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Short communication

Development of a performance test method for PEFC stack

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Abstract

It is important to obtain repeatable I–V characteristics in order to evaluate the steady-state performance of a PEFC stack. A performance test method would be useful for this purpose; so, we conducted experiments with several PEFC stacks to collect data.

In this study, we set two goals. One was to stabilize the PEFC stack output, and the other was to clarify the operating conditions and to determine the accuracy required to control the parameters that affect the I–V characteristic curve, including stack-operating temperature (coolant outlet temperature), gas operating pressure, gas utilization ratio (gas stoichiometry) and gas dew point.

Through experiments, we found a means of obtaining repeatable data with a stack voltage accuracy of ±1%.

Keywords: Polymer electrolyte fuel cells; Proton exchange membrane fuel cells; Performance test; I–V curve; Stack

1. Introduction

In light of the expanding use of fuel cell vehicles, the competition in the development of stacks, the main component of a fuel cell system, is expected to accelerate among stack makers in the world. Nevertheless, stack development is still at an early stage in terms of performance, cost, durability, etc., and the usage of stacks has not spread. For this to happen in a true sense, a standardized procedure for testing the performances of stacks is in demand by both automobile manufacturers and stack makers. In the present study, basic data on stacks were collected with regard to stack testing standardization, and from the collected data, the following two types of conditions were examined for the development of stacks with reproducible current–voltage characteristics [1–5]:

(1) warm-up conditions before the test;
(2) test conditions necessary for containing the variations of average cell voltage within ±1.0%.

2. Method and test apparatus

2.1. Test apparatus

The test apparatus employed is schematized in Fig. 1 [6]. Pure hydrogen was used as fuel and air as the oxidation agent. Each anode and cathode was provided with a humidifier to control the humidity of hydrogen and air, respectively. A dew point meter was set in the pipe connected between the stack and humidifier on both anode and cathode sides, and the pipes including the dew point meter areas were warmed with a heater to prevent condensation. Cooling water (coolant) was fed into the stack in such a way that the coolant temperature at the outlet of the stack was kept stable. An ion exchange resin was employed to keep the conductance of the coolant and humidifying water no higher than 0.2 μS cm^{-1}. The ambient temperature was maintained between 20 and 25 °C, while the stack was shielded from direct sunlight, forced airflow of the air conditioner and heat radiated from other test equipment. Under these experimental conditions, various tests were conducted on some stacks of 1.0, 2.5 and 5.0 kW classes (specifications are shown in Table 1) by applying the method below.

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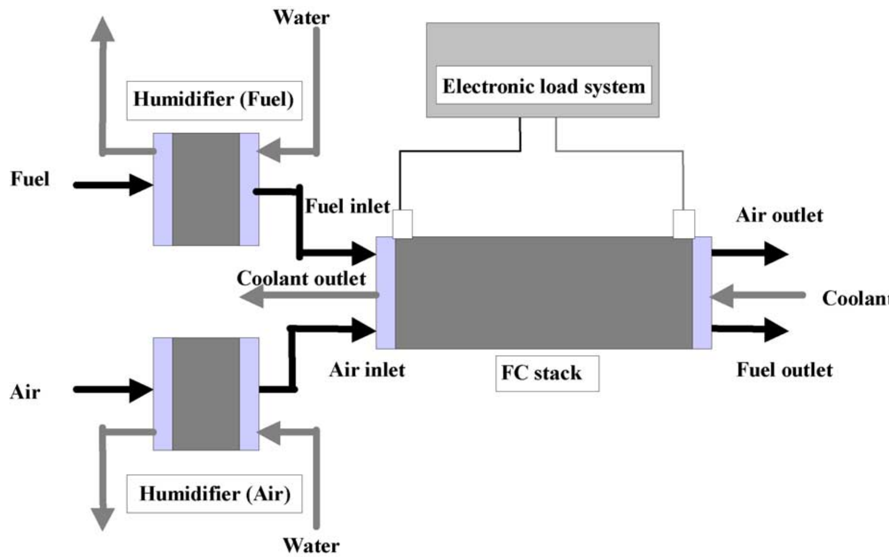

Fig. 1. Test apparatus.

2.2. Test method

2.2.1. Examination of warm-up conditions

The test procedures to confirm the warm-up conditions are shown in Fig. 2 for the case of increasing the power generation to the maximum output [7,8].

(a) Purge the anode and cathode flow fields with N_2 gas.
(b) Thermal-stabilize the stack with coolant.
(c) Warm-up to stabilize the moisture content of the polymer membrane inside the stack.
(d) Feed fuel and air into the stack at a flow-rate corresponding to the set current value. After confirming flow-rate stability, set the load value on the stack.
(e) Adjusting the coolant outlet temperature, dew point and operating gas pressure (=stack outlet gas pressure: ex. atmospheric pressure) to a standard value (Table 2).

Table 1
Specification of the stacks

Stack	A	B	C	D	E
Rated power (kW)	2.5	1.0	5.0	5.0	2.5
Rated current density ($mA\,cm^{-2}$)	450	400	570	500	450
MEA active area (cm^2)	225	80	300	200	225
Number of cells	40	50	50	80	40
Method of cooling	Water	←	←	←	←
Coolant inlet temperature (°C)	65	65	40∼70	72	65
Coolant flow-rate ($L\,min^{-1}$)	12	–	–	10	12
Fuel/air pressure (MPa G)	0∼0.2	←	0∼0.3	0	0∼0.2

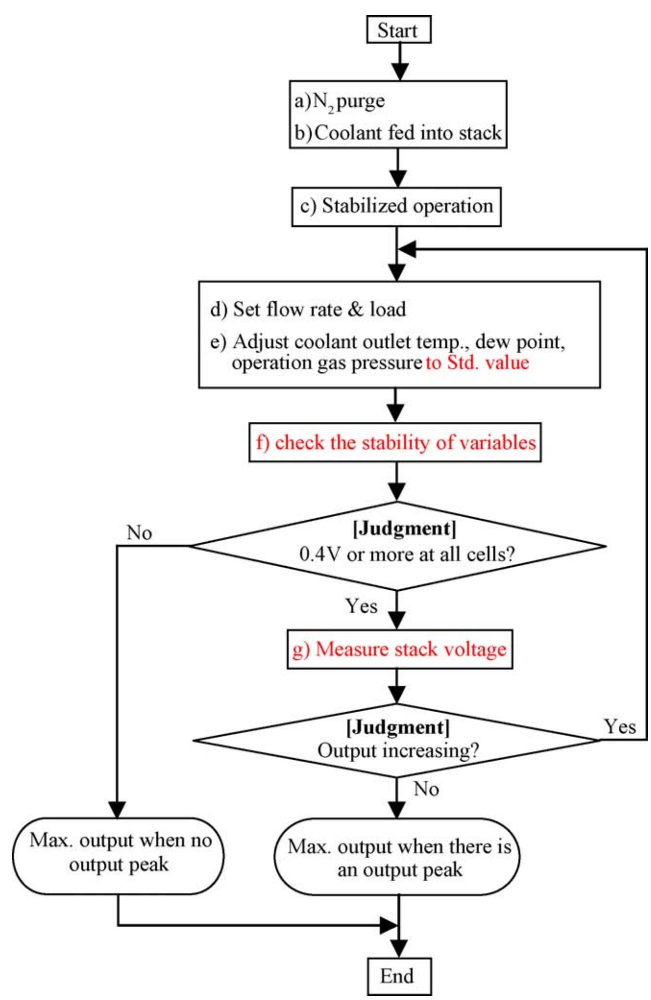

Fig. 2. Test procedures to confirm the warm-up condition.

Table 2
Standard values of test conditions

Test condition	Standard value
Coolant outlet temperature (°C)	75
Fuel dew point (°C)	65
Air dew point (°C)	65
Fuel utilization rate (%)	70
Air-utilization rate (%)	40
Operating gas pressure (MPa G)	0

(f) Check all the variables to have been stabilized by real time monitoring.
(g) Measure the stack voltage and terminate the test, when the peak output was obtained. While measuring the stack voltage, observe the voltage of each cell. When any one cell exhibit a voltage of 0.4 V or less, stop loading and end the test (more discussions needed on test ending criteria).

The "maximum output" is defined as the peak value of output power. In case there is no peak value, the maximum output power within the range of stable power generation is defined as maximum output. The procedures for the rated output test are identical with the above procedures, except that rated output value is applied as set value.

2.2.2. Examination of test conditions

Four parameters were selected as test conditions affecting the measurement of current–voltage characteristics: (a) coolant outlet (stack operation) temperature; (b) fuel/air dew points; (c) fuel/air-utilization rates; (d) operating gas pressure (back pressure). These parameters were varied, while the load on the test apparatus was kept constant, and changes in the average cell voltage were measured. Standard values were determined for the test conditions on the basis of the stack specifications provided by the stack maker (Table 2). When all the test conditions were set (near) to their standard

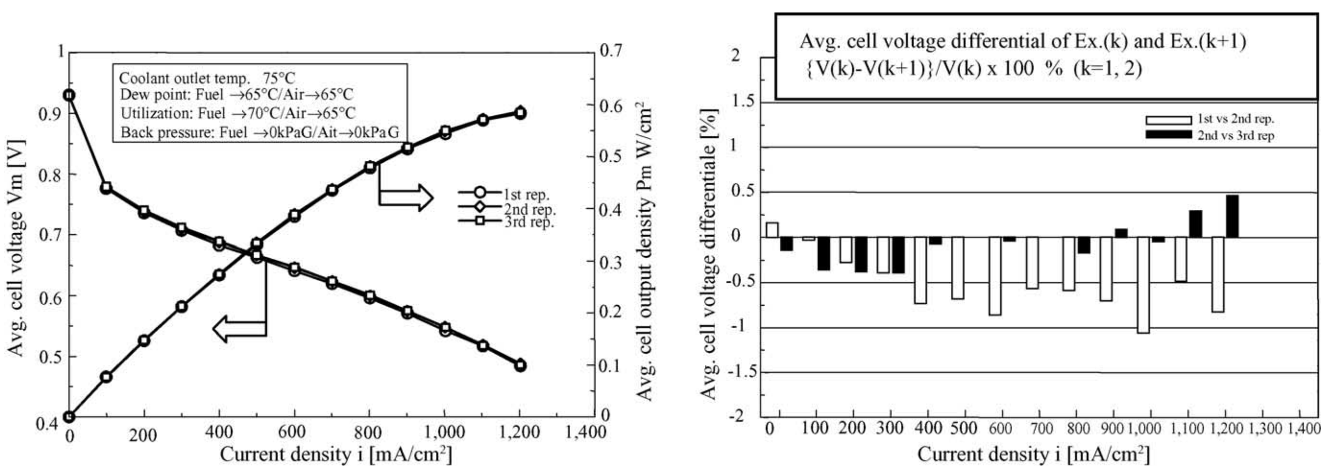

Fig. 3. Effect of warm-up on I–V curve: (a) I–V curve transition in three consecutive tests; (b) difference in average cell voltage between two tests.

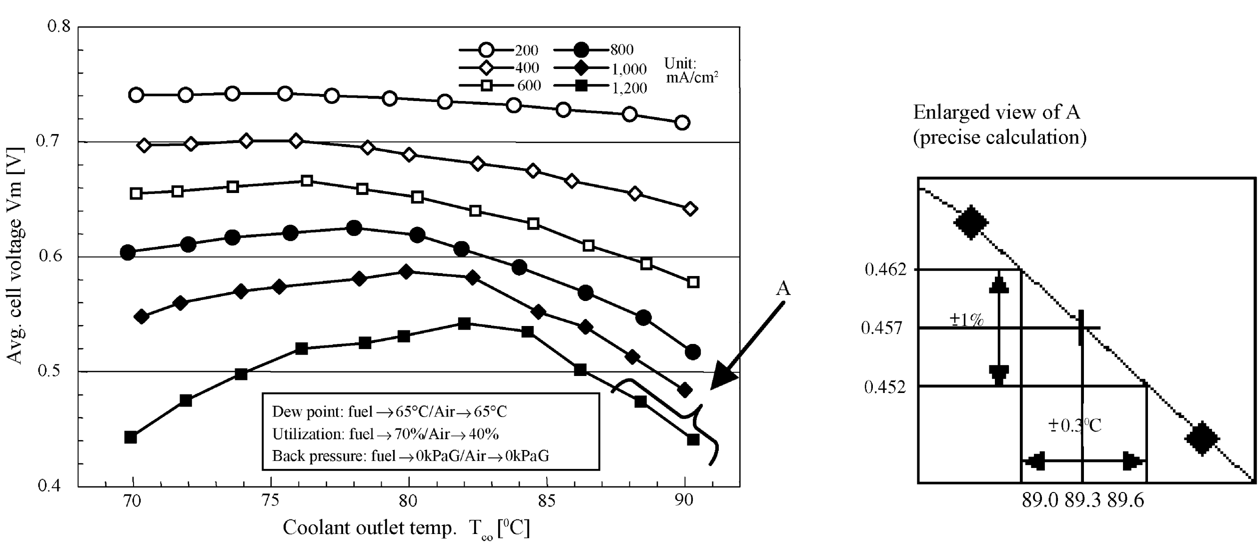

Fig. 4. Influence of coolant outlet temperature on average cell voltage (stack E).

Table 3
Control precision for coolant outlet temperature

Current density (mA cm^{-2})	Coolant outlet temperature (°C)	Control precision (°C)	Coolant outlet temperature (standard) (°C)	Control precision (°C)
200	89	±2.2	75	±6.2
400	89	±1.0	75	–
600	89	±0.6	75	±3.2
800	89	±0.3	75	±3.4
1000	89	±0.3	75	±2.1
1200	89	±0.3	75	±0.5

values, the overall condition was called "standard operating condition".

3. Results

The current–voltage characteristics of various stacks were measured, and the four parameters enumerated in the above Section 2.2.2 were examined. While this paper reports the results obtained from one type of stack (stack E in Table 1), similar results on warm-up and test conditions were obtained from the other stacks investigated in the present study.

3.1. Warm-up conditions

The measured current–voltage characteristics are shown in Fig. 3. After 5 min of continuous electric generation at the rated output level, the stack was operated until the maximum power output was observed, whereupon the test was terminated. This routine was repeated three times to verify the reproducibility of the test. The results of the first and second repetitions indicated that the average cell voltage was stable within ±1.1%. The results of the second and third repetitions indicated a ±0.5% stability. Thus, the warm-up conditions proved capable of yielding a ±0.5% reproducibility of current–voltage characteristics, once the stack is operated to the maximum output during the warm-up. Similarly the rated output test confirmed that 5 min of electric generation at the rated power output was sufficient to yield a ±1.0% reproducibility of current–voltage characteristics.

3.2. Setting of test conditions

The influence of coolant outlet temperature on average cell voltage is shown in Fig. 4. The average cell voltage rose with an increase in coolant outlet temperature at high current density levels, though not so much at low current densities. From a certain temperature upward, however, the average cell voltage declined with an increase in coolant outlet temperature.

Allowing the variations of average cell voltage with a ±1.0% range, the strictest control precision for coolant output temperature is given in Table 3. The table also shows the control precision for a coolant output temperature of 75 °C, which is a standard stack-operation temperature among many laboratories. As illustrated in the enlarged view of A in Fig. 4 above, control precision is expressed in terms of the coolant outlet temperature range necessary for the average cell voltage to converge within a ±1.0% range. Similar examination was made to determine the humidifying condition

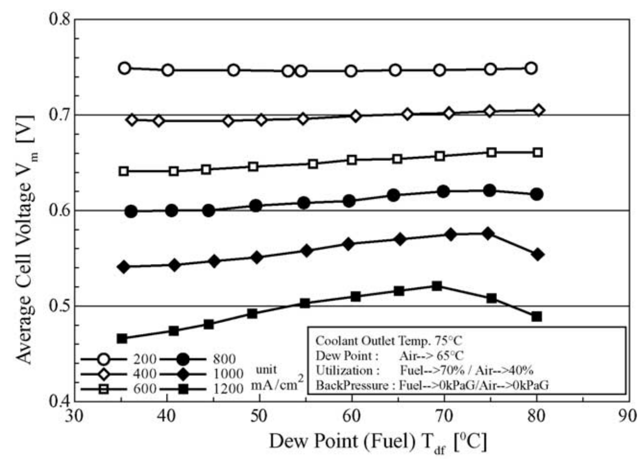

Fig. 5. Effect of fuel dew point (stack E).

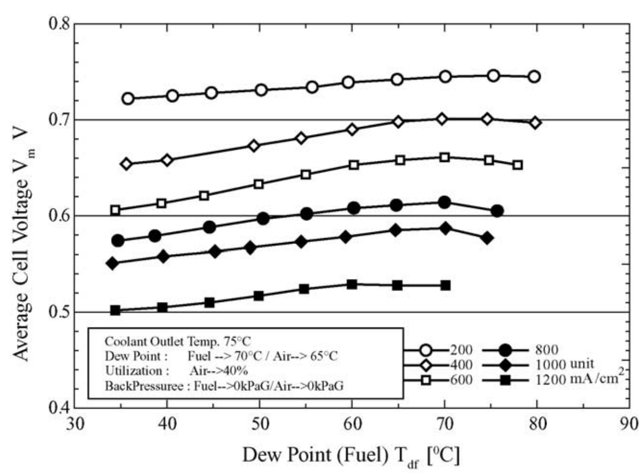

Fig. 6. Effect of air dew point (stack E).

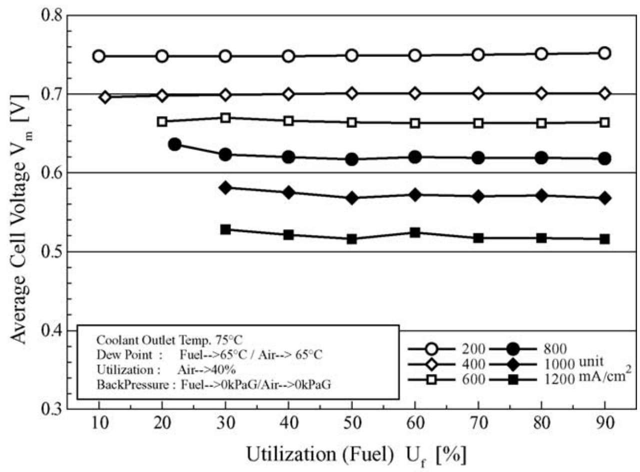

Fig. 7. Effect of fuel utilization (stack E).

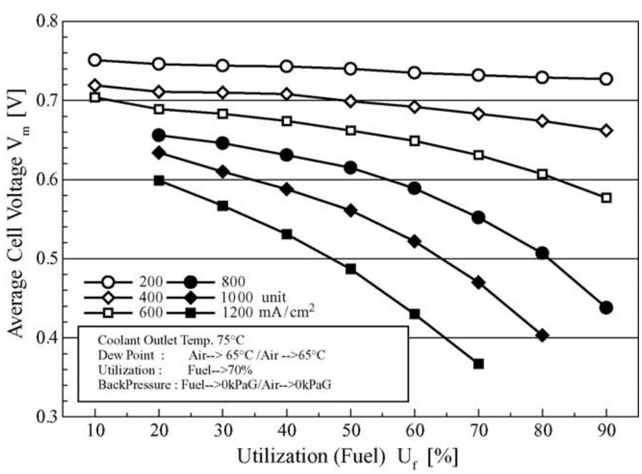

Fig. 8. Effect of air-utilization (stack E).

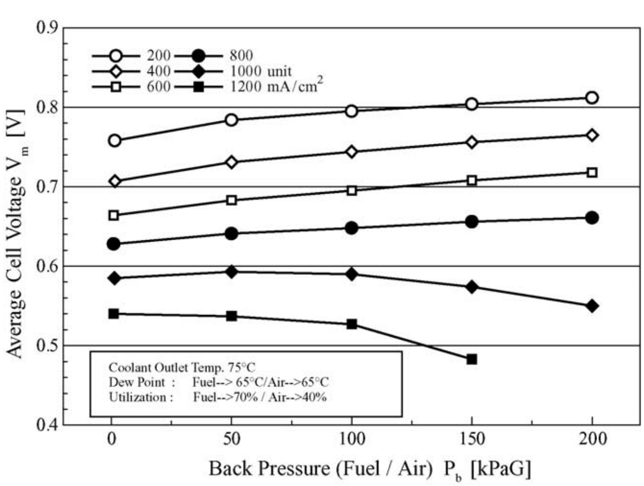

Fig. 9. Effect of fuel/air pressure (stack E).

Table 4
Proposed control precision for test conditions

Test conditions	Control precision	
	Rated output test	Maximum output test
Coolant outlet temperature (°C)	±1.2	±0.5
Fuel dew point (°C)	±4.1	±3.0
Air dew point (°C)	±3.7	±1.6
Fuel flow-rate (per electrode area) ($cm^3\ (min\ cm^2)^{-1}$)	±0.8	±0.6
Air flow-rate (per electrode area) ($cm^3\ (min\ cm^2)^{-1}$)	±0.9	±0.9
Operating gas pressure (kPa)	±5.0	±5.0

(Figs. 5 and 6), fuel/air-utilization rates (Figs. 7 and 8) and operating gas pressure (back pressure, Fig. 9).

4. Conclusion and discussion

A power generation test was conducted on various types of stacks in order to contribute to the standardization of test procedures for stack performance. The results obtained are summarized below.

4.1. Warm-up conditions

When tests were conducted according to the procedures in Fig. 2, the reproducibility of a stack's current–voltage characteristics was achieved with a stack voltage accuracy of ±1.0% by operating the stack to the maximum output one time in the case of a maximum output test and by generating power at the rated load for 5 min in the case of a rated output test.

4.2. Test conditions

The present study found that by satisfying the control precision levels for various test conditions as listed in Table 4, the average cell voltage of a stack could be contained with a stack voltage accuracy of ±1.0%. To ensure reproducibility, the control of coolant outlet temperature requires special care, as it requires a particularly strict control precision within ±0.5 °C. While in rated output test, acceptable value of this of ±1.2 °C could be applied. Precision in other test conditions is normally obtainable by existing instruments. Similar studies have also been carried out with large-sized fuel cells, and the results revealed that the control accuracy presented herein is sufficient.

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