Combined Two-Phase Co-Flow and Counter-Flow in a Gas Channel and Porous Transport Layer Assembly

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Abstract Text:

Polymer electrolyte fuel cells and electrolyzers are low temperature devices whereby both gases and liquids intermingle within the porous transport layers and open channels. The flow of the liquid and gas is of paramount importance to the functioning of the unit. This motion is poorly understood. Cell-level models typically employ volume-averaging techniques to describe the motion of the flowing reactants and products. Until recently, detailed analysis of the two-phase liquid gas mixture, employing front-tracking methods has proved too computationally prohibitive. Previous work [1,2] has considered the motion of liquid drops in gas channels, it being assumed the drops are formed at specific nucleation sites on the sides of the channels. The present work considers a detailed numerical analysis of combined liquid-gas co-flow in a gas channel with liquid-gas counter-flow in a porous transport layer (PTL). The geometry considered is a ‘T-shape’ with the porous transport layer in the form of a thin rectangular prism of dimensions 0.5×0.5×0.1 mm^3 located at the base of the ‘T’, and the gas flowing across the top channel, as shown in Fig. 1. The PTL is reproduced by digital reconstruction of nano-computer tomography images of a Freudenberg H2315 PTL as a stereolithography file*, see Figure 2(a). From this, the domain is tessellated with an unstructured castellated, or octree, type mesh, Fig. 2(b). Liquid water is introduced at an electrode at the base of the PTL and gaseous oxygen is simultaneously removed by electrochemical reduction; the resulting liquid-gas counter-flow in the porous transport layer effects liquid droplets being entrained in co-flow in the gas channel and being convected downstream, thereafter.

The equations of mass and momentum are solved by means of the open source software library OpenFOAM. A volume-of-fluid approach based on the multidimensional universal limiter for explicit solution was employed. At t = 0, the channel is presumed to be filled with gas, and the PTL partially saturated with liquid water. Gas is introduced at the inlet at a given velocity. Water is added and gas removed at the electrode (counter-flow), whereas both water and gas are removed at the outlet (co-flow). At the channel walls and on the PTL fibres, the static contact angle is fixed.

Some results are shown in Fig. 3(a-d). It can be seen that the location and size of the drops shed varies somewhat in space and time, i.e., there is a stochastic component to the motion of the fluid, due to the spatial distribution of the fibres in the PTL, the transient shedding process, and the merging of liquid streams flowing into the gas channel. Nonetheless a definite periodicity is observed, with drops being injected into the channel at a fairly regular rate. Some relatively minor switching with time is observed within the PTL due to the random packing of fibres, but these transients are relatively quiescent. In addition to providing important new information about flow and pressure losses in electrochemical cells as a function of current density and stoichiometry, the present model may be also used to enumerate properties such as relative permeability which can subsequently be employed in cell-scale models.

* The authors wish to thank Mr. Eugen Hoppe for constructing a stereolithography file of the porous material used in this study.

[1] Andersson, M., Beale, S.B., Reimer, U., Lehnert, W., Stolten, D., Int. J. Hydrog. Energy, 2018, 43(5): 2961-2976.

[2] Andersson, M., Mularczyk, A., Lamibrac, A., Beale, S.B., Eller, J., Lehnert, W., Büchi, F.N., J. Power Sources, 2018. 404: 159-171.

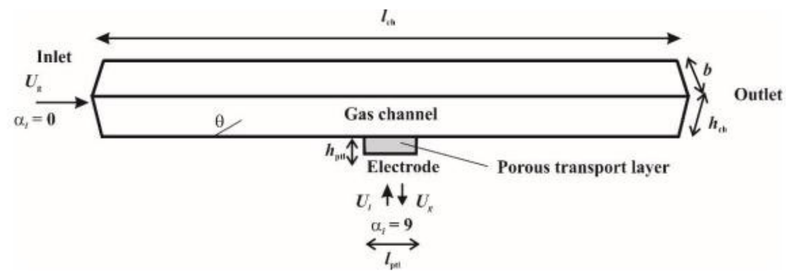

Figure 1. Schematic of problem under consideration.

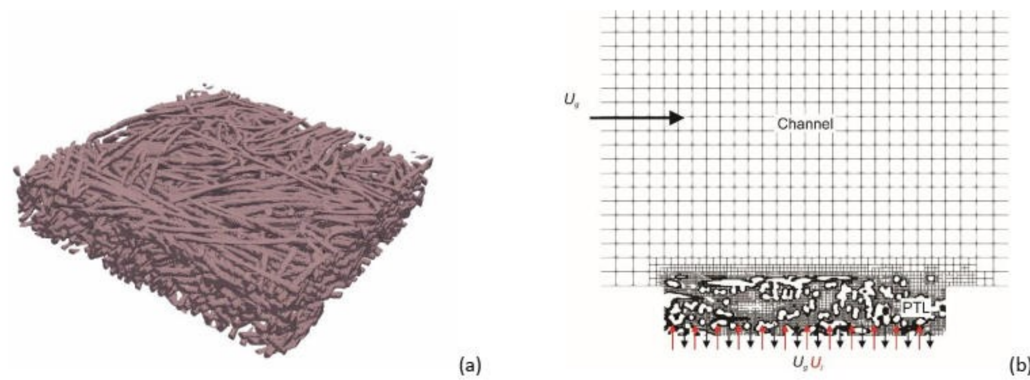

Figure 2. (a) Detail of the digitally reconstructed PTL (b) slice of castellated mesh showing channel and PTL regions in a centre-plane corresponding to the main flow direction.

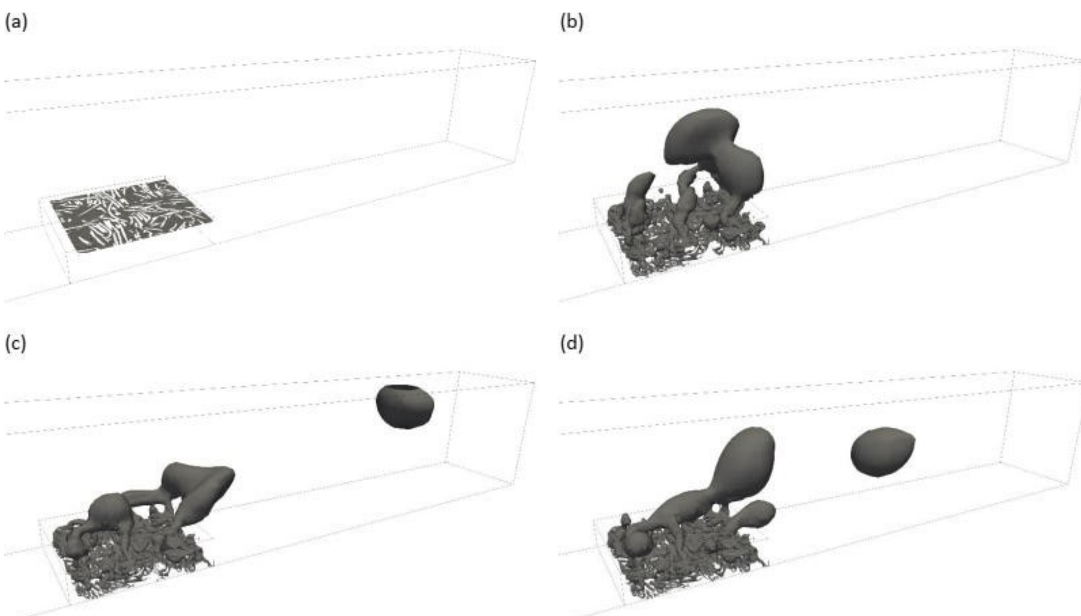

Figure 3. Drop formation in the PTL and subsequent convection downstream in the gas channel (a) T = 0s (b) T = 0.0008s (c) T = 0.0016s (d) T = 0.0024s.

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