NATURE-INSPIRED FLOW-FIELDS AND WATER MANAGEMENT FOR PEM FUEL CELLS

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Flow-field design is crucial to polymer electrolyte membrane fuel cell (PEMFC) performance, since non-uniform transport of species to and from the membrane electrode assembly (MEA) results in significant power losses. The long channels of conventional serpentine flow-fields cause large pressure drops between inlets and outlets, thus large parasitic energy losses and low fuel cell performance.

Here, a lung-inspired approach is used to design flow-fields guided by the structure of a lung. The fractal geometry of the human lung has been shown to ensure uniform distribution of air from a single outlet (trachea) to multiple outlets (alveoli). Furthermore, the human lung transitions between two flow regimes: 14-16 upper generations of branches dominated by convection, and 7-9 lower generations of space-filling acini dominated by diffusion. The upper generations of branches are designed to slow down the gas flow to a rate compatible with the rate in the diffusional regime (Pé ~ 1), resulting in uniform distribution of entropy production in both regimes.

By employing a three-dimensional (3D) fractal structure as flow-field inlet channel, we aim to yield similar benefits from replicating these characteristics of the human lung. The fractal pattern consists of repeating “H” shapes where daughter “H’s” are located at the four tips of the parent “H”. The fractal geometry obeys Murray’s law, much like the human lung, hereby leading to minimal mechanical energy losses. Furthermore, the three-dimensional branching structure provide uniform local conditions on the surface of the catalyst layer as only the outlets of the fractal inlet channel are exposed to the MEA.

Numerical simulations were conducted to determine the number of generations required to achieve uniform reactant distribution and minimal entropy production. The results reveal that the ideal number of generations for minimum entropy production lies between N = 5 and 7. Guided by the simulation results, three flow-fields with N = 3, 4 and 5 (10 cm^2 surface area) were 3D printed *via* direct metal laser sintering (DMLS), and experimentally validated against conventional serpentine flow-fields. The fractal flow-fields with N = 4 and 5 generations showed ~20% and ~30% increase in performance and maximum power density over serpentine flow-fields above 0.8 A cm^{-2} at 50% RH. At fully humidified conditions, though, the performance of fractal N = 5 flow-field significantly deteriorates due to flooding issues.

Another defining characteristic of the fractal approach is scalability, which is an important feature in nature. Fractal flow-fields can bridge multiple length scales by adding further generations, while preserving the building units and microscopic function of the system. Larger, 3D printed fractal flow-fields (25 cm^2 surface area) with N = 4 are compared to conventional serpentine flow-field based PEMFCs. Performance results show that fractal and serpentine flow-field based PEMFCs have similar polarization curves, which is attributed to the significantly higher pressure drop (~ 25 kPa) of large serpentine flow-fields compared to fractal flow-fields. However, such excessive pressure drop renders the use of a large scale serpentine flow-field prohibitive, thus favouring the fractal flow-field.

A major shortcoming of using fractal flow-field is, though, susceptibility to flooding in the gas channels due to slow gas velocity. This problem has led to the development of a nature-inspired water management mechanism that draws inspiration from the ability of the Thorny Devil (Australian lizard) to passively transport liquid water across its skin using capillary pressure. We have recently integrated this strategy with the fractal N = 4 flow-fields and verified the viability of the strategy using neutron imaging at Helmholtz-Zentrum Berlin (HZB). Implementation of this water management strategy is expected to circumvent remaining problems of high-generation fractal flow-fields.