Flow Field Patterns for Proton Exchange Membrane (PEM) Fuel Cells

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Flow field (FF) designs for Proton Exchange Membrane Fuel Cell (PEMFC) bipolar plates (BPP) are reviewed; these include FF designs that are: serpentine, parallel, mesh type, interdigitated or mixtures thereof as well as 2D circular and 3D tubular geometries, porous, fractal and biomimetic flow fields. The advantages/disadvantages and tendencies from field optimizations are briefly discussed. Efficient flow field designs give uniform gas distribution, low pressure drop for transport and sufficient rib area to provide high electronic conductivity. A performing FF should also: (i) prevent water condensation, (ii) remove water efficiently, and (iii) allow sufficiently high membrane moisture content. In this poster, it is highlighted that for an area-filling gas distributor, FF pattern development should aim at finding a flow field design in accordance with the principal of minimum entropy production, making an emphasis on multi-criteria optimization methods, rather than optimizing only one parameter like, for example, pressure drop or flow uniformity.

Introduction

Ever rising targets for PEM fuel cells in terms of performance, power density and durability, have created the need of better and more optimized flow field (FF) designs for bipolar plates (BPP). The BPP needs to achieve several different objectives [1]:

- Fuels need to be distributed uniformly
- High electronic conductivity
- Small pressure drop along the FF channels
- Simple and effective water removal
- Supply fuels to electrodes at sufficient speed

The FF design on the BPP has a great influence on the fuel cell performance. This study gives a brief summary of the current state of the art fuel cell FF designs and compares them to conventional designs. A summary of advantages and disadvantages of different FF patterns is shown in Table 1.

Conventional design

Conventional designs currently used are serpentine (Fig. 1a), parallel (Fig. 1b), interdigitated (Fig. 1c) and mesh patterns (Fig. 1e). These conventional FF patterns are further improved, for example by creating a parallel FF pattern with several multi-paths, which increases the pressure drop and improves gas flow distribution (Fig. 1d) [2]. Interdigitated patterns can also be modified to mimic biological flow patterns (Fig 1f/1g). CFD simulations have shown a 30% higher peak power compared to conventional serpentine/interdigitated patterns [3].

Channel improvements

Conventional patterns can be improved by changing the dimensions of the channels and ribs or by changing the cross-sectional shape. Simulations can be performed to find optimal dimensions for the FF patterns. As shown in [4,5], having narrower channels lead to a higher performance of the PEM fuel cell when serpentine designs are employed.

Fractal-type designs

Fractal patterns can be created with algorithms to create an area filling FFP pattern (Fig. 1i). For some operating conditions, these types of pattern have exhibited better performance than serpentine ones [6,7]. Closed end fractal pattern have also been tested, where dimensions have been calculated using a minimum entropy optimization procedure (Fig. 1j) [8,9]. The performance was, however, lower than the parallel design [10].

Biomimetic designs

During the last decade, novel types of FFP designs, inspired by nature and mimicking the structure of biological transport networks, have been elaborated [6,11,12]. The main objective has been that the FFP in PEMFC fulfills the same transport function observed in blood vessels, bronchial airways, and fluid conducting vessels in plants. Leaf-like structures have been investigated (Fig.1k/1l). Utilizing Murray's Law for scaling can lead to minimal energy dissipation [13,14].

Fig. 1f and 1g show an interdigitated FF designs based on the lung [3].

Table 1: Advantages/disadvantages of flow field pattern designs

Property tested / Design	Serpentine	Parallel	Mesh-type	Interdigitated	Channel Improv. (L/W)	Porous-type	Fractal-type	Biomimetic
Uniform gas distribution	-	-	-	+	+	-	+	+
Electrical conductivity					+			
Pressure drop	-	+		-	+/-	-	-	+
Water removal	+	-	-	+	+	-	-	
Diffusion limitations	-		-	+	+			

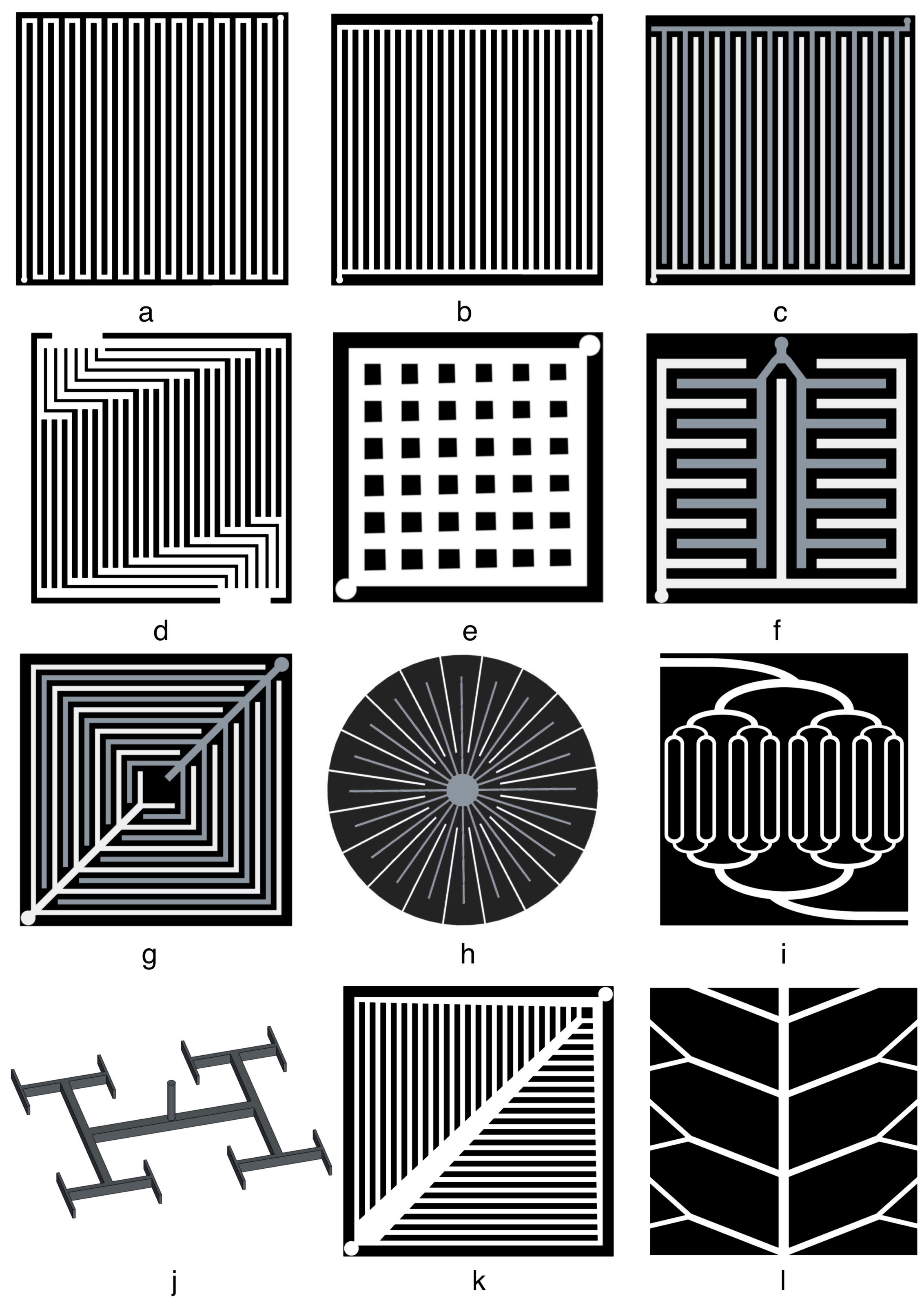

Figure 1: Examples for different flow field patterns in PEMFCs: 1-channel serpentine (a), parallel (b), interdigitated (c), parallel with several multi-paths (d), mesh-type design modified with gradually increasing/decreasing channel (e), interdigitated design modified to a non-fractal lung-type (f), interdigitated design modified to a leaf-type (g), radial design with 20 pairs of radial interdigitated channels (h), fractal design with smoothed angels (i), fractal design with closed channel fractal tree (j), leaf-inspired design with tapered channels (k) and leaf-inspired design with pinnate venations with two branching angles (l)

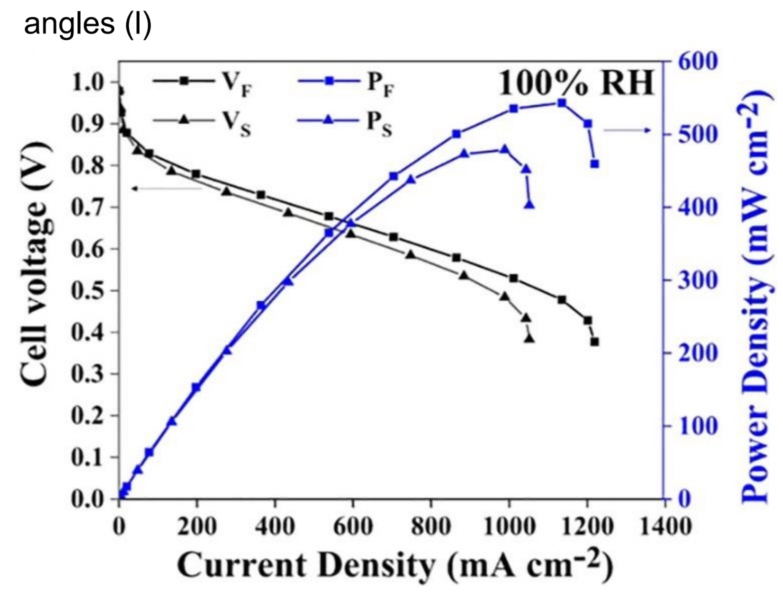

Figure 2: IV and power density curve of serpentine FF design (triangle) and lung-inspired FF design (square). Taken from [15].

Conclusion

1) From the literature review, we concluded that efficient FF designs for PEMFC BPP has not yet been found, despite great efforts to modify serpentine and other conventional designs, mixing them or developing entirely new designs.

2) Demands deemed as necessary for best PEMFC performance are sometimes contradictory, i.e. with respect to channel widths and lengths, distances between them and direct contact with the gas diffusion layer - GDL (lands). Therefore, a complete list of criteria for PEMFC optimization must be considered, making it into a multi-criteria optimization problem. Rather than optimizing a single hydraulic resistance, a pressure drop, or a uniform distribution, one should develop multi-optimization strategies.

3) As objective function for multi-criteria FFP design optimization, the entropy production or energy dissipation serves as a good objective function, because it includes all sources of the energy dissipation in the complex multi-physics system. Its applicability to describe best engineered performance in transport systems like lungs, blood vessels and conducting systems of plant leaves, has been reported.

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