INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 40 (2015) 16745–16759

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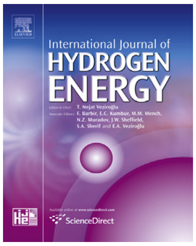

Improving the design of gas diffusion layers for intermediate temperature polymer electrolyte fuel cells using a sensitivity analysis: A multiphysics approach

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ARTICLE INFO

Article history:
Received 19 January 2015
Received in revised form
24 July 2015
Accepted 3 August 2015
Available online 28 August 2015

Keywords:
PEFC
Intermediate temperature
Gas diffusion layer
Multiphysics modelling
Metallic meshes and foams

ABSTRACT

Intermediate temperature (100–120 °C) polymer electrolyte fuel cells (IT-PEFCs) offer simplified water and thermal management compared to conventional PEFCs, since any water should exist in the vapour phase, allowing for easier removal. The higher operating temperature also facilitates greater temperature differentials between the fuel cell and the surrounding atmosphere, thus easing the thermal management of an IT-PEFC stack. However, the study of IT-PEFC is still a relatively poorly covered field within the literature and thus little information is available on performance characteristics.

We therefore present a simple multiphysics model as a quantitative tool for describing the IT-PEFC. This tool is then used to optimise different materials and parameters within an IT-PEFC. Experimental data is presented as a test of the model, and excellent quantitative agreement is demonstrated.

Having validated this model, we present a detailed study of the GDL materials in order to understand the influence of different parameters, namely: (i) porosity, (ii) permeability and (iii) electrical conductivity.

We report that the optimal porosity for IT-PEFC operation is 40–50%, whereas that the GDL permeability was found to have little impact on the cell performance.

Further, we used the model as a design tool: proposing a novel cell design, taking into account the considerable advantages when using a metallic GDL which yielded potential significant improvements in the system efficiency.

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http://dx.doi.org/10.1016/j.ijhydene.2015.08.001

Introduction

Polymer electrolyte fuel cells (PEFCs) technology still faces considerable challenges with both heat and water management [1–4]. The low temperature of the cell (sub 100 °C) means that the water formed by the fuel cell reaction will most likely exist in the liquid form, dependant also upon the partial pressure of water vapour and the saturation pressure of water vapour. This water is required to also keep the membrane/electrodes sufficiently hydrated. However, too much water leads to flooding which is one reason why water management is a vital issue. The low operating temperature also means that heat generated by the cell is not easy to remove from the cell without the aid of large cooling systems which often lower the system efficiency [1].

One of the ways of improving the performance of the PEFC is to increase the operating temperature above 100 °C thus creating a "high temperature" (HT) PEFC (100–180 °C). The benefits of high temperature operation include the improved tolerance to CO poisoning, simplified thermal and heat management. This is achieved by typically using an acid based membrane system. However, some of the downsides include longer start up time and increased degradation due to the acid [1]. As such, the HT-PEFC is unsuitable for automotive applications where quick start-up times are a requirement. These disadvantages can be reduced by limiting the operating temperature to 120 °C. We label this an intermediate temperature (IT) PEFC. It becomes possible to simplify heat and water management as higher temperature heat is produced alongside water that exists in the vapour phase. This in turn should lead to a more efficient system as the balance of plant required can be simplified. To this purpose the CO tolerance of the catalysts is of no importance so that we can use pure hydrogen fuel in our analysis and concentrate on the thermal management issues. However, material development is still required as conventional membrane electrode assemblies (MEAs) incorporating standard Nafion based electrolytes are not suitable. The technology becomes similar to phosphoric acid fuel cells (PAFCs) in some aspects, which will be discussed later.

The gas diffusion layer (GDL) is one component of the PEFC that has received little attention for IT-PEFC and HT-PEFC operation. GDLs are important components that direct the flow of the reactants (H_2 and O_2) to the catalyst layers (CLs) from the flow field plates (FFPs). The GDL also facilitates the heat and water management within the MEA by allowing the diffusion of water away from the catalyst layers of the MEA. The GDL is responsible for the electrical connection between the CL particles and the FFP (Fig. 1).

GDLs are typically made of porous, electrically conductive, carbon based materials which for conventional PEFCs are made hydrophobic (for example by adding PTFE) to prevent the blockage of water within the GDL pores. A GDL will typically feature a micro porous layer (MPL) which consists of PTFE and carbon. Typical material properties for conventional repeating unit cells is described in Table 1.

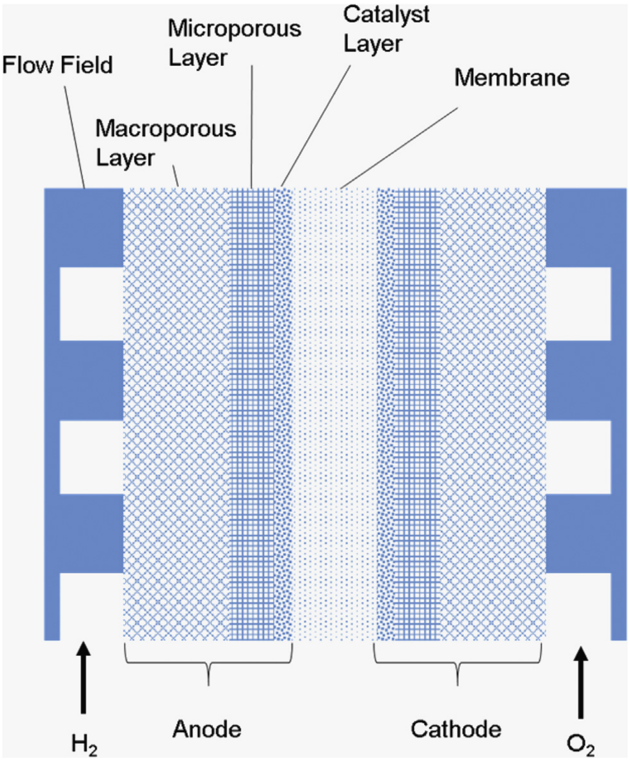

Fig. 1 – Cross section of an IT-PEFC repeating unit.

One method for the development of HT-PEFCs is to employ *ab initio* simulation studies as this allows for further information to be gained on what is happening within the MEA that would be difficult to ascertain empirically.

The first PEFC models were published in the early 1990s by Springer et al. [5,6] and Bernardi and Verbrugge [7,8] and were one dimensional models. These models were based on experimental studies carried out on phosphoric acid fuel cells. In these models, species transport, water balance and influence of relative humidity of reactant gases were investigated. Recently, the influence of several parameters were studied by Song et al. [9] using a dynamic two phase model that was non-isothermal in order to describe the multiphase dynamics within the GDL.

Current modelling work has focused on conventional low temperature PEFCs, see for example [10–15]. For HT-PEFCs in particular, research has been devoted to modelling of the membrane in order to understand and improve membrane design [16–20]. However, a study of membrane materials at intermediate temperatures is still lacking. For low temperature PEFC, a large focus has been on the transport phenomena within the cell [10–15] through to modelling of the stack [21–23].

With respect to simulating higher operating temperature PEFCs, Baschuk et al. [24] produced a comprehensive model for use within CFD software which included all elements of the PEFC, including mass, momentum and heat conservation as well as the fuel cell electrochemical reactions.