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Status of Commercial Phosphoric Acid Fuel Cell System Development

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Work performed for
U.S. DEPARTMENT OF ENERGY
Fossil Energy
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Abstract

A review of the current commercial phosphoric acid fuel cell system development efforts is presented. In both the electric utility and on-site integrated energy system applications, reducing cost and increasing reliability are the technology drivers at this time. The longstanding barrier to the attainment of these goals, which manifests itself in a number of ways, has been materials. The differences in approach among the three major participants (United Technologies Corporation (UTC), Westinghouse Electric Corporation/Energy Research Corporation (W/ERC), and Engelhard Industries) and their unique technological features, including electrodes, matrices, intercell cooling, bipolar/separator plates, electrolyte management, fuel selection and system design philosophy are discussed. Advanced research and technology efforts supporting the development of these systems are also mentioned.

Background

For a number of years the Phosphoric Acid Fuel Cell has been the leading candidate fuel cell power plant system for terrestrial applications. Initially, development funds came primarily from electric and gas utility sources, from fuel cell manufacturers, and from the Department of Defense (DOD). The emergence of the Nation's energy program provided new direction coupled with increased government support (chiefly the Department of Energy (DOE) and Tennessee Valley Authority (TVA)) for the development of commercial fuel cell power plant systems; currently DOE is the chief government sponsor of the National Fuel Cell Program. The Electric Power Research Institute (EPRI) and the Gas Research Institute (GRI) provide substantial support in the areas of interest to their respective utility constituents.

A major Department of Energy Fossil Energy (DOE/FE) goal is to displace oil and natural gas (premium fuels) with alternate fuel sources, particularly coal. A key element in DOE/FE's strategy for achieving this goal is its Coal Technology Strategy Objective to develop systems which will use coal in a more economic, efficient, and environmentally acceptable manner for the 1990's and beyond. The DOE/FE Fuel Cell Program is consonant with this strategy.

In the near term, phosphoric acid fuel cell power plant systems are being developed to quickly penetrate markets where significant quantities of premium fuels are used presently (utility, residential, commercial, and industrial). Phosphoric acid fuel cell systems will demonstrate capability to 1) use a variety of fuels from any source from which hydrogen can be derived (hydrocarbons, alcohols, coal-derived, hydrogen, etc.); 2) improve fuel utilization efficiency over competing systems; 3) conform to stringent environmental regulations; and 4) provide unique features for a variety of applications. In so doing, phosphoric acid fuel cell systems will more efficiently and cleanly utilize the premium fuels that have to be used during the near-term fuel-switching transition period; by providing highly efficient, environmentally benign energy conversion technology, will assist the fledgling synthetic fuels industry (which includes, in addition to coal-derived fuels, expensive unconventional sources); and, by gaining market acceptance for the fuel cell power plants, will assist the development of potentially high efficient, less advanced fuel cell technologies.

The National Aeronautics and Space Administration (NASA) through its Lewis Research Center, serving as the DOE Phosphoric Acid Fuel Cell Program Lead Center, is responsible for carrying out the DOE/FE Program. The overall objective of this program is to develop commercially viable phosphoric acid fuel cell power plant systems for a variety of applications. For electric utility and industrial applications multimegawatt power plant systems are appropriate; for residential, commercial, and small industrial applications, multikilowatt systems (particularly on-site/integrated energy systems, OS/IES) are appropriate. Currently, three major contractors or contractor teams are active in the terrestrial phosphoric acid fuel cell field developing systems for the commercial market: United Technologies Corporation (UTC), Westinghouse Electric Corporation/Energy Research Corporation (W/ERC), and Engelhard Industries. In addition, the following major efforts are being carried out to support the development of these fuel cell systems: 1) research and technology efforts to augment and advance the technology base, 2) studies to identify major potential applications and associated end-use sectors considering technical, economic, environmental, legal, institutional, and marketing factors, and 3) analyses to define system configurations, and associated system and subsystem performance and cost requirements.

In this paper a review of the status of the major phosphoric acid fuel cell development efforts is presented. In both the electric utility and on-site integrated energy system applications, reducing cost and increasing reliability are the technology drivers at this time. The longstanding barrier to the attainment

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of these goals, which manifests itself in a number of ways, has been materials. The differences in approach among the three major participants and their unique technological features, including electrodes, matrices, intercell cooling, bipolar/separator plates, electrolyte management, fuel selection and system design philolosphy are discussed.

At present, both UTC and W/ERC are working toward commercializing fuel cell power plants for both electric utility and on-site, integrated energy (OS/IES) applications. The UTC electric utility program is in the system-technology demonstration or operational feasibility phase with a 4.8 MW module test scheduled to be conducted on the Con Ed network in mid-1981. The UTC OS/IES program is in the engineering and design (E&D) phase of a preprototype 40 kW system. This is to culminate in a preprototype system verification test which will be completed in mid-1981. The E&D phase leads directly into a Field Test of up to 45 preprototype 40 kW power plants and a parallel Commercial Development Phase.

The 4.8 MW demo test represents an earlier phase of cell development than the 40 kW preprototype and, therefore, differences exist in the basic cell configurations of the two systems. However, it is expected that the general characteristics of the cell and stack technology to be developed for commercialization will be very similar for both applications. Both will employ catalyst layers, two-phase liquid cooling systems, fibrous carbon/graphite cell elements and similar reactant seal and supply systems. Though similar, some optimization of various aspects of the technology will be required to address the differences in design power level and operating conditions of the two applications. The present electric utility system (4.8 MW) will operate at 375°F and 50 psia over a profile from 1/4 to full-rated load; for the ultimate commercial power plant, current thinking by UTC is to utilize a large area cell operated at approximately 400°F and up to 120 psia. On the other hand, the OS/IES is to be operated at atmospheric pressure, 375°F, over a load profile from open circuit to full-rated load. The beginning stages have been initiated for multi-year programs aimed at advancing both the Electric Utility and On-Site/Integrated Energy Systems through the prototype level of development and into the initial stages of commercialization. Both of these programs will provide an opportunity for the user community to purchase a limited production version of the commercial power plant.

In 1977 DOE (then ERDA) contracted with ERC to apply the experience gained under their 7-year Army program to the somewhat different requirements of OS/IES. In 1978, ERC teamed up with Westinghouse to develop on-site systems, a marriage that added system analysis, system design, and marketing capability to ERC's electrochemical technology/engineering background. More recently Westinghouse has proposed a 7-year program that will result in a demonstration of a 7.5 MW power plant for utility applications.

The Westinghouse/ERC on-site program is at the point where most of the enabling electrochemical component technology has been developed. Presently, the electrochemical components are being optimized for cost and life, basic design and development is progressing for other power plant components and an initial system design effort is complete. The most unique characteristic of the W/ERC power plant is that one of the reactant gases, rather than a liquid, is used as the stack coolant. In the gas cooling scheme, the air feed stream is either split inside the manifold into a reactant stream and a coolant stream which flow independently through the fuel cell stack and are merged in the exit manifold, or separate reactant and cooling streams are maintained. The first gas cooling variation has been called DIGAS (standing for distributed gas) by ERC. In addition, external replenishment of the acid electrolyte as well as accommodation of volume changes during operation has been incorporated.

Westinghouse's approach is to develop the OS/IES to be able to market not just a fuel to electric conversion device, but a total energy system that will supply all the space conditioning, water heating, and electric power requirements for a residential or commercial application.

The Westinghouse utility program is at a point where only a rough conceptual design based on DIGAS cooling and an evaluation of this design have been completed. The results of this EPRI-funded study showed DIGAS cooling to be a feasible method of power plant cooling and that the power plant performance and cooling loop costs were estimated to be satisfactory. As in the Westinghouse/ERC on-site program the cooling method to be used has not yet been determined; a program is now underway at ERC to experimentally determine the merits of DIGAS vs. separated gas cooling.

Engelhard contracted with DOE in 1976 to study several fuel cell applications and to develop fuel cell stack technology. Their previous experience included building fuel cells for an Army lift truck development program, and building and marketing H_2/O_2 laboratory-size demonstration fuel cells. They also have an Army-funded fuel cell development contract. Engelhard has development stack components, and is beginning to define attractive applications in preparation of an OS/IES system conceptual design effort. The component development effort has resulted in several unique approaches to fuel cell design. One area of innovation is their bipolar plate, the device which separates and directs the flow of reactants as it provides electrical conduction between individual cells. The conventional bipolar plate is a single piece of conductive material with reactant flow channels either molded or machined on either side. Engelhard's approach is to split the bipolar plate into three sections, an impervious center section (for reactant separation), with an open cell foam section, with or without channels, on either side (for reactant flow). All sections are made from organic precursors that are graphitized then densified. This process is very compatible with mass production and promises considerable cost savings over one-piece, bipolar plates which must be individually molded or machined. Engelhard has also developed a low cost cooling plate that can be made of conventional materials and fabricated using conventional furnace brazing techniques. The coolant is a dielectric liquid. This cooler offers potential cost reduction over other liquid and ebullient liquid coolers. A complete 5 kW power plant incorporating a methanol reformer and a utility grid compatible power processor has been built and tested. Acid management capability that can accommodate volume changes during transients as well as acid addition as needed has been incorporated.

Phosphoric acid fuel cell technology and development efforts for both the electric utility and OS/IES applications are directed toward reducing cost, increasing performance, increasing life, and improving reliability. These, in turn, can be reduced simply to cost and reliability goals. In the technology area, the most vexing problem, the longstanding barrier to the attainment of these goals, has been materials. In the cell catalyst layer, the carbon support must resist oxidative corrosion while the catalyst must resist dissolution and sintering at the operating temperature, pressure, and potential. Both cell and fuel processor catalysts must possess sufficient tolerance to fuel contaminants. The carbon/graphite cell and stack materials must possess just the right combination of structural properties. The seals must seal well, be durable, and not contaminate. Metal parts throughout the system must possess the right structural and thermal properties, and also be durable. Finally, all materials must be cost effective and be easy to manufacture. It has been very difficult to find and to develop materials that could meet, simultaneously, the cost and reliability goals. The approach to solving these problems has involved technology/development efforts guided by system trade-off studies.

Beyond materials, a difficult problem has been the ability to provide the cell stack with sufficient electrolyte to attain a cost effective stack operation. In what follows some of these issues and their resolution by each of the major contractors will be discussed.

United Technologies Corporation

Cell Structure

The advanced cell structure concept commonly called the "paper" or integral ribbed substrate is UTC's approach to lowering cell system cost and, simultaneously, increasing electrolyte capacity. In part, the cost reduction is brought about by the substitution of a 2-3 day process in place of the conventional 2-week molding and curing process which produces a complex bipolar/separator plate. Aside from being complex, the molded processing method places a limitation on the size of the plate that can be fabricated. Eliminating the size constraint on the cell structure thereby provides the possibility to go to a larger and more cost effective cell.

The unique features of the integral ribbed substrate concept are: 1) replacing with a simple impervious flat plate the complex bipolar/separator (which normally contains a ribbed reactant flow field on either side perpendicular to each other); 2) transferring the function of each solid ribbed flow field onto a ribbed porous element which, after deposition of catalyst on one side, behaves like an electrode and which is also designed to act as an electrolyte reservoir. Figure 1 illustrates the differences between the molded cell and the ribbed substrate cell approach.

At present the ribbed substrate is fabricated in three steps. A blend of carbon fibers and resin are 1) made into a preform, 2) graphitized and 3) milled flat and ribbed in a single pass cut on a milling machine. In the ultimate these three operations might conceivably be incorporated into a single, automated mass production process. Ribbed substrate manufacture, which can be generally characterized as a paper-making type process, lends itself extremely well to the adaptation of most automation techniques.

Higher Temperature and Pressure Operation

Quantitative data on the performance increases due to higher temperature (375^{C} to $425^{\circ}F$) and to higher pressure operation (50 to 120 psia) have been obtained. At initial time, an expression was obtained for the effect of reactant pressure change (15 to 150 psia) upon IR-free cell voltage of a cell operating at a constant 300 ASF.

$$\Delta E_{cell} = b_s \log P_2/P_1 \qquad (1)$$

where P is reactant pressure and b_s is the sum of the anode Nernst (thermodynamic) effect and cathode Tafel slope (kinetic) at the given temperature.

At 120 psia, $400^{\circ}F$, 375 ASF, 2" x 2" subscale cells have achieved an initial performance increase of up to 90 mV compared to older type cells operating at 50 psia, $375^{\circ}F$, and 300 ASF. However, as expected, the higher temperatures and, to a lesser extent, pressures also cause an acceleration in the decay rates. In the UTC power plant system, increasing pressure without increasing temperature is not possible because of the interdependence of cell coolant and reformer conditions. Progress has been made at reducing the sharp cell performance decay rate occurring during high temperature and pressure operation. The rate of decay has been reduced from 60 mV per 1000 hours to approximately 12 mV per 1000 hours, which is the 4.8 MW decay rate at 50 psia. (See Figure 2)

Recently, 2" x 2" subscale cells have been successfully tested at 120 psia and $400^{\circ}F$ for periods of up to 2000 hours at performance levels 90 mV higher than the performance projected for the 4.8 MW, 50 psi and $375^{\circ}F$ power plant. Also, over the 2000 hour duration the performance decay matched the approximate 12 mV/1000 hour decay rate of the 4.8 MW projection. (See Figure 2)

From the overall plant standpoint, the optimum pressure and temperature depend not only on stack technology and development, but also on the cost and performance implications upon balance of system (turbocompressors, heat exchangers, piping, etc.)

Intercell Cooling

Two-phase water cooling is the method used. Thin-walled, 2-pass copper tubes with stainless steel headers are the latest design. The acid environment requires the copper tubes to be coated with a thin Teflon protective film; however, this reduces heat transfer somewhat. The chief disadvantage of these intercell coolers is their relatively high cost. The probability of cooler failure due to penetration of the film and subsequent corrosion of the copper has not yet been established. However, considerable test time has been accumulated on partial stack (24 cells) and full stack (270 cells) testing so as to provide an acceptable level of confidence in the reliability of the protective film. Tests up to 13,000 hours in duration have been run on partial stacks and 2000 hours has been achieved on a full 270-cell atmospheric pressure stack without any cooler tube failures.

Electrodes

Primary focus has been on the cathode. Stabilization of the carbon support of the Pt catalyst via heat treatment has been one important effort. This is especially important for the 40 kW system which experiences swings to much higher potentials. Investigation indicated that above 800 mV cathode losses attributable in great measure to oxidative corrosion of the C support occur. Other cathode treatments by UTC are aimed directly at the Pt catalyst to enhance activity without sacrificing stability. Recent work indicates progress in this area.(1,2) Work is being done to develop and optimize the catalyst layer for high temperature and pressure operation. The support carbon is being stabilized to inhibit corrosion, the wetproofing is being optimized to minimize diffusion losses, and techniques are being developed to improve the activity of platinum.

With total Pt electrode loading reduced to approximately 0.75 mg/cm^2, the Pt cost in the fuel cell system has been reduced to lesser importance than years ago when unsupported electrocatalysts were used. However, the recent sharp rise in Pt cost coupled with 50% lower power density operation for the 40 kW system(3) versus the 4.8 MW system has increased the importance of electrocatalyst cost particularly for the OS/IES system.

WESTINGHOUSE/ERC

Probably the most important innovation of the ERC technology program is the gas cooling method. One of these, the DIGAS method (see Figure 3) distributes process air to both the cathodes (via bipolar plates) and to special cooling plates. The total amount of air that is required for reaction plus that required for cooling is supplied to the air inlet manifold. The air then flows through the cell via both the cathode flow (cathodic) channels of the bipolar plate and the channels of a special cooling plate. All of the air is collected in a common exit manifold and flows to an external loop where heat is removed, some of the oxygen depleted air is purged and fresh air is added such that steady operation is maintained.

Since the cathodic channels of the bipolar plates and the cooling plate channels are parallel paths for air, the flow split is determined by the relative cross-sectional area, hence relative resistance, of the cathode and cooling channels. A typical design is a 10:1 split with three times the stoichiometrically required amount (3 stoich) of cathode gas going to the cells and 30 stoich gas going to the cooling plates.

Table 1 displays ERC's comparison of DIGAS and separate gas cooling to the two other commonly accepted cooling methods, process gas cooling and liquid cooling, performed under contract to DOE.(4) The estimates are based on selected configurations of the three cooling methods. No effort was made to optimize any of them; however, all systems are reasonable and are consistent for comparison purposes. For any system chosen by a particular manufacturer, some optimization of the values presented in Table 1 may be expected. Each of the system feature comparisons will now be discussed.

Construction Simplicity

DIGAS cooling is relatively simple. Depending on stack operating conditions, at regular intervals a cooling plate is added to the stack of cells in the same manner as a bipolar plate is stacked. No special manifolding, connections or seals are required.

Process gas cooling is the simplest of all. There are no special cooling plates or stacking procedures needed. Several times the

Table 1 - Comparison of Cooling Schemes for Phosphoric Acid Fuel Cell System

	DIGAS or Separate Gas Cooling	Process-Gas Cooling	Liquid Cooling
1. Construction Simplicity	Simple	Simple	Complex
2. Electrolyte Loss	Low	High	Low
3. Reliability	High	High	Low
4. External Heat Exchange	Fair	Fair	Good
5. Cost of Cooling Subsystem, % Stack Cost	5	5	25-50
6. Total Differential Temp. °F	45	60	20
ΔT_{cell} in stacking direction °F	15	0	15
ΔT_{cell} in flow direction °F	30	60	5
7. Total Auxiliary Power Req't., %	2	5	1
Stack Auxiliary Power Req't., %	0.5	3	<0.5
Balance of System Auxiliary Power Req't., %	1.5	2	0.5
8. Pressure Drop Across Cell, in. H_2O	0.4	3.5	0.4

stoichiometric requirement of cool air is supplied to the stack. All the air flows through the cathodic channels of the bipolar plate. Upon exiting the stack, the air can be vented or recycled as in the DIGAS method.

Separate gas cooling, the alternate to DIGAS, keeps the cathodic reactant air separate from the cooling system gas (air, helium, etc.). This improves electrical performance due to higher O_2 concentration of the cathode as well as reducing the need for acid resistant heat exchangers in the cooling stream.

Liquid cooling is by far the most complex and expensive. It involves passing a liquid coolant through special cooling plates inserted at regular intervals in the stack. The coolant may remain in the liquid phase at all times using only its sensible heat to cool the stack, or the coolant may partially vaporize using latent heat for part of the cooling load. The coolant must be either separately manifolded or supply lines must be connected to each individual cooling plate. Standard heat transfer materials, such as copper or aluminum, are corroded by phosphoric acid and must be protected if they are to be used. Standard, inexpensive fuel cell materials such as graphite or graphite/resin composites present difficulties in sealing and making connections. Finally, the liquid itself and coolant lines, if electrically conductive, provide a possible shorting path in the cell (shunt currents which result in parasitic losses) which must be minimized. In the UTC two-phase water cooling method water treatment is required.

Electrolyte Loss

Since the vapor pressure of phosphoric acid (hence electrolyte loss) is a weak function of temperature, the main consideration here is the amount of gas flowing past the electrodes to carry off electrolyte. In both gas and liquid cooling methods, a small excess of reactants flow past the electrodes, while in a process gas cooled stack all the cooling air must pass the electrodes. Process gas cooling has the highest electrolyte loss which translates into the shortest life or the shortest mean time between electrolyte replenishment.

Reliability

For gas cooling, reliability is high since there is no special cooling fluid and no complex manifolding or connections. Most air leaks could be ignored. A leak in the stack liquid cooling system could cause a shutdown while the leak was repaired or the defective cooling plate replaced.

External Heat Exchange

Heat recovery is by far best with a liquid or two-phase liquid cooling system. Heat recovery is possible, though more difficult, with either of the recirculating air cooling systems.

Cost Comparison

This is an estimate based on materials used and construction complexity; it reflects the materials and construction problems of liquid cooling.

Total Differential Temperature

This concerns temperature gradients across a fuel cell stack. The total temperature differential, ΔT, between any two points in the stack contains two components, a ΔT in the stack direction (perpendicular to both reactant flows) and a ΔT in the flow direction (parallel to one reactant flow). It is important to maintain the stack temperature within a fairly narrow band. If the temperature drops too low, CO poisoning of the catalyst becomes a problem, and if the temperature is too high, the operating limit of the stack materials is exceeded. A commonly accepted operating range is between 350 and 400°F. Since every cell is cooled equally in the process gas method, there is no stacking direction component of the total ΔT. Also, since the coolant directly contacts every cell, the inlet area is cooled more than in other methods; this accounts for the large ΔT in the flow direction. For both the gas and liquid cooling methods, the same number of cells between cooling plates is assumed. This sets the stacking direction ΔT at 15°F for both systems. The difference in flow direction ΔT results from the differences in liquid and gas heat transfer characteristics.

Total Auxiliary Power

These requirements are mainly a function of the amount of coolant circulated and the cross-sectional area of the coolant passages. As expected, the power requirements for pumping a liquid coolant is quite small. Since all the cooling air flows through the cathodic channels of the bipolar plate, the power requirement is quite large for the process gas method. Power for the other two gas systems lies between the two. The same amount of gas must be circulated through the stack as in the process gas method, but a large fraction passes through the large area cooling plate passages.

Pressure Drop Across Cell

This is a function of the air flow through the cathodic channels of the bipolar plate. The same amount of cathode air is required for both gas and liquid cooling, hence the same pressure drop. The high pressure drop for process gas cooling reflects the high air flow rate required through the cathodic channels.

Based on the above considerations, ERC has concluded that the gas cooling concept offers the best compromise between reliability, life-cycle cost, and heat recovery.

Westinghouse has recently made a more detailed study of gas cooling. Under DOE contract(5,6) they developed a lumped parameter fuel cell stack simulation code that calculates reactant gas composition, current-voltage characteristics, and heat transfer characteristics for a gas-cooled fuel cell stack. In the model, the cell area is broken down to a grid of finite elements so that power and heat generation can be calculated as functions of temperature and reactant composition, as each varies from point to point in a cell.

As discussed previously, one of the major drawbacks of gas cooling is a higher total differential stack temperature than that of liquid cooling. Westinghouse is presently redesigning the gas cooling plates in an effort to reduce the differential temperature. Results of the simulation show that a 28°F differential temperature can be achieved with proper design. This comes close to what can be achieved with liquid cooling.

Westinghouse expanded their computer model to include simulation of the other subsystems in the fuel cell power plant and total energy system. The model includes performance and economic calculations. Trade-offs have been made that optimize the total energy system as a whole rather than optimizing just the fuel cell power plant itself.

For electrolyte management an acid replenishment system has been built into the fuel cell stack. This system will also accommodate acid volume changes due to differing operating conditions.

The basic stack components that are used in the on-site system will be used for Westinghouse's electric utility power plant, and like UTC Westinghouse plans to operate the power plant at moderate pressure. The first year's work will center on two areas. The first will be to better define the power plant by developing a conceptual design, including trade-off studies, leading to a preliminary specification and a program requirements document. The other area of work will be to evaluate the on-site fuel cell components, including cooling system, at the higher temperatures and pressures under consideration and to begin any technology development as required.

Engelhard Industries

The unique features of the Engelhard OS/IES effort currently are in the following areas: 1) development of a fuel conditioner that will operate on methanol (methyl fuel); 2) novel bipolar plate approaches; 3) liquid intercell cooling; and 4) matrix and electrolyte transport reservoir technology. In the current two-year contract with DOE(7) the electrocatalysis task is solely funded by Engelhard. Therefore, the details of any unique developments are proprietary.

Fuel Processing

Methanol will be initially used in the Engelhard OS/IES. (The fuel chosen for both the UTC and W/ERC OS/IES programs was natural gas.) Methanol selection was based upon its projected availability from coal in the 1990 time frame. A 5 kW methanol fuel processor has been constructed.

Bipolar Plates

In the stack area, two novel bipolar approaches appear promising. Under subcontract, Pfizer is developing chemically resistant carbon (vitreous carbon and graphite) structures starting with reticulated vitreous carbons or cloths. One of these structures, the so-called B element, is impermeable to gas transport and will serve as the bipolar separator plate connecting two adjacent cells. See Figure 4. (In the UTC ribbed substrate integral cell concept, this is UTC's separator plate.) The other structure, the so-called A element, is porous to permit fuel or oxidizer transport to the electrochemically active electrode areas (which could be on the A elements). Graphite structure using Pfizer's chemical vapor deposition techniques are being utilized to help produce the required properties in both A and B elements. The resulting bipolar plate consists of a B element sandwiched between two A elements. Electrolyte storage can be accommodated in the A element.

In the second approach, thin graphite plates are separated by a gas-impermeable layer of a chemically resistant material (such as graphite) that permits satisfactory electrical and thermal conductivity. Grooves in each plate will permit reactant transport. If the graphite plates are porous and connected suitably to the matrix, they can provide an electrolyte reservoir for matrix replenishment or for overflow volumes resulting from changing conditions (volume tolerance). Several promising material combinations are under test. The Engelhard/Pfizer bipolar plate approach has some aspects in common with the UTC ribbed substrate integral cell approaches previously discussed.

Intercell Cooling

A brief discussion of the liquid intercell cooling approach employing a dielectric fluid, the Engelhard method, was discussed previously in connection with the Westinghouse/ERC cooling approach. The Engelhard design makes use of baffles to provide good heat transfer control yet is designed for ease of fabrication. The protection of the aluminum cooler so it will hold up for the five year stack life goal under the corrosive acid environment of the fuel cell stack is believed to be solved with suitable seals.

Matrix

The matrix effort emphasizes materials capable of operating at temperatures up to 400°F and construction that results in good electric and thermal conductivity, good transport (flow) properties, and satisfactory reactant crossover resistance. A thin SiC-fluorocarbon matrix that incorporates good electrolyte transport is laminated to each electrode.

Electrolyte Management

An acid replenishment system has been built into the stack. Acid volume changes are also handled by this sytem.

Advanced Research and Technology

The current focus is on improving the air electrode (cathode), where most of the fuel cell's inefficiency lies. Improved cathode electrochemical activity would permit either greater electrical efficiency or higher power density at the present operating temperature, or the option of the same efficiency and power density at lower operating temperatures. Lower temperature operation could be desirable in order to lower materials costs and to increase cell life. Another goal is to find a suitable, less expensive relacement for the platinum (Pt) catalyst material.

Specifically, DOE-sponsored research is being pursued in three areas: (1) developing a new non-platinum solid electrocatalyst (redox) material,[8,9] (2) optimizing the electrode manufacturing process through a parametric investigation of electrode component materials and technology, and (3) using the present electrocatalyst (Pt) in ways that are more electrically efficient, stable, and resistant to poisoning.[10] Most of this research is being conducted either by small private companies or at government or national labs. In addition, in the complementary EPRI-sponsored program[11,12] alternate acid electrolytes are under investigation.

Concluding Remarks

As part of the nation's energy program, three major contractor or contractor teams (UTC, Westinghouse/ERC, and Engelhard), active in the terrestrial phosphoric acid fuel cell field, are receiving government support to develop commercial fuel cell power plant systems. Both the UTC and W/ERC are working toward commercializing fuel cell power plants for both electric utility and OS/IES applications. Engelhard is addressing only the OS/IES program.

While similar in many respects, significant technological and system differences exist among the three contractors. These include intercell cooling, bipolar/separator plate, electrolyte management, materials, fuel selection, and system design philosophy. Phosphoric acid fuel cell technology/development efforts for both the electric utility and OS/IES applications are directed toward reducing cost and increasing reliablity. The longstanding barrier to the attainment of these goals, which manifests itself in a number of ways, has been materials.

In addition, for the electric utility application, UTC is pursuing higher temperature and pressure operation (400°F and up to 120 psia). The initial performance gains due to higher temperature and pressure must be balanced against possible shorter life as well as the cost and performance implications upon the balance of the system.

References

1. "Improvement in Fuel Cell Technology Base, Phase II," Final Report to Department of Energy under Contract No. DE-AC-03-79ET11301, April 1977 to March, 1980.

2. "Improvement in Fuel Cell Technology Base, Phase I," United Technologies Corp., South Windsor, CT, FCR-0735. Final Report to Department of Energy under Contract No. EY-76-C-03-1169, March 31, 1977.

3. "40 kW Field Test Power Plant Modification and Development, Phase II," Annual Report to Department of Energy for the Period July 1, 1978 thru June 30, 1979 under Contract No. DE-AC-03-77-FT-11302, June 1, 1978 to September 30, 1980.

4. "Technology Development for Phosphoric Acid Fuel Cell Power Plant, Phase I," Quarterly Reports to NASA under Contract DEN3-67, September, 1979 to November, 1980.

5. "Program to Develop and Test Fuel Cell Driven Total Energy System, Phase I - Cell and Stack Design Alternatives," Final Report to Department of Energy under Contract No. DE-AC03-78ET11300, September, 1978 to October, 1980.

6. "Program to Develop and Test Fuel Cell Driven Total Energy System, Phase II - Cell Modules and Fuel Conditioner Development," Quarterly Reports to NASA under Contract No. DEN3-161, October, 1979 to October, 1980.

7. "Phosphoric Acid Fuel Cell Stack and System Development," Quarterly Reports to Department of Energy under Contract No. DE-AC01-78ET15366, January, 1978 to November, 1980.

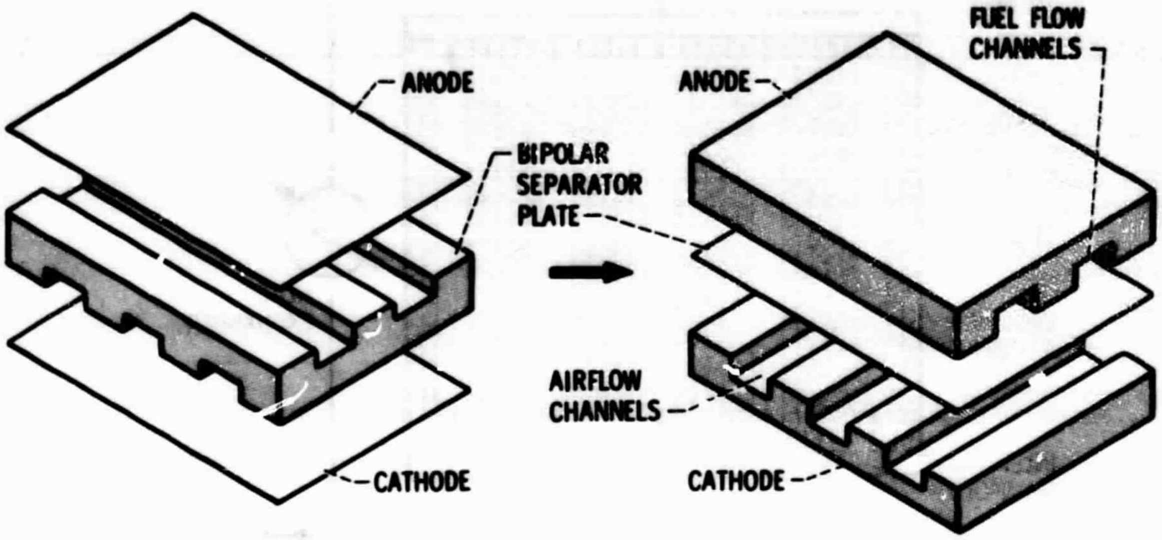
8. "Fabrication and Testing of TAA Bonded Carbon Electrodes," Final Report to the Department of Energy under Contract No. DE-78-C-03-1836, March, 1978 to May, 1979.

9. "Cathode Catalyst for Primary Phosphoric Acid Fuel Cells," 1st Quarterly Report to NASA under Contract No. DEN3-150, July to September, 1979, DOE/NASA/0150-79/1, NASA CR-159719
ibid, 2nd Quarterly Report, October to December, 1979, DOE/NASA/0150-80/2, NASA CR-159815
ibid, 3rd Quarterly Report, January to March, 1980, DOE/NASA/0150-80/3, NASA CR-159876
ibid, 4th Quarterly Report, April to June, 1980, DOE/NASA/0150-80/4, NASA CR-165135.

10. "Preparation and Evaluation of Advanced Electrocatalysts for Phosphoric Acid Fuel Cells," 1st Quarterly Report to NASA under Contract No. DEN3-176, January to March, 1980, DOE/NASA/0176-80/1, NASA CR-159843
ibid, 2nd Quarterly Report, April to June, 1980, DOE/NASA/0176-80/2, NASA CR-165132
ibid, 3rd Quarterly Report, July to September, 1980, DOE/NASA/0176-80/3, NASA CR-165179.

11. "Fuel Cell Catalyst Sintering Studies," Final Report to EPRI on Project 583-1-2, July, 1978.

12. "Improved Cathodes for Phosphoric Acid Fuel Cells," Final Report to EPRI on Project 634-1, June, 1977.



MOLDED CELL (CURRENT TECHNOLOGY)

INTEGRAL RIBBED-SUBSTRATE CELL (NEW TECHNOLOGY)

Figure 1. - Integral ribbed substrate cell characteristics.

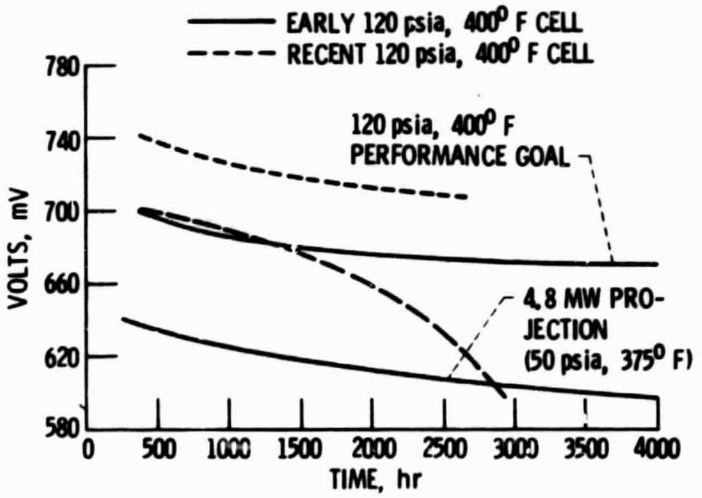


Figure 2. - Improvement in high temperature and pressure cell performance stability.

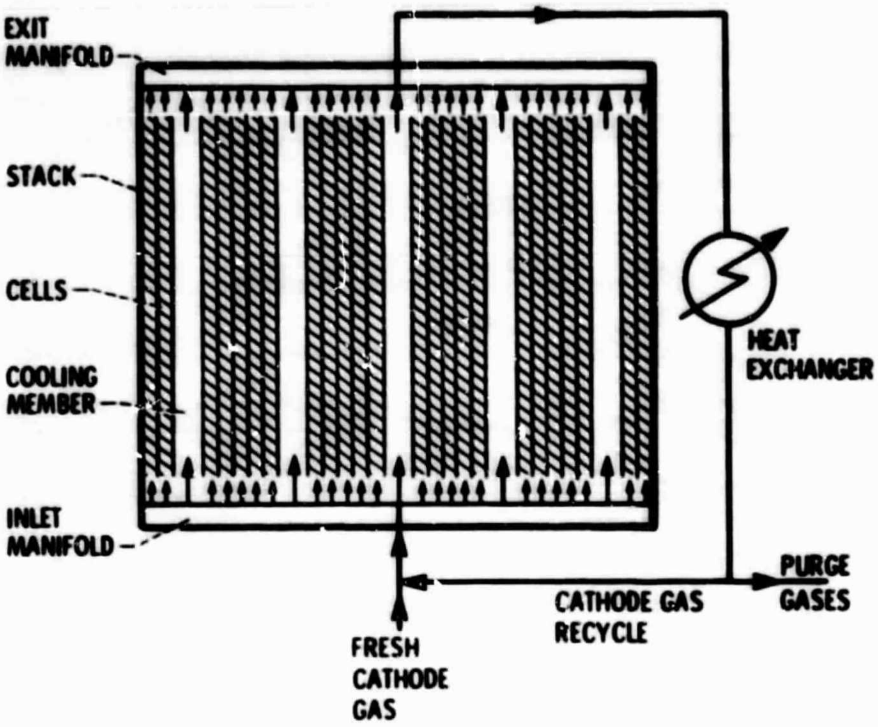


Figure 3. - Distributed-gas (DIGAS) cooling system.

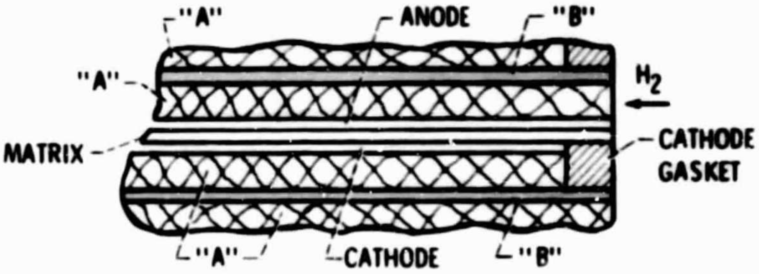


Figure 4. - A-B-A bipolar plate construction.