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Effect of anode micro-porous layer on species crossover through the membrane of the liquid-feed direct methanol fuel cells

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ABSTRACT

In this work, a two-dimensional two-phase mass transport model is applied to study the mass transport processes of methanol and water through the membrane electrode assembly of the liquid-feed direct methanol fuel cells (DMFCs). Emphasis is placed on exploring the influences of the structural properties of the anode micro-porous layer (MPL) on water and methanol crossover through the membrane. It is indicated that both the rates of water and methanol crossover can be reduced by thickening the anode MPL resulting from the increased mass transport resistance in the MPL. It is also shown that lowering anode MPL permeability by reducing the mean pore size of the MPL or avoiding the formation of mud cracks in the MPL can lower the liquid saturation in the anode, thus reducing both the rates of water and methanol crossover. In addition, it is found that increasing the anode MPL contact angle can significantly reduce the rate of methanol crossover, but it has little impact on water crossover.

1. Introduction

The direct methanol fuel cell (DMFC) has been regarded as a leading contender to compete with the conventional batteries for power supply due to its advantages of simple structure, fast refueling and high energy density of liquid fuel. Although significant progresses have been made over the past decade, the performance of the DMFC currently has not reached the expected level for powering the most energy-hungry electronic devices [1–5].

Technically, besides the sluggish kinetics of methanol oxidation reaction at the DMFC anode [6], the permeation of methanol through the membrane to the cathode, known as methanol crossover, is another barrier that limits the cell performance [7]. Methanol crossover not only causes the cathode mixed potential, decreasing the cell voltage, but also leads to the waste of fuel, lowering the fuel efficiency. As a result, the rate of methanol crossover has to be suppressed to minimize its detrimental impact. Conventionally, to alleviate the problem of methanol crossover, a diluted liquid methanol solution has to be fed to the DMFC anode such that the cell performance can be maximized. Although it can yield decent cell performance, the use of highly diluted methanol solution drastically reduces the specific energy of the fuel cell system. In addition, it also results in high rate of water crossover to the cathode, which further causes the two problems. First, the high rate of water crossover causes water loss from the anode and thus making up water to the anode is required. Second, it exacerbates the problem of cathode flooding, deteriorating the cell performance and operating stability. Therefore, it is also critical to suppress the rate of water crossover. To achieve these, it is essential to gain a deep understanding of the mechanisms of methanol and water transport through the membrane electrode assembly (MEA) and their dependence on the designs of the MEA.

During the past decade, great efforts have been paid to investigating the effects of operating conditions [8–10] and the structure designs of the MEA [11–17] on methanol crossover. To reduce methanol crossover, the mass transport resistance of methanol through the anode has to be increased by properly designing the anode gas diffusion layer, such as making the anode diffusion layer more hydrophobic, increasing the diffusion layer thickness and reducing the diffusion layer permeability [11–15]. In addition, it is proved that coating a fine micro-porous layer (MPL) to the anode diffusion layer also plays an important role in controlling methanol transport through the anode. For an example, the study by Shao et al. [16] indicated that the MPL with smaller carbon powders with higher surface area, such as Black Pearl 2000, could greatly enhance the mass transport of methanol, thus helping limit the rate of methanol crossover.

In addition to the study of methanol crossover, the problem of water crossover [17–31] has also been studied extensively. Xu and

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