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Start-up, testing and operation of 1000 kW class MCFC power plant

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Abstract

The MCFC Research Association has been conducting R&D of the 1000 kW class MCFC Power Plant under contracting research with New Energy and Industrial Technology Development Organization (NEDO) as a part of the New Sunshine Program, promoted by the Agency of Industrial Science and Technology (AIST), Ministry of International Trade and Industry (MITI). The plant consists of four 250-kW stacks, a reformer, two cathode gas recycle blowers, a turbine compressor, a heat recovery steam generator (HRSG). The power plant is the first Japanese practical external reforming pressurized type MCFC power generation plant intended for large-scale commercial plant in the near future. The construction of the 1000 kW MCFC power plant started in autumn of 1995 on Kawagoe test station in Kawagoe Thermal Power Station of Chubu Electric Power, which is located in the prefecture of Mie, Japan. The construction and installation of the plant progressed very well, and process and control (PAC) testing of the power plant (not including fuel cell stacks and inverters) was carried out through March–November of 1998. After the PAC test, the cell stacks and inverters were installed in the test site; currently, the power generation test has just started. This paper describes the outline of the plant, the status of the test and the future schedule.

Keywords: Molten carbonate fuel cell; PAC test; Power generation test; Japan

1. Introduction

For environmental conservation, development of new concept power plant with high efficiency and environmental protection has been required in Japan. MCFC power plant has a high efficiency, low emission and availability using various kinds of fuels. MCFC power plant can be applied to various power plants, such as alternative thermal power plant, dispersed power and in future, integrated coal gasification combined cycle power plant. In Japan, R&D of MCFC was started in FY1981 by the New Energy and Industrial Technology Development Organization (NEDO) as a part of the Moonlight Program, promoted by Agency of Industrial Science and Technology/Ministry of International Trade and Industry (AIST/MITI). By 1986, the R&D focused on the basic study related to cell and stack technology. The MCFC research association has been established to develop a 1000-kW plant in 1988. R&D of equipment and system studies were performed for demonstration of the 1000 kW pilot plant by 1993. All equipment for the balance of plant (BOP) and two 100-kW class external reforming MCFC stacks were demonstrated at the Akagi site in the Gunma prefecture.

The MCFC research association has performed the design, manufacture, construction and installation of the 1000 kW plant since 1993. At present, the association consists of electric power companies, BOP and stack manufacturers, gas companies and others.

2. Outline of the 1000 kW MCFC power plant

From the point of effective use of energy and environmental conservation, the MCFC power plant is expected to be ready for commercial use early in the 21st century in Japan.

2.1. Development targets and schedule of the power plant

The development targets for this power plant are as follows:

Rated power: 1000 kW (AC).
Plant efficiency: 45% (gross).
Stack decay rate: 1%/1000 h.
Operation time: 5000 h.

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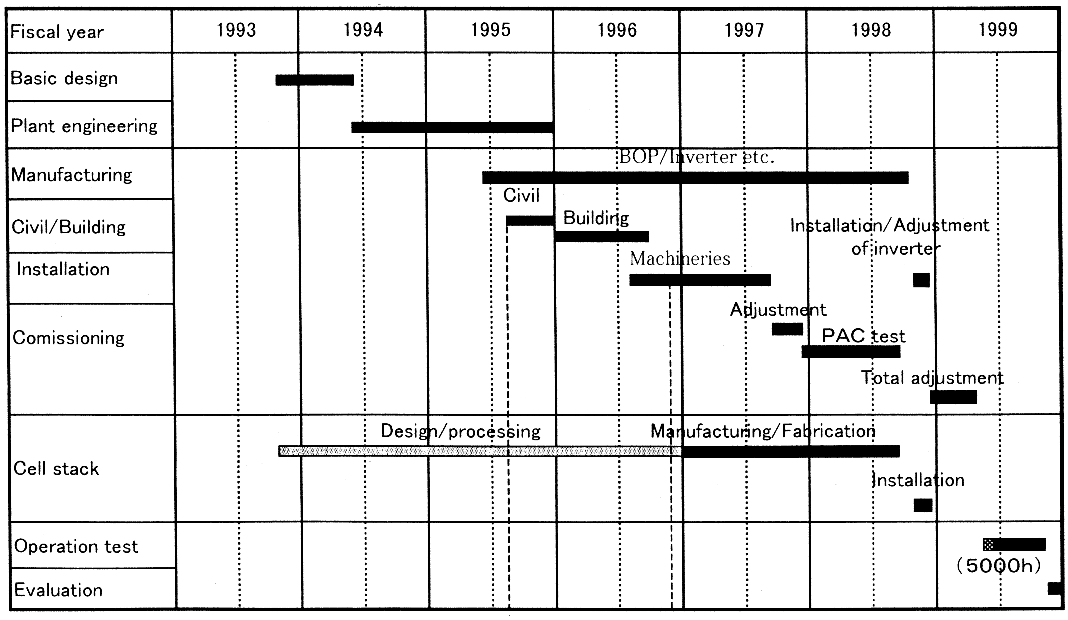
Table 1
Development schedule of 1000 kW MCFC power plant



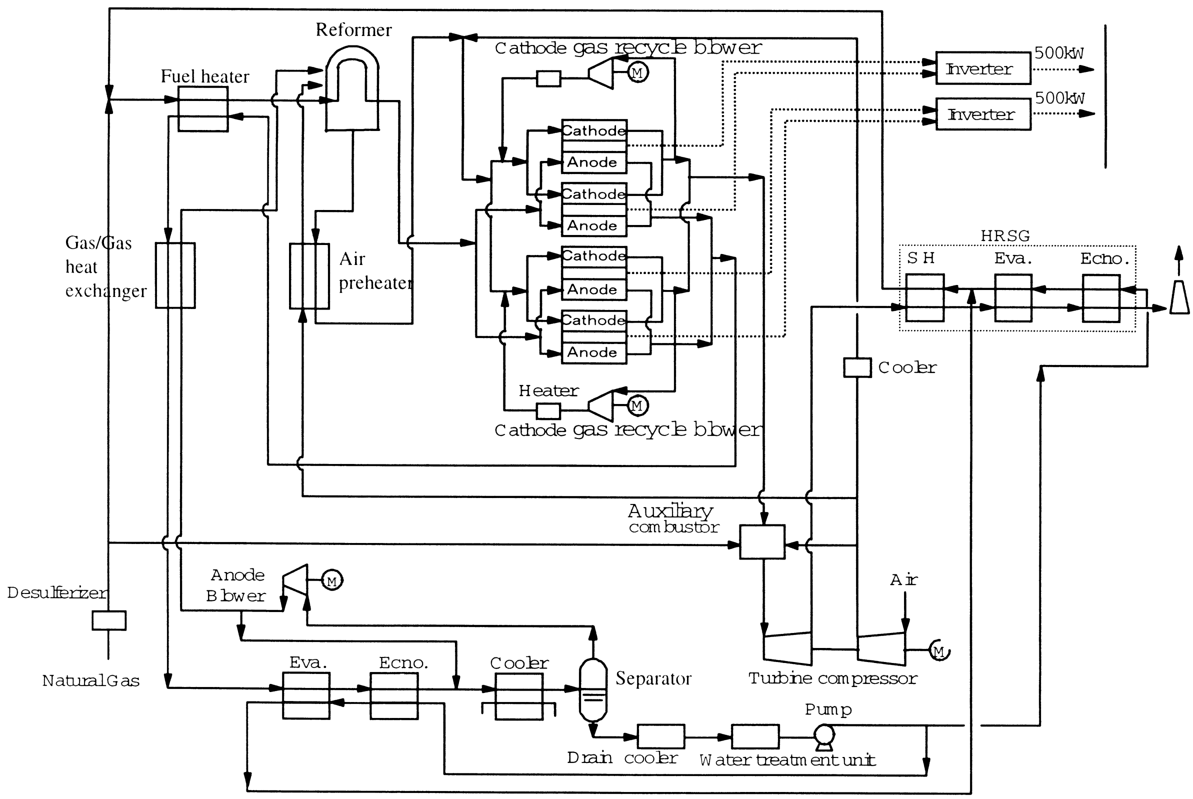


Fig. 1. Process flow diagram for 1000 kW power plant.

Environmental effect: Less than regulated value
Fuel: LNG

The power plant has the following objectives as well as the above targets.

- To establish a basic system for large scale commercial MCFC plant in the future.
- To confirm the safety, reliability and operational characteristics.
- To demonstrate the performance targets in the above development targets and the plant operation.
- To obtain data and issues for designing future MCFC power plants.

Table 1 shows the development schedule of the plant. According to the R&D schedule, the design, manufacture, installation, adjustment and operation test of the plant has been underway since FY 1993.

Presently, the test operation has just started, and will be continued until January 2000 when operating time reaches 5000 h.

Final evaluation for the plant will be scheduled around the end of FY 1999.

2.2. System configuration

The process flow diagram for the 1000 kW MCFC power plant is shown in Fig. 1.

The power plant consists of a *fuel processing system* including a reformer and an anode gas blower, *fuel cell stack systems A and B* including each two 250-kW stacks and a cathode gas recycle blower, respectively, an *exhaust heat recovery system* including a turbine compressor and heat recovery steam generator (HRSG), *a control system* and *utility system.*

The main characteristics of the system are as follows;

- Anode exhaust gas is used as the combustion fuel of the reformer.
- CO_2 produced in the anode is recycled to the cathode through the combustion chamber of the reformer.
- H_2O produced in the anode is separated and recycled as reforming steam through the HRSG.

Table 2
Plant specification

Item	Specification
Operating pressure	0.49 MPa
Operating temperature	Cathode in: 580°C
	Cathode out: 670°C
Stack A: Operating voltage	0.786 V
Current density	92.4 mA/cm^2
Stack B: Operating voltage	0.763 V
Current density	121 mA/cm^2
Fuel utilization	76.2%
Steam carbon ratio	3.5
Power output	1000 kW
Total fuel consumption	140.9 kg/h
Plant efficiency	46.7% (gross)

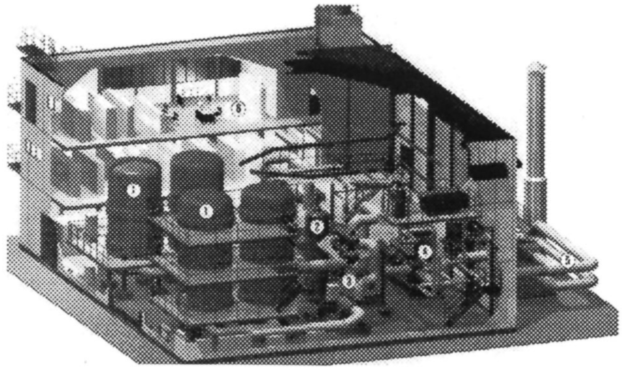


Fig. 2. Sectional view of the plant.

- The recycled cathode exhaust gas controls cathode inlet gas temperature.
- Cathode exhaust gas with high temperature (670°C max.) is used to run the turbine compressor and then used as the heat source for HRSG to produce the reforming steam.

The plant specification is shown in Table 2. A sectional view of the plant is shown in Fig. 2. Main components of the plant are located indoors except the HRSG.

3. Process and control (PAC) test

3.1. Objectives and features

Before the stacks are installed in the plant, plant characteristics, controllability and safety were confirmed and adjusted in the PAC test. These were performed for the purpose of carrying out smoothly the overall adjustment and operational tests after stack installation, and to confirm that each equipment satisfied the design specification.

Table 3
PAC test results

Test item	Test result
(1) Performance	
Max. capacity	1,000 kW (simulated)
Min. power	300 kW (simulated)
Load change rate	Max. 5%/min.
Emission, etc.	Less than regulation
	(Noxious waste water, noise, vibration)
(2) Reliability, operability, safety	
Operating time	T/C: 3200 h
	Refomer: 2500 h
Load operation	30–100% (simulated)
Load trip	30–100% to 0% (safety stop)
Differential pressure	Less than the specification
	(Final adjustment in operation)
(3) Operating procedure	
Start and stop procedure	Established
Start-up time	Cold start: about 7.5 h
	Hot start: about 5 h

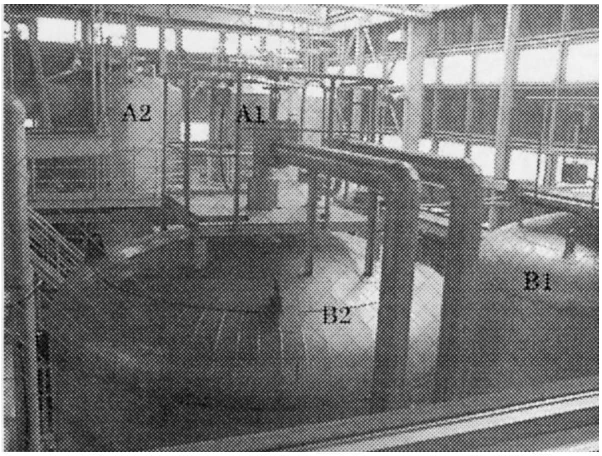


Fig. 3. The completed power plant.

The PAC test was performed in conditions as close as possible to the plant condition with actual MCFC stacks. Therefore, the following simulation was applied in this PAC test.

3.1.1. Simulation of cell voltage

The cell voltage was calculated with the plant conditions by means of a simulation program. The cell voltage determines the expected current density and process data.

3.1.2. Simulation of cell reaction

In order to simulate the volume changes of anode and cathode gases, heat generation and fuel consumption by fuel cell reaction, this plant has some flow control loops and electric heaters for the PAC test.

3.1.3. Simulation of differential pressure control

In order to simulate a pressure difference among anode, cathode and MCFC stack vessel without real MCFC stacks, this plant has a simulation vessel in each fuel cell stack systems A and B, respectively. Furthermore, orifices in piping simulate pressure drop in the real cell stack.

3.2. Results of PAC test

PAC test of the 1000 kW power plant was carried out from March to November in 1998.

Table 4
250 kW stack specification

Item	Stack A	Stack B
Gas flow type	Cross-flow	Co-flow
Stack constitution	six modules	two sub-stacks
Number of cell	300 cells (50×6)	280 cells (140×2)
Electrode area	1.21 m^2	1.0 m^2
Rated power	250 kW (AC)	250 kW (AC)
Cell voltage[a]	786 mV	763 mV
Current density[a]	92.4 mA/cm^2	121 mH/cm^2
Vessel size (mm)	ϕ 3600×10850	ϕ 3400×9400

[a] In high efficiency operation.

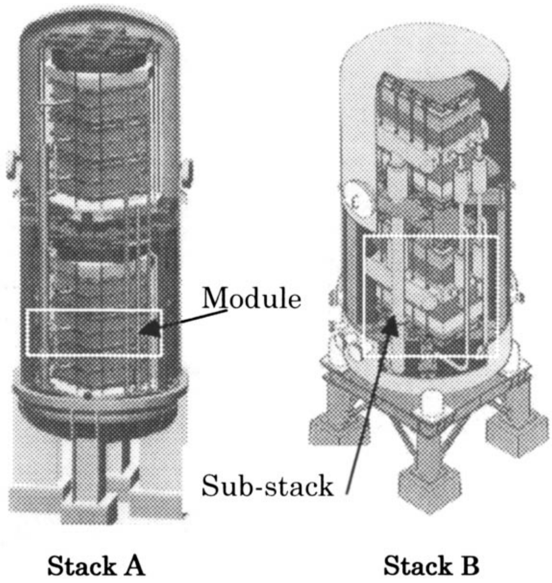


Fig. 4. Sectional view of the 250 kW stack.

According to the plant start-up procedure, the operational test of the heat recovery system including the HRSG and turbine compressor, the fuel processing system including the reformer, and fuel cell system including the cathode gas recycle blowers and the simulated stacks, were performed in sequence.

The total plant operational test, preliminary test and data collection before the official inspection, and plant check and maintenance were performed in accordance with our test schedule.

We achieved the objectives in a serial PAC test. Additionally, a forecast was obtained that included an efficiency of 45%, which was a development target from the analysis of many kinds of collected data.

Table 3 shows the results of PAC test.

4. Operation test

After the fuel cell stacks were pre-fabricated as modules or sub-stacks and preliminary testing was completed at

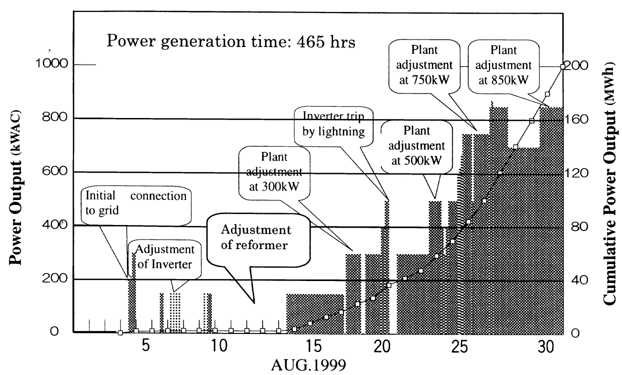


Fig. 5. Trend of power output in initial phase.

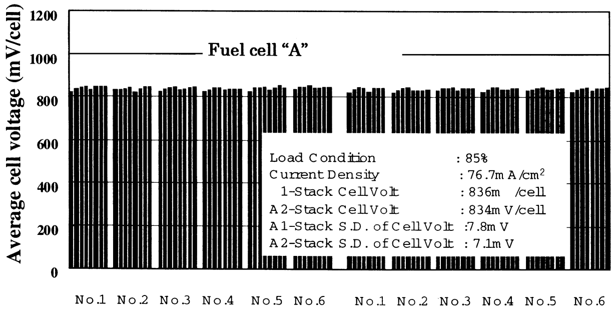


Fig. 6. Cell voltage distribution at 850 kW plant operation.

stack maker's works respectively, they were installed at the test site in March 1999. After an overall adjustment had been carried out, power generation test was started.

Fig. 3 shows the completed power plant after the installation of the fuel cells.

4.1. Structure and specification of stack

This plant has two different types of stack, one is a cross-flow type stack of Hitachi (fuel cell A), the other is a co-flow type stack of IHI (fuel cell B); each fuel cell consists of two 250-kW stacks. In fuel cell A, the 250 kW stack consists of six modules, which contain 50 cells each and in fuel cell B, two sub-stacks having 140 cells each are shown in Table 4.

Fig. 4 shows a sectional view of the 250-kW stacks A and B.

4.2. Status of the power generation test

At the beginning of July 1999, final conditioning of the stacks was completed at approximately 600°C and 5 ata. After that, final adjustment of BOP including the fuel cell was performed. On *August 4, 1999*, the first fuel gas was introduced into the stacks, and the plant produced its initial power.

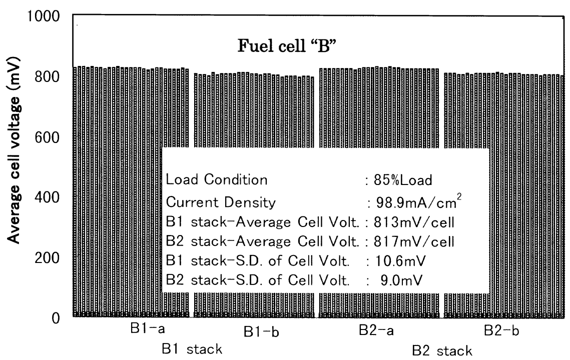


Fig. 7. Cell voltage distribution at 850 kW plant operation.

Table 5
Average cell voltage in OCV

Stack	A1 stack	A2 stack
No. of cells	300 cells	300 cells
Average cell voltage	947 mV	947 mV
Standard deviation	1.9 mV	2.1 mV
Stack voltage	284.1 V	284.1 V

The pattern of starting-up was as follows;

1. Turbine compressor starting,
2. Auxiliary combuster starting,
3. HRSG starting,
4. Reformer starting,
5. Fuel gas to stacks,
6. Connection to grid of inverter.

The start-up time of the plant from the cold condition was about 7.5 h, from the turbine compressor starting to the connection to grid with 30% load operation.

Fig. 5 shows the operating condition of the initial phase. So far, the differential pressure, the temperature and the cell voltage of the stacks have been keeping a stable condition in each load. We experienced an inverter trip due to low voltage during the 500-kW load operation at midnight on August 20, 1999, as shown in Fig. 5, but the plant was switched to no load automatically, and did not experience any problems. As of August 31, the plant has been operated at 850 kW, and the total generated power is 200 MW, as shown in Fig. 5.

Figs. 6 and 7 show the cell voltage distribution of fuel cells A and B, respectively, for the first 850 kW test of the power plant. The voltages are measured at every sixth or seventh cell in fuel cell A, and at every fifth cell in fuel cell B. The average cell voltages in Figs. 6 and 7 were calculated from measured voltages described above.

The average cell voltage in each fuel cell is almost flat. Stack performance and plant efficiency will be evaluated in near future.

Tables 5 and 6 show the cell voltage at open circuit in fuel cells A and B, for reference.

4.3. Future plan

The power generation test will be continued up to January 2000. During this test, we will confirm the

Table 6
Average cell voltage in OCV

Stack	B1 stack	B2 stack
No. of cells	280 cells	280 cells
Average cell voltage	956 mV	953 mV
Standard deviation	2.77 mV	3.22 mV
Stack voltage	267.7 V	266.8 V

1000 kW rated power, the plant efficiency, the decay rate of stack, partial load characteristics and after matters.

5. Conclusion

We hope to report the results that we obtain from the demonstration test at the next opportunity and continue the effort to commercialise the use of MCFC power plant.

6. Uncited references

[1,2]

Acknowledgements

This project has been conducted under a contract from NEDO as a part of the New Sunshine Program of MITI. We appreciate the advice and support of NEDO and MITI.

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