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Micro-tubular, single-chamber solid oxide fuel cell (MT–SC-SOFC) stacks: Model development

N. Akhtar*

Department of Chemical Engineering and Chemistry, Technical University Eindhoven, 5600 MB Eindhoven, The Netherlands

ABSTRACT

Our previously developed numerical model has been used to study the flow, species and temperature distribution in a micro-tubular, single-chamber solid oxide fuel cell stack. The stack consists of three cells, spaced equally inside the gas-chamber. Two different configurations of the gas-chamber have been investigated, i.e., a bare gas-chamber and a porous material filled gas-chamber. The results show that the porous material filled gas-chamber is advantageous in improving the cell performance, as it forces the flow to pass through the cell, which improves mass transport via convection and enhances the reaction rate. The cell performance in the case of a bare gas-chamber follows in the following order: cell 1 > cell 2 > cell 3. However, the performance order is reversed for the porous gas-chamber case. This is due to enhanced flow which is forced to flow through the downstream cells, as we move along the gas-chamber length.

Keywords: Modelling; Micro-tubular; Single-chamber; Fuel cell; Porous material

1. Introduction

Single-chamber solid oxide fuel cells (SC-SOFCs) offer great advantages over conventional (dual-chamber) solid oxide fuel cells (SOFCs), such as, simplicity in design, compact/portable systems, seal-less configuration and thermally self-sustained electrochemical power sources (Yano et al., 2007; Chung et al., 2006). The SC-SOFCs are operated with a uniform mixture of fuel and oxidant that is passed through the entire cell, i.e., both the electrodes (anode and cathode) are exposed to the same gaseous feed. The driving force is generated through different electro-catalytic activity of each electrode, e.g., the anode preferentially oxidizes the fuel and the cathode electro-catalytically reduces the oxidant (Hao and Goodwin, 2007). Besides their many advantages, the SC-SOFCs are still not applicable for practical use because of their quite low electrical efficiencies and poor fuel utilization (Hao and Goodwin, 2008). The reported fuel utilization for a planar SC-SOFC is about 5%, which is much lower than a conventional (dual-chamber) SOFC, having a typical value in the range of 65–85% (Suzuki et al., 2005; Colpan et al., 2007). Recently, Akhtar et al. (2009) proposed a micro-tubular design which was operated under SC-SOFC conditions. Their results show that a micro-tubular design offers some advantages over planar cells, such as elimination of counter electrode (i.e., cross mixing and diffusion) effects, quick start-up/shut-down and thermally shock resistant capability. It has been reported that the fuel utilization in a micro-tubular SC-SOFC can reach up to 11% depending upon operating conditions, such as, temperature, pressure, flow rate, current density and the mixing ratio (Akhtar et al., 2009). Besides operating conditions, fuel type, cell's material, cell's fabrication technique and microstructural parameters such as electrode area ratio, porosity and the exchange current density could also change the fuel utilization (Akhtar et al., 2011). In order to increase the power output from an SC-SOFC, higher flow rates are usually used which result in a lower fuel-utilization (Akhtar et al., 2009). Increasing the flow rate improves the performance via enhanced forced convection which ultimately reduces the concentration related polarization. However, it results in a short residence time, therefore, significant portion of the fuel is exhausted through the cell without being consumed. There are other factors responsible for lowering the fuel utilization, such as, parasitic loss of fuel at the cathode, non-optimized geometry and a shorter cell area employed for the reaction. The increase in the electrochemically active area of an SC-SOFC for the sake of power, fuel

* Tel.: +31 040 2473683; fax: +31 040 2446653.
E-mail address: navtar433@yahoo.com

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