A Means to a Cleaner Environment

ENERGY EFFICIENT PLATINUM-CONTAINING FUEL CELLS TO BE INTRODUCED COMMERCIALLY IN THE EARLY 1990s

The twelfth National Fuel Cell Seminar held in Phoenix, Arizona, U.S.A. from 26th to 28th November 1990, was attended by some 450 delegates from 17 countries, representing both developers and potential users worldwide. "Fuel Cells – An Answer to a Cleaner Environment" was the key theme running throughout the conference. This was strongly linked to the firm belief that fuel cells would make an important contribution to the world's energy needs over the next ten years as economically viable fuel cell power plants become commercialised. The conference heard that platinum containing phosphoric acid fuel cells (PAFC) are soon to be produced on a commercial basis. Both Fuji and Toshiba announced that they had opened PAFC production facilities in Japan during 1990. The key progress regarding development of Proton Exchange Membrane Fuel Cells (PEMFC) was the announcement of a U.S. Government sponsored programme, to be led by General Motors, to produce a PEMFC powered motor vehicle.

The conference reflected the growing extent of the multi-national collaborations that are now underway to develop fuel cell technologies. The Seminar Organising Committee comprised the United States Department of Energy, the Electric Power Research Institute, the Gas Research Institute, the National Aeronautics and Space Administration, and, for the first time, the Commission of the European Communities and the Fuel Cell Development Information Centre, Japan. Over half of the attendees were from Japan or Europe.

An Environmental Overview

The "Keynote Address" was given by J. Lents of South Coast Air Quality Management District (SCAQMD). Focus was directed towards the recently approved new U.S. Clean Air Act which will enforce ever more stringent emissions standards over the next 20 years. In Los Angeles in particular, the regulations will require 40,000 zero emission motor vehicles by 1998, increasing to 200,000 by 2003. This will provide a major incentive for the development of fuel cell powered vehicles. The SCAQMD is working with the U.S. Department of Energy to promote development of a viable fuel cell system. The new standards will also require greater efficiencies from the electricity generation industries. This will present further opportunities for the fuel cell developers.

The growing concern regarding environmental problems had accelerated Japan's fuel cell research and development programme, according to T. Sugimoto from the New Energy Development Organisation (NEDO). Coupled with the increasing pressure to produce more efficient energy generation technology, this has led the Japanese Ministry of International Trade and Industry to expect fuel cell plants to be generating 1.9 million kW of power by the year 2000, and 8.3 million kW by 2010.

It was predicted by K. Joon of the Netherlands Energy Research Foundation that in Europe too, current energy generating technologies would not be able to comply with future emission standards. With the imposition of carbon dioxide constraints, he forecast that fuel cells would achieve 10 per cent penetration of the Dutch combined heat and power (CHP) market by the year 2010. In Europe the PAFC is generally regarded as the market opener for the higher temperature molten carbonate and solid oxide fuel cell systems. K. Seip of the Centre for Industrial Research, Norway, reported on his work using a model to quantify the benefits of fuel cells versus coal- and gas-fired electricity generation plants in terms of their effects on the natural environment, buildings and materials, socio-economic, and health and safety impacts. His model predicted that on health costs alone, it would be cost effective to switch from coal produced to fuel cell produced electricity.

Phosphoric Acid Fuel Cells for Stationary Applications

Evaluation of PAFC demonstrator plants, both in the 50–200 kW CHP and multi-megawatt utility power generation modes, and the progress being made towards commercialisation of the technology, were reviewed by several speakers from Japan, Europe and the U.S.A. In recent years progress has been greatest in Japan.

Activities at Fuji were described by R. Anahara. Following the successful demonstration of a 50 kW on-site cogeneration plant by Tokyo Gas Company, Fuji have now received orders for 31 of these units with options on another 50. Seven sets of 100 kW have also been ordered. Although mostly destined for Japanese gas companies, four of the 50 kW units will be supplied for demonstration programmes in Europe. Based on the experience gained of a 1 MW power plant during the Moonlight Project, Fuji is now planning to construct 5 MW plants suitable for electric utilities, in association with Kansai Electric Power Company. Compactness is seen as a key design feature that will be a requirement for urban installation. Fuji opened a semi mass production facility in November 1990 to meet the early demand for 50 kW and 5 MW power plants. The current production capacity is 15 MW per year. Improved cell performance, principally through improved catalysis by the platinum based electrocatalysts, was seen by Fuji as critical to the reduction of both the cost and the size of the entire plant. Current power densities had improved to 160 mW/cm^2, from 80 mW/cm^2 in 1986. The target performance was cited as 230 mW/cm^2 by 1992. Fuji were confident that these targets would be met.

Progress by Toshiba in commercialising the PAFC for both electric utility and on-site use, was discussed by T. Matsushita. Toshiba intend to commence production of the 11 MW units during 1995–96. Plant size would be about one third of the current size of the prototype nearing completion at Tokyo Electric Power's Goi Thermal Power Station. Plant costs of \$2000/kW were said to be competitive in Japan, although the fully commercialised target cost would be \$1000/kW. For on-site systems Toshiba have supported the formation of a subsidiary company to International Fuel Cells (IFC), known as ONSI. Fifty-three 200 kW units have been ordered for U.S., Japannese and European customers. Toshiba also has its own programme for cogenerators in the 50–200 kW size range. They anticipate entering commercial production of these units in 1993. Matsushita reported that Toshiba had also opened a PAFC production plant during 1990, with current capacity of 10 MW/year. Although Toshiba are also working on molten carbonate electrolyte fuel cells (MCFC), they believe that it would be sometime into the 21st century before this technology could be commercialised. They saw the PAFC and MCFC playing a role alongside each other, rather than competing, from about the year 2010 onwards.

Progress on the 11 MW PAFC plant at Goi was outlined in more detail by N. Kato of Toshiba. The bulk of the plant has been installed, and process and control tests are currently ahead of schedule. The final fuel cell stack assemblies, being manufactured by IFC, are due to be installed early in 1991 with the plant becoming operational by the spring of the same year. Demonstration objectives will be to run for over 10,000 hours, with 3000 hours of uninterrupted operation, with electrical and heat efficiencies of 41.1 and 31.6 per cent, respectively. Several poster presentations described the operation of IFC's pre-production 200 kW cogeneration plants in office and hotel situations. Several thousand hours of operational experience has now been gained by both the gas and electricity power companies in Japan.

In the United States, the major customer for the ONSI 200 kW units is Southern California Gas Company who will start taking delivery of the first of their ten units in 1992. David Moard reported that customer interest had been very high; he commented that through the provision of Partial Energy Service (PES), fuel cells would be a profitable business for Southern California Gas. In this scenario the gas company purchases the fuel cell, and installs and maintains the unit on the customer's property while the producer is responsible for performance guarantees, provision of spare parts, etc. The customer has no primary responsibility for the fuel cell or its operation, nor direct investment in the capital equipment.

Westinghouse Electric Corporation are proceeding with the development of their air cooled PAFC system. With improved cell and stack technology they have now achieved cell performance of 702 mV, with a decay of only 6mV per 1000 hours. The 2.5 kW demonstration stack has so far achieved 5300 hours of operation. The ultimate Westinghouse product will be a 400 kW module, and the first demonstration will be at Norsk Hydro in Norway. This plant will be fuelled with by-product hydrogen from the chloralkali process. The demonstration, currently at the design stage, is intended for start-up in mid 1992. Westinghouse see a niche market for the PAFC in industrial applications.

In Europe the major PAFC demonstration is currently the 1 MW plant being built into a new civic centre development in Milan. The plant is being installed by Ansaldo using fuel cell stacks supplied by IFC. Site work is nearly finished with installation of the fuel cell system due for completion in September 1991. It is intended to commence power generation by mid 1992. The plant is rated at 1150 kW with an output voltage of 23 kV/50 Hz. The power will be supplied to the Milan electricity distribution grid.

Platinum Catalysts for Phosphoric Acid Fuel Cells

A paper on high stability platinum alloy electrocatalysts was presented by K. Tsurumi of Tanaka Kikinzoku Kogyo. He reported cell performances of 780 mV with the latest alloy material, compared to 680 mV with pure platinum systems. Using base metal dissolution as a guide to long term stability, this alloy showed very little decay in comparison to prior art alloys of platinum-vanadium, platinum-chromium, platinum-cobalt-chromium and platinum-nickel-cobalt. Platinum alloy electrocatalysts were also shown to have high activity for hydrogen oxidation in the presence of trace levels of carbon monoxide. At platinum loadings of 0.1 mg/cm^2 and with 2 per cent carbon monoxide in hydrogen, an alloy catalyst exhibited minimal over-potential at 200°C, although this performance declined as the temperature was reduced to 160°C.

A poster presentation by T. Ito of NE Chemcat Corporation, Japan described the production of a higher power density fuel cell system with improved cost performance by the use of platinum alloy catalysts with higher loadings of platinum than the conventional 10 per cent platinum supported on carbon. Platinum-iron-cobalt catalysts at 10, 20, 30 and 35 weight per cent platinum loadings gave performances of 734, 752, 765 and 769 mV, respectively, at 200 mA/cm^2. At 700 mV, this translated into 21, 36 and 39 per cent more power output with the higher loading materials compared to the conventional 10 per cent alloy catalyst. It was calculated that these increased power densities can lead to benefits which outweigh the extra cost of the catalyst.

Work at the Institute CNR-TAE in Italy on the influence of particle size of platinum catalysts in PAFCs was presented by N. Giordano. Catalysts with particle sizes ranging from 15–125 Å exhibited a particle size effect, as previously demonstrated by other groups, in which the smaller particles possessed intrinsically lower activity. Giordano believed that this was related more to a change in the proportion of specific crystal faces at the surface as the particle size changed, rather than to the influence of inter-crystallite separation as proposed by other workers.

Fuel Cells for Transportation Applications

Over the past two years there has been increased interest in the potential application of fuel cells to vehicular transportation. This has arisen due both to increased concern about, and regulation of, vehicle emissions in the United

States, and the recent technical advances in the performance of Proton Exchange Membrane Fuel Cells. For the first time, this year's seminar attached major importance to transportation applications.

Details of a major new programme, sponsored by the U.S. Department of Energy, to build an advanced reformate/air PEMFC power plant were revealed at the conference. The project will be led by the Allison Gas Turbine Division of General Motors, which will co-ordinate the effort between General Motors, Los Alamos National Laboratory, Ballard Power Systems, Dow Chemical Company and the South Coast Air Quality Management District. The overall aim of the six and a half year programme is an actual fuel cell/battery hybrid vehicle demonstration. Although it is intended that the fuel cell will take as much of the load as possible, batteries are included in the system to cope with part of the power surge demands. Target performances of the demonstration vehicle include fuel economy improvements of 60 per cent over conventional engines, a 40 per cent reduction in carbon dioxide emission, and a 90 per cent reduction of the emissions currently regulated in the U.S.A. A contract has been awarded for the first phase of the programme, which has the objective of producing a 10 kW power source system evaluator over a 24 month period. Component research and development will be carried out in this initial phase and will include studies to improve the efficiency of the platinum based electrocatalyst.

One of the greatest challenges in this programme will be the development of suitable methanol reformer technology. Several papers addressed reformer concepts. N. E. Vanderborgh of Los Alamos outlined the components of a reformer operating via the steam reforming route. For use with a PEMFC it is necessary to have three reactors in the fuel processing stage. After the initial fuel converter and shift reactors the hydrogen stream still contains 1 per cent carbon monoxide. To avoid severe poisoning of the platinum catalyst the reformate is passed through a preferential oxidation reactor, into which small quantities of oxygen are injected to selectively oxidise the carbon monoxide (in the presence of hydrogen) to the required levels of less than 10 ppm.

The benefits of a partial oxidation of methanol reforming process were outlined by R. Kumar of Argonne National Laboratory. Although less efficient than steam reforming, the direct heat transfer characteristics of this type of reformer facilitates good transient response to fluctuating load demands. This property is seen to be very important for a fuel cell automotive power system.

Ballard Power Systems of Canada will be producing the fuel cell stacks for the vehicle programme sponsored by the U.S. Department of Energy. In addition, D. Watkins reported that further applications for their PEMFC stacks include a 100 kW unit for a British Columbia bus programme, with an on-the-road demonstration by the end of 1992. Military and utility applications of the PEMFCs are also being considered. Demonstrations in small two-man submersibles and at the Dow chloralkali plant in Sarnia, Canada, are currently underway.

Other fuel cell types being evaluated for transportation applications were also reported at the seminar. In particular, PAFCs have an application in the 50–120 kW range for buses, trucks and heavy duty vehicles. R. Kevala of Booz, Allen and Hamilton, and K. Okano of Fuji presented updates on the Department of Energy funded PAFC/battery hybrid bus project. A 25 kW brassboard design has been successfully evaluated against typical bus driving cycles. The next phase of the project will address the design of the test buses incorporating both a 50 kW fuel cell and a 132 amp-hour lead acid battery.

Submarine and Space Applications

Fuel cells continue to be developed for the more specialised space power requirements, and certain marine applications. In particular there were several presentations on the use of PEMFCs as air-independent submarine propulsion systems. W. Bette reported that Siemens are currently developing a 34 kW laboratory module for this application. Performance targets are 540 mA/cm^2 and 684 mV per cell, with a cell active area of 1180 cm^2. Small single cells operating under 2 bar pressure of hydrogen and oxygen have exceeded this target and shown excellent stability up to 18,000 hours, with only 2 μV per hour decay. The cells comprised DuPont Nafion membranes and 4 mg of platinum/cm^2 electrode loading. Recent improvements in cell construction and water management have increased the current density to 700 mA/cm^2 at the rated cell voltage.

Emphasis on fuel cells for manned space missions is presently focused on the development of regenerative fuel cell systems, as evidenced by presentations from NASA, Los Alamos and the Hamilton Standard Division of United Technologies Corporation. The use of electrolysers powered from solar arrays in conjunction with either alkaline or PEM fuel cells, to provide power during dark orbiting periods, offers the best opportunity as energy storage systems for the long duration space missions being planned for Mars and beyond. PEMFCs appear to be attracting favour due to their potential for longer term catalyst stability compared to the alkaline systems.

Conclusions

"Fuel cells are five years from commercialisation" has been a frequently used phrase for many years! We now, however, appear to have reached the time when this phrase can be stated more in truth than in false hope. Led by the Japanese companies, Fuji and Toshiba, the phosphoric acid fuel cell will soon become a practical reality for 50–200 kW combined heat and power applications. Worldwide concerns about pollution and global warming continue to increase, and in the coming years this will serve to broaden further the scope for commercialisation of these fuel cells. Similarly, a major new opportunity for the Proton Exchange Membrane Fuel Cell has opened up, with the start of programmes to build fuel cell/battery hybrid power systems for transportation, which could lead to the development of pollution free motor vehicles. As noted by several speakers, "the future for fuel cells is brighter now than ever before."

G.A.H.

Quasicrystals in Rapidly Solidified Alloys

Five-fold electron diffraction patterns were found in a rapidly solidified aluminium-palladium alloy in 1978. Although a number of quasicrystals have since been identified in particular alloys of aluminium with a platinum metal, no systematic study has been made.

Now a series of papers on the topic, reporting work carried out in the P. R. China, has been published in the *J. Less-Common Met.*, 1990, **163**, (1). An overview of quasicrystals in aluminium-transition metal alloys in general, and aluminium-platinum group metals in particular, is presented by K. H. Kuo (Pages 9–17). Aluminium-ruthenium and aluminium-osmium alloys have been studied by Zhong-Min Wang, Yi-Qun Gao and K. H. Kuo, mainly by transmission electron microscopy. They observed icosahedral quasicrystals in melt-spun ribbons of Al_5Ru, but not in Al_5Os. Decagonal quasicrystals form readily in the latter, but only rarely in the former (Pages 19–26).

Rong Wang, Lina Ma and K. H. Kuo have discovered decagonal quasicrystals in both rapidly solidified Al_5Rh and Al_5Ir, and in addition have found two new hexagonal aluminium-iridium phases (Pages 27–35). L. Ma, R. Wang and K. H. Kuo confirm the presence of decagonal quasicrystals in rapidly solidified Al_5Pd, but not in Al_5Pt (Pages 37–49).

Grove Fuel Cell Symposium

The successful First Grove Cell Symposium, held in London, England during September, 1989, was reviewed here immediately after the conference (D. G. Lovering, *Platinum Metals Rev.*, 1989, **33**, (4), 169–177). A second meeting is now planned, and this will again be held at the Royal Institution, London, from 24th to 27th September, 1991.

In addition to those already engaged in fuel cell technology, the Symposium is expected to be of particular importance to people involved with advanced energy systems, and those responsible for energy and environmental policy making.

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