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An assessment on convective and radiative heat transfer modelling in tubular solid oxide fuel cells☆

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Abstract

Four models of convective and radiative heat transfer inside tubular solid oxide fuel cells are presented in this paper, all of them applicable to multidimensional simulations. The work is aimed at assessing if it is necessary to use a very detailed and complicated model to simulate heat transfer inside this kind of device and, for those cases when simple models can be used, the errors are estimated and compared to those of the more complex models.

For the convective heat transfer, two models are presented. One of them accounts for the variation of film coefficient as a function of local temperature and composition. This model gives a local value for the heat transfer coefficients and establishes the thermal entry length. The second model employs an average value of the transfer coefficient, which is applied to the whole length of the duct being studied. It is concluded that, unless there is a need to calculate local temperatures, a simple model can be used to evaluate the global performance of the cell with satisfactory accuracy.

For the radiation heat transfer, two models are presented again. One of them considers radial radiation exclusively and, thus, radiative exchange between adjacent cells is neglected. On the other hand, the second model accounts for radiation in all directions but increases substantially the complexity of the problem. For this case, it is concluded that deviations between both models are higher than for convection. Actually, using a simple model can lead to a not negligible underestimation of the temperature of the cell.
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1. Introduction

SOFCs are devices operating at temperatures ranging from 800 to 1050 °C for state of the art materials. Below this range, voltage losses due to ionic/electronic resistivity of materials increase noticeably as conductivity grows exponentially with temperature [1,2]. On the other hand, SOFCs cannot be operated continuously at a very high temperature, say 1100 °C, as this would lead to a considerable decrease in performance, probably caused by a thermal expansion mismatch between electrodes and electrolyte [3]. Therefore, the management of heat transfer inside a solid oxide fuel cell, either with tubular or planar technology, is essential in order to guarantee the reliability and long life demanded by the market to this sort of power generation devices. Fig. 1 shows the amount of energy released and/or consumed inside an SOFC fed with natural gas as a function of operating voltage and for different pressures.

Three reactions are considered to take place: hydrogen oxidation, Eq. (1), methane reforming, Eq. (2), and carbon monoxide shifting, Eq. (3).

$$H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O \quad (1)$$

$$CH_4 + H_2O \rightarrow 3H_2 + CO \quad (2)$$

$$CO + H_2O \rightarrow H_2 + CO_2 \quad (3)$$

The net amount of heat released according to Fig. 1 must be evacuated from inside the cell by the air mass flow, which is supplied well in excess with respect to the stoichiometry of Eq. (1). Thus, under normal operating conditions, only 15–20% of the air is used to oxidize the fuel.

This work deals with heat transfer characterization and modelling inside tubular SOFCs, particularly applied to a 1.5 m long Siemens Westinghouse cell with 100 W rated power for ambi-

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