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Numerical study on applicability of metal foam as flow distributor in alkaline anion exchange membrane fuel cell

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ABSTRACT

In this paper, a three-dimensional multi-phase non-isothermal numerical model is formulated to investigate the applicability of MF (metal foam) as flow distributor in AAEM (alkaline anion exchange membrane) fuel cell. The performance of the cell with MF flow field is compared with that of the cell with traditional channel-rib structure (serpentine channel flow field), the simulation results clearly show that using MF as flow distributor improves the performance greatly, and the improvement gets more and more obvious as the current density increases. The transport and distribution of water (including liquid water, membrane water, and water vapor) and reactants are analyzed to illustrate the performance improvement, and the analysis results agree with the conclusion.

Keywords: alkaline anion exchange membrane fuel cell, metal foam, numerical model, water transport, membrane water, liquid saturation

1. INTRODUCTION

Compared with PEM fuel cell, AAEM fuel cell shows great potential in cost reduction and performance improvement [1-3] for faster electrochemical kinetics and non-precious catalyst. The flow field of fuel cell should have good mechanical strength and preferable electrical conductivity [4]. However, the channel-rib structure of traditional flow fields may hinder the reactant transport and cause water accumulation. In the recent years, metal foam (MF) materials are attracting more and more attention for their distinctive thermal and physical properties [5, 6]. Researchers [4, 7] summarized advantages of the metal foam compared to the conventional flow fields, and performed experimental and computational study of the metal foam in PEM fuel cells, but to the best of our knowledge, it hasn't been applied in the AAEM fuel cell yet. In this work, the applicability of MF as flow distributor in AAEM fuel cells is investigated by developing numerical model. The performance of AAEM fuel cell with MF is compared with that of AAEM fuel cells with conventional channel-rib as flow fields, and the performance difference is analyzed from membrane hydration, water removal in anode, water utilization and transport in cathode, reactant transport and distribution.

2. NUMERICAL METHOD

2.1 Different cases of the AAEM fuel cell

In this work, the serpentine channel and the metal foam flow field are compared. Fig.1 shows the schematic of two cases, the serpentine channel case (Case1) consists of three single channels connected head-to-tail, and they are replaced by the entire MF flow distributor for comparison in the MF flow field case (Case2). The humidified hydrogen flows in the channels and diffuse into the catalyst layer (CL) through the gas diffusion layer (GDL) and micro-porous layer (MPL). To study the effects of flow channel designs on the performance of the fuel cell, all the geometric properties of the two cases are exactly the same.

2.2 Computational domain and model formulation

In this study, a whole-cell 3D multiphase non-isothermal model is developed for the hydrogen/air AAEM fuel cell (refer to previous article [8]). As shown in Fig.2, the computational domain includes the bipolar

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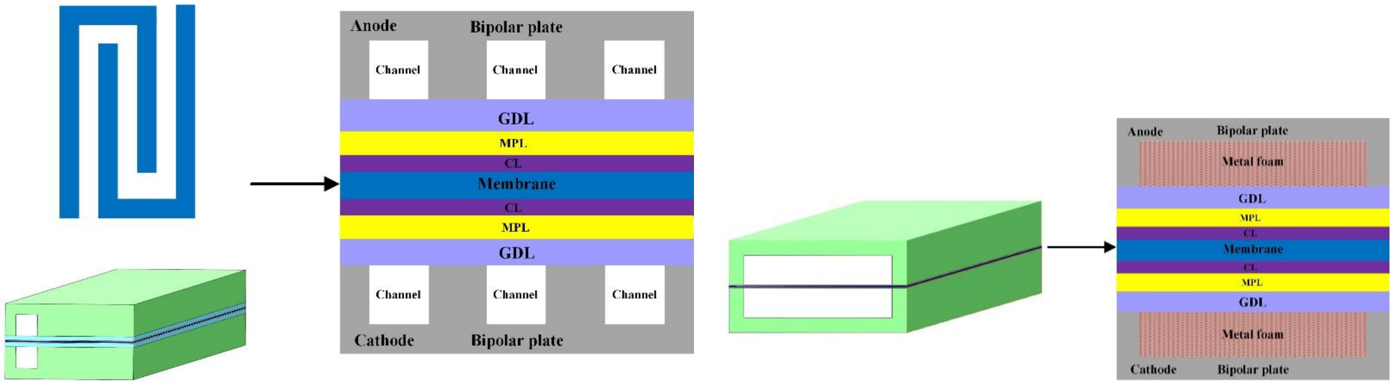

(a) (b)

Fig 1 Schematics of two different kinds of flow fields for AAEM fuel cells: (a) serpentine channel case, (b) metal foam case

plates (BPs), flow channels (FCs) or MF, GDLs, MPLs, CLs and membrane.

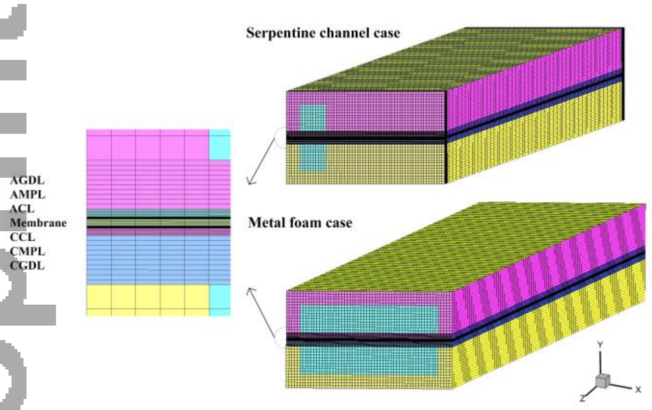

Fig 2 Computation domain and mesh of the MF field case

3. RESULTS AND DISCUSSION

3.1 *Applicability of metal foam in AAEM fuel cell*

In this section, the applicability of MF as flow distributor in AAEM fuel cell is studied by comparing the performance of different fuel cells with different flow fields, namely the MF flow field case and the serpentine channel case. In the above two cases, the same design parameters and operation conditions are adopted. The polarization curve of two cases is compared in Fig.3, it shows that the MF flow field case performances better than the serpentine channel case, and the difference becomes more and more obvious as the current density increases. It indicates that application of the MF promotes the performance when compared with the serpentine channel.

3.2 *Comparison of liquid water*

In the AAEM fuel cell, water is consumed in the cathode and produced in the anode, water flooding in the anode is one of the main factors that reduce the cell performance, as too much liquid water in the porous electrode will block the reactant gas transport for the electrochemical reaction, so water removal may be one of the reasons that promotes the performance. Fig.4 shows the variation of liquid saturation in anode CL for the two cases, it is obvious that the liquid saturation of the MF flow field case is lower than that of the serpentine channel case. This is due to the extremely porous structure of the metal foam, which attributes to larger flow area between GDL and the MF flow field than that between GDL and the conventional serpentine channel.

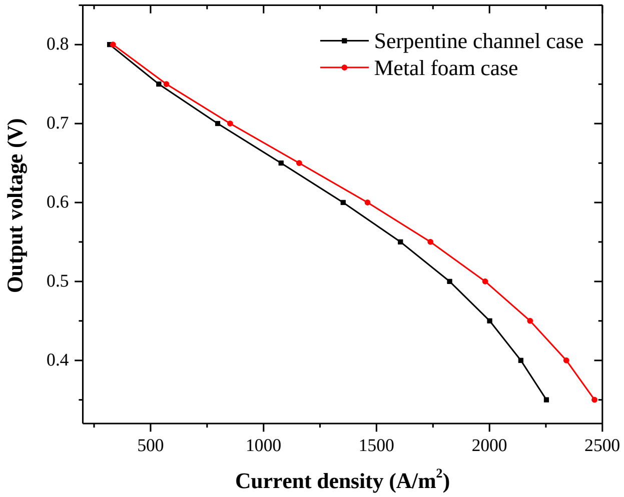

Fig 3 Comparison of polarization of the two cases

Fig. 5 gives the distribution of liquid saturation in Cl of the two cases at an output cell voltage of 0.5 V, it can be seen that the liquid saturation in cathode is almost zero in both the two cases because water is consumed by reaction and electro-osmotic drag in cathode, but the liquid saturation in the anode varies. Besides the lower liquid saturation, the distribution of liquid water of the MF flow field case is more even than that of the serpentine channel case.

3.3 Comparison of membrane water

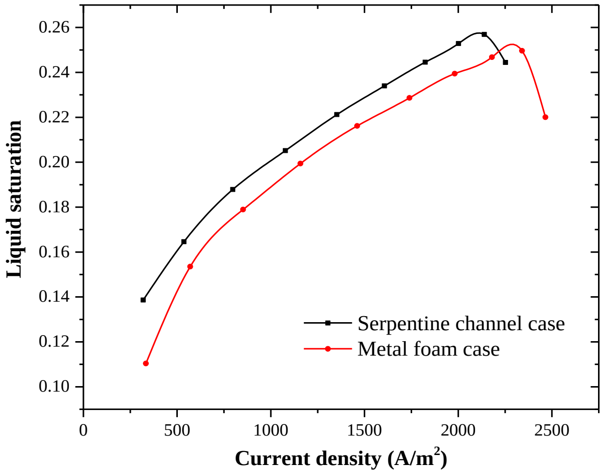

Fig 4 Variation of liquid saturation in anode CL for two cases

The water content in the membrane, namely the membrane water content, is vital for the AAEM fuel cell, as it is directly related to the ion transport capacity. Moreover, water is consumed in the cathode CL and brought to the anode CL due to the electro-osmotic drag effect, so the drying out in cathode CL and the membrane is another main factor affecting the performance. To further study the role of MF in the performance promotion, the variation of membrane water in the membrane for the two cases is shown in Fig.6, from which we can conclude that the membrane hydration in the MF field case is better than that in the serpentine channel case.

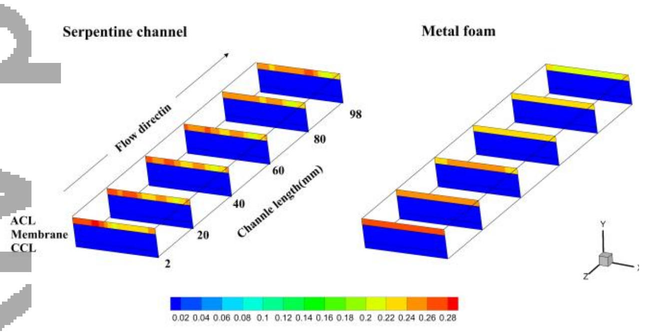

Fig 5 Distributions of liquid saturation for the two cases at output cell voltage of 0.5 V

Additionally, Fig.7 shows the membrane water distribution at output cell voltage of 0.5 V. The membrane water in both the cathode CL and the membrane in the MF case is higher. This may be attributed to the role of the MF in the water transport from cathode flow channel to the cathode CL. It is also proven by the variation of water vapor concentration in the cathode CL, which is shown in Fig.8. The water vapor concentration in the cathode CL of the MF flow field case is higher than that of the serpentine channel case. The reason is that the unique structure of the MF makes water transport to the CL more easily than the channel-rib structure.

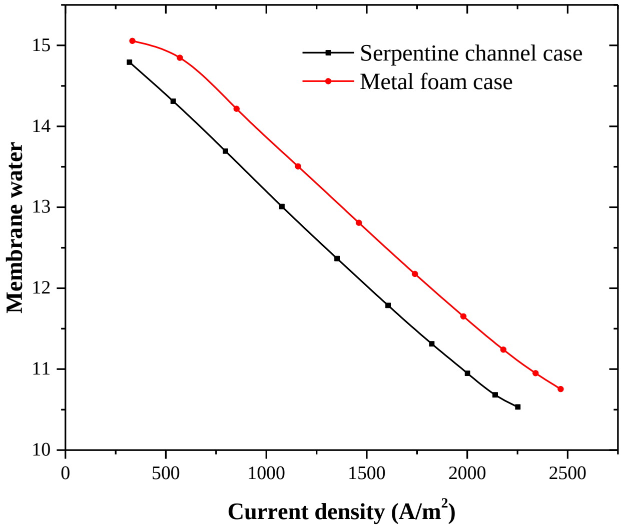

Fig 6 Variation of membrane water in the membrane for the two cases

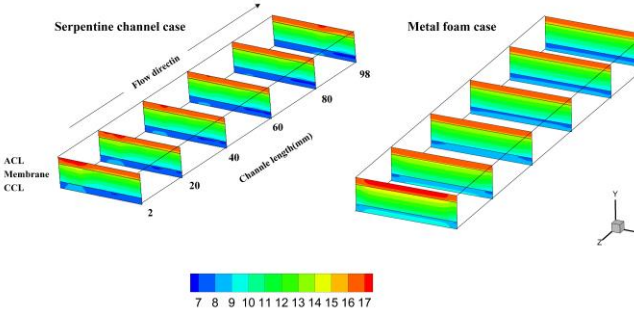

Fig 7 Distributions of membrane water for the two cases at output cell voltage of 0.5 V

3.4 Comparison of reactant concentration

Fig.9 gives the distribution of oxygen concentration for two cases at an output cell voltage of 0.5 V, it can be seen that the oxygen distribution in the serpentine channel case is not even because of the channel-rib structure, the oxygen concentration under the rib is lower than that under the channel, so the oxygen is not utilized fully. On the contrary, the oxygen distribution in the MF flow field case is much more even because of the porous structure of MF, which results in enhanced transport and uniform distribution of reactants, enhanced catalyst utilization, etc.

3.5 Conclusions

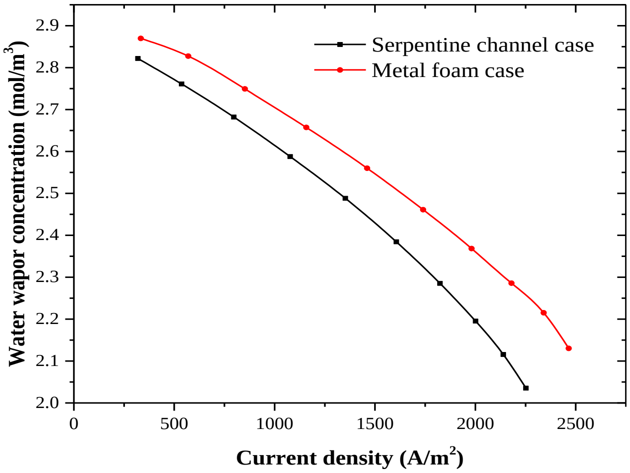

Fig 8 Variation of water vapor concentration in the cathode CL for the two cases

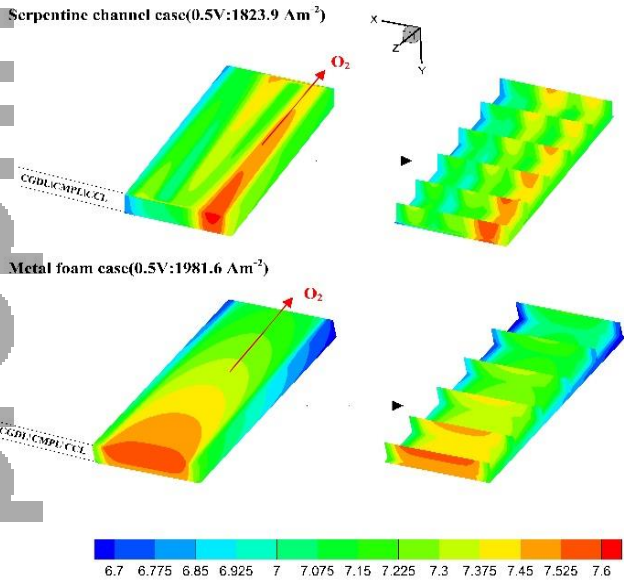

Fig 9 Distribution of oxygen concentration (mol m^{-3}) in cathode for the two cases at output cell voltage of 0.5 V

Numerical model is formulated to investigate the applicability of MF in AAEM fuel cell. The results show that MF is a promising alternative as flow distributor. The cell performance is improved significantly with MF flow field, and the improvement gets more obvious at higher current density. The transport and distribution of water and reactants are analyzed to explain the performance improvement, and it's well proven that both the water and the reactants distribution in the MF case are much more even than that in the serpentine channel case, which is beneficial for adequate utilization of reactants and catalyst. Meanwhile, the application of MF enhances the water removal in anode and water transport to CL in cathode, which will help prevent the AAEM fuel cell from flooding and drying out. All the above advantage is owe to the unique characteristics of MF materials, e.g. extremely porous structure, high electrical conductivity, controllable permeability and mechanical strength, etc.

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