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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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U.S. DEPARTMENT OF ENERGY
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(NASA-CR-168021) DEVELOP AND TEST FUEL CELL POWERED ON-SITE INTEGRATED TOTAL ENERGY SYSTEMS. PHASE 3: FULL-SCALE POWER PLANT DEVELOPMENT Quarterly Report, May - Jul. 1982 (Engelhard Industries, Inc.) 26 p
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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 range of 35-40% of the higher 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 methanol, including coal-derived methanol.

Engelhard has successfully completed the first two phases of a five-phase program. The next three phases entail an integration of the fuel cell system into a total energy system for multi-family residential and commercial buildings. The mandate of Phase III is to develop a full scale 50kW breadboard power plant module and to identify a suitable type of application site. Toward this end, an initial objective in Phase III is to complete the integration and testing of the 5kW system whose components were developed during Phase II. Following the test of this sub-scale system, scale-up activities will be implemented as a total effort. Throughout this design and engineering program continuing technology support activity will be maintained to assure the performance, reliability, and cost objectives are attained.

SECTION II. TECHNICAL PROGRESS SUMMARY

TASK I - 5kW POWER SYSTEM DEVELOPMENT (97046)

This task is of limited duration and has as its objective the complete integration of 5kW components developed during Phase II. This integrated 5kW system is automated under microprocessor control.

The fuel cell stack for this system is currently being rebuilt. To date three 12-cell sub-stacks of this rebuild have been assembled and individually tested for about two days each. The test conditions were 80% hydrogen utilization at 464-466 K (376-380 °F). At a current density of 161 mA/cm^2 (150 A/ft^2) the following voltages were observed in these sub-stacks:

#1 7.23V (Avg. 603 mV/cell)
#2 7.24V (Avg. 603 mV/cell)
#3 7.3V (Avg. 608 mV/cell)

These sub-stacks have been placed in storage fixtures at 393 K (248 °F) until the remaining sub-stacks have been assembled and tested.

TASK II - ON-SITE SYSTEM APPLICATION ANALYSIS (97047)

The purpose of this task is to develop an application model for on-site integrated energy systems, with some emphasis on a system of 50kW (electrical) modular capability. The model considers fuel availability and 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 is being carried out under subcontract by Arthur D. Little, Inc. (ADL).

The basic structure of the economic analysis has been to compute the internal rate of return to the building owner of various fuel cell-based OS/IES systems versus a conventionally-powered system. The four building types selected were:

- Hospital
- Retail Store
- Apartment Building
- Office Building

These were analyzed over four different electric rate structures representing four combinations of the basic conditions principally affecting charges for electricity:

- High load growth rate
- Low load growth rate
- High oil/gas
- Low oil/gas

Additional variables included in the analysis were climate (Houston, Washington, Chicago), use of centrifugal chillers or absorption chillers for air-conditioning, and the option of thermal storage for thermal-load levelling.

Although detailed conclusions on internal rates of return are still being refined and will be presented at a later time, certain general trends have already been observed:

- Electric rate structures are the single most important determinant of internal rates of return to building owners (besides choice of fuel).

- Because of the present relatively high cost of methanol compared to natural gas, the rates of return are much better for gas-fueled systems.

- Building size and heating/cooling load profiles affect the number of fuel cell modules that can be economically supported in a building.

- Rates of return are relatively insensitive to climate.

TASK III - ON-SITE SYSTEM DEVELOPMENT

This task forms the core of the Phase III Contract. Work under this task will result in the breadboard design of a system for an on-site application. The power plant will be designed for a rated output of 50kW (electrical) or some multiple thereof. The fuel processor and power conditioner will each be 50kW modules, while the 50kW fuel cell module will comprise two 25kW stacks. This task is accordingly broken down into four sub-tasks as follows:

3.1 Large Stack Development (97048)
3.2 Large Fuel Processor Development (97038)
3.3 Overall System Analysis (97051)
3.4 Overall System Design and Development (97064)

A large part of Sub-Task 3.3 is being carried out by Physical Sciences, Inc. (PSI) under subcontract.

LARGE STACK DEVELOPMENT (97049)

A full-sized 3-cell stack has been operated successfully for 700 hours. The cell size was 0.33 x 0.56m (13" x 22"). The stack was assembled and operated in the large-stack test fixture previously described. An advanced catalyst (E-1) was used in the cathodes and an Engelhard standard Pt catalyst in the anodes. The gas distribution plates consisted of grooved graphite A-elements, which were partially wet-proofed. (For a description of the HLM graphite material see later under Task IV.) The A-elements were assembled with Grafoil B-elements in an un-bonded sandwich arrangement. Perforated distribution pipes were run horizontally within each inlet manifold to improve reactant distributions across the faces of the stack. The test fixture was heated electrically and the top surfaces were insulated.

During most of the period of the test the stack was operated at 464 K (375 °F) on hydrogen at 80% utilization. Figure 1 shows the current-voltage characteristics of the stack at various times during the test. Figure 2 shows the open-circuit voltage and the voltage at 161 mA/cm^2 (150 A/ft^2) as functions of time. The average cell voltage at standard current was 605 mV. It is apparent from both figures that no decay in performance occurred during the period of the test.

The air flow to the stack was increased substantially above normal to maintain adequate air to the top cell. The necessity for this resulted from an anomalous leak in the air inlet manifold (where a tie rod penetrated the top plate).

Large amounts of acid were added to the cells during the first few hundred hours of the test. Acid was absorbed by the grahpite until saturation was reached. (A satisfactory method of wet-proofing graphite has since been developed - see under Task IV.) Running in the acid-saturated mode is an acceptable alternative to running in the completely wet-proofed mode; however, it would be preferable to pre-saturate the plates with acid in the case where acid is permitted to absorb into them.

No other problems were encountered in this test.

The next milestone project in this sub-task is the construction and testing of a 24-cell stack with the same plate size. This stack will depend upon further component improvements in progress on full-size cooling plates and graphite ABA plates. Construction is expected in late 1982.

LARGE FUEL PROCESSOR DEVELOPMENT (97038)

The construction of a 5kW methanol reformer based on a shell-and-tube heat exchanger was completed.

In the first test of this unit the catalyst tubes were loaded with T61 alpha alumina (an inert packing) to evaluate the heat exchanger using nitrogen as an inert gas. The temperature profiles resulting in both the tubes and the shell during this simulated full-load test are shown in Figure 3. The time required to reach the steady-state temperature condition is indicated in Figure 4. The fact that the flue gas and inert gas temperatures approach each other after only one-eighth of the catalyst bed length indicates excellent heat transfer properties of the unit.

One problem encountered in the design of this unit was that, when flue gas entered the bottom of the first tubes at high temperature (839 K), radial stresses were exerted that warped the flange faces slightly. This warpage was compensated by installing soft carbon gaskets on both sides of the existing Flexatallic gaskets. It is desirable with this unit to keep the inlet flue gas temperature down to about 755 K and to rely on sufficient superheating of the process gas stream to supply the required enthalpy to the reactor.

The reformer unit was also run with T2107 catalyst and methanol feed. Tests were run at both full load (Figure 5, conversion 86%) and half load (Figure 6, conversion 99+%).

A further test was conducted with increased inlet temperature of the process gas to determine if complete conversion at full load could be achieved. In this experiment the inlet flue gas temperature was held at 754 K and the inlet process vapor was superheated from the previous 578 K to 725 K. At full-load conditions this resulted in 99.8% conversion (See Figure 7). The process vapor superheat was accomplished by running it through a coil in the burner. Carbon monoxide levels were within acceptable limits at 1.4%.

In summary, the unit performs according to design expectations, with the shift of some sensible heat from flue gas to process gas.

OVERALL SYSTEM DESIGN AND DEVELOPMENT (97064)

Under a subcontract to contract DEN3-241, The Trane Co. carried out a preliminary assessment of how fuel cell systems should interact with HVAC subsystems in commercial, residential, and public buildings. Simple system models were developed to predict the annual utility costs of on-site integrated systems as well as conventional HVAC systems. Economic comparisons were made for hospitals, apartment complexes, retail stores and office buildings. Preliminary subcontract Task I conclusions were:

1. The best internal rates of return to fuel cell system owners resulted when fuel cells were sized for the base electrical loads of the sites.

2. The best net present values resulted when the fuel cells were sized for loads intermediate between the base and the average electrical loads.

3. Systems using absorption chillers alone yielded lower returns and lower net present values than systems using combinations of electric and absorption chillers or electric chillers alone.

4. Hot thermal storage substantially improves the economics of on-site fuel cell systems in apartments and hospitals, but has a lesser effect in retail stores and office buildings.

5. The best economics apply to hospitals and apartment buildings, with impressive after-tax internal rates of return ranging from 30% to 60%.

6. While the electric rate structures prevailing at various sites greatly affect profitability, the climate of the sites has very little economic effect.

7. The value of the fuel cell waste heat is a crucial economic factor. Without the utilization of waste heat in an HVAC sub-system, none of the sites yields a positive net present value or an attractive after-tax rate of return.

TASK IV - STACK SUPPORT (97049)

The purpose of this task, which will continue throughout the contract, is to investigate new materials and component concepts by experimentation and the use of small-stack trials. The criteria for choosing activities under this task will be the possibilities of improved performance or reduced cost, or both. Improvements in and performances of electrocatalysts, though generated under Engelhard-sponsored Task VI, will be reported under Task IV.

GRAPHITE GAS-DISTRIBUTION PLATES

Several high-density graphites have been examined as possible candidates for gas-distribution plate materials. The surface areas, as measured by the BET method with krypton, and the ranges of major porosity are given below:

Graphite	Surface Area	Range of Major Porosity	Cumulative Porosity, cm^3/g
Great Lakes HLM	0.7 m^2/g	1-20 microns	0.132
Airco 940G	0.7 m^2/g	2-7 microns	0.138
Airco 3499	0.6 m^2/g	1-3 microns	0.103

These surface areas may be compared with that of CVD-needled-felt which is less than 0.1 m^2/g.

It had been observed that graphite plates in cell tests tended to absorb a large amount of phosphoric acid. To counter this, the bipolar plates were wet-proofed with a suspension of Teflon in water plus a wetting agent. During curing of the plates at 500 °F (260 °C) following wet-proofing, delamination of the elements was observed. This problem was solved by curing the wet-proofed plates under mechanical pressure (50 psi, 3.5kg/cm^2) at 400 °F (204 °C). Under these latter conditions, neither delamination nor an excessive voltage drop was observed.

CORROSION CURRENTS OF GRAPHITE PLATE MATERIALS

Two types of extruded graphite materials were checked for corrosion currents: HLM (made by Great Lakes Carbon Co.) and 940G (made by Airco Spear). To help in the interpretation of the corrosion currents, measurements of the surface areas of these and other graphites and of their cumulative porosities between 20 and 10,000 angstroms were carried out (see the previous section of this report). The HLM graphite has a higher iron impurity content and a higher density than the 940G graphite. To check the effect of iron and other leachable impurities, corrosion measurements were made in 105% phosphoric acid at 200 °C and 0.9V vs. RHE, both before and after leaching the samples for 70 hours in a solution containing 30% HCl and 10% oxalic acid. The following table presents the corrosion currents (after 100 hours' testing) of HLM, 940G, and, for reference, Pfizer-made CVD-needled-felt:

Material	Corrosion Current mA/cm^2 of geometric area
HLM Graphite, not leached	0.096
940G Graphite, not leached	0.025
HLM, leached	0.015
940G, leached	0.011
CVD-Needled-Felt, not leached	0.006

The cumulative porosities of HLM and 940G are comparable and do not account for the slightly lower corrosion current of 940G. On the other hand, the surface area of the HLM graphite (0.71 m^2/g) compared to that of CVD-needled-felt (0.06 m^2/g) is in the right direction to explain the relative corrosion rates of these two carbons (see data above). The data suggest that for equal surface areas, the corrosion-resistance of the graphite material would actually be superior to that of the needled-felt. The difference in corrosion rates is, however, too small to dictate the choice of one over another since other considerations are involved.

NEW CATHODE CATALYST

High performance as well as good stability for 1000 hours was obtained when a new cathode catalyst (E-2) was employed in a single-cell test with a wet-proofing of 50% TFE. The performance of this catalyst is strongly temperature-sensitive. At 436 K (163 °C) the cell voltage (IR-free) was 650 mV at 161 mA/cm^2; this is the average voltage of a standard catalyst under these conditions. At 464 K (191 °C), the IR-free voltage increased to 710 mV, which is 20-30 mV higher than the voltage of a standard catalyst. The current voltage characteristics and the voltage stability with time are shown for this catalyst in Figures 8 and 9, respectively. Both H_2/air and H_2/O_2 data are shown.

TASK V - FUEL PROCESSING SUPPORT (97050)

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 methanol/steam reforming. This task is now complete, and the conclusions were summarized in the Quarterly Report for February-April, 1982.

TASK VI - IMPROVED ELECTROCATALYSTS (97039)

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

ENGELHARD

SECTION III. CURRENT PROBLEMS

NONE.

SECTION IV. WORK PLANNED

TASK I

- Improvements to be made in 5kW system. Stack rebuild to be completed.

TASK II

- Arthur D. Little to correct some inputs to models for economic analysis and revise certain conclusions.

TASK III

- Evaluation of existing technology for steam-reforming of natural gas to be started.
- Further tests on 5kW shell-and-tube reformer planned.

TASK IV

- Continue development of graphite bipolar plates and non-metallic cooling plates.

TASK V

- Completed.

SECTION V. FINANCIAL MANAGEMENT ANALYSIS

TASK I - 5kW POWER SYSTEM DEVELOPMENT

Labor was expended on stack testing during July. About $7000 remains in the revised budget for this task.

TASK II - ON-SITE SYSTEM APPLICATION ANALYSIS

Expenditures incurred on this task in July were according to plan. However, the total spending to date remains well below projections. Work is now expected to continue through the balance of 1982.

TASK III - ON-SITE SYSTEM DEVELOPMENT

1. Large Stack Development

Labor hours for this sub-task were well below plan for July but are essentially at the pro-rated budget level to date. Materials expenditures remain above projections.

2. Large Fuel Processor Development

Cost and hours for July were above projected level. Expenditures overall, however, reamin about 10% below plan to date.

SECTION V. - CONTINUED

3. System Analysis

Physical Sciences Inc. subcontract billing has been completed. Internal labor charges through July are about $35,000 ahead of plan, reflecting a high level of system analysis activity using the PSI-developed programs.

4. System Integration

Internal labor on this task increased markedly in July, but total expenditures to date remain well below budget. A high level of system integration activity is expected to continue in upcoming months.

TASK IV - STACK SUPPORT

Manpower expenditures for this task were again above the plan level in July, but total expenditures to date are about 15% below projections. Pfizer subcontract spending is still lagging the projections after a late start.

TASK V - FUEL PROCESSING SUPPORT

Manpower requirements for methanol reforming catalyst evaluation have been completed. Total expenditures required were well below those projected.

SECTION V. - CONTINUED

TASK VI - IMPROVED ELECTROCATALYSTS

The development of advanced anode and cathode catalysts is proceeding under Engelhard sponsorship. Evaluation of these catalysts is accomplished under Task IV.

TASK VII - MANAGEMENT AND DOCUMENTATION

Expenditures in the management and documentation area are proceeding substantially according to plan.

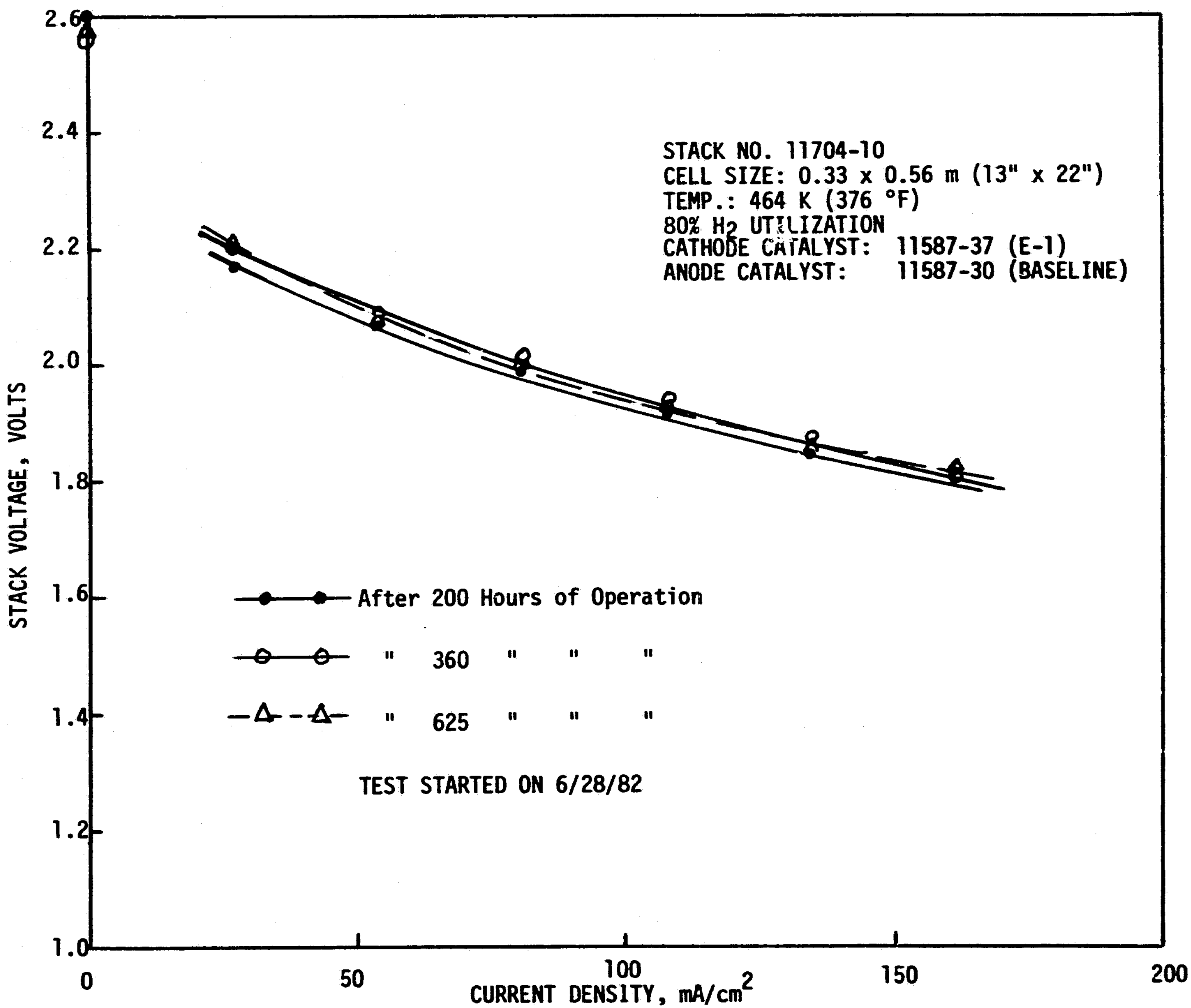

FIGURE 1 PERFORMANCE OF 3-CELL STACK (2 SQ. FT.)

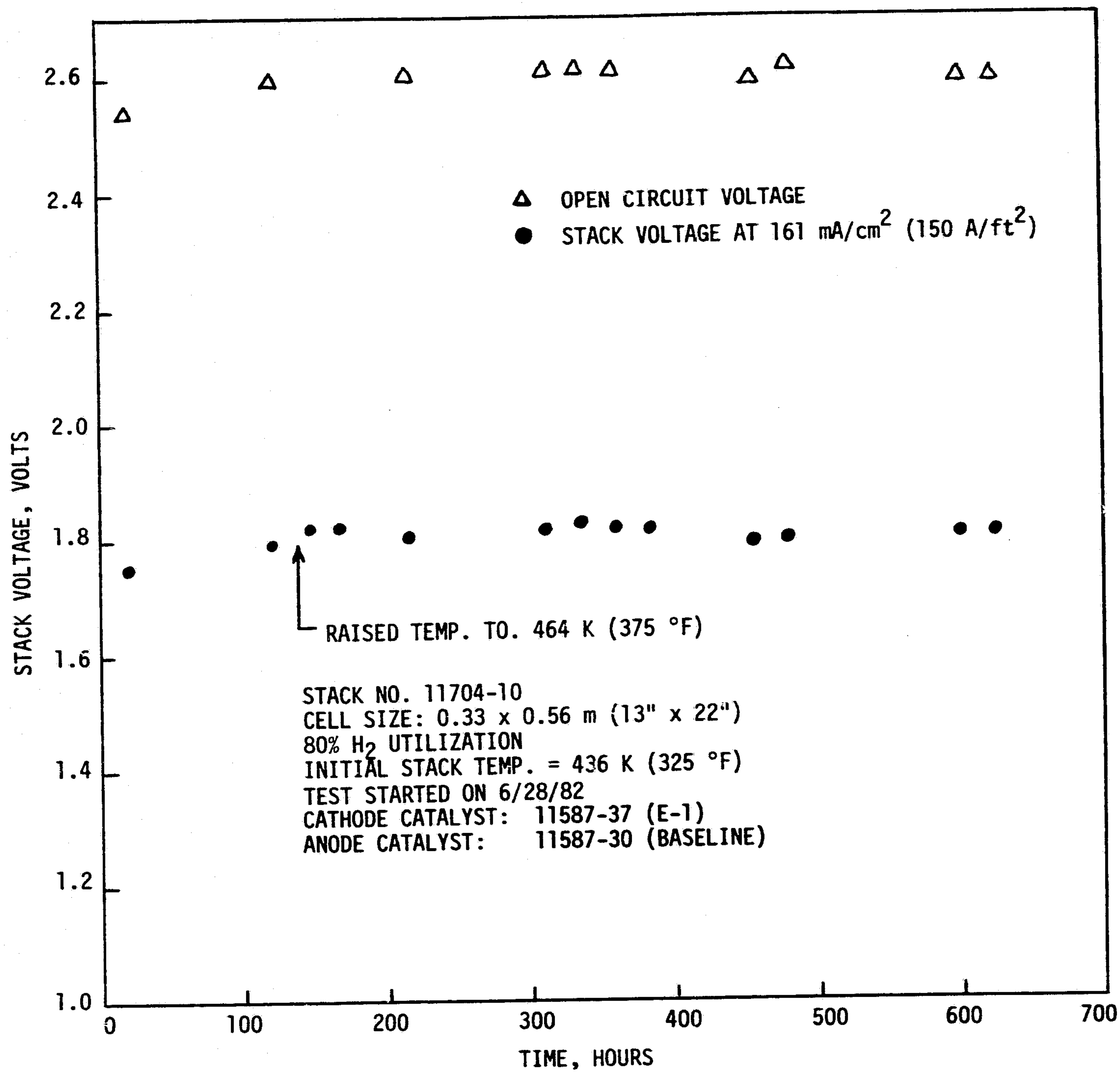

FIGURE 2 PERFORMANCE STABILITY OF 3-CELL STACK (2 SQ. FT.)

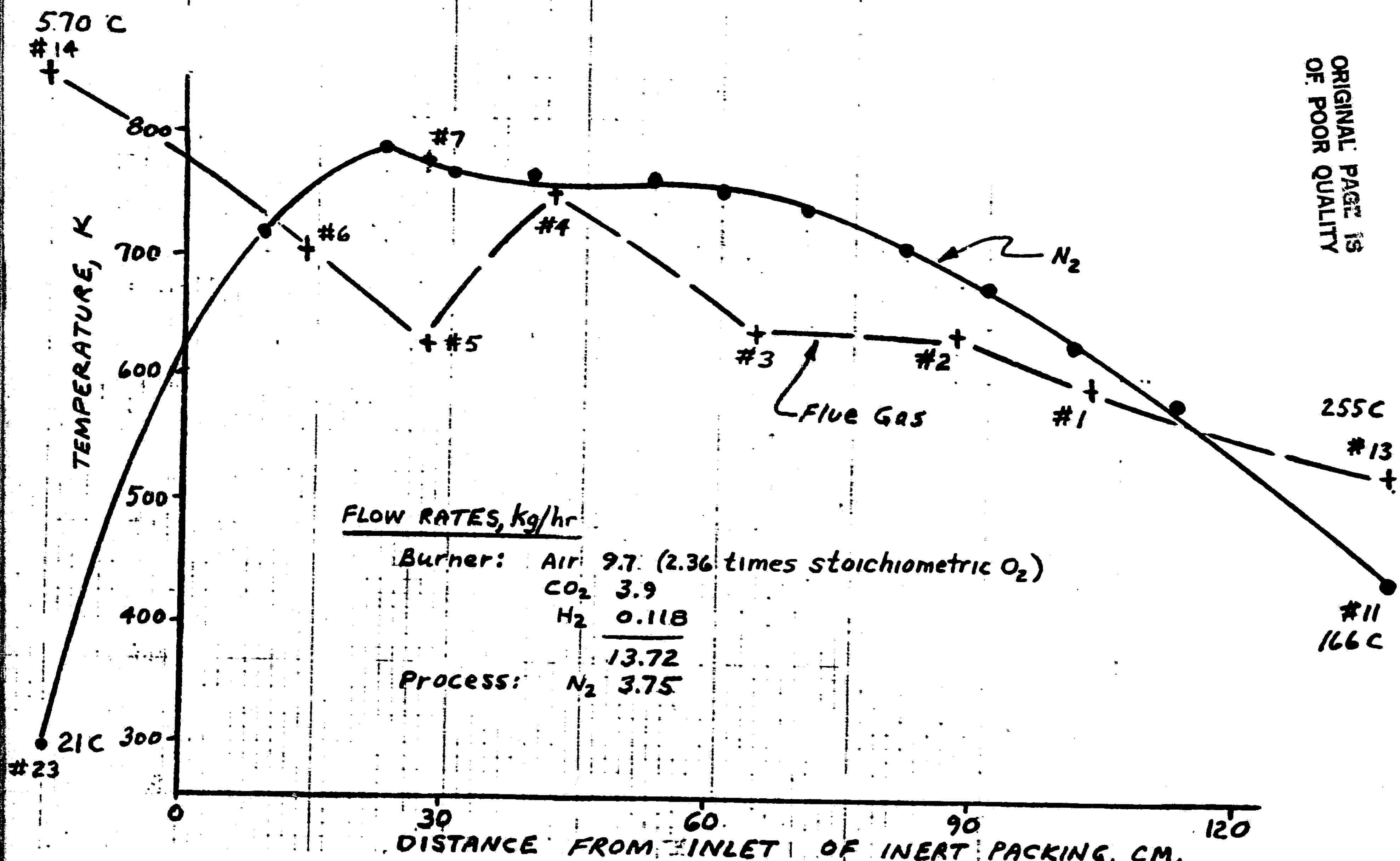

FIGURE 3 TEST OF 5kW-SCALE REFORMER WITH INERTS - FULL LOAD

REACTOR TYPE: COMMERCIAL SHELL-AND-TUBE HEAT EXCHANGER (INERT PACKING IN TUBES)
RUN NO.: 11738-5

J.A. Whelan
6-8-82

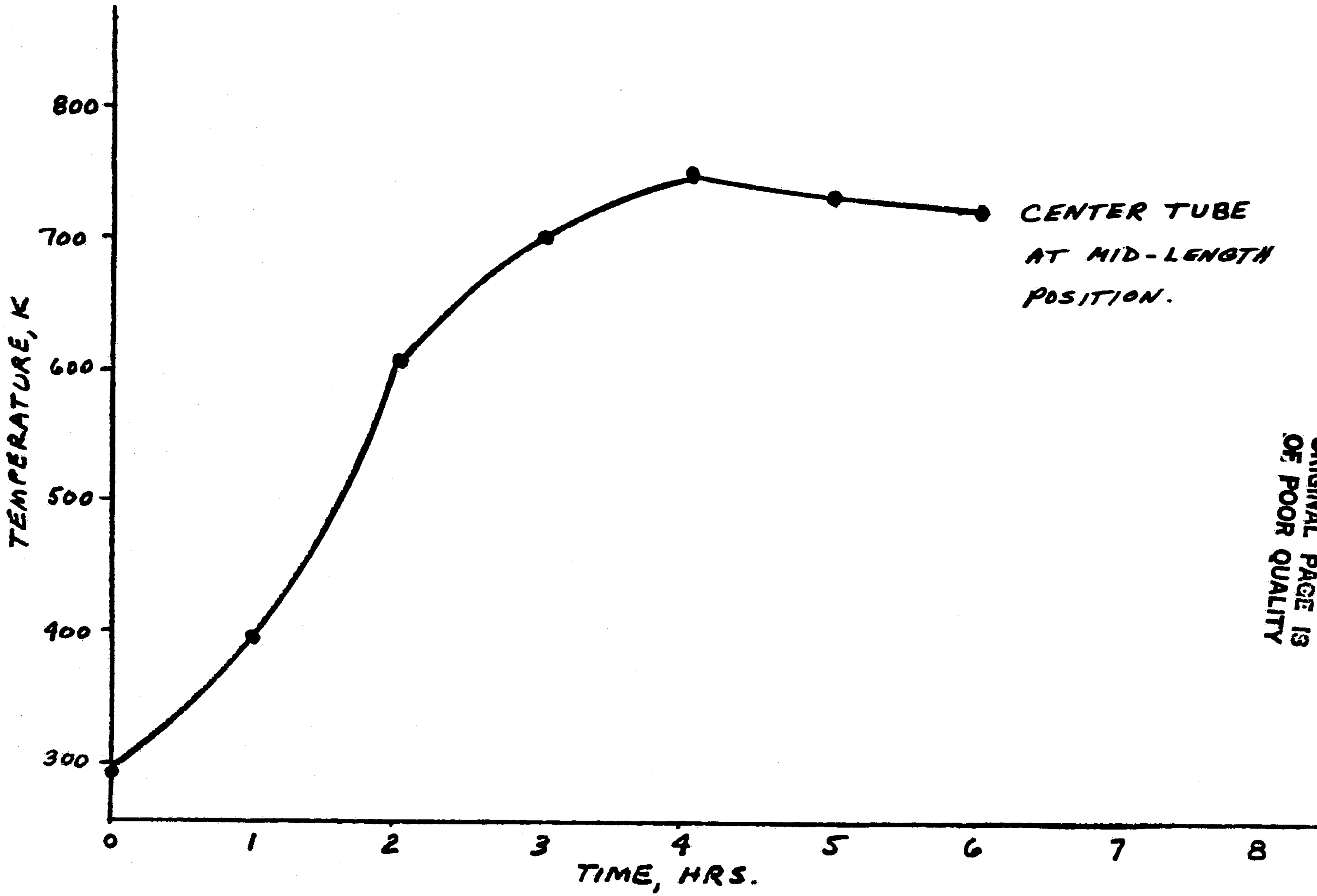

FIGURE 4 HEAT-UP OF 5kW-SCALE REFORMER

REACTOR TYPE: COMMERCIAL SHELL-AND-TUBE HEAT EXCHANGER (INERT PACKING IN TUBES)

PROCESS GAS SIMULATION: NITROGEN, FULL LOAD

J.A. WHELAN
6-8-82

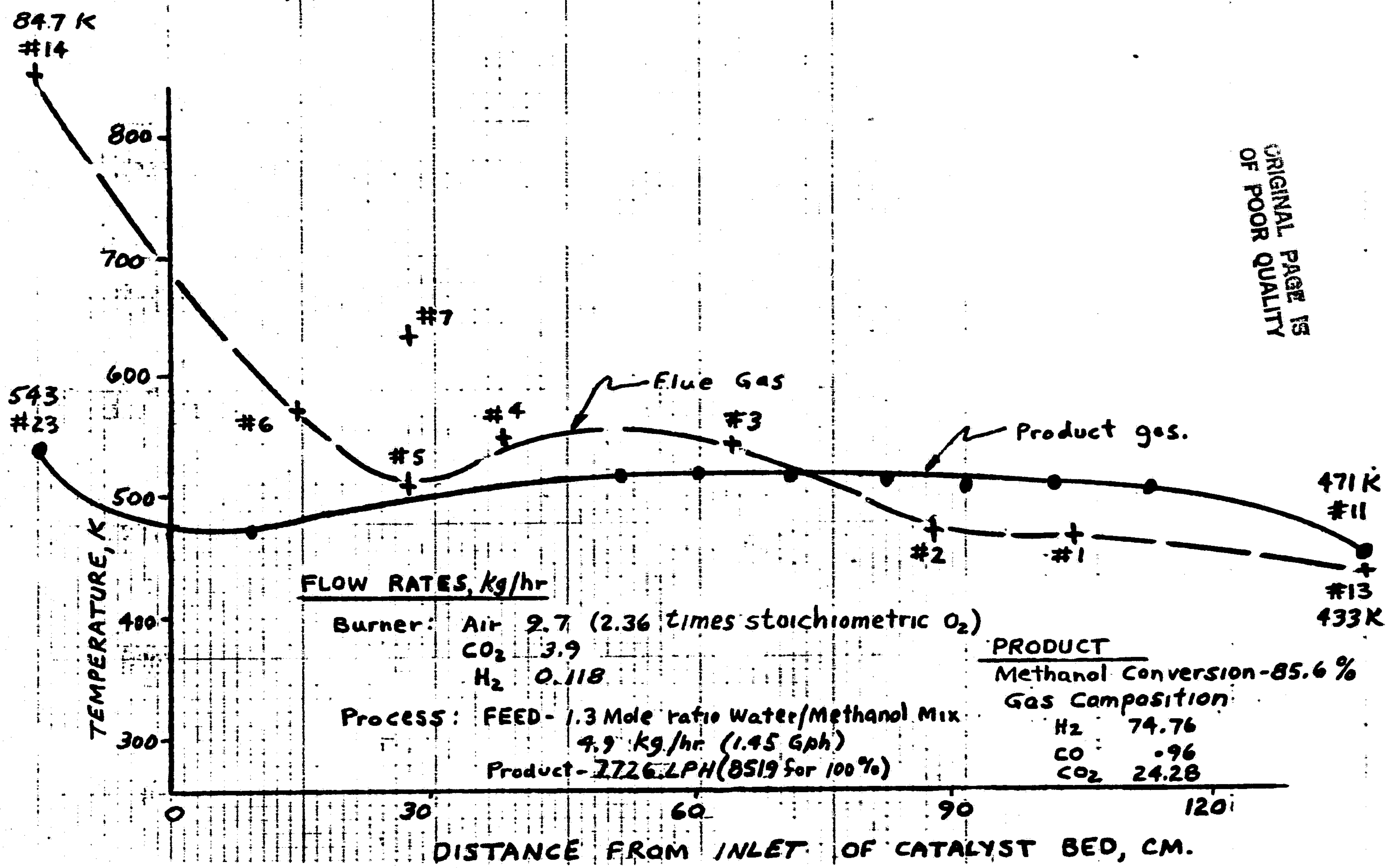

FIGURE 5 TEST OF 5kW-SCALE METHANOL-STEAM REFORMER - FULL LOAD

REACTOR TYPE: COMMERCIAL SHELL-AND-TUBE HEAT EXCHANGER (T2107 CATALYST IN TUBES)

RUN NO.: 11717-34

J.A.Whelan
6-11-82

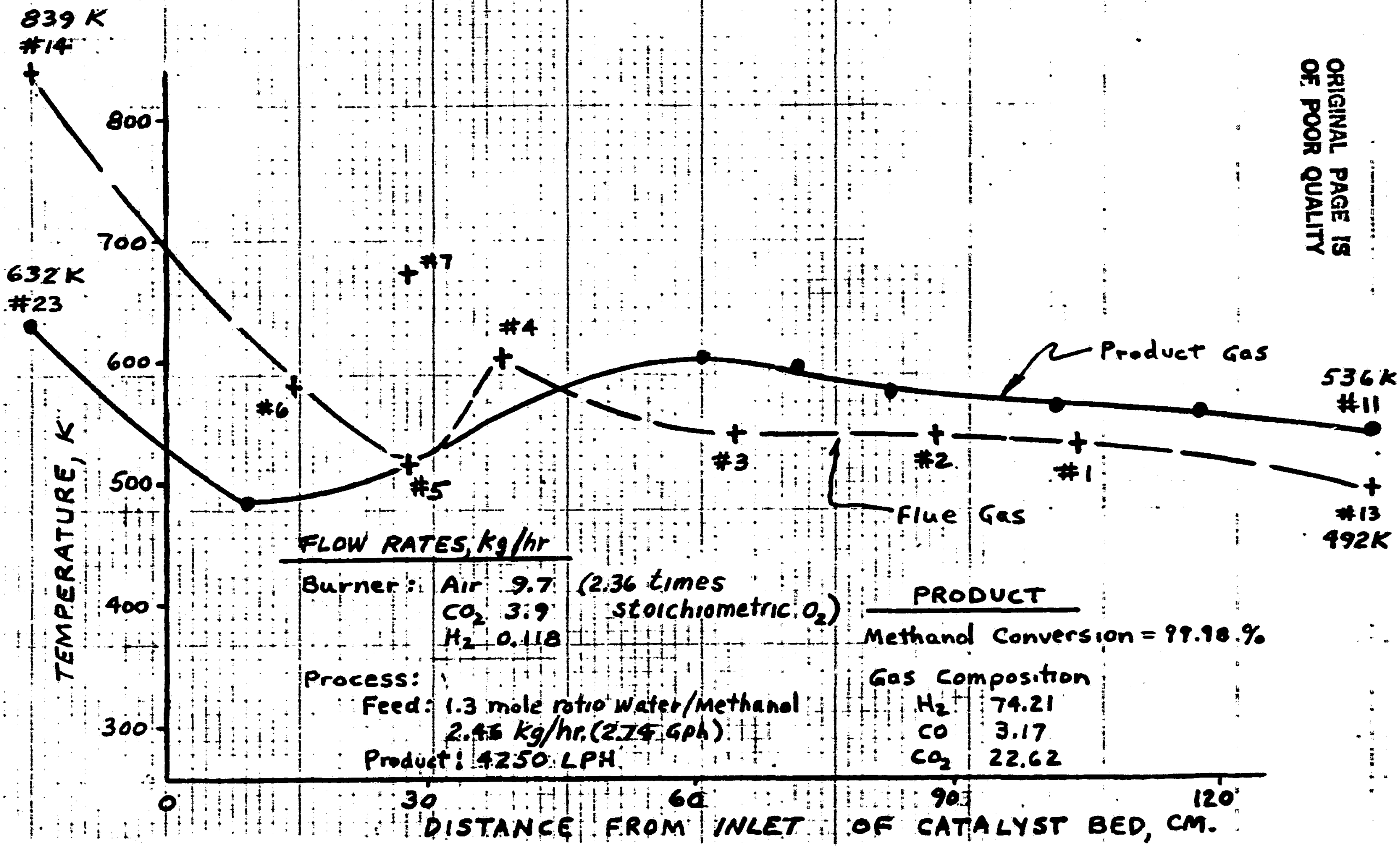

FIGURE 6 TEST OF 5kW-SCALE METHANOL-STEAM REFORMER - HALF LOAD *

REACTOR TYPE: COMMERCIAL SHELL-AND-TUBE HEAT EXCHANGER (T2107 CATALYST IN TUBES)

RUN NO.: 11738-41

J.A. Whelen
6-10-82

* BURNER FEED AT FULL LOAD

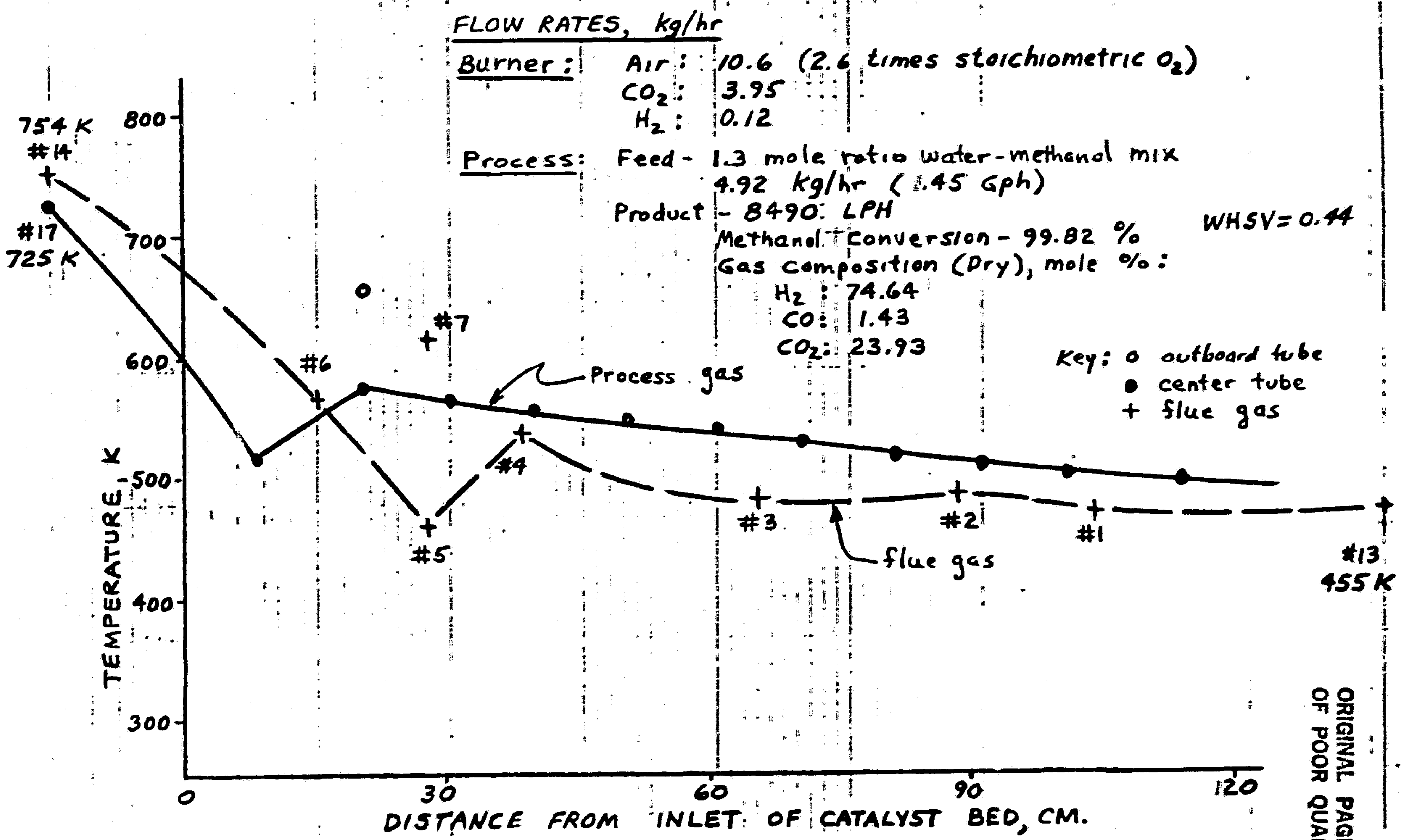

FIGURE 7 TEST OF 5kW-SCALE METHANOL-STEAM REFORMER USING UPSTREAM HEAT EXCHANGER - FULL LOAD

REACTOR TYPE: COMMERCIAL SHELL-AND-TUBE HEAT EXCHANGER (T2107 CATALYST IN TUBES)

RUN NO.: 11717-43

J.A. Whelan 6-25-82

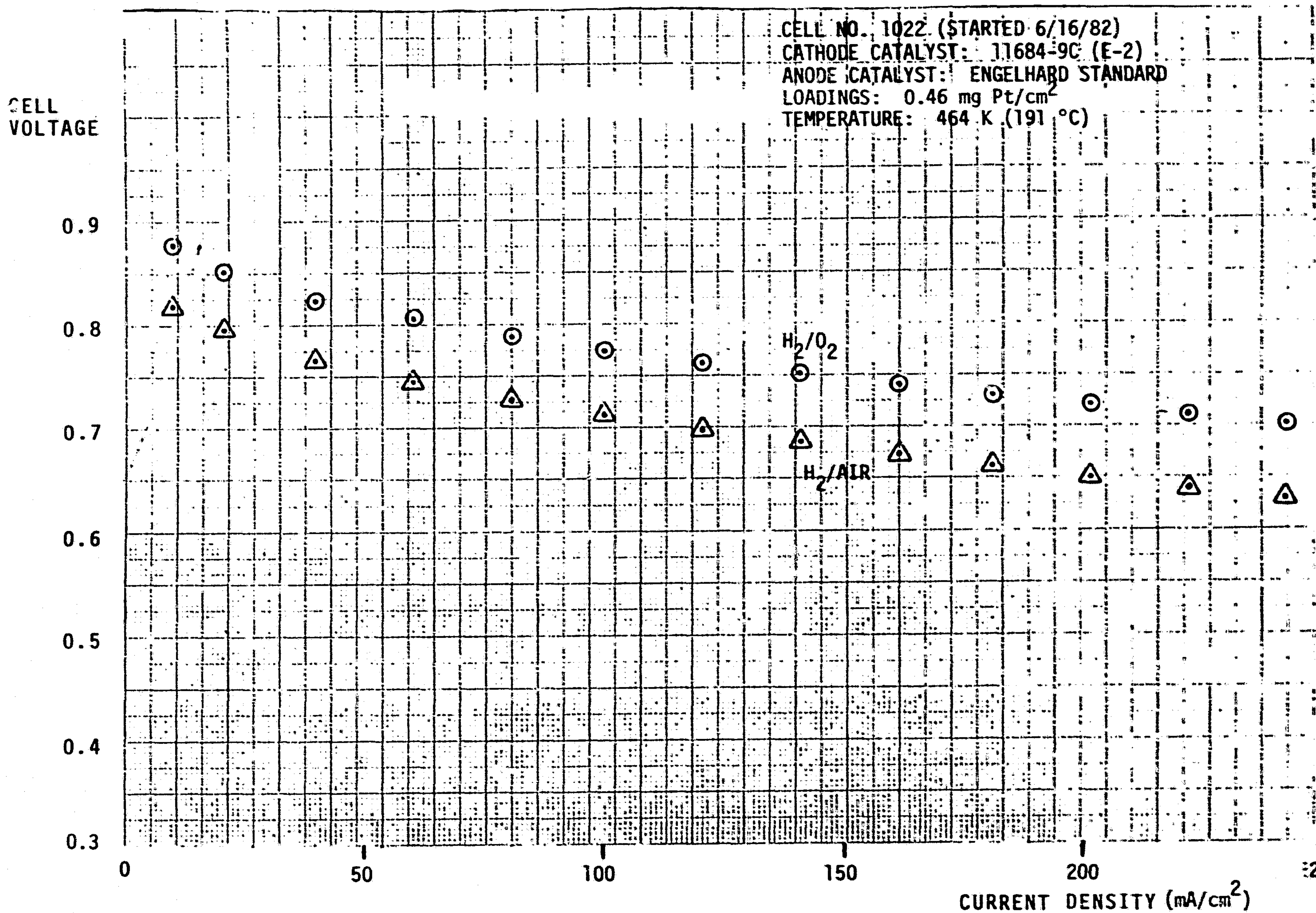

FIGURE 8 CURRENT-VOLTAGE CHARACTERISTICS OF E-2 CATHODE CATALYST

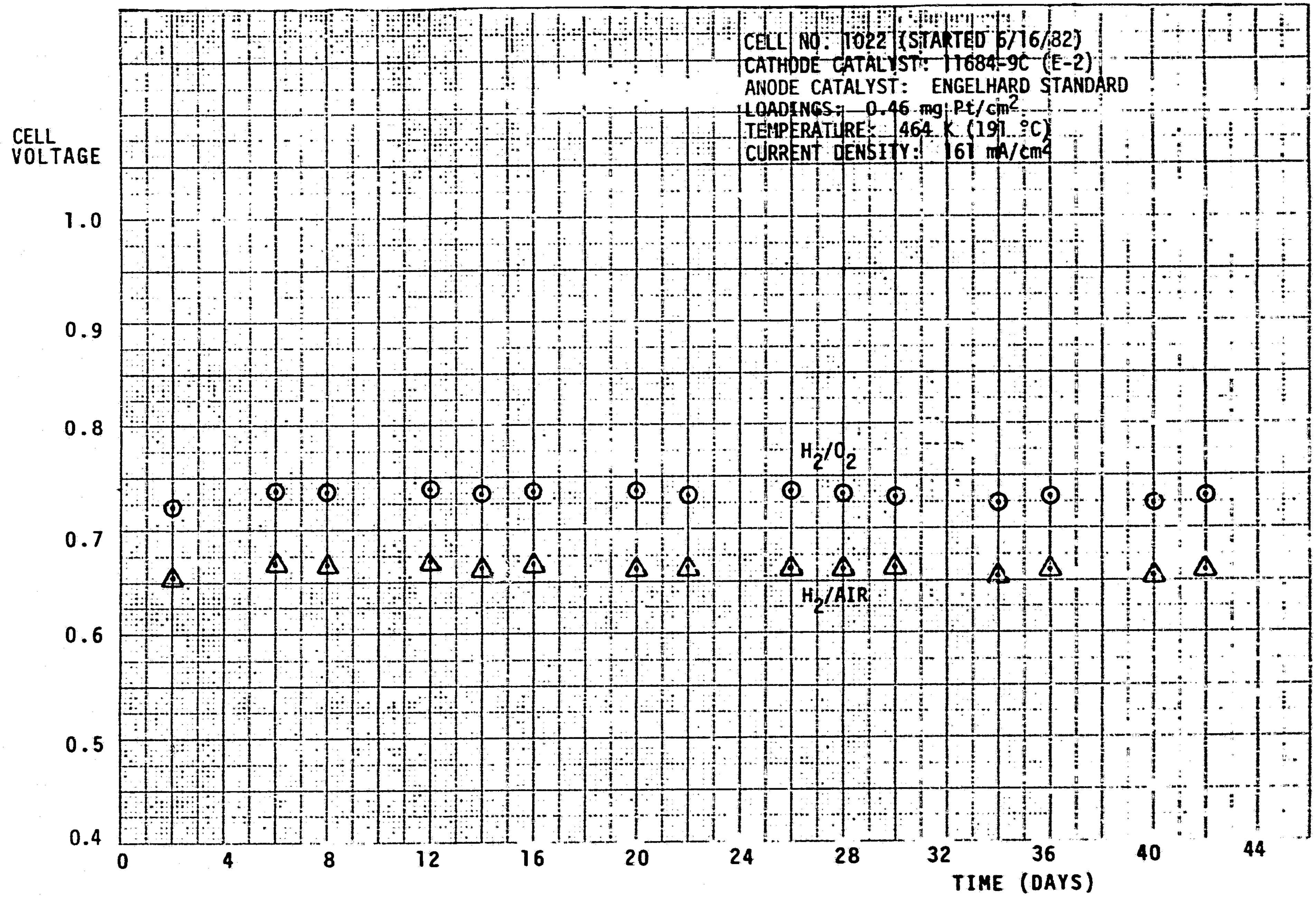

FIGURE 9 PERFORMANCE STABILITY OF E-2 CATHODE CATALYST