ADVANCED WATER-COOLED PHOSPHORIC ACID**FUEL CELL DEVELOPMENT****TECHNICAL PROGRESS REPORT NO. 23****A QUARTERLY REPORT
for
JANUARY, FEBRUARY, MARCH 1990****Contract DE-AC21-88MC24221****FCR-10999****Prepared for****U.S. Department of Energy
Morgantown Energy Technology Center
P.O. Box 880, 3610 Collins Ferry Road
Morgantown, WV 26505-0880****DISCLAIMER**

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

P.O. Box 730
195 Governors Highway
South Windsor, Connecticut 06074

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

Section	Page
PROGRAM HIGHLIGHTS	iv
I. INTRODUCTION	1-1
II. STATUS	2-1

PROGRAM HIGHLIGHTS

- Fabrication of repeat parts for the small area short stack is nearing completion and assembly activities are being initiated.
- Electrolyte Reservoir Plates (ERP's) were completed and processed into
- Integral Separator Plates (ISP's), and acid fill of parts was initiated.
- Fabrication of electrodes was also completed including catalyzation and applications of seals and matrices.

I. INTRODUCTION

The Advanced Water Cooled Phosphoric Acid Fuel Cell Development program is being conducted by International Fuel Cells Corporation (IFC) to improve the performance and minimize the cost of water cooled, electric utility phosphoric acid fuel cell stacks.

The program adapts the existing on-site Configuration B cell design to electric utility operating conditions and introduces additional new design features. Task 1 consists of the conceptual design of a full-scale electric utility cell stack that meets program objectives. Tasks 2 and 3 develop the materials and processes required to fabricate the components that meet the program objective. The design of the small area and three 10-ft² short stacks is conducted in Task 4. The conceptual design also is updated to incorporate the results of material and process developments, as well as results of stack tests conducted in Task 6. Fabrication and assembly of the short stacks is conducted in Task 5 and subsequent tests are conducted in Task 6. The Contractor expects to enter into a contract with The Electric Power Research Institute (EPRI) to assemble and endurance test the third 10-ft² short stack. The management and reporting functions of Task 7 provide DOE/METC with program visibility through required documentation and program reviews.

This report describes the cell design and development effort that is being conducted to demonstrate by subscale stack test, the technical achievements made toward the above program objectives.

II. STATUS

TASK I – CONCEPTUAL DESIGN

Objectives

The objective in this task is to define the conceptual design for a cell stack having a performance level of at least 175-W/ft² and a manufactured cost of less than \$400/kW. The stack must be capable of operating for a minimum of 40,000 hours at electric utility conditions.

Activity

This activity was completed. Conceptual design updates will be reported in Task 4 – Stack Design.

TASK 2 – COMPONENT DEVELOPMENT

Subtask 2.1 – Materials Development

Objectives

The objectives of this subtask are to provide an improved substrate, verify the stability of low cost substrate and electrolyte reservoir materials at pressurized cell operating conditions, and increase the thermal conductivity of the electrolyte reservoir.

Activity

There was no activity on this task this month.

Subtask 2.2 – Single Cell Testing

Objectives

The objectives of this subtask are to test subscale cells to evaluate improvements in cell components consisting of substrates, electrolyte reservoir plates (ERP), catalyst and matrix; verify performance and endurance of components fabricated for short stacks; optimize the hydrophobicity of catalyst layers from the GSB18 and GSB18P catalysts for operation at power densities of 200 WSF or greater; evaluate a higher performing laboratory catalyst for this application, and define the permissible range of operating limits.

Activity

(1) Electrode Optimization Trials

At the start of quarter, four cells continued on test to provide information on the impact of Teflon content and compaction pressure of electrodes made with the production methods on cell decay rates. All four cells have short stack catalysts. All cells except build 4404 were shutdown prior to the end of the quarter.

Data from build 4387 is also included in Table 2.2-1 for comparison. This cell was fabricated with laboratory made electrodes to qualify anode and cathode catalysts for the short stack. A complete performance history of cell 4387 is shown on Figure 2.2-1.

Table 2.2-1. Electrode Optimization Trials Performance at 300 ASF/415°F/14.7 psia GSB18 Short Stack Cathode Catalyst				
Build No.	Hours	Volts	Hours	Volts
4390	1389	.591	2386	.584
4391	1452	.613	3540	.608
4401	1095	.619	1937	.605
4404	1019	.627	3107	.607
4387	1601	.623	3451	.605

(2) Subscale Cell Tests on Optimized Electrodes

After establishing the catalysts for the short stack and using teflon contents and compaction pressures selected based on optimization testing, four optimized cells were put on test to gain insight into the performance characteristics and effect of long term operation. These cells were operated initially at the 300 ASF/415°F baseline condition to evaluate performance relative to the extensive IFC database. After verifying acceptable performance, conditions were changed to 225 ASF and 400°F (Table 2.2-2) for endurance evaluation.

Table 2.2-2. Performance of Cells Testing at Short Stack Rated Power Conditions						
Initial Performance 300 ASF/ 415°F			Endurance 225 ASF/ 400°F			
Build No.	Hours	Volts	Hours	Volts	Hours	Volts
4430	131	.634	491	.650	1860	.639
4431	133	.626	469	.645	1838	.632
4432	131	.623	371	.649	1740	.635
4433	133	.606	349	.630	1289	.620
E-Line	130	.616	400	.633	1800	.625

Five additional cells, fabricated similar to the forementioned cells, were brought to test to evaluate the effect of elevated temperature on endurance. The first four of these cells were also evaluated at the atmospheric baseline condition of 300 ASF at 415°F to confirm acceptable operation. One cell (build 4449) was found to have unacceptable performance and was replaced on test. Following the performance verification, test conditions were changed to 225 ASF and 425°F (Table 2.2-3).

Table 2.2-3. Performance of Cell Testing at Elevated Cell Temperature						
Initial Performance 300 ASF/ 415°F			Endurance 225 ASF/ 425°F			
Build No.	Hours	Volts	Hours	Volts	Hours	Volts
4448	128	.595	153	.633	1233	.627
4450	117	.639	275	.658	1210	.650
4451	135	.624	169	.660	1191	.651
4457	133	.591	287	.631	1021	.630

Initial performance of the cells in Tables 2.2-2 and 2.2-3 has been included for comparison purposes. As expected, initial performance of the elevated temperature cells was higher than the baseline 400°F, and the 425°F cells are also showing a higher decay rate. A graphic comparison is presented in Figure 2.2-2.

A subscale cell (build 6654) went on test at the beginning of the quarter containing optimized short stack electrodes with the purpose of demonstrating operation at 120 psia and 400°F. Initial cell voltage at 200 ASF was .790 volts (183 hours) which was 10 mV higher than typical configuration "A" 2x2 cells under similar conditions. Initial performance at 300 ASF was .758 volts at 270 hours while after 1863 hours performance is .741 volts.

At the end of the quarter, two cells (builds 4473 and 4474) of six planned cells, built from short stack electrodes, were put on test to track the short stack. Early life operation has not yet achieved baseline conditions. Two of the six cells will be run at 120 psia.

(3) GSB18P Cathode Catalyst

During the first quarter of 1990, nine (9) cells were run to provide information on the performance impact of GSB18P cathode catalyst with 1 mg/cm² loading. Six of the builds were tested at atmospheric pressure while three were run at 120 psia. The cells were fabricated using the current generation substrates. The baseline cell (build 4394) has electrodes fabricated in the laboratory. Its performance history is shown on Figure 2.2-3.

The five ambient cells (builds 4439, 4441, 4446, 4447 and 4456) with production electrodes were operated at the short stack rated power conditions of 225 ASF, 400°F and 14.7 psia to evaluate production fabrication methods as well as the decay characteristics of this cathode catalyst and loading (Table 2.2-4). None of these five cells achieved the level of performance demonstrated by the baseline laboratory cell.

Table 2.2-4. Performance of Cell with GSB18P Cathode Catalyst 1 mg/cm² Catalyst Loading 14.7 psia						
Initial Performance 300 ASF/ 415°F			Endurance 225 ASF/ 400°F			
Build No.	Hours	Volts	Hours	Volts	Hours	Volts
4394	131	.670	2497	.673	3372	.670
4439	122	.661	326	.666	1394	.648
4441	84	.661	193	.672	1429	.660
4446	85	.632	407	.648	1107	.644
4447	134	.652	384	.656	1233	.627
4456	130	.608	310	.646	887	.650

The three cells (Table 2.2-5) put on test for the purpose of running under pressurized conditions of 120 psia were run initially at the baseline ambient conditions (300 ASF/415°F) to verify cell performance acceptability. These cells like their ambient counterparts, did not achieve the performance goal of the laboratory made cell. Late in February the cells were brought to 120 psia at the pressurized baseline conditions (300 ASF/400°F) and exhibited performance below expectations. Efforts will continue to define a production procedure to duplicate the performance potential shown by the laboratory cell.

Table 2.2-5. Performance of Cell with GSB18P Cathode Catalyst 1 mg/cm² Catalyst Loading						
Build No.	14.7 psia 300 ASF/ 415°F		Hours	120 psia 225 ASF/ 400°F		Hours
	Volts	Volts		Volts	Volts	
6660	72	.636	546	.754	1050	.740
6661	144	.626	478	.752	980	.737
6662	69	.644	400	.751	904	.732

(4) Improved Catalyst Layers

Five additional cells (Table 2.2-6) went to test this quarter utilizing improved catalyst layers developed from previously run laboratory made cells (builds 4405, 4406 are shown for reference) but fabricated through production methods. The purpose of the test is to verify production scale-up from laboratory techniques.

Table 2.2-6 Improved Catalyst Layers 300 ASF/415°F/14.7 psia				
Build No.	Initial Performance		Current Performance	
	Hours	Volts	Hours	Volts
4442	120	.613	710	.592
4443	115	.619	712	.590
4444	124	.589	700	.584
4445	152	.622	695	.586
4454	66	.613	235	.591
4405	82	.626	1597	.600
4406	135	.631	1578	.591

Figure 2.2-1 Performance History of Cell 4487

Figure 2.2-2 Impact of Elevated Temperature

Figure 2.2-3 Catalyst GSP-18P w/ 1 mg/cm² Loading

TASK 3 – PROCESS DEVELOPMENT

Subtask 3.1 – Substrates

Objective

The objectives of this subtask are to develop the process technologies required to produce electrode substrates and electrolyte reservoir plates that meet the technical requirements and cost objectives established in the conceptual design.

Activity

This activity was completed.

Subtask 3.2 – Integral Separator

Objective

The objective of this subtask is to develop the process technology to fabricate integral separators, up to 10-ft² in size, that meet the technical requirements and cost objectives established in the conceptual design.

Activity

There was no activity on this task this month.

Subtask 3.3 – Seals and Matrix**Objective**

The objective of this subtask is to develop the technology to fabricate higher integrity seals and matrices that meet the technical requirements and cost objectives established in the conceptual design.

Activity

This activity was completed.

Subtask 3.4 – Advanced Coolers

Objective

The objective of this subtask is to develop material and process technology to fabricate coolers 10-ft² in size that meet the technical requirements and cost objectives established in the conceptual design.

Activity

Work to develop molded coolers was completed. The remainder of this task activity was directed towards the development of an encapsulated cooler assembly.

The series of component tests aimed at evaluating edge seal and cover plate approaches to encapsulate the cooler and to prevent the electrolyte penetration were completed. Test conditions were severe in an attempt to accelerate the findings. The edge seal configurations tested are described in Table 3.4-1 and the results are shown in Table 3.4-2.

The edge seal configuration 5 with two fluoropolymer film acid barriers was selected for scale-up and fabrication.

Table 3.4-1. Edge Seal Encapsulation Approaches For Cooler Holder Assembly

Edge Seal Acid Barrier Approaches		
Type	External Barrier	Internal Barrier
1	Fluoropolymer Dispersion Coating	Fluoropolymer and Graphite Film
2	Fluoropolymer Dispersion Coating	Thin Fluoropolymer Film
3	Fluoropolymer Dispersion Coating	Thick Fluoropolymer Film
4	Fluoropolymer Dispersion Coating	Two Separate Fluoropolymer Films
5	High Density Graphite Composite and Fluoropolymer Film	Thick Fluoropolymer Film

Table 3.4-2. Cooler Edge Seal Encapsulation Trials

Seal Edge Approach	Thermal Cycle @ 400°F W/Acid	Acid Thru Outer Edge Barrier Yes/No	Dye Thru Outer Edge Barrier Yes/No	Acid Thru Inner Edge Barrier Yes/No	Dye Thru Inner Edge Barrier Yes/No
1	Yes Yes Yes Yes	Yes @ 94 Hrs.	Yes @ 168 Hrs.	No @ 94 Hrs. No @ 408 Hrs. No @ 600 Hrs. No @ 840 Hrs.	No @ 168 Hrs.
2	Yes Yes Yes Yes	No @ 72 Hrs. Yes @ 384 Hrs.	Yes @ 72 Hrs.	No @ 72 Hrs. No @ 384 Hrs. No @ 576 Hrs. No @ 816 Hrs.	No @ 72 Hrs.
3	Yes Yes	No @ 48 Hrs. Yes @ 312 Hrs.	Yes @ 48 Hrs.	No @ 48 Hrs. No @ 312 Hrs.	No @ 48 Hrs. No @ 312 Hrs. No @ 487 Hrs.
4	Yes Yes Yes	No @ 126 Hrs.	Yes @ 126 Hrs.	No @ 126 Hrs. No @ 456 Hrs. No @ 624 Hrs. No @ 1104 Hrs.	No @ 126 Hrs. No @ 624 Hrs. No @ 1104 Hrs.

Table 3.4-3. Dye Test Results for Subscale Encapsulated Coolers with Separate Fluoropolymer Film Edge Seals

Sample #	Hrs.	Results	Comments	Edge Seal Configuration #
A	239	No dye penetration of any acid barriers, edges, corners or sides		4
B	626	Dye penetrated along one of the tubes to the interior of the part but did not penetrate the internal barrier to what would be the upper half of the cooler holder	Part thermocycled 10 times to 400°F	4
C	1032	Dye has penetrated the lower half of the plain corners and down the sides of the mock tubes but did not get into the interior of what would be the top and bottom cooler holders		4
D	1773	No dye penetration except at the four corner joints.		5

Subscale coolers were made incorporating the edge seal configurations 4 and 5, and cover plates made of fluoropolymer composite. The results from the dye tests for the subscale coolers are summarized in Table 3.4-3. Sample D, made of dye configuration 5 edge seals, was tested in dye for 1773 hours. The results indicate the edge seal and cover plate performed as designed.

Testing to determine the effect of tube diameter and pitch on the thermal resistance of subscale coolers was completed. The thermal resistance of the smaller diameter tube is shown as a function of tube groove spacing in Figure 3.4-1. Results indicate that smaller diameter tube coolers degrade in thermal performance as shown in Figure 3.4-2. The standard on-site tube size cooler thermal performance was stable with time as shown in Figure 3.4-3.

Figure 3.4-1. Subscale Cooler Thermal Performance with Small Diameter Tubes

Figure 3.4-2. Subscale Cooler Thermal Resistance with Small Diameter Tubes

Figure 3.4-3. Subscale Cooler Thermal Resistance with Standard On-Site Tubes

TASK 4 – STACK DESIGN

Objective

The objective of this task is to update the full-scale conceptual design and to define designs for one small area development stack and three 10-ft² subscale stacks.

Activity

The electrode and ERP/ISP component drawings were updated to reflect the development and evaluation activities being concurrently conducted in task 3.2.

The commercial graphite cooler component drawings were updated to reflect the development and evaluation activities being concurrently conducted in task 3.4. The design of an alternately encapsulated cooler with commercial graphite holders was also completed. The design incorporates the baseline on-site cooler cover and a fluoropolymer film internal edge barrier.

TASK 5 – FABRICATION

Subtask 5.1 – Repeat Components

Objective

The objective of this effort is to fabricate the repeat components for one small area development stack and three 10-ft² subscale stacks each consisting of approximately 30 cells. These stacks will be of the Configuration B cell design. The repeat components consist of the substrates, electrodes, electrolyte reservoir plates, and cooler assemblies.

Activity

The subscale cooler assembly trials to assemble the edge seals, cover plates, cooler halves and tube in a one-step bonding cycle were successfully completed using a subscale fixture. Examination of sample cross-sections show sufficient fluoropolymer film barriers for acid protection. The immersion test in acid and dye tests indicate that the assembly concepts are satisfactory, and a full size assembly fixture was designed and fabricated.

The 3/8 inch diameter cooler array was selected for the short stack and arrays were ordered. A template to inspect the arrays was designed and fabricated. Five (5) coolers with two types of encapsulation methods were fabricated for the short stack. One cooler features an ISP cover with a Configuration 5 (see Task 3.4) edge seal barrier. The second cooler type fabricated features a conventional on-site cover plate with an internal fluoropolymer acid barrier formed at final assembly. Both cooler types employ commercial graphite cooler holders.

One hundred and fifty (150) electrolyte reservoir plates (ERP's) were graphitized, microground, and were impregnated with a small particle size graphite to create an edge seal. These ERP's were processed into integral separator plates (ISP's).

Fabrication and delivery of the ISP's for the small area test stack was completed this period. Three (3) types of ISP's (see January Quarterly) were fabricated and installed in the stack for a "side-by-side" evaluation. All configurations bond the Electrolyte Reservoir Plates (ERP's) into the final assemblies.

The substrates were trimmed to rough planform, density checked and treated to improve wettability. The holdout coat was screen printed, the electrodes catalyzed and the edge seals were impregnated.

These electrodes had the fillerband applied by the curtain coating process. The matrix was applied to the electrodes with a Gravure coater and electrodes were delivered to assembly.

Subtask 5.2 – Non-Repeat Components

Objective

The objective of this effort is to fabricate the non-repeat components for the small area development stack and three 10-ft² subscale stacks of approximately 30 cells each. These stacks will be of the Configuration B cell design. The non-repeat components consist of reactant manifolds, coolant manifolds, axial load system, power take-off hardware and pressure containment vessel.

Activity

Two new types of cooler connecting hoses were evaluated to reduce hose costs and to qualify an additional supplier. The test configuration is shown in Figure 5.2-1.

One of the new hose assembly types (Type R2) was fabricated with a modified dielectric hose formulation. All other hose materials and connecting system hardware are identical to the baseline assembly (Type R1). The second type of hose assembly (Type T1) employs an alternate dielectric concept and connectors. Five of the Type R2 hoses and four of the Type T1 hoses were tested.

Test conditions are as follows:

Coolant Flow Rate	150 pph
Coolant Inlet Temperature	350°F
Coolant Inlet Pressure	145 psig
Coolant Inlet Subcooling	13°F
Applied Voltage	200 Volts d.c.
Water Quality	
pH	6–8.5
O ₂ Conc.	30–500 ppb
Turbidity	0.5–1.0 NTU
Conductivity	< 0.5 x 10 ⁻⁶ mho's

After the hoses accumulated a total test time of 3500 hours, one hose from each type was examined in detail. Both hose assembly samples were in satisfactory condition and without indications of unusual wear or corrosion.

The remaining hoses were burst pressure tested at 428°F. The results are shown in Table 5.2-1.

The Type R2 cooler connector assembly with the modified hose material formulation was selected for the small area planform short stack test.

Table 5.2-1. Cooler Connecting Hoses Burst Test Results	
Baseline Configuration with Alternative Hose Material	
S/N	Burst Pressure
1	5000 psig
2	4950 psig
3	5600 psig
4	5400 psig
Average	5240 psig
Alternate Supplier and Dielectric Approach	
1	3500 psig
2	4200 psig
3	3600 psig
Average	3765 psig

Figure 5.2-1. Cooler Connecting Hose Evaluation Set-Up

Subtask 5.3 – Stack Assembly

Objective

The objective of this effort is to assemble the small area development stack and two 10-ft² subscale stacks of Configuration B cells for testing at 120 psia. The third 10-ft² subscale stack will be assembled and tested under an anticipated EPRI program.

Activity

The non-repeat hardware for the small area development stack was used to fabricate a mock-up stack so that the test stand/stack interfaces could be defined prior to delivering the actual stack to test. A plywood box was used to represent the repeat components. The non-repeat hardware was assembled on the box to verify hardware fit and to define the piping datums.

The assembly instructions for the small area development stack were completed. Electrode and ISP filling was initiated.

All non-repeat hardware is available for final stack assembly.

TASK 6 - STACK TESTING

Subtask 6.1 - Small Area Development Stack Testing

Objective

The objective of this task is to obtain early feedback on improved Configuration "B" cell packages at atmospheric and pressurized operating conditions.

Activity

Test stand preparation was completed. A simulation of stack operation is being conducted to verify test stand operational procedures and test stand operational control sequencing.

TASK 7 - MANAGEMENT AND DOCUMENTATION

Objectives

The objective in this task is to provide the program management necessary to maintain technical and budget control of the program activities, and to provide adequate documentation of its progress per contract requirements.

The following reports were submitted during the period January 1 - March 31, 1990.

- Monthly Technical Progress Report No. 18 for October (FCR-10737) was submitted on January 2, 1990.
- Cost Management Report No. 20 for December (FCR-10835) was submitted on February 6, 1990.
- Monthly Technical Progress Report No. 19 for November (FCR-10781) was submitted on February 8, 1990.
- Cost Management Report No. 21 for January (FCR-10886) was submitted on February 20, 1990.
- Quarterly Technical Progress Report No. 20 for October - March, 1989 (FCR-10836) was submitted on March 5, 1990.
- Cost Management Report No. 22 for February (FCR-10950) was submitted on March 28, 1990.

END

**DATE
FILMED**

3 / 30 / 93