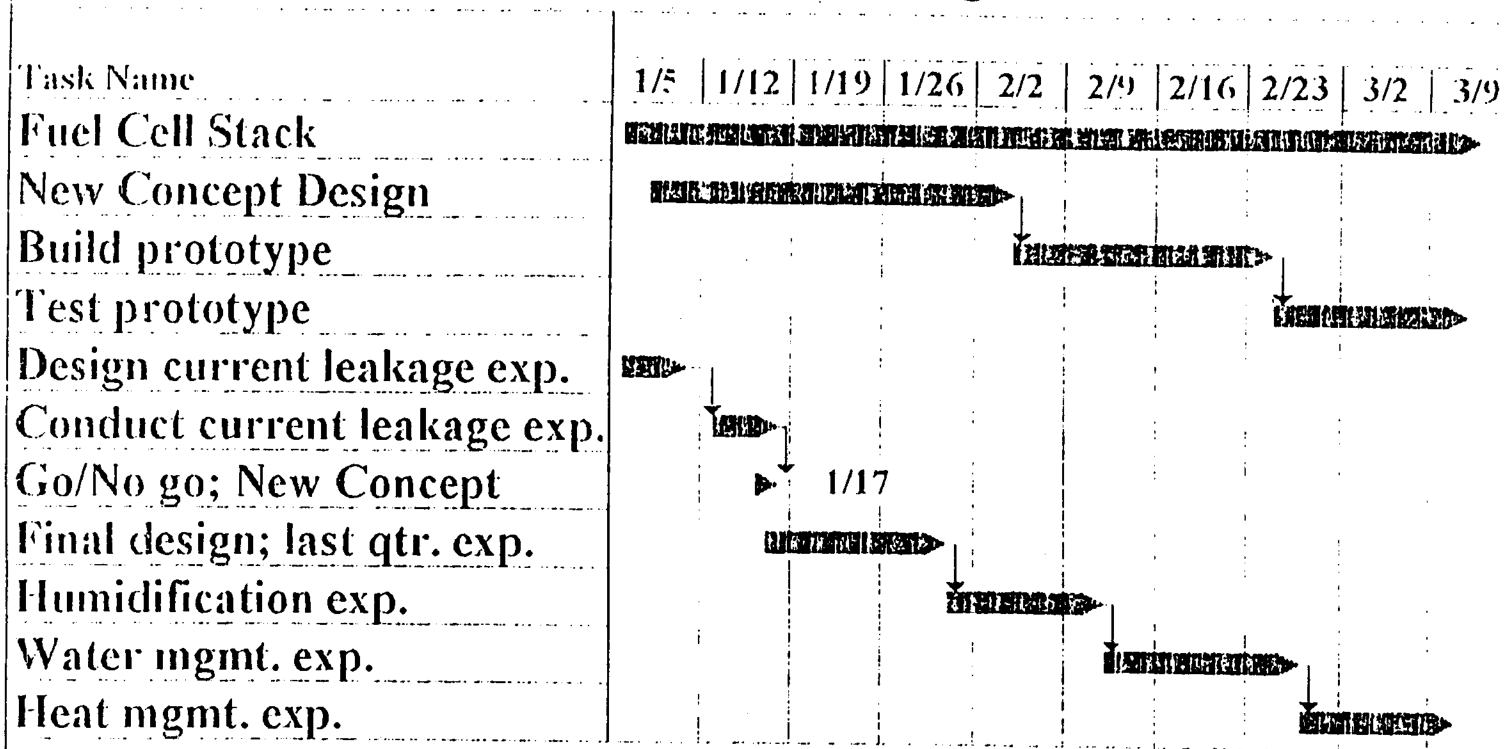
H2O carried out
0.22746255

Appendix D

Gantt Chart

Appendix D

Fuel Cell Stack Design



Appendix E

Trademarks

Araldite 2042; Ciba-Giegy, Corp.

Lexan; General Electric, Corp.

Nafion; Perma Pure, Inc.

Plexiglas; Atohaas Americas, Inc.

Weld-on 16; IPS, Corp.

Appendix F

Work Summary

KevinHouger
Nicole Miller

Work Summary- Kevin Houger

Appendix F

Week	*Efforts*	*Accomplishments*
1	Meet with team. Review Fall Quarters Recommendations.	Developed the Gantt Chart. Organized priorities
2	Design of current leakage exp. Conduct experiment	Designed and built the test stand Created wiring schematic
3	Review results of experiment Design prototype Research materials.	Designed the prototype.
4	Review materials Prepare Progress Report	Select Materials Turn in Progress Report.
5	Characterize the materials collected by group. Work on design.	Autocad drawing. Made measurements of materials. Made wiring harness. Tab design.
6	Find components for prototype. Work on getting space for group in the ILF.	Priced aluminum and Lexan sheets. Emailed Prof. Calkins about space.
7	Start building prototype. Discuss elements of prototype with group.	Worked in shop, made tabs. Located fittings.
8	Discuss flow of gases through plates. Develop milling procedures.	Ordered fittings. Located space in the ILF (no lock yet). Draw milling layout.
9	Work on adhesive test.	Talked with Tom Collins, he suggested contacting Port Plastics about Adhesives. They suggested Weld-on 16.
10	Work on prototype. Work with Weld-on 16. Work on report.	Tab grooves and recessed cell area milled into plates. Supply, feed, exhaust hole drilled. Adhesive test of Weld-on 16 started. Worked on final report.
11	Work on report	Work on report.

Work Summary- Nicole Miller **Appendix F**

Week	*Efforts*	*Accomplishments*
1	Meet with team. Review Fall Quarters Recommendations.	Researched Fuel Cell Operation Organized priorities
2	Design of current leakage exp. Conduct experiment	Contributed to experiment Design Developed Experimental Procedures
3	Review results of experiment Design prototype Research materials.	Contributed to Design of the Prototype. Searched for Proper O-ring Materials
4	Review materials Prepare Progress Report	Chose and Picked up Seal Materials Wrote 50% of Progress Report
5	Characterize the materials collected by group. Work on design.	Contributed to Prototype Dimensions and geometry
6	Find components for prototype. Work on getting space for group in the ILF.	Emailed Prof. Calkins about space. Continued to work on prototype orientations/geometries.
7	Start building prototype Begin heat and water calculations using prototype Discuss prototype with group.	Began simple heat calculations Contributed 30% to water management spreadsheet .
8	Discuss flow of gases through plates. Develop milling procedures. More Calculations	Located space in the ILF (no lock yet). Modified water management spreadsheet. Heat – cavity calculations
9	Modify water spreadsheet	Modify Spreadsheet based on PV=nRT instead of extrapolating tables
10	Work on prototype. Work on report.	Worked on final report. (heat and Background) Organized Oral Presentation
11	Work on report	Collaborated all members work. Formatted, did tables, appendices etc.(Approx. 10hrs on report alone)

Appendix B: Data from Experiments 1a & 1b

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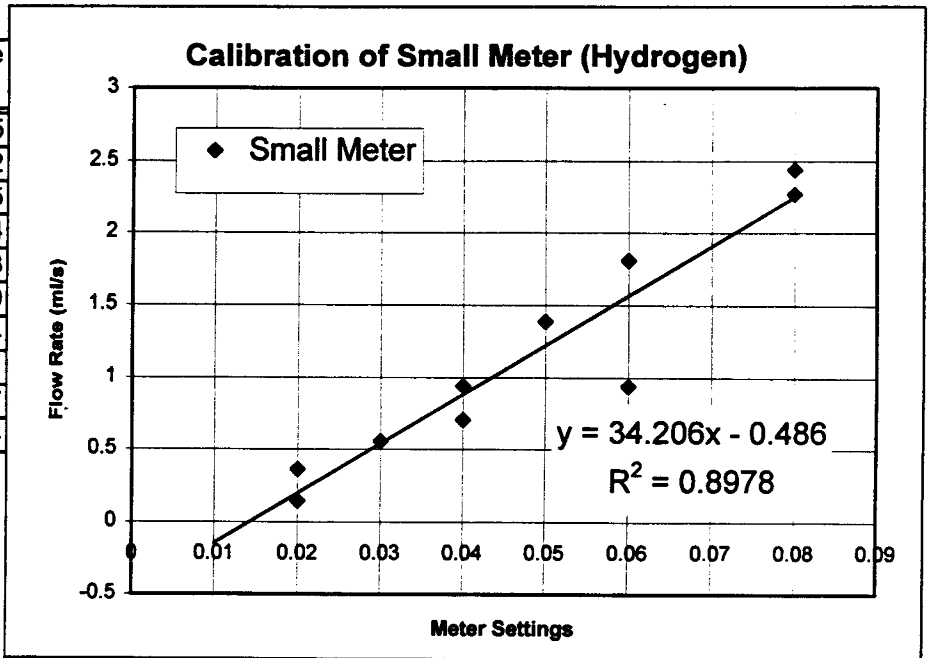
CALIBRATION

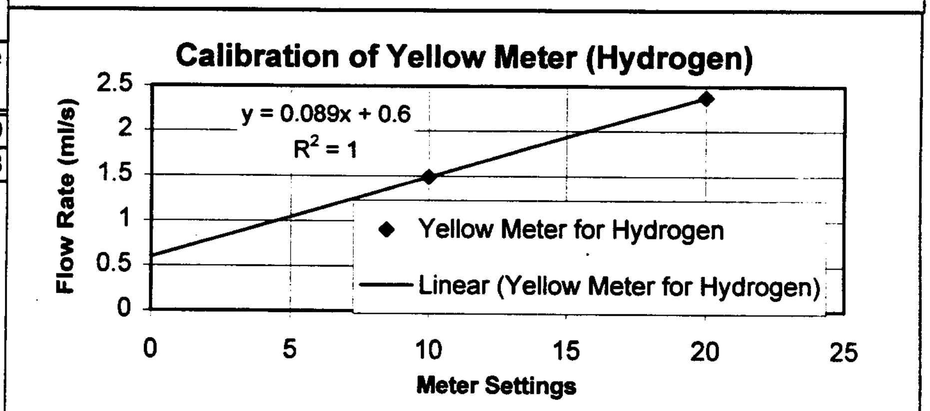
SMALL METER

Meter Setting	Flow Rate ml/s
0.02	0.145
0.02	0.362
0.03	0.555
0.04	0.704
0.04	0.943
0.05	1.39
0.06	0.94
0.06	1.81
0.08	2.27
0.08	2.44

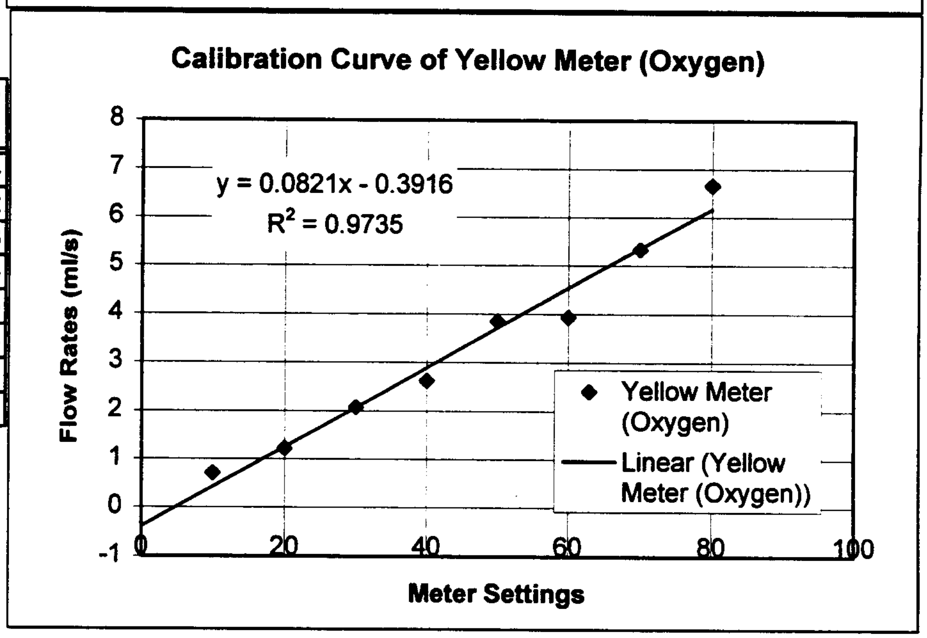


YELLOW METER

Meter Setting	Flow Rate ml/s
10	1.49
20	2.38



Meter Setting	Flow Rate ml/s
10	0.714
20	1.22
30	2.08
40	2.63
50	3.85
60	3.93
70	5.33
80	6.66



FUEL CELL STACK GROUP Names:

Experiment#

Date 5/21/97 Time 9:38

	Resistance in ohms								
	1	5	10	25	35	50	65	80	100
Series	0.016	0.11	0.286						
Parallel	0.072	0.444							
INDIVIDUALS Cell 1	0.016	.0.125	0.236						
INDIVIDUALS Cell 2	0.02	0.145	0.243						
INDIVIDUALS Cell 3	0.031	0.189							
INDIVIDUALS Cell 4	0.026	0.167							
Total	0.093	0.626							

Comments:Started first run with membrane rotated180 degrees. At 10 ohms reduced Vari-Ac to 40

Needed to refilled oxygen humidification supply

Experiment#

Date Time 9:40

	Resistance in ohms								
	1	5	10	25	35	50	65	80	100
Series									
Parallel									
CONNECTED Cell 1	-0.628	-0.811	-0.339						
CONNECTED Cell 2	-0.026	0.042	-0.025						
CONNECTED Cell 3	0.356	0.461	0.344						
CONNECTED Cell 4	0.333	0.41	0.311						
Total	0.035	0.102	0.291						

Comments:Vari-Ac H2=60, O2=60, PH2=9lb, PO2=10.5lb , Flow stopped in 10ohm readings clogged?

At 5ohms: 1&2=0.062V, 1-3=0.039, 1-4=0.028V

FUEL CELL STACK GROUP Names:

Experiment#

Date 5/21/97 Time 9:38

		Resistance in ohms								
		1	5	10	25	35	50	65	80	100
Series		0.016	0.11	0.286						
Parallel		0.072	0.444							
INDIVIDUALS	Cell 1	0.016	0.125	0.236						
	Cell 2	0.02	0.145	0.243						
	Cell 3	0.031	0.189							
	Cell 4	0.026	0.167							
Total		0.093	0.626							

Comments: Started first run with membrane rotated180 degrees. At 10 ohms reduced Vari-Ac to 40

Needed to refilled oxygen humidification supply

Experiment#

Date Time 9:40

		Resistance in ohms								
		1	5	10	25	35	50	65	80	100
Series										
Parallel										
CONNECTED	Cell 1	-0.628	-0.811	-0.339						
	Cell 2	-0.026	0.042	-0.025						
	Cell 3	0.356	0.461	0.344						
	Cell 4	0.333	0.41	0.311						
Total		0.035	0.102	0.291						

Comments: Vari-Ac H2=60, O2=60, PH2=9lb, PO2=10.5lb , Flow stopped in 10ohm readings clogged?

At 5ohms: 1&2=0.062V, 1-3=0.039, 1-4=0.028V

FUEL CELL STACK GROUP

Names:

Experiment#

Date Time

	Resistance in ohms								
	1	5	10	25	35	50	65	80	100
Series	0.023	0.107	0.227	0.5	0.706	0.935	0.935	1.285	1.515
Parallel	0.082	0.408	0.66	0.825	0.867	0.881	0.881	0.903	0.916
INDIVIDUALS Cell 1	0.02	0.089	0.188	0.416	0.553	0.682	0.750	0.8	0.837
INDIVIDUALS Cell 2	0.023	0.118	0.221	0.463	0.568	0.686	0.775	0.801	0.844
INDIVIDUALS Cell 3	0.031	0.148	0.275	0.521	0.631	0.715	0.78	0.801	0.834
INDIVIDUALS Cell 4	0.027	0.123	0.236	0.495	0.636	0.731	0.775	0.793	0.814
Total	0.101	0.478	0.92	1.895	2.388	2.814	3.08	3.195	3.329

Comments: Var-Ac H_2=52, O_2=52, PH_2=12, PO_2=8 lbs

Experiment#

Date Time

	Resistance in ohms								
volts	1	5	10	25	35	50	65	80	100
Series	0.023	0.107	0.227	0.5	0.706	0.935	0.935	1.285	1.515
Parallel	0.082	0.408	0.66	0.825	0.867	0.881	0.881	0.903	0.916
CONNECTED Cell 1	-0.634	-0.78	-0.428	-0.313	-0.151	-0.037	-0.037	0.125	0.264
CONNECTED Cell 2	0.005	0.143	0.055	0.13	0.138	0.189	0.189	0.253	0.306
CONNECTED Cell 3	0.382	0.451	0.39	0.399	0.386	0.432	0.432	0.465	0.468
CONNECTED Cell 4	0.275	0.356	0.234	0.26	0.327	0.36	0.36	0.431	0.482
Total	0.028	0.17	0.251	0.476	0.7	0.944	0.944	1.274	1.52

Comments:

FUEL CELL STACK GROUP Names:

Experiment#

Date 5/21/97 Time 11:57

	Resistance in ohms								
	1	5	10	25	35	50	65	80	100
Series	0.036	0.15	0.257	0.538	0.716	0.844	1.077	1.354	1.48
Parallel	0.134	0.474	0.69	0.846	0.852	0.879	0.897	8.906	0.915
INDIVIDUALS Cell 1	0.028	. 0.124	0.208	0.49	0.486	0.646	0.726	0.777	0.818
INDIVIDUALS Cell 2	0.03	0.132	0.234	0.48	0.557	0.666	0.752	0.802	0.84
INDIVIDUALS Cell 3	0.042	0.178	0.303	0.565	0.624	0.719	0.768	0.803	0.835
INDIVIDUALS Cell 4	0.044	0.173	0.292	0.58	0.61	0.71	0.764	0.81	0.825
Total	0.144	0.607	1.037	2.115	2.277	2.741	3.01	3.192	3.318

Comments: TO2=60C, Started over after gas clogged, PH2=9lb, PO2=10-9lbs, Var H2=60

Var O2=40, take to 50 after it fell to 50C. The voltage started high then dropped off.

Experiment#

Date Time

	Resistance in ohms								
	1	5	10	25	35	50	65	80	100
Series	0.036	0.15	0.257	0.538	0.716	0.844	1.077	1.354	1.48
Parallel	0.134	0.474	0.69	0.846	0.852	0.879	0.897	0.8906	0.915
CONNECTED Cell 1	-0.435	-0.404	-0.31	-0.222	-0.122	-0.108	0.052	0.13	0.194
CONNECTED Cell 2	-0.042	-0.033	-0.031	0.048	0.08	0.156	0.183	0.247	0.3
CONNECTED Cell 3	0.189	0.3	0.304	0.42	0.43	0.489	0.493	0.519	0.526
CONNECTED Cell 4	0.325	0.29	0.309	0.282	0.317	0.31	0.348	0.438	0.465
Total	0.037	0.153	0.272	0.528	0.705	0.847	1.076	1.334	1.485

Comments: The voltaged increased as Pressure increased in the H2 side when it is dead ended.

When the H2 side is purged, the voltage increases.

CALCULATIONS

POTENTIAL

		CONNECTED							
Series		Cell 1		Cell 2		Cell 3		Cell 4	
i, amp	V,volts	i, amp	V,volts	i, amp	V,volts	i, amp	V,volts	i, amp	V,volts
0.023	0.023	-0.634	-0.634	0.005	0.005	0.382	0.382	0.275	0.275
0.021	0.107	-0.156	-0.780	0.029	0.143	0.090	0.451	0.071	0.356
0.023	0.227	-0.043	-0.428	0.006	0.055	0.039	0.390	0.023	0.234
0.020	0.500	-0.013	-0.313	0.005	0.130	0.016	0.399	0.010	0.260
0.020	0.706	-0.004	-0.151	0.004	0.138	0.011	0.386	0.009	0.327
0.019	0.935	-0.001	-0.037	0.004	0.189	0.009	0.432	0.007	0.360
0.014	0.935	-0.001	-0.037	0.003	0.189	0.007	0.432	0.006	0.360
0.016	1.285	0.002	0.125	0.003	0.253	0.006	0.465	0.005	0.431
0.015	1.515	0.003	0.264	0.003	0.306	0.005	0.468	0.005	0.482

		CONNECTED							
Series		Cell 1		Cell 2		Cell 3		Cell 4	
i, amp	P, watts	i, amp	P, watts	i, amp	P, watts	i, amp	P, watts	i, amp	P, watts
0.023	0.001	-0.634	0.402	0.005	0.000	0.382	0.146	0.275	0.076
0.021	0.002	-0.156	0.122	0.029	0.004	0.090	0.041	0.071	0.025
0.023	0.005	-0.043	0.018	0.006	0.000	0.039	0.015	0.023	0.005
0.020	0.010	-0.013	0.004	0.005	0.001	0.016	0.006	0.010	0.003
0.020	0.014	-0.004	0.001	0.004	0.001	0.011	0.004	0.009	0.003
0.019	0.017	-0.001	0.000	0.004	0.001	0.009	0.004	0.007	0.003
0.014	0.013	-0.001	0.000	0.003	0.001	0.007	0.003	0.006	0.002
0.016	0.021	0.002	0.000	0.003	0.001	0.006	0.003	0.005	0.002
0.015	0.023	0.003	0.001	0.003	0.001	0.005	0.002	0.005	0.002

		INDIVIDUALS							
Parallel		Cell 1		Cell 2		Cell 3		Cell 4	
i, amp	V,volts	i, amp	V,volts	i, amp	V,volts	i, amp	V,volts	i, amp	V,volts
0.082	0.082	0.020	0.020	0.023	0.023	0.031	0.031	0.027	0.027
0.082	0.408	0.018	0.089	0.024	0.118	0.030	0.148	0.025	0.123
0.066	0.660	0.019	0.188	0.022	0.221	0.028	0.275	0.024	0.236
0.033	0.825	0.017	0.416	0.019	0.463	0.021	0.521	0.020	0.495
0.025	0.867	0.016	0.553	0.016	0.568	0.018	0.631	0.018	0.636
0.018	0.881	0.014	0.682	0.014	0.686	0.014	0.715	0.015	0.731
0.014	0.881	0.012	0.750	0.012	0.775	0.012	0.780	0.012	0.775
0.011	0.903	0.010	0.800	0.010	0.801	0.010	0.801	0.010	0.793
0.009	0.916	0.008	0.837	0.008	0.844	0.008	0.834	0.008	0.814

		INDIVIDUALS							
Parallel		Cell 1		Cell 2		Cell 3		Cell 4	
i, amp	P, watts	i, amp	P, watts	i, amp	P, watts	i, amp	P, watts	i, amp	P, watts
0.082	0.007	0.020	0.0004	0.023	0.0005	0.031	0.0010	0.027	0.0007
0.082	0.033	0.018	0.002	0.024	0.0028	0.030	0.0044	0.025	0.0030
0.066	0.044	0.019	0.004	0.022	0.0049	0.028	0.0076	0.024	0.0056
0.033	0.027	0.017	0.007	0.019	0.0086	0.021	0.0109	0.020	0.0098
0.025	0.021	0.016	0.009	0.016	0.0092	0.018	0.0114	0.018	0.0116
0.018	0.016	0.014	0.009	0.014	0.0094	0.014	0.0102	0.015	0.0107
0.014	0.012	0.012	0.009	0.012	0.0092	0.012	0.0094	0.012	0.0092
0.011	0.010	0.010	0.008	0.010	0.0080	0.010	0.0080	0.010	0.0079
0.009	0.008	0.008	0.007	0.008	0.0071	0.008	0.0070	0.008	0.0066