Development of Lifetime Estimation Method for MCFC Stack

Background

Cell voltage of molten carbonate fuel cell (MCFC) decreases with operating time since the electrolyte in the cell is consumed by mainly corrosion of cell components. Since MCFC power plants are operated for long time, lifetime estimation of MCFC stack would be a strong tool to improve stack performance and to optimize the plant operation. Lifetime estimation method for single cells has been already developed. Application of lifetime estimation method to the stacks is desired.

Objectives

Stack lifetime estimation method is developed for stack performance improvement, estimation of stack lifetime and optimal plant operation.

Principal Results

(1) For application of lifetime estimation method to stacks, an electrolyte content equation for the stack as shown in Table 1 is essential. Especially, parameters e_0 and Scor in step ① in Table 1 have to be determined. For single cells, e_0 and Scor can be determined using measured internal resistance (IR). However, measurement of IR for stacks is difficult because of large cell area. Therefore, e_0 and Scor were determined using measured cell voltages of 0.4 m^2 and $1m^2$ stacks. As shown in Table 2 and Fig.1, e_0 for 0.4 m^2 stack was in the range from 2.95 to 3.3. e_0 for $1m^2$ stack was in the range from 2.35 to 3.3. Scor was 6.3 for both 0.4 m^2 and $1m^2$ stacks. Finally stack lifetime estimation method has been developed as shown in Table1. For verification of the method, measured and estimated electrolyte contents after 10,000 hours were compared in Fig.2.Estimated electrolyte content agrees with measured electrolyte content. Precision of the method was confirmed.

(2) Each cell voltage of a stack was analyzed. A low initial electrolyte content cell had low cell voltage. It was confirmed that difference in cell voltages of a stack originates from initial electrolyte content as shown in Table 2. In addition, e_0 for a stack with larger cell area is lower than that for a stack with smaller cell area. Low e_0 for a stack with larger cell area would be caused by non-uniformity of stack tightening pressure in electrolyte impregnation process. Stack tightening pressure becomes non-uniform since stack height decreases by impregnation of the electrolyte into the matrix. Pre-impregnation process has to be adopted to avoid stack height change. In addition, since Scor depends on metal surface area of a separator plate, reduction of the metal surface area by improvement of the separator design is important.

(3) Using the stack lifetime estimation method, cell voltage change up to 40,000 hours was estimated. Estimated cell voltages were shown as base line in Fig.3. Base line means cell voltages were estimated with center temperature of the stack at 638°C. A high initial electrolyte content cell in a $1m^2$ stack is able to keep 90% of initial cell voltage after 40,000 hours. Therefore, a high initial electrolyte content cell would achieve lifetime target of 40,000 hours. Subsequently, effect of center temperature of the stack on cell voltage was investigated as shown in Fig.3. Lower center temperature of the stack has made lifetime longer.

Consequently, MCFC lifetime estimation method has been developed by a compilation of CRIEPI's MCFC development activities, even though a lifetime estimation method for other fuel cells has not been achieved. By the stack lifetime estimation method, optimal MCFC plant operation has been achieved.

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References

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Table 1 Stack lifetime estimation method based on reaction resistance model

①Electrolyte content at certain time (e)	$e = e_0 - \frac{(90.43 + 9.02S_{cor})t^{0.5} + 30.48 + 2.029S_{cor}}{1000}\exp\left(\frac{-10170}{1/T - 1/923}\right)$
②Reaction area (S_{H_2}, S_{H_2g})	$S_{H_2} = 0.318e$ 、 $S_{H_2g} = 1.75S_{H_2}$
③Parameters (A_1, A_2)	$A_1 = RT\delta_{H_2} / F^2n^2K_{H_2}D_{H_2}S_{H_2}$ 、 $A_2 = R^2T^2 / F^2n^2K_{H_2R}S_{H_2g}$
④Reaction resistance (R_a)	$R_a = (A_1 + A_2P^{0.5})P_{H_2}^{-0.5}$
⑤Cell voltage (V)	$V = E - \eta_{NE} - j(R_a - R_c - R_{ir})$

e: Electrolyte content, e_0: Initial electrolyte content, Scor: Coefficient of corrosion area, t: Time, T: Temperature, S: Reaction area, A: Coefficient of anode reaction resistance, D: Diffusion constant, R: Gas constant, K: Henry constant, F: Faraday constant, n: Electron number, δ: Diffusion distance, P: Pressure, E: Open circuit voltage, j: Current density, η_{NE}: Nernst loss, Ra: Anode reaction resistance, Rc: Cathode reaction resistance, R_{ir}:Internal resistance, g: Gas phase

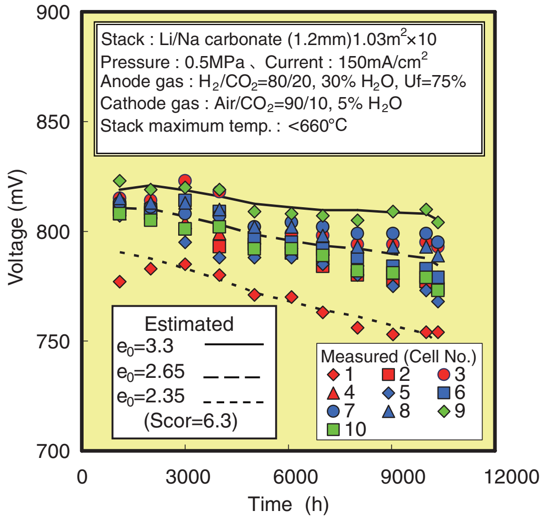

Fig.1 Comparison between measured and estimated cell voltages of 0.4 m^2 stack

e_0 and Scor are able to determined using measured cell voltages.

Table 2 Summary of e_0 and Scor

Cell area	Cell voltage	e_0	Scor
$0.4m^2$	High	3.3	6.3 (According to Separator configurations of $0.4m^2$ and $1m^2$ stacks are same)
	Mean	3.15	
	Low	2.95	
$1m^2$	High	3.3	
	Mean	2.65	
	Low	2.35	

Cell voltage depends strongly on e_0.

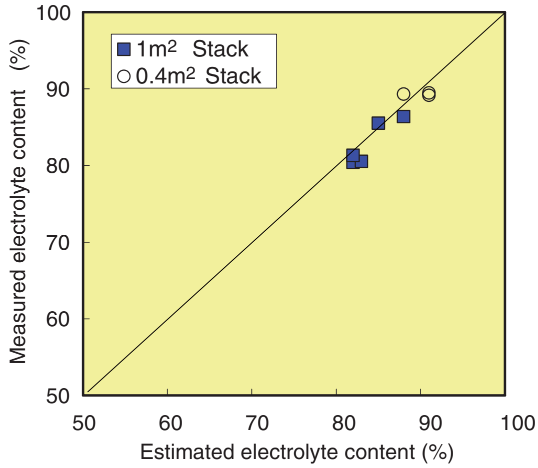

Fig.2 Comparison between measured and estimated electrolyte contents after operations

Measured electrolyte contents agree with estimated electrolyte contents.

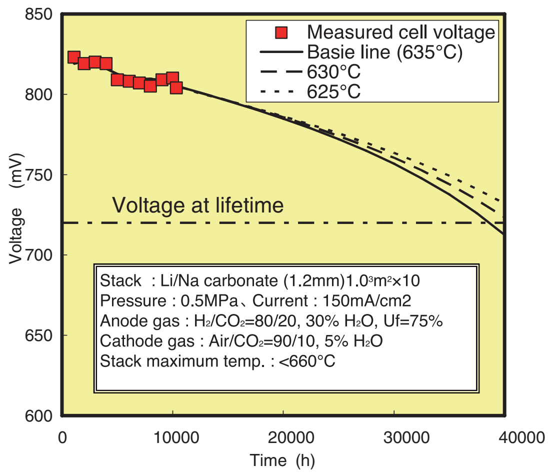

Fig.3 A result of estimated lifetime of $1m^2$ stack

Target of lifetime (40,000 h) would be achieved.