The Effect of Operational Temperature on the Performance and Durability of Solid Oxide Fuel Cells and Solid Oxide Electrolysis Cells

Yueying Fan[1,2]; Jian Liu[1]; Bo Guan[1,2]; Richard Pineault[1]; Richard Addis[1,2]; Harry Abernathy[1]; Thomas Kalapos[1,2]
[1]National Energy Technology Laboratory, 3610 Collins Ferry Road, Morgantown, WV 26505, USA; [2]NETL Support Contractor, 3610 Collins Ferry Road, Morgantown, WV 26505, USA

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Introduction

- Solid oxide fuel cells (SOFC) and solid oxide electrolysis cells (SOEC) have received great interest due to their highly effective reversibility as power generation and H_2 production systems without releasing any greenhouse gases into environment.
- The Lanthanum strontium cobalt ferrite (LSCF) electrode exhibits a higher structural and performance stability under both SOFC and SOEC operation due to its mixed ionic and electronic conductivity, and there is no immediate delamination taking place during the initial several hundred hours operation.
- However, the LSCF-based air electrode still presents significant performance degradation (with the increased resistance) over the prolonged operation, such as over 1,000 hours of operation under SOFC and SOEC modes. The influencing factors for the cell's performance and stability need to be optimized to improve the power generation for SOFC and H_2 production for SOEC.
- The effects of operational temperature on the performance and durability for both SOFC and SOEC are electrochemical operation dependent. The performance and performance durability for over 1,000 h were currently studied under optimized operational temperatures for reversible SOFC/SOEC.

1. Sun-Dong Kim, Doo-Won Seo, Arun Kumar Dorai and Sang-Kuk Woo, "The effect of gas compositions on the performance and durability of solid oxide electrolysis cells", international Journal of Hydrogen Energy 38 (2013) 6569-6576.
2. Jiming Yuan, Zeming Li, Benfeng Yuan, Guoping Xiao, Tao Li and Jianqiang Wang, "Optimization of high-temperature electrolysis system for hydrogen production considering high-temperature degradation", Energies 2023, 16, 2616.

Purpose of the Study

- Study the effect of operational temperature on the performance and performance degradation for SOFC and SOEC.
- Optimize the operational temperature as one of the influence factors to improve the power generation for SOFC and H_2 production for SOEC.
- Study reversible SOFC/SOEC under optimized operational temperatures.

Experimental Methods

Commercially available Nexceris cells were used in this study:

- Air electrode: LSCF-SDC
- Electrolyte: YSZ
- Fuel electrode: Ni-YSZ

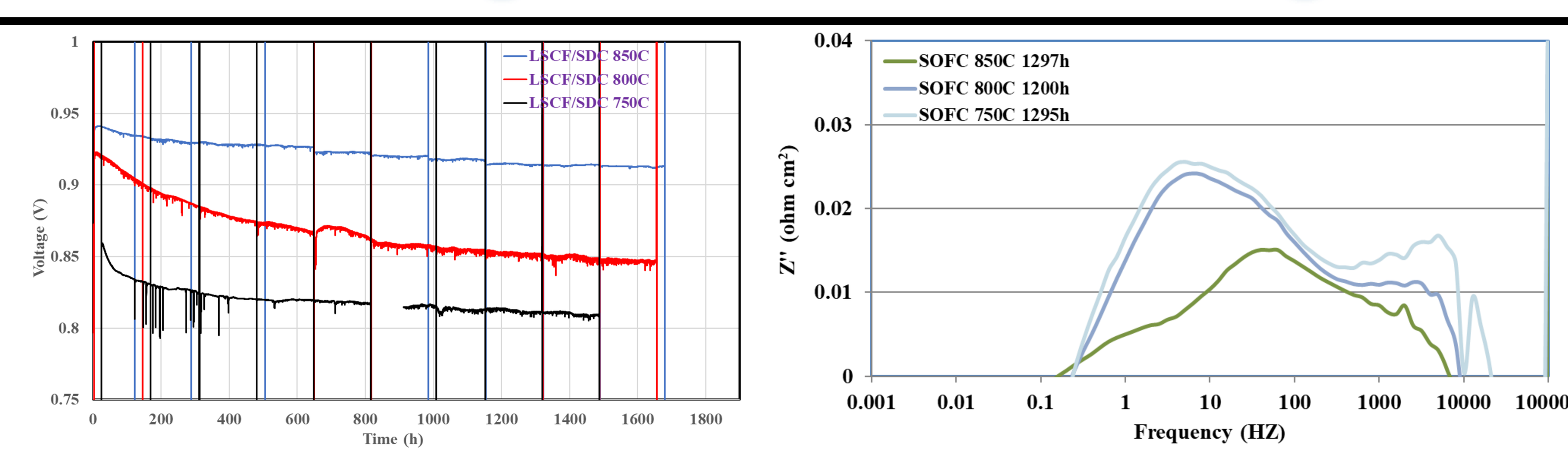
SOFC and SOEC performance stability tests:

- Temperature: 750 °C, 800 °C or 850 °C
- Current density: 0.5 A/cm²
- Steam concentration in H_2 electrode for SOEC: 50%

Reversible SOFC/SOEC studies:

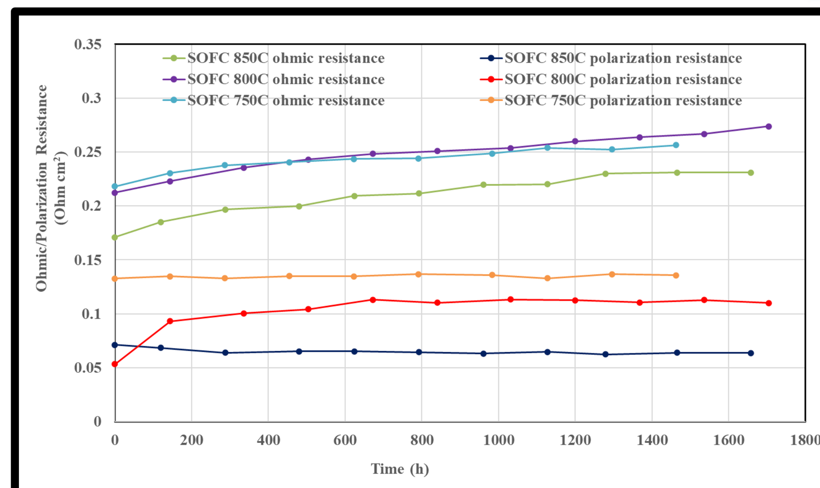
- Operation switch mode

Stability Tests of LSCF/SDC Cells Under Different Temperatures for SOFC Operation



- The SOFC performance of the LSCF/SDC cell showed much better performance under higher operation temperatures. The performance may degrade severely under higher temperatures for over 10,000 h. The trade-off between the performance and durability should be considered.
- The SOFC performance degradation rate: 37.3 mV/1,000 h @ 750 °C; 42.7 mV/1,000 h @ 800 °C; and 15.2 mV/1,000 h @ 850 °C. SOFC performance degraded the least under higher temperatures for the first 1,500 h.
- The impedance of both air electrode and H_2 electrode was significantly decreased at higher temperatures for SOFC operation.

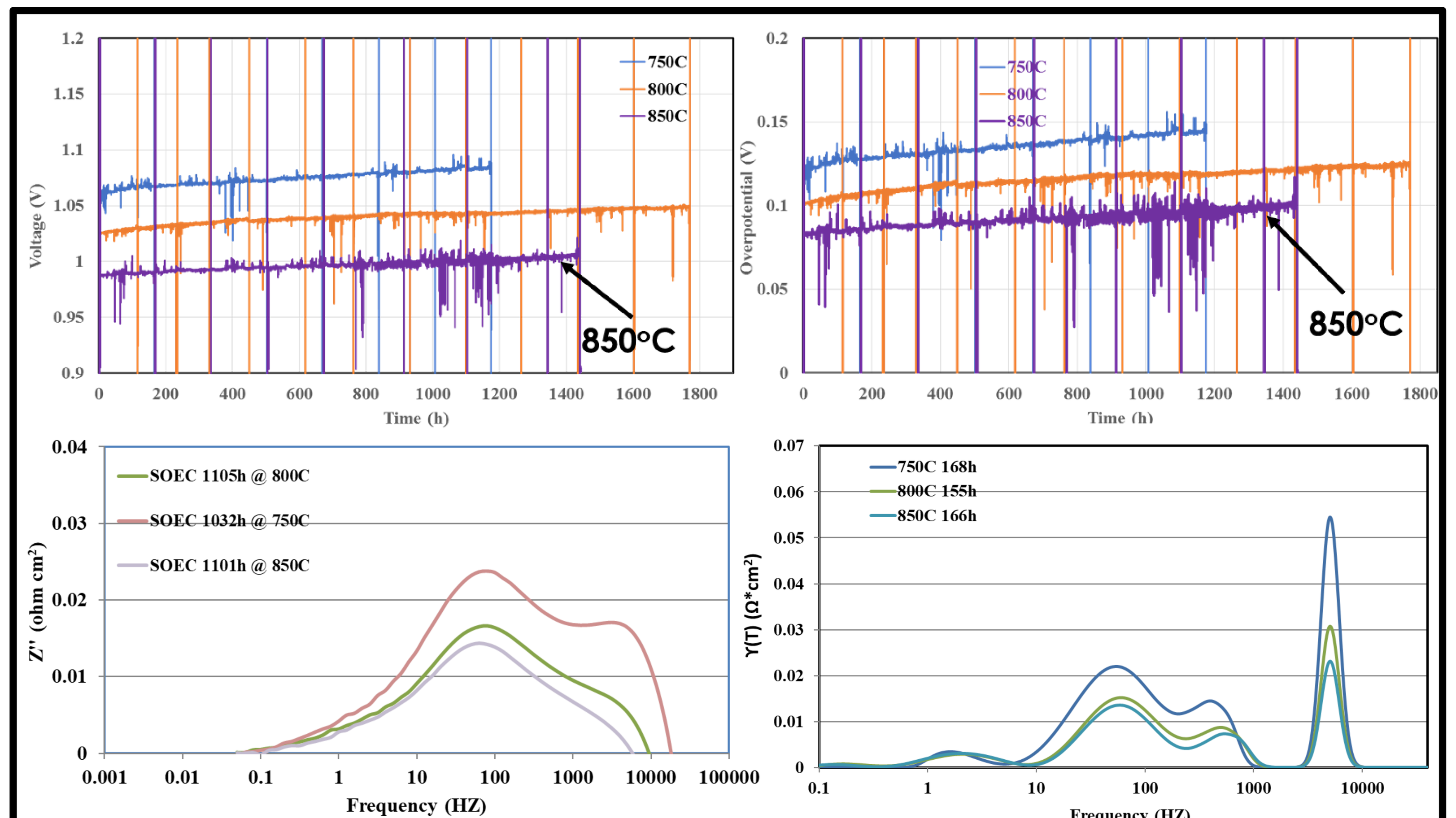
EIS Studies of LSCF/SDC Cell Under SOFC Operation



Operational Temperature (°C)	Ohmic Resistance Increase Rate (mΩ cm²/1,000 h)	Polarization Resistance Increase Rate (mΩ cm²/1,000 h)
750	26.3	2.1
800	43	20.8
850	36.2	-4.6

- Ohmic/polarization resistance was significantly lower for the cell operated under higher temperatures for SOFC operation. Therefore, the LSCF/SDC cells need relatively higher temperature to be activated for SOFC operation.
- Ohmic resistance increased the most under higher temperature for long-term SOFC operation, which could be caused by the formation of non-conductive nanomaterials or nano-crack.
- However, polarization resistance was apparently decreased for long-term SOFC operation under higher temperatures @ 850 °C.
- Polarization resistance change may dominate the overall performance degradation for long-term SOFC operation even though ohmic resistance increased the most under higher temperatures, since the cell's overall performance degraded the least under higher temperatures.

Stability Tests of LSCF/SDC Cells Under Different Temperatures for SOEC



- Test Conditions: 50% steam (H_2/H_2O ratio: 1:1) and 0.5 A/cm²
- OCV: 0.9395 @ 750 °C; OCV: 0.9242V @ 800 °C; OCV: 0.9046 V @ 850 °C
- Operational temperature also played an important role for the cell's performance and performance degradation under SOEC.
- The LSCF/SDC cell showed better SOEC performance under higher temperatures.
- Performance degradation rate: 18.4 mV/1,000 h @ 750 °C; 14.1 mV/1,000 h @ 800 °C; 12.7mV/1000 h @ 850 °C. SOEC performance degradation rate was less under higher temperatures for the first 1,500 h. The cell's SOEC performance may degrade severely under higher temperatures. The trade-off between performance and performance degradation needs to be considered too.

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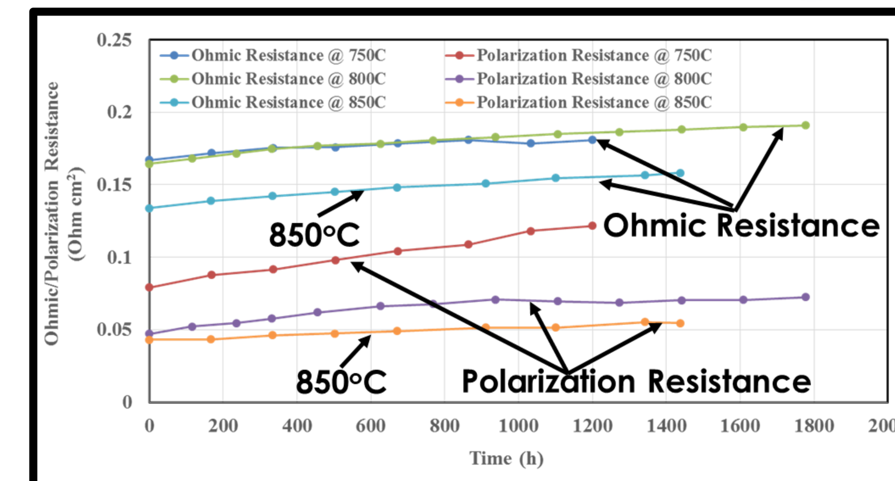
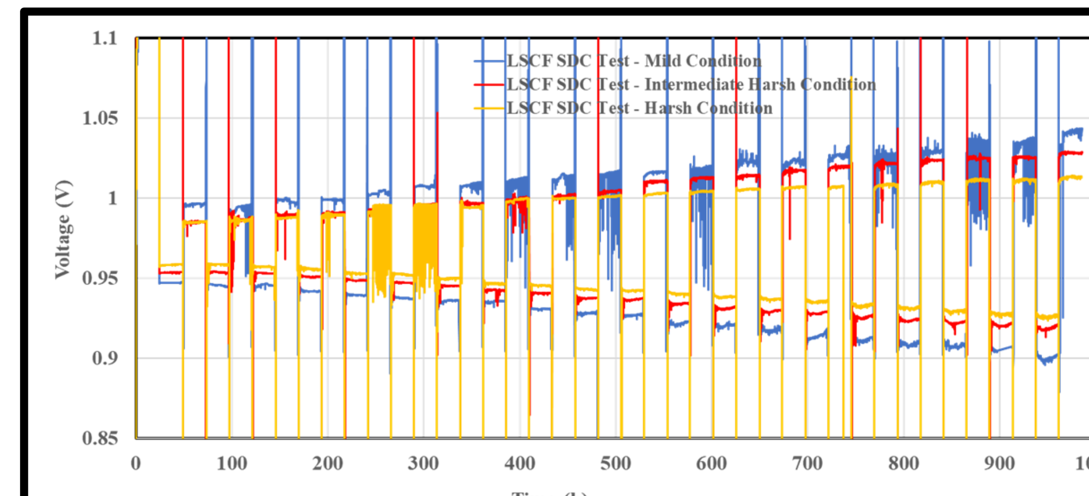
EIS Studies of LSCF/SDC Cell Under SOEC Operation



Operational Temperature (°C)	Ohmic Resistance Increase Rate (mΩ cm²/1,000 h)	Polarization Resistance Increase Rate (mΩ cm²/1,000 h)
750	11.6	35
800	15	14
850	17.1	8

- Ohmic/polarization resistance was significantly lower for the cell operated under SOEC at 850 °C. Therefore, the LSCF/SDC cells need relatively higher temperature to be activated for SOEC operation too.
- Ohmic resistance increased the most under higher temperatures which could be caused by the formation of non-conductive nanomaterial or nano-crack in the interface between electrolyte and electrode.
- However, the polarization resistance increase rate was apparently less for the cell operated under higher temperatures.
- Polarization resistance change may contribute more on the performance degradation than the ohmic resistance, since the cell's performance degraded less under higher temperatures.

Stability Tests of LSCF/SDC Cells Under Reversible SOFC/SOEC



- Mild operational mode switch protocol: 45 min of OCV stabilization after operational mode switch without current load.
- Intermedium harsh operational mode switch protocol: No OCV stabilization waiting time after operational mode switch after unloading the current for the cell.
- Harsh operational mode switch protocol: No OCV stabilization waiting time after operational mode switch with current loading on.

- Test Conditions: 850 °C and 0.5 A/cm² for both SOFC and SOEC; 50% steam and 50% H_2 for SOEC.
- Performance degradation rate: 2.25 mV/cycle under mild conditions.
- Performance degradation rate: 1.61 mV/cycle under intermediate harsh conditions.
- Performance degradation rate: 1.55 mV/cycle under harsh conditions.
- The cell's performance degradation rate did not show much difference under the three cases of switch modes.
- There is no need for unloading current and waiting for stabled OCV when switching operational modes.

Summary & Conclusion

- Operational temperature has strong effects on the performance and performance degradation of the LSCF/SDC cell for both SOFC and SOEC.
- The impedance and ohmic/polarization resistance of both SOFC and SOEC was significantly decreased under higher temperatures, which induced better electrochemical reaction and better initial performance of both SOFC and SOEC under higher temperatures for the first 1,500 h.
- The performance degradation was also surprisingly mitigated for both SOFC and SOEC under higher temperature for the first thousand hours. The long-term (over 10,000 h) mitigated performance degradation under higher temperatures need to be studied and confirmed.
- The trade-off between the performance and performance degradation may need to be considered for over 10,000 h of SOFC and SOEC.

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