In-Situ Temperature Sensing of SOFC during Anode Reduction and Cell Operations using Multi-Junction Thermocouple Network

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Understanding in-situ temperature distribution of a SOFC stack while in operation is very important for its performance and degradation studies. The available efforts in literature are incapable of measuring the temperature from electrodes. The proposed multi-junction thermocouple network, which requires only 2N thermo-elements for N2 measuring points, can measure the temperature directly from electrodes. A thermocouple network having 9 temperature measuring points (about 10mm pitch) was fabricated by spot welding of K-type thermocouple wires (ϕ 0.25mm) to measure the cathode temperature of 50mmx50mm, NextCell-5 test cell during an anode reduction process and during a normal cell operation while the air/fuel ratio varies. The gas temperature was measured simultaneously using a commercial K-type thermocouple from 5 mm adjacent to the cathode. The monitored cathode temperature via the in-situ sensors was directly correlated with the cell's OCV whilst the commercial thermocouple 5mm adjacent to the electrode showed a dull change to them.

Introduction

Temperature driven performance degradations is one of the major problems that impedes the successful commercialisation of Solid Oxide Fuel Cell (SOFC) technology. Thermal cycling at high temperature (usually in the range from 600^0C - 900^0C) and uneven temperature distribution in SOFC stack leads to severe mechanical failures such as, delamination and cracking of cell components, promoting premature degradation. Attempts were made to model and predict such failures based on estimated temperature distribution over cell (1)-(4). However, in order to gain a comprehensive understanding of the causes of such phenomena and of other degradation mechanisms as well as to better understand the performance characteristics, it's is highly beneficial to know the actual temperature distribution within a SOFC stack while it is in normal operation.

Prevalent methods found in literature on understanding SOFC stacks' temperature distribution can be broadly classified into two domains: (a) modelling and simulation (b) experimental measurements. Among them, there are a decent number of publications found in literature pertaining to modelling and simulation done using physical modelling techniques (5)-(12) and Artificial Neural Networks (ANN) (13)-(16). However, the number of literature pertaining to experimental temperature measurements is comparatively very limited.

Experimental temperature measurements, if carried out successfully, have unique advantages over temperature simulations. Due to very complicated electro-chemical and thermo-electrical behavior of a SOFC stack, all the physical models rely on some level of simplification assumptions. However, such simplifications may not necessarily exist in a real SOFC stack and hence, the simulation may divert from real behavior of the stack weakening the strength of simulated results to represent actual temperature distribution. In contrast, an ANN model of a SOFC stack does not require a functional model of the stack; it correlates the inputs and outputs based on training data with no concern over electro-chemical or thermo-electric behavior of the stack. Hence, ANN models are free from problems created by simplification assumptions. However, the accuracy of an ANN model relies greatly on the accuracy of the experimental data set used to train the model; experimental data are still required. Further, detrimental evolutions in temperature profile that are triggered by changes in operating conditions such as current, flow rate, etc17(17) are not easily detectable or predictable with any type of simulations. More comprehensive way of detecting such phenomenon is temperature monitoring. Therefore, temperature monitoring has been understood as a prime necessity and different researchers have attempted it in different ways.

Extensive investigation of published researches on temperature measurement revealed their strengths and limitations. Morel et al18(18) used electrochemical impedance spectroscopy (EIS) to in-situ evaluate the temperature gradient along a cell. However, this method cannot measure localised temperature. In a study by Saunders and Davy19(19) to investigate the steam-methane reforming process within direct internal reforming SOFC (DIR_SOFC), a commercial IR thermometer (Omega Vanzetti Model No. 1562) was used to measure point temperature at 10mm separation on the anode along the center line of 100mm x 50mm cell. The cell was placed inside an oven having a transparent window to make the cell visible to thermometer. However, this approach is not feasible with multi-cell stacks where inner cells are not exposed. Contact thermometry appears more promising than non-contact thermometry for stack temperature measurements. Razbani et al(1420) inserted 5 K-type thermocouples (ϕ 0.5mm) inside the middle cell of a 5-cell (110mm x 86mm) short stack to measure the temperature at the four corners and at the middle. Further, they state that researchers at Jülich GmbH were able to measure the temperature profile of a 5kW SOFC stack by inserting 36 thermocouples. Guan et al (21) and Bedogni et al(2122) have also used the method of inserting thermocouples to measure gas flow temperature at inlet and outlet of a stack.

Thermocouple thermometry appears to be promising for stack temperature monitoring. However, none of the above approaches could measure cell level temperature distribution, which is more important than mere gas channel temperature. Further, the spatial resolution of measurement was also highly restricted. Embedding a large number of thermocouples to a stack to enhance spatial resolution accompanies a mammoth technical challenge and introduces a greater level of disturbances to stack’s operation. The proposed multi-junction thermocouple technology could overcome these barriers in a greater extent while preserving the merits of thermocouple thermometry and measures temperature distribution on the cell. A successful application of multi-junction thermocouple network for cell temperature measurement under extremely rigorous thermal condition is presented and discussed in the proceeding sections.

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