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Representative model and flow characteristics of open pore cellular foam and potential use in proton exchange membrane fuel cells

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ABSTRACT

This study develops a Representative Unit Cell Structure (RUCS) model for Open Pore Cellular Foam (OPCF) material, based on a dodecahedron cell. Pressure, velocity and flow regime analysis is performed on simulation results of six different OPCFs, (10, 20, 30, 40, 45, 80 and 100 ppi), at five different inlet velocities (1 m/s, 3 m/s, 6 m/s, 9 m/s & 12 m/s). Pressure drop results were verified by numerical models (Dupuit–Forchheimer, Ashby and Fourie and Du Plessis mathematical models) and experimental results from literature.

From this study OPCF material can have benefits if used in a PEM fuel cell; in place of or in conjunction with conventional flow plates. It is concluded that OPCF materials can reduce the permeability of the gas flow through a flow plate, creating a more tortuous path for the fluid, allowing for diffusion plus convection based flow, unlike conventional flow plates.

Introduction

The Proton Exchange Membrane (PEM) fuel cell is a low temperature electrochemical device that offers a promising, possibly green, alternative to traditional power sources, and other fuel cell types, in many applications, without air polluting issues [1–3]. PEM fuel cells use a solid polymer in the form of a solid phase proton conducting membrane as an electrolyte. PEM fuel cells have many advantages over other fuel cell types; including low temperature operation, high power density, fast start up, system robustness, flexibility of fuel type (with reformer) and reduced sealing, corrosion, shielding or leaking concerns [4]. A conventional PEM fuel cell consists of a Membrane Electrode Assembly (MEA) sandwiched between two flow plates. The flow plate distributes the fuel and oxidant to the reactive catalyst sites of the MEA.

One of the key strategies for improving the performance of the PEM fuel cell is the effective design of the flow plate. The flow plate is a vital component of a PEM fuel cell and can constitute to 80% of the weight and 30% of the total cost in a fuel cell stack [5]. It supplies fuel and oxidant to reactive sites,

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collects produced current, removes reaction products, manages water through the cell and provides mechanical support for the cells in a stack [6].

By improving the design, layout and configuration of the flow plate with the use of low-cost lightweight construction materials and optimal fabrication methods, the weight, volume and cost of a PEM fuel cell stack can be reduced significantly [7].

In conventional flow fields, as the flow field length increases, the pressure decreases across the MEA from inlet to outlet, this can lead to the effectiveness of the fuel cell decreasing rapidly from inlet to outlet. Increasing the inlet pressure can increase cell performance, however it may reduce the efficiency of the system as Balance of Plant (BOP) equipment is needed to power this pressure increase [8].

As an alternative to conventional flow plates, Open Pore Cellular Foam (OPCF) materials have recently been used as a flow distributor in flow fields [9–15]. OPCF, shown in Fig. 1(a), is a relatively new class of cellular material with the ability to be manufactured with tailored mechanical, thermal and electrical properties by varying the material's relative density and cell morphology [16].

Having the ability to tailor a flow plate's design, e.g. to provide an acceptable pressure drop, can ensure improved PEM fuel cell performance. Understanding pressure gradients and developing models to simulate flow regimes through different OPCF material is therefore an important research area.

Early work by Du Plessis et al. [11] attempted to capture the relevant characteristics of OPCF based on a set of rectangular prisms. They used the results of an analytical flow analysis on this model to solve the flow through OPCFs on a larger scale with relatively good results. Lu et al. [17] took the approach of modelling fluid flow through open cell metal foams as a system of cylinders in their combined flow and heat convection model. Krishnan et al. [18,19] simulated thermal transport in open cell metal foams using different periodic unit-cell geometries. The periodic unit-cell structures were constructed by assuming the pore space to be spherical and subtracting the pore space from a unit cube of the metal. Different types of packing arrangement for spheres were considered including; body centred cubic, face centred cubic and A15 lattice, which give rise to different foam structures. Effective thermal conductivity, pressure drop and Nusselt number are computed by imposing periodic boundary conditions for aluminium foams saturated with air or water. The computed values compare well with existing experimental measurements and semi-empirical models for porosities greater than 80%.

The 14-sided tetrakaidecahedron cell has long been considered the optimal packing cell, first proposed by Lord Kelvin in 1887, decided upon mainly through experimentation. A study by Fourie and Du Plessis [20] used a 14-sided tetrakaidecahedron, to simulate pressure drop and flow in an open cell metal foam model. Boomsma et al. [21] also simulated flow through OPCF using the tetrakaidecahedron cell. Xu et al. adopted the tetrakaidecahedron model to systematically investigate the flow patterns in porous media and the relationship between fluid flow parameters and foams structure characteristics [22]. However other researchers such as Ozmat et al. [23] have noted in literature that the isotropic Open Pore Cellular Foam consists of randomly oriented polygon shaped cells that could be approximated by a dodecahedron, a model that has been researched little in literature.

From reviewing the literature OPCF materials of between 10 and 40 ppi have been researched, however limited research for smaller pore sizes (greater than 40 ppi) has been cited.

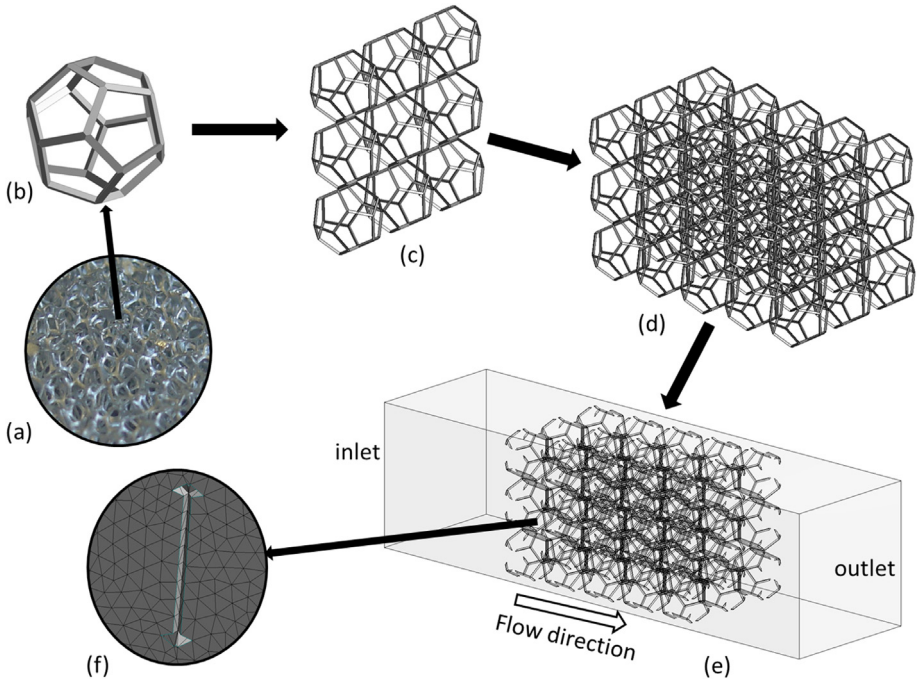

Fig. 1 – Dodecahedron model matrix development (a) OPCF sample (b) Doadecahedron pore (c) Pore pattern (d) Pore matrix (e) Computational domain (f) Close up of ligament surface mesh.