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# Improving the Performance of PEM Fuel Cell

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## Abstract

In order to develop a novel proton exchange membrane fuel cell (PEMFC), new materials were investigated in order to increase the water uptake of the membrane known commercially as “Nafion” by casting it with zirconium metal organic frameworks (MOFs) (i.e., MOF 801 and 808) to form a composite using sol-gel method. It was found that the water uptake of the composite membrane (NAF-MOF) was increased in a significant way, and ion exchange capacity was improved in comparison with the commercial membrane at various temperatures. Actual runs using PEM fuel cell at 80°C and Naf-MOF (801 and 808) membranes were performed to assure the efficiency of using these membranes.

**Keywords:** membrane, metal organic frameworks (MOFs), zirconium, temperature, flowrates

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## 1. Introduction

At high temperatures, membrane dehydration and decrease in proton conductivity within PEM fuel cells (PEMFC) are significant issues. Basically, membrane dehydration causes shrinking, cracking, and loss of mechanical stability.

The ability of a polymer exchange membrane in a PEMFC to absorb and transport water is crucial to its function. Low water content in the membrane increases the ionic resistance of the cell, but too much hydration leads to excessive swelling. Huge literature related to water transport through an operating fuel cell is existing, but few research works concentrate on the materials research strategies that promote the net transport of water to the anode in order to offset the effects of dehydration of the anode and flooding of the cathode. The permeation of water through a membrane involves sorption, transport within the membrane, and desorption. Permeability can be determined by measuring the flux of water under a chemical potential gradient induced by a concentration or pressure gradient of water [1].

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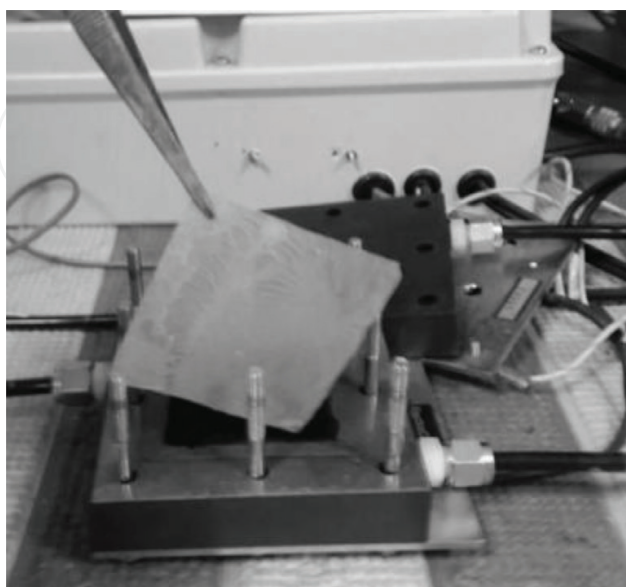
Incorporating inorganic fillers such as metal oxides within Nafion improved the water uptake [2]. It was found that using the  $\text{SiO}_2$  particles will increase the water uptake in the composite membrane due to the hygroscopic nature of metal oxides ( $\text{SiO}_2$ ) [3, 4].

The composite membrane water uptake depends on membrane hydration; however, the increased hydration improves membrane proton conductivity and fuel cell performance. Moreover, temperature and water content strongly affect Nafion's viscoelastic response, which are of direct importance for operating PEMFC. Accordingly, it is expected that the composite membrane has higher performance than the commercial Nafion membranes [3].

In this work, new materials [i.e., zirconium (IV) metal organic frameworks (MOFs) (i.e., MOF 801 and 808)] were added to Nafion in order to produce composite membranes (Naf-MOF) and compare its water uptake at various temperatures with commercial Nafion membrane. In addition, actual runs using PEMFC at  $80^\circ\text{C}$  and Naf-MOF (801 and 808) membranes were performed to assure the efficiency of using these membranes.

## 2. Experimental work

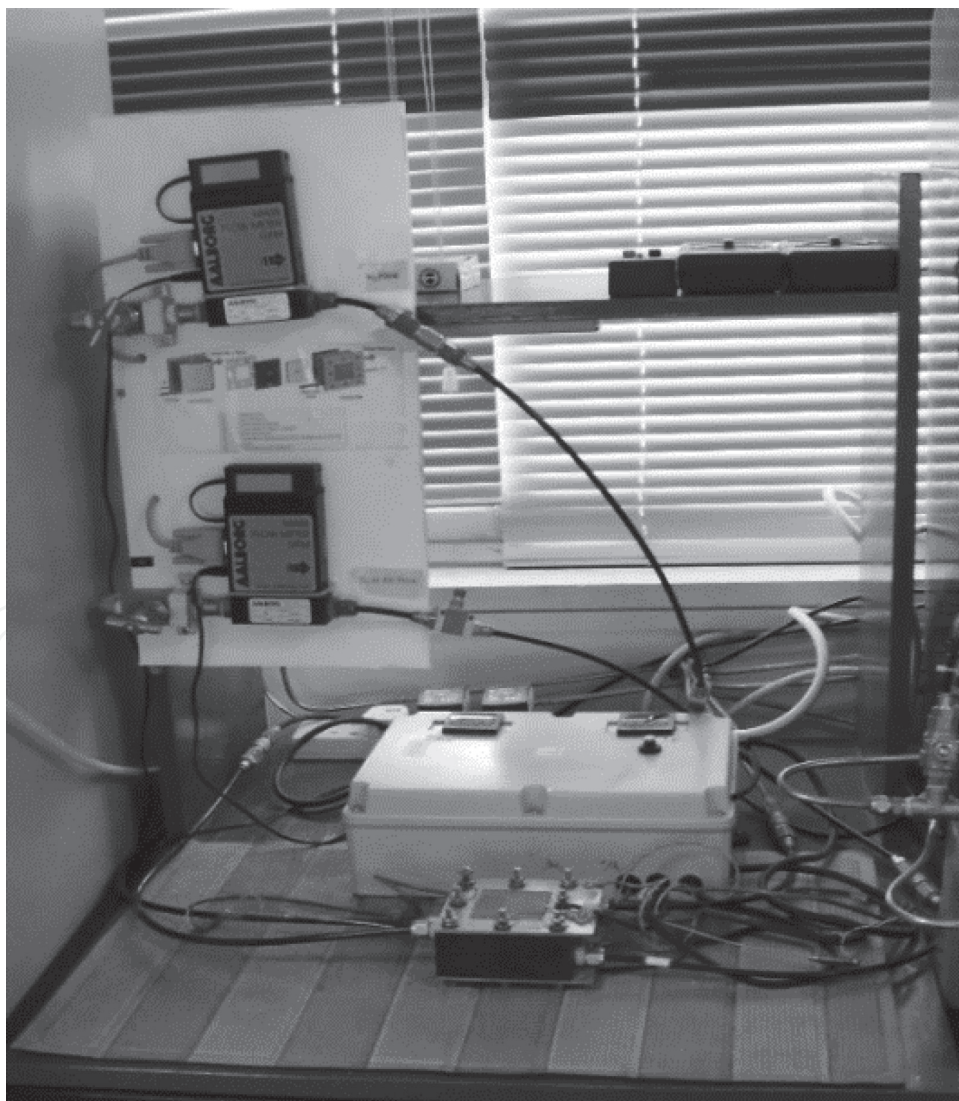
The Nafion-zirconium (IV) metal organic frameworks (MOFs) membranes were casted from Nafion (sulfonated tetrafluoroethylene) dispersion, containing 4% by weight, supplied by Electrochem Co. using sol-gel method [5]. The isopropanol and Nafion dispersion were mixed at a certain volume ratio, and then, a significant weights of MOF (801 and 808) obtained from Yaghi group at University of California at Berkeley were added to the selected samples. These samples were kept in an oven at  $100^\circ\text{C}$  until all solvents were evaporated, and the polymeric ionomer formed a solid polymer membrane known as Naf-MOF composite membrane. Then, the formulated membrane film was activated using diluted  $\text{H}_2\text{SO}_4$  at  $80^\circ\text{C}$ . Finally, it was rinsed in boiling distilled water for 1 h.



**Figure 1.** Adding the MEA to PEMFC.

The electrodes (anode and cathode) of PEMFC were prepared by dispersing carbon black mixed with iso-propanol on the surface of  $5 \times 5$  cm carbon paper and then left in the oven at  $100^{\circ}\text{C}$  for 30 min in order to evaporate the isopropanol. Slurry of Pt-Ru (40–20% by wt.)/C, Nafion ionomer, PTFE, and iso-propanol was loaded over the carbon black layer in the form of continuous wet film using a brush, it was then dried in an oven for 30 min at  $150^{\circ}\text{C}$ . Nafion ionomer acted as a binder, while PTFE with pores at the cathode provided a network to expel water in order to minimize the occurrence of water flooding [3]. The water uptake of the Naf-MOF (801 and 808) composite membranes was investigated at (40, 60, 80, 100, and  $120^{\circ}\text{C}$ ).

In order to investigate the performance of PEMFC using Naf-MOF (801 and 808) membranes at  $80^{\circ}\text{C}$  and counter current flow of air and hydrogen at 20 ml/min, an MEA (membrane electrode assembly) was sandwiched between graphite bipolar plates and gold-plated current collectors as shown in **Figures 1** and **2**. It is worthy of mention that the heaters connected to the PEMFC were connected to a temperature controller in order to keep the PEMFC stable at the desired temperature during the run.



**Figure 2.** Fuel cell setup used to conduct the needed experiments.

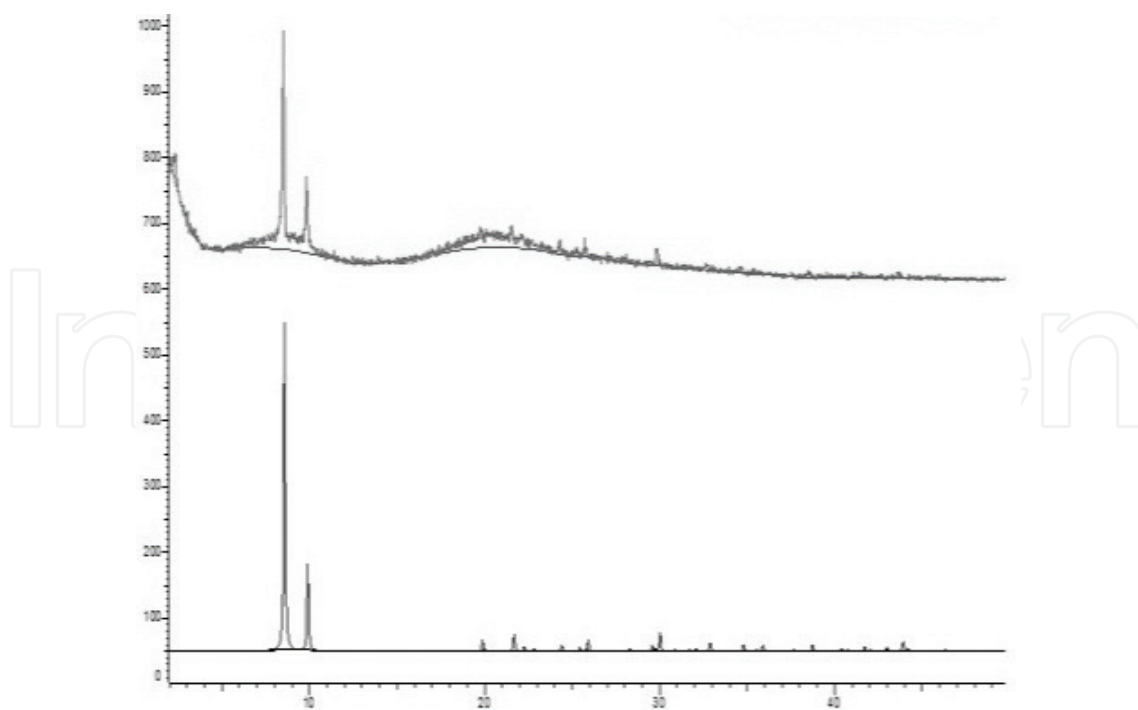
### 3. Results and discussion

The PXRD patterns of zirconium (IV) MOF 801 and 808 shown in **Figures 3** and **4** assure that the crystalline structure of these materials when added to Nafion dispersion forms Naf-MOF (801 and 808) composite membranes as shown in **Figures 5** and **6**. The SEM and polarized microscope images given in **Figures 7–10** revealed in a clear way the MOF particles within the polymeric ionomer.

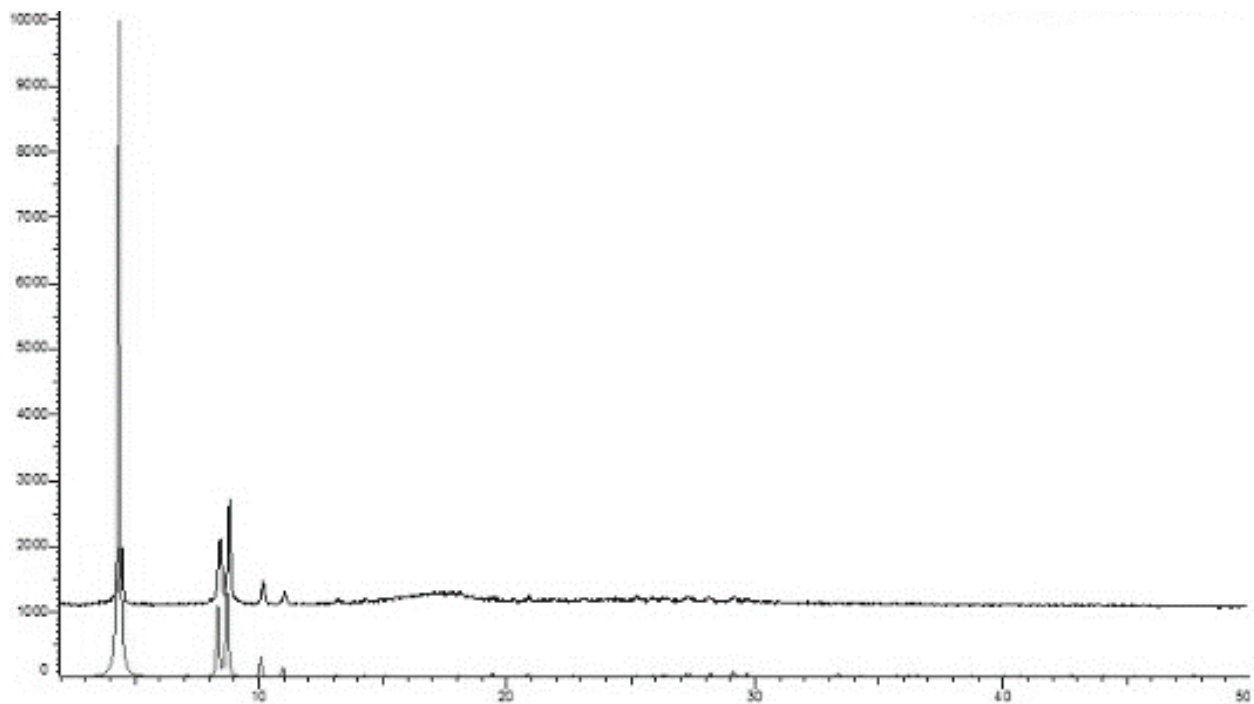
Samples of Naf-MOF (801 and 808) composite membranes in addition to commercial Nafion membrane were kept inside distilled water containers for 1 h at various temperatures (40, 60, 80, 100 and 120°C) in order to investigate the water uptake of the mentioned membranes as shown in **Figure 11**. The results revealed clear ability of Naf-MOF (801 and 808) composite membranes in keeping water at 80 and 100°C in comparison with commercial Nafion membrane. Naf-Mof 808 showed an extraordinary ability in comparison with Naf-MOF 801 in keeping water at 120°C. It is worthy of mention that the water uptake of both Naf-MOF (801 and 808) composite membranes at 80°C is higher than Naf-SiO<sub>2</sub> composite membrane given in [3].

The results given in **Figure 11** are in agreement with the findings of Yaghi et al. [6] in which they showed that zirconium (IV) MOFs (i.e., 801 and 808) have the ability to keep water because they possess appropriate pore molecules for water adsorption.

On the other hand, actual runs using PEM fuel cell at 80°C and Naf-MOF (801 and 808) membranes were performed to assure the efficiency of using these membranes. Hydrogen and air



**Figure 3.** PXRD patterns of MOF 801.

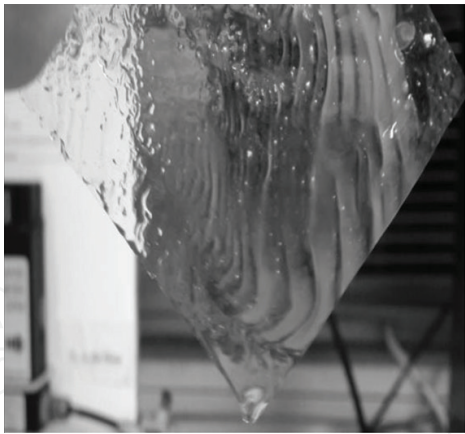


**Figure 4.** PXRD patterns of MOF 808.

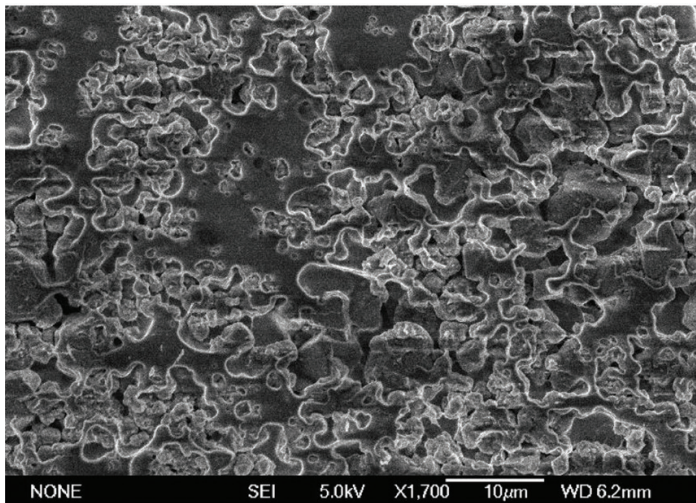
flow rates were equal to 20 ml/min for both membranes. It is clear from the results given in **Figure 12** that there is an obvious shift toward higher voltage and power in comparison with commercial Nafion membrane given in [7]. It is worth of mention that NAF-MOF 808 showed better performance in terms of currents, voltages, and power densities with time in comparison with NAF-MOF 801.



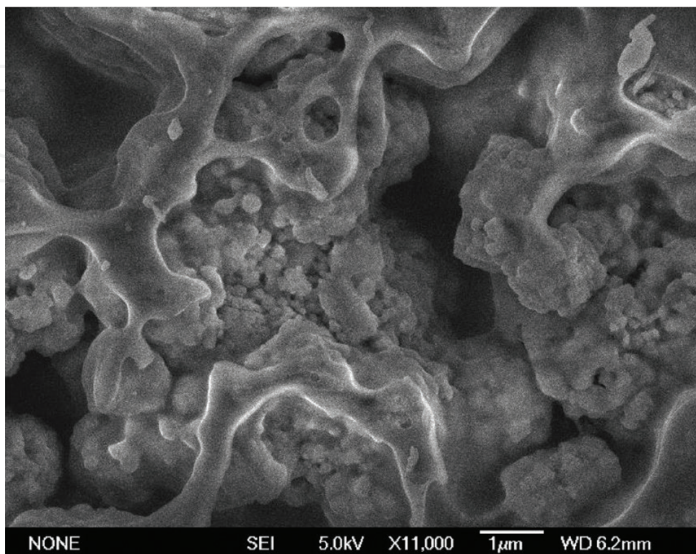
**Figure 5.** Image of Naf-MOF 801 composite membrane obtained from the sol-gel casting process.



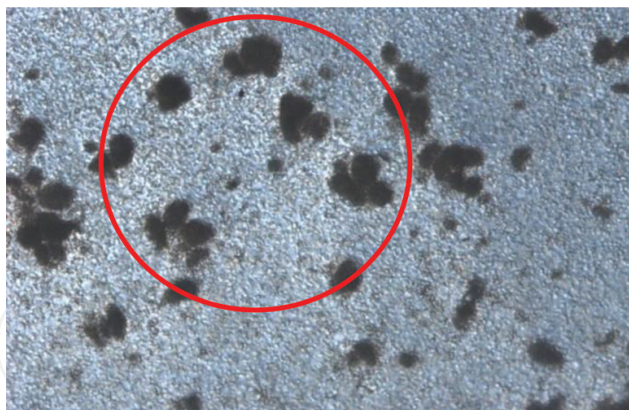
**Figure 6.** Image of Naf-MOF 808 composite membrane obtained from the sol-gel casting process.



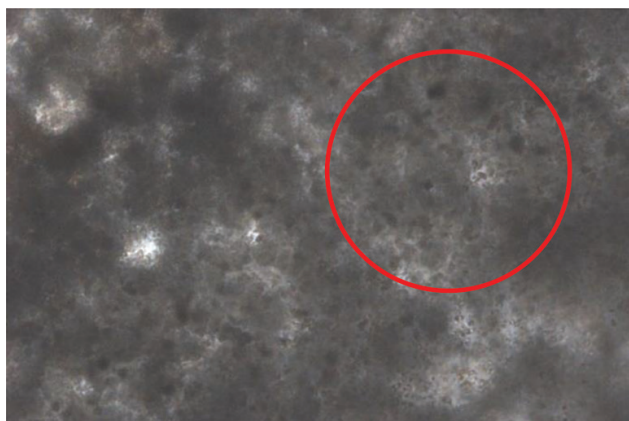
**Figure 7.** SEM image with magnification power (X 1700) of Naf-MOF 801 composite membrane after conducting the sol-gel casting process. The image reveals the shape of MOF particles within the polymeric ionomer.



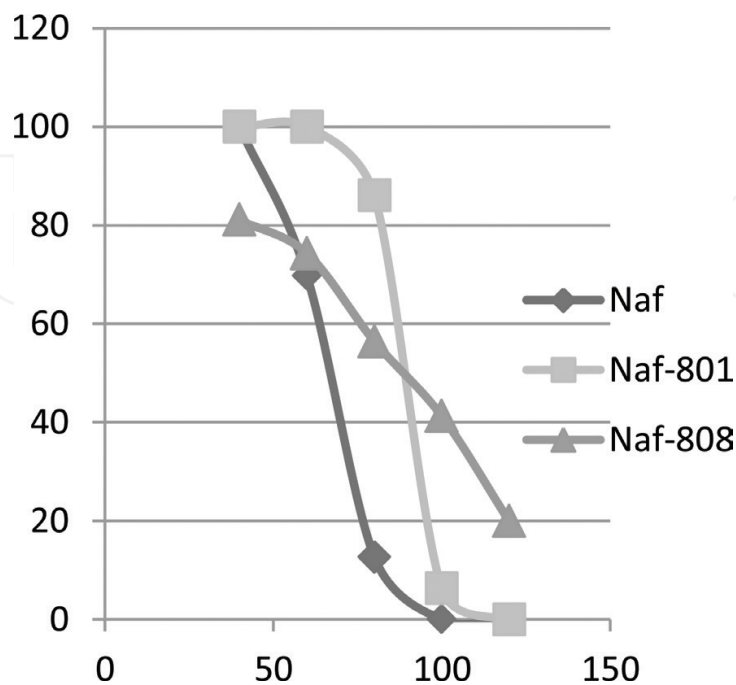
**Figure 8.** SEM image with magnification power (X 11000) of Naf-MOF 801 composite membrane obtained from the sol-gel casting process. The image reveals the shape of MOF particles within the polymeric ionomer.



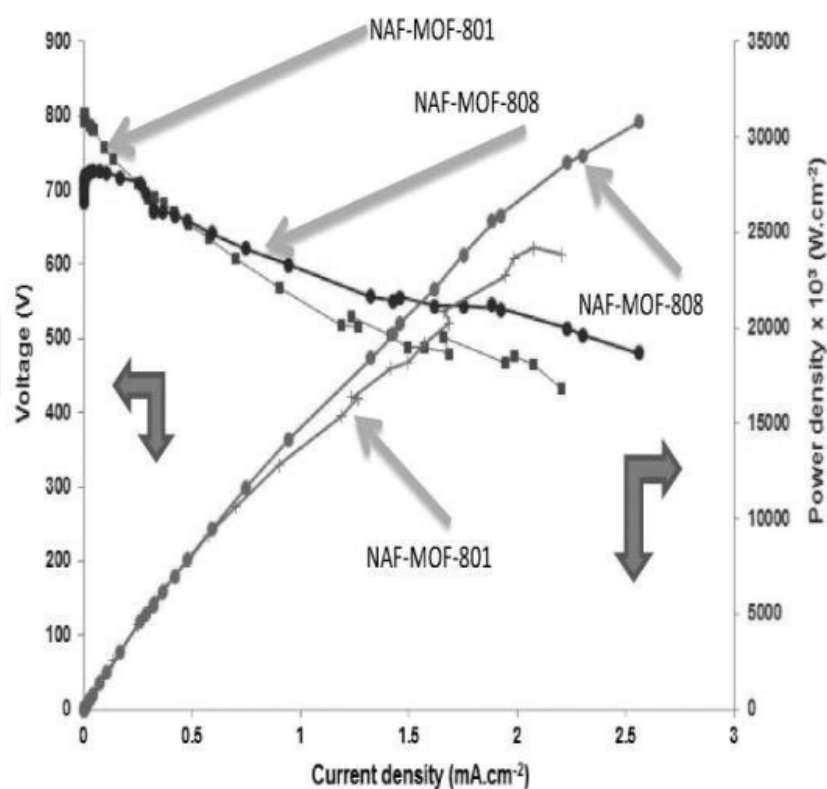
**Figure 9.** Polarized microscope image of Naf-MOF 808 composite membrane after obtained from the sol-gel casting process. The red circle shows the MOF particles within the polymeric ionomer.



**Figure 10.** Polarized microscope image of Naf-MOF 801 composite membrane obtained from the sol-gel casting process. The red circle shows the MOF particles within the polymeric ionomer.



**Figure 11.** Water content of Naf-MOF (801 and 808) composite membranes and commercial Nafion membrane at various temperatures (40, 60, 80, 100 and 120°C).



**Figure 12.** Polarization curves of NAF-MOF 801 and NAF-MOF 808 at 80°C, counter current flow of hydrogen and air = 20 ml/min.

#### 4. Conclusions

1. It was found that the modified Nafion composite membrane containing zirconium (IV) MOF 801 and 808 produced in situ is better than the commercial Nafion membrane in combating dehydration at 80, 100, and 120°C because the water uptake of the modified Nafion composite membrane containing zirconium (IV) MOF 801 and 808 is greater than the commercial Nafion membrane.
2. The polarization curve obtained from the fuel cell using the modified Nafion composite membrane containing zirconium (IV) MOF 801 and 808 showed an obvious shift toward higher voltage and power in comparison with commercial Nafion membrane.
3. NAF-MOF 808 showed better performance in terms of currents, voltages, and power densities with time in comparison with NAF-MOF 801.

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