ORIGINAL PAPER

MODELING AND SIMULATION OF WORKING GAS FLOW THROUGH CHANNELS CONFIGURED ON THE SURFACE OF A PEM FUEL CELL'S BIPOLAR PLATE

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Abstract. *A bipolar plate design must take account of the functional role it plays within the basic nucleus of the fuel cell and consequently its functional role in the cell stack. The structure and geometry of the active, sealing, supplying and fixing surfaces is directly related to the electrochemical processes that take place in the cell and to the method of supply and distribution of the working gas and cooling water. Opting for design solutions involving the gas supply and distribution across the active surface of a bipolar plate strongly influences the performance of the basic cell. The active area cooling method is equally important for achieving high performance. H_2 and O_2 working gas flow simulation using the SolidWorks application's Flow Simulation module enables the optimal design of the flow channels.*

Keywords: *modeling, simulation, flow gas.*

1. INTRODUCTION

A bipolar plate design must take account of the functional role it plays within the basic nucleus of the *PEM* fuel cell and consequently its functional role in the cell stack. The structure and geometry of the active, sealing, supplying and fixing surfaces is directly related to the electrochemical processes that take place in the cell and to the method of supply and distribution of the working gas and cooling water [1, 2]. Opting for design solutions involving the gas supply and distribution across the active surface of a bipolar plate strongly influences the performance of the basic cell. The active area cooling method is equally important for achieving high performance [1-3].

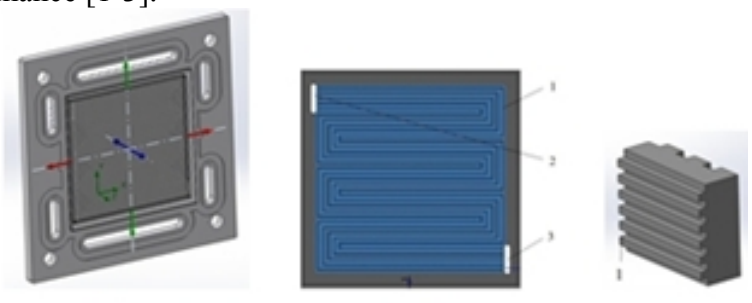

Figure 1. a) bipolar plate; b) bipolar plate active area: 1- working gas flow channels; 2 - gas inlet; 3 - gas outlet; c) gas flow channels.

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2. MODELING AND SIMULATION METHOD

2.1. CHANNEL GEOMETRY MODELING

The geometry and shape of the channels (the routing) were modeled keeping in mind that in order to achieve high performance, the gas (H_2 and O_2) must be present at certain parameters (flow, pressure) across the entire ionic transfer surface of the proton exchange membrane [4-6]. The routing (the active area) is comprised of five channels following a "path" that must be as long as possible in order to efficiently run through the diffusion layer and enable the reactions (1.1,1.2, and 1.3) underlying the functioning of a PEM fuel cell.

$$2H_2 + O_2 \rightarrow 2H_2O \quad (1.1)$$

$$2H_2 \rightarrow 4H^+ + 4e^- \quad (1.2)$$

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \quad (1.3)$$

On the opposite side, corresponding to the active area, cooling water channels were designed (as shown in Fig. 2) to enable the efficient cooling of the plate in the active area, which will help maintain the operating temperature of the cell (80 °C). The cooling water routing was designed to cross-cut the gas flow direction for two purposes:

- to ensure a highly efficient heat transfer;
- to enable the positioning of the water inlets and outlets on the unused sides of the plate (the other two sides accommodate the gas inlet and outlet).

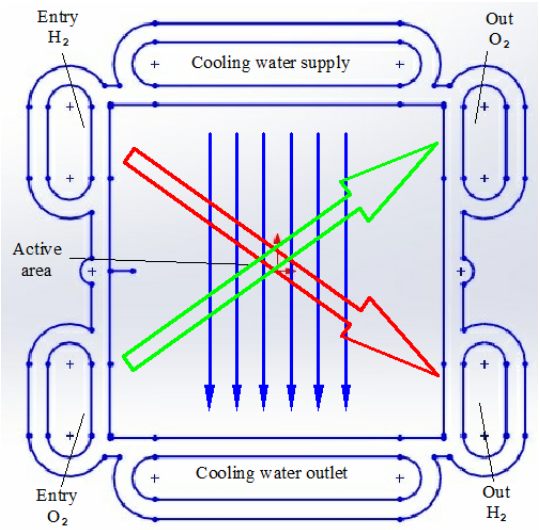

Figure 2. Working gas and cooling water inlets and outlets

The separation of the three routes is easily designed after establishing the trajectories and the inlets. As seen in Fig. 2, finding a way to achieve a countercurrent gas flow designed to optimize the electrochemical reactions over the entire active surface of the bipolar plate was attempted [1, 7-9]. A correct countercurrent flow cannot be achieved because of the difficulties resulting from including a single design for the anode and cathode used, the positioning of the inlets and outlets, and the routing geometry, which is why the solution shown in Fig. 2 was selected [10-12].

Designing the bipolar plate using the *3D SolidWorks* software is easy and helps view many of the issues that occur when establishing certain design details. The working gas flow and cooling water routing was easily designed, and the modeling and remodeling, after having encountered some issues consisting in interfering trajectories or wrong dimensions such as the

plate thickness resulting after building the channels, were achieved quickly and with the confirmation of the right decisions [13-15].

2.2. SIMULATION METHOD

The virtual simulation of the working gas (H_2 and O_2) flow through the channels made on the active area of the bipolar plate was carried out using the *Flow Simulation* module available in the *SolidWorks* application. This module contains mathematical calculation resources required for the study of fluid and gas flow through various systems. This calculation feature takes into account the type of gas or fluid, its properties (purity, viscosity, etc.), the operating temperature and pressure, the flow regime (streamline flow, turbulent flow), the nature of the material the flow passage is made of (bakelite-BG graphite), the condition of the contact surfaces between the fluid (or the gas) and the flow channel, the absorption or diffusion degree [1, 2, 12]

To achieve a PEM's maximum efficiency, the working gas flow through the channels located on the active area must take place under certain conditions, as shown in Table 1.

Table 1. Minimum and maximum operating parameters

Parameters	Values	Units
Hydrogen purity	99.99	%
Air oxygen content	30	% (din vol.)
Maximum supply pressure measured on the anode (H_2)	500 (0.05)	mbar (MPa)
Minimum supply pressure measured on the anode (H_2)	300 (0.03)	mbar (MPa)
Maximum supply pressure measured on the cathode (O_2)	0 -300 (0.03)	mbar (MPa)
Minimum supply pressure measured on the anode (O_2)	30 (0.003)	mbar (MPa)
Maximum temperature of incoming working gas	60-65	°C
Minimum temperature of incoming working gas	5-10	°C
Maximum temperature of outgoing working gas	75	°C

The input parameters for the simulation are set for each of the two working gas types shown in Table 2.

Table 2. Working parameters for the H_2 and O_2 routes

The route set for H_2	**Values**	**Units**
Hydrogen purity	99.99	%
Flow regime	streamline flow + turbulent flow	-
Maximum pressure of outgoing gas as measured on the anode (H_2)	300 (0.03)	mbar (MPa)
Gas transport average speed	0.2	m/s
Maximum temperature of incoming working gas	65 (338.2)	°C (K)
The route set for O_2	**Values**	**Units**
Oxygen purity	99.99	%
Flow regime	streamline flow + turbulent flow	-
Minimum pressure of outgoing gas measured on the cathode (O_2)	200 (0.02)	mbar (MPa)
Minimum pressure of incoming gas measured on the anode (O_2)	30 (0.003)	mbar (MPa)
Maximum temperature of incoming working gas	65 (338.2)	°C (K)

The input parameters for the simulation performed were set for the actual operating conditions of a cell in a PEM. Working gas flow simulation using the SolidWorks software's *Flow Simulation* module provides numerous data required for the flow study. Among these there were analyzed: the distribution of the gas pressure and speed over the entire active area (the routing designed) for both working gas types (H_2 and O_2), the resulting weight flow and volumetric flow rates, and the temperature distribution across the active area.

3. RESULTS AND DISCUSSION

3.1. RESULTS AND DISCUSSIONS

The routing geometry for all five channels was designed to cover the active area as uniformly as possible. The disadvantage of this type of geometry consists in the fact that the channels change their direction (by 90°) at the edge of the active area. At these points, pressure and flow speed drops are expected to occur.

The hydrogen flow simulation using the parameters listed in Table 2 resulted in the pressure distribution shown in Fig. 3. The main condition was the minimum discharge pressure to be 300 Pa (0.03 MPa). The pressure drops resulting from frictions and changes of direction have shown that the supply pressure must be higher than 310.22 Pa (0.031 MPa). The hydrogen pressure across the entire flow trajectory does not show sudden drops or increases, but it maintains the desired average values.

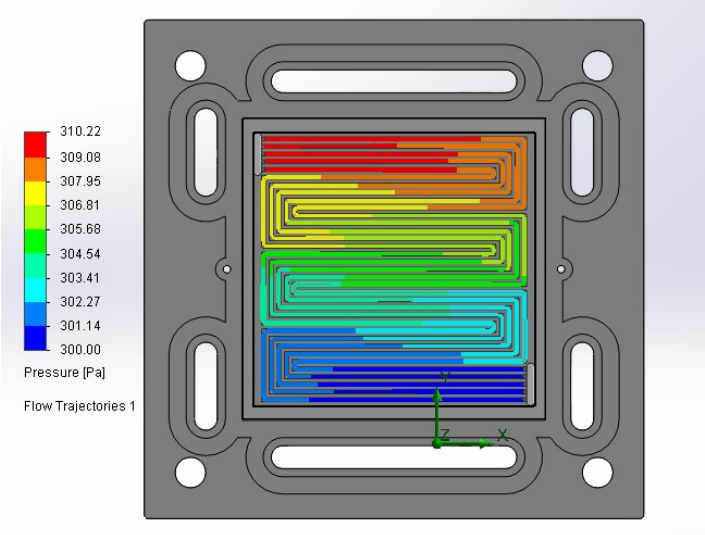

Figure 3. H_2 pressure distribution across the active area.

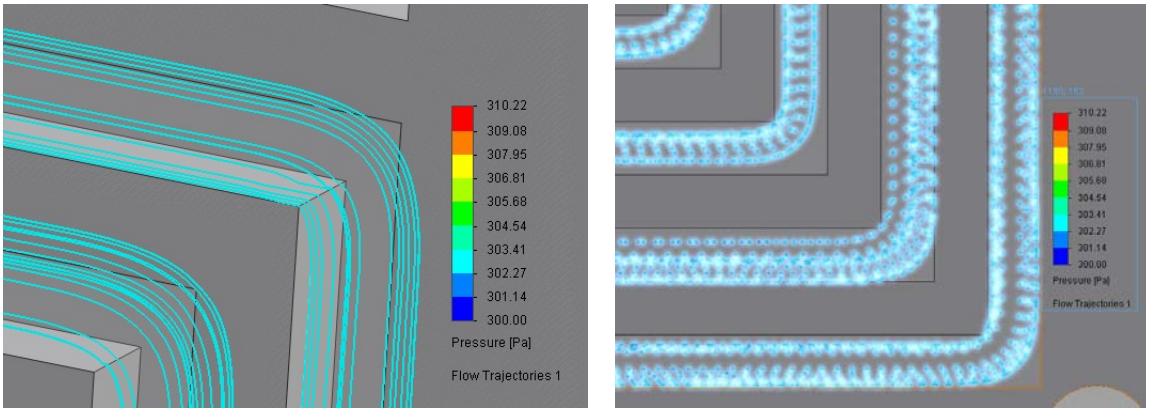

Figure 4. H_2 turbulent flow at elbows.

The simulation of hydrogen flow through 90° bends shows a turbulent flow regime occurring at elbows (Fig. 4). Maintaining an average pressure and a streamline flow regime through the channels is also due to the optimal flow speed of hydrogen.

The Flow Simulation module enables determining the weight flow and volume flow rates that can result from the geometry of the five channels. The values for hydrogen are shown in Table 3.

Table 3. Hydrogen weight flow and volume flow rates

Hydrogen	Unit	Value	Average Value	Maximum Value	Minimum Value
Weight Flow Rate	[kg/s]	2.19557E-10	2.16219E-10	2.19557E-10	2.12526E-10
Volume Flow Rate	[m^3/s]	1.02078E-06	1.00526E-06	1.02078E-06	9.88107E-07

Another result determined with the help of Flow Simulation is the speed distribution across the entire trajectory hydrogen follows from the inlet to the outlet point. The optimal average flow speed is around 0.2 m/s.

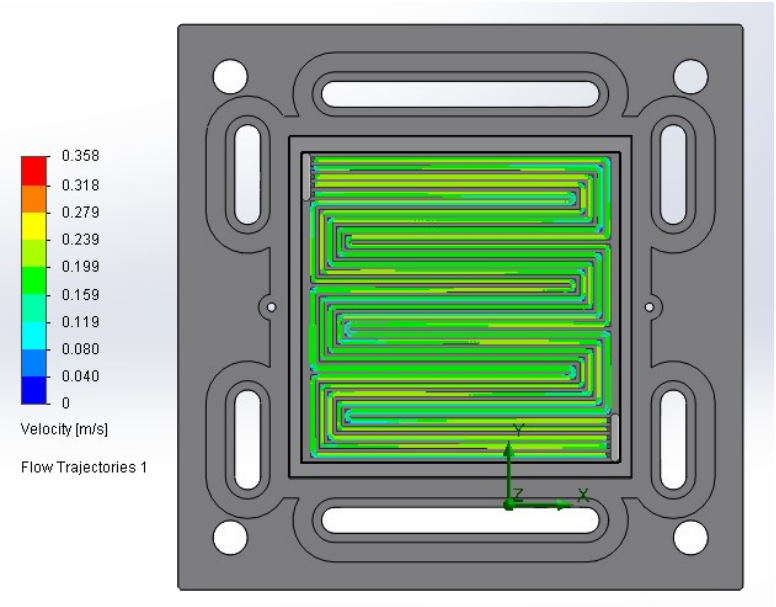

Figure 5. H_2 speed distribution across the active area.

The speed distribution resulting from the simulation shows that the flow speed is around the optimal average value all over the active area, except for the elbows, where it drops to 0.159 m/s.

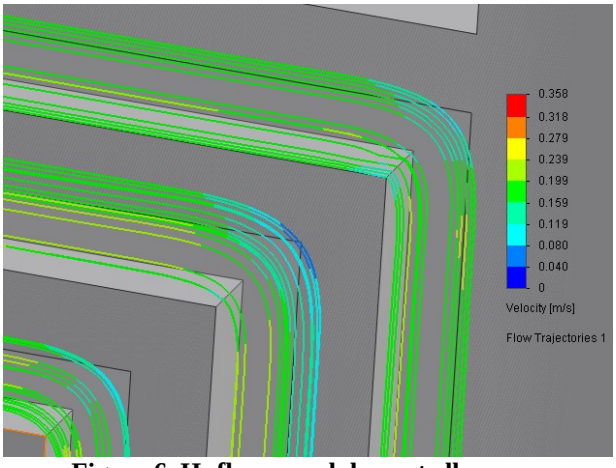

Figure 6. H_2 flow speed drop at elbows.

The oxygen flow simulation using the parameters listed in Table 2 resulted in the pressure distribution shown in Fig. 7. The most important condition is that the discharge minimum pressure is 200 Pa (0.02 MPa). The pressure drops resulting from frictions and changes of direction have shown that the supply pressure must be higher than 310 Pa (0.031 MPa). The oxygen pressure across the entire flow trajectory does not show sudden drops or increases, but it maintains the desired average values.

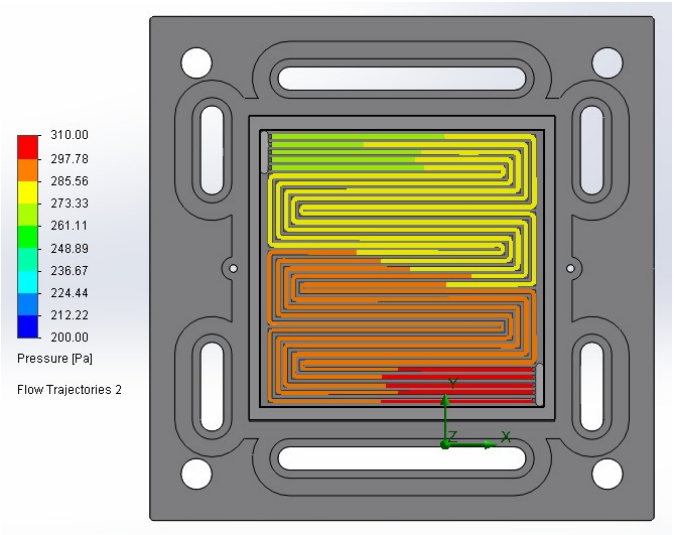

Figure 7. O_2 pressure distribution across the active area.

The speed distribution resulting from the simulation shows that the flow speed meets the optimal average value (0.2 m/s) as shown in Table 2, all over the active area.

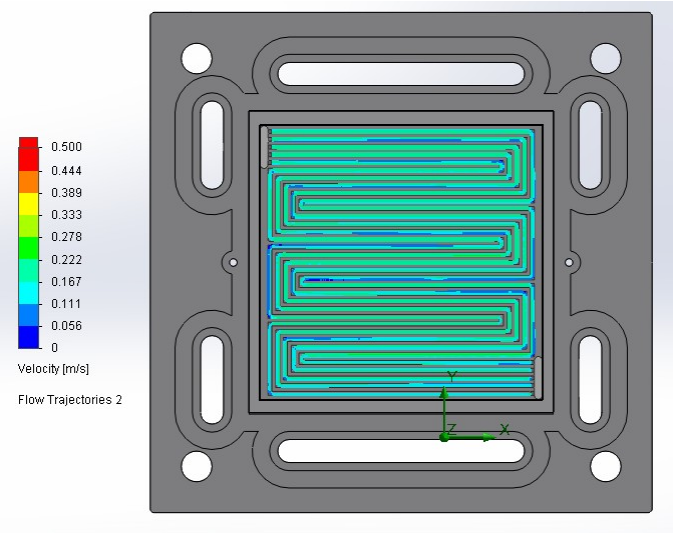

Figure 8. O_2 speed distribution across the active area.

At elbows the speed drops to lower, almost null values (*0.038 m/s*). The areas where the flow speed is null are the points where water accumulation occurs (water being a reaction product as shown in formula 1.3). In this case the operating temperature (*65°C = 338.2K*) plays an important role in achieving an optimal humidity level and in preventing the water that results from the reactions occurring in the fuel cell from accumulating in large amounts (Fig. 9).

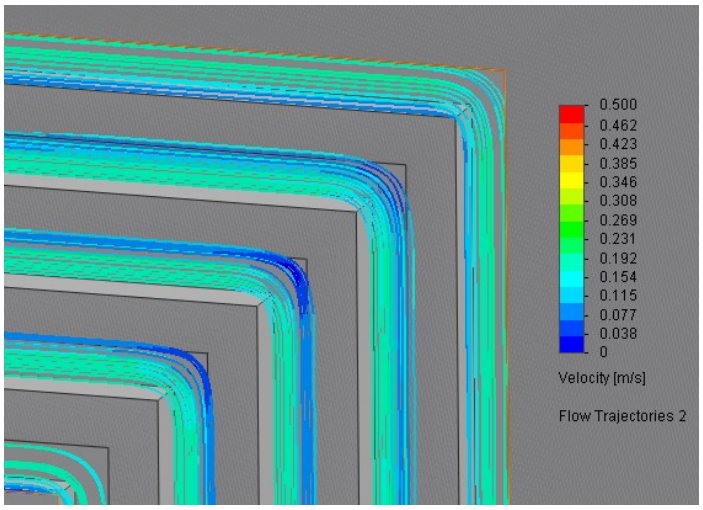

Figure 9. O_2 flow speed drop at elbows.

For a PEM fuel cell to work at the optimum parameters, the relative humidity in the cell must be 80%. The presence of humidity enhances the MEA (proton exchange membrane) performance. The excess water is converted into vapours and thus removed. The total pressure of the reactant on the cathode (the O_2 circuit) is:

$$P_t = P_{vap} + P_{O2} \tag{1.4}$$

where:

P_{vap} – partial pressure of the formed vapours[Pa];
P_{O2} – partial pressure of the reactant (oxygen) [Pa].

The molar flow rate of the two phases may be expressed by the formula:

$$\frac{N_{vap}}{N_{O2}} = \frac{P_{vap}}{P_{O2}} = \frac{P_{vap}}{P_t - P_{vap}} \tag{1.5}$$

The weight flow and volume flow rates for the oxygen, as determined using the Flow Simulation module, are presented in Table 4.

Table 4. Oxygen weight flow and volume flow rates

Oxygen	Unit	Value	Average Value	Maximum Value	Minimum Value
Weight Flow Rate	[kg/s]	3.07319E-09	3.08637E-09	3.10584E-09	3.07319E-09
Volume Flow Rate	[m^3/s]	9.96347E-07	9.96992E-07	9.99521E-07	9.96347E-07

4. CONCLUSIONS

The flow channel geometry modeling for the two types of working gas (H_2 and O_2) was performed taking into account the parameters listed in *Table 2* and the need to cover a reaction surface of *6,178.57 mm^2* (*$6.18 \cdot 10^{-3} m^2$*). The issues generated by stacking the bipolar plates has led us to adopt the five-channel design solution and the routing shown in Fig. 1. The channel section size is bxh = 1x1mm and the length is L = 489 mm. The working gas pressure and flow rate through these channels are determined for the reactions occurring in the fuel cell (*formulas 1.1-1.3*).

The analysis of the working gas flow through channels was assisted by the *SolidWorks* software's *Flow Simulation* module. The simulation of the actual operating conditions has shown that the required pressures are achieved across the entire length of the designed routing and the gas flow speed enables achieving high performance. The channels' sudden changes of direction result in turbulent flow and speed drops at elbows. This causes water (which is a reaction product) to accumulate in the channels' corners. The cell's functioning at an optimal temperature (65°C = 338.2 K) leads to the partial evaporation of the water and helps maintain a humidity level of 80 % in the proton exchange membrane (MEA), which enables maximum performance.

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