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## Radiation Heat Transfert in $\text{ZrO}_2$ -8% $\text{Y}_2\text{O}_3$ Electrolyte Of SOFC Fuel Cell

S. Abdessemed<sup>1</sup>, B.Zitouni<sup>1</sup>, H.Benmoussa<sup>2</sup>, B rousseau<sup>3</sup>

*1 Laboratoire d'Etude des Systèmes Energétiques Industriels (LESEI). Universités de Batna. Algérie*

*2 Unité de Recherche Appliquée en Energies Renouvelables (URAER). Centre de Développement des Energies  
Renouvelables (CDER). Ghardaïa. Algérie*

*3CEMHTI UPR CNRS 3079, 1D avenue de la Recherche Scientifique, 45071, Orléans cedex 02, France*

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# Radiation Heat Transfert in $\text{ZrO}_2\text{-8\% Y}_2\text{O}_3$ Electrolyte Of SOFC Fuel Cell

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<sup>1</sup> Laboratoire d'Etude des Systèmes Energétiques Industriels (LESEI). Universités de Batna. Algérie

<sup>2</sup> Unité de Recherche Appliquée en Energies Renouvelables (URAER).

Centre de Développement des Energies Renouvelables (CDER). Ghardaïa. Algérie

<sup>3</sup>CEMHTI UPR CNRS 3079, 1D avenue de la Recherche Scientifique, 45071, Orléans cedex 02, France

Corresponding author: abdesmad.sou@gmail.com

**Abstract** – SOFC operating temperature is relatively high. This last one is imposed by the electrolyte mode operating which becomes ionic conducting at these high temperatures (1000-1300K). The exact contribution of the thermal radiation to the total heat balance is not well known. The thermal radiation can play a very significant role in the thermal combination of transfer through the various SOFC structure layers. The thermal radiation utilizes another mechanism which is the electromagnetic radiation. In this case, atoms, molecules and free electrons of the SOFC components can lose a part of their kinetic energy by emission of an electromagnetic radiation received by the components. Electrolyte and electrodes are considered as semi-transparent medium. They can absorb disperse and emit the thermal radiation. In this work, we study the temperature gradient following a conduction-radiation model in the SOFC electrolyte. The approximation of Schuster-Schwarzschild is used to evaluate the Radiatif heat flow through the electrolyte SOFCs. The results obtained by the finite volume method show the effect of spectral parameters and optical dimensions on the spatial distribution of temperature in SOFC electrolyte.

**Keywords:** Electrolyte SOFC, temperature, radiation, Optical dimensions.

## I. Introduction

The fuel cell SOFC is a technology solutions the most effective to control pollution resulting from the modern world's dependence on fossil fuels. The SOFC is a cell operating at high temperature. Electrolytes for fuel cells SOFCs are usually zirconia doped with yttrium, it was used with a thickness of 100 to 200µm, if the maximum conductivity is achieved with a 8%percentage of yttrium, Materials are cheap and very stable although it is an ionic conductors of oxygen ions  $\text{O}^{2-}$  to high operating temperatures. Therefore the heating system has ensured the end of ionic conductivity is the approach of the cell. SOFC systems couple to different modes of heat transfer. Operating at a temperature of 600-1000 ° C, the thermal radiation is involved in the combination of heat transfer through the electrolyte of SOFC fuel cell. [1], [8] and [9]

## II. Modeling of Radiatif Transfer in SOFC

### II.1. Modeled from the equation of Radiatif Heat Transfer

For a semi transparent, gray, absorbing, and disseminating emissivity and local thermodynamic equilibrium. Radiatif transfer is described in each area of the SOFC by equation "Eq. 1" [6] and [7]

$$\frac{dI_{\lambda}}{d\tau_{\lambda}} = -I_{\lambda} + (1 - \omega_{\lambda})I_{b\lambda} + \frac{\omega_{\lambda}}{4\pi} \int_{4\pi} I(S_i) \phi(S_i, S) d\Omega_i \quad (1)$$

The radiative boundary condition of a gray area in transmission and diffuse reflection as is expressed by "Eq.2"

$$I_{\phi}(\bar{\Omega}) = \frac{\varepsilon_{\phi} \sigma T_{\phi}^4}{\pi} + \frac{1 - \varepsilon_{\phi}}{\pi} \int_{\bar{\Omega}', \bar{n}_{\phi} < 0} I_{\phi}(\bar{\Omega}') |\bar{\Omega}' \cdot \bar{n}_{\phi}| d\Omega' \quad (2)$$

The heat transfer by radiation is modeled using the radiative transfer equation RTE for determining the radiant flux by integrating the field luminance in all directions and all wavelengths. The ETR, taken in its complex form has no analytical solution. It appears necessary to use a numerical method to solve the equation. In practical terms, one of the main difficulties in the numerical solution of the ETR lies in the calculation of a function of seven variables three position coordinates, two angular coordinates, variable temporal and spectral parameters. Moreover, the RSD being type integro-differential, the other major problem to solve comes from the integral term and the no homogeneous term which takes the temperature and generally requires coupling of the ETR to the conservation equation energy.

Numerical methods exist to solve "Eq.1" are quite numerous, were cited: Monte Carlo Method areas, multi-stream methods, discrete ordinate method, spherical harmonics method, discrete transfer method, finite volume method. Each of the above methods has its advantages and disadvantages. The problems you may encounter are very diverse, including the nature of the environment and to study the thermal radiative properties of SOFC component materials, and variety of boundary conditions can be treated. Xiongwen Zhang et all [3] David L et all [8], modeling the effect of radiative heat transfer within SOFC-PEN planar geometry is through the equation: Xiongwen Zhang et all [3] "Eq.4" and David L et all [8] "Eq.4"

$$\vec{N} \cdot \left( I(\vec{r}, \vec{s}) \vec{s} \right) + (a_s + a) I(\vec{r}, \vec{s}) = an^2 \frac{\sigma_s T^4}{\pi} + \frac{a_s}{4\pi} \int_{4\pi} I(\vec{r}, \vec{s}') \theta(s, s') d\Omega_i \quad (3)$$

$$\frac{dI_\lambda}{d\tau_\lambda} = -I_\lambda + (1 - \omega_\lambda) I_{b\lambda} + \frac{\omega_\lambda}{4\pi} \int_{4\pi} I(S_i) \phi(S_i, S) d\Omega_i \quad (4)$$

Solving equations is done by the method of discrete ordinates and the radiative heat flux is given by "Eq.5"

$$qr = \int_0^\infty \int_{4\pi} I_\lambda(s) s d\lambda d\Omega \quad (5)$$

David L et all [8], the modeling effect of radiative heat transfer between the insulator and interconnectors is done by writing the equation "Eq.6", the resolution is still done by the method of discrete ordinates.

$$\cos \theta \frac{dI}{ds} = -\beta I + kn^2 I_b + \frac{\sigma}{2} \int_0^\pi I(S_i, \theta') \sin \theta' d\theta' \quad (6)$$

## II.2. Modeling by the Methods of Approximation

Among the various existing methods there are known approximate methods. These methods typically give simplified forms of formal solutions among which the methods known as the Rosseland approximation and diffusion approximation model and the two streams. In some cases, these two methods to approach the exact solutions. They have the added advantage of allowing to represent the radiative transfer as a phenomenon of diffusive and radiative conductivity defined by analogy with the thermal conductivity. [1], [5], [6], [8] and [9]

### 1) Approximation Rosseland

The radiative heat flux is approximated as a diffusive flow through a radiative conductivity called the Rosseland radiative conductivity. "Eq.7"

$$q_{rad} = -\frac{16n^2\sigma T^3}{3\beta_R} \nabla T \quad (7)$$

### 2) Approximation of Schuster-Schwartzchild

The radiative effects of trade are significant for electrolytes thicker model or dual-stream approximation of Schuster-Schwartzchild is used to approximate the flow of heat radiation through the YSZ electrolyte. The flux of radiative heat exchange through the surface d`electrolyte can be approximated by "Eq.8"

$$q_{rad} = -\sigma(T_{top}^4 - T^4)e^{-2kL} + \sigma(T_{bott}^4 - T^4)e^{-2kx} \quad (8)$$

## II. Model Conducto-Radiative in SOFC Electrolyte

### II.1. Physical modeling (see Figure 1).

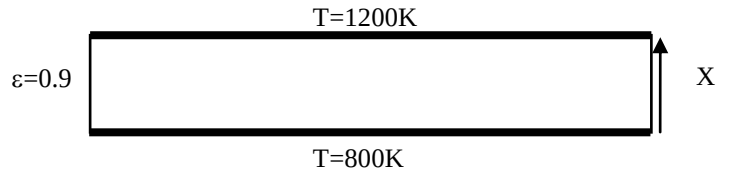


Figure 1: Electrolyte SOFC field conduction and radiation

### II.2. Equations Modeling

In the SOFC electrolyte, energy is transported by two mechanisms, conduction and radiation in the electrolyte, neglecting the effect of any heat source and considering that the steady evolution of temperature is done by a single X direction L`overall equation that governed the transfer of heat within d`electrolyte reflects two streams: diffusive and radiative takes the following form: "Eq.9"

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left( \lambda_{eff,ele} \frac{\partial T}{\partial x} \right) + S_{T,ele} \quad (9)$$

The expression of radiative heat flux "Eq.10"

$$q_{rad} = C_1 e^{2kL} + C_2 e^{-2kx} \quad (10)$$

C1 and C2 are constant-Schwartzchild Schuster, is given by: "Eq.11"

$$\begin{aligned} C_1 &= -\sigma(T_{top}^4 - T^4)e^{-2kx} \\ C_2 &= \sigma(T_{bott}^4 - T^4) \end{aligned} \quad (11)$$

The ohmic source is given by: "Eq.12" and the electrical conductivity of the electrolyte is given by: "Eq.13"

$$S_{ohm,ele} = \frac{i}{\sigma_{ele}} \quad (12)$$

$$\sigma_{ele} = 3.34 \cdot 10^4 \exp \left[ \frac{-10300}{T} \right] \quad (13)$$

It is then a problem of radiation conduction including resolution of equations of energy carried by the finite volume method.

### II.3. Thermal Radiative Propriety

For a linear medium, the absorption coefficient spectral refractive index, the coefficient spectral dispersion and dispersion, provide a complete set of properties phenomenological necessary to model propagation of radiant energy. Furthermore, emissivity and reflectivity must be provided to clarify the boundary conditions. These radiative properties change with the typical wavelength. The determination of properties radiative material concerned is carried out either by the through experimental methods or models predictive. Accurate knowledge of these properties function of wavelength and temperature is currently the biggest obstacle to the fair provision of radiative heat transfer in the PEN-SOFC systems.

For operating temperatures of 900K-1100k, the index of refraction of the electrolyte is 1.8 or 90% of the emissive power is contained in the region of wavelengths  $0.9\mu\text{m} < \lambda < 7.8\mu\text{m}$ . The determination of radiative properties of materials involved is done either through experimental methods or by predictive models. Accurate knowledge of these properties based on the wavelength and temperature is currently the biggest obstacle to the fair include radiative heat transfer in electrodes and electrolyte of SOFC systems. (see Table 1) and

Table1 Thermo radiatives coefficients [8]

| Coefficients                    | Expression                                   |
|---------------------------------|----------------------------------------------|
| Adsorption spectral Coefficient | $k = \frac{4\pi K}{n\lambda}$                |
| Extinction spectral Coefficient | $\beta_\lambda = k_\lambda + \sigma_\lambda$ |
| Spectral optical thickness      | $\tau_\lambda = \int_0^s \beta_\lambda ds$   |
| Adsorption Coefficient          | $K = -\frac{n\lambda \ln[\tau]}{4\pi d}$     |

Table 2 Emissivity and scattering coefficient

| Reference                          | scattering coefficient YSZ [ $\text{m}^{-1}$ ]                                                                      |                                                |
|------------------------------------|---------------------------------------------------------------------------------------------------------------------|------------------------------------------------|
| Coefficients                       | [8]                                                                                                                 | [7]                                            |
| $\beta$ [ $\text{m}^{-1}$ ]        | $\beta = 160$ $0.0 < \lambda < 3.5$<br>$\beta = 110$ $3.5 < \lambda < 5.0$<br>$\beta = 50$ $5.0 < \lambda < \infty$ | $\beta = 10260$<br>$\lambda \geq 3\mu\text{m}$ |
| E                                  | 0.9                                                                                                                 | 0.9                                            |
| $\sigma_s + k$ [ $\text{m}^{-1}$ ] | /                                                                                                                   | 500                                            |

## VI. Results

### VI.1. Effect of Optical Thickness

Within the assumed dense electrolyte, energy is transported by two mechanisms related to sound conduction and thermal radiation. The transport equation also takes into account ohmic losses which may be significant. The radiation exchange is more significant than the thickness of the electrolyte is important. The radiative term is obtained after applying the method to two streams or approximation of Schuster-Schwartzchild to complete the term of the equation of radiative transfer. This approximation is based on the fact that the radiance is isotropic in the two hemispheres of dissemination. The case of conducto-radiative transfer in SOFC electrolyte medium for disseminating non-planar geometry, environment that is contained between two isothermal surfaces maintained at different temperatures, including temperatures of upper and lower surfaces of electrolyte are fixed at 800K and 1200K respectively, The approximation of Schuster and Schwartzchild is used for a thin electrolyte  $\tau_L \ll 1$ . The temperature profile is given for different values of spectral optical thickness  $\tau$ ,  $\tau = (0.001, 0.1, 0.075 \text{ and } 0.24)$ . For  $\tau_L = 10^{-2}$  m,  $n = 1.8$  and an absorption coefficient of YSZ  $k = 162\text{cm}^{-1}$ . The is a dimensionless factor, which is equal to the optical depth thickness of electrolyte  $L$  and the absorption coefficient  $k$ , which increases the thickness of electrolyte leads to the increase in value of  $\tau$ . A comparison of results shows that the increase of spectral optical thickness leads to a significant variation and a large difference in temperature. (see Figure 2).

Table 3. Adsorption coefficient of  $\text{ZrO}_2$ -8%  $\text{Y}_2\text{O}_3$  [8]

| n    | $\lambda$ [ $\mu\text{m}$ ] | K [ $\text{cm}^{-1}$ ] |
|------|-----------------------------|------------------------|
| 1.38 | 1.0                         | 175                    |
| 1.90 | 2.0                         | 163                    |
| 1.80 | 2.5                         | 162                    |
| 1.83 | 3.0                         | 159                    |
| 1.85 | 5.5                         | 50                     |
| 1.84 | 6.0                         | 40                     |
| 1.82 | 6.5                         | 34                     |
| 1.75 | 7.5                         | 47                     |

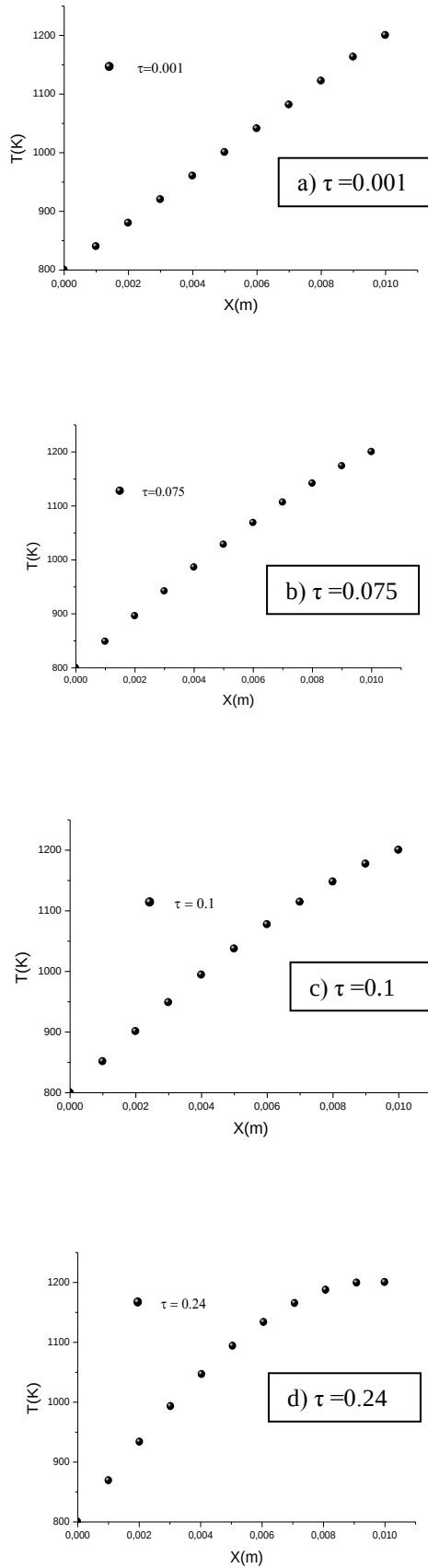


Figure 2: Effect of spectral optical thickness on temperature profile  
a)  $\tau=0.001$ , b)  $\tau=0.075$ , c)  $\tau=0.1$ , d)  $\tau=0.24$

## VI.2. Effect of Refractive Index

The electrolyte ionic conductor of the SOFC stack composed of YSZ supposed to come as an isotropic medium, homogeneous, gray and semitransparent  $\varepsilon=0.9$ . whose emittance surfaces electrolyte is The thermal radiative properties of YSZ have a significant spectral variation with wavelength and index of refraction of the medium. (see Figure4) and (see Table 3). The increase of refractive index medium leads to a heat diffusion. (see Figure 3).

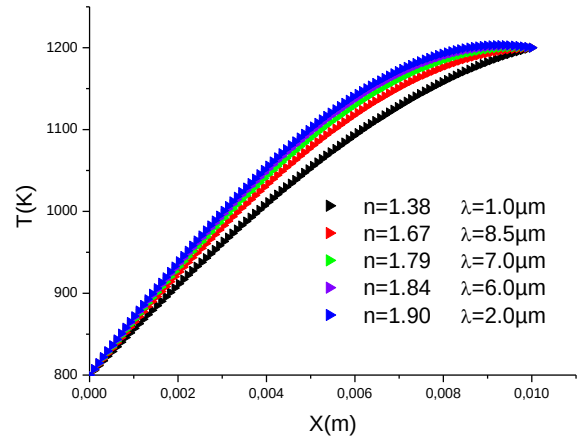


Figure 3: Profile of temperature for different values of refractive index

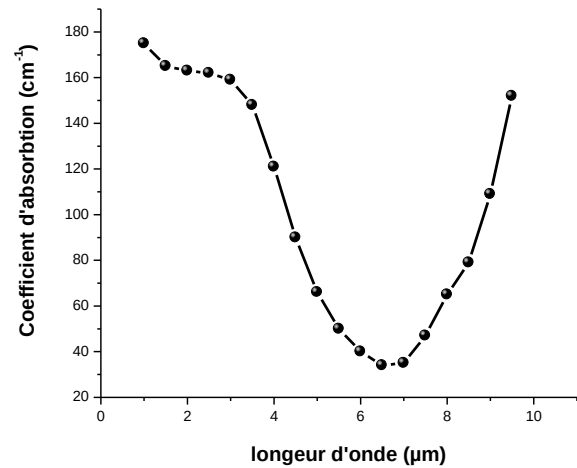


Figure 4: (a) variation of absorbance coefficient versus wavelength,

## Conclusion

The exact contribution of thermal radiation to total energy balance remains uncertain. Thus, little data on the radiative heat different parts of the stack are now available for normal working temperatures. This task is even harder than the materials of interest are often textured: porous ceramic cathode, porous cermet for the anode, metal alloy

for inter connectors, so having values different from those measured on homogeneous systems similar chemical composition. This ignorance leads to a failure to take account of this phenomenon. Accurate knowledge of these properties as a function of wavelength and temperature is currently the biggest obstacle to the fair provision of radiative heat transfer in electrodes and electrolyte of SOFC systems.

The results show that the effect of heat transfer by radiation on the spatial distribution of temperature is significant for an electrolyte ears. This is due to the semi-transparent nature of YSZ, which allows the transport of electromagnetic waves through the SOFC electrolyte and the electrolyte-electrode surfaces. For cons the opaque nature of SOFC electrodes led to neglect the effect of thermal radiation in the electrodes.

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