The Sixth Grove Fuel Cell Symposium

FUEL CELL DEVELOPMENT FOR EVERY POWER SUPPLY NEED

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Fuel cells represent the largest single potential market for platinum group metals in the next century if, as appears increasingly likely, they are successfully developed for road vehicles and stationary power generators. The technology has made considerable progress in the ten years since the first Grove Symposium was held and is rapidly gathering momentum, aided by financial and technical support from many leading companies in the transport and power supply industries.

The Sixth Grove Fuel Cell Symposium was held in London from the 13th to 16th of September 1999. The Grove Symposium is well established as one of the principal world gatherings for the fuel cell community, and attracted nearly 400 delegates from 33 countries, almost half from outside Europe, to hear invited papers from representatives of industry and universities on all aspects of fuel cell developments and utilisation. In addition to the developers and researchers, notable at this Symposium were the number of representatives from major oil companies, motor manufacturers, and gas and electricity suppliers, many of whom are participating in ventures to develop commercial products.

The theme of this Symposium, "Fuel Cells – The Competitive Option for Sustainable Energy Supply" was chosen to examine the progress made in developing these highly efficient power generators. It was also aimed at identifying some of the potential markets and opportunities, and at highlighting new developments and demonstration programmes.

Energy Conservation

The Symposium was preceded by a Workshop entitled "Fuel Cells – the New Dimension in Energy Conversion?" Three invited speakers from outside the fuel cell community provided their own perspectives of the background in which fuel cells are being developed.

The views of the United States Government were outlined by B. McNutt of the Department of Energy, those of a gas supply utility by M. Tallantyre of BG Technology, and J. Gummer MP spoke from a political standpoint. The debate was then thrown open to questions and comments from the audience. It was generally agreed that while improved energy efficiency and pollution characteristics are highly desirable, any successful device will need to demonstrate positive benefits to the consumer. Since the Kyoto Global Climate Conference of December 1997, there has been a commitment to reduce greenhouse gas emissions as well as other pollutants. This can only be met by fundamental changes in lifestyle by the developed nations or by the introduction of new technology.

The keynote lecture was given by H. Jørgen Koch, of the International Energy Agency, who posed some of the challenges facing mankind. Firstly, crude oil supplies are expected to peak within the next forty to fifty years. In order to meet a forecast growth rate of 2 per cent per annum in fuel consumption, it will be necessary to produce an increasing proportion of energy from sustainable sources. Moreover, in order to make a substantial impact on greenhouse gas emissions, existing energy supplies will have to be consumed more efficiently. To achieve this, it will be necessary to take immediate and sustained action to implement new technology.

Grove Medal

The fifth platinum Grove Medal was presented to Bernard S. Baker, who has devoted his entire professional career to developing and promoting fuel cells. As President of Fuel Cell Energy (until earlier this year called Energy Research Corporation) from 1970 to 1997, Bernie Baker directed research and development on a variety of fuel cells, batteries and hybrid systems. Many of the concepts pioneered by Energy Research Corporation, including molten carbonate fuel cells incorporating internal reforming, are still actively being developed.

The first day of the Symposium saw BG plc and Alstom announce an agreement to work together to exploit natural gas fuelled proton exchange membrane (PEM) stationary power generation systems internationally. The two companies will also co-operate to develop a natural gas processing system. In December 1997 Alstom reached an agreement with Ballard Generation Systems of Canada, which provided the basis for these two companies to introduce stationary PEM fuel cell systems into the evolving world energy business.

Fuel Supplies and Processing

The operation, performance and durability of several types of fuel cells have been extensively demonstrated, and emphasis has now moved to detailed improvement and cost reduction of stack components. Other work is being concentrated on the "balance of plant" which constitutes the remainder of the system, and is a high proportion of the total cost. The ability to convert (or reform) other fuels into hydrogen, which is consumed by the fuel cell stack, is critical to their success.

Most reformers and their associated gas treatment systems utilise supported platinum group metal catalysts. In the case of existing gasoline and diesel reformers, the pre-treatment and post-treatment plant is often considerably bulkier than the reformer itself, a problem which is currently being addressed.

W. Heuer of DaimlerChrysler A.G. described efforts by a consortium of car, truck and energy producers, in collaboration with the German Government, to identify renewable energy sources for the next century. From an initial list, five potential fuels were selected, and their production steps subjected to close examination. Two fuels: compressed hydrogen and methanol have been chosen and, fortunately, both are prime candidates for use in fuel cell systems. The selected method of hydrogen generation is by the electrolysis of water using wind, wave or hydroelectric power. There is well established technology to improve the efficiency of the electrolysis process by catalysing the electrodes with small amounts of platinum, and this represents another large potential market for this metal.

Compact reformer technology is critical to building fuel cell power plants for cars. S. G. Chalk of the U.S. Department of Energy described their collaboration with the American motor industry in the Partnership for a New Generation of Vehicles (PNGV), to develop vehicles capable of carrying 6 passengers at 80 miles per gallon. Effort is currently centred on designing micro-channel steam reformers, which it is hoped, will enable the use of gasoline as a fuel for hydrogen generation. In parallel, the PEM stacks which are being used have been made more tolerant to carbon monoxide in their feed gas, and costs are being reduced by switching to moulded graphite separator plates in the stack construction.

As a prelude to his talk "Fuel Reforming with Shell's Catalytic Partial Oxidation (CPO) Technology", H. P. C. E. Kuipers of Shell Global Technology described the reasons why Shell is participating in programmes to develop fuel cells. He emphasised that although crude oil supplies are expected to last for a considerable time, they will become progressively more difficult to extract, and by 2050 roughly half of all energy consumed will need to be from renewable sources. Shell is collaborating with Daimler Benz Ballard (dbb) to develop a partial oxidation system which will enable a range of fuels including gasoline to be reformed into a hydrogen-rich gas which can be used to supply PEM fuel cells. The operating characteristics of this platinum-catalysed system are such that a reactor with a catalyst volume of only 100 millilitres could supply the requirements of an automobile-scale fuel cell.

In his talk entitled "The CAPRI Project – Advances in Methanol Reforming for Transport

Applications", A. Konig of Volkswagen A.G. described how a consortium consisting of Volkswagen, Volvo, Johnson Matthey and ECN, are collaborating to build methanol-fuelled reformers with outputs of hydrogen capable of operating 15 kW PEM fuel cells for vehicle traction applications. The technology is based on the Johnson Matthey "HotSpot™" reformer and gas clean-up systems.

For military applications, it has become apparent that it will be essential to develop systems which will operate on diesel or jet propulsion fuels since these are the only supplies in the logistics network. Several speakers emphasised the fact that for every tonne of fuel consumed on the battlefield, some 5 or 6 tonnes are used to transport it there, and any savings are therefore multiplied in proportion.

Fuel Cell Technology

Proton Exchange Membrane Fuel Cells

The feasibility and durability of platinum-catalysed PEM fuel cells has been amply proven, and many of the projects described at the Grove Symposium are aimed at improvements in systems design, and also demonstration trials. Several presenters described installations of PEM fuel cells in domestic and small industrial applications, while others are carrying out car or bus scale vehicle trials. All low-temperature fuel cells are dependent on platinum for efficient operation, and in the past few years enormous progress has been made in reducing the platinum group metal content and in increasing the power density from the electrodes to make them economically viable for mass production.

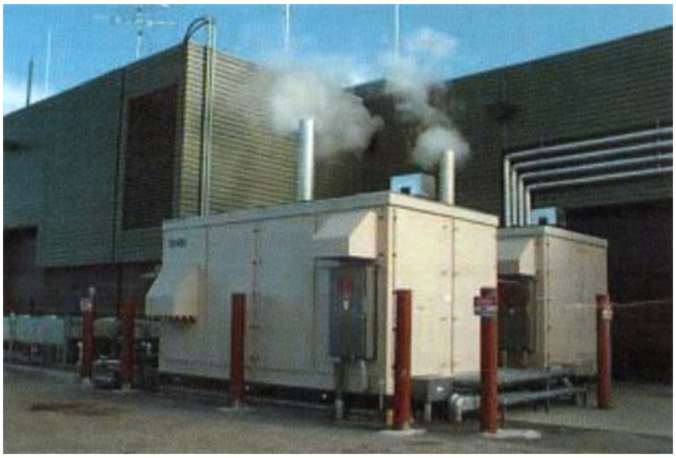
Guido Gummert of Hamburg Gas Consult described how their consortium has installed fuel cells for residential power generation with heat recovery systems. In collaboration with American Power Corporation, they have developed small individual power plants based on PEM fuel cells and are now engaged in on-site trials. The generators are capable of providing 3.5 kW of electrical power and up to 8 kW of heat, depending on seasonal requirements.

Bewag Aktiengesellschaft, in collaboration with Electricité de France, Hamburgische Electricitätswerke, PreussenElecktra and VEAG is carrying out the first demonstration of a 250 kW PEM fuel cell in the Treptow region of Berlin. M Pokojski of Bewag explained that the system works on reformed natural gas at 4 bar, using a turbo-compressor to minimise parasitic power requirements. The system is being supplied by Alstom in collaboration with Ballard. Installation and commissioning is planned for late 1999, with the intention of using waste heat for general domestic heating.

R. J. Nowack of the United States Defense Advanced Research Projects Agency (DARPA), spoke of the need for portable power systems for military and civilian applications. Apart from larger generators for military bases, modern fighting soldiers have a wide range of equipment which needs electrical power, preferably with low heat and sound emissions to minimise detection. DARPA is supporting development of a number of fuel cell systems including small PEM cells with reformers. As an alternative to batteries, PEM fuel cells in combination with hydrogen stores based on lithium aluminium hydride give an astounding 400 watt hours per kilogram of power. DARPA is also supporting research on direct methanol fuel cells; this was described later by S. Gottesfeld of Los Alamos National Laboratories.

In his talk entitled "Fuel Cells – Going On-Board" G. Sattler of Ingenieurkontor Lübeck (IKL), explained that IKL have studied options for using fuel cells on merchant and naval surface ships in a range of applications, but most of these are not likely to be fulfilled in the foreseeable future. However, trials of fuel cell power plants are being carried out in surface ships in Germany, Italy, the U.S.A. and the United Kingdom.

Air-independent propulsion (AIP) systems developed by IKL are now being installed in submarines. PEM fuel cells are used in conjunction with liquid oxygen tanks and hydrogen stored in the form of metal hydrides. Started in 1998, six class 212 vessels have been under construction at Howaldtswerke-Deutsche Werft A.G. (HDW) for the German Navy, and another



An ONSI PC25C fuel cell installed by the DoD at Fort Richardson in Ancorage, Alaska. Many similar fuel cells are being operated in different climates worldwide, so that their range of performances under various conditions can be assessed

By courtesy of the U.S. Army Corps of Engineers

two are being built for the Italian Navy at La Spezia. The complete system fits into an additional section of hull, which can also be installed in existing submarines to improve their underwater capabilities. The metal hydride/liquid oxygen system is acknowledged to have limitations in energy storage capability, and work is in progress to develop a hydrogen supply based on reformed methanol.

Phosphoric Acid Fuel Cells

Phosphoric acid fuel cells are one of the few systems which are commercially available for trials, and some of these demonstrations have been described in previous issues of *Platinum Metal Review* (1). Considerable numbers of phosphoric acid fuel cells are being evaluated worldwide, particularly in America, Japan and Europe, mainly using the PC25 type 200 kW generators made by ONSI Corporation. These platinum-catalysed fuel cells operate on reformed natural gas, and are suited to combined heat and power applications.

Since 1993, the United States Department of Defense has been carrying out trials of PC25 power plants as possible replacements for outdated equipment at military facilities. M. J. Binder of the U.S. Army Construction Engineering Research Laboratory (USACERL) described how a total of thirty of these units have been installed on army, air force and naval bases in climates ranging from desert to arctic. The sites have been selected to expose the power plants to some of the most challenging operating conditions which a military generator might encounter in service. Applications include combined heat and power, with central heating at eleven sites, seven hospitals, and three swimming pools and gymnasia. USACERL has monitored performance and failure modes, and a modification programme has been implemented by ONSI to correct deficiencies which have been revealed. Monitoring of the pollution characteristics of the fuel cells at several sites indicates that in nearly all cases, emissions are considerably lower than the maximum quoted limits. The trial is proceeding, and despite the rugged conditions the fuel cell generators continue to perform with improved reliability following the various modifications.

Solid Oxide Fuel Cells

Solid oxide fuel cells operate at temperatures around 1000°C, which means that they are capable of reforming hydrocarbon fuels into hydrogen-rich gas streams, without an external reformer. Many of the catalysts used for these internal reforming reactions incorporate ceramic supported platinum group metals.

R. A. George of Siemens Westinghouse Power Corporation described their trials of a 100 kW field test unit in the Netherlands which incorporates internal reforming of natural gas. The fuel cell stack is built up from a total of 1152 tubular-shaped single cells arranged in bundles. It is currently operating at 127 kW direct current electrical output representing 53 per cent efficiency, and is providing hot water for district heating. The trial will continue to obtain the maximum of data.

The performance of solid oxide fuel cells is improved by operating at elevated pressures. Solid oxide fuel cells are being considered for use in combination with gas turbine generators, with the fuel cell replacing the combustion section of the turbine. Compressed air is fed to the fuel cell, where it is heated and returned to the turbine expansion section. By this means, power is obtainable both from the turbine and the fuel cell. Siemens Westinghouse are building a 220 kW unit, with a 170 kW fuel cell in combination with a 50 kW gas turbine. Operating on natural gas, the fuel to electricity efficiency is forecast to be 60 per cent, with the fuel cell running at 3 bar pressure. Modelling studies have indicated that pressure transients will need to be carefully controlled for the successful operation of the system.

Theoretical studies have shown that the high temperature of solid oxide fuel cells should make them capable of reforming an excess of natural gas into a hydrogen-rich stream which can be utilised in a PEM fuel cell or as a chemical plant feed gas. H.-E. Vollmar of Siemens A.G. described how this concept is being explored experimentally, with solid oxide fuel cells showing no signs of deterioration even at cell voltages as low as 0.5 volts, when more hydrogen than power is generated. A similar combination of solid oxide and PEM cells has been modelled by BG Technology and Intensys Ltd., as poster prize winner, A. Dicks, explained. The system offers considerable flexibility in terms of which type of fuel cell produces most power, and offers overall efficiencies in excess of 60 per cent.

Molten Carbonate Fuel Cells

J. P. P. Huijsmans, of ECN presented an analysis of the endurance issues facing molten carbonate fuel cells (MCFC). These mainly arise from the corrosive nature and volatility of the electrolyte, combined with other materials problems encountered at the operating temperature of around 650°C. Possible means to overcome these have been devised, but have yet to be demonstrated in long term trials, bearing in mind that a minimum stack life of 40,000 hours is needed. T. Ishikawa of the MCFC Research Association of Japan described the construction of a 1 MW power plant in Japan. Construction started in 1995, and trials with the complete system including four 250 kW MCFC stack modules have now begun. To date, power output has been progressively increased to 900 kW. The trials are due to last for 5000 hours, and the plant is expected to operate at 45 per cent overall efficiency on liquefied natural gas using an external reformer system.

Posters

The Symposium attracted a record number of poster presentations, several of the systems described by the six poster winners use platinum group metals either in the fuel processing section or the fuel cell itself. The majority of the posters, together with the invited papers will be published in a special edition of the *Journal of Power Sources.*

The Future for Fuel Cells

The current status of fuel cell development was summarised by Gary Acres, Chairman of the Symposium in his concluding remarks. Recent emphasis on reformers and overall systems has led to considerable advances in the technology. The industry has overcome the myth that the supply of platinum might not be sufficient to meet demand should fuel cells become widely used. This has been helped in the case of the PEM fuel cell by drastically reducing the platinum loading on the electrodes and, at the same time, by increasing power densities, making them economically more viable.

The huge investments being made by the automotive and oil industries to mass produce fuel cell powered vehicles are likely to reduce capital costs, particularly of PEM fuel cells which are preferred for mobile applications. This will in turn will favour their implementation in stationary power applications.

Several factors, including the gradual phasing out of giant central power stations, combined with increased use of natural gas for power generation, and liberalisation of the power market all favour fuel cells. With many nuclear power stations reaching the end of their lives, there is a need to replace them with power generation systems which do not create large amounts of greenhouse gases.

Overview

In overview, it is now clear that all the key players involved in the fuel cell industry are now assembled. There are many reasons why this technology is being so actively researched, promoted and is becoming successful. The use of fuel cells for all aspects of power supply is gradually occurring and the next few years will reveal whether their long awaited promise will be fulfilled.

It is anticipated that the Seventh Grove Fuel Cell Symposium will take place in London in September 2001.

Reference

1 D. S. Cameron, *Platinum Metals Rev.*, 1997, **41**, (4), 171; G. A. Hards, *Platinum Metals Rev.*, 1995, **39**, (4), 160; D. J. Lovering, *Platinum Metals Rev.*, 1991, **35**, (4), 209

Carbonylation Reactions Using Platinum Metals Catalysts

Journal of Molecular Catalysis A: Chemical: Recent Achievements in Carbonylation Reactions

GUEST EDITOR: PHILIPPE KALCK, 1999, Special Issue, Volume 143, Numbers 1–3

This special edition of the *Journal of Molecular Catalysis A: Chemical* is devoted to carbonylation and covers recent significant contributions to the field in several important research areas: (i) water soluble catalysis; (ii) reaction mechanism and rational design of ligands; (iii) exploration of new catalytic systems and; (iv) synthesis of fine chemicals. Approximately 85 per cent of the 32 articles deal with carbonylation reactions using platinum group metals as catalysts.

In the area of biphasic catalysis, Boy Cornils reviews the field with special emphasis on processes involving carbonylation, such as the manufacture of *n*-butyraldehyde from propylene via hydroformylation and the synthesis of phenylacetic acid using benzyl chloride as the starting material via hydrocarboxylation. F. Bertoux and co-workers emphasise the industrial and academic importance of biphasic hydrocarbonylation of organic halides, alcohols and olefins, and in a second contribution describe findings that the addition of polyvinyl alcohol and salts improves the thermal stability of water soluble catalysts in hydrocarbonylation.

The investigation of homogeneous catalyst structure and mechanism remains an active area of interest. A molecular modelling study by R. Paciello and co-workers reports on the relationship between ligand structure and catalyst activity for the rhodium catalysed hydroformylation of alkenes. M. Diéguez and colleagues also investigate hydroformylation and the influence of pressure, temperature and chelating ring size for structurally related bisphosphines.

An important area covered by this journal is that of new catalytic systems and reactions. An interesting paper by M. C. Bonnet and colleagues reports on the palladium catalysed chlorocarbonylation of olefins using carbon monoxide and hydrogen chloride to yield acyl halides. J. S. Kim and co-workers report the first example of the catalytic formation of polyamides, a high strength polymeric material, from aryl chlorides, diamines and carbon monoxide. The reaction is catalysed by palladium.

The final topic area to be covered is fine chemical synthesis. E. M. Campi and co-workers describe the synthesis of fused 6,7 oxygen heterocyclic compounds via hydroformylation. These compounds could be used in the synthesis of cyclic polyether natural products.

M. Sperrle and colleagues used cationic palladium complexes containing chiral ligands to catalyse the enantioselective bis-alkoxycarbonylation of 1-olefins to substituted succinates; these compounds have application as intermediates to pharmaceuticals. E.-I. Negishi and co-workers report a study that details the scope of the synthetically useful intramolecular trapping of acylpalladium compounds with *O*-enolates.

Overall, this issue covers recent developments in the area of carbonylation well, with relevant, up-to-date articles from a good cross-section of contributors and research topics. Practitioners in the field will find the sections on new reactions and applications in synthesis of particular interest.

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