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METHODOLOGY FOR PREDICTING
LONG-TERM FUEL CELL PERFORMANCE
FROM SHORT-TERM TESTING

Quarterly Technical Progress Report No. 1
For Period June 6 - September 5, 1979

Contract No. DE-AC-05-79ET15381

By

M. Hooper, H. Maru, D. Patel, C. Ware

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EXECUTIVE SUMMARY

The objective of this program is to develop a methodology for predicting long-term fuel cell performance from short-term testing, applying the perturbation technique. The technique will be experimentally and theoretically applied to the phosphoric acid fuel cell (PAFC). During the first quarter, efforts were concentrated on three main task areas: aging model development, design of experiments, and testing. The details are presented below.

Aging Model Development

- Experimental (operating and cell component) variables to be studied under this program were identified. A simple decay rate model consisting of these variables was formed.
- The parameter α_u in the model was estimated by fitting previous data from two cells operated at high temperature to the model. A value of $\alpha_u = 1$ was obtained for both the cells.

Design of Experiments

- A factorial design was recommended to study cell component variables.
- For operating variables, a factorial design and a balanced incomplete block design (BIBD) were considered: BIBD was preferred.
- Preparations are being made to build cells for preliminary testing. This will include testing of a special cell component (e.g., anode) selected for this program and testing of proposed levels of operating variables for attainability.

Testing

- Planning and design of the test facility are almost completed, all of the equipment has been ordered, and gas and electricity distribution systems have been installed.
- Plumbing in the pressurized test stand has been completed, the pressure vessel has been cleaned for sealing, and a safety system has been designed for the test stand.

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● Experiments were conducted to establish a method to measure limiting current. The linear relationship between limiting current and oxygen concentration was verified.

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INTRODUCTION

Considerable progress has been made in improving the performance, life, and cost of the fuel cell systems. Significant advances have also been achieved in characterizing the instantaneous performance of the cells. In addition, system costs can be estimated using a combination of prototype cost data and standard cost analysis techniques.

The life of the fuel cells, however, is difficult to predict without actually running the cells for long periods. Some estimates of cell life can be obtained by operating the cells at more severe conditions ("accelerated tests") and then extrapolating the results to operating conditions. However this procedure may be unreliable if the "severe" conditions change the decay mechanisms. An alternative approach, based on the "perturbation technique", has been proposed by ERC. This approach involves small changes in the operating variables so that the decay mechanisms are not altered.

An illustration of the perturbation technique is given in Figure 1. The operating variable undergoing perturbation is temperature. As seen, the cell is operated at normal temperature initially until it stabilizes. The temperature is then increased a small amount, which elevates the decay rate without changing the decay mechanism. The cell is operated at this temperature until a prefixed amount of decay is observed. The temperature is then reduced so that it is less than normal (a small change again). The decay rate is now even less than under normal conditions. The cell is operated at this condition until the decay is the same as that observed at high temperature. The cell is now brought back to normal temperature to check whether the system is behaving normally. The whole sequence can be repeated.

The perturbation technique has certain advantages: perturbation on the same cell provides results free of cell-to-cell variation effects. And since less cells are required than in accelerated testing, perturbation testing is more efficient and cost-effective.

FIGURE 1. PERTURBATION TECHNIQUE (EVOLUTIONARY OPERATION)

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The phosphoric acid fuel cell has been selected for application of this technique because a considerable technical background is available and most of the cell components are well defined.

TASK I. AGING MODEL DEVELOPMENT

The objectives of this task are to:

- Develop a model of the rate of decay of fuel cell performance by fitting it to laboratory data (perturbation testing).
- Verify the model by predicting long-term operation and comparing it with laboratory data (unperturbed tests).

I.1 Performance Decay Modes in the Phosphoric Acid Fuel Cell

Although prior assumptions on decay modes are not essential, a knowledge of possible decay modes and important parameters affecting the decay is desirable to perform cost effective and efficient predictive testing. A primary decay mode limiting PAFC life appears to be related to cathode performance decay.¹ A brief discussion of various decay modes based on available information is presented below.

A. Diffusion Limitation - Progressive Loss

Progressive increase in diffusion loss occurs with time and is caused by two processes: carbon corrosion and Teflon degradation.

• Carbon Corrosion

Present PAFC electrodes consist of platinum, carbon, and Teflon. The carbon support is used to provide a conductive and highly dispersive base for the Pt catalyst crystallites and the Teflon mainly to impart hydrophobicity to the structure. Although the exact interaction between carbon, Pt, and Teflon is not fully understood, it is believed that the corrosion of carbon ($C + 2H_2O \rightarrow CO_2 + 4H^+ + 4e^-$) takes place especially at high potentials on the cathode side. Consequently, this results in

separation of the carbon support from the Teflon, thereby losing the hydrophobicity provided by the Teflon. This in turn causes acid to encroach upon and eventually fill the pores of the catalyst, causing a severe liquid phase diffusional problem in an aged cell.

• Acid Attack on Teflon

Although Teflon is quite stable and resistant to phosphoric acid at room temperature, it may be subjected to attack if left in a highly concentrated H_3PO_4 acid environment at a high temperature. This condition could result in further loss of hydrophobicity, creating additional diffusional problems to those derived from carbon corrosion.

B. Platinum Deactivation (Crystallite Growth and Dissolution in Acid)

Current PAFC electrodes contain approximately 10 wt% Pt with a Pt surface area of 50 to 100 m^2/g . Stability of this high surface area is important to minimize electrode polarization, especially at the cathode. There is, however, some controversy as to the nature of the role of long-term platinum stability and its activity under load or open circuit operating conditions, long-term carbon stability under similar conditions, interfacial stability, and the role of Teflon type. We believe, however, that as the catalyst ages, Pt crystallites do grow and this growth is enhanced at high potentials. It is also believed that Pt may dissolve in the acid at high potentials. Thus the crystallite growth may lower the extent of Pt activity and the dissolution results in a net loss of catalyst.

The above decay modes relate to the cathode side. Other decay modes (such as anode poisoning, matrix bubble pressure loss or bipolar plate corrosion) appear to be only secondary modes and are omitted from this study.

I.2 Form of the Aging Model

A simple form of the aging model is decay rate expressed as a function of variables affecting the decay. These variables can be called experimental variables and classified into two types: cell component variables and operating variables. A list of important variables from each type is presented in Table I.1. Discussion of these variables is given below.

Carbon support type can be subdivided into carbon type and heat treatment temperature of carbon. Because the changes in carbon properties can lead to difficulties with wetting and diffusion polarizations, a study of this variable was postponed.

Since the price of platinum is rising, catalyst loadings on the electrodes are reduced considerably, but the effect of loading on decay rate has not been studied. So it is important to study this variable.

The degree of wetproofing can be controlled by varying the Teflon content or the degree of sintering. For this program, wetproofing will be varied by the Teflon content in the electrode because this is easily accomplished without involving any other complications.

The decay modes considered for this program are directly affected by the following operating variables:

<u>Decay Mode</u>	<u>Variables Affecting the Mode</u>
1. Carbon corrosion	Temperature (T) Voltage, IR-free (V_{IR}) Acid Concentration
2. Platinum crystallite growth and dissolution	V_{IR}
3. Acid attack on Teflon	T, acid concentration

Since acid concentration depends primarily on temperature and partial pressure of water vapor (P_{H_2O}), the independent operating variables that affect the decay rate directly are T, V_{IR} , and P_{H_2O} . Variables such as total pressure (P) and P_{O_2} may or may not directly

TABLE I.1
EXPERIMENTAL VARIABLES

CELL COMPONENT VARIABLES

- Carbon Support Type
 - Carbon Type
 - Heat Treatment
- Platinum Loading
- Degree of Wetproofing
 - Teflon Content
 - Degree of Sintering

OPERATING VARIABLES

- Temperature
- Voltage (IR Free)
- Partial Pressure of Water Vapor (P_{H_2O})
- Pressure
- Partial Pressure of Oxygen (P_{O_2})

affect decay rates. To evaluate the effect of pressure, a pressurized test is also planned. This will provide information on the effect, if any, of pressure on the decay rate. To achieve the desired voltage levels, pure O_2 will be used as a cathode gas. The partial pressure of water vapor in the cathode gas will be varied by controlling the humidification of O_2 . Since P_{H_2O} is selected as the independent variable, P_{O_2} will not be an independent variable but will depend on P_{H_2O} . For this program it will be assumed that there is no effect of P_{O_2} on decay rate.

Representation of decay rate requires measures of decay. Catalyst utilization can be used as a measure of decay by the platinum deactivation mode. It can be estimated from measured fuel cell performance and limiting current using the performance model.² The limiting current can be used as a measure of decay by the diffusion limitation mode.

Using the recommended variables and measures of decay as specified above, a simple decay rate model can be written:

$$-\frac{dCU}{dt} = k_{uO} \exp(-E_u/RT) CU^{\alpha_u} V_{IR}^{\beta_u} P_{H_2O}^{\gamma_u} \quad (1)$$

where,

CU = catalyst utilization

t = time

$k_{uO} = k_{uO}$ (Teflon content, platinum loading)

E_u = activation energy for decay mode

R = universal gas constant

$\alpha_u, \beta_u, \gamma_u$ = statistical parameters

$$-\frac{di_L}{dt} = k_{iO} \exp(-E_i/RT) i_L^{\alpha_i} V_{IR}^{\beta_i} P_{H_2O}^{\gamma_i} \quad (2)$$

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where,

E_i = activation energy for decay mode

i_L = limiting current density

$k_{i_0} = k_{i_0}$ (Teflon content, platinum loading)

$\alpha_i, \beta_i, \gamma_i$ = statistical parameters

The above simple form will be used with existing data to develop a preliminary aging model.

I.3 Preliminary Aging Model

At constant temperature, voltage, and partial pressure of water, a simple model for deactivation processes can be developed. Taking the logarithm of both sides of equation (1) and denoting the rate of decay by $r_u = -\frac{dCU}{dt}$

$$\ln r_u = \ln k_{u_0} - \frac{E_u}{R} \left[\frac{1}{T} \right] + \alpha_u \ln CU + \beta_u \ln V_{IR} + \gamma_u \ln P_{H_2O} \quad (3)$$

Expanding Equation (3) in a Taylor's series for $\ln r_u$ about the center points of the independent variables³

$$\begin{aligned} \ln r_u = & (\ln r_u)_0 + a_1 \left[\frac{1}{T} - \left(\frac{1}{T} \right)_0 \right] + a_2 [\ln CU - (\ln CU)_0] + a_3 [\ln V_{IR} - (\ln V_{IR})_0] \\ & + a_4 [\ln P_{H_2O} - (\ln P_{H_2O})_0] + \frac{1}{2} a_{11} \left[\frac{1}{T} - \left(\frac{1}{T} \right)_0 \right]^2 + \frac{1}{2} a_{22} [\ln CU - (\ln CU)_0]^2 \\ & + \frac{1}{2} a_{33} [\ln V_{IR} - (\ln V_{IR})_0]^2 + \frac{1}{2} a_{44} [\ln P_{H_2O} - (\ln P_{H_2O})_0]^2 \\ & + a_{12} \left[\frac{1}{T} - \left(\frac{1}{T} \right)_0 \right] [\ln CU - (\ln CU)_0] + a_{13} \left[\frac{1}{T} - \left(\frac{1}{T} \right)_0 \right] [\ln V_{IR} - (\ln V_{IR})_0] \end{aligned}$$

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$$\begin{aligned}
 & + a_{14} \left[\frac{1}{T} - \left(\frac{1}{T} \right)_0 \right] \left[\ln P_{H_2O} - \left(\ln P_{H_2O} \right)_0 \right] + a_{23} \left[\ln CU - \left(\ln CU \right)_0 \right] \left[\ln V_{IR} - \left(\ln V_{IR} \right)_0 \right] \\
 & + a_{24} \left[\ln CU - \left(\ln CU \right)_0 \right] \left[\ln P_{H_2O} - \left(\ln P_{H_2O} \right)_0 \right] + a_{34} \left[\ln V_{IR} - \left(\ln V_{IR} \right)_0 \right] \\
 & \left[\ln P_{H_2O} - \left(\ln P_{H_2O} \right)_0 \right] + \dots \dots \dots \quad (4)
 \end{aligned}$$

where,

$$a_i = \left(\frac{\partial \ln r_u}{\partial X_i} \right)_0$$

$$a_{ij} = \left(\frac{\partial^2 \ln r_u}{\partial X_i \partial X_j} \right)_0$$

$$X_1 = \frac{1}{T}$$

$$X_2 = \ln CU$$

$$X_3 = \ln V_{IR}$$

$$X_4 = \ln P_{H_2O}$$

A simple preliminary aging model is formed by fitting a linear version of equation (4) to the data, all $a_{ij} = 0$.

$$\text{Then, } a_1 = -E_u/R$$

$$a_2 = \alpha_u$$

$$a_3 = \beta_u$$

$$a_4 = \gamma_u$$

At constant temperature, cell voltage, and water concentration, the deviation terms in these variables will be eliminated, leaving

$$\ln r_u = (\ln r_u)_0 + a_2 [\ln CU - (\ln CU)_0] \quad (5)$$

A: Catalyst Utilization Decay

Values of catalyst utilization can be calculated by a combination of the following equations from the phosphoric acid fuel cell model ².

$$V - E_{avg} + N = 0 \quad (6)$$

where,

V = cell voltage

E_{avg} = reversible EMF of the cell or Nernst potential evaluated at the average reactant concentrations

N = polarizations

$$E_{avg} = E^0 + \frac{RT}{nF} \ln \left[\frac{(Y_{H_2})_a (Y_{O_2})_c^{1/2} P_a}{(Y_{H_2O})_c (P_c)^{1/2}} \right]_{avg} \quad (7)$$

where,

E^0 = standard EMF of cell

R = universal gas constant

T = cell operating temperature

n = number of electrons transferred in overall reaction

F = Faraday's constant

Y = mole fraction

P_a, P_c = total pressures at anode, cathode

$$N = N_a + N_d + N_r \quad (8)$$

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where,

N_a, N_d, N_r = activation, diffusion and resistance polarizations

$$N_a = (N_a)_{\text{anode}} + (N_a)_{\text{cathode}} \quad (9)$$

$$(N_a)_{\text{anode}} \text{ is accepted as } 0.05 \text{ mV} / (\text{mA/cm}^2) \quad (10)$$

$$(N_a)_{\text{cathode}} = \frac{RT}{\alpha nF} \ln \left[\frac{i}{i_o (SA) (CL) (CU)} \right] \quad (11)$$

where,

α = transfer coefficient, assumed to be 0.5

i = current density, mA/cm^2

i_o = exchange current density, mA/cm^2

SA = specific surface area of Pt, cm^2/g

CL = catalyst loading, g/cm^2

$$N_d = \frac{RT}{nF} \ln \left[\frac{i_L}{i_L - i} \right] \quad (12)$$

where,

N_d = is approximated by change in oxygen gain with cell life, reinitialized at each temperature change

i_L = limiting current density

$$N_r = rI$$

where,

r = internal resistance of cell at zero current

I = total cell current

By substitution and rearrangement

$$CU = \left[\frac{i}{i_o (SA) (CL)} \right] \exp \left[-M \frac{\alpha n F}{RT} \right]$$

where,

$$M = -N_d - (rI) + E_{avg} - V - (0.05i)$$

Performance data⁴ for two phosphoric acid fuel cells (1230, 1258) operated at normal and relatively high temperatures was analyzed to estimate parametric values in the simple model.

Each temperature period was divided into several time intervals, then CU was calculated and plotted against time (Figures I.1 and I.2). As expected, the rate of change of CU with time increased with an increase in temperature. Note also that the value of CU itself increased immediately following a temperature change.

Plotting $\ln r_u$ versus $[\ln CU - (\ln CU)_o]$ (subscript o represents mean for the constant temperature period) from equation (5) for both cells at each of the operating temperatures yielded a slope of approximately 1.0 ($= \alpha_u$) (see Figures I.3 through I.5). This signifies that the rate of catalyst utilization decay is directly proportional to CU.

TASK II. DESIGN OF EXPERIMENTS

II.1 Statistical Design

For the perturbation experiments (based on operating variables), two types of designs were considered: a factorial design and a balanced incomplete block design (BIBD)⁵. A complete cycle for factorial design is presented in Table II.1. All three operating variables are perturbed in each cell. It can be observed that in one cycle there are two periods (9 and 11) when all variables are at low levels. The lower decay rate at these conditions will require a longer constant condition period for measurement. Center point in the design is desirable because:

1. Testing about center point provides a check on system behavior,

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FIGURE I.1 CU AS A FUNCTION OF TIME FOR CELL 1230

FIGURE 1.2 CU AS A FUNCTION OF TIME FOR CELL 1258

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FIGURE 1.3 PLOT OF LN R_U VS [LNCU-(LNCU)₀] FOR CELL 1230

FIGURE I.4 PLOT OF $\ln r_u$ VS $[\ln CU - (\ln CU)_0]$ FOR CELL 1258 AT 191°C

FIGURE I.5 PLOT OF $\ln r_u$ VS $[\ln CU - (\ln CU)_0]$ FOR CELL 1258 AT 204°C

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TABLE II.1

A COMPLETE CYCLE FOR FACTORIAL DESIGN
(Based on Operating Variables)

Time Period	T	V _{IR}	P _{H₂O}
1	O	O	O
2	H	H	H
3	H	H	L
4	H	L	H
5	H	L	L
6	L	H	H
7	L	H	L
8	L	L	H
9	L	L	L
10	O	O	O
11	L	L	L
12	L	L	H
13	L	H	L
14	L	H	H
15	H	L	L
16	H	L	H
17	H	H	L
18	H	H	H
19	O	O	O
Variable Levels: H-High, O-Center, L-Low			

2. It helps estimate coefficients of the squared terms in the regression equation,
3. It provides information on experimental error in operation.

Factorial experiments with center points give an estimate of the sum of the coefficients of the squared terms in the regression analysis. Thus, it may or may not detect nonlinearity in the decay rate equation. A complete cycle for BIBD is presented in Table II.2. In this design, only two of the three variables are perturbed in each cell. To get information on main effects and 2-factor interactions, three identical cells of each type are required, to include all three possible pairs of perturbed variables. This design has some advantages over the factorial design. BIBD gives an estimate of the coefficient of each squared term which enables detection of any nonlinearity in the model. Also a measurable decay can be attained in a reasonable period since there is always at least one variable at center level, in this case. Consequently, BIBD is preferred to the factorial design. The tentative factor levels are presented in Table II.3

The factorial experiments based on cell component variables with possible variable levels are listed in Table II.4. This requires four different types of cells. The experiments will evaluate the effect of platinum loading and Teflon content along with their interactions.

A summary of all cells to be tested is presented in Table II.5. Since three identical cells of each type are required for perturbation experiments, a total of 12 cells are required. Six of these cells (cells of Types C₁ and C₄) will be replicated. The replicates provide information on cell-to-cell variation of both the initial performance and long-term performance. Also, if a cell or test fails, all the information from that experiment is not lost.

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TABLE II.2
A COMPLETE CYCLE FOR BIBD

Time Period	T	V _{IR}	P _{H₂O}
1	O	O	O
2	H	H	O
3	H	L	O
4	L	L	O
5	L	H	O
6	O	O	O
7	L	H	O
8	L	L	O
9	H	L	O
10	H	H	O
11	O	O	O
Variable Levels: H-High, O-Center, L-Low			

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TABLE II.3

LEVELS OF OPERATING VARIABLES

VARIABLE	LEVEL		
	High H	Center O	Low L
T, °C	191	184	177
V _{IR} , Volts	0.86	0.81	0.76
P _{H₂O} , kPa	46	40	34

TABLE II.4

FACTORIAL EXPERIMENTS
(Based on Cell Component Variables)

Cathode Type	Pt Loading, mg/cm ²	Teflon Content, W/O
C ₁	0.3	40
C ₂	0.6	40
C ₃	0.3	45
C ₄	0.6	45

TABLE II.5
SUMMARY OF CELLS

CELL NO.	TYPE	PERTURBATION VARIABLES	REPLICATE NO.
1	C ₁	T, V _{IR}	1
2	C ₁	V _{IR} , P _{H₂O}	1
3	C ₁	P _{H₂O} , T	1
4	C ₁	T, V _{IR}	2
5	C ₁	V _{IR} , P _{H₂O}	2
6	C ₁	P _{H₂O} , T	2
7	C ₂	T, V _{IR}	1
8	C ₂	V _{IR} , P _{H₂O}	1
9	C ₂	P _{H₂O} , T	1
10	C ₃	T, V _{IR}	1
11	C ₃	V _{IR} , P _{H₂O}	1
12	C ₃	P _{H₂O} , T	1
13	C ₄	T, V _{IR}	1
14	C ₄	V _{IR} , P _{H₂O}	1
15	C ₄	P _{H₂O} , T	1
16	C ₄	T, V _{IR}	2
17	C ₄	V _{IR} , P _{H₂O}	2
18	C ₄	P _{H₂O} , T	2

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Four more cells of Type C₄ will be operated without perturbations to establish baseline performance and generate long-term data for model verification. Two of these will simulate the pressurized operation and the other two, atmospheric pressure operation. The operating conditions are tabulated in Table II.6 below.

TABLE II.6
OPERATING CONDITIONS FOR BASELINE TESTS

Conditions	T, °C	i, mA/cm ²	P _{H₂O} , kPa	P _{O₂} , kPa
Atmospheric Pressure Operation	177	161	26	6
Pressurized Operation	191	250	41	49

This makes a total of 22 cells operating at atmospheric pressure. In addition, as mentioned previously, one cell of Type C₄ will be pressurized to 50 psia to carry out perturbation experiments.

II.2 Preliminary Testing

The rolled electrodes to be tested are listed below in Table II.7. All of the electrodes are 10 wt% Pt on untreated vulcan. The anodes in all cells will be the same.

TABLE II.7
COMPONENTS IN THE PRELIMINARY TEST CELLS

Electrode Type	% PTFE	Pt Loading, mg/cm ²	Backing, %FEP
Cathode C ₁	40	0.3	40
C ₂	40	0.6	40
C ₃	45	0.3	40
C ₄	45	0.6	40
Anode A	35	0.5	20

The suggested levels of operating variables will be tested to determine whether they 1) are attainable and 2) cause measurable decay.

TASK III TESTING

III.1 Test Facility

Planning and design of the test facility was started and is almost completed. The test station layout has been finalized and design of the test stands is complete. The electricity and gas distribution systems are installed. All of the equipment for the 22 atmospheric test stations (except for the humidifiers and some ammeter shunts) is on hand. The meters are being calibrated and the test stations are being built.

All plumbing in the pressurized test stand has been completed. The pressure vessel has been cleaned and prepared for sealing. A safety system has been designed and is presently under construction.

III.2 Limiting Current Experiments

Experiments were conducted to establish a method for measuring limiting current and for verifying the relationship between limiting current and oxygen concentration. The results are discussed below.

Limiting currents are expected to be directly proportional to the oxygen concentration at the cathode. Measurements were made for several inlet oxygen concentrations at different stoichiometric flows as shown in Table III.1. The stoichiometric flow was based on 10A of current. From the measured value of limiting current, the corresponding geometric mean oxygen concentration ($Y_{O_2}^{GM}$) at the cathode can be calculated. Plotting the measured limiting current versus geometric mean oxygen concentration yields a nearly linear correlation (see Figure III.1). This verifies the expected theoretical relationship

$$i_L = C Y_{O_2}$$

where C is a constant

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TABLE III.1
LIMITING CURRENT MEASUREMENTS FOR CELL .1316

% O ₂ at Inlet	i _L , Amp	Stoich (@ 10A)	Stoich (@ i _L)	y _{O₂} ^{GM}
2	3.10	1.83	5.90	0.0182
4	4.25	1.25	2.94	0.0317
4	4.85	1.52	3.13	0.0328
4	4.90	1.83	3.74	0.0340
4	5.50	2.29	4.16	0.0347
6	6.50	1.83	2.82	0.0477
13	12.80	2.00*	2.19	0.0930

Cell Life: 1920 hours
Temperature: 177°C

*14 amp flow

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FIGURE III.1 LIMITING CURRENT AS A FUNCTION OF OXYGEN CONCENTRATION

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REFERENCES CITED

1. Maru, H.C., Christner, L., "Phosphoric Acid Fuel Cell Cathode," in National Fuel Cell Seminar abstracts, San Francisco, CA, July 11-13, 1978.
2. Baker, B., Maru, H., and Patel, D., "Fuel Cell Power Configurations," Final Report Prepared by Energy Research Corporation for Science Applications, Inc. under Contract No. 04-117-01, August 1978.
3. Ware, Charles H. Jr., "Chemical Reaction Rate Equations from Experimental Data," Proceedings of the 1975 Summer Computer Simulation Conference, p. 368.
4. Christner, L., George, M., "Electrode Optimization for Phosphoric Acid Fuel Cells," Monthly Technical Status Report No. 7, Contract ET-78-C-03-1873, Prepared for U.S. Department of Energy by Energy Research Corporation, Danbury, Ct., December 1978.
5. Hicks, Charles, "Fundamental Concepts in the Design of Experiments," Second Edition, Holt, Rinehart and Winston, 1973.