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DEVELOPMENT AND COMMERCIALIZATION OF ON-SITE FUEL CELL IN JAPAN

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Activities in Japan to develop the on-site fuel cell and to bring it into the market have been actively carried forward with the phosphoric acid fuel cell (PAFC) and solid oxide fuel cell (SOFC). To achieve this, potential users, such as gas companies, have been supporting and cooperating with American and Japanese manufacturers of fuel cells.

The PAFC project, aiming for the commercialization of the 50 kW to 200 kW-class on-site units, is currently being carried out. For SOFC, an experimental unit with a capacity of 25 kW will soon be tested.

The development and commercialization of the fuel cell for on-site cogeneration systems can be said to be a pressing and important subject because of its expected contribution to energy conservation and to reducing environmental pollution (Table 1).

On-site phosphoric acid fuel cell

Systems manufactured by the American company, International Fuel Cells Corp. (IFC), have been given field tests involving four PC18 (40 kW) units at Japanese gas companies. Testing of the PC25 (200 kW) preprototype model units has also started in Japan.

In joint development with Japanese manufacturers, about 20 units of 50, 100 and 200 kW trial units are now being fabricated by Mitsubishi Electric, Fuji Electric, and others. These will be field-tested by gas, electric power and petroleum companies.

TABLE 1

NOx content in fuel cell exhaust gas

Fuel cell	NOx (ppm, O_2 = 5%)	Measured date
IFC, PC18, 40 kW PAFC	9	14/1/84
IFC, PC25 preprototype, 200 kW PAFC	< 2	4/7/89
MELCO (Moonlight Project), 200 kW PAFC	6	8/6/89
Fuji Electric, 50 kW PAFC	< 2	22/5/89
Westinghouse Electric, 3 kW SOFC	< 2	21/6/88

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For the commercialization of the on-site PAFCs, three gas companies (Osaka Gas, Tokyo Gas and Toho Gas) plan to introduce a total of 21 IFC PC25 (200 kW) units and monitor operations at customer's sites. The three gas companies and Fuji Electric Co. have entered into a contract to conduct a joint development project of commercial units.

Field test of PC18 (40 kW)

Osaka Gas and Tokyo Gas each purchased one IFC PC18 (40 kW) prototype for testing. Tests were conducted on two PC18 units out of 46 field demonstrations in the GRI Field Test Program.

The two field test units for the GRI program supplied power to the actual load and delivered heat at the test site for three years from 1984 to 1987. They operated for 11 400 and 15 600 h respectively.

In performing these field tests, characteristics of on-site PAFC were profoundly understood, including the confirmation of its remarkable response to load change, allowing it to follow instantaneous ramp rates from 0 to 100% in 0.03 s with a voltage variation as low as 3 V.

PC25 preprototype (200 kW)

Four PC25 preprototype model units have been supplied by IFC for testing in Japan: two units by Tokyo Electric Power, one unit by Osaka Gas and one unit by Nippon Oil. The two units introduced by Tokyo Electric Power are already in operation.

The Osaka Gas unit has been installed at Umeda Center Building (Fig. 1), an office complex near Osaka Station, and will be operated connected to the utility grid. The reject heat is planned to be used for the building's hot water supply. The unit is now being checked for operation. This project will be carried out by Osaka Gas in cooperation with Takenaka Koumuten, one of the largest construction firms in Japan, which designed and constructed the Umeda Center Building. The aim of the demonstration

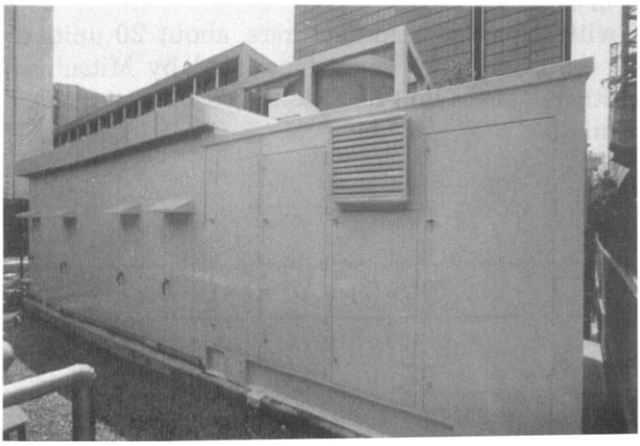

Fig. 1. PC25 preprototype at Umeda Center Building.

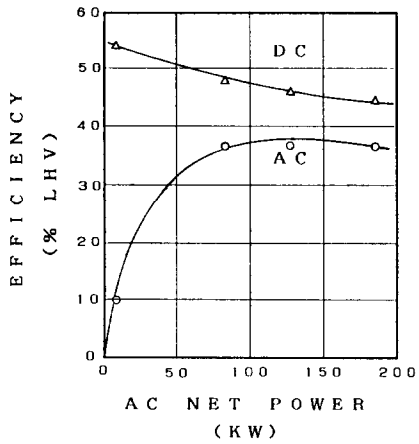

Fig. 2. PC25 preprototype electrical efficiency (%, LHV).

will be to accumulate experience in operation and maintenance of an on-site PAFC. This will serve as a demonstration to future users, as well as to help determine the technical capabilities of this preprototype (Fig. 2).

Commercialization program for the IFC 200 kW unit

IFC is preparing to manufacture the first lot of PC25 units at the present time. They will require an installation area that is smaller than the preprototype model and the unit is expected to have increased performance.

The three major gas companies in Japan, including Osaka Gas, have ordered a total of 21 PC25 units. Although delivery dates are not yet fixed, these will probably be delivered in 1991 or 1992. Most are to be installed at customers' sites and operated for monitoring purposes, in preparation for commercial marketing of PC 25 units.

Development of a 200 kW unit under the Moonlight Project

An on-site PAFC with a capacity of 200 kW (Table 2, Fig. 3) is being developed under the Moonlight Project, with field testing expected this summer (1989) at the Hotel Plaza in downtown Osaka.

The project is being sponsored by NEDO, with Mitsubishi Electric being charged with component development and manufacture of the 200 kW trial unit, and Osaka Gas and Kansai Electric Power carrying out the field tests and evaluating performance.

For this project, a new cell structure was developed and cell characteristics and cell durability were improved. In addition a new compact reformer was developed. Based on these improvements, a 200 kW system was designed and one unit was constructed. In May through July of 1989, component adjustments and power generation tests were conducted at the manufacturer's facilities. Then the unit was installed at the test site at the end of July, and field tests are planned for two years.

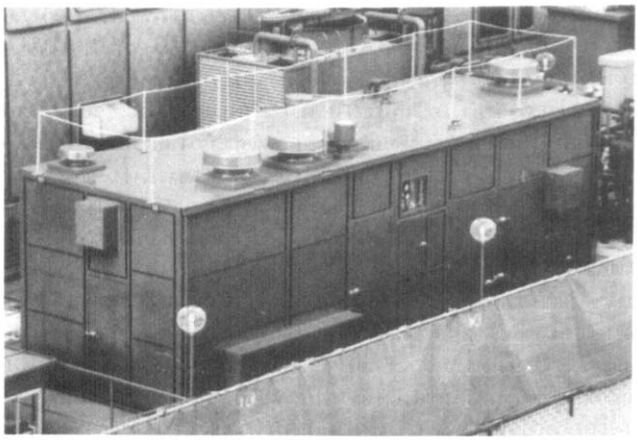

Fig. 3. 200 kW PAFC at Hotel Plaza.

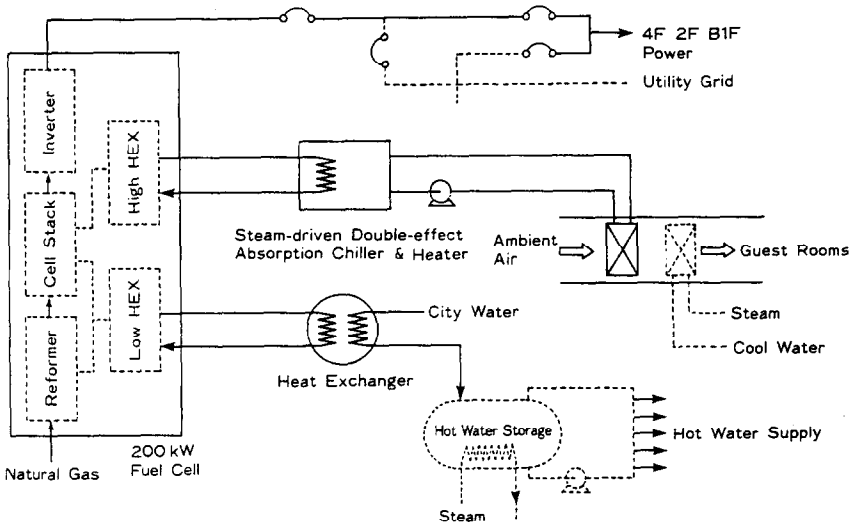

Fig. 4. Moonlight Project 200 kW PAFC field test system.

The unit can be operated both in the grid-connected and grid-independent modes, and will supply hot water to the hotel (Fig. 4). Furthermore, using a double-effect absorption chiller and heater, its rejected heat will also be used to air-condition the building. During the test period, the unit is expected to supply about 10% of both the electric power and thermal demand of this urban hotel, which has 550 guest rooms.

50 kW and 100 kW unit trial manufacture

Tokyo Gas has ordered one 50 kW trial PAFC unit from Fuji Electric and one 100 kW unit from Hitachi. These will be tested at the R&D Institute of Tokyo Gas.

TABLE 2

200 kW PAFC specifications (Moonlight Project)

Rated power (kW)	200
Electrical efficiency (%, HHV)	36 (40%, LHV)
Total efficiency (%, HHV)	80 (89%, LHV)
Fuel	natural gas
Operation	grid-connected, grid-independent
Road following	0 to 100% within 1 min 20% instantaneous
Heat-up time (h)	3
Total harmonic distortion (%)	less than 2 (grid-connected) less than 5 (grid-independent)
Heat recovery temperature (°C)	170 (steam) 70 (hot water)
Dimensions (m)	W 3.1 x L 10.0 x H 3.2
Cell stack	100 kW x 2
Reformer	100 kW x 2

The 50 kW trial unit has been assembled and continues to undergo power generation tests at the manufacturer's facilities. It will be delivered shortly to Tokyo Gas.

Commercialization of 50 kW and 100 kW unit by three gas companies and Fuji Electric

Three gas companies (Osaka Gas, Tokyo Gas and Toho Gas) and Fuji Electric have jointly begun a new project to develop 50 kW and 100 kW on-site PAFC commercial units.

Based on the technology of Fuji Electric, developed under the Moonlight Project, using the systems design, operation and maintenance know-how accumulated by the three gas companies, this project plans to achieve market entry of commercial units in 1993 (Fig. 5).

In this project, a total of about seventy primary, secondary and production model trial units will be manufactured. Of these 50 production trial

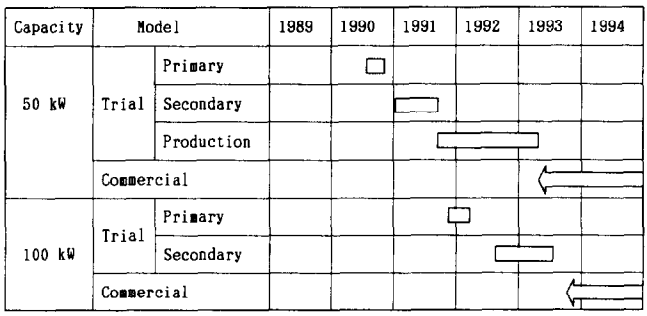

Fig. 5. Commercialization of 50 and 100 kW PAFC.

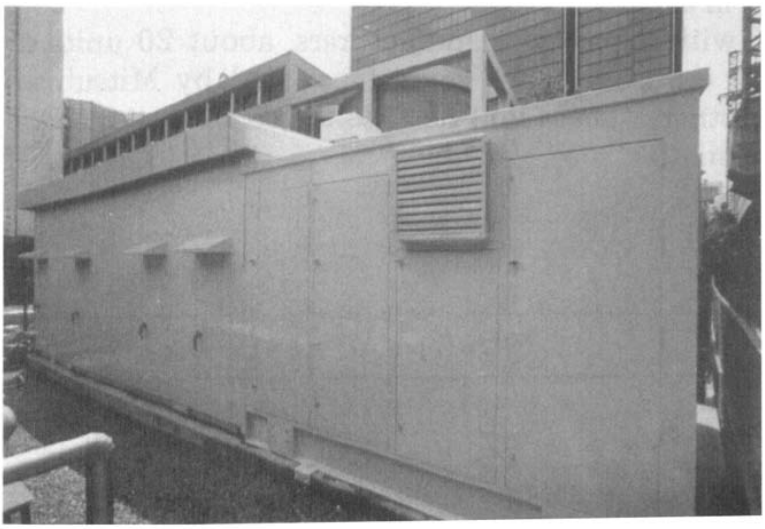

Fig. 6. 50 kW unit for Tokyo Gas.

units will be manufactured in 1991 and 1992. The footprint for the 50 kW package will be 4.0 m^2, its height will be 2.2 m and the target for its electrical efficiency is 40% (Fig. 6).

Other considerations

There are a number of technical and economical aspects which must be addressed prior to the market entry. Among these, the most important is improvement of the cell power density to reduce the package volume and the cost. At this time, power densities of approximately 1 kW/m^2 have been demonstrated using Japanese technology. A cell performance study is actively being conducted to increase power density to 1.5 - 2.0 kW/m^2 maintaining the system power generating efficiency at 40% (LHV).

Development of solid oxide fuel cell

Osaka Gas and Tokyo Gas entered into a contract with Westinghouse Electric in 1986, and have sponsored the development of the SOFC at Westinghouse, which has now reached an exceptionally high technical level. Osaka Gas operated two separate 3 kW experimental units in 1987 and 1988 and evaluated their technical status. Next, tests of a 25 kW generator unit are planned (Fig. 7).

The reason Osaka Gas became involved in the development and commercialization of the SOFC, in addition to the PAFC, is because of several technical advantages:

(1) its power generation efficiency is 10% higher than that of the PAFC

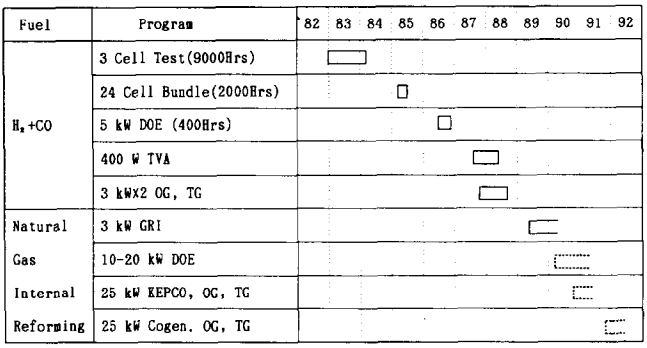

Fig. 7. Westinghouse SOFC program summary.

(2) its reject heat is at several hundred degrees Celsius

(3) it has a high system simplicity, due to its internal fuel reforming capability

(4) it has a highly stable performance, owing to the use of solid state cell materials

Experimental 3 kW SOFC units [1]

These units were designed to generate 3 kW d.c. at maximum power, and contain 8 bundles of cells, each of which has 18 cell tubes. To evaluate the performance and durability of the cell module (144 tubular cells), operational tests were performed, primarily using H_2 and CO mixtures (Table 3).

TABLE 3

3 kW SOFC specifications

Maximum output power	3 kW d.c.
Fuel	H_2, H_2 + CO, reformed gas
Operating temperature	900 to 100 °C
Generator pressure	0 to 20 inch H_2O
Fuel utilization	55 to 85%
Air stoichiometry	3 to 7

TABLE 4

Operational results of the 3 kW generator system

	Osaka Gas #1	Osaka Gas #2	Tokyo Gas
Operating period	Nov/87 - Mar/88	Mar/88 - Aug/88	Nov/87 - Jun/88
Operating time (h)	3012.5	3683	4882
Availability (%)	97.9	99.1	
Average load (kW)	2.02	2.00	2.00
Start-up (times)	4 (including 2 at Westinghouse)	2	2

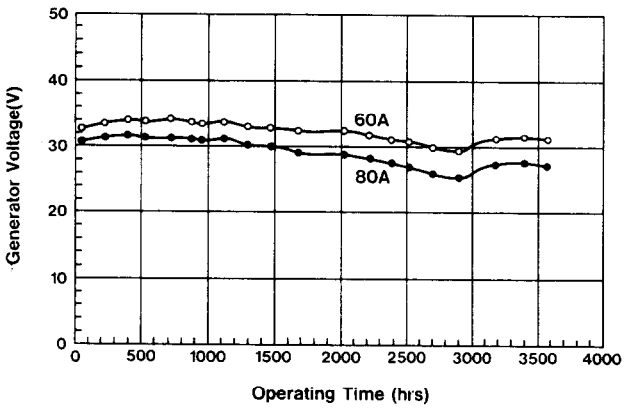

Fig. 8. 3 kW SOFC voltage performance.

Osaka Gas evaluated two cell modules and Tokyo Gas one module, achieving 12 000 hours of total operation (Table 4). The first generator at Osaka Gas was fully tested as planned, but the operation of the second unit at Osaka Gas and that at Tokyo Gas were stopped early due to difficulties with the control system, and not because of cell tube conditions.

It was found that the initial performance of the cell was as expected, but that durability was insufficient. Resistance to thermal cycles was not adequate. After the operation mentioned, the voltage was found to have dropped by 6% at 2 kW output (at about 60 A) (Fig. 8).

In parallel with this project, Westinghouse has improved initial performance, durability and resistance to thermal cycling by improving cell manufacturing methods. The company is, presently, investigating internal reforming methods.

25 kW SOFC generator unit

In view of the technical evaluation of 3 kW experimental units and recent progress in technical improvement by Westinghouse, Kansai Electric Power, Osaka Gas and Tokyo Gas have decided to conduct a joint test of the 25 kW SOFC generator unit equipped with an internal reforming system. This unit will be installed at the research field establishment of Kansai Electric Power, and testing will commence in 1990. The generator consists of two cell modules, each module having 576 cell tubes with 50 cm active length. Its rated power is 25 kW, but can produce a maximum of 40 kW.

Throughout this testing, Westinghouse will accumulate cell production experience and obtain performance data on a large number of cells.

SOFC future project

In addition to the project mentioned above the design and manufacturing of a 25 kW SOFC cogeneration system package is also being studied. This joint development project is being conducted by Osaka Gas and Tokyo Gas along with Westinghouse.

TABLE 5

On-site fuel cell project in Japan[a]

Project		Company	Manufacturer	Power (kW) × units	Operation
PAFC					
Technical development	PC18 Prototype	OG, TG	IFC	40 × 2	1982 - 1985
	PC18 GRI Program	OG, TG	IFC	40 × 2	1984 - 1987
	PC25 Preprototype	OG, TEPCO, Nippon Oil	IFC	200 × 4	1988 -
	Moonlight Project	OG/KEPCO	Mitsubishi	200 × 1	1989 -
	Trial machine	TG	Fuji, Hitachi	50 × 1, 100 × 1	1989 -
	Others	NEDO, PEC, etc.	Fuji, Sanyo, Mitsubishi	50, 100, 200 approx. 20	1990 -
Commercialization	PC25	OG, TG, THG	IFC	200 × 21	(first lot 1991 -) (commercial 1993 -)
	Commercial unit	OG, TG, THG	Fuji	50, 100, approx. 70	trial unit 1990 - commercial 1993 -
SOFC					
3 kW Experimental unit		OG, TG	Westinghouse	3 × 2	1987 - 1988
25 kW Generator		KEPCO/OG/TG	Westinghouse	25 × 1	1990 -
25 kW Cogeneration package		OG, TG	Westinghouse	25 × 2	(1991 -)

[a]OG: Osaka Gas, TG: Tokyo Gas, THG: Toho Gas, PEC: Petroleum Energy Center.

The next step will be field testing of a 100 kW cogeneration system. If technical improvement and cost reduction proceed as expected, it may be possible to introduce the on-site SOFC into the market by 1997.

Economics

Although the cost of the on-site PAFC is 1.0 - 1.5 million yen per kW (7000 - 10 000 dollars/kW), assuming that one unit is ordered at the present time, we believe that through the experiences gained in conducting many PAFC projects, costs for this on-site technology will decrease to the target value of 200 - 300 thousand yen per kW (1400 - 2000 dollars/kW).

Demand for on-site fuel cells will fluctuate sharply depending upon future energy conditions. But, assuming that these remain unchanged from those at present, demand for on-site fuel cell systems in Japan, based on the projected demand for the Osaka Gas service territory, is estimated to be 100 000 kW or more yearly in the mid 1990s, equivalent to 1000 units of 100 kW each, or more. However, in order to disseminate on-site fuel cells in the market, several models of different capacity up to 1000 kW must be developed.

Conclusions

Japan's three major gas companies have been actively promoting the development and commercialization of on-site fuel cells in Japan [2]. Through these activities the know-how for various techniques for systems design, operation and maintenance of on-site fuel cell units has been acquired.

Based on this experience, we will continue to support technical development and commercialization of fuel cell manufacturers and expect to bring PAFC into the market from around 1993, with SOFC to be introduced several years later (Table 5).

References

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2 N. Hashimoto, Overview of the Osaka gas on-site fuel cell program, *Ext. Abstr. Int. Seminar Fuel Cell Technology and Applications, The Netherlands, Oct. 1987.*