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Introduction

Major development efforts on molten carbonate fuel cells (MCFC) are currently underway in the United States and Japan. More recently, efforts were revived in Europe to develop MCFC technology. The purpose of this paper is to review current MCFC technology, with particular emphasis on a summary of the industrial participants in the development programs, the status of cell/stack tests, and a brief discussion of some important research issues. A review of fuel cell technologies was recently published (1) which provides more details on MCFC R&D.

Industrial Participants

Table 1 lists the major industrial organizations that are actively involved in MCFC technology. The efforts of the industrial participants in the United States and Japan are directed at the cell scale up and endurance tests of stacks. Because the European participants have only recently (i.e., ~1985) revived their efforts in MCFC technology, the primary emphases of their programs are to acquire experience in the technology and to conduct basic studies on research issues. The reports from the recent Fuel Cell Seminar (2) and the 23rd Intersociety Energy Conversion Engineering Conference (3-5) provide summaries of the status of MCFC technology.

Various options in cell and stack designs are being pursued by MCFC developers. For example, internal manifolding of the fuel and oxidant gases in the MCFC stacks is used by several Japanese developers (i.e., Hitachi, IHI) as an alternative to external manifolding, which is the typical arrangement used by U.S. developers. Cell and stack designs that permit internal reforming of hydrocarbon fuel gases provide exciting options to obtain higher system efficiencies than those projected for MCFC power plants with external fuel processors. MCFCs that incorporate internal reforming are being developed at ERC and M-C Power in the United States, Mitsubishi in Japan, and NERF in Europe (Netherlands).

Cell/Stack Tests

Major advances have been reported in the scale up of electrode area, stack size and stack endurance, and some of the recent results are summarized in Table 2. Electrodes of >2000-cm^2 (~2 ft^2) area, and in multi-cell stacks of up to 20 kW, have been successfully tested for over 1000 h by many industrial organizations. The largest electrodes (7200 cm^2) that were tested in a MCFC stack was reported by IFC, and IHI has tested cells containing electrodes of 10,000-cm^2 which will soon be evaluated in a 10-kW stack. Studies underway at IFC (2) project that a 100% increase in power density and a 40% decrease in stack component costs are achievable.

Degradation in cell/stack performance can be attributed to many factors, including corrosion and electrolyte loss, electrode creep, and NiO dissolution. Much of the R&D effort in MCFC technology is directed at resolving these issues, and the discussion in the following section indicates that substantial progress has been made.

Research Issues

Dissolution of NiO from the cathode and corrosion of metallic cell components are still research issues that are continuing to receive attention. The operating conditions under which NiO dissolution occurs in molten carbonate electrolytes are well documented. The dissolution of nickel from the NiO cathode and subsequent deposition of nickel in the molten carbonate electrolyte is a major problem that is exacerbated by increasing the partial pressure of CO_2 in a MCFC. NiO cathodes are not expected to last more that 10,000 h in pressurized operation with low-Btu coal gas as a fuel, but may be satisfactory for 40,000 h at atmospheric-pressure operation. In addition, molten carbonate electrolytes that are acidic (e.g., K_2CO_3-rich melt) or basic (e.g., Li_2CO_3-rich melt) accelerate NiO dissolution. Experimental evidence indicates that the solubility of NiO in binary carbonate melts is a minimum at compositions that are intermediate between the extremes of highly acidic and basic compositions. These observations led to research that identified electrolyte compositions in which NiO dissolution was reduced:

- The NiO dissolution rate is lower in 60 mol% Li_2CO_3/40 mol% Na_2CO_3 than it is in 62 mol% Li_2CO_3/38 mol% K_2CO_3 according to ERC.
- The addition of alkaline-earth carbonates (e.g., 5 mol% $CaCO_3$ or $MgCO_3$) to 62 mol% Li_2CO_3/38 mol% K_2CO_3 reduces the dissolution rate of NiO.

In addition, research at Argonne National Laboratory (2) has identified certain cathode materials, Mn-doped $LiFeO_2$ and Li_2MnO_3, which could be viable alternatives to NiO. However, optimizing the performance of metal oxides, and determining their solubility in molten carbonate electrolytes, have not been completed.

Creep (compression) of the porous electrodes (as well as other structural components) in MCFC stacks results in dimensional changes that are detrimental to long-term performance. Research at the Institute of Gas Technology (2) demonstrated that oxide-dispersion-strengthened (ODS) anodes have better creep resistance and improved mechanical strength than the state-of-the-art Ni-Cr anodes. The ODS anodes contain ≤5% Al which oxidizes to form a dispersion of oxide particles in the nickel phase that inhibits sintering and deformation of the nickel. Compaction of the NiO cathode limits stack life to about 15,000 h, however this may not be a problem with an internal-manifold design. Research on modifications to the cathode (i.e., use of screen or fiber reinforcement) offer some encouragement that a solution to this problem is attainable.

The corrosion of structural components (i.e., bipolar separators, current collectors, gas manifolds) in molten carbonate electrolytes limits the life of MCFCs. Nickel is an acceptable material in the anode environment, and nickel-based alloys and various stainless steels appear to be acceptable in the cathode environment, at least in short-term tests. However the cost of some of these materials, their ease of fabrication into practical components, and their long-term corrosion stability are issues that have prompted efforts to develop alternative materials. Efforts in this direction were described at the recent Fuel Cell Seminar (2).

Two other technical issues that continue to confront industrial developers of MCFCs are: (i) the sensitivity of MCFCs to low concentrations of contaminants (e.g., sulfur compounds) present in the gas steams, and (ii) the lack of a practical "CO_2 transfer device" that will select CO_2 from the anode exhaust and transfer it to the oxidant gas. Efforts to resolve these issues are underway, but no practical alternatives are currently available.

Concluding Remarks

Major advances in MCFC technology have been achieved since the early 1980s. Multi-cell stacks up to 20 kW, and electrodes of 7200 cm^2 area, were tested for over 1000 h. Technical issues still remain with regard to the endurance of cell components, but recent progress in the development of alternative and/or improved components suggests that significant improvements in the operating life of larger stacks are feasible.

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Table 1. Major Industrial Participants in MCFC Technology

Industrial Participants	Country
• ANSALDO	Italy
• Energy Research Corporation (ERC)	United States
• Fuji Electric	Japan
• Hitachi Ltd.	Japan
• Institute CNR/TAE	Italy
• Ishikawajima-Harima Heavy Industries Co. (IHI)	Japan
• HOOGOVENS	Netherlands
• M-C Power	United States
• Matsushita Electric Industrial Co. Ltd.	Japan
• Mitsubishi Electric Corp.	Japan
• Netherlands Energy Research Foundation (NERF)	Netherlands
• Toshiba Corp.	Japan
• International Fuel Cells Corp.(IFC)	United States

Table 2. Recent Cell/Stack Tests by MCFC Developers

Industrial Developer	Stack Size (kW)	Number of Cells	Area (cm^2)	Duration of Test (h)
ERC	5	60	800	>500
ERC	5	11	3700	2000
Fuji	7	24	2500	500
Hitachi	10	40	3600	>1800
IFC	20	20	7200	1700
IHI	10	29	3600	600
IHI	1	1	10000	1100
M-C Power	1	10	1000	500
Mitsubishi	10	40	2000	1000
Toshiba	10	63	1600	500

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