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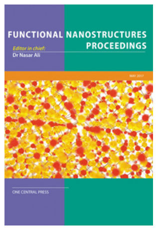

Cathode temperature distribution of a solid oxide fuel cell measured via a thin film multi-junction thermocouple array

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ABSTRACT

The electrode temperature distribution of a solid oxide fuel cell (SOFC) is an important parameter to consider for gaining better insight into the cell performance and its temperature-related degradations. The present efforts of measuring gas channel temperatures do not accurately reveal the cell surface temperature distribution. Therefore, the authors previously proposed a cell-integrated multi-junction thermocouple array to measure the electrode temperature distribution from an SOFC. In this work, the authors sputter deposited a thin film thermocouple array (K-type), having four sensing points, on the cathode of a commercial solid oxide fuel cell (SOFC, NextCell-5) and, the temperature of the cell was measured under varying fuel compositions of hydrogen and nitrogen. Two commercial Ktype thermocouples were also fixed in adjacency onto the cathode for comparison purposes. The thin film thermocouple array showed excellent temperature correlation with the fuel flow rate and with the open circuit voltage (OCV) of the cell while the commercial thermocouples showed a very dull response throughout the experiment. Further, cell temperature measurements via thin film thermocouple array enabled detecting potential fuel crossover to the cathode. This diagnostic approach is applied to commercial SOFCs, yielding insights into key degradation modes including gas-leakage caused temperature instability, its relation to the theoretical OCV and current output, and propagation of structural degradation. It is envisaged that the use of the thermocouple array technique will lead to major improvements in the design of electrochemical energy devices, like FC and batteries and their safety features.

I. INTRODUCTION

Premature degradation of cells and stacks is a significant challenge to ensure the longevity of SOFCs and to make them commercially viable technology to produce cleaner electricity. Among various factors affecting the premature degradation of SOFCs, thermal cycling at high temperatures (usually in a range from 600 °C to 900 °C) and uneven temperature distribution are two dominant factors. Severe mechanical failures such as formation and propagation of cracks and failures in gas sealing are typical temperature-driven failures at cell level, while failures of interconnect sealing is one of the stack level problems aggravated by uneven temperature distribution. Despite aforementioned problems of high operating temperature, some unique meritorious characteristics of SOFC such as fuel flexibility, high energy conversion efficiency, and liberation from the expensive catalyst at the anode, are inherited from the high operating temperature. Therefore, acquiring a comprehensive knowledge of the cell and stack level temperature distribution is vital to mitigate premature degradation while preserving the meritorious characteristics of SOFC. Further, in-situ temperature sensing enables to investigate the detrimental evolutions of temperature profiles induced due to changes in the operating conditions such as current, flow rate, etc. [1] thus, facilitating real-time health monitoring.

Thermocouple thermometry appears to be the most widely used technology [2]. Further, compared to the above techniques, thermocouples require relatively low stack modifications to accommodate them in an SOFC system. Thus, they can make a more realistic temperature measurement, which may be strictly comparable to the operating temperature of a cell/ stack under its normal operation. However, a principal drawback of thermocouples in SOFC temperature sensing is its inability to measure the electrode temperature with sufficiently high spatial resolution. To overcome this problem while preserving the meritorious characteristics of thermocouples, especially of thin film thermocouples, the authors proposed cell integrated thin film multi-junction arrays [3]. This sensor architecture can independently measure temperature from *{N}* number of sensing points with only *{N+1}* number of thermoelements whereas; sets of conventional thermocouples require *{2N}* number of thermoelements for *{N}* number of sensing points. Thus, a significant reduction in the number of thermoelements, e.g. *{N-1}*, can be archived via utilising the thermocouple array.

This report demonstrates and discusses the application of a thin film thermocouple array to measure the temperature distribution over the cathode of an SOFC under varying fuel compositions. Furthermore, a temperature-OCV correlation, an OCV-fuel composition correlation, and a detection of fuel crossover to cathode are discussed. We track for the first time the progression of rapid internal temperature distribution leading up to and during electrochemical activities. This new approach allows us to observe the effects of gas leakage, venting and elevated temperature on the surface of internal layers of commercial SOFCs and to evaluate the influence of SOFC operational engineering on cells safety and performance.

II. EXPERIMENTAL

From among different high-temperature thermocouple materials, K-type materials (alumel - Ni:Al:Mn:Si 95:2:2:1 by wt. and chromel - Ni:Cr 90:10 by wt.) were chosen for thermoelements as it has sufficiently broader range to cover the entire operating temperature range of a typical SOFC (from room temperature to about 800 °C) [4].

A thermocouple array having four sensing points, hence five thermoelements only, was sputter deposited on the cathode of a 50 mm × 50 mm commercial SOFC (NextCell-5) using Quorum QT 150TS sputter coater [4].

Table 1 Volumetric flow rates.

Flow Region	Flow rates (ml /min) H_2 / N_2	Time (min) (Approx.)
A	100 / 150	10
B	150 / 100	10
C	200 / 50	10
D	250 / 0	10
E	200 / 50	10
F	150 / 100	10
G	100 / 150	10

The furnace of SOFC test rig was heated at 500 °C per hour up to 750 °C. Nitrogen was supplied to the anode chamber at a rate of 300 ml/min since the beginning of the heating process to expel air inside the anode chamber to facilitate anode reduction. Hydrogen was introduced at a volumetric rate of 15 ml/min from approximately 650 °C to start the reduction process and continuously supplied for about 30 min (at 750 °C cell temperature) for the anode reduction to complete. After the reduction process, a mixture of hydrogen and nitrogen, having the total volumetric flow rate of 250 ml/min, was supplied at varying volumetric compositions as listed in T 1.

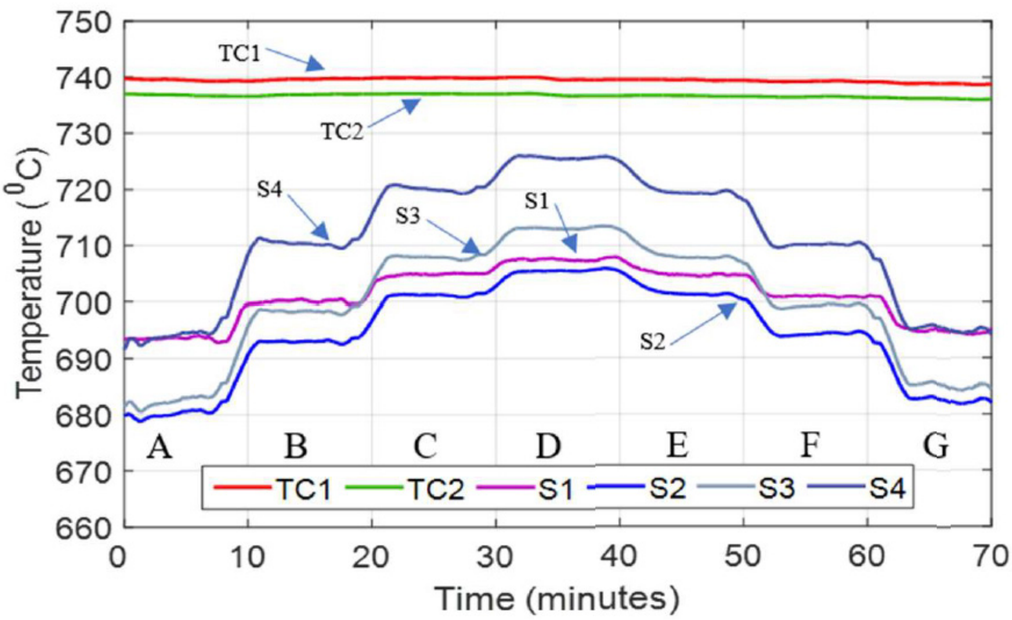

Figure 1 Temperature response to varying flow rates.

Fig. 1 shows the temperature measured by the thin film thermocouple array and the two commercial thermocouples under varying fuel compositions. Regions marked by letters from A to G are the flow configurations given in T 1. Since the thermocouples were placed in the cathode chamber and the cathode was not provided with any air supply, no cooling effect can be expected on commercial thermocouples. Thus, it can be speculated that the observed temperature discrepancy is likely to be an actual temperature gradient present across the furnace. The presence of a temperature gradient between the two commercial thermocouples themselves (TC1 and TC2) supports this argument. Throughout the experiment, the cell temperatures measured by the thin film thermocouple array were noticeably lower than the temperature measured by the commercial thermocouples, which were not more than 3 mm from the cathode. This behaviour can be ascribed to a cooling effect that took place on the cell due to the impinging of non-preheated gas on the cell. Since the cell was not active, no net heat generation could have taken place on the cell. Thus, the cooling effect predominantly determines the cell temperature distribution.

Cell temperature measured by the thin film thermocouple array shows that cell cooling due to chilled gasses and fuel leakages can introduce significant temperature gradients across the cell, which may in turn potentially lead to cell failure in long term operation due to induction of high level thermal stresses which is undesirable.

The reversibly proportional correlation between the OCV and the cell temperature, as suggested by the Nernst equation could deserve further experimental investigation.

III. REFERENCES

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