

# Dependence of high-temperature PEM fuel cell performance on Nafion® content

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## Abstract

Operating a proton exchange membrane (PEM) fuel cell at elevated temperatures (above 100 °C) has significant advantages, such as reduced CO poisoning, increased reaction rates, faster heat rejection, easier and more efficient water management and more useful waste heat. Catalyst materials and membrane electrode assembly (MEA) structure must be considered to improve PEM fuel cell performance. As one of the most important electrode design parameters, Nafion® content was optimized in the high-temperature electrodes in order to achieve high performance. The effect of Nafion® content on the electrode performance in H<sub>2</sub>/air or H<sub>2</sub>/O<sub>2</sub> operation was studied under three different operation conditions (cell temperature (°C)/anode (%RH)/cathode (%RH)): 80/100/75, 100/70/70 and 120/35/35, all at atmospheric pressure. Different Nafion® contents in the cathode catalyst layers, 15–40 wt%, were evaluated. For electrodes with 0.5 mg cm<sup>-2</sup> Pt loading, cell voltages of 0.70, 0.68 and 0.60 V at a current density of 400 mA cm<sup>-2</sup> were obtained at 35 wt% Nafion® ionomer loading, when the cells were operated at the three test conditions, respectively. Cyclic voltammetry was conducted to evaluate the electrochemical surface area. The experimental polarization curves were analyzed by Tafel slope, catalyst activity and diffusion capability to determine the influence of the Nafion® loading, mainly associated with the cathode.

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## 1. Introduction

Operating high-temperature proton exchange membrane (PEM) fuel cells has numerous advantages: it reduces the effect of carbon monoxide poisoning of the anode from an impure hydrogen feed, provides easier heat rejection, produces more usable waste heat to increase system efficiency and accelerates the electrochemical reaction kinetics. High-temperature PEM fuel cells have increasingly received worldwide attention due to their potential use in the hydrogen economy. From a systems viewpoint, they are desired to be operated close to the atmospheric pressure to reduce system complexity by eliminating the need for an air compressor and

make the system more durable. However, the water uptake and consequently proton conductivity decreases considerably at elevated temperature and low relative humidity, leading to a large resistive loss and a reduction in cell voltage and efficiency. Numerous works have been done on improving membrane conductivity and other characteristics [1–7]. Ionomem Corp./University of Connecticut (UConn) has reported an innovative proton exchange high-temperature membrane that provides good ionic conductivity at the elevated temperatures and under-saturated environment [8]. So, in this study, the membrane used was the Ionomem/UConn high-temperature membrane, known as NTPA membrane. The catalyst layer, referred to as the active layer, is the location of the electrochemical reactions in PEM fuel cells. The catalytic activity for oxygen reduction in the cathode is reduced, as water is lost [9–11]; and the reduction of mass transport losses particularly

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at high current densities becomes necessary [12]. The catalyst layers need to be optimized to obtain high catalytic activity, proper gas diffusion properties, as well as good chemical and physical durability. Numerous works on catalyst layer optimization, such as catalyst loading, ionomer content, reactant diffusivity and ionic and electrical conductivity, have been reported [13,14].

As one of the critical parameters, the Nafion<sup>®</sup> ionomer was applied into the catalyst layer by impregnation or other incorporation methods. Many related studies have been reported on the effects of Nafion<sup>®</sup> content on the electrode performance [15–27]. However, different researchers suggested different optimal Nafion<sup>®</sup> loadings in the electrodes they studied due to the catalyst type [15–22] or pre-treatment conditions [26,27]. Even though most of the researchers provided the test results based on the same commercial catalyst 20% Pt/Vulcan XC-72 supplied by E-TEK [15–18,20,24,25], the electrodes providing the best cell performance and the highest power density comprised different optimal Nafion<sup>®</sup> loadings. Xu et al. [26] took advantage of the ethanesulfonic acid group to make carbon catalyst-support particles possess both electronic and protonic conductivities. Fuel cell electrodes made using the sulfonated catalyst showed a 60% higher performance than the untreated counterpart, while the optimal Nafion<sup>®</sup> content within the catalyst layer was reduced by nearly half. Similarly, the surface modification of carbon supported Pt fuel cell catalysts by attachment of a sulfonated silane was reported [27]. Optimum performances for both types of modified catalyst were reached at a 10 wt% Nafion<sup>®</sup> loading in the fuel cell catalyst layer and were significantly better than that for an untreated standard catalyst with 10 wt% Nafion<sup>®</sup> loading. The optimum performance of the untreated catalyst, at 30 wt% Nafion<sup>®</sup> loading, was slightly better than that of the best-treated catalyst. However, these studies about Nafion<sup>®</sup> loading in the electrodes did not report the effect of Nafion<sup>®</sup> content on the PEM fuel cell performance at the elevated temperatures (>100 °C). Most of the catalysts mixed with the optional Nafion<sup>®</sup> were evaluated at room temperature [18,19,21–25] or less than 100 °C [15–17,20].

In our previous study, the quantity of Nafion<sup>®</sup> in the Pt black catalyst layer was examined to optimize the characteristics of the reaction layer and to improve the cell performance at elevated temperature and low relative humidities under atmosphere pressure [28]. In this study, the catalyst used in the cathode catalyst layer as received was 46.7% Pt/C supplied by Tanaka Kikinzo Kogyo, Tokyo, Japan. This high surface area catalyst is becoming one of the most commonly used electrocatalyst for oxygen reduction in the PEM fuel cells. The properties of this active catalyst, including the electrochemical characteristics, have been discussed, and a preliminary test result of the Nafion<sup>®</sup> loadings at the 120 °C condition was presented [29]. In this paper, the dependence of the cell performance on the Nafion<sup>®</sup> content in the cathode catalyst layer was examined at three different test conditions (cell temperature (°C)/anode (%RH)/cathode (%RH)): 80/100/75,

100/70/70 and 120/35/35, ambient pressure, which represent a near fully humidified, a moderately humidified and a low humidified condition, respectively. The effect of Nafion<sup>®</sup> loadings, 15, 25, 35, 37 and 40 wt%, on the cell performance at these three different test conditions was studied and the detailed experimental results on the influence of the Nafion<sup>®</sup> loadings on the cell performance were first reported. The electrochemical surface area (ECA) of the electrodes with the different Nafion<sup>®</sup> contents was investigated on the electrodes by a cyclic voltammetry measurement. The dependence of the catalyst activity and gas diffusion on the Nafion<sup>®</sup> content was investigated. And the cathode activation overpotential from the Tafel slope was analyzed to further understand the effect of the Nafion<sup>®</sup> content on the high-temperature PEM fuel cell performance.

## 2. Experimental

### 2.1. Membrane electrode assembly (MEA) preparation

All of the catalyst-coated membranes (CCM) were prepared in-house by an identical procedure [10]. Ionomem/UConn high-temperature membrane ( $25 \pm 2 \mu\text{m}$  in thickness) was used [8]. The cathode catalyst layers were prepared by using 46.5% Pt supported on carbon catalyst (Tanaka Kikinzo Kogyo, Tokyo, Japan) and Nafion<sup>®</sup> 5 wt% solution (EW1100, supplied by Solution Technology Inc.). Catalyst mixtures were prepared in the following way: Pt/C catalyst was mixed with Nafion solution and a certain amount of alcohol. After a few minutes of stirring, the mixture was then processed by sonication for at least 1 h. The catalyst ink was stirred again for a few minutes to avoid the solid materials settling. Then, the mixture was sonicated for another 1 h. These two steps, stirring and sonication were repeated several times until the catalyst was distributed well in the mixture. The solid materials did not readily precipitate from the solvent. The anode catalyst layers comprised two kinds of catalysts: Pt–Ru black (1:1 atomic ratio) with a Nafion<sup>®</sup> loading of 10 and 30% Pt–Ru/C (1:1 atomic ratio) with a Nafion<sup>®</sup> loading of 25 wt%. Both of these two anode catalysts were supplied by Alfa Aesar (Ward Hill, MA). The loadings of precious metals were  $0.50 \pm 0.05$  and  $0.40 \pm 0.05 \text{ mg cm}^{-2}$  for the cathode and the anode, respectively. After spraying both the cathode and the anode catalyst layers onto the membrane, the CCM was dried at 80 °C for 30 min and then hot pressed at 130 °C under 75 psi for 3 min.

The gas diffusion layers (GDL) used were prepared “in-house” using a silk-screening technique [30]. The heat-treated catalyst-coated membrane was “sandwiched” between two gas diffusion layers to obtain a  $25 \text{ cm}^2$  MEA for single cell polarization and voltammetry measurements. In the single cell test fixture (Fuel Cell Technologies Inc., NM), a single-serpentine pattern graphite flow field was used with an active area of  $25 \text{ cm}^2$ .

## 2.2. Cyclic sweep voltammetry (CV) measurement

One additional diagnostic tests was used besides the polarization tests. Cyclic sweep voltammetry was measured to determine the electrochemical surface area (ECA) of the cathode electrodes available for reactant adsorption. A Solartron SI1287 Potentiostat (Solartron Analytical, Houston Texas) was used for these measurements. A flow rate of  $200 \text{ cm}^3 \text{ min}^{-1}$  of hydrogen on the anode and  $200 \text{ cm}^3 \text{ min}^{-1}$  of nitrogen on the cathode were applied. The reference and counter electrode leads were connected to the anode, while the working electrode lead was connected to the cathode. A sweep rate of  $20 \text{ mV s}^{-1}$  with a total of 5 cycles was used in the potential range of 0.01–0.80 V for the CV. The electrochemical surface area of the cathode electrode is calculated based on the relationship between the surface area and the hydrogen adsorption charge on the electrode determined from the CV measurement, hydrogen adsorption charge on a smooth Pt electrode of  $210 \text{ mC cm}^{-2} \text{ Pt}$  and the Pt loading in the catalyst layer. The ECA of the cathode electrode was calculated using the following equation [31]:

$$\text{ECA}(\text{cm}^2 \text{ Pt g}^{-1} \text{ Pt}) = \frac{\text{charge} (\mu\text{C cm}^{-2})}{210 (\mu\text{C cm}^{-2} \text{ Pt}) \times \text{catalyst loading} (\text{g Pt cm}^{-2})} \quad (1)$$

The test was done at  $25^\circ\text{C}$ . The gases were humidified at room temperature.

## 2.3. Cell-performance evaluation

The cell performance was evaluated by obtaining polarization curves at three difference test conditions (cell temperature ( $^\circ\text{C}$ )/anode (%RH)/cathode (%RH)): 80/100/75, 100/70/70 and 120/35/35, ambient pressure. PEM fuel cell was connected to a fuel cell test station (100A Model 890B Scribner load box, Scribner Associates, Southern Pines, NC). Hydrogen was used as the anode reactant and air or oxygen as the cathode reactant. All of the gases were certified 99.999% pure. Constant reactant utilization conditions were used as the current was varied: 33% hydrogen utilization, 25% oxygen utilization for air and 5% oxygen utilization for pure oxygen. Both fuel and air were externally humidified by water-bubbles in the anode and cathode saturators. The cell temperature and saturator temperatures (dew points) were calibrated for the quoted relative humidity. The temperatures of the anode and cathode saturators were set at 80 and  $73^\circ\text{C}$ , respectively, at the cell temperature of  $80^\circ\text{C}$  to obtain the anode relative humidity of  $100 \pm 2\%$  and the cathode relative humidity of  $75 \pm 2\%$ . When the cell temperature increased to 100 or  $120^\circ\text{C}$ , the temperatures of both the anode and cathode saturators were set at  $90^\circ\text{C}$  in order to obtain the relative humidity of  $70 \pm 1\%$  and  $35 \pm 1\%$ , respectively. The anode and cathode gas line temperatures were always set  $10^\circ\text{C}$  above the cell temperature to ensure no water condensation in the inlet gas lines. All data were obtained at atmospheric

pressure. Current was stepped up from zero to the maximum test current density in increments of  $10 \text{ mA cm}^{-2}$  between 10 and  $100 \text{ mA cm}^{-2}$  and in increments of  $100 \text{ mA cm}^{-2}$  between 100 and  $2000 \text{ mA cm}^{-2}$ . Five minutes were spent at each current density with cell voltage collected every 20 s. The average values were reported in all polarization curve plots and the data analysis in this paper. The maximum test current density was either the maximum current limit of the load box or the current density, where the cell voltage went below a minimum set point of 0.3 V. The cell resistance was measured and recorded using interrupt technique built into the same load box with the Scribner V.3.1b Fuel Cell Software at the current densities higher than  $100 \text{ mA cm}^{-2}$ . The resistance values were only measured and reported at current densities higher than  $100 \text{ mA cm}^{-2}$ , because the IR voltage loss in the small current range was too small to accurately measure.

## 3. Results and discussion

The electrodes with the different Nafion<sup>®</sup> contents, 15, 25, 35, 37 and 40 wt%, were prepared. All of these electrodes contained the same catalyst loading of  $0.50 \pm 0.05 \text{ mg Pt cm}^{-2}$  at the cathode. They were tested at three operating conditions (cell temperature ( $^\circ\text{C}$ )/anode (%RH)/cathode (%RH)): 80/100/75, 100/70/70 and 120/35/35 under ambient pressure. Fig. 1 shows the cell performance of these electrodes at the 80/100/75 test condition, when the reactants were hydrogen and air under ambient pressure. The voltage characteristics of the electrodes with the different Nafion<sup>®</sup> contents in the cathode catalyst layers are shown in Fig. 1(a). The cell performance improved with an increase in the Nafion<sup>®</sup> content from 15 to 35 wt%. This was expected since the application of Nafion<sup>®</sup> to the electrode improves the proton transport through the entire catalyst layer. The ionic conductivity of such a catalyst layer was proportional to the volume fraction of Nafion<sup>®</sup> in the composition mixture [18,32]. A high cell voltage of 0.70 V was recorded at a moderate current density of  $400 \text{ mA cm}^{-2}$ , when the Nafion<sup>®</sup> loading was 35 wt%. However, a significant decrease in cell voltage with a little further increase in Nafion<sup>®</sup> content to 37 wt% was found. The cell voltages of the electrode with a Nafion<sup>®</sup> content of 37 wt% dropped to 0.62 V. When Nafion<sup>®</sup> was increased to 40 wt% in the cathode catalyst layer, the cell voltage decreased to as low as 0.55 V at the same current density of  $400 \text{ mA cm}^{-2}$ . This behavior was due to the high Nafion<sup>®</sup> concentration in the cathode catalyst layer, which then blocked the catalyst sites as an electronic insulator, reducing the electronic conductivity and gas permeability in the catalyst layer. The electrode with 2 wt% higher Nafion<sup>®</sup> content in the catalyst layer performed about 80 mV lower at  $400 \text{ mA cm}^{-2}$  compared to the electrode with 35 wt% Nafion<sup>®</sup>. Therefore, the Nafion<sup>®</sup> content in the catalyst layer must be controlled very precisely in order to achieve the best cell performance with a

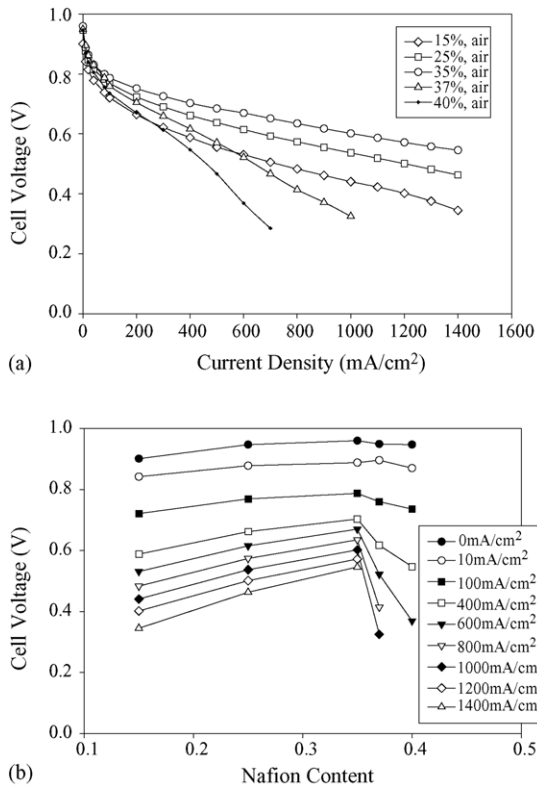


Fig. 1. Effect of Nafion<sup>®</sup> content in the cathode catalyst layer on cell performance at 80 °C on hydrogen and air under ambient pressure: (a) current–voltage characteristics of electrodes with various Nafion<sup>®</sup> contents and (b) comparison of cell voltage at various current densities.

good balance among catalyst activity, porosity, gas permeability and other factors. From Fig. 1(b), it can be clearly seen that when the Nafion<sup>®</sup> loading in the cathode catalyst layer was changed from 15 to 35 wt%, the open circuit voltage (OCV) of the electrodes rapidly went up to the maximum and then reduced with a continued increase in the Nafion<sup>®</sup> content to 37 and 40 wt%. At a low current density of 10 mA cm<sup>-2</sup>, the same trend was observed. It indicated that the catalyst mixed with 35 wt% Nafion<sup>®</sup> in the electrode resulted in the best activity. The cell performance in a current density range of 0–1400 mA cm<sup>-2</sup> displayed an almost parallel rise when the Nafion<sup>®</sup> loading was changed from 15 to 35 wt% in the layers. These simultaneous increases in cell performance illustrated that the catalyst activity improved and the gas diffusion capability through the catalyst layer was not affected very much by the Nafion<sup>®</sup> loading varying from 15 to 35 wt%. It was noted that the cell performance of the electrode with 37 wt% Nafion<sup>®</sup> became worse than that with 15 wt% Nafion<sup>®</sup> starting at the current density of 600 mA cm<sup>-2</sup>, and the cell performance of the electrode with 40 wt% Nafion<sup>®</sup> did as well starting at a lower current density of 250 mA cm<sup>-2</sup>.

When the cell temperature was increased to 100 °C and the relative humidities at the anode and the cathode were both 70%, the electrode with 35 wt% Nafion<sup>®</sup> provided the

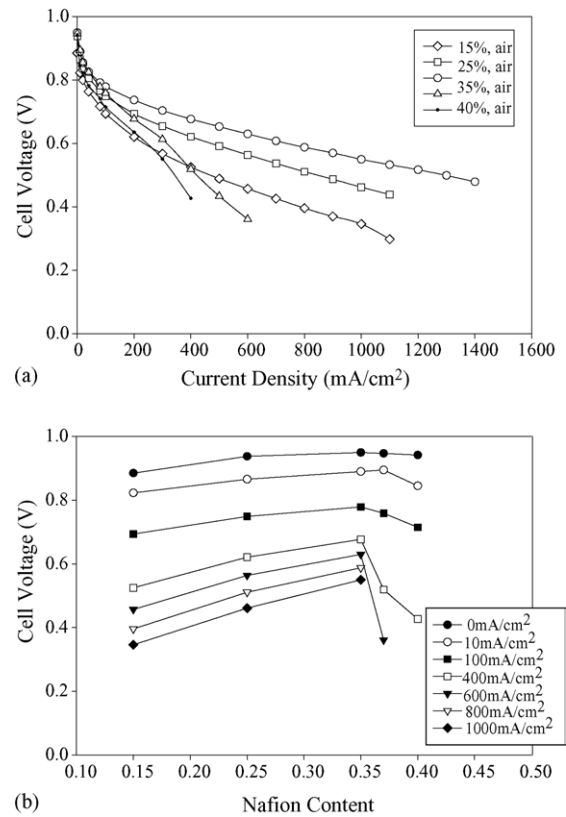


Fig. 2. Effect of Nafion<sup>®</sup> content in the cathode catalyst layer on cell performance at 100 °C on hydrogen and air under ambient pressure: (a) current–voltage characteristics of electrodes with various Nafion<sup>®</sup> contents and (b) comparison of cell voltage at various current densities.

best cell voltage of 0.68 V at 400 mA cm<sup>-2</sup>, as shown in Fig. 2(a). Compared to the performance of the electrode with the same concentration Nafion<sup>®</sup> at the 80 °C operating condition, the cell voltage at the 100 °C operating condition decreased almost 30 mV at this moderate current density. The electrode with 37 wt% Nafion<sup>®</sup> content performed better than the one with 15 wt% Nafion<sup>®</sup> at the current density below 400 mA cm<sup>-2</sup>, while the cell voltage of the electrode with 40 wt% Nafion<sup>®</sup> was lower than the cell with 15 wt% Nafion<sup>®</sup>. It was also found that the cell voltage of the electrode with 37 wt% Nafion<sup>®</sup> dropped sharply, when the current density reached 600 mA cm<sup>-2</sup>. The cell voltage was too low to be recorded, when the current density was increased to 700 mA cm<sup>-2</sup> or higher since a minimum voltage of 0.3 V was set up in the polarization program, clearly seen in Fig. 2(b). These data results showed that the cell performance was influenced by the factor of Nafion<sup>®</sup> content at 100 °C more than that at 80 °C. An accurate control of Nafion<sup>®</sup> content became essential, when the cell operating temperature was increased to 100 °C, especially, for the high cell performance at the higher current densities.

The cell performance on hydrogen and air at the operating condition 120/35/35 is shown in Fig. 3. Fig. 3(a) provides the current–voltage characteristics of the electrodes



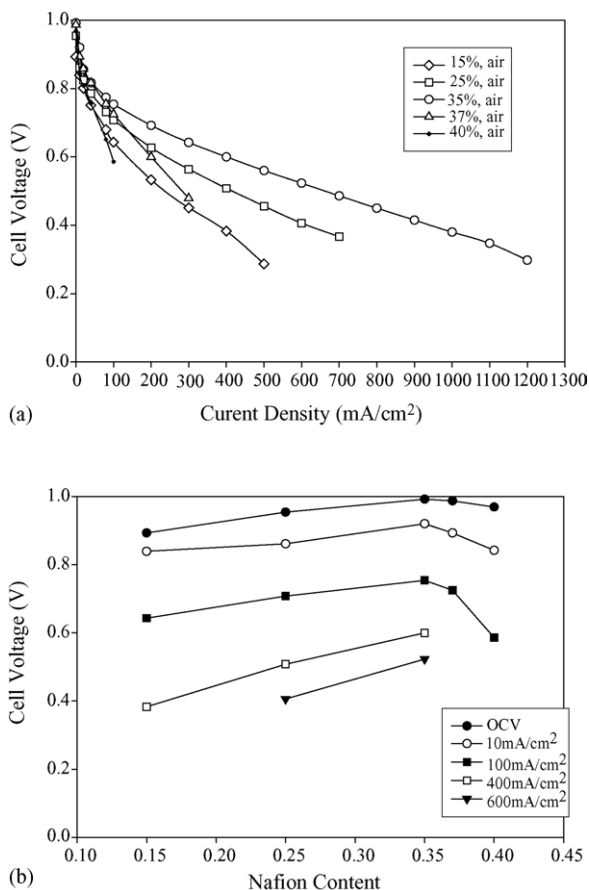


Fig. 3. Effect of Nafion® content in the cathode catalyst layer on cell performance at 120 °C on hydrogen and air under ambient pressure: (a) current–voltage characteristics of electrodes with various Nafion® contents and (b) comparison of cell voltage at various current densities.

with various Nafion contents. The cell performed worse at this operation condition: high cell temperature and lower relative humidities, compared to that at the near fully humidified and moderately humidified operating conditions: 80/100/75 and 100/70/70. The best cell voltage of 0.60 V at this low humidified condition was achieved at the current density of 400 mA cm<sup>-2</sup>, when the Nafion® content was 35 wt% in the cathode catalyst layer. Compared to that of state-of-the-art PEM fuel cell performance at 120 °C and relative humidity of 35 wt% as reported by others [33–35], this is so far the highest cell voltage disclosed at the similar under-saturated operation conditions under ambient pressure. The cell voltages of the electrodes with the relatively low Nafion® contents, 15 and 25 wt% at 400 mA cm<sup>-2</sup> were 0.38 and 0.51 V, respectively. When the Nafion® loading increased to 37 and 40 wt%, no performance data at 400 mA cm<sup>-2</sup> recorded since the cell voltage was lower than 0.30 V, the minimum set point. The cell performance of the electrode with 37 wt% Nafion® dropped to lower than that of the electrode with 15 wt% Nafion® at the current density slightly higher than 300 mA cm<sup>-2</sup>. The cell voltage of the electrode with 40 wt% Nafion® was even lower than that of the electrode with

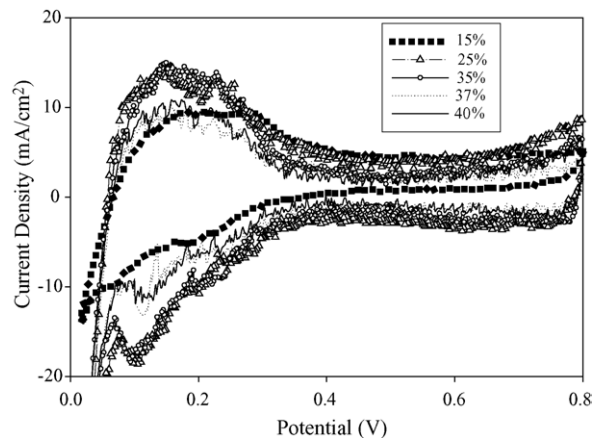


Fig. 4. Cyclic voltammety of electrodes with various Nafion® contents at 25 °C 200 cm<sup>3</sup> min<sup>-1</sup> pure H<sub>2</sub> on the anode and 200 cm<sup>3</sup> min<sup>-1</sup> N<sub>2</sub> on the cathode scan rate 20 mV s<sup>-1</sup>, potential range 0.01–0.8 V.

15 wt% Nafion® at 40 mA cm<sup>-2</sup>. Fig. 3(b) clearly shows the comparison of cell voltages at various Nafion® contents. The cell voltage at current densities lower than 600 mA cm<sup>-2</sup> at 120 °C also showed an increase with the increase of Nafion® content from 15 to 35 wt% and then a drop at 37 wt% Nafion®. The performance reduction at the 120 °C operating condition was more serious than the reduction at the 80 and 100 °C conditions, when the Nafion® content was increased from 35 to 37 wt% Nafion® and 40 wt%.

Besides polarization curve measurements, the electrodes with various Nafion® contents were tested using cyclic voltammety to determine the electrochemical surface area of the cathode electrode available for hydrogen adsorption. Fig. 4 shows the cyclic voltammety measurement results at 25 °C. The ECAs of the cathode electrodes calculated using Equation (1) are listed in the Table 1. The cathode catalyst mixed with 35 wt% Nafion® provided the maximum surface area, 107.9 m<sup>2</sup> g<sup>-1</sup>Pt. Considering the total metal surface area of 134 m<sup>2</sup> g<sup>-1</sup>Pt (provided by the manufacturer), the utilization of the catalyst surface area was nearly 80.5%, associated with this optimum Nafion® content. At a relatively lower Nafion® content range of 15–25 wt% in the cathode catalyst layers, the utilizations of the catalyst surface areas obtained were 51.4 and 71.3%, respectively. And the catalyst utilizations of the electrodes with 37 and 40 wt% Nafion® loadings were 58.1 and 57.1%, respectively. Therefore, an even slightly higher Nafion® content (37 wt%) than the optimum value (35 wt%) would influence the catalyst electrochemical surface area more than a lower Nafion® content.

The current–voltage characteristics of the cells was also evaluated, using hydrogen and oxygen reactants at the 80 and 120 °C operating conditions, respectively. Oxygen was typically used instead of air due to its broader activation–control region that gives more accurate catalyst activity. Plotting oxygen IR-free cell voltage against current density on a semilog scale produced a straight line with a slope called the Tafel slope. The Tafel slope in the kinetically control region was

Table 1  
ECA, OCV on air, Tafel slope and current density at 0.85 V on oxygen of electrodes with various Nafion<sup>®</sup> contents at different test conditions

Nafion content	Test conditions (°C)	15%	25%	35%	37%	40%
ECA (m <sup>2</sup> g <sup>-1</sup> )–Pt	25	68.9	95.6	107.9	77.9	76.5
OCV (V)	80	0.90	0.95	0.96	0.95	0.95
	120	0.89	0.95	0.99	0.99	0.97
Tafel (mV dec. <sup>-1</sup> )	80	95	78	77	91	99
	120	125	104	97	99	105
Current density at 0.85 V	80	8	14	20	18	11
	120	4	8.2	16	12	8

called the kinetic Tafel slope, which was determined experimentally from the oxygen polarization curve. The decade of 10–100 mA cm<sup>-2</sup> was used as the activation–control region for Tafel slope calculation since 10 mA cm<sup>-2</sup> is high enough to make the effect of hydrogen crossover negligible, while 100 mA cm<sup>-2</sup> is low enough to make the concentration overpotentials negligible too. The IR-free cell voltage versus current density on oxygen at two different test conditions: 80/100/75 and 120/35/35 are plotted in Fig. 5. The kinetic Tafel slopes taken from the 10–100 mA cm<sup>-2</sup> range of the oxygen polarization curves were calculated and shown

in Table 1. The kinetic Tafel slopes of 77 and 97 mV dec<sup>-1</sup> at a Nafion<sup>®</sup> content of 35 wt% were closer to the theoretical values of 70 and 78 mV dec<sup>-1</sup> at 80 and 120 °C, respectively, than other lower or higher Nafion<sup>®</sup> contents in the cathode catalyst layers.

In addition, the current density at a fixed cell potential of 0.85 V can be simply used as one of the practical parameters representative of catalyst activity, which is also tabulated in Table 1. The current density of 20 and 16 mA cm<sup>-2</sup> at 0.85 V was obtained at 80 and 120 °C, respectively, when the electrode comprised 35 wt% Nafion<sup>®</sup> in the cathode catalyst layer under hydrogen and oxygen. This result demonstrated that catalyst activity of the electrode with a Nafion<sup>®</sup> loading of 35 wt% was significantly higher than that with other un-optimized loadings at the 80 and 120 °C operating conditions, combined with the results of the ECA and cell open circuit voltage, which are summarized in Table 1.

#### 4. Conclusions

High-temperature PEM fuel cells have received increasing attention as a result of several advantages over current PEM fuel cell technology operating at temperatures lower than 100 °C. The study of an optimized catalyst layer has become an integral part of electrochemical research in recent years, especially, for an optimum amount of Nafion<sup>®</sup> ionomer in the catalyst layer. The effect of Nafion<sup>®</sup> loading on the electrode polarization characteristics of a PEM fuel cell was investigated in terms of both hydrogen/oxygen and hydrogen/air performance at three operating conditions (cell temperature (°C)/anode (%RH)/cathode (%RH)): 80/100/75, 100/70/70 and 120/35/35, at ambient pressure. The experimental data reported in this paper indicated an optimal Nafion<sup>®</sup> content of 35 wt% at a catalyst loading of 0.5 mg cm<sup>-2</sup> in the cathode at all these three different operating conditions. The best cell voltages of 0.70, 0.68 and 0.60 V were achieved at 80, 100 and 120 °C under hydrogen and air, respectively. The influence of Nafion<sup>®</sup> content on the cell performance at the cell temperature of 120 °C was more significant than that at relatively lower temperatures of 100 and 80 °C. Therefore, the Nafion content should be controlled more precisely at that high-temperature condition. The slightly higher Nafion

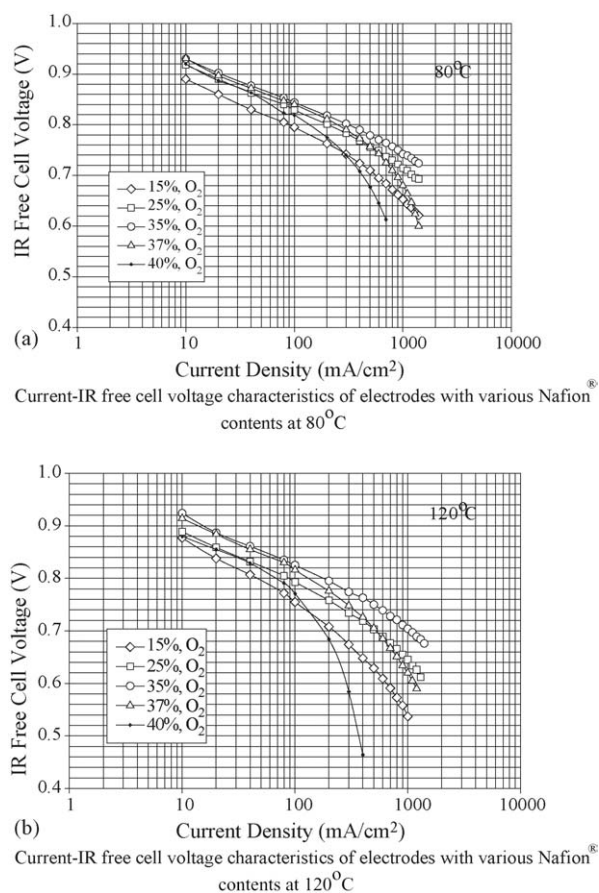


Fig. 5. Effect of Nafion<sup>®</sup> content in the cathode catalyst layer on IR-free cell performance at 80 and 120 °C on hydrogen and oxygen under ambient pressure.

percentage than the optimal value resulted in a mass transport problem and the cell performance was reduced suddenly. The electrochemical surface area was evaluated using cyclic voltammetry to determine the catalyst utilization. A high catalyst utilization of 80.5% was observed. The analysis of kinetic Tafel slopes, current density at 0.85 V, open circuit voltage from the oxygen IR-free polarization curves at 80 and 120 °C further proved that the 35 wt% Nafion content in the cathode catalyst led to the best catalyst activity and reactant diffusion in the electrode.

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