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Modeling liquid water re-distributions in bi-porous layer flow-fields of proton exchange membrane fuel cells

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HIGHLIGHTS

- A bi-porous layer flow-field has a secondary porous layer attached to a BP.
- Secondary porous layers cause liquid water re-distribution inside flow-fields.
- Liquid water re-distribution enhances water management and mass transport.
- Flooding occurs if the permeability ratio exceeds a threshold.
- Flooding in secondary porous layers results in poor cell performance.

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ABSTRACT

A bi-porous layer flow-field features a secondary porous layer of smaller permeability attached to a bi-polar plate to remove excessive liquid water from the main flow-field by capillary-induced liquid water re-distributions, therefore enhances liquid water management of a proton exchange membrane fuel cell (PEMFC). In this work, we present a two-dimensional two-phase model to elucidate the underlying physics of liquid water re-distribution inside a bi-porous layer flow-field. We reveal that liquid water re-distribution can improve liquid water management in the flow-field and gas diffusion layer, leading up to significant enhancement in oxygen diffusion to the catalyst layer. However, if permeability of the secondary porous layer is too low and the permeability ratio exceeds a threshold, the secondary porous layer may suffer from flooding. This causes liquid water build-up in the main flow-field and GDL, which leads poor oxygen diffusion to the catalyst layer and hence operational instability. The threshold permeability ratio is analytically derived, and flow behaviors at conditions above and below the threshold permeability ratio are explored numerically and analytically. We suggest choosing a permeability ratio below the threshold permeability ratio to avoid flooding in the secondary porous layer and to fully utilize the benefits of liquid water re-distributions.

1. Introduction

Improper management of liquid water in flow-fields and adjacent gas diffusion layers (GDLs) causes detrimental loss in durability and performance of proton exchange membrane fuel cells (PEMFCs), especially for automotive applications of PEMFCs due to high current density operation. First, liquid water accumulation in flow-fields results in higher liquid water saturation in GDLs, which causes oxygen starvation in catalyst layers (CL) and greatly increases mass transport losses. Second, liquid water droplets in flow-fields block pathways for reactant gas and therefore cause cell voltage oscillations and even shut-down reactant gas flow [1], which decreases cell's active area and also causes detrimental consequences to cell durability [2]. A novel approach for effectively removing excessive liquid water in flow-fields of PEMFCs is in urgent need for improving performance and stability of PEMFC.

One way to enhance liquid water management in PEMFC flow-fields is using a capillary force to re-distribute liquid water inside flow-fields. For example, as schematically shown in Fig. 1a, one can attach a secondary porous layer of lower permeability to a bi-polar plate to absorb excessive liquid water from the main flow-field by using the capillary force, like a sponge absorbing liquid water. Subsequently, this liquid water imbibed inside the finer porous layer is forced to move toward the outlet under the longitudinal pressure drop created by reactant gas flowing in adjacent main flow-field. This “liquid water re-distribution”

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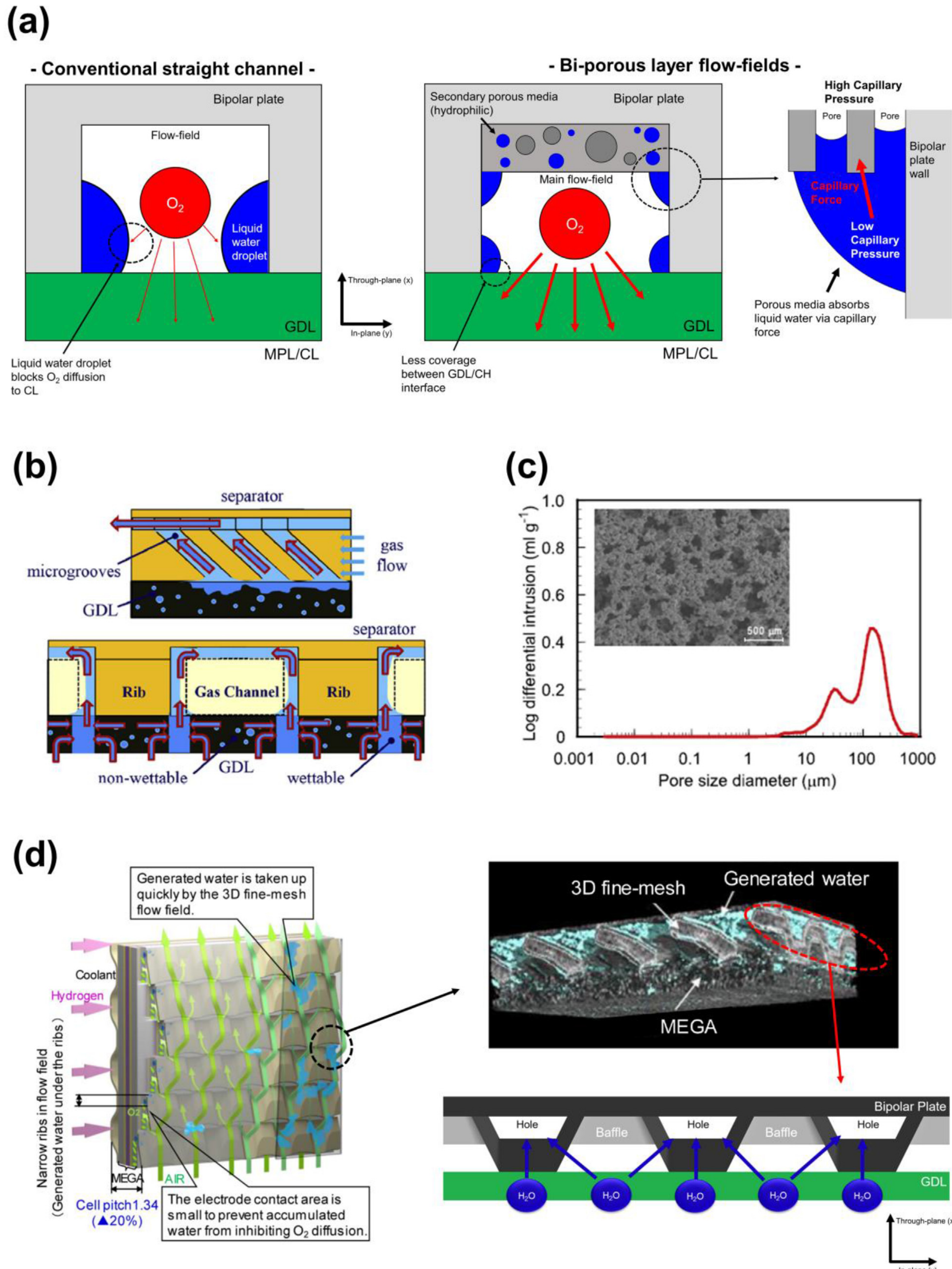

Fig. 1. **(a)** Schematics and working principles of bi-porous layer flow-fields, **(b–d)** Examples of flow-fields utilizing liquid water re-distribution: **(b)** micro-grooved flow-fields [7] **(c)** bi-porous flow-fields [8] **(d)** 3D fine-mesh flow-fields of Toyota Mirai (macro flow-fields [9] and CT image [9]).