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Use of fractals to improve a proton exchange membrane fuel cell performance

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Abstract.

One of the most important and effective elements in the improvement of efficiency and power density of proton Exchange membrane fuel cells (PEMFC) are the flow field plates. The flow field plate design and its pattern considerably affect the effectiveness of mass transport as well as electrochemical reactions inside the cell. A goal of the flow field plate configuration is to ensure a low pressure drop over all the channels in a cell or over all the cells in a stack. As a result, the aim of this research was use biological inspiration to improve the anode flow hydrogen area without improve the pressure loss in a parallel flow field plate (PFFP), by inserting fractals in a classic PFFP design. The results showed that, fractals can increase the hydrogen flow area without improve the pressure loss and repeat the PFFP fluid dynamic behavior at smaller scales in the same plate.

Key words

Fuel cells, flow field design, fractals.

1. Introduction

The main driving force for fuel cell research, development, and commercialization is the increasing concern about global pollution caused by energy emissions, especially from transportation and stationary applications [1, 2].

Fuel cells, in particular the proton exchange membrane fuel cell (PEMFC) are extensively being studied today because of their potential as an alternate energy source for a wide range of applications. Fuel cells have unique technological attributes: efficiency, absence of moving parts and very low emissions. [3]

A PEMFC is an electrochemical device in which the free energy of combustion of hydrogen is converted into electrical energy. Oxygen from air is used as oxidant. It produces more electricity per mass of fuel than any other non-nuclear method of power production. [4]

One of the most important and effective elements in the improvement of efficiency and power density of PEMFC are the flow field plates. These components supply fuel and oxidants, remove generated water, collect produced current and provide mechanical support for the brittle membrane electrode assembly in fuel cell stack [5].

The flow field plate design and its pattern considerably affect the effectiveness of mass transport as well as electrochemical reactions inside the cell. The optimal design of the channels dimension, shape, pattern and configuration will lead to an improved and enhanced bipolar plate [5].

A goal of the flow field plate configuration is to ensure a low pressure drop over all the channels in a cell or over all the cells in a stack [6].

2. Objectives

The aim of this research was use biological inspiration to improve the anode hydrogen flow area without increase the pressure loss in a parallel flow field plate (PFFP), one of the most popular PEMFC flow field plate design.

3. Methodology

3.1. Creation of PFFP with fractals

Fractal branching patterns in nature can be found in crystal formations, landscapes shaped by water drainage, lightning bolts and certain plants and in the human body.

Figure 1 shows examples of fractal anatomic systems.

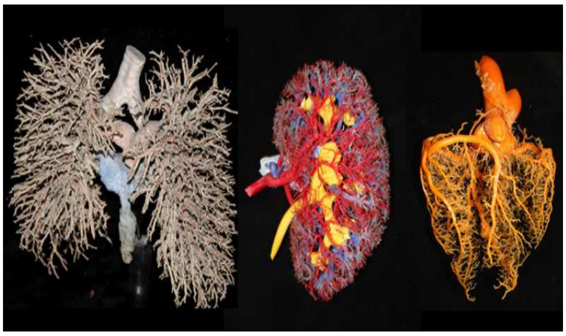

Fig. 1. Examples of “tree-like” fractal anatomic systems. From left to right: bronchial tree, renal vascular and urinary systems, and heart coronary system. [7]

Fractals are more than just stunning visual effects – they open up new ways to model nature and allow us to quantify terms like ‘irregular’, ‘rough’ and ‘complicated’[8].

More generally, the works of Man, as the engineer and the builder, are typically flat, round or follow the other very simple shapes of the classical schools of geometry.

By contrast, many shapes of nature – for example, those shapes of mountains, clouds, broken stones, and trees – are far too complicated for Euclidean geometry.

Mountains are not cones. Clouds are not spheres. Island coastlines are not circles [9].

As shown in Figure 2, the most important parts of PEMFC are the MEA and the bipolar / flow field plates.

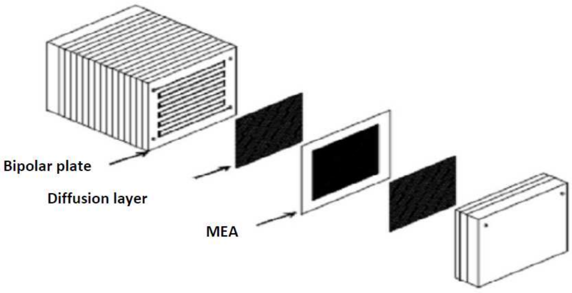

Fig. 2. General view of a PEMFC stack.

Despite this, a peripheral structure is always necessary to execute lab tests, as shown in Figure 3.

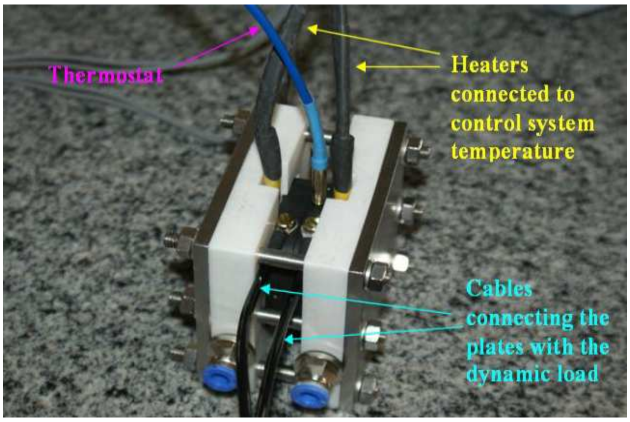

Fig. 3. PEMFC prototype of UFRGS University

Fractal designs for PEMFC may be present in the flow field designs and are characterized by a repeating self-similarity at different size scales with a focus on the branching pattern [10] and to insert fractals in a classic PFFP design was created connections between every channels of the flow field. Each connection with self-similarity at smaller size scales.

Figure 2 shows the new parallel flow field plate with fractals (FPFFP) created in the SOLIDWORKS software for the computational fluid dynamic (CFD) tests and the Figure 3 shows the classic PFFP, also created in the SOLIDWORKS software to comparing the fluid dynamic behavior with the new FPFFP.

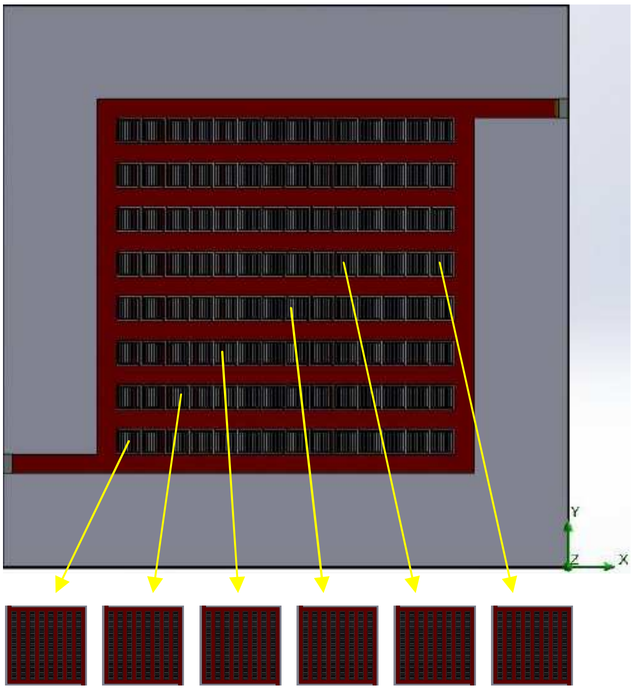

Fig. 4. FPFFP created in SOLIDWORKS.

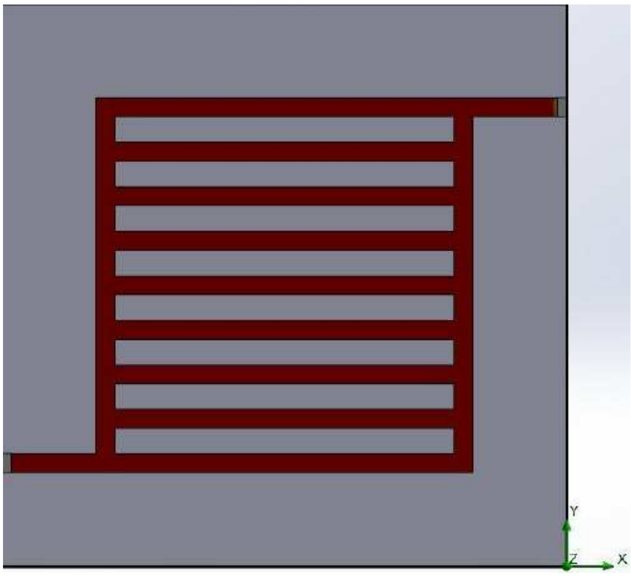

Fig. 5. PFFP created in SOLIDWORKS.

3.2. CFD tests

These tests were performed at the UNOESC University and it was employed the SOLIDWORKS software 2013 with flow simulation tool in a computer model Alienware Aurora Desktop – BRH3171 (3.2 GHz, 8 MB L3 cache; 24GB DDR3 1333MHz memory (6x4GB)) with an highperformance liquid cooling (Alienware®), equipped with a Intel® Core™ i7-960. Two tests were performed one with the classical PFFP and other with the new FPFFP. In the simulations both flow fields plates had the temperature controlled in 100° C, received a volume flow of 1 L/min (hydrogen at 25ºC) in the inlet and environment pressure in the outlet.

4. Results and Discussion

According to Figure 6 and Figure 7, the result had shown a similar behavior in the FPFFP and in the PFFP fluid dynamic, respectively. In both simulations the hydrogen pressure loss improves as the reagent approaches the flow field outlet. By the fractals present in the FPFFP, the hydrogen fluid dynamic behavior was repeat at smaller scales in the same plate.

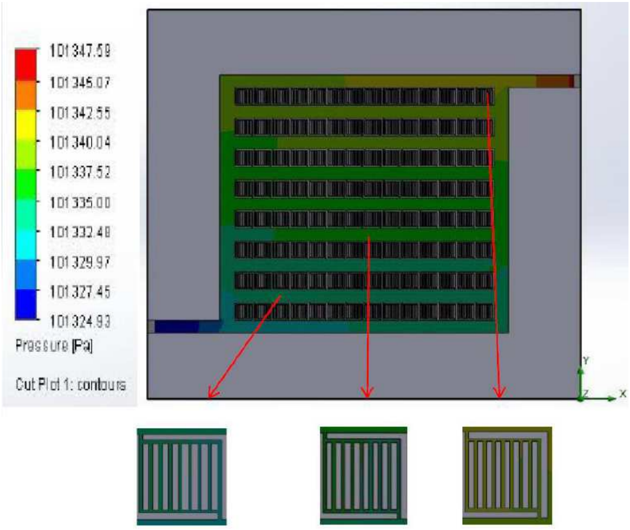

Fig. 6. CFD simulation with FPFFP

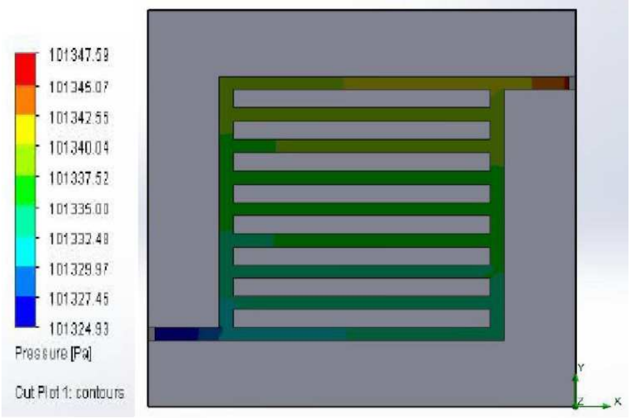

Fig. 7. CFD simulation with PFFP

According to Table I (Minimum/Maximum FPFFP CFD table) and Table II (Minimum/Maximum PFFP CFD table), the results shown that in both flow field plates the minimum pressure value was 101324.93 Pa and the maximum pressure value was 101347.59 Pa. As a result, both flow field plates had the same pressure loss ($\Delta P = -22.66$ Pa).

Table I. – Min/Max FPFFP CFD table

Name	Minimum	Maximum
Pressure [Pa]	101324.93	101347.59
Temperature [K]	298.15	373.15
Density [kg/m^3]	0.07	0.08
Velocity [m/s]	0	10.739
Velocity (X) [m/s]	-10.739	2.237
Velocity (Y) [m/s]	-9.026	1.739
Velocity (Z) [m/s]	-2.682	2.710
Temperature (Fluid) [K]	298.15	373.15
Temperature (Solid) [K]	372.80	373.15
Mach Number [ ]	0	7.32e-003
Vorticity [1/s]	0	51040.651
Shear Stress [Pa]	0	1.62
Relative Pressure [Pa]	-0.07	22.59
Heat Transfer Coefficient [W/m^2/K]	7.284e-014	2367.446
Surface Heat Flux [W/m^2]	-56.488	188677.647
Heat Flux [W/m^2]	0	146972.979
Overheat above Melting Temperature [K]	-3627.348	-3627.000

Table II. - Min/Max PFFP CFD table

Name	Minimum	Maximum
Pressure [Pa]	101324.93	101347.59
Temperature [K]	298.15	373.15
Density [kg/m^3]	0.07	0.08
Velocity [m/s]	0	10.739
Velocity (X) [m/s]	-10.739	2.241
Velocity (Y) [m/s]	-9.026	1.740
Velocity (Z) [m/s]	-2.685	2.711
Temperature (Fluid) [K]	298.15	373.15
Temperature (Solid) [K]	372.80	373.15
Mach Number [ ]	0	7.32e-003
Vorticity [1/s]	2.198	51038.952
Shear Stress [Pa]	1.83e-005	1.62
Relative Pressure [Pa]	-0.07	22.59
Heat Transfer Coefficient [W/m^2/K]	7.405e-013	2367.448
Surface Heat Flux [W/m^2]	-0.234	188678.372
Heat Flux [W/m^2]	0	146974.586
Overheat above Melting Temperature [K]	-3627.348	-3627.000

4. Conclusion

The results showed that, in the anode of a PEMFC equipped with PFFP, fractals can increase the anode hydrogen flow area without improve the pressure loss and repeat the PFFP fluid dynamic behavior at smaller scales in the same plate. As a result the MEA active area was bigger, improving the current density and consequently the fuel cell power density.

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References

[1] J. St-. Pierre, D. P. Wilkinson, "Efficient and Cleaner Power Sorce", AlChe Journal, Vol. 147, pp. 1482-1486, 2001.
[2] D. L. Trimm, Z. I. Önsan, "On-board fuel conversion for hydrogen fuel cell driven vehicles", Catalysis Reviews-science and Engineering, v. 43, p. 31-84, 2001.
[3] D.S. Falcão, P.J. Gomes, V.B. Oliveira, C. Pinho, A.M.F.R. Pinto, "1D and 3D numerical simulations in PEM fuel cells". International Journal of Hydrogen Energy, Vol. 36, pp. 12486-12498, 2011.
[4] C-J. Tseng, B.T. Tsai, Z-S. Liu, T-C. Cheng, W-C. Chang, "A PEM fuel cell with metal foam as flow distributor". Energy Conversion and Management, Vol. 62, pp. 14-21, 2012.
[5] R. Roshandel, F. Arbabi, M. G. Karimi, "Simulation of an innovative flow-field design based on a bio inspired pattern for PEM fuel cells". Renewable Energy, Vol. 41, pp. 86-95, 2012.
[6]J. Wang, H. Wang, "Discrete approach for flow field design of parallel channel configurations in fuel cells". International Journal of Hydrogen Energy, Vol. 37, pp. 10881-10897, 2012.
[7] B. Mandelbrot, The fractal geometry of nature, W. H. Freeman and Company, New York (1983), pp.113.
[8] I. Stewart, The colours of infinity, Springer, New York (2010), pp. 2-23.
[9] B. Mandelbrot, The colours of infinity, Springer, New York (2010), pp.38-57.
[10] A. Arvay, J. French, J-C. Wang, X-H. Peng, A.M. Kannan, "Nature inspired flow field designs for proton exchange membrane fuel cell". International Journal of Hydrogen Energy, Vol. 38, pp. 3717-3726, 2013.