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Parametric studies on the membrane arrangement and porous properties of the flowing electrolyte channel in a flowing electrolyte–direct methanol fuel cell

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ABSTRACT

A parametric study is conducted using a previously described one-dimensional, multiphase model of a flowing electrolyte–direct methanol fuel cell (FE–DMFC). The anode and cathode membrane (AM and CM) thicknesses and porous properties (porosity and permeability) of the flowing electrolyte channel (FEC) were each individually varied, and recommendations on conditions which yield maximum power density and minimal methanol and water crossover are provided. The results of this study suggest that a thin AM and thick CM arrangement should be used; on the order of 25.4 μm and 183 μm respectively – corresponding to Nafion® 112 and 117 membranes respectively. The results also suggest that a fully open FEC (porosity of one) will provide the greatest performance. Although this configuration contradicts existing experimental data, considerations such as the choice of catalyst layer (CL) wettability and back pressure within the FEC are provided to achieve a membraneless FE–DMFC with a fully open FEC. If a porous FEC is to be used, the results suggest that a permeability greater than 10^{-11} m^2 provide sufficient hydration within the CM. The trends regarding the membrane arrangement and FEC permeability are consistent with trends found from previous experimental studies.

Introduction

The flowing electrolyte–direct methanol fuel cell (FE–DMFC) is a potential solution to the long standing methanol crossover problem for the DMFC [1]. In this fuel cell, shown in Fig. 1, the anode and cathode are separated by a porous flowing electrolyte channel (FEC), whereby a diluted liquid electrolyte, such as sulfuric acid, is flown through, to remove any methanol that attempts to crossover.

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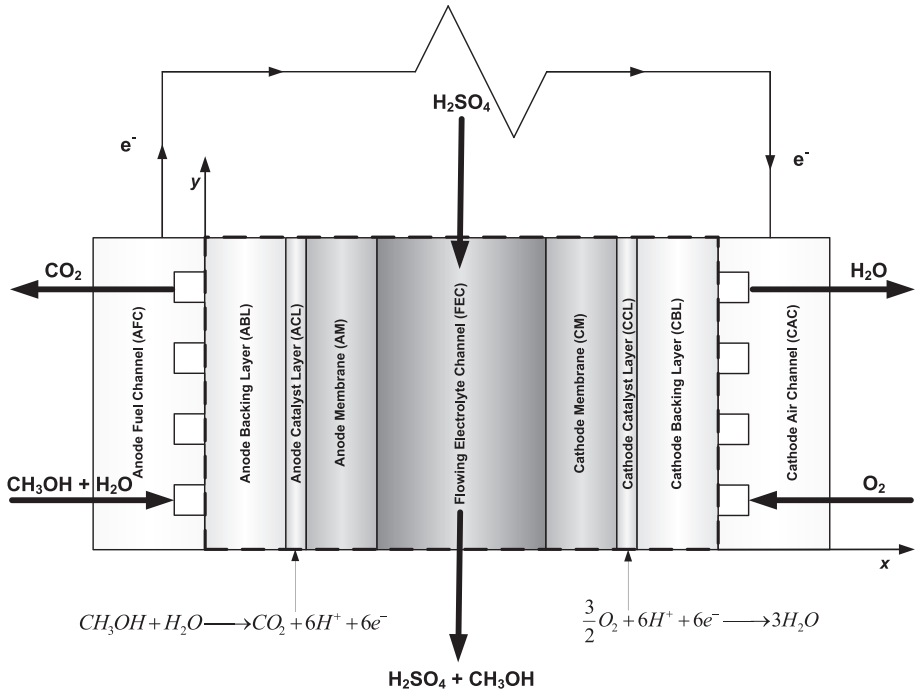

Fig. 1 – Schematic of a flowing electrolyte–direct methanol fuel cell (FE–DMFC). The dashed box and the *x* and *y* axes represent the computational domain and the *x* and *y*-directions for the model [8].

Since the introduction of this fuel cell, several single phase hydrodynamic studies [2–5], single phase models [6–8], and recently a two-phase single domain model of this fuel cell have been proposed [9]. These models have been used to perform parametric studies on various operating conditions, as well as understand the effectiveness of the FEC. Experimental studies have also been conducted on the FE-DMFC [10–13], and just like in the modeling studies, parametric studies were carried out on the operating conditions of a single cell [10,11,13] and short-stack FE–DMFC [12]. Of particular interest, in Sabet-Sharghi et al.'s [10] and Duivesteyn's work [11], they also respectively found a membrane arrangement and set of porous properties for the FEC that should be used to increase the fuel cell's performance. Unfortunately in these studies, the range of conditions that they tested was narrow, and little theoretical backing to their findings were provided.

Since the FE-DMFC sustains higher ohmic losses than the DMFC due the additional membrane and the FEC, and for the FE–DMFC to perform effectively, the choice of porous properties of FEC need to be understood. This is especially important since current FE-DMFC literature mainly discusses the effect of operating conditions on the performance of this fuel cell. Therefore, this study is devoted to utilizing the two-phase single domain model proposed by Ouellette et al. [9] to understand the effect that the porous properties (porosity and permeability) of the FEC and the anode and cathode membrane (AM and CM) thicknesses have on the performance of the FE–DMFC. The conditions which yield minimal methanol and water crossover will be discussed, as well as the conditions which provide the highest power output are pointed out. This parametric study will be used to understand the dynamics of methanol and water crossover, within this fuel cell. These findings are intended to provide guidance towards more efficient FE–DMFC designs.

Overview of model

The model in this study follows the two-phase and single domain multiphase mixture model (MMM) that the authors have previously proposed [9]. A brief summary of this model is provided in this section, however for further details, the reader is referred to the cited work.

Modeling assumptions

The assumptions used in this work are listed below. For further information, the reader is referred to Ref. [9].

1. The fuel cell operates under steady state and isothermal conditions;
2. All fluids are ideal and exist in equilibrium;
3. Each media is homogeneous and isotropic;
4. All crossed over methanol is fully consumed at the CCL-CM interface;
5. The FEC velocity profile is uniform;
6. The BLs and CLs have the same porous properties;
7. The water introduced by the FEC occurs at a constant rate.

Notation

The subscripts *e*, *g*, and *l* refer to the electrolyte, gaseous and liquid states respectively; while the subscripts *i* and *lg* refer to