Modeling a High Temperature PEM Fuel Cell focusing on its thermal behavior.

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1. Introduction

High Temperature PEM Fuel Cells (HT PEMFC) have several advantages compared with low temperature PEM Fuel Cells. The main one is a higher operating temperature, above 120ºC. Hence, water is only present in vapor state, what avoids water management problems. However, HT PEMFCs have other difficulties that LT PEMFCs do not have. For example, to reach and maintain operational temperatures, an excellent thermal management is necessary.

First, an external heating source is needed to warm-up the fuel cell until temperatures above 120ºC. The next thermal challenge is to keep the fuel cell at an optimal operating temperature.

A cooling system should be used as well to not exceed 160ºC once the fuel cell is working. Air cooling is the recommended technique for power output systems <5kW.

The aim of this work is to develop a Computational Fluids Dynamics model using COMSOL Multiphysics, focusing on the thermal behaviour of the system. Energy management is the main concern as a better refrigeration system is needed for the studied HT PEMFC system. Using the model simulations at high current conditions can be done without exposing the real stack to temperatures above 180ºC, and therefore, to degradation. Simulations are performed in order to compare different refrigeration designs.

2. System description

The fuel cell used for this work delivers an electrical power of 120W and has 12 cells. The working temperature range goes from 140ºC to 180ºC.

The stack is placed inside an insulation case for two reasons: to maintain operational temperature and to avoid thermal losses during the heating process.

Inside the case there is as well a resistance to heat the air and a fan to spread it. The purpose of this fan is to avoid temperature gradients above 2.5 K/min, otherwise mechanical stresses can be a serious problem. The stack bipolar plates are designed to actuate as fins in order to provide good refrigeration properties.

Figure 1 shows a drawing of the system. Air enters through a small window at the bottom of the case towards the fan. The fan forces the air to go inside the fuel cell compartment. Then, the air is heated up thanks to the resistance and transfers this heat to the fuel cell. At low currents, below 18A, the air flow recirculates because the window at the top of the case is closed.

However, at high currents, the air flow has two options after heating the fuel cell: it can recirculate or can exit the case through a small window above the stack to avoid excessive heating.

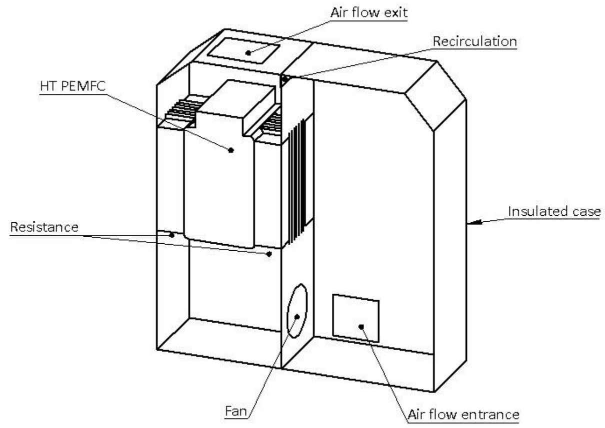

Fig. 1. System scheme with main components

3. Experimental Data

Experimental tests were performed to measure different variables of the HT PEMFC in order to study the fuel cell thermal behaviour. This data is used to fit the model to the real system.

In figure 2 we can see part of the experimental data obtained when the fuel cell is working at high currents, the resistance is off and the windows are open. In this figure, two variables were shown: the stack temperature, in orange; and the stack current, in blue. When the current is augmented, a dynamic change in the stack temperature can be observed. Even though the step size is always the same, the increase in temperature is not. Therefore, the system is nonlinear.

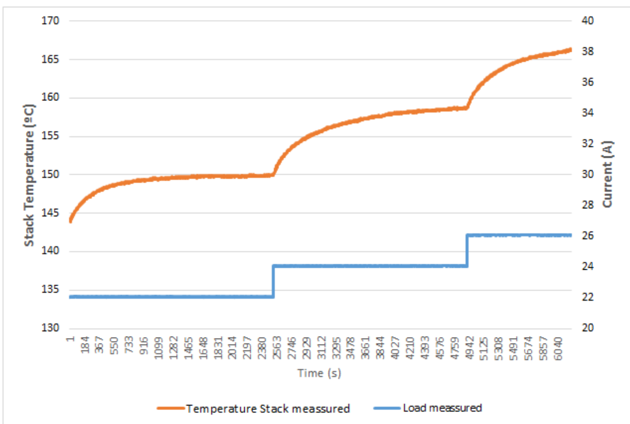

Fig. 2. Experimental curves of temperature facing current steps

Even though the fuel cell is supposed to deliver till 60 A, the maximum operating temperature is reached at much lower currents. Therefore, a new refrigeration system is required in order to be able to operate at high currents.

4. Numerical model description

The developed numerical model is a three-dimensional CFD model of the previously explained fuel cell. The idea of this finite element model is to obtain all the variables of interest in any point of the system at any time and for different operation conditions. The most important elements used to control the temperature in the fuel cell are the fan, the resistance and the windows.

The governing equations of the model are mass, line momentum and energy conservation, as follows:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \boldsymbol{u}) = 0$$

$$\rho \frac{\partial \boldsymbol{u}}{\partial t} + \rho \boldsymbol{u} \cdot \nabla \boldsymbol{u} = -\nabla p + \nabla\left(\mu(\nabla \cdot \boldsymbol{u} + (\nabla \cdot \boldsymbol{u})^T) - \frac{2}{3}\mu(\nabla \cdot \boldsymbol{u}) I\right) + \boldsymbol{F}$$

$$\frac{\partial E}{\partial t} + \nabla \cdot (E + p)\boldsymbol{u} = \nabla\left(\mu(\nabla \cdot \boldsymbol{u} + (\nabla \cdot \boldsymbol{u})^T) - \frac{2}{3}\mu(\nabla \cdot \boldsymbol{u}) I\right)\boldsymbol{u} + \nabla \cdot (k \nabla T) + \boldsymbol{F}\,\boldsymbol{u}$$

where ρ is density, t is time, **u** is fluid velocity vector, μ is dynamic viscosity, p is pressure, I is the unit tensor , F are the forces on the body, C_p is specific heat at constant pressure, T is temperature and k is thermal conductivity.

In Figure 3, an image taken from COMSOL, corresponding to the system with open windows, resistance off and 24A of current is shown. The flow streamlines and temperature can be observed.

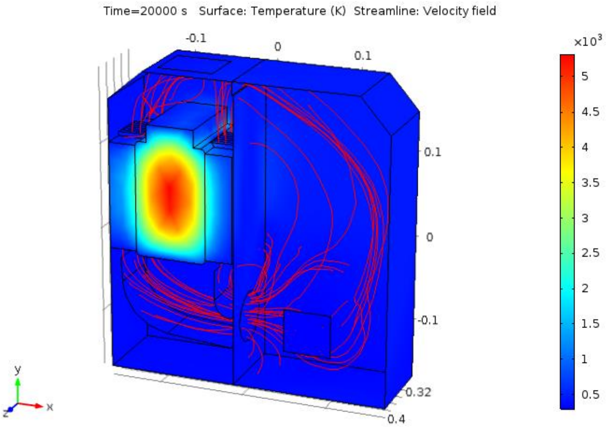

Fig. 3. COMSOL figure

Model parameters estimation is a difficult task due to the complex geometry inside the case, the high number of parameters and also the continuous changes in the working conditions. By comparing simulation results to the experimental data, it is possible to check if this model fits correctly to the experiments. Only a preliminar parameter fitting has been performed up to now using the difference between the temperature measured close to the stack and its corresponding point in the model.

Solving the modelling equations, the fluid dynamics and the thermal behavior can be obtained. Moreover, a sensitivity analysis of the parameters can also be made. For this model, the parameters are: fan's hydraulic performance, geometry, dimensions, materials and operation level of the fuel cell. Since a new refrigerator system is required to work at high currents, the sensitivity analysis is focused on the fan characteristics.

5. Results of the sensitivity analysis

Different studies were performed in order to observe the influence of three different fans.

A first study is carried out with a fan very similar to the implemented in the real system. A second study is performed with a fan whose characteristic curve is smaller to the previous one. Finally, the last fan moves larger mass flow quantities.

A comparison between the three results can be observed in figure 4.

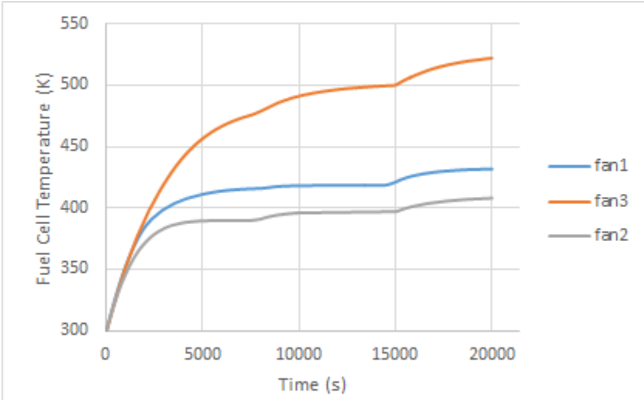

Fig. 4. Simulation results for three different fans

6. Conclusions

Experimental results show that the system is nonlinear, especially when working at high currents. Since overheating occurs at high currents, the fuel cell can not work at high power conditions.

Developing a numerical model is important to simulate operational conditions that the fuel cell can not reach due to overheating. A study of the sensitivity of the most important parameters is also possible thanks to this model.

Because of the large number of parameters and the non- linearity of the system, the model is difficult to fit.

7. Acknowledgements

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