Journal of Zhejiang University SCIENCE A
ISSN 1673-565X (Print); ISSN 1862-1775 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

Studying on the increasing temperature in IT-SOFC: Effect of heat sources

ZITOUNI Bariza[1], BEN MOUSSA Hocine[†‡1], OULMI Kafia[2]

(*[1]Laboratore d'Étude des Systèmes Énergétiques Industriels (LESEI), Faculty of Engineering, University of Batna, Batna, Algeria*)

(*[2]Laboratoire de Chimie et de Chimie de L'environnement, Faculty of Science, University of Batna, Batna, Algeria*)

[†]E-mail: H2SOFC@gmail.com

Received Apr. 30, 2007; revision accepted July 26, 2007

Abstract: The dimensions and the materials type limit the performance of fuel cell. The increase of the temperature in electrodes and electrolyte of the cell, is due to the over potential of activation (transfer of load), the over potential Ohmic (resistance of polarization), the over potential of reaction (heat released by the chemical reaction) and the over potential of diffusion. In this paper, 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 this increasing temperature of a single cell of an 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 every element of the cell.

Key words: IT-SOFC, Thermo-electrical, Joule effect, Activation energy, Temperature, Voltage, Geometric configuration
doi:10.1631/jzus.2007.A1500 **Document code:** A **CLC number:** TM911

INTRODUCTION

Fuel cell converts directly the chemical energy in the fuel to electrical energy without the intermediate steps of heat and mechanical energy conversion as is the case in conventional methods based on combustion. Solid oxide fuel cell (SOFC) operates at elevated temperature producing heat which can be used for heating purposes or for feeding gas turbines to produce more power. Fuel cells have been attracting more attention in the search for new efficient and eco-friendly energy sources for future.

Numerical modelling plays a dominating role in the fuel cell research. It can be used to predict the performance of a particular design of fuel cell under various operating conditions and to understand the processes that occur inside the fuel cells and to identify the critical ones which limit the others. Also, the effects of various parameters on different processes inside the fuel cell can be studied and understood by experimental studies (Briois, 2005) or by fuel cell modelling (Bove *et al*., 2005; Huang *et al*., 2005).

In SOFC, the heat is generated by Ohmic polarization, activation polarization and chemical reaction polarization. In this work we studied the Joule effect and chemical reaction heat losses, across a single cell of an intermediate temperature solid oxide fuel cell (IT-SOFC).

On the other hand, the SOFCs present several geometrical configurations such as electrolyte supported, cathode supported (CS) or anode supported (AS). The last one presents a better performance (Leah *et al*., 2005; Verbraeken, 2005; Yakabe *et al*., 2000; Baron *et al*., 2004; Zhao and Virkar, 2005; Wincewicz and Cooper, 2005; Chen, 2003).

Through this study, a thermo-electrical model shows the relationship between heat losses and temperature distribution at several cell voltages and the effects of heat losses on the temperature distribution in

---

[‡] Corresponding author

SOFC with anode or cathode supported and at several material types and operating temperatures (Fig.1).

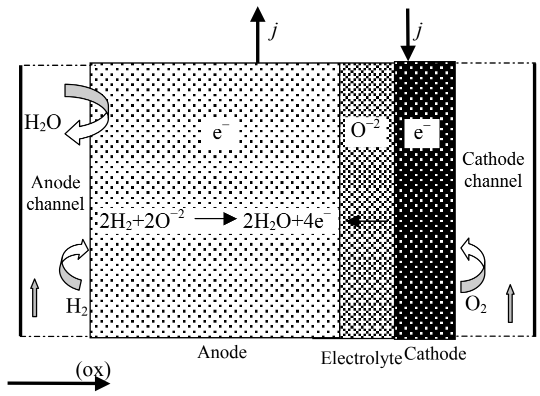

Fig.1 SOFC components

MATHEMATICAL MODEL

The values of the ionic or electronic conductivity of the SOFC components depend on the material and the operating temperature. This electrical property affects the SOFC performance in the term "polarization" and the thermal performance in the term "heat source". In this work, the SOFC is studied according to a thermo-electrical model (Fig.2).

Thermal model

This numerical study is conducted in the aim to quantify these values of heat losses in various types of SOFCs. These heat losses are appreciated with the term source of the conservation equation of energy.

$$\rho C_{\mathrm{p}} \frac{\mathrm{d}T(x)}{\mathrm{d}t} + \nabla(k\nabla T) + S = 0\,, \qquad (1)$$

where S is the heat source, ρ is gas density (kg/m^3), C_{P} is heat capacities [J/(mol·K)], k is the thermal conductivity [W/(m·K)], T is temperature (K).

In the one-dimensional and stationary case, Eq.(1) takes the following expression:

$$\frac{\mathrm{d}}{\mathrm{d}x}\left(k\frac{\mathrm{d}T(x)}{\mathrm{d}x}\right) + S = 0\,. \qquad (2)$$

Source term expression

In this study, we considered two types of heat sources. The first one is caused by the polarization Ohmic in the three components of SOFC: Cathode, Electrolyte and Anode (CEA). The second kind of source is the polarisation activation energy, which is 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.

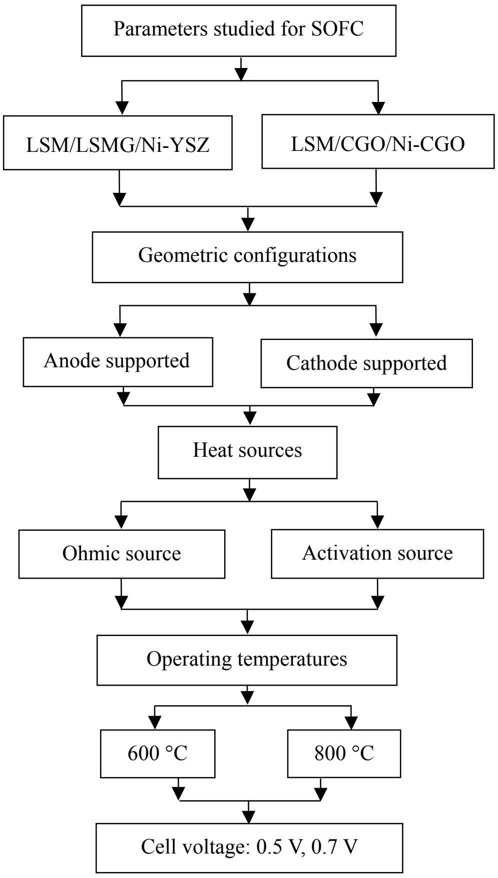

Fig.2 Parameters studied

The heat source by Joule effect is given by the following expression:

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

where j is current density (A/m^2), σ is ionic/electronic conductivity (S/m), S_{Ohm} is Joule effect, i=anode, cathode, electrolyte.

For AS and CS, the parameters values: electrical/ionic conductivity, thermal conductivity and the electrode and electrolyte thickness are respectively given in Tables 1~3 (Chen, 2003; Bove *et al*., 2005; Leah *et al*., 2005; Sylvia *et al*., 2004; http://unit.aist.go.jp/energy/fuelcells/english/database/).

Table 1 Electronic conductivity

System	T (K)	σ (S/cm)		
		Cathode	Electrolyte	Anode
LSM/CGO/Ni-CGO (LeMasters, 2004)	873	121.69	0.018	800
	1073	127.92	0.089	800
LSM/LSGM/Ni-YSZ (LeMasters, 2004)	1073	127.92	0.140	303.15

Table 2 Heat conduction of the material

System	k [W/(m·K)]		
	Cathode*	Electrolyte**	Anode*
LSM/CGO/Ni-CGO	2	1.75	2
LSM/LSGM/Ni-YSZ	2	2.08	2

*from (Campanari and Lora, 2004); **from http://unit.aist.go.jp/energy/fuelcells/english/database/

Table 3 Components thickness of SOFC (μm)*

		Cathode	Electrolyte	Anode
LSM/LSGM/Ni-YSZ	CS	500	50	100
	AS	50	50	800
LSM/CGO/Ni-CGO	CS	300	15	20
	AS	50	15	200

* from (Zhao and Virkar, 2005; Campanari and Lora, 2004; Kharton *et al.*, 2004; http://unit.aist.go.jp/energy/fuelcells/english/database/)

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

$$S_{\text{ch}} = \frac{T\Delta S}{2F}\frac{j}{e}, \tag{4}$$

or

$$T\Delta S = \Delta H - \Delta G, \tag{5}$$

where S_{ch} is the heat of chemical reaction, ΔS is entropy standard [J/(mol·K)], F is Faraday constant (C/mol), e is thickness (m), ΔG is Gibbs free energy (J/mol), ΔH is enthalpy (J/mol).

The thermodynamics values are given by Table 4.

Table 4 Thermodynamics values

T (K)	ΔH (kJ/mol)	ΔG (kJ/mol)	$T\Delta S$ (kJ/mol)	E_{Nernst} (V)
873	244.70	214.10	30.60	1.109
1073	246.40	203.60	42.80	1.055

Electrical model

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

$$U_{\text{Cell}} = E_{\text{Nernst}} - \eta_{\text{Ohm}} - \eta_{\text{act}} - \eta_{\text{conc}}, \tag{6}$$

where U_{cell} is cell voltage (V), E_{Nernst} is Nernst potential, η is polarization (V).

The Ohmic over potential is given by Ohm Low:

$$\eta_{\text{Ohm}} = R_{\text{Ohm}} j, \tag{7}$$

$$R_{\text{Ohm}} = \frac{e_{\text{an}}}{\sigma_{\text{an}}} + \frac{e_{\text{ca}}}{\sigma_{\text{ca}}} + \frac{e_{\text{elec}}}{\sigma_{\text{elec}}}, \tag{8}$$

where R_{Ohm} is Ohmic resistance (Ω).

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

$$j = \frac{U_{\text{Cell}} - E_{\text{Nernst}}}{R_{\text{Ohm}}}. \tag{9}$$

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 two types of sources heat. These results are analyzed for two geometrical configurations (AS or CS) and shown in Tables 5 and 6.

Table 5 Value of increasing temperature [Δ*T* (K)] in S1 CEA SOFC

T (K)	U_{cell} (V)	Joule effect		Activation energy	
		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 6 Increasing temperature [Δ*T* (K)] in S1 and S2 CEA SOFC

System	U_{cell} (V)	Joule effect		Activation energy	
		CS	AS	CS	AS
S1: LSM/LSGM/Ni-YSZ	0.5	5.40	3.70	2.00	1.50
	0.7	2.50	1.75	1.50	1.00
S2: LSM/CGO/Ni-CGO	0.5	3.00	6.80	1.07	2.50
	0.7	1.30	3.00	0.71	1.70

EFFECTS OF OPERATING CONDITIONS AND GEOMETRIC CONFIGURATION

Geometric configuration effects

For a temperature and tension imposed, the losses by Joule effect and activation energy are the highest for the supported anode configuration. At the operating temperature of 1073 K, the anode supported (AS) has the greatest temperature increasing (about 6.8 K) for the voltage operating 0.5 V. At the operating temperature of 873 K, the lowest one is with cathode supported (CS) for the voltage operating 0.7 V (Figs.3 and 4).

Operating temperature effects

At the same operating voltage with anode or cathode supported, the increasing temperature is more important when the temperature operating passed from 873 K to 1073 K.

Operating voltage effects

As operating voltages raise, the heat losses decrease. The same quantity of heat is dissipated by a cell with cathode supported working in 0.5 V as that a cell with anode supported working in 0.7 V (Table 5).

Effects of materials system

The heat source caused by activation energy has a less effect than that caused by Joule effects for all the geometric configurations and for the two systems S1, S2 (Table 6). For anode supported, the system S2 has higher 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 heat source and for all cell voltages (Fig.5).

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 types of energy source: Joule effect and activation energy.

The operating temperature, voltage and the geometric configuration (AS and CS) limit the Ohmic losses and the polarization activation.

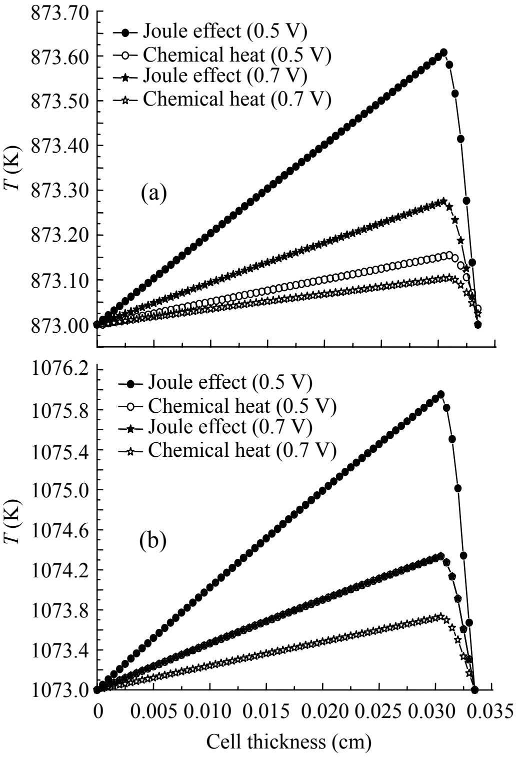

Fig.3 Temperature distribution in LSM/CGO/Ni-CGO with cathode supported. (a) *T*=873 K; (b) *T*=1073 K

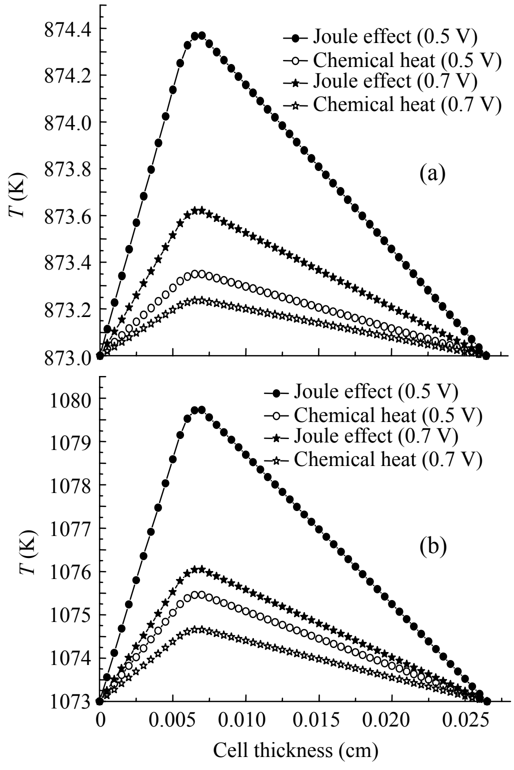

Fig.4 Temperature distribution in LSM/CGO/Ni-CGO with anode supported. (a) *T*=873 K; (b) *T*=1073 K

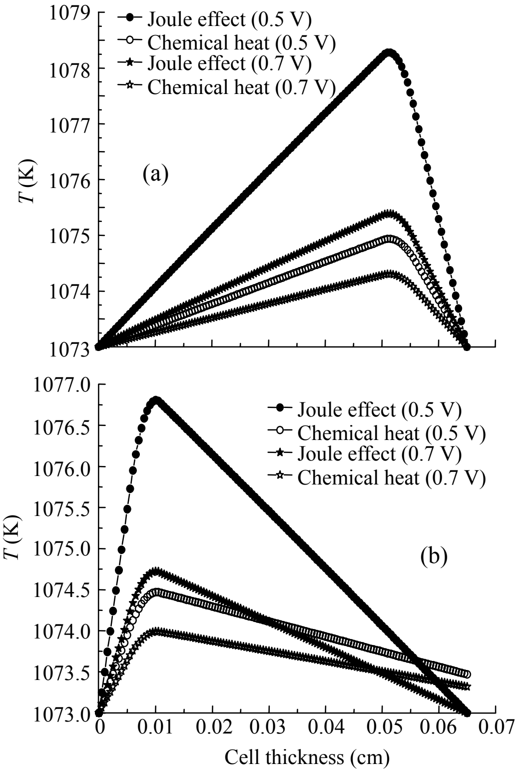

Fig.5 Increasing temperature in LSM/LSGM/Ni/YSZ SOFC. (a) Anode supported; (b) Cathode supported

The heat produced by Joule effect is controlled by the temperature and cell voltage. Polarization activation has 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.

References

Baron, S., Brandon, N., Atkinson, A., Steele, B., Rudkin, R., 2004. The impact of wood-derived gasification gases on Ni-CGO anodes in intermediate temperature solid oxide fuel cells. *Journal of Power Sources*, **126**(1-2):58-66. [doi:10.1016/j.jpowsour.2003.09.042]

Bove, R., Lunghi, P., Nigel, M., 2005. Mathematic model for systems simulation. Part one: from a detailed to macro-black-box model. *International Journal of Hydrogen Energy*, **30**(2):181-187. [doi:10.1016/j.ijhydene.2004.04.008]

Briois, P., 2005. Synthèse par Pulvérisation Cathodique et Caractérisation D'électrolyte Solides en Couche Minces Pour Piles à Combustible à Oxyde Solide (SOFC) Fonctionnant à Température Intermédiaire. Ph.D Thesis, Institut National Polytechnique de Lorraine (INPL), Nancy, France.

Campanari, S., Lora, P., 2004. Definition and sensitivity analysis of a finite volume SOFC model for a tubular cell geometry. *Journal of Power Sources*, **132**(1-2):113-126. [doi:10.1016/j.jpowsour.2004.01.043]

Chen, C., 2003. Solid Oxide Fuel Cell Electrolyte Membrane Fabrication. Master Thesis, University of Virginia.

Huang, J., Chen, C.K., Ai, D.Y., 2005. Computational analyze of species transport and electrochemical characteristics of a SOFC. *Journal of Power Sources*, **140**(2):235-242. [doi:10.1016/j.jpowsour.2004.08.028]

Kharton, V.V., Marques, F.M.B., Atkinson, A., 2004. Transport properties of solid oxide electrolyte ceramics: A brief review. *Solid State Ionics*, **174**(1-4):135-149. [doi:10.1016/j.ssi.2004.06.015]

Leah, R.T., Brandon, N.P., Aguiar, P., 2005. Modelling of cells, stacks and systems based around metal-supported planar IT-SOFC cells with CGO electrolytes operating at 500~600 °C. *Journal of Power Sources*, **145**(2):336-352. [doi:10.1016/j.jpowsour.2004.12.067]

LeMasters, J., 2004. Master of Science in Mechanical Engineering. Thermal Stress Analyses of LCA-based Solid Oxide Fuel Cells. Georgia Institute of Technology.

Verbraeken, M., 2005. Advanced Supporting Anodes for Solid Oxide Fuel Cells. Master Thesis, Faculty of Science and Technology, University of Twente.

Wincewicz, K.C., Cooper, J.S., 2005. Taxonomies of SOFC material and manufacturing alternatives. *Journal of Power Sources*, **140**(2):280-296. [doi:10.1016/j.jpowsour.2004.08.032]

Yakabe, H., Hishinuma, M., Uratani, M., Matsuzaki, Y., Yasuda, I., 2000. Evaluation and modeling of performance of anode-supported solid oxide fuel cell. *Journal of Power Sources*, **86**(1-2):423-431. [doi:10.1016/S0378-7753(99)00444-9]

Zhao, F., Virkar, A.V., 2005. Dependence of polarization in anode-supported solid oxide fuel cells on various cell parameters. *Journal of Power Sources*, **141**(1):79-95. [doi:10.1016/j.jpowsour.2004.08.057]