PEM Fuel Cell: numerical sensoring with CFD

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Abstract

The possibility of numerical simulation means a great competitive advantage in engineering projects with short runtime. In retrospective, this paper presents some works developed in the Centro de Células a Combustível e Hidrogênio – CCCH, that made use of Computational Fluid Dynamics – CFD to improve the understanding of the Proton Exchange Membrane Fuel Cell-PEMFC. The use of volume and boundary visualizations are not fully effective in many cases, so it is need to define some geometric entities that will examine the region of sensoring. Lines and planes represent these entities forms of measuring and capture important aspects of the fuel cell. The reading of values of velocity, pressure, mole fraction, water saturation, or the integral calculus over lines, surfaces or volumes of the PEMFC model make quantification possible and reach beyond the overview of fields distributions.

Keywords

PEM Fuel Cell; Sensoring; Numerical Analysis; CFD Simulation.

1. Introduction

The fuel cell laboratory at IPEN is responsible for research on new technologies in Proton Exchange Membrane - PEM type fuel cells that make use of unitary PEM fuel cells (Robalinho *et al.*, 2010), and modules of unitary fuel cells, called stacks (Cunha, 2009). The prototypes presented here are unitary cells, with different geometries. An important aspect of fuel cells study is the measure of its performance. This measure is done by taking readings of current density *versus* potential. Since to know the values of current density and potential are not enough, researchers look for other measures, such as velocities, pressures and mole fractions (Barbir, 2005; Linardi, 2010). Depending on the objective of the work, there will be a specific CFD line or plane sensoring, which can lead to important insights on the process or system (Burden and Faires, 1989; Carnes and Djilali, 2005).

The objective of this paper is to present four research projects that were developed in CCCH laboratories and represent applications of CFD in those engineering projects. That projects were presented in conferences and academic publishing, and the operating conditions of the cells are available on the respective references. The first application (A) shows the flow channels study (Cunha *et al.*, 2007a; Cunha *et al.*, 2007b, Robalinho *et al.*, 2007; Robalinho, 2007; Andrade, 2008), with full and partial geometric domains and the respective simulations results. The development of a unitary 144 cm^2 PEM fuel cell with two complementary tridimensional geometric domains provide the second example (B) of this paper (Robalinho, 2009; Robalinho *et al.*, 2014). A study of geometric sensitivity in terms of flow channels, with 5 cm^2 of geometric area fuel cell (Paulino *et al.*, 2013a; Paulino *et al.*, 2013b, Isidoro *et al.*, 2014), with water and oxygen mole fractions measurements, is the third example (C). The last application (D) is the study of water condensation at cathode in a 5 cm^2 of geometric area fuel cell, with the demonstration of water flooding (Sandro *et al.*, 2013; Sandro *et al.*, 2014).

2. PEM fuel cell applications

A) Gas distribution channels study

The gas distribution channels are very critical point in the graphite plates development process. In a PEM fuel cell, the design of the gas distribution plates are tested firstly in a CFD software, in order to avoid dead zones. Another aspect is the very difficult manufacturing that make the cell more expensive when the drawing is more refined. In Figure 1, the real plates and the geometric domains (left), the partial CFD tests showing the velocities and the pressures distributions (center), and the quantification of velocity and pressure values by respective graphics (right), are showed.

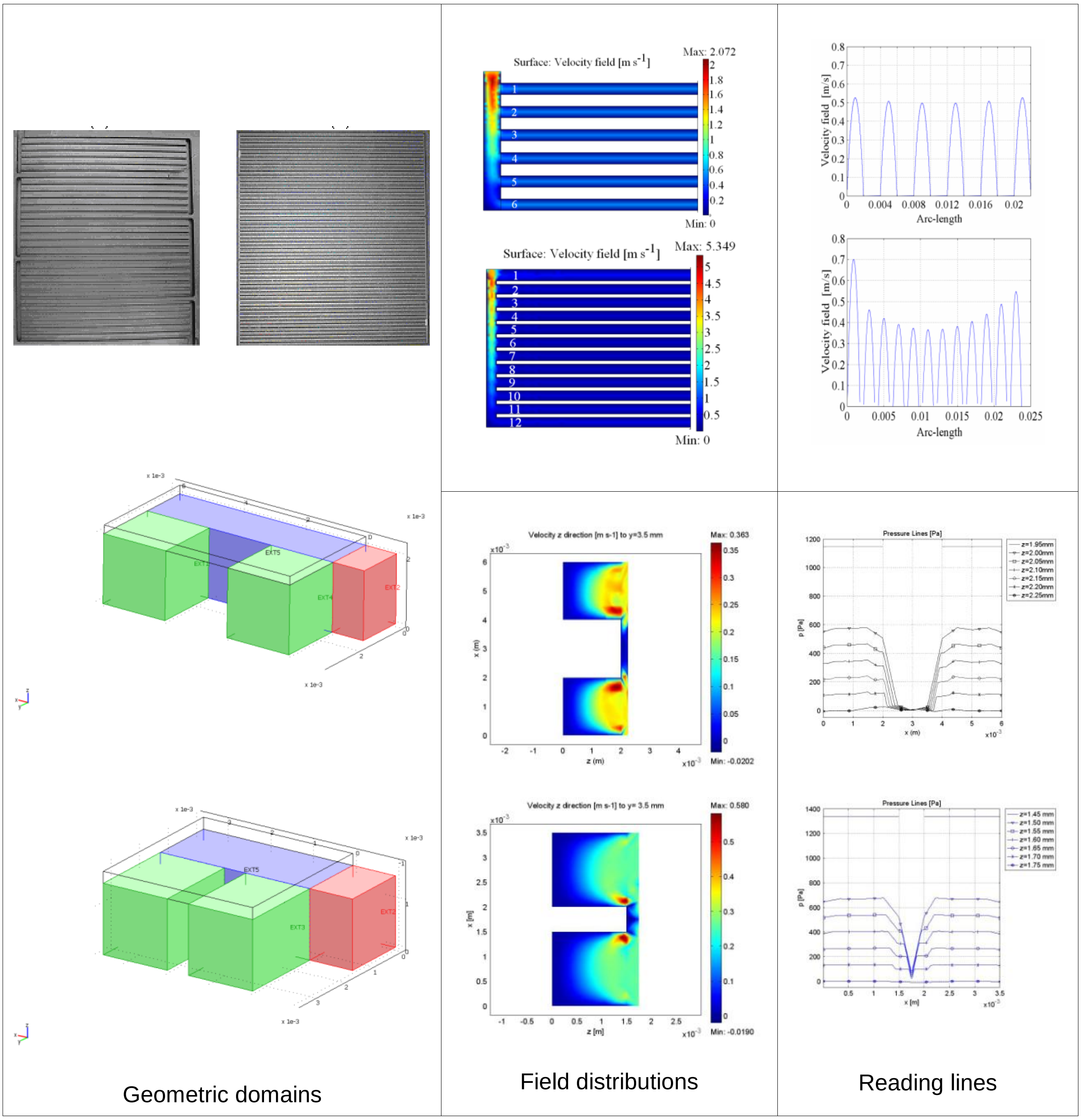

Figure 1: Real plates and geometric domains (left); flow channels study with two types of CFD results: field distributions (center), and lines lectures (right); (Cunha *et al.*, 2007a; Cunha *et al.*, 2007b, Robalinho *et al.*, 2007; Robalinho, 2007; Andrade, 2008).

B) Development of a unitary 144 cm² PEM fuel cell

This work combined laboratory and computational efforts to obtain the best result in terms of operating conditions and current density. In Figure 2, one can see a sketch of some steps in the development of a unitary 144 cm^2 PEM fuel cell. The prototype plates and calculus domains are showed (left). The simulation results were read in lines and planes, with the use of integral calculus (right). It can be noted the CFD field distributions for velocity, pressure and mole fraction (center). The balance between experimental and numerical analysis was clearly helpful in this case and contributed for the final performance of the cell, approximately 480 mA cm^{-2} for the operating potential of 0.6 V.

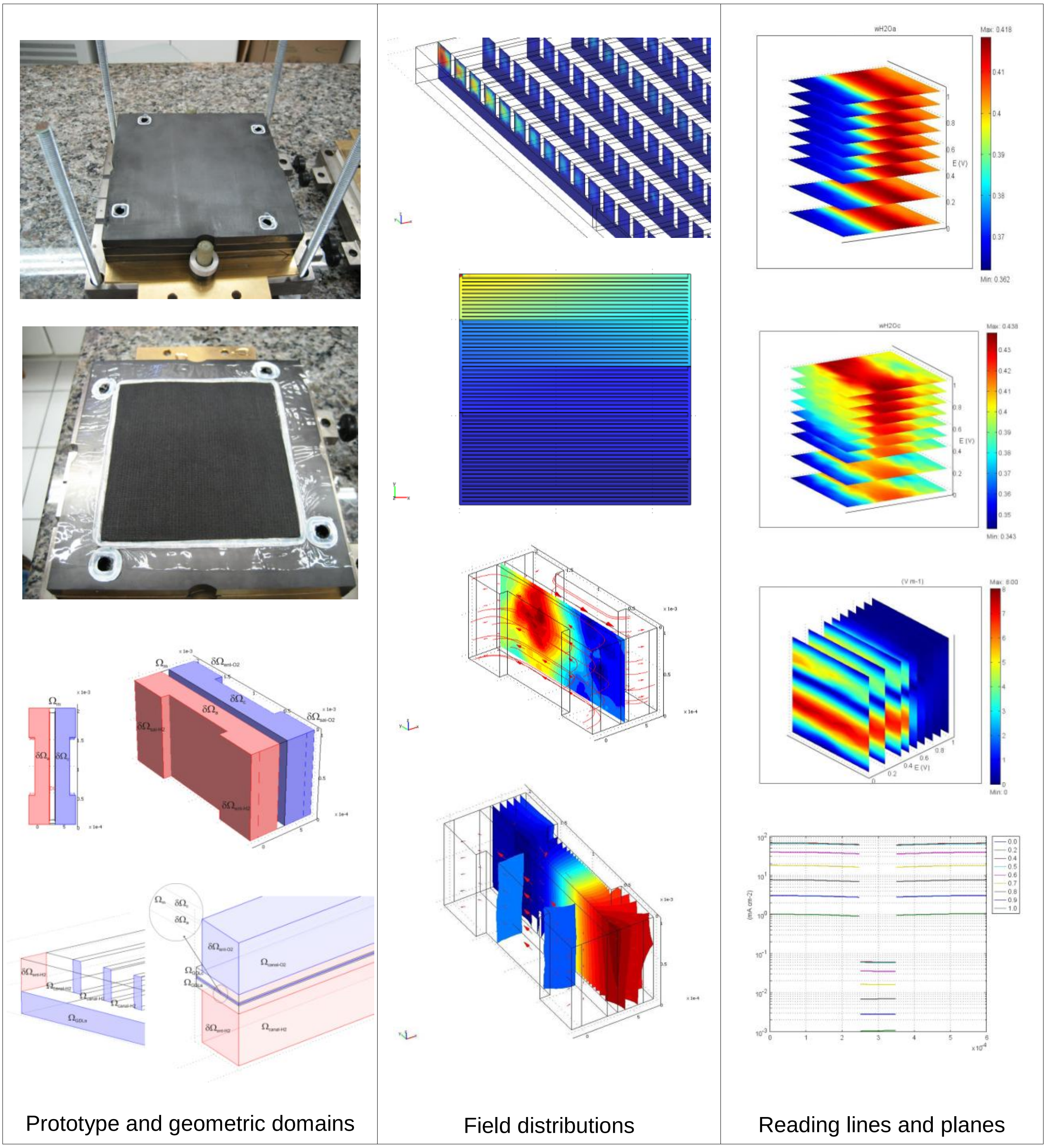

Figure 2: Prototype plates assembly (left); CFD results: field distributions (center), and integral calculus over planes and lines (right); (Robalinho, 2009; Robalinho *et al.*, 2014).

C) Performance of PEM fuel cell with different flow channels patterns

This work investigated the difference between two different flow channels geometries: serpentine and interdigitated, and three different channel configurations: retangular with a step, trapezoidal and retangular. A prototype of PEM fuel cell with 5 cm^2 of geometric area was operated at laboratory. CFD analysis was carried out in order to direct the experiments. Figure 3 presents the fuel cell used in laboratory, with respective geometric domains (left). The results of CFD simulations in terms of field distributions and graphics made by using lines as numerical sensoring are showed in Figure 3 (center and right, respectively).

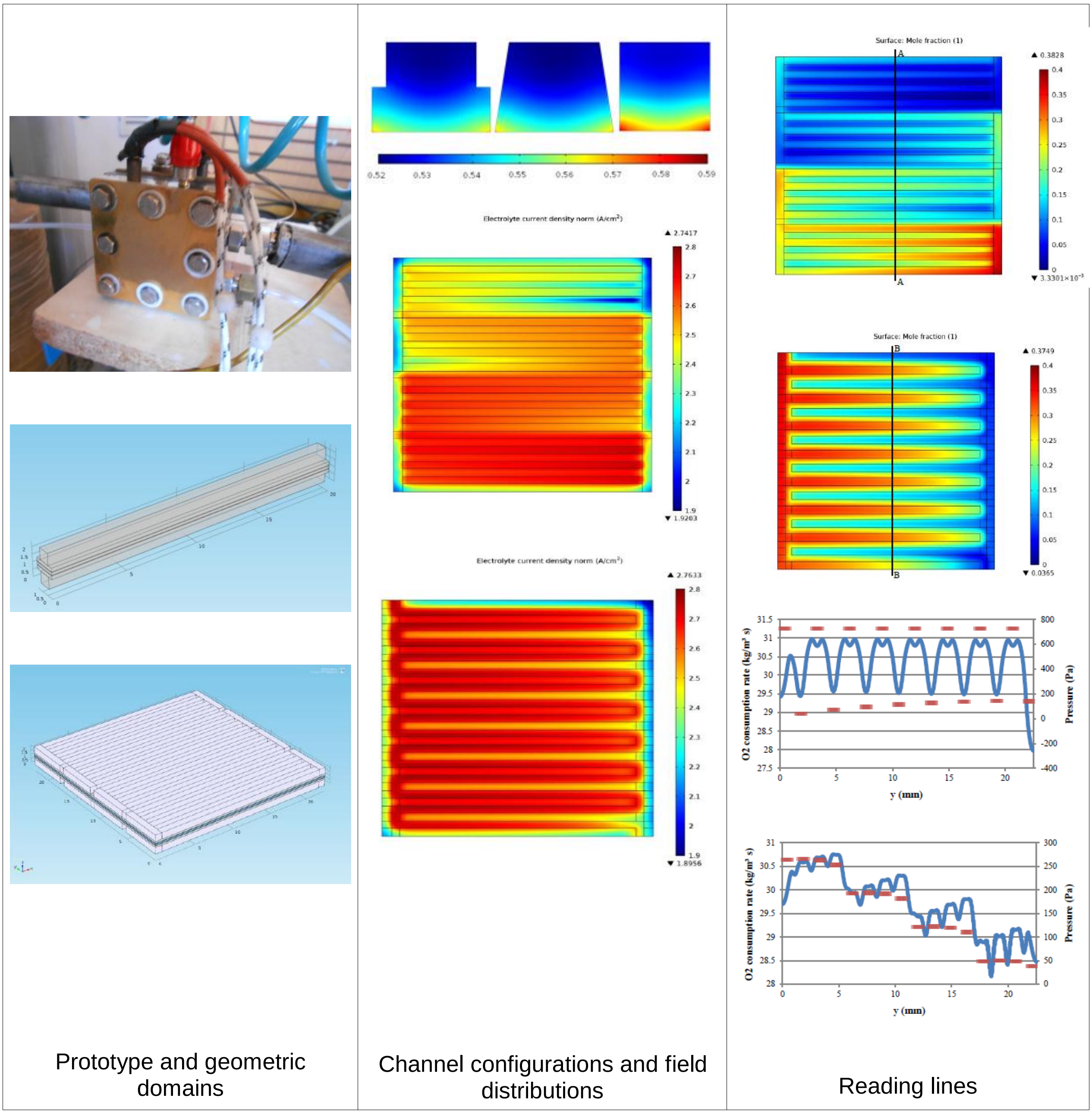

Figure 3: Prototype and geometric domains (left); CFD results: channel configurations and field distributions (center), and reading lines (right); (Paulino *et al.*, 2013a; Paulino *et al.*, 2013b, Isidoro *et al.*, 2014).

D) Study of water condensation at cathode

This fourth and final example shows the usefulness of application of CFD techniques in order to study the behavior of the cell under certain operating conditions. Particularly in this case, the simulations allowed to predict the behavior of the PEM fuel cell when it works in low temperatures, that is, condition in which the efficiency control is more difficult because usually problems of flooding are observed under this operating conditions. This work makes use of numerical simulations and experimental results in order to predict cathode flooding situations.

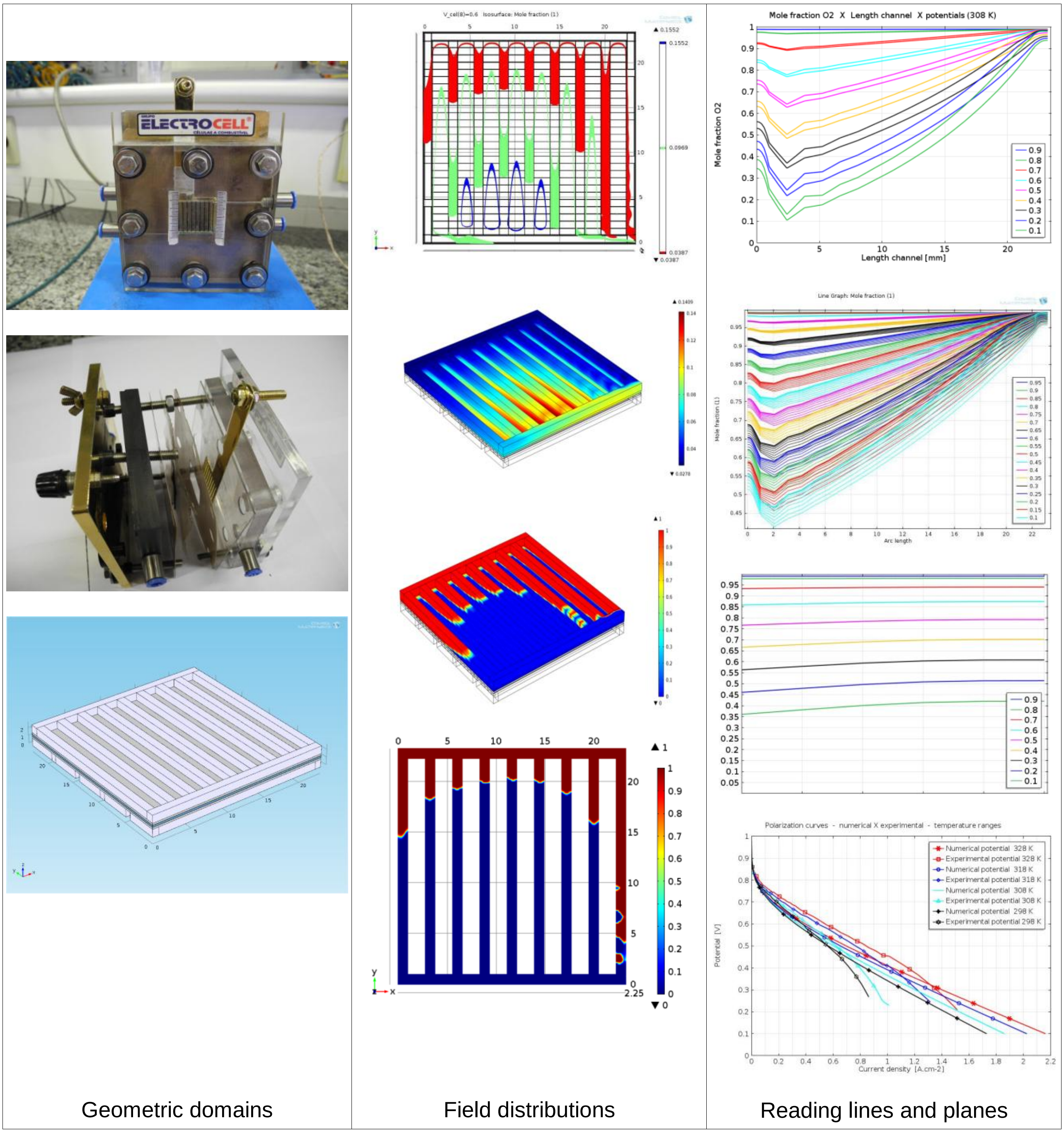

Figure 4: Prototype and geometric domains (left); CFD results: field distributions (center), and reading lines and planes (right); (Sandro *et al.*, 2013; Sandro *et al.*, 2014).

3. Concluding remarks

Considering the examples given above, the use of numerical techniques in PEM fuel cell sensoring represents an advantage of project engineering, reducing the costs and accelerating the manufacturing of prototypes. The details of mathematical and computational implementations and the characteristics of the fuel cell experiments are available in the respective references. The use of computational software allowed the implementation of different problems and complex multiphysics. Finally, the knowledge of how to sensor with lines and planes, and how to generate data with integral calculus depend on a well-trained specialist.

4. Acknowledgements

This work was supported by CNPq and IPEN/CNEN-SP Laboratories.

5. References

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