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# Improvement in solid oxide fuel cell performance through design modifications: An approach based on root cause analysis

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ABSTRACT

Performance of the solid oxide fuel cell (SOFC) is significantly affected by ohmic and concentration losses. The ohmic losses increase with reduction in macroscopic and microscopic contact area at the interfaces of different components. On the other hand, the concentration losses depend on the distribution of fuel and oxidant over the active area. Present work aims to investigate the performance improvement through design modifications obtained from root cause analysis. The influence of the interfacial resistance (ohmic), both, in terms of the external compression load, i.e., the interaction at the microscopic level and macroscopic contact area, is minimised. The effect of the uniformity of the flow distribution on the performance of the scaled up SOFC is analysed. To these objectives, the base configuration is modified and the influence of the different modifications on the electrochemical performance is studied. At 0.7 V, the performance is observed to be enhanced by 62% through minimization of the contact resistance between interconnect and electrode. It is further improved by 100% with an increase in the apparent contact area for a given cell. Additional 50% enhancement in performance is observed by achieving better uniformity in the flow distribution. Overall ~212% enhancement in the performance is achieved with a design, which consists of all the modifications in one cell.


## Introduction

Solid Oxide Fuel Cell (SOFC) has been identified as one of the promising candidates for alternate power generation because of its high efficiency, low emission of pollutants, and fuel flexibility [1–4]. In an SOFC, the ceramic electrolyte is placed between two porous electrodes, which are further sandwiched between a pair of bipolar plates that form the housing of the cell. The bipolar plates (interconnect) also act as current collectors, as well as pathways for fuel and oxidant.

Performance of SOFC has been a topic of interest in last few decades. Basu et al., have mainly focused on developing material for improved performance and have achieved current

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**Nomenclature**

| | |
|---|---|
| $A_r$ | cell active area, $cm^2$ |
| $\alpha$ | index for flow uniformity |
| $d_h$ | equivalent diameter of the channel, m |
| F | Faraday's constant, C $kmol^{-1}$ |
| $f$ | friction factor |
| $J_s$ | current density, A $cm^{-2}$ |
| $L$ | length of channel, m |
| $\lambda$ | stoichiometry factor |
| $\dot{m}$ | mass flow rate, kg $s^{-1}$ |
| M | molecular mass of fluid, kg $kmol^{-1}$ |
| $\mu$ | viscosity of fluid, kg $m^{-1}$ $s^{-1}$ |
| $n$ | moles of electron |
| $n_c$ | number of channels |
| P | pressure, MPa |
| $P_A$ | total pressure drop between inlet and outlet of the manifold, Pa |
| $P_B$ | pressure at the outlet of the exit manifold, Pa |
| $P_{channel}$ | pressure drop in the channel, Pa |
| $P_{exit-manofold}$ | pressure drop in the channel exit, Pa |
| $Re_h$ | Reynolds number based on the equivalent diameter |
| $\rho$ | density of fluid, kg $m^{-3}$ |
| $u$ | velocity of fluid, m $s^{-1}$ |
| $\overline{u}$ | mean velocity for a particular flow rate, m $s^{-1}$ |
| $u_i$ | velocity magnitude at the inlet of the active area region, m $s^{-1}$ |
| $\overline{v}$ | average velocity of fluid, m $s^{-1}$ |

*Abbreviations*

| | |
|---|---|
| ASR | area specific resistance, $\Omega$ $cm^2$ |
| CFD | computational fluid dynamics |
| LSM | lanthanum strontium manganite |
| SOFC | solid oxide fuel cell |
| 8YSZ | 8 mol% Yttria stabilized Zirconia |

density as high as ~1.4 A $cm^{-2}$ at 0.7 V [5] in a coupon cell. However, a sharp decrease in the performance is, observed in scaled up cells, which is detrimental to commercial applications [6,7]. The increase in the ohmic and mass transport losses is identified as the primary contributor towards the fall in performance of scaled up SOFC [8].

In case of laboratory scale cell, it is easy to maintain sufficient and uniform compression force to achieve minimum and homogeneous contact resistance. On the other hand, with the increase in the active area, the ohmic loss increases due to improper contacts at the interfaces of the electrodes and interconnects. The ohmic loss arising from the microscopic scale due to inherent roughness of every surface can be minimised by applying uniformly distributed adequate mechanical load [9,10].

Concentration or mass transport polarisation depends on the availability of reactants on the active area, which in turn is affected by the distribution of fuel and oxidant [11]. A variety of flow geometries have been explored to study the effect of reactant distribution across the active area of cells [12–27]. Huang et al. have reported that the performance of a particular flow field is strongly linked to the Reynolds number within the flow domain. They also used guide-vanes to improve flow homogeneity and achieved performance increment up to 11% [12]. Along with velocity, the flow-path also determines the spatial performance observed across the cell active area. In this respect, significant local voltage deviation has been identified by Metzger, especially at low hydrogen concentration levels of ~2% [13]. Using an electrochemical model, Moussa et al. demonstrated that increase in the cell length in parallel type flow field improves hydrogen utilization; however, the performance is lowered [14]. The cross-sectional shape of channels has also been deemed as an important parameter, which can be varied to enhance the performance [15]. The effect of inlet/outlet position and the influence of the flow configuration (co, counter, and cross) have also been studied in detail [19–21]. Depending on the nature of the parameter being explored, researchers have developed two and three-dimensional models possessing various degrees of complexity. Three-dimensional modelling have focused primarily on obtaining the distribution of the electrical potential, temperature, concentration of the chemical species and thermal stresses within the cell during operation [19,22–24]. With the aid of these models, it is possible to analyse various flow configurations. It has been observed that, in most of the reported modelling work, the role of active area has been pivotal as far as the domain of interest is concerned [25–27]; however, the flow occurring in the manifold has received very little attention.

The objective of the present work is to investigate the influence of the interfacial resistance (ohmic) in terms of both the external compression load and macroscopic contact area, and the uniformity of the flow distribution on the performance for a given SOFC other than coupon cells. To that end, the SOFC configuration proposed by Blum et al. [28,29], is considered as the base design for present investigation on which recommended improvements stated in our previous work [8], are implemented sequentially. The flow distribution is numerically simulated to understand the effect of the manifold design on the flow distribution and the proposed manifold configuration is fabricated for experimental validation. The detailed methodology of the experiments and simulation are discussed in the next section.

## Methodology

The base configuration as proposed by Blum et al., consists of a cell placed between mesh type flow field at the anode and straight channels at the cathode side (Fig. 1) [28]. At each of the development steps, a modified SOFC is fabricated by incorporating an improved feature in the design used during preceding study. At the first step, the contact resistances between the electrodes and interconnect are minimized through the enhancement in the contact area at microscopic scale with appropriate compression load. Thereafter in the second step, the contact area at macroscopic scale is enhanced by modifying the flow geometry. Finally, to diminish the losses arising