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DEVELOP AND TEST FUEL CELL POWERED ON SITE INTEGRATED TOTAL ENERGY SYSTEMS: PHASE III, FULL-SCALE POWER PLANT DEVELOPMENT

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SECTION I. INTRODUCTION

Engelhard's objective under the present contract is to contribute substantially to the national fuel conservation program by developing a commercially viable and cost-effective phosphoric acid fuel cell powered on-site integrated energy system (OS/IES). The fuel cell offers energy efficiencies in the neighborhood of 40% of the lower heating value of available fuels in the form of electrical energy. By utilizing the thermal energy generated for heating, ventilating, and air-conditioning (HVAC), a fuel cell OS/IES could provide total energy efficiencies in the neighborhood of 80%. Also, the Engelhard fuel cell OS/IES, which is the objective of the present program, offers the important incentive of replacing imported oil with domestically produced fuel.

Engelhard has successfully completed the first two phases of this program. The culmination of the pre-commercialization program will be the integration of the fuel cell system into a total energy system for multi-family residential and commercial buildings. The mandate of the current Phase III effort is to develop a full-scale 25kW breadboard power plant module. An accomplished objective in Phase III was the integration and testing of the 5kW system whose components were developed during Phase II. In addition to the development and testing of this sub-scale system, scale-up activities have been carried out under Phase III. Throughout this program, continuing technology development activity will be maintained to assure that the performance, reliability, and cost objectives are attained.

SECTION II. TECHNICAL PROGRESS SUMMARY

TASK I - 5kW POWER SYSTEM DEVELOPMENT

The objective of this task was to complete integration of the 5kW components and sub-systems developed during Phase II.

Steady-load testing of the 5kW integrated system, with regular shutdowns, was completed during August 1983. Subsequently, load-following testing was carried out successfully, as the system was operated in the fully-automatic mode. (See the August-October 1983 Quarterly Report.)

TASK II - ON-SITE SYSTEM APPLICATION ANALYSIS

The purpose of this task was to develop an application model for on-site integrated energy systems. The model considers fuel availability, costs, building types and sizes, power distribution requirements (electrical and thermal), waste heat utilization potential, types of ownership of the OS/IES, and grid connection vs. stand-alone operation. The work of this task was carried out under subcontract by Arthur D. Little, Inc. (ADL), and this work has been completed. The main conclusions are summarized in the May-July 1983 Quarterly Report.

TASK III - ON-SITE SYSTEM DEVELOPMENT

This task forms the core of the Phase III contract effort. Work under this task will result in the breadboard design of a system for an on-site application. The power plant is being designed for a rated output of 25kW (electrical). This task is broken down into four sub-tasks as follows:

III-1. Large Stack Development
III-2. Large Fuel Processor Development
III-3. Overall System Analysis
III-4. Overall System Design and Development

The activities under this contract are focusing on Sub-Task III-1. Effort on the other sub-tasks is being carried out under private sponsorship.

SUB-TASK 1. LARGE STACK DEVELOPMENT

A. LONG-TERM TEST STACKS

A key activity in the current program is long-term reliability testing of stacks incorporating state-of-the-art components and concepts. This effort will serve to verify their effectiveness and durability; alternatively, if problem areas (or potential problem areas) are exposed over the course of this program, modifications will be implemented as appropriate to attain long-term durability.

This phase has consisted of the construction, testing and evaluation of 25-cell, 13 inch x 23 inch stacks (4kW), each incorporating non-metallic cooling plates at a five-cell interval. The first two stacks have been essentially the same, each incorporating both the E-3 type and E-7 type of developmental cathode catalysts. Much of the testing has utilized synthetic reformate fuel (75% H_2, 25% CO_2, 1% CO, moisturized to about 15% H_2O).

Stack No. 1 in the 1984-85 series was shut down after operating over 7000 hours on load. Stack No. 2 is operating at 0.55V on average at 161mA/cm^2 (reformate-air) after being on load for a total of 8300 hours. This stack will be shut down during the first week of August. At that time, a teardown exercise will be carried out during which the various components and hardware will be inspected. Based on this inspection, indicated modifications and alternative approaches will be reflected in the upcoming Stack No. 3 where appropriate.

Stack No. 3 will also contain 25 cells of the 13 inch x 23 inch size. Several new technology assessments are already planned for this stack with respect to the technology employed in Stack No. 1 and Stack No. 2. These include: (i) alternative bipolar plate B-element (separator) materials (polyetheretherketone and PFA Teflon) in comparison with polyethersulfone; (ii) new cathode catalyst types, including those on more corrosion-resistant supports; (iii) an alternative acid-transport layer configuration; and (iv) use of a single-component liquid coolant (triethylene glycol) in place of mineral oil. The fabrication of components for this stack has begun.

B. 25kW STACK

The 25kW stack components were based primarily on those that were successfully employed in the two 25-cell stacks (above). Where appropriate in light of experimental results obtained on the smaller stacks, design modifications were implemented for the 25kW stack. These involved acid collection/drainage means to avoid corrosion at the bottom of the gas manifolds and a 0.0015 inch thick gold foil layer at the bottom current-collecting plate interface, also to avoid corrosion as well as the buildup of interfacial IR-loss.

The cells (175 of them, 13 inches x 23 inches) were stacked during May using cooling plates at the five-cell interval. After assembly of the stack hardware a light compressive load was applied. This was followed by completion of plumbing for the fuel, air, and coolant lines to and from the stack.

Completion of the acid-addition and compressive loading sequences was delayed into June by a series of unplanned stack heating system shutdowns (see below). When these tasks were accomplished, the reactant gas manifolds were fully tightened. For the most part the stack was sustained in the hot-standby mode during June (about 120°C; no load); however, interruptions in system operation caused many temperature cycles (to and from room-temperature) over the course of the month.

The stack was started on load in early July. The load was brought up gradually, as the cells appeared to be breaking in very slowly. Acid was added (and taken up) in piecemeal fashion as the stack's load and temperature were increased. Performance appeared to be slowly improving through the end of the month. At this time the load has reached 9kW at a stack voltage of about 100V with the temperature reaching 155°C. The temperature and load will continue to be increased during August, and acid-addition will be carried out in accordance with the apparent needs of the stack.

C. 25kW SUPPORT SYSTEMS

A 50kW methanol processing sub-system has been prepared for use as a hydrogen generator for the 25kW stack. Performance testing of this unit to confirm its readiness was completed during May. The test activity required considerable trouble-shooting, but satisfactory results were produced. The reformer was operated at flow rates equivalent to 32kW, and essentially complete methanol conversion was obtained (>99% based on condensate analysis). Also, outside analysis of an effluent gas sample indicated satisfactory composition despite an unrecognized peak that showed up on the in-house chromatograph. The results are shown in Table I. (The in-house equipment and procedures are being reviewed.)

There was some reformer performance deterioration in June, during a period in which various system upsets were encountered (see below). An apparent decline in reformer catalyst activity was traceable to two out-of-limits conditions that, by design, should have instigated system shutdown (an over-temperature excursion and a methanol-water soak that was caused by reformer-burner flameout). A catalyst change-out will be executed at a suitable juncture.

The installation of control system hardware and wiring as well as debugging of the software was completed during May. (A software error, uncovered in June, allowed the aforementioned reformer catalyst soak to occur during a period of unattended operation.) The electrical load bank (resistive, variable) was installed, and custom rework activities were carried out on this unit in May. This involved additional circuitry to allow for automatic switching that is required in emergency or out-of-limits situations.

The outdoor methanol storage facility became operational in June. A temporary permit allowing operation was issued by the Township of Union. A few minor items remain to be carried out before a full permit is granted.

Numerous shutdowns were experienced during automatic operation of the 25kW system during June and July. These were primarily related to the methanol pump that feeds the reformer-burner and to the microprocessor computer itself. The pump is being equipped with a heavy-duty motor, and the contacts of the computer are being cleaned and sprayed with a protective coating. These actions are expected to provide greater tolerance to the heat, humidity, and dust that the system is subjected to in its current environment.

TASK IV - STACK TECHNOLOGY

The purpose of this task, which will continue throughout the contract, is to investigate new materials and component concepts through bench-testing and stack trials. The criteria for selecting activities under this task are the prospects for improved performance, reduced costs, or improved reliability. Improvements in the performance of electrocatalysts, generated under Engelhard-sponsored Task VI, are reported under Task IV.

A. PERFORMANCE OPTIMIZATION

CATALYSTS

A new batch of ternary cathode catalyst (E-8) has started up in single-cell evaluation. Compared to the corresponding binary catalyst (E-7), it is showing an improvement of about 20mV (average of two cells each). One comparison is illustrated in Figure 1. However, the binary catalyst is performing about 20-30mV lower than typical; and it is not known if this improvement would translate equally to a high-performing binary precursor. This question will be pursued with upcoming catalyst batches and single-cell tests.

ALTERNATIVE ACID-TRANSPORT LAYERS

A single-cell employing an alternative acid-transport layer showed a peak hydrogen-air performance of about 0.710V IR-free at 161mA/cm^2 and 191°C, as shown in Fig. 2, with an open-circuit voltage of 0.86V. It then rapidly lost performance to about 0.700V; the cause was not clear, but it did not appear to be related to the acid-transport layer (no change in IR-loss or open-circuit voltage).

After 2500 hours of operation the cell IR-free voltage was 0.695V, as shown in Figure 2. Subsequently, the cathode oxygen-gain began to increase, indicating electrolyte flooding of the cathode, with attendant loss of open-circuit voltage as the electrolyte-matrix became acid-deficient. More testing is required to determine if the acid-transport layer configuration played a role in this behavior.

An objective in the development of alternative acid-transport layers is reduction of cell IR-loss. The IR-loss of the above cell was 50mV at 161mA/cm^2, thereby showing no improvement over that of a typical cell with a standard acid-transport layer. Other cells of this type have shown lower IR-loss, however; and it is apparent that a greater degree of reproducibility is required for the new configuration.

A parallel activity involves the simple substitution of a new carbon fiber material for the Kureha paper (no longer available) that currently serves as the acid-transport layer. Several materials have been examined for acid-transport properties and for corrosion behavior, as shown in Table II (immersion conditions) and Figure 3 (potentiostatic conditions). Most of these materials are acceptable in both respects, and the thinner ones will be evaluated in single-cells.

B. COST REDUCTION

CURRENT COLLECTORS

The concept of current collectors made of base metal coated with a protective and electronically conductive carbon-polymer composite is being set aside. While such configurations have performed reasonably well, irregular flaws have occurred often enough to cast doubt on the achievability of a five-year life for this component. Of particular concern is the fact that, as things now stand, a corroded or delaminated current collector (at the bottom) cannot be repaired or replaced without taking the entire stack apart.

The test of a 0.0015 inch thick gold sheet backed up by a layer of Grafoil continued successfully in 1984 Stack No. 2 without any sign of significant interface resistance.

Corrosion tests of a less expensive current collector concept, based on Engelhard-fabricated gold-clad base metal wire, have begun. Such wires would not only be inherently cheaper, but would also save on the cost of connecting stacks to the external load. Analysis of a design based on this type of collector indicates that the cost of the recoverable gold cladding would be well under $10/kW in a 25kW stack. Electrical tests on small graphite coupons show an IR-drop under 100 millivolts (out of a stack voltage of over 100 volts).

NON-METALLIC COOLING PLATES

Design and experimental work have been conducted with larger diameter cooling tubes than the ones used on present stacks. This would reduce costs by eliminating two out of four end-connections. Performance and reliability tests on the tubes and end-connections at 200°C were successfully carried out to 70 psi. The design and fabrication of sample grooves that can accommodate the larger tubing were also accomplished.

C. RELIABILITY

CARBON SUPPORTS

Single-cell Run No. 1424 (Fig. 4 of February-April quarterly report) was conducted to assess the stability of the E-3 cathode catalyst on Shawinigan Black support. This test was terminated at 3072 hours due to increasing electrode flooding and reactant gas cross-over. However, tear-down examination of this cell showed that significant corrosion product from the single-cell aluminum blocks had accumulated under the carbon plates. This increased the stress on the carbon paper and caused it to crack, resulting in the flooding and cross-over. Additional testing of this catalyst formulation will be carried out using modified single-cell hardware (see below) to enhance long-term durability.

Full-size electrodes (13" x 23") were also prepared using the E-3/Shawinigan Black cathode catalyst. Short-term single-cell evaluation of sections cut from these electrodes (2-3/4" x 2-3/4" active area) showed an IR-free voltage of 0.724V at 191°C and 161mA/cm^2, H_2/air. This performance is similar to that obtained with 10.7" x 14" electrodes.

LIFE-TESTING IN SINGLE-CELLS

A new fixture for testing single-cells is being fabricated. It has a carbon paper layer that is resin-bonded to the aluminum block to give better corrosion resistance. It will be used for long-term stability evaluation of single-cells. Simultaneously, a fixture in which the aluminum is replaced by Type 316 stainless steel is being prepared; this is also expected to allow more meaningful long-term tests to be conducted without the complicating effects of fixture corrosion.

BIPOLAR PLATES

Wetproofing of ABA bipolar plates requires that the fluoropolymer wetproofing be cured at elevated temperature, preferably at 550°F (288°C). However, the presence of the PES B-element in the finished ABA plate requires a lower curing temperature to avoid a loosening of the film bond. Films of polyetheretherketone (PEEK) and PFA Teflon are now available; unlike PES, they are not expected to soften at 288°C. Tests to determine the suitability of these two materials as substitute B-elements have been carried out; they showed electrical and sealing properties as good as those of PES, provided the film-bonding temperatures are 700°F (370°C) for PFA and 750°F (400°C) for PEEK. These tests also showed that care must be taken to maintain a uniform temperature throughout the plate being bonded. Such results are enhanced through the use of a thick layer of thermal insulation around the edges.

Permeability tests on ABA coupons using PES B-element films were carried out with both helium and hydrogen. The tests confirm previous findings that the leakage rates are equivalent to current densities of a fraction of an ampere per square foot.

STACK SHUTDOWN AND START-UP

The five-cell, 10.7" x 14" stack designed to examine the effectiveness of the shutdown/start-up procedure has now logged about 2200 hours, including six room-temperature shutdowns. The loss from peak performance remains similar to the loss pattern in stacks not subjected to periodic shutdowns. The history of this stack is illustrated in Figure 4.

TASK V - FUEL PROCESSING SUPPORT

The intent of this task was to provide background data and information to support the design and construction of an optimized 50kW fuel processor under Task III. Most of the effort of this task was devoted to screening and longevity testing of catalysts for steam reforming of methanol. This task is now complete.

TASK VI - IMPROVED ELECTROCATALYSTS

Developmental electrocatalyst formulations are being prepared under Engelhard sponsorship. These are provided to the main program, and results are reported under Task IV.

Development is being pursued on both cathode and anode catalysts and supports; however, the major activity at the present time is directed toward improved cathode stability and activity (see Task IV).

SECTION III - CURRENT PROBLEMS

- Eliminate unplanned shutdowns in 25kW system.

SECTION IV - WORK PLANNED

TASK III - ON-SITE SYSTEM DEVELOPMENT

- Continue testing of 25kW stack.

TASK IV - STACK TECHNOLOGY

- Continue evaluation of alternative acid-transport layers.
- Prepare for 25-cell Stack No. 3.

TABLE I

Composition Analysis of Reformate Gas Sample

Compound	Gas Composition, Vol. %
H_2	77.8
CO	1.40
CO_2	21.0
CH_4	<0.05

TABLE II

IMMERSION CORROSION* OF CARBON FIBER MATERIALS

Product	Product Type	Thickness, mils Nominal	Thickness, mils Measured	Results
Panex** PWB3	Woven Carbon Fabric	14	10	Slight discoloration of acid
Panex PWB6	Woven Carbon Fabric	25	16	Slight discoloration of acid
Panex SWB8	Woven Carbon Fabric	32	19	Acid remains clear.
Panex CFP30-70	Carbon Fiber Paper	-	8	Slight discoloration/small particles in acid.
Panex KFB	Knit Carbon Fabric	32	20	Acid remains clear.
Panex CFP30-20	Carbon Fiber Paper	-	18	Material dissolved.
Kureha Paper***	Carbon Fiber Paper	8	8	Acid remains clear.

*: 400°F (204°C), 105% H_3PO_4 (air), 600 hours.
**: Registered trademark of Stackpole Fibers Co.
***: Kureha Co.

FIGURE 1 SINGLE-CELL PERFORMANCE STABILITY

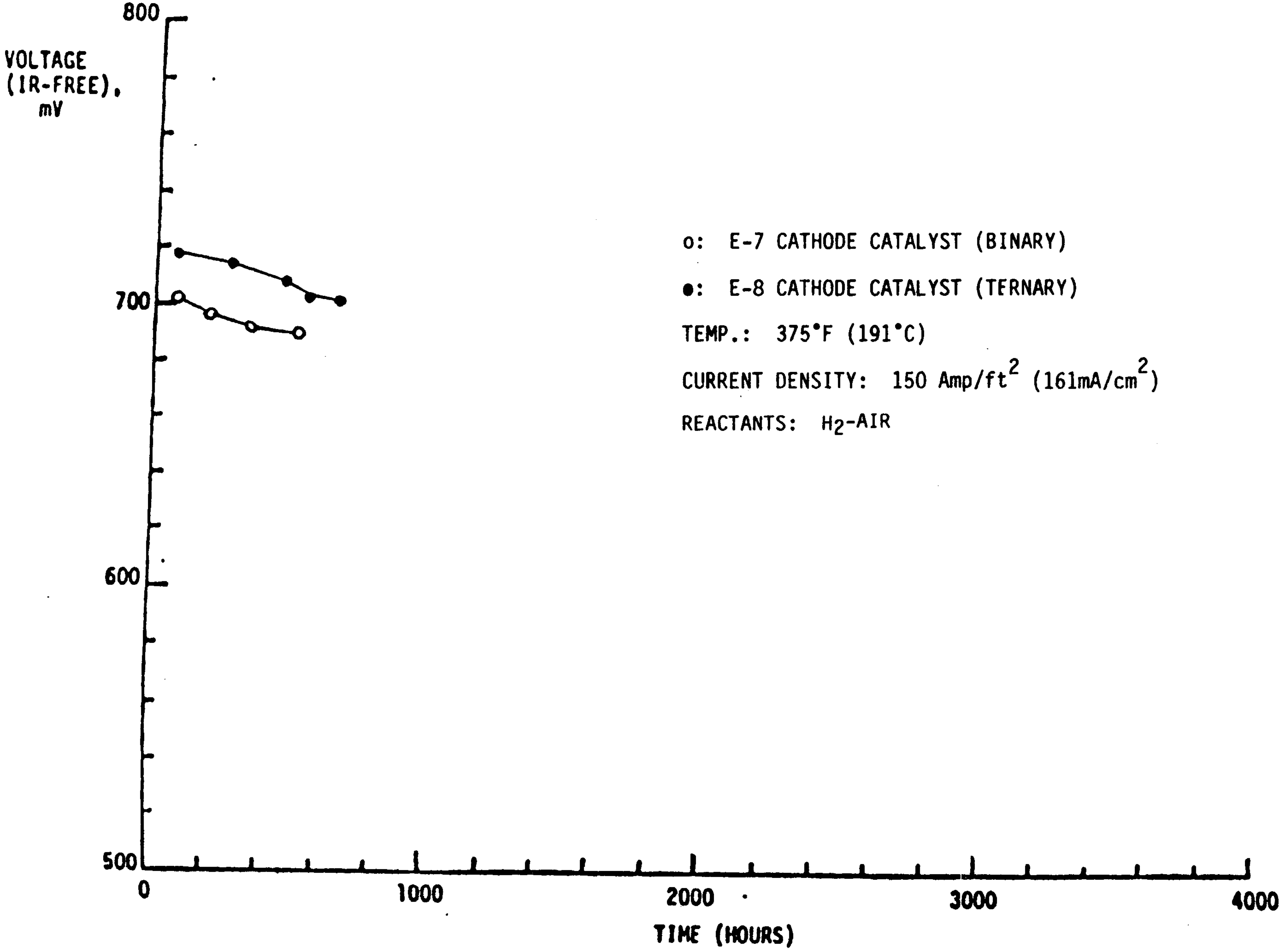
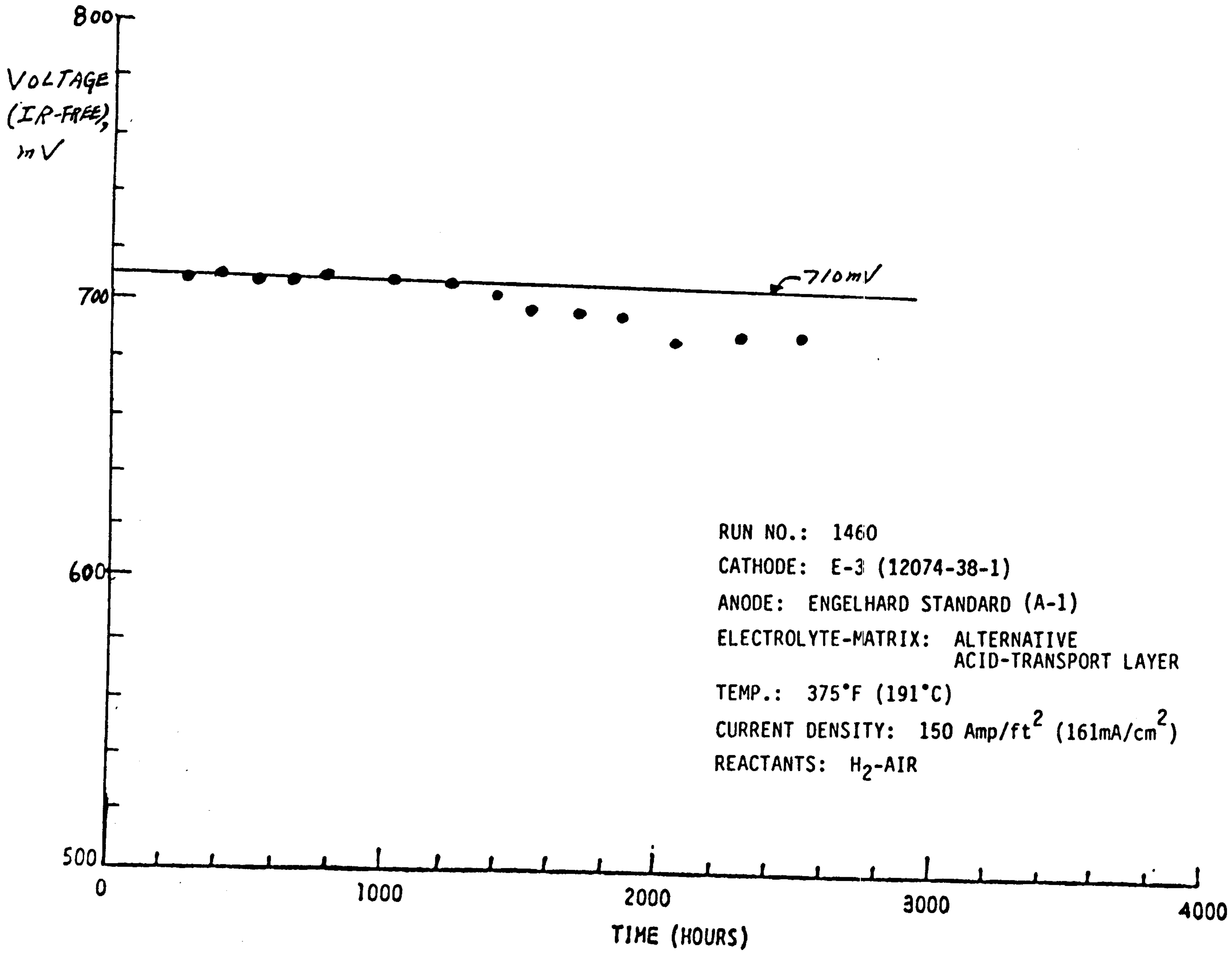


FIGURE 2 SINGLE-CELL PERFORMANCE STABILITY



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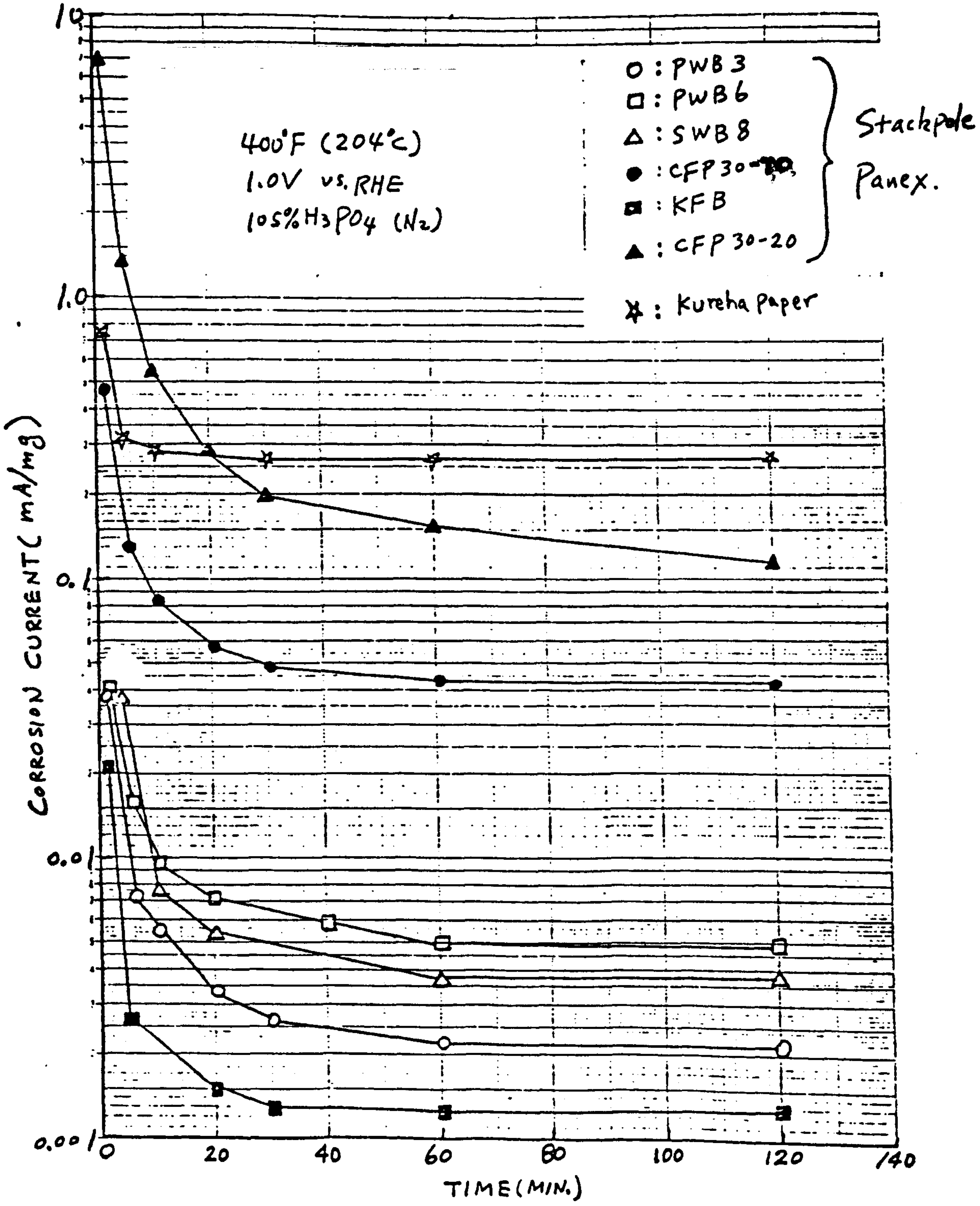

FIGURE 3 CORROSION BEHAVIOR OF CARBON FIBER MATERIALS

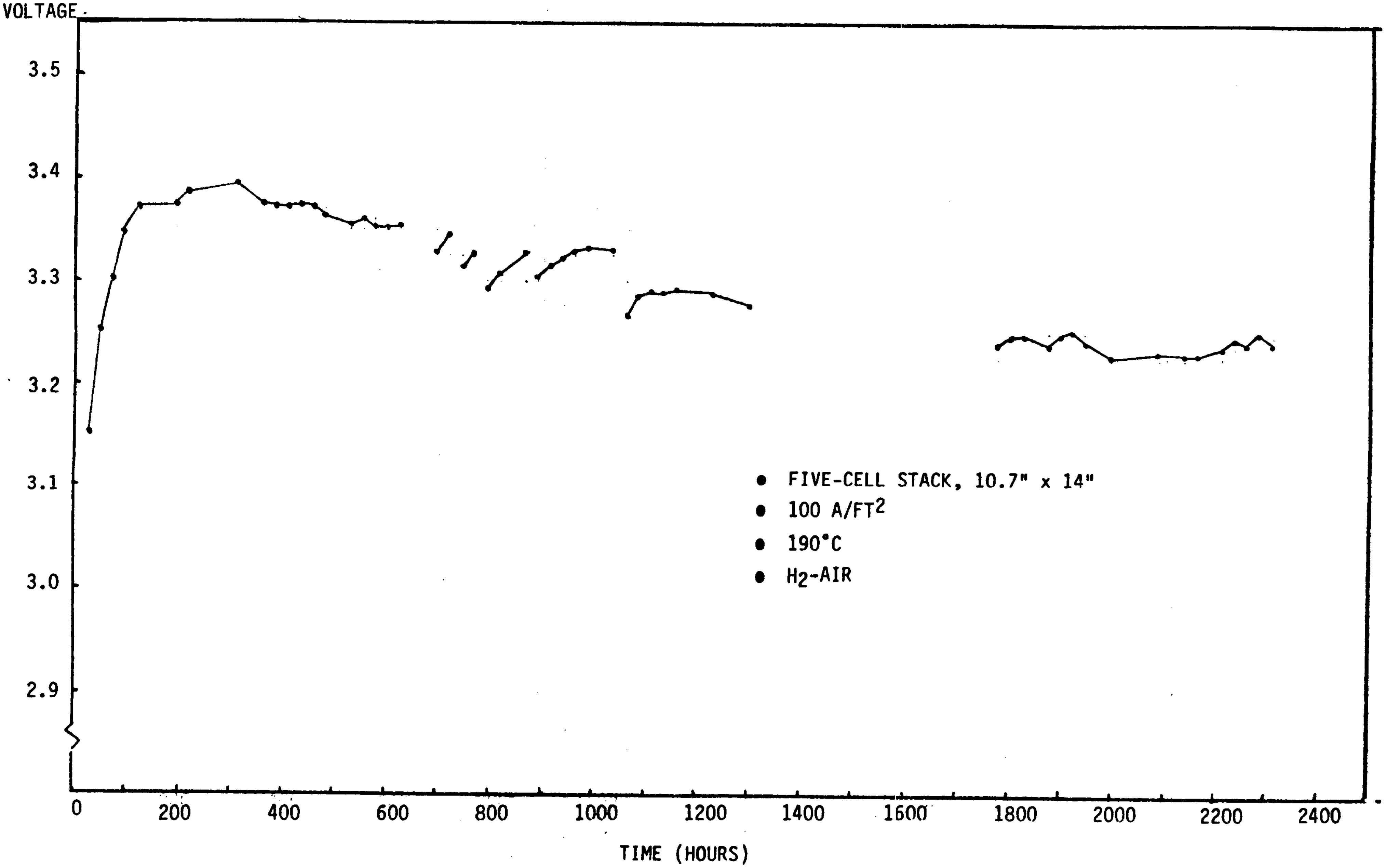

FIGURE 4 SHUTDOWN/START-UP TEST STACK

SKS-85

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15. Supplementary Notes

16. Abstract

A 25-cell stack of the 13 inch x 23 inch cell size (about 4kW) remains on test after 8300 hours, using simulated reformate fuel. A similar stack was previously shut down after 7000 hours on load. These tests have been carried out for the purpose of assessing the durability of fuel cell stack components developed through the end of 1983. A 25kW stack containing 175 cells of the same size and utilizing a technology base representative of the 25-cell stacks has been constructed and is undergoing initial testing. A third 4kW stack is being prepared, and this stack will incorporate several new technology features.

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