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Journal of Power Sources 61 (1996) 73-77

JOURNAL OF POWER SOURCES

Phosphoric acid fuel cells in Japan

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Abstract

Japanese gas companies have taken a keen interest in the energy-saving characteristics and superior environmental friendliness of fuel cells; since 1972 they have vigorously pursued the development of phosphoric acid fuel cells (PAFCs) for on-site generation purpose. The Japan Gas Association has been contributing to these activities. At present, field tests are carried out on 55 units on PAFC systems with a total capacity of approximately 8000 kW, including a US-made 200 kW unit, and Japanese-made 50, 100, 200 and 500 kW units. 24 units of PAFC systems out of 55 units have received a subsidy from the national government as a NEDO Field Test Project. In addition, a 1000 kW unit constructed with the assistance of a national government subsidy is to begin operation in 1995. As the results of field operations of many PAFC systems, valuable data on performance and durability were obtained, and useful maintenance techniques were accumulated towards commercialization. Both hardware and software of PAFC systems have been greatly improved, reflecting the experience gained from field operation. The durability of the cell stack differs with manufacturers and system models. For certain models of 200 kW systems, the performance almost satisfies the target of 20 000 h operation. One of the future tasks is to verify the durability and the reliability of PAFC systems for 40 000 h operation. Another one is manufacturing cost reduction.

Keywords: Phosphoric acid fuel cells; Japan

1. Introduction

Japanese gas companies have taken a keen interest in the energy-saving characteristics and superior environmental friendliness of fuel cells. Since 1972 the major Japanese gas companies, Tokyo Gas, Osaka Gas and Toho Gas, have vigorously pursued the development of phosphoric acid fuel cells (PAFC) for on-site generation which is the most promising application. The Japan Gas Association has been contributing to these activities.

At present, field tests are being carried out on 55 units PAFCs with a total capacity of approximately 8000 kW, including a US-made 200 kW unit, and Japanese-made 50, 100, 200 and 500 kW units. 24 units of PAFC systems out of 55 units have received a subsidy from national government as a New Energy and Industrial Development Organization (NEDO) Field Test Project, which is one of the NEDO projects to promote the research and development of fuel cell technologies. In addition, a 1000 kW unit constructed with the assistance of a national government subsidy is to begin operation in 1995.

In Japan, there are 94 units of PAFC systems in the 50-200 kW range with a total capacity of approximately 11 000 kW undergoing operational evaluation.

In this paper, the current status of PAFC demonstration field test in Japan is described, focusing on the activity of gas companies for on-site application. The subjects of commercialization of on-site PAFC are also mentioned.

2. PAFC development by Japanese gas companies

Japanese gas companies have been developing PAFC for on-site application in order to accomplish early commercialization. The target is to reach market entry of a co-generation type of PAFC by 2000 for commercial buildings, small factories, etc. The Japanese gas companies have been, therefore, mainly executing field tests at various sites as joint projects with manufacturers or government in order to propose ideas for technology improvement. The PAFC unit is of course the packaged unit as a co-generation system fueled with natural gas and operated at ambient pressure.

3. Overview of field test

3.1. Objectives

The objectives of the field test are the following:

(i) to verify the performance of PAFC on-site, such as applicability to the electrical and thermal demand of sites,

PII S0378-7753(96)02339-7

output characteristic, durability and reliability, maintainability and economic feasibility;

(ii) to promote the recognition of fuel cell availability, and

(iii) to accumulate the operational know-how which will be useful for the commercialization of fuel cells.

3.2. Current status

Fig. 1 shows the number of operating units of PAFC which were field testing in the world, June 1995. Japan has 96 units which are now under operation, and 56 units, that is the majority of them, are run by the gas companies.

Details of 56 units are given in Table 1. 24 of them are operated under the joint NEDO field test with MITI subsidy. On the other hand, the 1000 kW unit is operated under the joint project with the Ministry of International Trade and Industry (MITI) subsidy from NEDO and Phosphoric Acid Fuel Cell Technology Research Association in which Tokyo Gas, Osaka Gas, Toho Gas and Saibu Gas participate.

3.3. NEDO joint field test project

Fig. 2 shows the accumulated number of units installed by Japanese gas companies each year. The number has greatly increased since 1992. There are two reasons: (i) the appropriate start time for the production and verification of quasi-mass production PAFC units, and (ii) the enforcement of the NEDO joint field test with governmental subsidy.

MITI of the Japanese government intended to promote the development of PAFC to execute the government subsidiary field test with the trust to NEDO. The scheme of this project is that MITI supplies one third of the expenses of purchasing and installing an on-site PAFC unit at the customer's site to NEDO. Users, mostly gas companies, are charged with two-thirds of the cost and should execute the field test jointly with NEDO. The framework is a five-year field test to accumulate

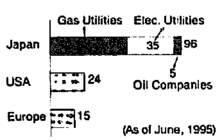

Fig. 1. Operating units of PAFC.

Table 1
Operating PAFC units by Japanese gas companies

Manufacturer	Capacity (kW)	No. of units	No. of units in NEDO joint field test
Fuji	50	18	9
Fuji	100	13	6
Fuji	500	3	2
Toshiba	200	1	
ONSI	200	20	7
Toshiba	1000	1	
Total		56	24

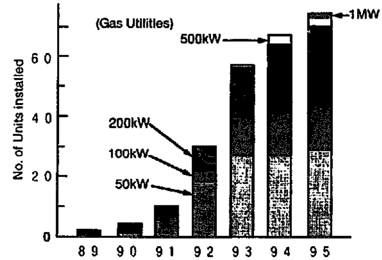

Fig. 2. Number of installed units by Japanese gas companies.

the actual data obtained form customers in 33 categories with different load patterns such as hotels, hospitals, schools, etc. for installation in the period 1992–1994.

There are 23 and 27 applicable sites and units participating in the subsidiary field test, respectively. The total subsidy is approximately 1900 million yen.

4. Activities for each unit type

4.1. 200 kW system manufactured by US ONSI

On the basis of previous experiences, this 200 kW fuel cell (PC25A) was produced from 1992 through 1994 as a quasi-commercial mass-production system. At present there are 56 units installed and in operation throughout the world.

In Japan, Tokyo Gas, Osaka Gas, and Toho Gas operate ten, nine and one of these units, respectively, and since 1992, these companies have undertaken field tests at their customer's facilities, etc. The longest running unit to date has a record of 20 000 h of operation, and while there is still a little time needed to prove its durability, the unit is demonstrating the performance that was anticipated for it. The specification of the PC25A 200 kW system is shown in Table 2.

In order to reduce costs, a development and marketing program for the improved commercial PC25C unit by ONSI and Toshiba is on-going. It is understood that the PC25C is an improved unit with two-thirds size and weight and near feasible cost for early market entry from on-site use. Several

Table 2
Specification of a 200 kW unit

Output	200 kW (a.c.)
Voltage/frequence	210 V, 3 phase, 50/60 Hz
Application	Grid connected/grid independent
Electric efficiency	40% (LHV base)
Thermal efficiency	44% (74 °C hot water)
	Option 12% (90 °C hot water)
	32% (74 °C hot water)
Power module	7.3 m(l) × 3.0 m(w) × 3.5 m(h)
	27.3 ton
Cooling module	5.1 m(l) × 2.4 m(w) × 2.2 m(h)
	2.7 ton

of these units will be put into operation, and their evaluation as initial commercial systems is planned.

4.2. *50 and 100 kW systems manufactured by Fuji Electric*

The three gas companies, Tokyo Gas, Osaka Gas and Toho Gas, joined with Fuji Electric in 1989 to advance the development of on-site fuel cells. As at the end of March 1995, 31 experimental systems were undergoing running tests by the three gas companies at both in-house and other facilities. With more than ten units already exceeding 10 000 h of cumulative operating time, tests on cell durability and reducing the cost, commercialization will be undertaken.

4.3. *Toshiba 200 kW system*

In order to develop Japan-made 200 kW system meeting Japanese regulations and customer's needs, Osaka Gas introduced a prototype manufactured by Toshiba in 1994. The system has a feature to generate steam which can be utilized for air conditioning using absorption chillers. At present, the second prototype has started its operation in a field test.

4.4. *Mitsubishi Electric 200 kW system*

Mitsubishi Electric supplied two units of 200 kW system to Osaka Gas in July 1995. For the time being, the company plans to manufacture, yearly, several demonstration units for the evaluation by electric power companies and gas companies.

4.5. *500 kW experimental model manufactured by Fuji Electric*

Osaka gas started to develop a 500 kW system with Fuji Electric for the use of industrial and district heating. The first trial model was installed at its Torishima Works in 1993. Two units of the demonstration model followed to start operation from April 1994 at the Asia–Pacific Trade Center in Osaka. One of the features of this system is to maximize steam recovery by realizing low steam-to-carbon operation and by employing a direct cooling system. The unit is designed to be separated into several parts to facilitate its transportation and installation.

Table 3
Specification of a 1000 kW unit

Output	1000 kW (a.c.)
Voltage/frequence	6.6 kV, 3 phase, 50 Hz
Application	Grid connected
Electric efficiency	40% (LHV base)
Thermal efficiency	23.2% (steam 170 °C), 13.0% (HW 65 °C)
Power module	12.5 m(l) × 8.0 m(w) × 3.2 m(h)
Stack	2 stacks, size: 1 m × 1 m, atmospheric conditions

4.6. *1000 kW units*

Tokyo Gas, Osaka Gas, Toho Gas and Saibu Gas participated in the Phosphoric Acid Fuel Cell Technology Research Association (PAFC Association), formed in April 1991; having obtained a national government subsidy, a 1000 kW system has been developed. manufactured by Toshiba. The unit achieved a rated output in March 1995, and the demonstration test is scheduled for the end of 1996, in the Tokyo Gas's Tamachi District. The specification of the 1000 kW system is shown in Table 3. This is currently the maximum size of the atmospheric type of PAFC. It is designed for use at a district heating and cooling center or an industrial factory as the co-generation system.

5. Results of the field test

5.1. *Durability and reliability*

The most important aspects for the commercialization of fuel cells are durability and reliability, because customers are requesting less time and labor to run a power plant.

In case of on-site PAFC, the requested durability is to exchange cell stacks per five years (40 000 h) or longer. The catalysts in the fuel processing subsystem should also have the same durability, as they affect the cycle-life cost.

The requested reliability is to continue the operation for 8000 h without shut-down: the scheduled maintenance in stop condition should be one per year.

Fig. 3 shows the results of field tests as from June 1995 in terms of reliability. Accumulated operation hours shown on the horizontal axis and longest continuous operation hours on the vertical axis represent the reliability of the units. The target reliability has not yet be reached but favorable results are emerging in the field test. The accumulated operating hours of 40 units are over 10 000 h. The 200 kW units present relatively better results and are expected to proceed forward to the target.

5.2. *Results of the 200 kW unit*

Focusing the results of the 200 kW units, 16 units are operating over 10 000 h and one of them is over 20 000 h as from June 1995, see Table 4.

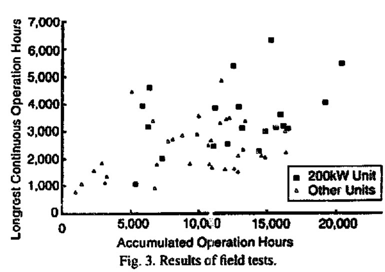

Fig. 3. Results of field tests.

Table 4
Results of 200 kW units in field test

Accumulated operation hours	over 10000 h	16 units
	longest	over 20000 h
Availability	over 80%	12 units
	average	84%
Power rate	over 80%	13 units
	average	85%
Continuous operation hours	over 3000 h	15 units
	longest	6325 h (9 months)
Mean time between forced outage	average	0.6 times/1000 h
	recently	0.3 times/1000 h

Both availability and power rate are also showing good figures which are near to our requirements. As for the continuous operation hours, 3000 h is currently easily achieved. The longest operation period is approximately nine months and is estimated to be able to reach the target of one year continuous operation. But another way, the mean time between forced outage is much prolonged by the correction of initial troubles of the system.

The cell voltage decline curve in Fig. 4 represents the durability symbolically. A 10% drop in cell voltage during 40 000 h operation hours from the start of the run corresponds to a 0.25% drop per 1000 h which is the target generally requested. Three curves in Fig. 4 show typical examples of the 200 kW unit's performance. Curve (1) and curve (6) are the worst and the best units, respectively. In any case, the performance of the 200 kW units is better than the target decline curve and, by extrapolating, projects 40 000 h durability.

Analysis of these curves shows that the cell voltage drop arises mainly at emergency shut-down by some trouble and less during continuous operation. The 200 kW units have an average 0.10% per 1000 h cell drop during continuous run, nevertheless they have the average 0.36% per 1000 h since start of run. This means that the durability could be extended for longer than 40 000 h by the reduction of components troubles causing plant shut-down.

Concerning the catalysts in the reformer, the shift converter and the desulfurizer, their durability should be as long as that of cell stack. As for this catalyst durability, no degradation of catalysts performance has been found during 20 000 h operation.

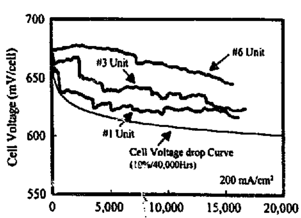

Fig. 4. Cell performance of a 200 kW unit.

5.3. *Evaluation of cell durability by NEDO*

Although the favorable result of operation hours up to 20 000 h has been accumulating, it is needed to continue the field test for more three years in order to evaluate the durability of the cell stack and finally to obtain confidence in the commercialization of the PAFC. There are on the other hand some cases of large declines in cell stack performance in units of a certain type. Therefore, it is important to find a method to predict the durability of a cell stack at early stages of operation. This is even more important in the case of a market entry with a newly designed type of unit.

Considering the situation above, the research project to evaluating cell durability by NEDO with governmental subsidy has started this year for two years. The purpose of this project is to elucidate the cell performance decline mechanism and to establish the accelerated method to test the cell durability. Gas companies cooperate with NEDO and they are expecting good results.

5.4. *Evaluation of field test results*

The evaluation of the field test is summarized as follows.

1. As results of field operation of many PAFC systems, valuable data on performance and durability were obtained, and useful maintenance techniques were accumulated towards commercialization. Both hardware and software of PAFC systems have been greatly improved, reflecting the experiences gained and lessons learned from field operations.

2. As for the current status of operating units under field test, the reliability of the units is evaluated to be almost satisfied because of the higher availability and the long mean time between forced outage. But, the durability of the cell stack differs with manufacturers and system models, and even 200 kW units have verified only half way to the target of 40 000 h. One of the future tasks is the verification, by actual field test, to the full 40 000 h of durability.

It is understood that the manufacturer will produce an improved and cost-reduced unit for market entry and guarantee the durability of the new system, being an essential point whether we can recommend the system to customers or not. Therefore, an early verification field test of the new designed unit is necessary.

6. Commercialization of on-site PAFC

6.1. *Subjects of commercialization*

The last hurdle in order to accomplish the real commercialization of the on-site PAFC system is undoubtedly the cost reduction of the system by technical improvement and by mass production.

Evaluation of the durability of the system at short periods of operation also contributes to the market entry. Customers cannot afford to wait for 40 000 h of real time test.

6.2. *Market entry and penetration*

According to the Basic Guidelines for New Energy Introduction expressed in December 1994 derived from the Prospects of Long-term Energy Supply and Demand by MITI, the target figures for fuel cell market penetration at the year 2000 and at 2010 are 200 MW and 2200 MW, respectively. These figures are expected to be achieved by PAFCs, MCFCs, SOFCs and PEFCs for on-site application and dispersed power generation application, and 80% of the former figure of 200 MW is expected to be contributed by on-site PAFCs.

Taking into account the current situation, this is a very hard target to be achieved. However, the commercialization of fuel cells is a nationwide desire for long years and the development of an on-site PAFC has now stepped within sight of commercialization.

7. Conclusions

It is now an important time for the on-site PAFC to enter the market. In order to promote the commercialization, the desirable circle between cost reduction through mass production and customer's purchasing need should be established. It is also important to encourage the wide and strong cooperation between manufacturers, utility companies and customers. It is also desired that the governmental promotion and subsidy lead to commercialization.

Japanese gas companies (and the Japan Gas Association) and NEDO will make efforts towards the commercialization and would like to ask the cooperation of all who relate to the technology development of the fuel cell and have an understanding of fuel cell systems.