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REPORT

SPE WATER ELECTROLYSIS TECHNOLOGY DEVELOPMENT FOR LARGE SCALE HYDROGEN PRODUCTION

Contract EY-76 - C-02-2675. *000
(Formerly Contract #E(11-1)-2675)

Progress Report No. 6

Reporting Period: January 1, 1977 through March 31, 1977

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Progress Report No. 6

1.0 INTRODUCTION

1.1 This is the fifth quarterly progress report describing effort in Water Electrolysis Technology Development for Large Scale Hydrogen Production being performed by the General Electric Company, Direct Energy Conversion Programs (GE/DECP), for the Energy Research and Development Administration (ERDA) under Contract No. EY-C-02-2675. *000 (Formerly E(11-1)2675.)

This progress report covers the effort from January 1, 1977 through March 31, 1977.

1.2 Report Format

This report has been structured to provide technical information from all parts of the Bulk Hydrogen Generation program to all customers.

To do this, and satisfy each customer's contractual needs, this and subsequent quarterly reports will be structured as follows:

Cover page and Section 1, Introduction, will contain program and contractual information primarily unique to a specific customer and will be different for each customer.

Section 2, Technical Progress, and Section 3, Plans for Next Quarter, will cover all aspects of the program and will be common to all customers. Sponsorship of the individual tasks will be indicated.

2.0 TECHNICAL PROGRESS

2.1 Summary of Progress

The following is a summary of the technical results of the bulk hydrogen generation development program during the last quarter.

2.1.1 Task 1.1 - Low Cost Current Collector Development (ESEERCO Sponsored)

- . Completed 3000 hr 180°F, evaluation of each of three alternative anode support materials. Perforated Ti foil, porous Ti plate and single layer expanded 6/0 Ti screen are all viable.
- . Perforated Ti foil selected as anode support for use in large size cell scale up.
- . Pyrolytic Graphite unacceptable as anode support due to corrosion under anodic conditions.

2.1.2 Task 1.2 High Temperature Operation (ESEERCO Sponsored)

- . Life testing of cells containing all three alternative anode support materials at 300°F was continued. Up to 2600 hours demonstrated to date.

2.1.3 Task 1.3 - Catalytic Electrode Development (NMPC Sponsored)

- . 3000 hour extended evaluation of selected alloy anodes is underway with two alloys and two baseline cells.
- . 16 composition variations of three types of alloy anodes has been completed and evaluation of these anodes has begun.
- . RuO_x catalyst studies of performance decay mechanism are continuing.
- . Various techniques for depositing low loadings of platinum for cathode electrodes are being evaluated.

2.1.4 Task 1.4 - Low Cost Polymer Development (NMPC Sponsored)

- . 500 hour performance evaluations of the grafted TFS membrane have been completed.
- . Studies into the performance decay mechanism are continuing.

Presence of residual materials from the sulfonation process may be responsible for operational performance decay.

2.1.5

Evaluation of the Effect of Hydrogen Enrichment on Older Gas Pipelines (NMPC Sponsored)

- . All planned hydrogen exposure, post-exposure burst testing of the carbon steel samples have been completed.
- . All planned diffusion testing on the high density polyethylene sample has been completed.
- . Gross leakage was found at the bell joints of cast iron samples which prohibited further testing.

2.1.6

Task 1.5 Cell and SPE Optimization (GE Sponsored)

- . A cation concentration method has been developed which allows reliable measurement of cationic contamination in the ppb range.
- . Work was started toward development of an F-selecting resin for use as an anion concentrator.
- . Effort is in process at GE's Corporate Research and Development center aimed at characterizing the instability of RuO_x as an oxygen evolution catalyst.

2.1.7

Task 2.1 Cell Assembly Design (ERDA Sponsored)

- . Preliminary Design of the 2.5ft^2 current collector have been completed.
- . Verification field flow distribution and pressure drop tests are in process.
- . Mechanical strength test on molded carbon collectors indicate compatibility with design needs.

2.1.8

Task 2.2 Stack Assembly Design (ERDA Sponsored)

- . The preliminary hydraulic end plate layout has been completed. Simplifying modifications are being studied.
- . Stress and deflection analysis of the end plate is in process.

2.1.9 Task 2.3 Manufacturing Process Development (ERDA Sponsored)

- Evaluation of collector molding alternatives is in process. Mold definition is being worked out with several potential mold vendors and potential collector molders are being investigated to form the bases for a collector "make or buy" decision.

2.1.10 Task 3.1 System Analysis and Definition (ERDA Sponsored)

- Preliminary system design of the 6 cell module test facility has been completed. Sizing of components is in process.

2.2 Discussion of Results

2.2.1 Task 1.1 Low Cost Current Collector Development (ESEERCO Sponsored)

2.2.1.1 M & E Support Development

Operational evaluation at 180°F of the alternative anode support candidates continued up to 3000 hours load time during this reporting period. The endurance results in Figure 1 show all to be viable supports. Of the three - (1) single layer 6/0 titanium screen, (2) Ti porous plate, and (3) Ti perforated foil, the latter, has been selected for use in the 2.5 ft² development cell based on cost and availability.

All three configurations are under evaluation at 300°F, see paragraph 2.2.2.1 of this report.

The use of high temperature carbon fibers (Hercules'A' fibers) as a low cost anode support was operationally evaluated and found to be unacceptable due to corrosion of the fibers.

Unacceptable results were also obtained with pyrolytic graphite coated carbon fiber paper as an anode support. Although considerably more resistant to corrosion than carbon fiber or carbon paper, the pyrolytic graphite coated carbon fiber paper was less stable than metal supports.

The search for potential low cost stable anode support material is continuing.

Figure 1. Results of Anode Support Evaluation

2.2.1.2

Molded Carbon Collector Development

Molded carbon collectors in the bipolar configuration were manufactured and operationally evaluated at 300°F and 100 psig. The initial performance was good but external leakage developed and was traced to too thin a cross-section between the deepest part of the H₂ and O₂ flow fields.

Plates 60 mils thicker were fabricated and static water pressure tested to 500 psig with no leakage. No leakage was observed at 320 psig and 100 psig differential pressures.

Use of a dry powder form of the resin has improved the ease of mixing the resin and graphite and resulted in improved uniformity of density of the molded parts. The use of mold stops has been shown feasible with improvement in the reproducibility and uniformity of thickness of the molded plates.

Operational evaluation of dry powder mold, thicker (180 mils), bipolar plates is in progress at 180°F and 120 psig with good initial performance. Testing at higher pressures awaits completion of machining of the high pressure deionizer.

A new laboratory size mold (5" x 5") which more closely simulates the 2.5ft² cell inlet port configuration, molded inlet exit parts, and field dimensions was designed and machining is 90% complete.

2.2.2

Task 1.2 High Temperature Operation (ESEERCO Sponsorship Pending)

The three candidates for anode M & E support are currently being evaluated at 300°F, 100 psig in hydraulic hardware. All continue to show promise on the basis of support and performance. The endurance test results are shown in Figure 2 for the three anode support tests.

(1) Single layer 6/0 titanium screen (5 Ti 7) as the anode support in cell HT-67 attained 1702 hours of stable operation at 1.71 VDC @ 1000 ASF but suffered screen damage to the M & E assembly necessitating shut down of the cell. A replacement cell HT-79 with screen edge seal area protection started with good initial performance of 1.71 VDC @ 1000 ASF but suffered from excessive decay, which is under investigation.

(2) The titanium porous plate anode support being evaluated in cell HT-75 has been very stable at 1.71 VDC @ 1000 ASF for 1100 hours.

(3) The perforated titanium foil anode support has been stable for 2600 hours at 1.73 VDC @ 1000 ASF in cell HT-68.

Figure 2. Endurance Tests - 300°F Electrolysis Cells 1000 ASF

2.2.3 Task 1.3 - Catalytic Electrode Development (NMPC Sponsored)

2.2.3.1 Alternative Binary and Ternary Anode Catalysts

A total of 15 cells selected from the 48 hour survey test plus 9 baseline cells have completed 500 hour tests. Three catalyst systems were selected for further study. These were Pt/Ru/Ta, Ru/Ir/Ta and Pt/Ru.

Evaluation of these more promising candidates for extended periods (3000 hours) has begun. Four cells are presently being tested under this phase of the program. They are:

<u>Cell Number</u>	<u>Anode</u>
(1) NM 05-1	Pt/Ru/Ta
(2) NM 17-2	Ru/Ir/Ta
(3) BL #9	E 50
(4) BL #10	E 50

See figure 3 for performance curves of these four cells to date.

Preparation of anode alloy catalysts which contain the same basic ingredients as the three promising systems selected but with varying percentages of these ingredients has been completed. Each of the 16 alloy variations will be operationally evaluated to assess optimum composition.

Three of the above alloys have been evaluated thus far. Two were removed from test after 48 hours and the third continues on test to the present time. See figures 4 and 5 for operational data on cells NM-125, NM-126 and NM-127.

Evaluation of these alloys is continuing.

2.2.3.2 RuO_x Stabilization

Attempts to stabilize RuO_x anode catalyst by chemical cleaning, baking and teflon binder variations have been unsuccessful to date.

Samples of cells with RuO_x anodes before and after operation have been sent to Surface Science Laboratories for electron spectroscopy chemical analysis (ESCA), to GE R&D center Schenectady for microprobe studies and to GE Electronics Laboratory in Syracuse for X-Ray diffraction examination.

Results of the studies so far indicate the following:

Figure 3. Extended Evaluation of Alternate Anode Cells

Figure 4. 48 Hour Comparative Performance of Ternary and Binary Allow Variation Relative to E50 BL No. 1

Figure 5. 500 Hour Comparative Performance of Selected Ternary and Binary Alloy Variations Relative to BL #2

(1) There is essentially no change in the RuO_x catalyst chemical composition when viewed from the outer surface before and after operation.

(2) Ru or RuO_x from the anode/membrane interface migrate into the membrane during electrolysis and is possibly reduced by hydrogen diffusing from the cathode.

(3) The particle size of the RuO_x tends to get larger during electrolysis. The mixed oxide tends to approach RuO_2 during operation.

The performance decay mechanism appears, from our present knowledge, to be associated with a dissolution of RuO_x at the anode interface and/or an increase in electrode resistivity due to recrystallization or change in oxide state.

Studies of RuO_x stabilization are continuing.

2.2.3.3 Reduced Catalyst Loading

2.2.3.3.1 Cathode Electrode

A total of 9 low loaded cathode cells were made and evaluated this quarter. The cells were made using various techniques such as:

- (1) Sputtering on graphite paper (3 cells)
- (2) Depositing Pt directly on/in membrane (2 cells)
- (3) Electroplating Pt onto a foil and transferring to the membrane (3 cells)

None of the cells operated as well as low loaded Pt decals or Poco graphite decals sputtered with platinum. Figures 6 and 7 contain 48 hour survey data on the nine cells.

Sputtering platinum onto a graphite fiber substrate followed by attachment to the membrane with temperature and pressure was the more reproducible of the techniques attempted. However, attaching a semi rigid material such as graphite paper to a plastic material such as the SPE membrane is difficult to accomplish. Expansion, contraction and flexure of the membrane causes detachment of the graphite paper from the SPE membrane. Cells 117-11, 12 and 13 all had wrinkles and blistered detachment areas on the graphite paper electrode.

Depositing platinum directly in or on the membrane is an interesting low loading technique but the high contact resistance resulted in poor perform-

Performance Compared to Baseline (mv)

Baseline
Loading mg/cm²
Catalyst
Substrate
T-30 Imp reg.
M&E Fixture
Cell No.

Figure 6. Comparative Performance of Low Loaded Cathode Electrodes

Figure 7.

ance for both cells NM 117-14 and NM 124.

Electroplating platinum onto a foil followed by transfer to the membrane is a procedure which could be easily automated. The three cells made with electroplated cathodes (cells NM 120, 121, and 123,) all had poor performance. Low surface area of catalyst was considered to be the major problem with these electrodes.

The final cell (NM 122) was made with a cathode which was sputtered onto a foil then transferred with temperature and pressure to the membrane. This procedure proved difficult to reproduce. The single cell successfully made had poor performance.

2.2.3.3.2 Anode Electrode

Investigations have begun into the direct reduction of iridium and/or ruthenium catalyst on perforated titanium foil and porous titanium support material. The initial approach was direct thermal reduction which requires temperatures in the range of 400 to 500°D. This approach was found not practical due to severe oxidation of the titanium which would lead to high electrode resistance.

Other techniques for the reduction of iridium on the titanium foil are being explored.

2.2.4 Task 1.4 Lower Cost Membrane Development (NMPC Sponsored)

RAI membrane sample 125-1 completed its 500 hour evaluation test this quarter. This membrane was made from a 5 mil thick FEP film and had a 25% graft level of TFS.

Initial performance was good but after 125 hours there was a drastic change in performance which continued for about 150 hours. See figure 8. The performance decay rate then settled down to a rate of about 110-120 μ v per hour.

2.2.4.1 Performance Decay Mechanism

The performance decay of RAI membrane cells seems to be more associated with catalyst activation losses than with membrane resistivity increase. Of the 10 RAI cells operated thus far seven had resistance increases equal to or less than 0.8 milliohms which does not account for the observed performance decay. Thus membrane contamination is not the major factor in performance decay.

Catalyst activation losses are most likely the major cause of performance decay. Indications are that residual materials from the membrane

Figure 8. Alternate Membrane Evaluation

manufacturing process may be leaching from the membrane during cell manufacture and cell operation resulting in a contamination of the electrode catalysts. One possible source is the incomplete hydrolysis of sulfonyl chloride in the membrane. Chloride ion leaching from the membrane would have a detrimental effect on electrode performance.

To test this theory a membrane RAI 122-2 was put through a cell manufacturing procedure without electrodes. The membrane was then rinsed and the washings collected. An analysis of these washings detected chloride ion at a level of about 100 ppm.

A sample of the RAI membrane 122-2 was pyrolyzed in the presence of a copper wire and found to give a positive test for chloride ion.

The membrane was cleaned up by boiling, autoclaving and treatment in caustic to remove as much chloride ion as possible. This membrane RAI 122-2 will be made into a cell and evaluated for performance characteristics with time.

A sample of RAI membrane was ordered which has been grafted but not sulfonated. It is planned to sulfonate this membrane in our own laboratory under controlled conditions in an attempt to improve on the sulfonation procedure. A membrane thus treated may provide an answer to our performance decay problem.

Cell NM 211 which completed its 500 hour evaluation this quarter (see paragraph 2.2.4) was treated in boiling water and 1 N sulfuric acid. The cell was then returned to test where an initial improvement of 150 mv was observed. See figure 9. Operation of this cell continued for 234 hours and a performance decay rate of about 120-130 μ v/hr was recorded. Analysis of the membrane from this cell gave a positive test to chloride ion.

Studies of the performance decay of RAI membrane cells are continuing.

2.2.5 Evaluation of the Effect of the Hydrogen Enrichment on Older Gas Pipelines (NMPC Sponsored)

The test plan, Appendix A of prior quarterly monthly report, NMPC -4 dated January 14, 1977, was initiated and completed accordingly to schedule.

Two (2) Baseline (i.e. no hydrogen exposure) carbon steel specimens s/n 005 & 006 were initially burst tested. High density polyethylene plastic tube specimen s/n 010 and carbon steel specimens s/n 007 & 009 were exposed to

Figure 9. Effect of Re-exchange and Boiling on TFS Cell Performance

a 90% methane 10% H₂ mixture for 30, 60 and 30 days respectively. Steel specimens S/N 004, and 008 were exposed to a daily variable mixture of methane and hydrogen for 30 and 60 days respectively. Following exposure completion, all carbon steel specimens were hydrostatic burst tested. Metallurgical analysis is in process.

Cast iron specimens S/N 001, 002 and 003 leaked water at the dresser assemblies and the bell joints below the intended exposure pressure. Subsequent attempts to make weld-plate cast iron pressure vessels were unsuccessful with cracks developing in the plates, cylinders and weld passes despite technique changes with various electrodes and thermal cool down control.

A comparison of the burst pressure results for the baseline specimens versus the methane - hydrogen exposure specimens shows no sensitivity to the hydrogen. Results are as follows:

<u>Condition</u>	<u>Specimen S/N</u>	<u>Burst Pressure (psig)</u>
Baseline	005	3060
Samples	006	3100
	004	3125
Exposure	007	3100
Samples	008	3000
	009	2950

These rupture levels provide a 10:1 safety factor over the normal operating pressure of 300 psig.

Detail data analysis is progressing towards the issuance of a final report during the next quarter.

2.2.6 Task 1.5 Cell and SPE Optimization (GE Sponsored)

2.2.6.1 Water Purification

Work is being done to measure the contamination level in electrolyzer feed water in the parts per trillion range. The measurement method consists of using the Atomic Absorption Spectrometer (AAS) in conjunction with a cation concentrator currently being developed. The concentrator consists of finely divided particles of DuPont Nafion membrane in the acid form over which the contaminated water is passed. The resin accumulates the cation contaminant which is subsequently leached from the resin with relatively concentrated hydrochloric acid. The resultant eluent is analyzed on the AAS whose sensitivity is in the parts per

million range. By suitable concentration, water has been analyzed to 1 ppb to date. Characterization is complete for Na, Fe, Cu, Ni, Ca with Al scheduled. These metals were chosen since they are most likely species present in the ancillary equipment of the electrolyzer.

2.2.6.2 Fluoride Selective Ion Exchange Resins

It is possible that during unusual operating conditions some small quantities of fluoride will be released. Presently available ion exchange resins are not effective in removing fluoride and build up of fluoride could cause corrosion of ancillary equipment. A fluoride selective resin is being developed under GE Sponsorship by ECO-Control Corporation, Cambridge, Massachusetts. The resin and crosslinker have been prepared and work is continuing to provide spherical ion exchange beads. It is expected that the resin will be manufactured and tested by the end of the next quarter.

2.2.6.3 Catalyst and Membrane Characterization

The GE Corporate Research and Development Center (CR & D) is working on the understanding of catalyst behavior on the electrolysis cell. To date it has been determined that the hydrogen cathode catalyst is unaffected in size and configuration after cell operation. For the Ruthenium Anode System observations from electron microscopy have revealed a migration of Ru from the catalyst bulk into the membrane with some enlargement of the catalyst particle size (sintering). This indicates that for RuO_x systems alloying would be a direction to pursue to minimize this phenomenon.

2.2.7 Task 2.1 Cell Assembly Design (ERDA Sponsored)

2.2.7.1 Collector Design

During the last quarter preliminary design studies were initiated for the scale-up of the graphite current collector to 2.5 ft². This configuration is shown in Figure 10a and 10b. The initial scale up design was based on the 6"x6" graphite collector used for in-house testing during last year's program. Initial design dimensions of flow field channels were .020" wide x .030" deep with .050" pitch as shown in the above drawings. The width and pitch of the slots in the flow field are close to final design, the adequacy of which in supporting the membrane has already been proved. The depth of the slot is subject to change depending on the pressure drop of the fluid flowing in the slots.

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Figure 10a. Current Collector Plate - O₂ Side

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Figure 10b. Current Collector Plate - H₂ Side

Fluid Flow Fixture To supplement the preliminary design above with test data, a fluid flow fixture shown in Figure 11 was designed and built. The test fixture is providing pressure drop and flow distribution data as a function of flow field channel depth. This information is of great importance as proper electrolyzer operation depends on sufficiently high field pressure drop to uniformly distribute fluid flow in the numerous parallel flow field channels, and low enough to prevent excessive power consumption.

Computer Program A computer program was also set up for the current collector to predict two phase flow pressure drops at various operating conditions. Figure 12 shows preliminary computer results of field pressure drops at a possible running condition of 300°F and 500 psia.

Two cases are shown, a single pass and a 3 pass. In the 3 pass system a larger groove depth is possible since the path length is higher (the flow traverses the cell in three segments), and the velocity is higher in the single pass system. The pressure drop with the present 30 mil depth is only 0.5 psi which is judged too small for proper flow distribution within the cell and from cell to cell. Figure 12 shows an area labelled "estimated operating region for optimal flow distribution." Past experience indicates that the pressure drop should be 2.5 to 5 psi for good distribution. In the overall problem, the entire manifold, distribution system and number of cells must be considered in the overall flow adequacy.

Another region on Figure 12 shows the "desirable region for foil forming." One of the alternatives in applying the titanium protective covering on the collector will be to form the foil directly in the mold. This requires a shallow draw of about 8 to 10 mils otherwise the foil cracks. Before a finalization of the collector design, a trade off must be made between foil forming, pressure drop and minimum channel height.

Verification Flow Test Results

Initial results from the field flow test fixture showed relative poor flow distribution with the .030 internal field manifold due to large manifold pressure drops. Increasing the manifold to .125" minimized the pressure drop and improved fluid flow field distribution.

Empirical test results of field pressure drop for the fluid flow fixture at atmospheric pressure are shown in Figure 13. Initial results of 0.58 psi pressure drop for a .030" channel depth proved to be low based on an estimated design goal of 2.5 psi to 5 psi at pressurized conditions. Decreasing the flow field channels to 0.015" resulted in increased pressure drops, however, the pressure drops are still marginal and shallower flow fields will be investigated.

Figure 11. ΔP Test Fixture

Figure 12. ERDA 2.5 Ft² Two-Phase Flow Calculations

Figure 13. Results of Two Phase Fluid Flow Tests

Graphite Tensile and Flexure Tests

Mechanical tests were run on several molded graphite specimens from 75°F to 300°F to determine yield stress and Young's modulus of elasticity. Results of several samples tested and testing apparatus can be seen in Figures 14, 15, and 16. Tensile strengths of samples tested were in the range of 4500 - 6000 psi at 75°F and 2500 - 5500 psi at 300°F, all well within the minimum allowable stress for the collector manifold holes at 500 psi. Young's modulus results were found to be in the ranges from 1.3×10^6 - 1.65×10^6 psi at 75°F and $.27 \times 10^6$ - $.89 \times 10^6$ psi at 300°F, in agreement within published literature for molded phenolic

A calculation was made for the amount of stress if the plate were fabricated with a bend in it. At room temperature the plate can withstand 3/8 inch deflection at the center without breaking if the bend is gradual.

2.2.7.2 Cell Assembly Drawings

An isometric drawing (Figure 17) of a portion of a single cell has been made to show the general layout of the cell components. The molded graphite current collector is shown laid-up on the end plate and bus plate. Internal fluid ports transport water through the collector frames and direct it via slots to an internal manifold running edgewise along the frame. The feed water then runs orthogonally to the internal manifold in slots along the active cell surface. Exit porting is similar to entrance porting in design but larger in size.

On the surface of the ribbed collector is laid up a perforated titanium foil which supports the membrane and prevents creep into the ribs. It has been proved by many small cell tests that the membrane without the aid of the support creeps into the ribs and cracks the conducting catalyst layer. With the perforated support, essentially no creep of the membrane has been observed.

The next component to be assembled is the membrane electrode (M & E) assembly. Port holes in the membrane seal directly to the graphite current collector with no rubber gaskets. This concept (gasketless sealing) has also been demonstrated to be highly effective and reliable for sealing high pressures.

On the other side of the M & E is laid up a porous carbon fiber paper which serves the same function as the perforated titanium on the anode side. That is, the carbon paper keeps the membrane from creeping into the rib slots. The ribs on the cathode side of the current collector run orthogonally to the ribs on the anode side so that precise alignment is not necessary in assembling multicell stacks.

Figure 14. Apparatus for Stress-Strain Measurements

Figure 15. Tensile Strength of Molded Graphite/Phenolic Plate

Figure 16. Young's Modulus (E) of Molded Graphite/Phenolic Resin
vs.. Temperature

Figure 17. Single Cell Assembly

Finalization of the cell assembly design and detailed drawings are scheduled for completion in June.

2.2.8 Task 2.2 Stack Assembly Design (ERDA Sponsored)

2.2.8.1 Stack Configuration

Figure 18 shows a general view of an electrolysis stack. The hydraulic loading provides uniform face loading with simultaneously good current collector contact pressure and adequate fluid sealing.

In this system, the end plate or center plate is provided with a flexible diaphragm which is pressurized to provide stack clamping force. The fluid manifolds are incorporated into the end plates which are held at ground potential (negative). Electrical power is supplied through a positive center plate.

A hydraulic end plate was laid out and detailed, Figure 19. Also the hydraulic cylinders which hold the stack together were detailed, Figure 20.

Two sets of 28 pistons and cylinders are needed to hold the 300,000 lb. load on the stack when it is delivering 500 psi gas. Two sets were chosen for redundancy in case a hydraulic pump fails.

In view of the complexity of this approach, a second design approach is being investigated where the pistons are replaced by tie bolts (one inch diameter) and a flexible diaphragm extending over the entire active cell area and the sealing area is provided either in the end plates or in the center plate.

2.2.8.2 Stress Analysis of End Plate

The end plate shown in Figure 19 was analyzed for deflection profiles, maximum stress due to bending and stress concentration factors at the edge hole pattern assuming simple support at the hydraulic cylinder pitch lines. A detailed discussion of this analysis is included as appendix A.

A three dimensional computer analysis of the plate for stress and deflections is in process. Results are expected to be available early in the next reporting period.

Figure 18. Water Electrolysis Stack

Figure 19. Hydraulic End Plate

2.2.9

Task 2.3 Manufacturing Process Development (ERDA Sponsored)

Detailed technical discussions are in process with several potential collector mold makers. Results to date indicate:

(a) Present GE/DECP press plate size is marginal for a compression mold sized for 2.5 sq. ft. active area, but could accomodate a collector mold sized for 2.0 ft² active area.

(b) With a practical mold installed, the working opening of the present GE/DECP press will be 6" or less.

In view of these restrictions, efforts are in process to define alternatives which include:

- Utilization of existing presses at other GE locations.
- Molding of the collectors by an outside molding vendor.
- Slight reduction in area and extention of GE/DECP press opening to allow in house manufacture of collectors.

2.2.10

Task 3.1 System Analysis and Definition (ERDA Sponsored)
Six Cell System Definition

Figure 21 shows the system schematic developed during the 1975 system study performed for BNL scaled down to a 6 cell system containing 2 1/2 ft² cells. The heat and mass fluxes shown are for 300°F, 500 psi operation.

For the in-house 6 cell test facility several changes from the typical schematic are planned.

(a) The feed water purification unit is unnecessary since clean feed water will be available from the in-house distilled water supply.

(b) The dryer and Deoxo system are not required for in-house testing.

(c) Additional instrumentaion and sample parts to allow complete analysis of the system.

Design of the ancillary system component and test area enclosure based on the above consideration has begun.

Figure 21. 6-Cell System, 300°F, 500 Psia

Power Supply
Output Maximum 7500 Amp 18 vdc
(135 Kw dc)

- 3.0 PLANS FOR THE NEXT QUARTER
- 3.1 Task 1.1 - Low Cost Current Collector (ESEERCO Sponsored)
- Search for low cost stable anode supports
 - Start molding trials with new mold
 - Operationally evaluate bipolar cell at 400 psig.
- 3.2 Task 1.2 - High Temperature Operation (ESEERCO Sponsored)
- Continue 300°F evaluation of carbon collectors, anode supports and cathode supports.
- 3.3 Task 1.3 - Catalytic Electrode Development (NMPC Sponsored)
- Continue efforts to stabilize RuO_x as an anode catalyst
 - Evaluate promising alternative anode catalysts for extended (3000 hour) periods
 - Evaluate variations in ternary and binary catalyst components
 - Continue to search for techniques for making low loaded anode and cathode electrodes.
- 3.4 Task 1.4 - Low Cost Polymer Development (NMPC Sponsored)
- Evaluate final 10 mil TFS grafted membrane
 - Sulfonate RAI grafted membrane and evaluate performance
 - Continue study of performance decay mechanism.
- 3.5 Evaluation of the Effect of Hydrogen Enrichment on Older Gas Pipe Lines (NMPC Sponsored)
- Complete the post-exposure metallurgical analysis of the carbon steel samples
 - Issue final report of this task.
- 3.6 Task 1.5 - Cell and SPE Optimization (GE Sponsored)
- Complete calibration of the "cation concentrator" for prevalent cations.

- Evaluate F⁻ selective resin as an anion concentrator
- Continue characterization of the instability of RuO_x as an oxygen evolution catalyst.
- 3.7 Task 2.1 - Cell Assembly Design (ERDA Sponsored)
 - Complete fluid flow studies. Correlate data.
 - Complete collector design.
- 3.8 Task 2.2 - Stack Assembly Design (ERDA Sponsored)
 - Complete end plate design.
- 3.9 Task 2.3 - Manufacturing Process Development (ERDA Sponsored)
 - Make collector make-or-buy decision
 - Release mold to vendor for manufacture
 - Begin large M and E manufacture
 - Determine optimum method of installing foil in collector.
- 3.10 Task 3.1 - System Analysis and Definition
 - Continue component design for 6-cell test system.
- 3.11 Task 4.1 - Test Facility
 - Define facility
 - Begin procurement of components.

APPENDIX A

End Plate Stress and Deflection Analysis

The present-design end plate was analyzed for deflection profiles, maximum stress due to bending, and stress concentration factors at the edge hole pattern. A computer program was prepared for the calculation of the deflection of the plate assuming simple support at the hydraulic cylinder pitch lines (all four edges) and 700 Psi uniform pressure in the pressure diaphragm region. The analysis did not take into account the effect of integrally welded diaphragm or the pressure chamber (cavity) in the plate. The analysis is based on the theory by Timoshenko, Ref.: Theory of Plates and Shells, (1959), Pages 135-141, Case 33.

A three dimensional analysis of the plate for stresses and deflections is in progress. This analysis uses the "BIG 3D" computer program and analytical technique developed by S. Levy (GE/CR and D). The input data are ready and the program is being debugged at present.

End Plate Model: The end plate model is approximately 28.4" x 25.9" x 4.0" thick in overall dimensions, the diaphragm size is 22.0" x 19.5", the hydraulic cylinders' pitch line area is 25.36" x 22.86" and the plate is symmetrical. The plate is simply supported on all four sides along the cylinders' pitch line and the plate sees a 700 psi pressure in the diaphragm area.

Deflection Data: The calculated deflection data are tabulated in the enclosed TSS output sheet and plotted in the enclosed chart (Table A1). Due to the symmetry of the plate, support, and the loading, only one quadrant of the plate was considered. The table is self-explanatory.

The chart shows the deflection profile of the plate deflection at the plate section lines parallel to the X and Y coordinates. All deflection data are only in Z -direction (perpendicular to the plate plan).

It is seen from the data that the maximum deflection is at the center of the plate and it is approximately 0.0051". The maximum deflection of the plate at the cell stack boundary relative to the diaphragm or the pressure boundary is approximately 0.00064". The maximum slope of the plate edge will be approximately 0.037° at the hydraulic cylinder pitch line.

Further study has shown that the plate deflections will increase to 2.37 and 4.10 times the deflections of the 4.0" thick plate, if the plate thickness is reduced to 3.0" and 2.5", respectively; the maximum deflections for 3.0" and 2.5" plates will be 0.0122" and 0.0211" respectively.

These results will be compared with the three-dimensional analysis results in the near future or as soon as the the 3-D data becomes available. The diaphragm deflection can also be investigated using the BIG 3D program.

Stress Analyses: The maximum stresses (bending) are estimated to be approximately 7,400 Psi at the center of the plate, this does not take into account any stress concentration due to holes or the diaphragm. The stresses increase to 13,150 and 18,950Psi for 3.0" and 2.5" thick plates, respectively.

A complete stress analysis of the plate is being done using the BIG 3D program. The program will give exact history of the stresses in the plate. For all practical design purposes, the above estimates seem to be adequate for the time being.

Stress Concentrations: From close examination of the plate geometry and the hole pattern, it becomes apparent that holes near the plate edges are affected by cylindrical bending of the flat plate. The manifold holes are smaller and farther away from the edges and other plate discontinuity locations thereby less affected. The bolts holes are much smaller in diameter, not through the plate, and near the larger holes. The larger holes help relieve the concentration at these points. These points are not considered to cause any concern in the over-all plate design.

The stress concentration factors were estimated for the holes near the plate edges for two cases: (1) edge effect, and (2) in-line hole pattern (or series).

The analytical study shows that the maximum stress at the edge of the hole is approximately 3 to 3.5 times the applied stress distant from the hole. The maximum stress will be experienced in the hole at a point nearest to the plate edge. The applied stress distant from the hole will be much smaller than the plate stress. This problem will be further studied when the complete stress history of the plate is available from the 3-D analysis.

The concentration caused by the hole pattern is found to be of lesser concern. For the one-inch (nominal) diameter holes near the edge, the stress concentration factor (maximum stress/applied stress) is estimated to be approximately 2.1. These stress concentrations will occur at the nearest points between two consecutive holes. As stated earlier, the low value of the applied stress near the holes will keep the maximum stresses at the holes below the maximum plate stress.

The analyses at this point indicate that the plate will be adequately strong under given loading. It is a well established fact that rounding or chamfering of the hole edge and thickening of the hole edge reduce stress concentration factor (local) significantly. Maximum use of these features will be made in the final design.