Breakdown of losses for SOFCs: a simplified approach

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1. Introduction

Individual contributions to the total cell resistance of Ni–based anode supported thin electrolyte cells with LSM-based composite cathodes, comprising ohmic, concentration polarisation (gas conversion and diffusion) and electrode polarisations, can be obtained by deconvolution of the full cell impedance spectra, using a complex non-linear least squares (CNLS) approximation to a R(RQ)(RQ)(RQ)(RQ)(RQ) equivalent circuit (Figure 1)[1,2].

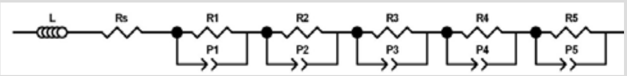

Figure 1: Schematic of the equivalent circuit used to model impedance spectra of Ni-based anode supported cells with LSM-based composite cathodes, where R is a resistance, L is an inductance and P (or Q) corresponds to a constant phase element (CPE).

This procedure is crucial to assess the validity of the model and obtain detailed behaviour of each electrode, but too complex and time consuming for practical use as a quick diagnostic tool.

The present work shows that spectra obtained for various cells, manufactured using different techniques, can be consistently deconvoluted using a simpler approach, where relative perfection (macroscopic) and microstructural differences can be picked up.

2. Full cell spectra deconvolution

Record impedance spectra at various temperatures and one sided gas-changes (anode or cathode)

Correct all spectra for inductance

Determine equivalent circuit and power exponent (n-values) for each process

Symmetric cell data, ADIS[3], etc…

Full model branch:

- Determine parameters for concentration polarisation (CP) arcs – diffusion and gas conversion
  Use the high temperature spectra, where electrode polarisations are minimised
- CNLS: fit remaining spectra with fixed CP parameters and n-values
- CNLS: re-fit all spectra keeping n-value constraints
- Determine and compare the R and f_{summit} behaviour of each process
- Is the chosen model and general behaviour suitable and meaningful?
  - NO → Re-assess model or determine different set of constraints
  - YES →

Accurate breakdown
- E_a for each process;
- Behaviour of each process under different operating conditions;
- Time consuming, several iterations;

Simplified model branch:

- Chose spectra recorded at conditions where one of the CP contributing processes is negligible
  Example: at 750 °C, air on cathode and ~20 % H_2O content in the fuel gas minimises diffusion contributions, but gas conversion arc still possible to deconvolute
- CNLS fit spectra recorded under those conditions with simplified equivalent circuit
  Keep the pre-determined n-value constraints for each process
- Is the simplified model valid?
  Use post-mortem microscopy and comparison with full model results
  - NO → Re-assess simplification and chosen recording conditions for the spectra used
  - YES →

Approximate breakdown
- Quick feed-back to production
- Useful diagnostic tool

3. Validation of the simplified model

- The use of the simplified equivalent circuit gives a breakdown of contributions similar to that obtained using the full model for the chosen operating conditions. This is exemplified for cell A in Figure 2.

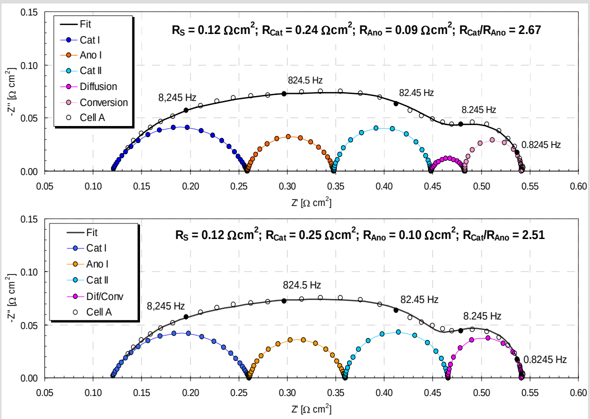

Figure 2: Nyquist plots and corresponding CNLS fits of inductance corrected cell A spectrum recorded at 750 °C and 83 % H_2 + 17 % H_2O as fuel gas and air as the cathode gas using both the full (top) and simplified model (bottom). Cell A: Ni/ScYSZ anode, ScYSZ electrolyte and LSM based composite cathode.

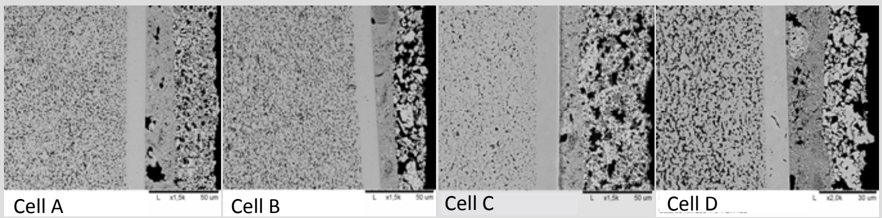

Figure 3: Cross-sections of four tested anode supported cells with Ni-based anodes and LSM composite cathodes.

- Post-mortem microstructural analysis (Figure 3) performed on tested cells also reveals that the resistance values obtained are consistent with the expected differences in electrode performance (Figure 1 and 4):

  - In view of the amount and size of defects (agglomerates and holes) that can be seen in the cathode layers, the lowest contribution was expected for cell B;
  - High cathode contributions expected for cell A, C and D. Such defects on the cathode can have detrimental impact on both the R_p and the R_s of a working cell[1]. Due to the presence of large amounts of both type of defects, cell A should exhibit the highest contribution;
  - Cell C should exhibit the highest anode contribution, due to a comparatively denser half-cell. That impact is confirm on both the anode and concentration polarisation arcs;

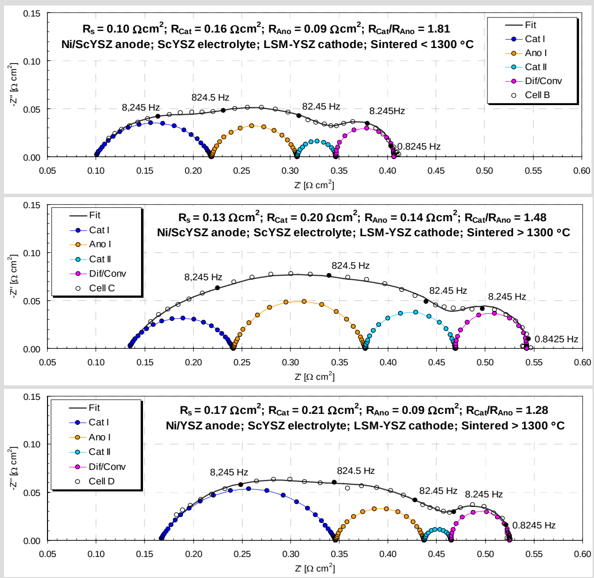

Figure 4: Nyquist plots and corresponding CNLS fits of inductance corrected spectra for cells B-D recorded at 750 °C and 83 % H_2 + 17 % H_2O as fuel gas and air as the cathode gas using the simplified model.

4. Conclusion

The simplified approach to the breakdown of losses for SOFCs has proven to be a valid method, picking up on expected performance differences between different cells and electrodes. When necessary care is taken, this approach provides a diagnostic tool that can be used during testing , provide quick feed-back to production teams and help guide post-mortem analysis.

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References:
[1] R. Barford, M. Mogensen, T. Klemensø, A. Hagen, Y-L Liu and P.V. Hendriksen , *J. Electrochem. Soc.*, 154 (2007), B371;
[2] T. Ramos, J. Hjelm, M. Wandel, A. Hagen, and M. Mogensen, *ECS Transactions*, Vol. 13, (2008) 235;
[3] S.H. Jensen, A. Hauch, P.V. Hendriksen, M. Mogensen, N. Bonanos, T. Jacobsen, *J. Electrochem. Soc.*, 154 (2007), B1325.