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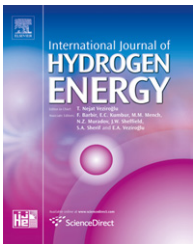

Numerical simulation for rib and channel position effect on PEMFC performances

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ABSTRACT

Simulation is an important method for engineers to probe the detailed transportation and reaction information inside fuel cells and guide their designs without large amount of experiments. Although many papers discussing fuel cell flow fields design could be found in documents, relative positions of the ribs and channels in the anode and cathode flow field plates haven't been paid attention to surprisingly. In this paper, simulation results were given to explain the influences of relative positions of the ribs and channels in the anode and cathode flow field plates on the proton exchange membrane fuel cell (PEMFC) performances. It is interesting that the influence differs with several factors and the information will be helpful for fuel cell design.

1. Introduction

Proton Exchange Membrane Fuel Cells (PEMFCs) have aroused wide attentions in these years, especially for automobile producers [1]. To furthering the understanding of the transportation and reaction phenomena inside fuel cells and guiding the designs to provide better performances, modeling and simulation have become to be important methods and are very useful in fuel cell research and development. Since the pioneering work of Springer et al. [2] and Bernadi and Verbrugge [3], many papers in fuel cell modeling and simulation have been published and been reviewed by several authors [4]. After computational fluid dynamics (CFD) method was introduced into fuel cell modeling by Gurau et al. [5] in 1998, computational fuel cell dynamics (CFCD) [6] has achieved success and commercial CFD packages are available now. The CFD method is helpful for the flow field pattern design and optimization, which is important for fuel cell performance enhancement. The influences of geometric parameters like flow field pattern, rib and channel size scale have been well discussed in documents [7]. However, the rib and channel position effect have seldom been noticed by fuel cell researchers. In this paper, this effect was numerically simulated and interesting results were given.

2. Simulation method

2.1. Simulation region

In traditional PEMFC, the ribs in the anode plates face to the ribs in the cathode plates, as we called as rib-to-rib (RTR) distribution shown in Fig. 1(a). Here we present another rib-channel distribution pattern as shown in Fig. 1(b), in which the ribs of the anode plates face to the channels of the cathode plates, named rib-to-channel (RTC) distribution. The rib and channel position change will affect the gas transportation and

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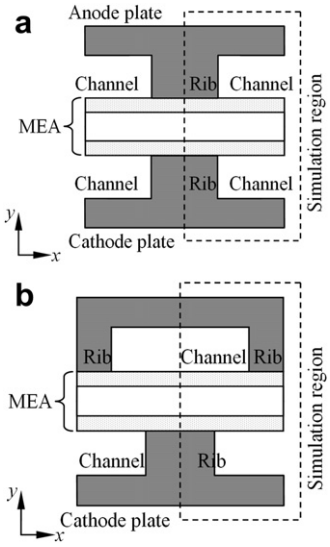

Fig. 1 – Rib and channel relative position in PEMFC (a) Rib-to-rib distribution (RTR) (b) Rib-to-channel distribution (RTC).

current density distribution, and the fuel cell performance, which could be seen in the following sections.

The simulation regions are also shown in Fig. 1. Half of a rib and a channel in both anode and cathode were included in the simulation. The rib width is 1 mm and half that of the channel as often used in our fuel cells. Along the channel direction, 5 cm calculation region was simulated. The computational domain was divided to 61,500 cells.

2.2. *Simulation method*

CFD-ACE+ V2003 solver was used for the simulation, model equations and detailed information could be found in Ref. [8]. Heat transfer module was not included in the simulation and the temperature of the fuel cell was set to be 343 K constantly. Liquid water was not taken into account. Parameters in the model are listed in Table 1. Anode and cathode inlet velocity are set to be 1.0 m s^{-1} and 2.5 m s^{-1} respectively. To calculate the fuel cell performance curve, the cathode overpotential was set to vary from −0.1 V to −1.0 V with 0.1 V potential interval. In this work, a fixed open circuit voltage (OCV) 1.1 V was used for all cases, not Nernst voltage as many model used. Because the aim of the simulation was to explore the differences in both performances and distributions between the RTR and RTC, the simplification in OCV did not cause much influence for the cases.

The computation work was conducted with a personal computer with Intel Pentium IV 2.4 GHz processor and 1.0 GB RAM. The problem converged after around 300 iterations and took around 1360 s for each case.

3. Results and discussions

3.1. *Performance comparison*

Fig. 2 shows the performance comparison of the fuel cell with RTR and RTC arrangements. It shows that in high cell voltage region, the performances with RTR and RTC are almost identical; however, RTC fuel cell shows better performance in low cell voltage region compared with RTR fuel cell. For a performance polarization curve of a fuel cell, the deviation of the curve out of semi-logarithmic relationship in low cell voltage region is caused by several factors: diffusion overpotential caused by geometric mass transfer resistance and flooding, ohmic overpotential caused by electric resistance of plates, gas diffusion layers (GDLs) and ionic resistance in proton exchange membrane (PEM) and catalyst layers (CLs). In this simulation, GDL flooding is not a matter to result in the performance difference for RTR and RTC because liquid water is not taken into account. The change of relative position will change the mass transfer in the GDLs and in turn change the current density distribution. Fig. 3 shows the current density

Table 1 – Parameters in the simulation.

Parameters	Value	Parameters	Value
Width and length		Permeability	
Rib width	1 mm	GDL & CL	1.76×10^{-11} m^2
Channel width	2 mm	PEM	1.8×10^{-18} m^2
Channel length	50 mm	Electric conductivity	
Thickness		Plate	3000 S/m
Channel	0.8 mm	GDL	1250 S/m (base case)
Bipolar plate	1.2 mm	CL	1250 S/m
Gas diffusion layer (GDL)	200 μm	PEM	1.8×10^{-20} S/m
Catalyst layer (CL)	20 μm	Ionic conductivity	
Proton conducting membrane (PEM)	50 μm	CL	4.2 S/m
Porosity		PEM	Ref. [2]
GDL	0.6	Exchange current density	
CL	0.5	H_2 oxidation	1.0×10^9 A m^{-3}
PEM	0.28	O_2 reduction	2.0×10^5 A m^{-3}
Tortuosity		Operation condition	
GDL & CL	1.5	H_2/air temperature	343 K
PEM	10	H_2/air relative humidity	90%
		Outlet H_2/air pressure	0.1 MPa

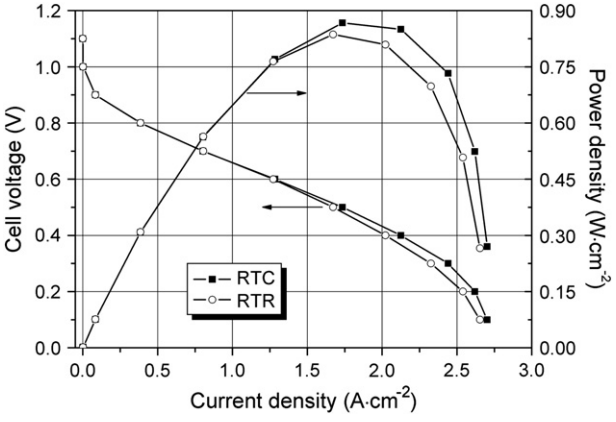

Fig. 2 – Fuel cell performance comparison for RTR and RTC.

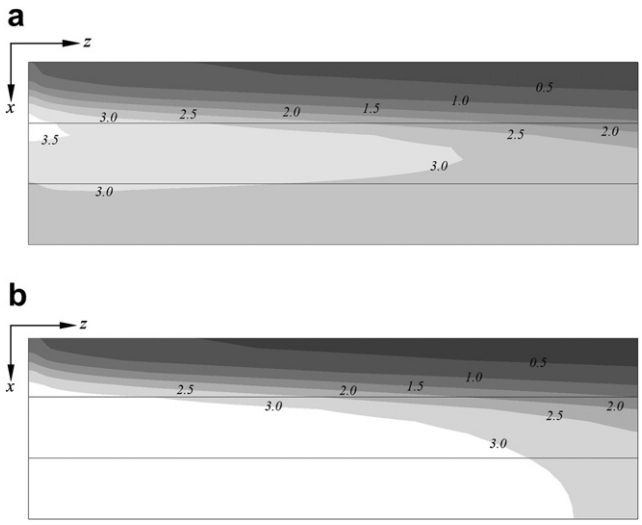

Fig. 3 – Membrane phase current density distribution comparison for RTR and RTC (a) RTR (b) RTC.

distribution in RTR and RTC fuel cells respectively, in which the current density is the membrane phase current density in the x–z section across the center of the membrane, with cathode overpotential to be 0.8 V. In RTR case, the greatest current density area is beneath the channel and near the rib of the inlet. Although the mass transport resistance of the gases from the channels to the catalyst layers beneath the channel is the lowest, the current density in the center of the channel is even lower than the area near the rib. For the RTC case, the greatest current density area is beneath the anode rib near inlet.

Why the current density distribution is so different for RTR and RTC with just relative position change? It is because the transport process in the two cases is different. In our former research, it was found out that electric resistance and mass transport resistance impact current density distribution most greatly, in which the GDL conductivity (especially in x direction), permeability and porosity are the most important factors [9]. With very high GDL conductivity, the highest current density area is beneath the center of the channel near inlet, while with very high GDL porosity and permeability, the greatest current density area is beneath the rib near inlet. As a result of the membrane phase current density change, the solid phase current distribution and electric resistance will also change. Fig. 4 shows the electric current density distribution in the solid phase for both RTR and RTC case. It shows that the electric current path for RTC case seems to be shorter than the RTR case, which results in lower GDL ohmic loss. It also shows that the more current vectors are pointing to x direction, with means that the ohmic loss in x direction is more important than the y direction.

3.2. *GDL conductivity influence*

For different GDL conductivity, the performance of difference between RTR and RTC will also change. Fig. 5 shows

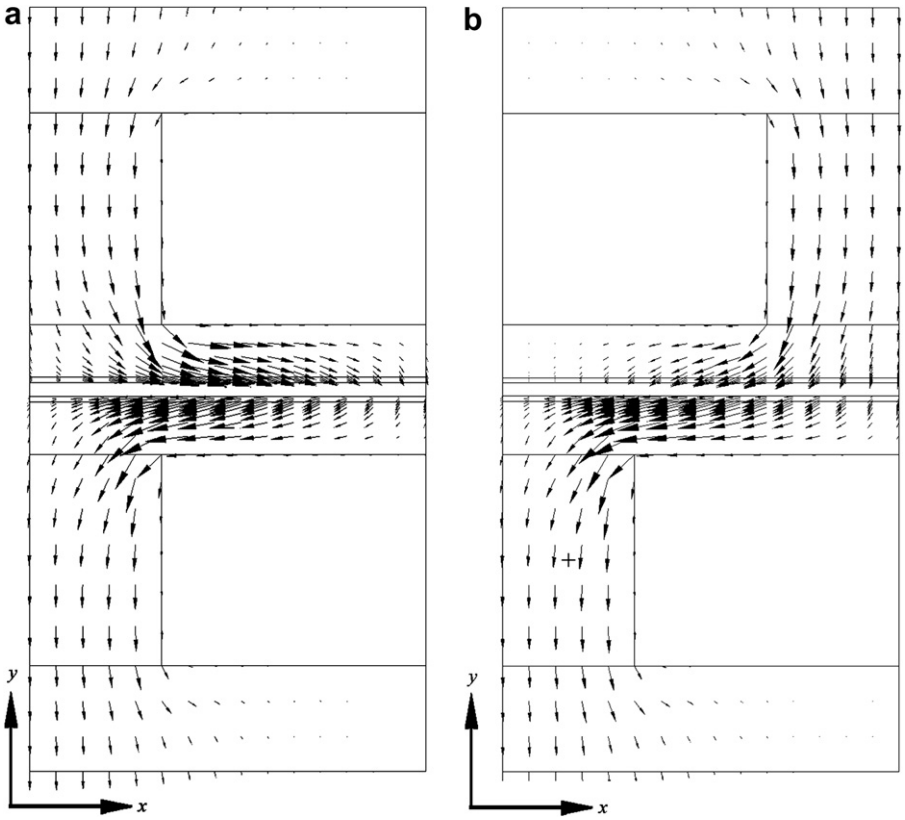

Fig. 4 – Solid phase current density distribution comparison for RTR and RTC (a) RTR (b) RTC.

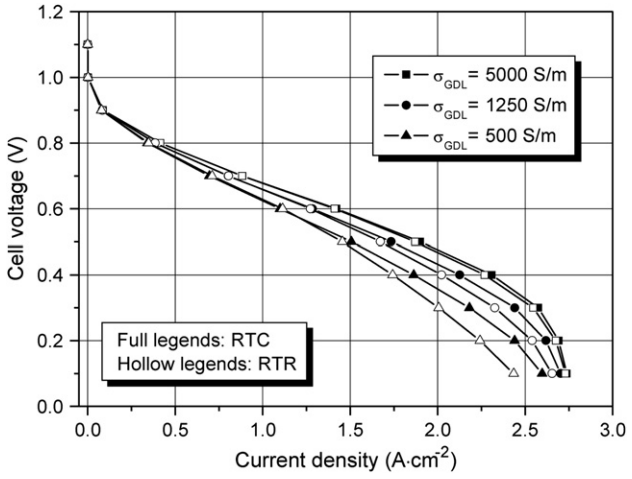

Fig. 5 – Fuel cell performance comparison with different GDL conductivities for RTR and RTC.

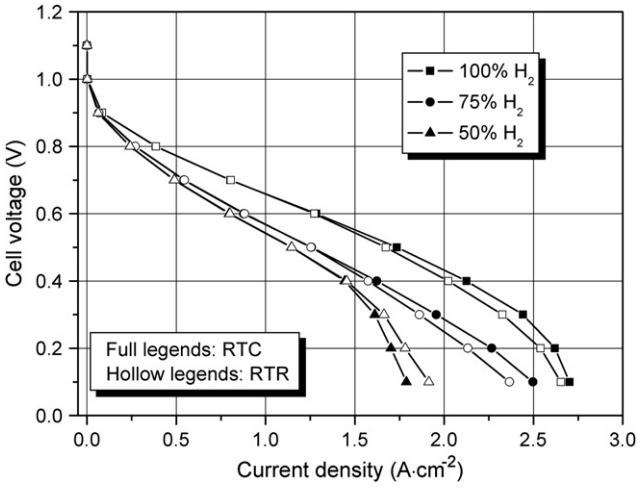

Fig. 7 – Fuel cell performance comparison with different hydrogen molar ratios for RTR and RTC.

the simulated polarization curves of RTR and RTC fuel cells with GDL conductivity to be 500 S/m, 1250 S/m and 5000 S/m respectively. It is very clear from the figure that with low GDL conductivity, the performance difference between RTR and RTC is greater in low cell voltage region. With 5000 S/m GDL conductivity, the performance difference is very small. In Fig. 6, the current density distributions are compared for 5000 S/m, which shows very small difference. It is clear that the performance for RTC is better. Although the performance increase is not so significant for high GDL conductivity case, the idea of RTC is useful in the process of flow field design because the GDL conductivity could not be designed to be very high for the limit of fuel cell materials.

3.3. *Reformed fuel operation*

For the case of reformed hydrogen operation, with the RTC pattern increase the fuel cell performance? In Fig. 7, the polarization curve of 100% H_2, 75% H_2 and 50% H_2 (with CO_2 as balance gas) are compared for RTR and RTC fuel cells. It is interesting that for the former two cases, RTR fuel cells performances are better than RTC fuel cells, however, for the 50% H_2 case, the RTR fuel cell performance is better. Fig. 8 shows the current density distribution of the RTR and RTC cases with 50% H_2 feeding. It shows that there appear two low current density regions in the RTC, beneath the cathode rib and anode rib near the outlets. When hydrogen concentration drops too low (50% in this case), the mass transfer resistance of hydrogen goes to be very high, especially near the hydrogen outlet.

The simulation results are useful for fuel cell flow field pattern design: For pure hydrogen operation, it is better to arrange the anode and cathode channels and ribs to be RTC to increase fuel cell performance, even the GDLs conductivity is high; for reformed hydrogen operation with very low hydrogen concentration, it is better to design the channels

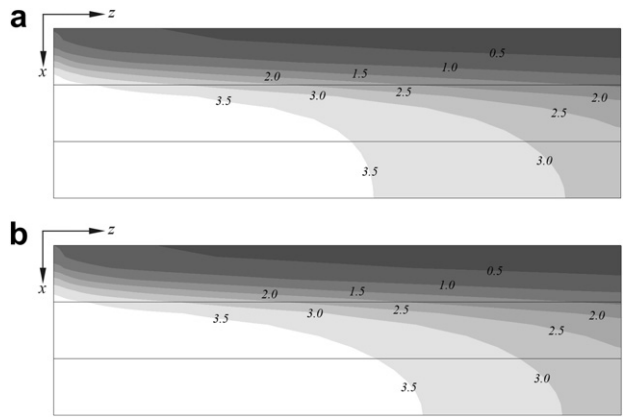

Fig. 6 – Membrane phase current density distribution comparison for RTR and RTC with 5000 S/m GDL conductivity.

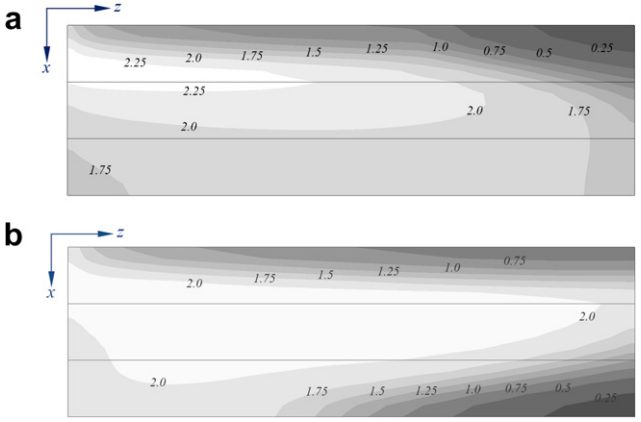

Fig. 8 – Membrane phase current density distribution comparison for RTR and RTC with 50% hydrogen feeding (a) RTR (b) RTC.

and ribs to be RTR to decrease the influence hydrogen transfer resistance.

4. Conclusion

The influence of anode and cathode channels and ribs relative positions to fuel cell performances has not been paid attentions for the fuel cell researchers. In this paper, the fuel cell performances are numerically simulated for rib-to-rib (RTR) and rib-to-channel (RTC) cases. The simulation results are useful for fuel cell design: for pure hydrogen operation, it is better to arrange the anode and cathode channels and ribs to be RTC to increase fuel cell performance, even the GDLs conductivity is high; for reformed hydrogen operation with very low hydrogen concentration, it is better to design the channels and ribs to be RTR to decrease the influence hydrogen transfer resistance.

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