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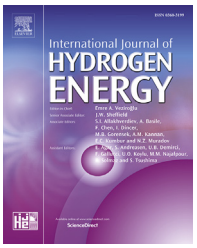

Effects of compression on water distribution in gas diffusion layer materials of PEMFC in a point injection device by means of synchrotron X-ray imaging

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ABSTRACT

In this study, ex-situ experiments performed with a point injection device are conducted to evaluate water distributions in gas diffusion layer (GDL) materials which serve as porous transport media in polymer electrolyte membrane fuel cells (PEMFCs). In this regard, GDL samples manufactured by SGL Group are placed into the point injection device and visualized by means of synchrotron X-ray radiographic and tomographic imaging. The resulting image data undergoes a coordinate transformation that ascertains water agglomerations in GDL pores with regard to their radial displacements from the injection point. In this way, water transport in two different GDL samples possessing the same structural characteristics, but with unique compression rates, are investigated in terms of in-plane water distribution. The radial displacement analysis indicated that the pore saturation of the compressed GDL is higher in both the micro porous layer (MPL) region and the carbon fiber substrate region than that of the uncompressed GDL. The water agglomerations in the uncompressed GDL are predominantly observed in the vicinity of the injection point, indicating a limited in-plane transport. Conversely, in the compressed case water accumulations are detected far from the injection point, even at the edge of the GDL, pointing out that compression promotes the

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in-plane transport. Prior to the ex-situ experiments, both GDL samples have undergone an ageing procedure to mimic realistic cell operating conditions.

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Nomenclature

p_c	Capillary pressure [Pa]
σ	Surface tension between carbon fiber substrate and water [N/m]
θ	Contact angle of water [°]
r	Effective capillary radius of a pore space [m]
I_w	Beam intensity values of the wet GDL samples [W/cm^2]
I_0	Beam intensity values of dry GDL samples [W/cm^2]
μ_w	Energy dependent attenuation coefficient of water [1/cm]
d_w	Depth of liquid water in the beam path [cm]
H	Hydrogen atom
H^+	Hydrogen ion

Abbreviations

BAM	Federal Institute for Material Research and Testing
CCD	Charged Couple Device
GDL	Gas Diffusion Layers
IDL	Interactive Data Language
MAVI	Modular Algorithm for Volume Images
MEA	Membrane Electrode Assembly
MPL	Micro Porous Layers
PEMFC	Polymer Electrolyte Membrane Fuel Cell
PTFE	Polytetrafluorethylene

Introduction

Polymer electrolyte membrane fuel cells (PEMFC) are a promising energy conversion technology, which is more efficient than internal combustion engines via the direct conversion of chemical energy stored in hydrogen into electrical energy [1–13]. As a result of the electrochemical reaction in PEMFC, no greenhouse gases are emitted locally to the atmosphere, making the development of PEMFC invaluable in the future development of clean energy sources [2,4,5,14]. Despite of these advantages, the endurance of fuel cell operation needs to be enhanced to ensure its competitiveness in the energy market. In this regard, improving water management and thereby reducing the oxygen transport resistance yielding an increase in the oxygen concentration in the diffusion media is one of the significant challenges [3].

Water management mainly aims at the removal of product water resulting from the electrochemical reaction at the cathode electrode of the membrane-electrode-assembly (MEA) and the membrane hydration accounting for the conductivity of hydrogen ions (H^+) [15,16]. To initiate the electrochemical reaction in PEMFC, the educts "hydrogen and oxygen" are led to the anode and cathode electrodes via gas diffusion channels which are assigned for homogeneous transport of the reactant gases in the gas diffusion layers (GDL) respectively [17–23]. The educts penetrating the GDLs reach the catalyst layers at both electrodes, inciting current generation and the ionization of H. Then, the hydrogen ions travel through the polymer electrolyte membrane from the anode to the cathode electrode, while the liberated electrons at the catalyst layer of the anode move through the GDL to the bipolar plate. The oxygen molecules diffused by the GDL to the catalyst layer at the cathode are reduced by these electrons, so they interact with the hydrogen ions there. As a result of this reaction, water molecules are formed. Water formation at the cathode electrode is utilized for the hydration of the membrane. However, large amount of generated water at high current densities may not be drained through the GDL at a sufficient rate especially in the degraded fuel cells operated especially at high relative humidity and lower temperatures. As a result, "water flooding" of the GDL, obstructing the transport of reactant gases to the catalyst layer, takes place [18,24–29]. Therefore, water distribution in the GDL structure is decisive on the resistance against the reactant gas transport. In this context, the study of Garcia-Salaberri et al. [30] indicates that the gas transport resistance due to liquid water formation is particularly dependent on the peak saturation, and not just the average saturation of the GDL.

There are numerous studies focusing on the water transport and discharge characteristics in GDL materials. In one of those investigations, the effect of randomly arranged holes in the micro porous layers (MPL) within a GDL on water transport is studied via synchrotron X-ray radiography and tomography. To detect the changes in water transport characteristics, a reference cell and a modified cell containing a perforated MPL are tested at operating temperatures of 40 °C and 55 °C. For the operation at 40 °C, liquid water travels through the perforated holes in the modified cell, making more pores available for the transport of reactant gases. However, no considerable change is observed for the water transport through GDL structures in the reference and perforated cells at 55 °C. Depending on this finding, it is discerned that at elevated operating temperatures product water is prevailingly discharged in gaseous form through the MPL [31]. According to Manahan et al. [32] and Markötter et al. [33], GDL structures with perforations may reduce performance for low humidity operations at high current densities. Nevertheless, cell operation driven at high relative humidity benefits from these perforations [33]. The optimum perforation diameter is found out as 60 μm, ensuring an improved draining effect on the area around the perforation [34].

In the study of Antonacci et al., the thickness of the MPL is taken into consideration to analyze mass transport properties

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