Electro-Mechanical Study of the Increasing Temperature in IT-SOFC: "Effect of Heat Sources"

[1]Bariza Zitouni, [1]Hocine Ben Moussa and [2]Kafia Oulmi
[1]Laboratory (LESEI), Department of Mechanics, Faculty of Engineering,
[2]Laboratoire de Chimie et de Chimie de l'Environnement,
Department of Chemistry, Faculté de Science, Université de Batna, Algeria

Abstract: The increasing temperature in electrodes and electrolyte of a fuel cell is caused by the activation over potential, the ohmic over potential and by the heat released by the chemical reaction. In this contribution, we studied the thermo-electrical performance of an Intermediate Temperature Solid Oxide Fuel Cell (IT-SOFC) with electrode supported. The aim of this work is to study the increasing temperature of a single cell (IT-SOFC) under the influence of the following parameters: heat sources, functioning temperature and voltages of the cell, geometric configuration and materials type. The equation of energy in one dimension is numerically resolved by using the method of finite volumes. A computing program (FORTRAN) is developed locally for this purpose in order to obtain fields of temperature in anode, electrolyte and cathode of a single cell.

Key words: IT-SOFC, thermo-electrical, Joule effect, activation energy, temperature, voltage, geometric configuration

INTRODUCTION

The Fuel cells appear as one of the means of energy production in future, in parallel renewable energies, because they do not produce pollutants when they are fed by pure hydrogen. Several previous works were conducted in SOFC heat modelling. Jason (2004) developed a finite difference code able to perform preliminary design calculations for the thermal-stress analysis of solid oxide fuel cells. This model analyzes the manufacturing, start-up and steady state operating conditions of the hybrid solid oxide fuel cell. The finite difference code was originally developed for steady-state thermal analysis. The code was significantly modelled to include material changes, new heat sources (fuel cell electro-chemistry), counter flow conditions and different fluid properties. The finite difference code compared well with FLUENT. Eduardo (2004) has been developed an electrochemical-thermal model to simulate the SOFC performance under different operating conditions and geometrical factors. Temperature, current, gas distribution and fuel utilization were calculated with the model in the different regions. The modelling results showed that the novel design was successful in reducing the steep temperature gradients inside the cell but at lower fuel utilization than a conventional co-flow design. Srividya (2005). In his research characterizes the thermal stresses arising during the operation of planar solid oxide fuel cells which is a critical factor in the development of an efficient fuel cell. The thermal stresses are calculated from the temperature fields using ANSYS. A coupled thermal stress analysis approach is implemented for the two-dimensional stack fuel cell model and a structural analysis for the three-dimensional single stack fuel cell. Jinliang *et al.* (2003). In this study, gas flow and heat transfer were analyzed by a three-dimensional calculation method in an anode duct of medium temperature Solid Oxide Fuel Cell (SOFC). It was revealed that, among various parameters, the duct configuration and properties of the porous anode layer have significant effects on both gas flow and heat transfer of anode-supported SOFC ducts. Masayuki *et al.* (2003) a series of numerical simulation is performed for investigation of the heat and mass transport coupled with electrochemical reactions in a planar-type Solid Oxide Fuel Cell (SOFC). The simulation results show that the temperature difference in the cell becomes larger with the increase of cell length. Based on the results, they propose an improved cell design, which uses a material with low electrical resistance and high thermal conductivity. The calculated output voltage of the newly designed cell is about 7-10 % higher than that of the conventional cell. Additionally, the maximum temperature of the cell is reduced by 10-40 K.

The increasing temperature in the solid part of SOFC, anode, electrolyte and cathode, is due to the polarizations which behave like heat source. In this research we studied
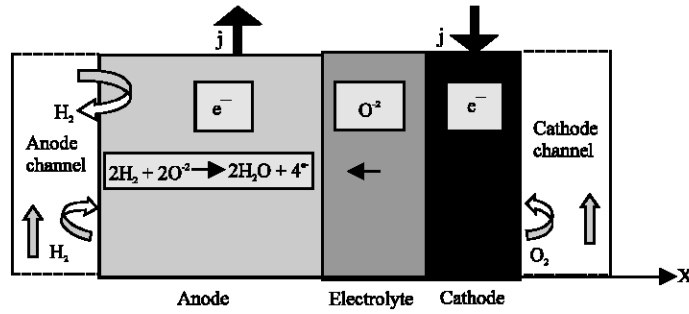
Fig. 1: SOFC components

the Joule effect and chemical reaction heat losses, across a single cell of an IT-SOFC. The thermo-electrical model shows the relation between heat losses and temperature distribution at several cell voltages. The effects of both heat losses on the temperature distribution in SOFC with anode or cathode supported and at several material type and operating temperatures (Fig. 1).

MATHEMATICAL MODEL

The values of the ionic or electronic conductivity of the SOFC components depend in the material and the temperature operating. This electrical property affects the SOFC performance in the term "polarization" and in the thermal performance in the term "heat source". In this study, the SOFC cell is study according to a thermo-electrical model.

Thermal model: This numerical study is conducted, in the aim to quantify these values of heat losses in various types of solid oxide fuel cell. These heat losses are appreciated with the term source of the conservation equation of energy.

$$\rho Cp \frac{dT(x)}{dt} + \nabla.(k\nabla T) + S = 0 \qquad (1)$$

S: Heat source.

In the one-dimensional and stationary case; the Eq. 1 takes the following expression:

$$\frac{d}{dx}\left(k.\frac{dT(x)}{dx} \right) + S = 0 \qquad (2)$$

The source term expression: In this study, we considered two types of sources of heat. The first is caused by the polarization Ohmic in the 3 components of SOFC; cathode, electrolyte and in the anode. The second kind of source is the polarisation activation energy; it is

Table 1: Electronic conductivity (Chem, 2003; Fergusson and Faird)
$\sigma(S\ cm^{-1})$

LSM/CGO/Ni-CGO

T (K)	Cathode	Electrolyte	Anode
873	121.69	0.018	800
1073	127.92	0.089	800
LSM/LSGM/Ni-YSZ			
1073	127.92	0.14	303.15

Table 2: Heat conduction of the material (Campanari and Iora, 2004; http://unit.aist.go.jp/energy/fuelcells/english/database.)
$k\ (W\ K^{-1}m^{-1})$

System	Cathode	Electrolyte	Anode
LSM/CGO/Ni-CGO	2	1.75	2
LSM/LSGM/Ni-YSZ		2.08	

generated by the chemical reaction. As we are interested in the geometrical configurations, supported anode and supported cathode, we suppose that the chemical reaction occurs in the electrolyte.

The source by effect joule is given by the following expression.

$$S_{Ohm,i} = \frac{j^2}{\sigma_i} \qquad (3)$$

I = Anode, cathode, electrolyte.

For the Supported Anode (AS) and Supported Cathode (CS), the numerical values are given by Table 1 and 2.

The heat of chemical reaction loss in the SOFC cell is given by the expression:

$$S_{ch} = \frac{T\Delta S}{2F}.\frac{j}{e} \qquad (4)$$

$$\text{Or:} \quad T.\Delta S = \Delta H - \Delta G \qquad (5)$$

The thermodynamics values are given by Table 3.

Table 3: Thermodynamics values

T (K)	ΔH (KJ mol⁻¹)	ΔG (KJ mol⁻¹)	T ΔS (KJ mol⁻¹)	ENernst (Volt)
873	244.70	214.1	30.60	1.109
1073	246.40	203.60	42.80	1.055

Table 4: Value of increasing temperature in CEA SOFC

		ΔT (K)			
		Joule effect		Activation energy	
(T K)	U_{cell}	CS	AS	CS	AS
873	0.5	0.60	1.40	0.16	0.35
	0.7	0.27	0.60	0.10	0.23
1073	0.5	3.00	6.80	1.07	2.50
	0.7	1.30	3.00	0.71	1.70

Table 5: Increasing temperature in CEA SOFC
ΔT (K)

		Joule effect		Activation energy	
CEA SOFC	U_{cell}	CS	AS	CS	AS
S1: LSM/LS GM/Ni-YSZ	0.5	5.4	3.7	2.0	1.5
	0.7	2.5	1.75	1.5	1.0
S2: LSM/C GO/Ni-CGO	0.5	3.00	6.80	1.07	2.50
	0.7	1.30	3.00	0.71	1.70

Electrical model: In the case of a single cell, the tension is given by:

$$U_{Cell} = E_{Nernst} - \eta_{Ohm} - \eta_{act} - \eta_{conc} \qquad (6)$$

The Ohmic over potential are given by Ohm low:

$$\eta_{Ohm} = R_{Ohm} \cdot j \qquad (7)$$

$$R_{Ohm} = \frac{e_{an}}{\sigma_{an}} + \frac{e_{ca}}{\sigma_{ca}} + \frac{e_{elec}}{\sigma_{elec}} \qquad (8)$$

Under the effect of Ohmic polarization, the current density for several cell voltages imposed, is given by:

$$j = \frac{U_{Cell} - E_{Nernst}}{R_{Ohm}} \qquad (9)$$

The activation and concentration polarizations are neglected.

RESULTS AND DISCUSSION

The thermo-electrical model shows the sensibility of the increase of temperature for operating voltages and temperatures of a single cell IT-SOFC and for 2 types of sources heat. These results are analyzed for 2 geometrical configurations (anode supported or cathode supported) Table 4 and 5.
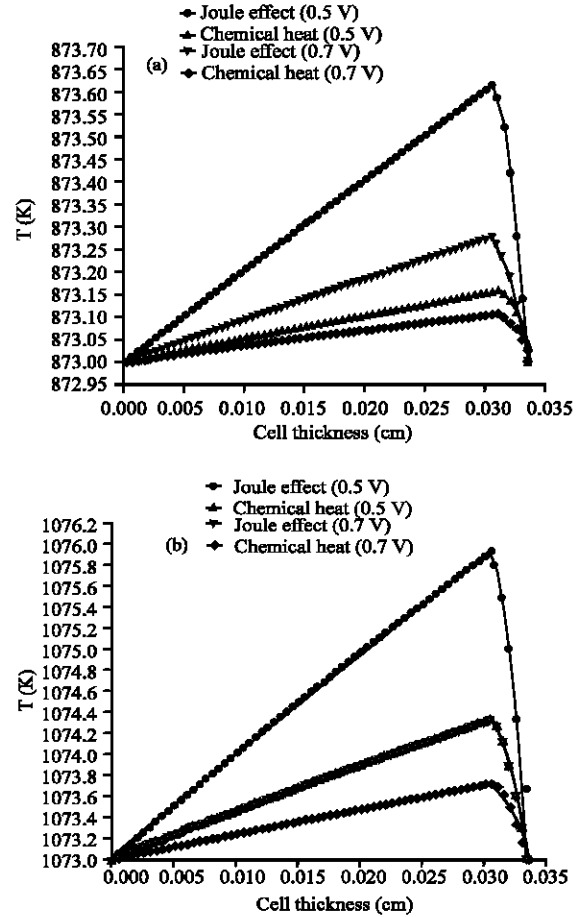

Fig. 2: Temperature distribution in LSM/CGO/Ni-CGO with cathode supported (a): T = 873 K (b): T = 1073 K

Effects of operating temperature and geometric configuration

Geometric configuration effect: For a temperature and tension imposed, the losses by effect joule and energy of activation are highest for the supported anode configuration. At operating temperature 1073K, the Anode Supported (AS) has the greatest increasing temperature (about 6.8 K) for the voltage operating 0.7 V. At operating temperature 873 K, the lowest one is with Cathode Supported (CS) for the voltage operating 0.5 V (Fig. 2 and 3).

Operating temperature effects: At the same operating voltage and with anode or cathode supported, the increasing temperature is more important when temperature operating passed from 873 to1073 K.

Operating voltage effects: In operating voltages raised, the heat losses decrease. The same quantity of heat is
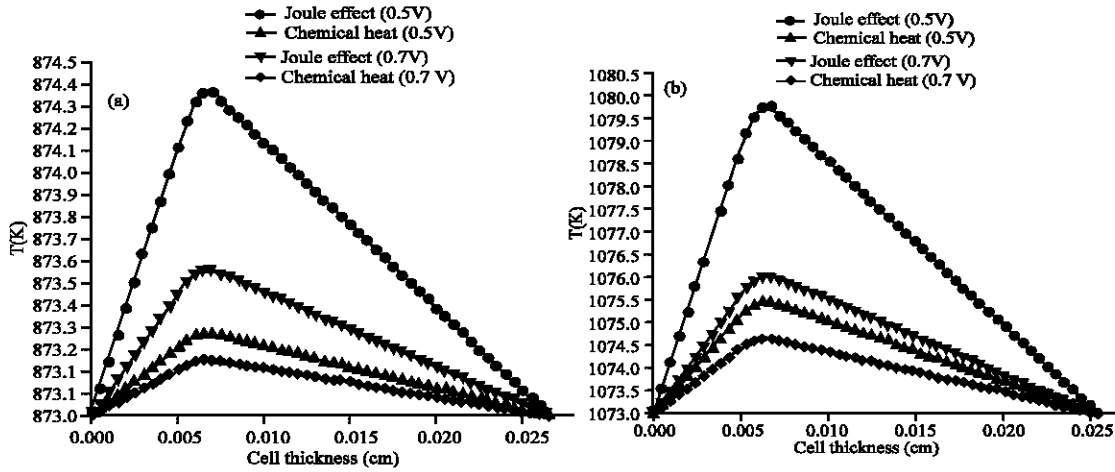
Fig. 3: Temperature distribution in LSM/CGO/Ni-CGO with anode supported (a): T=873 K? (b): T= 1073 K
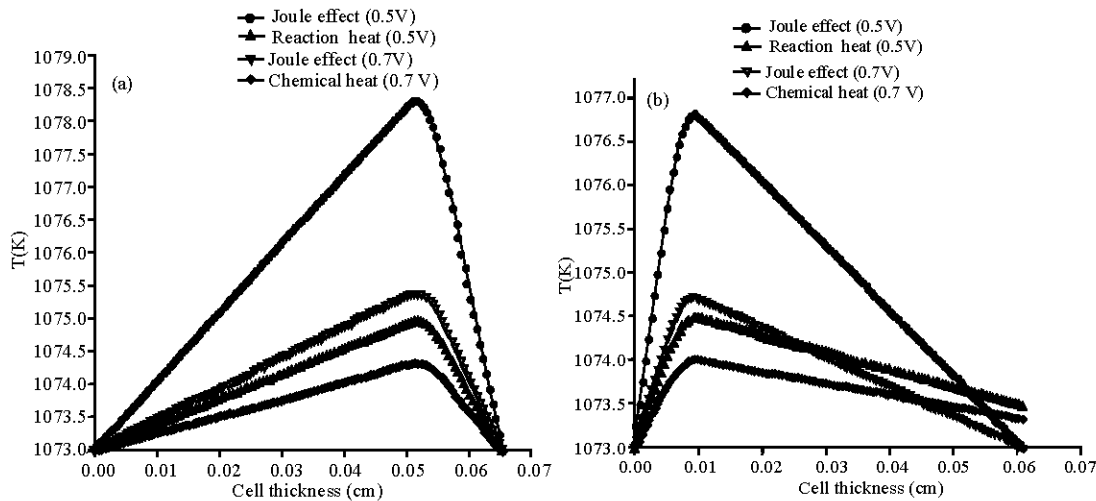

Fig. 4: Increasing temperature in LSM/LSGM/Ni/YSZ SOFC (a): anode supported, (b): cathode supported

dissipated by a cell with cathode supported working in 0.5V that a cell with anode supported working in 0.7V (Table 4).

Effects of materials system: The heat source caused by activation energy has a less effect than the heat source caused by Joule effects for all the geometric configurations and for the two systems S1, S2 (Table 5). For anode supported, the system S2 has the high temperature elevation than the system S1. But for the cathode supported, the system S1 has the greatest increasing temperature than system S2, for the two types of the source of heat and for all cell voltages (Fig. 4).

CONCLUSION

The aim of this study is to investigate the sensibility of the increasing temperature to the components materials, geometric configuration anode supported or cathode supported and to the operating voltage and temperatures. The results are discussed under the effects of two type of energy source: Joule effect and under activation energy. The operating temperature, voltage and the geometric configuration (AS and CS) limit the Ohmic losses and the polarization activation. The heat produced by Joule effect is controlled by the temperature and cell voltage. Polarization activation has a less effect in the increasing temperature than the Ohmic polarization. Under

the same operating conditions, more effect on increasing temperature is caused by LSM/CGO/Ni-CGO with anode supported and by LSM/LSGM/Ni-YSZ with cathode supported.

Nomenclature:

e	Cell voltage (V)
U_{cell}	Power density (W m^{-2})
S	Ohmic resistance (Ω)
R_{ohm}	Nernst potential
E_{nernst}	Polarization (V)
η	Current density (A m^{-2})
j	Thickness (m)
e	Ionic or electronic conductivity (S m^{-1})
σ	Gibbs free energy (J mol^{-1})
ΔG	Enthalpy (J mol^{-1})
ΔH	Entropy standard (J mol^{-1} K^{-1})
ΔS	Heat capacities (specific heat) (J mol^{-1} K^{-1})
C_p	Heat conduction of the material (Wm^{-2})
k	Temperature (K)
T	Faraday constant (C mol^{-1})
F	Cathode supported
CS	Anode supported
AS	
Greek letters	
ρ	Gas density (kg m^{-3})
η	Over potential (V)
Subscripts	
Ohm	Ohmic resistance
act	Activation
conc	Concentration
an	Anode
ca	Cathode
cell	Single cell
CEA	Cathode, Electrolyte and Anode

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