Nickel Coarsening Study on SOFCs Operated at High Fuel Utilizations

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Motivation

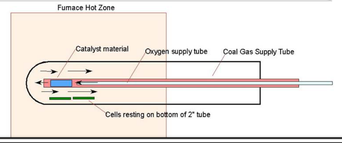
❑ **High fuel utilization conditions are likely to exist towards the cell exit.**
❑ **Nickel in catalysts and SOFC anodes is susceptible to coarsening when exposed to high steam concentration at high temperatures.**
❑ **Coarsening would lead to the SOFC aging because the exchange current density is directly related to the nickel particle size.**

Objective

❑**Systematically evaluate performance of Ni/YSZ anodes in both anode- and YSZ electrolyte-supported cells in synthetic reformate at high fuel utilizations and determine whether high fuel utilization leads to accelerated performance losses for SOFCs.**

Experimental

8 button cells installed per box furnace, with individual gas flow controls; 6 furnaces

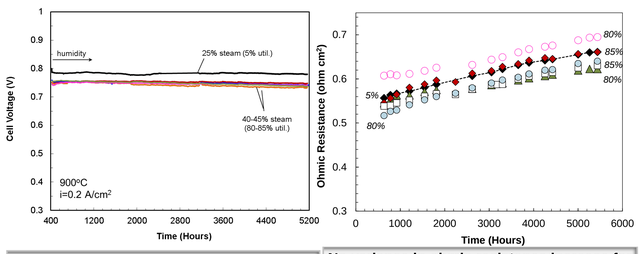


Coupon test configuration

Approach

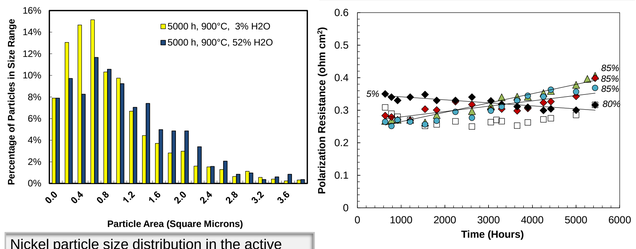
❑ **Multiple in-house and commercially prepared Ni/YSZ anode-supported cells with LSM cathodes were tested for over 4,000 hours at 800 and 900ºC at humidity levels corresponding to 80-90% fuel utilization.**
❑ **Multiple commercially available YSZ electrolyte-supported cells with Ni/YSZ anodes and LSM cathodes were tested for over 5,000 hours at 900ºC to eliminate glass seal aging effects.**
❑**Separately, to eliminate glass seal aging effects, multiple Ni/YSZ coupons (pre-sintered Ni/YSZ anode supports with Ni/YSZ active anodes and YSZ electrolytes) were exposed to high humidity levels corresponding to 90% fuel utilization at 700, 800, 900, and 1000ºC in a controlled gas-tight environment without polarization.**
❑ **Post-test characterization was performed using SEM/EDS mapping.**
❑ **The maps were analyzed using Image J™ software and statistical analysis to evaluate the statistical significance of the differences in average particle sizes.**

5,000 h Test at 900ºC at High Fuel Utilization: Electrolyte-Supported Cells with Ni/YSZ Anodes



Cell performance at different humidity levels

No variance in ohmic resistance increase for 80-85 % fuel utilization vs 5% fuel utilization.



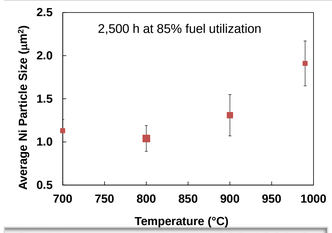
Nickel particle size distribution in the active anode after 5,000 exposure to 3 and 52% of steam at 900ºC. 52% steam corresponds to 90% fuel utilization.

Polarization resistance increases faster for cells operated at 80-85% fuel utilization.

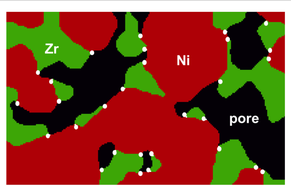
- High humidity levels corresponding to 80-85% fuel utilization at 900ºC led to accelerated degradation of YSZ electrolyte-supported cells during over 5,000 hour tests.
- Impedance spectroscopy revealed changes in both polarization and ohmic losses.
- Increases in ohmic losses were independent of fuel gas humidity (25-45% H_2O).
- Changes in electrodic resistance were mostly observed for cells operated with >~40% fuel humidity and were insignificant for cells tested at lower fuel humidity, indicating that such changes were related to Ni/YSZ anodes.
- Degradation was attributed to Ni particle growth in the active anode, as also confirmed independently using Ni/YSZ coupons.

Nickel Particle Growth Model for SOFC Anodes

At least 10 elemental maps of active anode per condition were collected and analyzed.

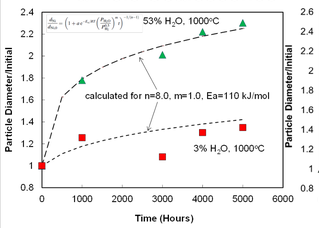


Significant coarsening at 900-1000ºC.

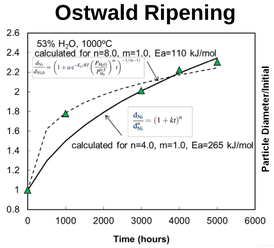


Number of triple points (active sites) was calculated.

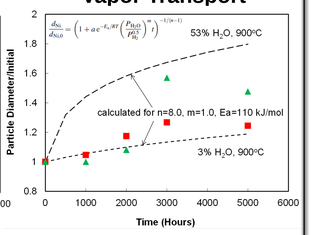
Particle Coalescence



Ostwald Ripening



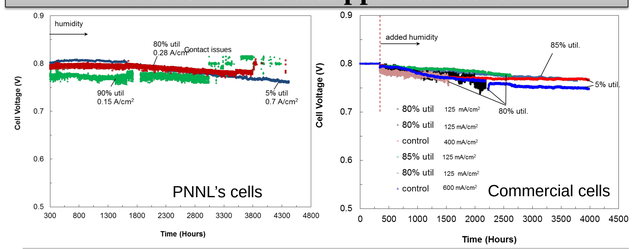
Vapor Transport



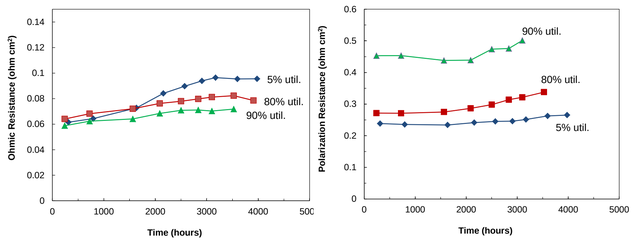
Conclusions

❑ **Ni coarsening mechanism is a "hybrid" between particle coalescence and Ostwald ripening**
  ❑ **Surface complex formation in high steam leads to enhanced mobility**
  ❑ **Migration as single complexes or clusters, not as particles**
❑ **Approach shows promise for predicting long-term aging of SOFC anodes**
❑ **Expect accelerated anode aging at high pressure.**

4,000 h Tests at 800ºC at High Fuel Utilization: Ni/YSZ Anode-Supported Cells



Cell voltage of anode-supported cells at fixed current densities tested in synthetic reformate at low, 5% (control), and high, 80-90%, fuel utilizations.



Ohmic resistances increased independent of fuel utilization.

Polarization resistances increased after ~2,000 h of operating at high fuel util.

- In dc tests for over 4,000 hours, no accelerated degradation was apparent observed at high humidity levels (high fuel utilizations) compared to control cells operated on equilibrated reformate.
- However, impedance spectroscopy analysis discriminated more rapid changes in polarization losses of anodes operated at elevated humidity after > 2,000 hours.
- Similar results were obtained using commercially available cells from different manufacturers.
- Higher electrodic losses were attributed to Ni particle coarsening in the active anode, as verified by SEM analysis.

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ACKNOWLEDGEMENTS

The authors wish to thank B. White for valuable discussions. We also thank Chris Coyle and Jared Templeton for their assistance with cell fabricating and assembling.

This work was funded by the U.S. Department of Energy's Solid-State Energy Conversion Alliance (SECA) Core Technology Program.