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ScienceDirect

Journal of Power Sources 160 (2006) 842–845

JOURNAL OF POWER SOURCES

www.elsevier.com/locate/jpowsour

Short communication

Molten carbonate fuel cells: A high temperature fuel cell on the edge to commercialization

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Abstract

The Molten Carbonate Fuel Cell (MCFC) technology has been developed in USA, Japan, Korea and Europe for many years. What has started about 30 years ago as an interesting laboratory object has now matured to a potential alternative to conventional power generation systems. Especially the combined heat and power (CHP) generation is an area, where MCFC power plants can be applied with great advantage, due to the high efficiencies which can be achieved. It was demonstrated by several manufacturers that in the sub-MW region MCFC power plants can reach electrical efficiencies of 47%. By making use of the heat generated by the system, total efficiencies of more than 80% can be achieved.

The present paper will discuss some aspects of the development work going on with a focus on the role of the molten carbonate contained in the cells. An outlook will be given for the future prospects of this young technology in a changing energy market.

Keywords: Molten carbonate fuel cell; System demonstrations; Commercialization

1. Introduction

Fuel cell technology is rapidly advancing with substantial investments of private sector and public sector financial and intellectual capital. Fuel cells have proven themselves capable of providing superior energy efficiency and environmental performance, and yet, their adoption for widespread use is still uncertain due to high initial capital cost.

Presently manufacturers of MCFC stacks and systems run demonstration projects and field tests from 30 kW up to about 2000 kW all over the world [1]. Main locations for the tests are hospitals, hotels, office buildings and industrial applications. Nevertheless, there is still working going on in the laboratories to further improve the technology. The work is focused on three main targets:

- improvement of the component durability to achieve longer operating times for the stacks, 40,000 h are the goal;
- increase of the cell performance;
- cost reduction to make the systems competitive in the market for power producing equipment.

Similar to all other fuel cells, the working principle of the MCFC is based on the indirect combination of hydrogen and oxygen to water via an electron carrying electrolyte (Fig. 1). On the anode side of the cell hydrogen reduces the $CO_3{}^{2-}$ ion to CO_2 releasing the two electrons and generating the electrical power. On the cathode side new $CO_3{}^{2-}$ ions are formed by combining the CO_2 of the anode exhaust and the oxygen from the air with two electrons taken from the outer load circuit thus closing the chemical and electrical loops.

The hydrogen supply for the anode reaction is generated from natural gas within the fuel cell block by a process known as steam reforming. Assisted by a catalyst, methane, the energy carrier in natural gas, combines with water to combust the carbon and to release all the hydrogen from the methane as well as from the water. This process absorbs waste heat from the fuel cell and translates it back into primary energy increasing the total system efficiency by approximately 12 percentage points (Fig. 2).

After having removed the sulfur and higher hydrocarbons from the fuel, a molten carbonate fuel cell with internal reforming can be fed directly with a mixture of natural gas and water—we call it the direct fuel cell (DFC).

2. MCFC development at MTU

The German MCFC program is carried out by MTU CFC Solutions GmbH, a subsidiary of MTU Friedrichshafen and

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doi:10.1016/j.jpowsour.2006.04.118

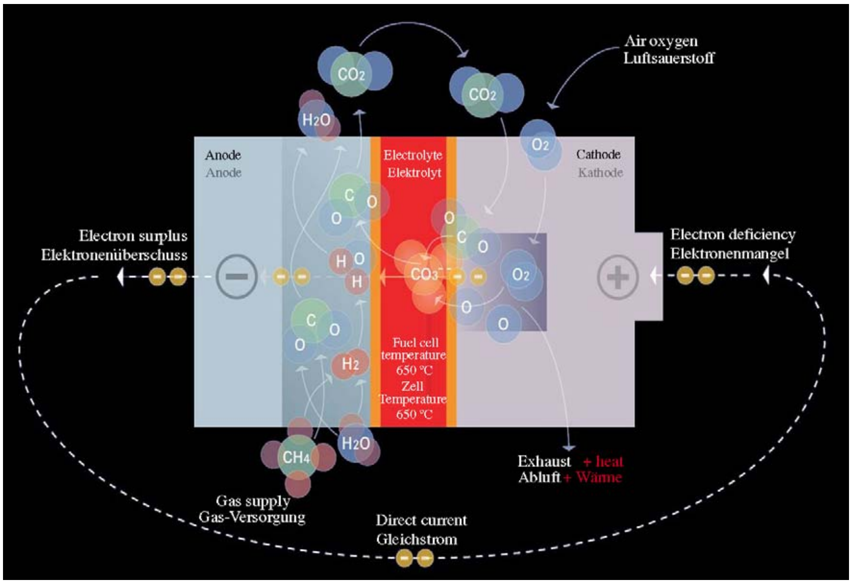

Fig. 1. Working principle of a molten carbonate fuel cell (MCFC).

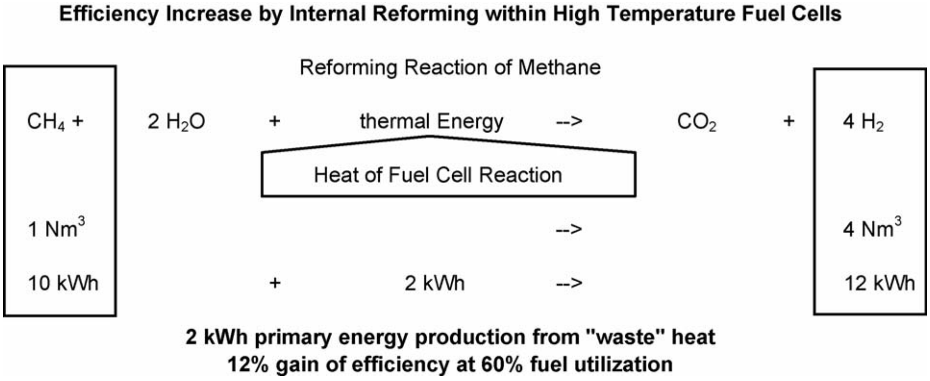

Fig. 2. Increase of efficiency by internal reforming.

RWE in Essen. The company shares a license and technology exchange agreement with Fuel Cell Energy, Inc., Danbury, Connecticut, USA (formerly Energy Research Corp., ERC). The program was started in 1990 and covers now a period of about 15 years. The highlights of this program up to date are:

- considerable improvements regarding material and component durability have been achieved and demonstrated on laboratory scale;
- the manufacturing technology has been developed to a point which enables the fabrication of the porous components on full scale;
- a new cell design called the EUROCELL with a potential to decrease cost and increase performance was developed and is now in the evaluation phase.

As far as the system design is concerned it was realized that conventional systems do not hold the promise for competitive power plants. A system analysis led to the conclusion that a new innovative design approach is required. As a result the “Hot Module” system was developed. A Hot Module combines all the components of a MCFC system operating at the similar temperatures and pressures into a common thermally insulated vessel. The HotModule is part of sub-megawatt fuel cell power plants which were developed in a collaborative effort utilizing the Direct FuelCell® technology of FuelCell Energy, Inc. and the Hot Module® balance of plant design of MTU CFC Solutions.

- About 16 large area stacks with about 8000 cm^2 cell area and a power range of 220–250 kW in an HotModule environment have been tested so far at the facilities in Munich (Germany) and at costumer facilities in Germany and Spain as field test units (Fig. 3). The cells for these stacks were supplied by FCE. FCE itself has built and tested about 45 sub-MW systems in the US and in Japan based on the HotModule Technology.
- In standard field tests natural gas is used as a fuel. However, methanol has also been tested successfully in a full size HotModule which was capable to run on dual fuel (natural gas and methanol). It could be demonstrated that switching form on fuel gas to the other and vise-a-versa was possible without upsetting the fuel cell system. Additionally biogas from a fertilizer was utilized in small-scale stacks as fuel.

Fig. 3. Hot Module power plants in Magdeburg and in Berlin.

As a result of our test so far we can draw the following conclusions:

- The HotModule system concept is suitable for industrial fuel cell application in the power range of 250 kW as demonstrated in numerous field tests.
- The safety concept has been convincingly proven – though in part unintentionally.
- The achieved electrical power level of up to 250 kW allows validation of the concept with reasonable degree of confidence.
- Horizontal stack operation – an essential innovation of the Hot Module concept – is feasible.
- The fuel processing subsystem worked reliably as expected.
- After initial problems in the inverter control software the electrical and control subsystem operated to full satisfaction.
- Stable automatic operation is possible not only under various load conditions, but also in idle mode, hot parking mode, and grid-independent stand alone mode.

3. The road to commercialization

The molten carbonate fuel cell (MCFC) is one of the fuel cell technologies that has proven efficiency and environmental performance. In addition, significant reductions in carbonate fuel cell capital cost are expected in the next few years. In particular, the use of carbonate fuel cells in the distributed power market could offer an ideal solution to increased energy demands with concurrent expectations for reliability and environmental sensitivity. The carbonate fuel cell concept involves conduction of carbonate ions (CO_3^{2-}) within an immobilized mixture of molten carbonate salts. Other cell components are based on nickel and stainless steels, which contribute to initial capital cost, but, are significantly less expensive than the precious metal catalysts used in lower temperature fuel cells. Since the charge carrier is an oxidant, several fuel species can be oxidized within the anode compartment leading to inherently greater fuel flexibility. To-date, carbonate fuel cells have been operated on hydrogen, carbon monoxide, natural gas, propane, landfill gas, marine diesel, and simulated coal gasification products.

The typical operating temperature of a carbonate fuel cell is around 650 °C. This temperature is almost ideal from the system perspective, since it allows higher Nernst potential (ideal Nernst potential increases with decreasing temperature) while still providing high temperature thermal energy sufficient to sustain and support reformation chemistry. Thus carbonate fuel cell system designs typically contain an internal reformer.

The carbonate fuel cell demonstrations to-date have been able to show the highest fuel-to-electricity conversion efficiencies (>50%) of any stand-alone fuel cell type. The primary developers of this type of fuel cell are FuelCell Energy Corporation, the developer and manufacturer of the Direct FuelCellTM concept and MTU CFC Solutions with their concept of the HotModule system. FuelCell Energy and MTU have demonstrated carbonate fuel cells from 10 kW to 2 MW of electrical output on a variety of fuels. Hitachi and IHI in Japan are also developing carbonate fuel cells for stationary power and have successfully demonstrated the technology in Kawagoe, Japan. Ansaldo Fuel Cell has demonstrated a 100 kW carbonate fuel cell in Milan, Italy and is now on the road to a 500 kW system. Carbonate fuel cell technology is more fuel flexible than lower temperature fuel cell technologies and is well suited to marine, military, and traction applications [2].

The high temperature thermal effluent of a carbonate fuel cell allows significant cogeneration and/or integration with a heat engine cycle, typically called a “hybrid.”

Several carbonate fuel cell hybrid systems with fuel-to-electricity efficiencies greater than 70% have been conceptualized with some under development today. The system currently in development by FuelCell Energy and Capstone Turbine in Danbury, Connecticut is the prime example [3].

The high efficiency, low emissions, and fuel flexibility features of carbonate fuel cells together with recent demonstrations of robust and reliable operation, and the potential for dramatic cost reductions make carbonate fuel cells a key emerging technology for meeting future energy demands.

4. Outlook for the MCFC technology

Molten Carbonate fuel cells have reached a stage, were field demonstrations at costumer sites are possible. However, this does not mean that this technology is readily available already. There are still are still a number of barriers to overcome, to make a MCFC power plant a commercial product. This can be easily understood if one realizes that the components of the stacks today are still practically hand-made. There is a strong necessity to develop manufacturing methods and tools for volume production to bring the cost down. Furthermore, though lifetimes of about 26,000 h have been achieved so far in the filed and some of these tests are still going on it is unlike that the commercial goal of 40,000 h can be reached already with today's technology. Therefore further work is urgently required to develop and qualify materials which offer the required functionality and show a stable performance for the whole lifetime. The companies involved in MCFC technology development work hard to overcome these problems. The continuous progress during the recent years proofs that they are on a good path.

5. Conclusion

The Molten Carbonate Fuel Cell technology merits a number of promising features to help solve the future energy problems due to its high efficiency and negligible pollution load on the environment. The technology has reached an advanced stage already, however, for a commercial breakthrough there is still considerable financial commitment required on private and public sides.

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