FUEL CELL EXPERIENCES AND IMPRESSIONS

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In July, 1961, Columbia entered into an agreement with the Pratt and Whitney Aircraft Division of United Aircraft Corporation for the joint development and field testing of a 500 watt prototype hydrox fuel cell powerplant. So promising was this initial venture that a second agreement for the development of a 3.75 KW natural gas-air fuel cell powerplant was negotiated in September, 1963. In February, 1967, a group of 27 natural gas industry companies formed TARGET, "Team to Advance Research for Gas Energy Transformation, Inc.", to sponsor and guide a multi-million dollar research program for the development of a marketable fuel cell powerplant operating on natural gas. Pratt and Whitney Aircraft is prime contractor for the TARGET program with the Institute of Gas Technology as subcontractor.

Columbia has one primary reason for participating in fuel cell R & D programs: to sell more natural gas! We know that a fuel cell consuming methanol, or hydrazine, or hexamethyl chickenfat is basically unsuited for our requirements. Since natural gas, which is predominantly methane with lesser amounts of the heavier paraffin hydrocarbons, is quite unreactive electrochemically, we had followed some devious routes in building prototype demonstration hardware. We are interested in any fuel cell type, acid, alkaline, high temperature, or what-have-you that economically utilizes natural gas to produce electricity.

Economical Energy Transmission

It is the high efficiency with which the chemical energy of a fuel is converted to more valuable electrical energy that attracts our interest. The most modern multi-megawatt central generating stations operate at about 40 percent efficiency. And, transmission of energy as electricity introduces other inefficiency. Line losses represent a significant portion of the power produced as it is wired from the central plant to the ultimate consumer.

Fortunately for the gas industry, it is a simple engineering and economic fact that the electrical industry cannot supply energy units as inexpensively as the gas industry. The electric industry has to convert chemical energy to electrical energy in central power stations and then transport the energy through wires to the point of consumption. The cost of doing this is far greater than the cost of transporting natural gas energy to the consumer. The result is that throughout the United States, regardless of the class of customer, electricity costs 3 - 10 times more than natural gas at the meter for an equivalent amount of energy. Although a utilization efficiency correction factor must be applied to gas costs, it does not significantly affect the basic cost relationship.

Conventional central power stations are very well known contributors to air pollution. A typical coal consuming central station will produce 7.7 pounds of solid exhaust emissions per million Btu. Very substantial quantities of sulfur dioxide are also released to the atmosphere. The natural gas fuel cell produces none of these.

500 Watt Hydrox Powercel

Columbia's first, and the free world's first industrial fuel cell engine, was developed by Pratt and Whitney Aircraft Division of United Aircraft Corporation. This 500 watt, hydrogen-oxygen Bacon-type unit was delivered to us in December, 1962, where it was installed at our Stanton, Kentucky, transmission compressor station--located in the hills of southeastern Kentucky.

The 28 cu. ft. engine package consisted of 17 cells arranged electrically in series, chemically in parallel. Each folded can cell contained four dual-porosity nickel electrodes, each 5 inches in diameter, and fuel and oxidant chambers separated by a space for the 85 percent potassium hydroxide electrolyte. The Powercel PC5A1 operated at 450°F cell-electrolyte temperature and atmospheric pressure. The correct operating temperature and electrolyte water concentration were maintained by circulating an excess quantity of fuel through the cells. This fuel, carrying the heat and water, was pumped out of the cells and circulated through a heat exchanger-condenser system.

Open circuit voltage of the powerplant was 20 VDC corresponding to 1.2 VDC per cell. At full load, the output voltage dropped to 15 VDC of 0.88 VDC per cell. Actual hydrogen consumption rate was 0.056 lb/hr. at maximum power corresponding to an overall fuel to DC buss efficiency of 49 percent. Parasitic power requirement was 60 watts to operate the hydrogen circulating pumps.

Predictably, there were some unique problems associated with startup and operation of the prototype powerplant. One of our first problems was holding a small positive pressure on the cells anytime the unit was hot to prevent flooding. Flooding can occur as a result of loss of reactant pressure within the cells at operating temperature, or inadequate removal of the excess water. Ultimately, these problems were traced to plugging at the hydrogen inlet lines.

The fuel cell was operated at partial load first on P&WA hydrogen containing 8 ppm CO_2 and then on Stanton hydrogen containing 195 ppm CO_2. A water column manometer was connected across the modul hydrogen system. During the test with P&WA hydrogen, no increase in pressure drop was observed during the course of the 12-hour run, but performance gradually decayed. Water content of some cells increased from the normal 15 percent to 27 percent at the conclusion of this test. A subsequent test using the Stanton hydrogen terminated after 30 minutes due to cell plugging.

One cell was split open to recover a plug deposit sample for analysis. The plugs occur at the point of maximum hydrogen velocity where the inlet hydrogen impinges on the coarse por sinter. The analysis by X-ray diffraction indicated potassium carbonate.

Clearances on the hydrogen inlets to the cells can be extremely close. Cell X-ray photos indicate clearance ranging from 0.067 inches maximum to less than 0.020 inches between the hydrogen line in the outer shell and the sinter. Turrets were installed at a lower position on the cells where clearance is greatest. The turrets also serve to lower the inlet hydrogen velocity. Use of the turrets necessitates redesign of the internal module heaters.

In view of the definite existence of carbonate plugs and the apparent relation to fuel carbon dioxide level but the complete absence of potassium hydroxide or carbonate in the circulating control system, visualizing the source of KOH for the plug buildup caused a problem. However, P&WA's physical chemists have experimentally established that at least a monomolecular layer of KOH exists at the coarse pore-fuel interface. The KOH migrates from the electrolyte through the adjacent fine pore and through the coarse pore to the external coarse pore surface which forms one face of the hydrogen inlet chamber. This KOH acts as a natural CO_2 scrubber.

The experience to date is very typical of the difficulties that occur in trying to get an instrument or process from the laboratory into the field. Though there had been many problems found in the shakedown of this system, they have been of a simple and troublesome nature rather than deep-rooted.

3.75 KW Natural Gas-Air Powercel

Our second working prototype powerplant was delivered in July, 1966. This unit was also built by P&WA. It is installed at Columbia's Marble Cliff, Ohio, research laboratories where it provides the power requirements for a simulated homw.

The 43 cu. ft. engine package is a completely self-contained demand-responsive powerplant, providing 3.75 KW at the buss bar. Parasitic power consumption is 300 watts to supply an air pump, a cooling oil pump, water pump and electronic controls. The Powercel generates electricity at a nominal 28 VDC at full load consuming 0.645 SCFM of natural gas for an overall efficiency of 38 percent.

Desulfurized natural gas and demineralized water are fed through a boiler into the reformer. To achieve maximum hydrogen production, the primary reactor product gas stream is cooled somewhat and passed to a secondary carbon monoxide shift reactor. In this process, the carbon monoxide formed during the previous processes reacts chemically with water to form additional hydrogen and carbon dioxide. Hydrogen is removed from the reformate by diffusion through palladium--silver diffusers.

This ultra-pure hydrogen is piped to the cell stacks. Separator waste gases are burned external to the reformer to provide heat for the endothermic gas steam reaction. Excess steam is provided in the reactor to prevent carbon deposition.

The hydrogen generator is designed to operate over a wide range of hydrogen production flows, depending on the fuel cell requirements. A surge tank located downstream of the hydrogen purifier unit supplies hydrogen to the fuel cells on demand and allows the generator to adjust to a new steady state load level.

Process air supply serves the dual purpose of providing oxygen for the fuel cell reaction and removing water produced by the electrochemical reaction. Since this is an alkaline electrolyte system, process air is conditioned to remove carbon dioxide. Electrolyte water concentration is maintained by recycling a portion of the oxygen-depleted moist air.

Two stacks of 36 cells each, arranged electrically in parallel provide the net 3.75 KW output. The compact hydrogen-air fuel cells used in this system have an active area of 7.5 inches by 7.5 inches. Each cell contains two catalyzed porous electrodes separated by an asbestos matrix containing an aqueous solution of potassium hydroxide. The individual cells are separated by metal cooling plates with integral cooling flow passages. The cooling plates also serve as gas distribution housing, current collector, and cell mechanical structure. The entire cell including electrodes, electrolyte, gas housing and cooling plate is about 0.17 inches wide, or a pitch of about six cells per inch.

The PC-10 operates at a gross power density of 150 watt/sq. ft.

Extensive monitoring instrumentation was provided at this Powercel installation so that we could observe fuel cell system performance under conditions of rapidly changing load. The fuel cell would sustain transient overloads of 100 per cent, limited more by protection devices within the unit than by process considerations. However, the solid state static inverter used to convert the 28 VDC fuel cell output to 120 VAC would not sustain an overload, even instantaneously.

Why is this short term overload capability important? In an effort to simulate a normal domestic power requirement, we have loaded the fuel cell with some standard AC home appliances--clothes washer, gas clothes dryer, refrigerator, toaster, electric iron, coffee maker, vacuum sweeper, and some not-so-standard DC appliances--a DC air conditioner. Electric motors characteristically require a tremendous current surge to start: the starting current can be five times the normal run current, but lasts for less than one second. As an example, a popular brand washer comes equipped with a ½ horsepower split-phase motor--this unit draws almost 50 amps to start but runs at 8 amps. For this program, a capacitance start motor was substituted which drew 22 amps to start and 7 amps run current.

The homeowner just doesn't concern himself with these problems because he does not pay a demand charge on his domestic electric bill. And, the electric company is not concerned because the transformer on the pole in the backyard serves eight to ten houses: the odds on two housewives creating a simultaneous surge is small. But, starting surges are important considerations in designing a system to provide all domestic energy requirements.

Reason for Columbia's Interest in Fuel Cells

Columbia is chartered to sell energy--energy in the form of the premium fuel natural gas. We have captured 92 per cent of the residential and commercial heating markets within our operating areas. Direct industrial sales account for about a quarter of Columbia's total annual natural gas sales, which are in excess of a trillion cubic feet--and this market is growing. Columbia is actively seeking new markets.

A vast market potential exists for natural gas in on-site power generation. Columbia already has installations where gas provides all of the energy requirements, including electricity, of industrial plants, shopping centers, high-rise apartments, hospitals, and hotels. These installations use gas engines or gas turbines and loads are above 50 KW. For small commercial establishments, apartments, and homes where the total power requirement is less than 50 KW, gas engines and gas turbines are not economical.

However, the fuel cell does appear economically feasible for these applications. Projections indicate that by the year 1980 nearly 200,000 new homes will be built each year in Columbia's service area. Assuming that only half of these are truly all-gas homes, they would generate approximately $24 million in new gas sales annually.

With the fuel cell, we will introduce an entirely new concept in home comfort conditioning. The homeowner will be able to purchase or lease one package which will heat and air condition the home, clean and humidify the air in the home, cook the food, heat the water, and supply all electricity using one economical dependable source of fuel, natural gas.

Surprisingly little is known about patterns of electrical energy requirements for the American homeowner. The 1965 average residential power consumption was 4,933 KWH according to Electrical World. Now this consumption figure works out to a steady requirement of less than 500 watts over the year, yet the electrical service connected to the home is commonly 100 amperes at 240 VAC with power companies constantly pushing for 200 ampere installations. The mismatch is apparent when one considers that the transformer on the pole in the backyard has 25 KVA capacity and serves 8 to 10 homes. It is apparent that the power company has sized the transformer on the generally valid assumption that all homeowners served will not require maximum demand simultaneously. However, in the single home on-site fuel cell system, no such diversity exists: the system must be capable of handling any power requirement on demand.

Design of the fuel cell system necessitates information on exact power requirements with an accuracy that is not available. To this end, Columbia has instrumented several homes with rapid response wattmeters and fast response recorders to define and document present consumer power consumption patters.

TARGET--Why an Industry-Wide Joint Venture

Fuel cell technology has advanced to the point where an aggressive, greatly expanded program which has as its goal the production and sale of competitive natural gas fuel cell systems is justified. The Institute of Gas Technology has operated high temperature molten carbonate single cells continuously for over a year. Pratt and Whitney has engineered a self-contained demand-responsive prototype natural gas-air fuel cell system. But, technology has reached that stage of sophistication where little more can be accomplished through continued low cost laboratory type experimentation. Through the American Gas Association and industry, the gas industry has put significant funds into fuel cell research at IGT. The transition to high expenditure, semi-manufacturing scale, prototype hardware is the essential next step in the development of natural gas consuming fuel cell power systems.

Appraisal of the state of fuel cell technology indicates that a properly supported and staffed program could force the entry of the fuel cell into the market by 1975. However, our cost studies project a need for $20 million to finance the first three-year phase of the program. For an individual company to undertake a major program of such sweeping significance to an industry would not be practical. So, 27 natural gas utilities have joined in the formation of TARGET, Inc.--Team to Advance Research for Gas Energy Transformation.

The benefits to the gas industry from the development of competitive natural gas fuel cell systems for residential, commercial, and industrial application are threefold. These benefits are that:

1. New loads will be obtained.
2. Base load sendout will be increased.
3. The gas industry will gain a competitive answer to the all-electric concept.

The goal of TARGET is the development of a complete comfort package for homes, apartments, and businesses which will be better than any of the methods presently used for environmental conditioning. This package will provide for complete control of temperature and humidity year-around along with generation of electricity for all needs on-site, using safe, dependable natural gas. Reduction of air pollution is a corollary benefit.

The exact target at which our industry effort is aiming is the development and marketing of fuel cells specifically designed to operate on natural gas and air. Present plans call for development of marketing, economic, and technological information necessary to establish the competitive position and usefulness of fuel cell total energy and environmental conditioning packages of various sizes by Pratt and Whitney Aircraft under the supervision of TARGET.

The first phase of the development program is an extensive market evaluation.