

Development of Residential PEFC Cogeneration

Systems at Osaka Gas

S. Higashiguchi, K. Hirai, N. Shinke, S. Ibe, O. Yamazaki, K. Yasuhara,
M. Hamabashiri, Y. Koyama and T. Tabata
Residential Cogeneration Development Department
Osaka Gas Co., Ltd.

ABSTRACT

Osaka Gas has been developing 0.7 - 1.0 kW class PEFC cogeneration system for Japanese residential market, targeting its market entry in FY 2005. We have developed its fuel processor and CO preferential oxidation catalyst for this application. The fuel processor has already achieved the targeting thermal efficiency, which is 82%(HHV) so far, and its targeting durability over 90,000 hours can be also expected from our test results.

From a user's point of view, we are evaluating PEFC MEAs of major manufacturers since 1998. The results have shown that the present MEA cannot be operated under semi-dry conditions, considered our targeting durability over 90,000 hours.

Effective use of the electric power and heat outputted from the PEFC system is very important for saving energy. Osaka Gas developed heat recovery system and operating control software of a micro gas engine system, and commercialized residential gas engine co-generation system in March, 2003. Now we are developing the heat recovery system and operating control software for PEFC system, based on the data and the knowledge of the gas engine co-generation systems.

We have developed several prototypes of PEFC cogeneration units, and verified our targeting system performance. Since 2003, we have entered into a new development stage, and have started the joint development programs individually with four promising manufacturers.

1. PEFC Cogeneration system for residential application

Osaka Gas has been developing the PEFC cogeneration system for the Japanese residential market, and we are targeting its market entry in FY 2005.

Commercial electricity is highly reliable in Japan. So, systems that generate only electricity are not marketable unless its power generation efficiency always exceeds 40% (HHV). Therefore, the cogeneration system is necessary for energy savings and reduction of energy costs.

Fig.1 shows the basic concept of the residential PEFC cogeneration system.

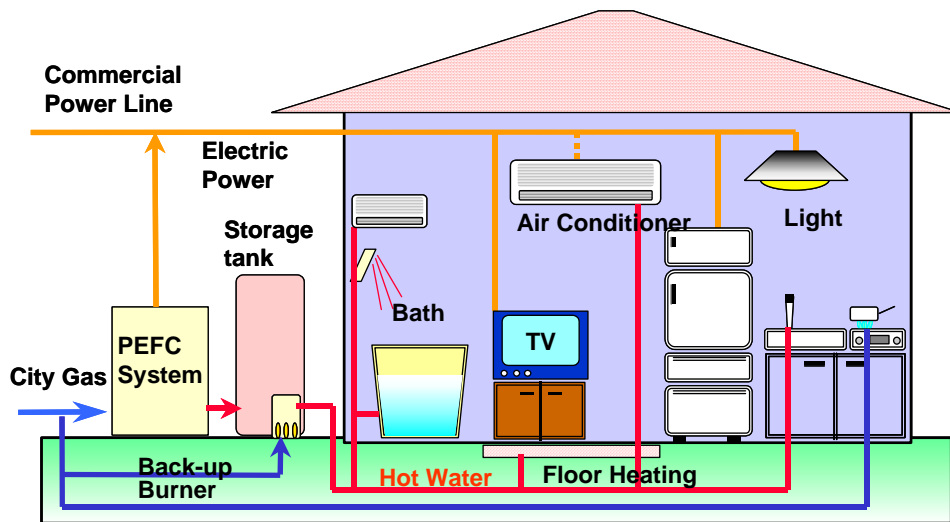


Fig.1 Image of PEFC Cogeneration system for residential application

Generated electricity is grid-connected, and is supplied to electric appliances. Exhaust heat is recovered as hot water and is stored in a storage tank. Then it can be used for hot water supply and floor heating.

This system has a back-up boiler to supply hot water in case the amount of hot water in the tank is not sufficient.

Specification of PEFC cogeneration system

We are developing 700 W to 1 kW class PEFC cogeneration systems. This capacity was decided upon residential energy demand in Japan.

In order to ensure system reliability and durability, we are considering continuous operation, which means that the PEFC system must be operating even at times of low

electric power demand, for example, through the nighttime.

Therefore, turn down ratio and system performance at a partial load are quite important. These target efficiencies have been determined by the performance of various proto-type systems.

Table 1 shows the targeting specifications for our commercial units

Table 1 Targeting specifications for commercial units

Capacity (Rating)	750W	1kW
Turn Down (W)	250 / 500 / 750	300 / 500 / 750 / 1000
Electric Eff (HHV%)	>27.0 > 30.5 >31.5	>27.0 >30.0 >31.0 >31.5
Heat Recovery Eff (HHV%)	>23.0 > 34.0 >39.0	>24.0 >33.0 >38.0 >41.0
Temperature in the Storage Tank	>60degC	
Operation Mode	Continuous / Step-wise Operation	
Durability	10 years	

The target electric efficiencies are 31.5% at rated load and 27% at minimum load. These numbers are expressed on the higher heating value (HHV) basis.

Heat recovery efficiency is also very important, and we have set a target for heat recovery efficiency at each electric power output point.

The lifetime of domestic gas appliances is normally 10 years. By introducing this system to a normal customer, we estimate 20% saving in overall energy costs. To recover the system cost within 5 years, the system cost has to be achieved US\$5,700

System configuration of PEFC cogeneration system

Fig.2. shows the configuration of PEFC cogeneration system.

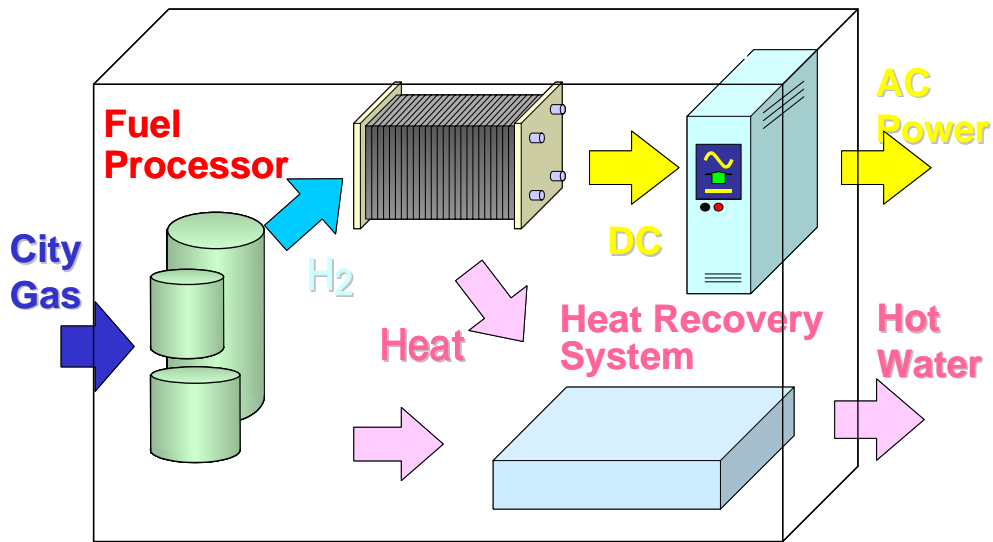


Fig.2 Configuration of PEFC cogeneration system

To extract hydrogen, city gas is processed in the fuel processor, which is comprised of desulfurizer, reformer, shift converter, CO remover and steam generator.

From this hydrogen and oxygen (air), DC power is generated at the fuel cell. This DC power is converted to AC power with the inverter, and is connected to the commercial power line.

Waste heat from a cell stack and a fuel processor can be recovered as hot water. This recovered heat is once stored in a storage tank, and then is used for hot water supply and room heating.

Market

Fig.3 shows the market size in the Osaka Gas supply area.

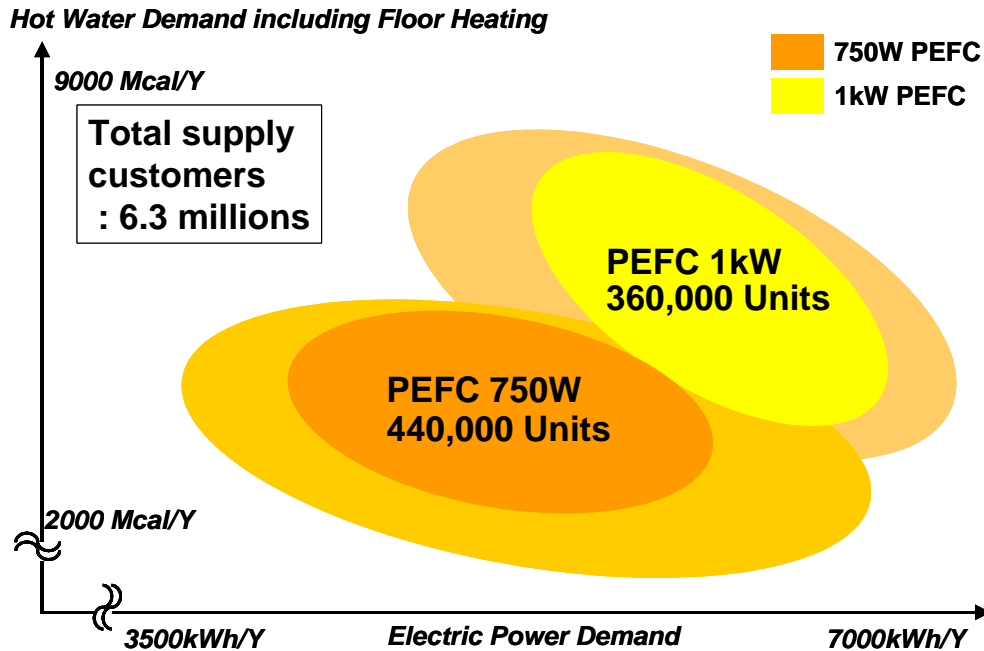


Fig.3 Residential Cogeneration Market in Osaka Gas Supply Area

We are supplying gas to 6.3 million households. Among them the number of individual houses is about 3 million. Considering the installation space and running merits, about 800,000 customers will be the initial target for these systems.

Technical challenging points

There still remains many technical problems to be solved in system components, such as cell stack, fuel processor, heat recovery system and so on. Major technical challenging points are described below.

Cell durability on hydrogen fuel has been being verified over 20,000h. However, cell durability using the CO containing reformed gas has not been confirmed sufficiently. In addition, further cell performance improvement is necessary to achieve higher electric efficiency.

On the fuel processor development, small scale natural gas fuel processor is required. Capacity of conventional fuel processor for onsite PAFC co-generation system ranges from 50 to 1,000 kW class. Even if this fuel processors are scaled down for residential unit, sufficient thermal efficiency would not be achieved due to their relatively large amount of heat radiation loss. Therefore, small scale fuel processor, which has excellent characteristics on thermal efficiency, load change, start-up & shutdown, and durability has to be developed. In addition, development of catalyst for CO remover is also

indispensable.

Besides cell stack and fuel processor development, following development is required.

- a. Heat Recovery System, which recovers waste heat from cell stack and fuel processor, and utilizes them for hot water supply and room heating.
- b. Water Treatment System, which produces pure water for steam reforming of natural gas and for humidification of cell stack.
- c. Power Conditioner, which converts low voltage DC power from cell stack to AC power efficiently.

Needless to say, dramatic cost reduction of these components are prerequisite for the commercialization of residential PEFC cogeneration unit.

PEFC development activities at Osaka Gas

Fig.4 shows the PEFC development activities at Osaka Gas.

By using our catalyst technologies, we have developed all kinds of catalysts for steam reforming processes, as well as fuel processors for this application.

We are not developing cell stacks by ourselves, but the durability of cell stacks is one of the key points to commercialize the PEFC cogeneration system.

Therefore, we are evaluating the MEA's performance under various conditions from the user's point of view.

We are also developing heat recovery systems.

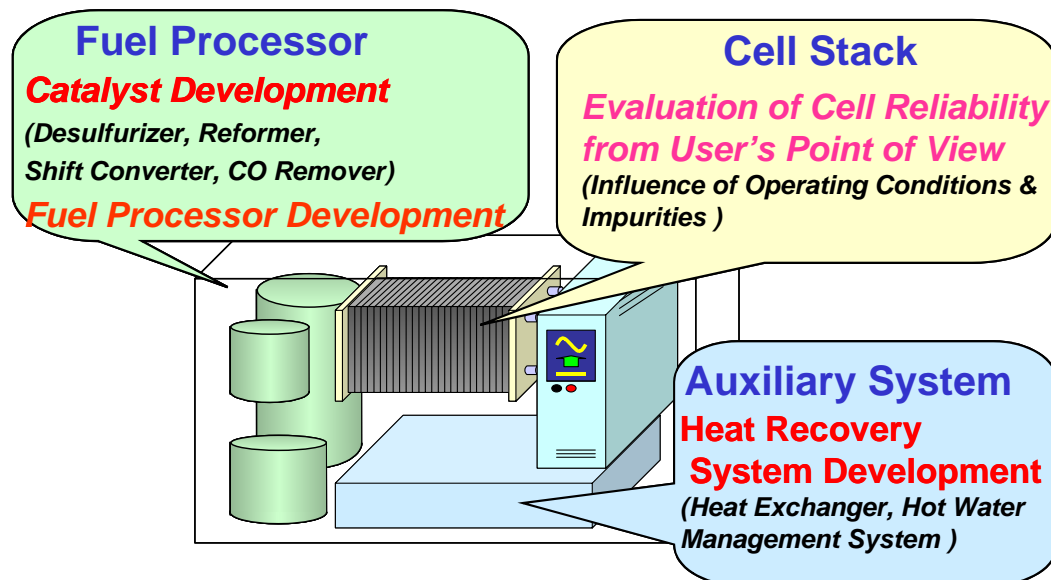


Fig. 4 PEFC Development Activities at Osaka Gas

2. Development of Natural Gas Fuel Processor for Residential PEFC Cogeneration System

Osaka Gas's fuel processor

Osaka Gas developed the steam reforming process for PAFC, utilizing our unique catalyst technologies developed by 1989, and its durability has been verified for more than 50,000 hours without changing their catalysts at the commercial PAFC units ¹⁾. Combining this technology and the newly developed CO preferential oxidation catalyst²⁾, the natural gas fuel processor for 0.5 – 1.0kW class PEFC cogeneration system has been developed³⁾.

Fig.5 shows 1kW class Osaka Gas's fuel processor.



W 280mm × D 440mm × H 395mm

Composition of Reformed Gas

H ₂	75.5 %
CO ₂	20.1 %
CH ₄	1.5 %
CO	0.8 ppm
N ₂	2.9 %

Fig.5 Appearance of 1kW class Osaka Gas's Fuel Processor

The natural gas fuel processor has already achieved the target thermal efficiency over 82% (HHV) at normal output and very low CO concentration below 1ppm.

Durability under continuous test

One of the main features of our natural gas fuel processor is its long durability. Our fuel processors are designed to maintain their normal performances for more than 90,000 hours without changing any catalysts, including that for desulfurizer.

Fig.6 shows the change of thermal efficiency and CO concentration under the continuous durability test.

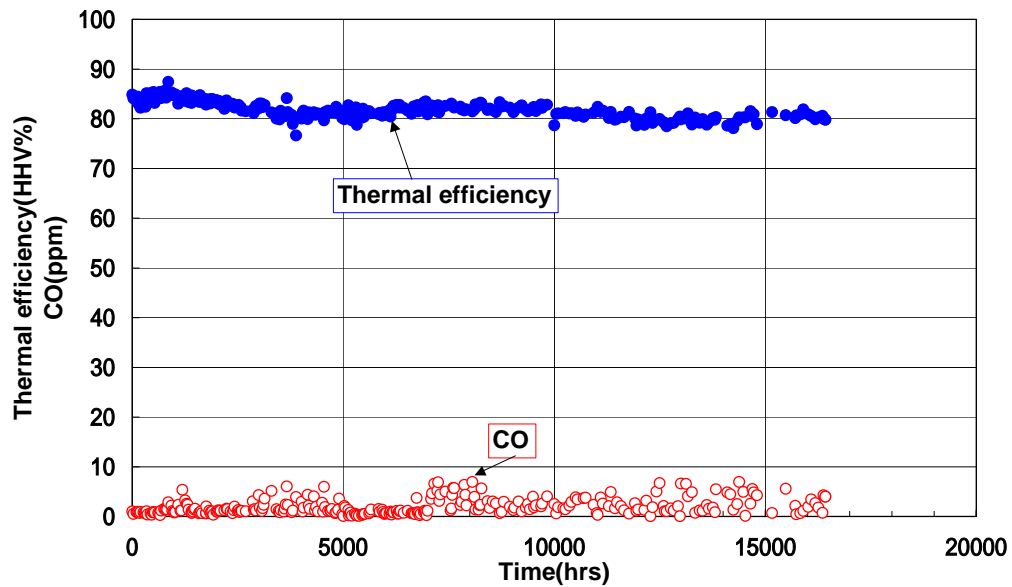


Fig.5 Durability under Continuous Test

Our fuel processor achieves very high efficiency over 82% on HHV basis.

This thermal efficiency is defined as the hydrogen energy consumed at the cell stack divided by input fuel gas energy.

Even after 16 thousand hours, neither thermal efficiency of the fuel processor nor the CO concentration show major changes.

In order to estimate the fuel processor performance after 90,000 hours operation, we checked the fuel processor performance using degraded catalysts, which are prepared as “end of life” (after 90,000 hours system operation) catalysts by our accelerated degradation technique.

Our 1kW class natural gas fuel processor was examined for this test, and steam carbon ratio was set at 2.5. The change in thermal efficiency and CO concentration is shown in Fig. 6. It was confirmed that sufficient performance of fuel processor can be expected even after 90,000 hours operation by this test.

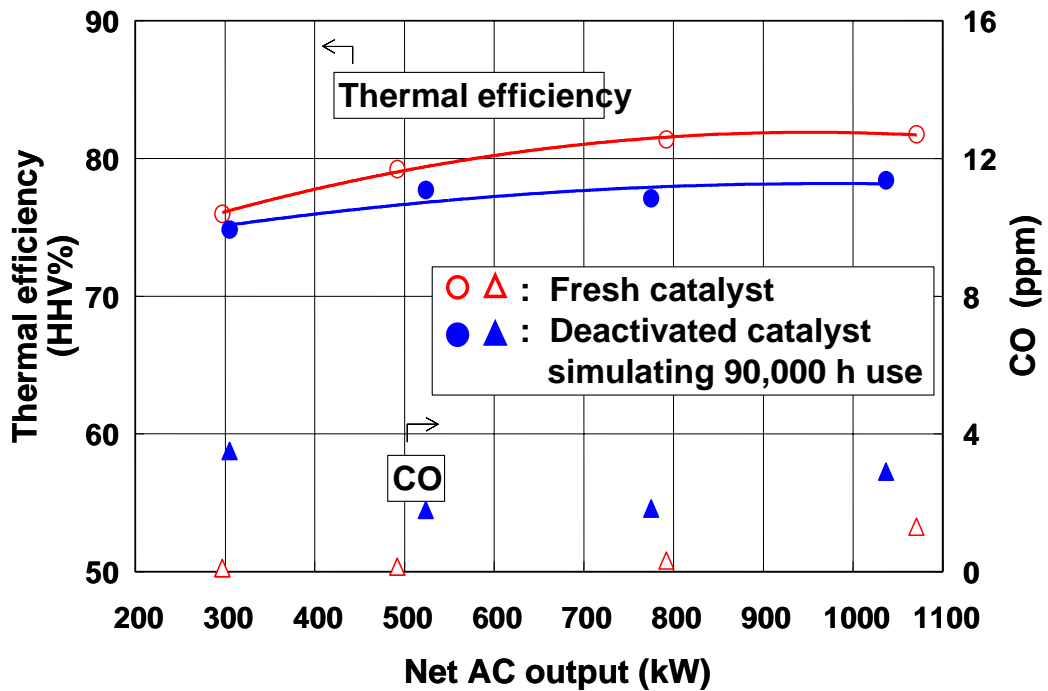


Fig.6 Thermal Efficiency and CO Concentration of Fuel Processor using deactivated catalyst

In addition, we have analyzed all vessels of the fuel processor after long-term durability tests, and it is verified that all structural material of fuel processor will withstand for more than 90,000 hours from the results of their corrosion trends.

Durability under start-up and shutdown test

For residential use, it is unavoidable to eliminate N2 purge process for start-up and shutdown stages. The start-up and shutdown sequence without N2 purge was established for our fuel processors, and it was confirmed on our natural gas fuel processor. The results are shown in Fig.7.

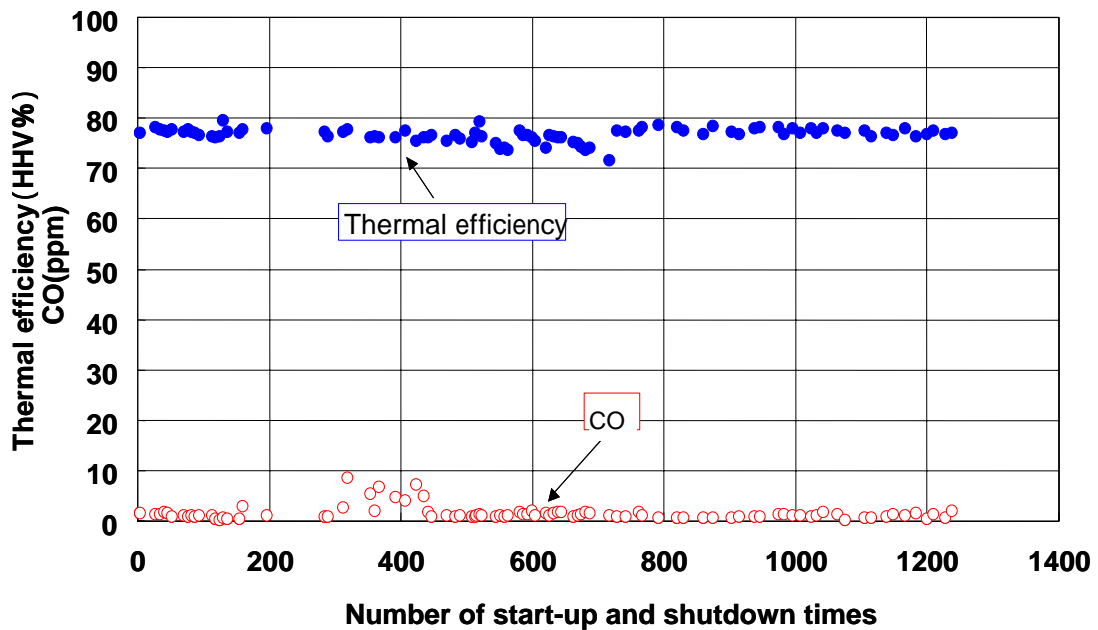


Fig.7 Thermal Efficiency and CO Concentration under start-up and shutdown test

Steam carbon ratio was set at 2.5. The fuel processor was maintained at rated load for 1 hour, and the time interval between start-up and shutdown was 4 hours. The thermal efficiency of the fuel processor and CO concentration does not show remarkable change, even after 1200 start-up & shutdown operations. It is considered that the fuel processor has sufficient performance and durability required for the target specification of PEFC system listed in Table 1. We are not only licensing these fuel processing technologies, but also selling fuel processors to PEFC system manufacturers. Several companies have been already utilizing our fuel processors and our technologies.

3. Cell Evaluation Technology

Osaka gas has carried out the evaluation study of PEFC single cells from a user's standpoint since 1998, because the durability of MEA and cell stack is one of the key points to commercialize the PEFC cogeneration system. The target cell voltage is more than 700mV at the current density of 300mAcm^{-2} . The target ratio of cell voltage drop is less than 10% over a period of 10 years. Accordingly the degradation rate should be within $0.7\text{mV} / 1000$ hours. We have been evaluating the durability of major manufacturers' MEAs with 37 sets of test stands, and have accumulated operating hours over 1,400,000 hours.

From the viewpoint of both the parasitic power reduction and the enhancement of heat recovery efficiency, it is desirable that the cell stack can be operated under semi-dry conditions. Fig. 8 and 9 show the cell durability under the saturated humidification and semi-dry conditions.

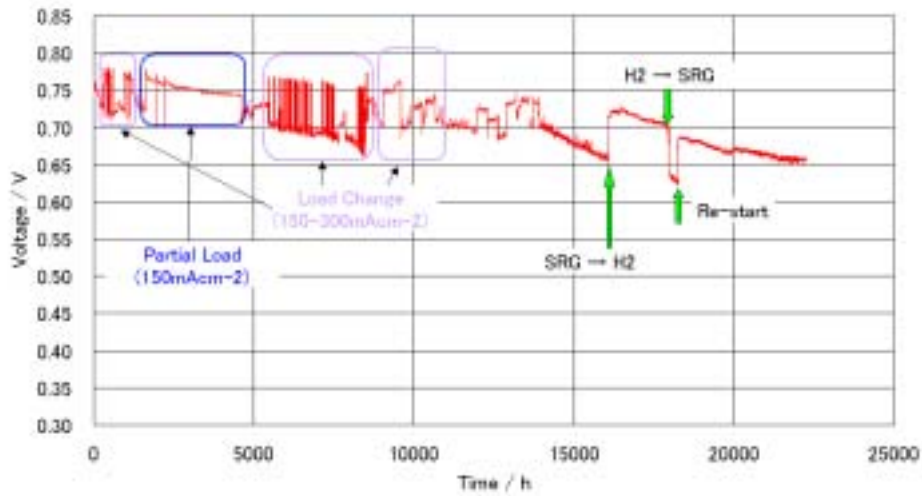


Fig.8 Durability under the saturated humidification condition

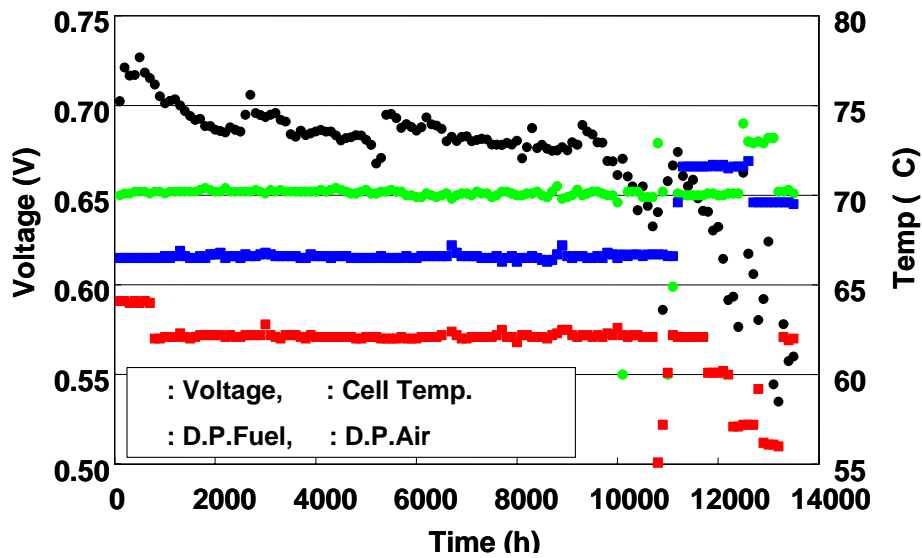


Fig.9 Durability under the semi-dry humidification condition

In Fig.8, The degradation rate of the cell voltage is approximately 3mV / 1000h. Even after 22 thousand hours, this cell is still operating

On the other hand, under semi-dry conditions, the initial voltage operated by simulated reformed gas showed more than 700mV as shown in Fig.9. However, the cell voltage decreased gradually and its rapid drop was observed after around 10,000 hours

Under fully saturated conditions, eight MEAs from several manufacturers have been operated for more than 10,000 hours. Three of them are still operating, and the longest operating hours exceeded 30,000 hours. On the other hand, no MEAs were operated for more than 10,000 hours under semi-dry conditions, although 7 MEAs from several manufacturers have operated stably for several thousand hours. From these results, it is concluded that the present MEA cannot be operated under semi-dry conditions, considered our targeting durability over 90,000 hours.

Even under saturated conditions, the degradation rate of 3 mV/1000h is not a satisfactory value. Therefore, the durability of cell is the most important issue to commercialize PEFC systems.

4. Development of heat recovery system for residential PEFC system

Effective use of the electric power and heat outputted from the PEFC system is very important for saving energy. Osaka Gas developed heat recovery system and operating control software of a micro gas engine system, and commercialized residential gas engine co-generation system in March, 2003.

This heat recovery system of gas engine type is equipped with the function to predicts the amount of heat demand for one day and time for when it will be used (according to previous demand data) and decides what time to start and stop the engine based on this for energy and cost saving. Thus, the system comes equipped with a learning capability that enables the hot water tank to run very efficiently, with little heat loss.

Compared to the gas engine type, the temperature of heat storage of PEFC type is rather low and the daily operation time of it is rather long. Therefore, it is more complicated to optimize the system. Now we are developing the heat recovery system and operating control software for PEFC system, based on the data and the knowledge of the gas engine cogeneration systems. Fig.10 shows the proto-type heat recovery unit for PEFC cogeneration system.



Fig.10 proto-type heat recovery unit for PEFC cogeneration system

5. Evaluation of PEFC system Performance

We have operated PEFC cogeneration systems since 1999 to evaluate the system's reliability and durability. In order to achieve our target energy savings, system operation mode and system power control are also very important. We are accumulating energy demand and operational data, and establishing the power control strategy

We have started extensive field testing of prototype units since April, 2002, and evaluating system reliability and durability at real customers' houses. The total accumulated system operating hours exceeds 100,000 hours as of July 30, 2004.

Fig.11 shows PEFC Cogeneration Systems at our customers' houses.



Fig.11 PEFC cogeneration systems at real customers' houses

The performance of the system has been demonstrated at the target level. By means of the laboratory experiences and field monitors, Osaka Gas accomplished that the PEFC system unit could improve more than 15% on energy conservation.

However reliability of system is still low and the cost is far higher than our target. To prevail the PEFC system widely, these issues must be overcome.

6. Future Development and Commercialization Plan

Fig.12 shows the commercialization schedule of PEFC co-generation system.

Fiscal Year	2003	2004	2005
1 Operation & Evaluation of Prototype Units (Including Cell Stack Evaluation)	Evaluation of Technical Level	Field Testing of Pre- Commercial Units	Preparation of Commercialization
2 Evaluation of Pre-Commercial Units			
Evaluation of Pre- Mass Produced Units			
Maintenance & Quality Control			
Market entry			

Fig.12 Commercialization schedule of PEFC cogeneration system

Since FY 2003, we have started the joint development programs to commercialize these PEFC cogeneration systems individually with four different companies, Ebara Ballard Corporation, Matsushita Electric Industrial Co., Ltd., Sanyo Electric Co., Ltd. and Toshiba International Fuel Cell Corporation.

After our evaluation of system reliability and durability through field testing, we are targeting at their market entry into Japanese residential markets within fiscal year 2005, collaborating with manufacturers selected from those four companies.

7. Conclusion

The fuel processor has already achieved the targeting thermal efficiency and its targeting durability over 90,000 hours can be also expected.

The durability of MEA can still be predicted only for about 20,000 hours under the saturated humidification.

The performance of PEFC cogeneration system has been demonstrated at our target level. But it is necessary for the commercialization to improve the system reliability and durability. In addition, cost reduction of the system is very important for its market penetration.

We are evaluating system reliability and durability through field testing, and developing the heat recovery system and operating control software for improvement on

energy conservation.

Osaka Gas is developing PEFC cogeneration system targeting its Japanese market entry in FY 2005.

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For details, please contact Seisaku Higashiguchi (seisaku-higasiguchi@osakagas.co.jp) at Residential Cogeneration Development Department, Osaka Gas Co., Ltd.