Evaluation of Realistic Stack Performance Using Improved SOFC-MP Modeling Tools

Kevin Lai, Brian J. Koeppel, Wei Xu

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

Introduction

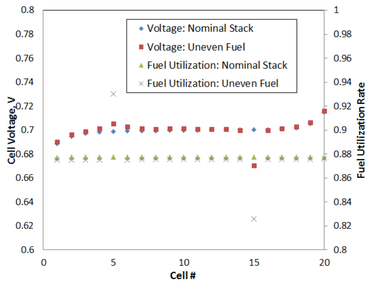
The SOFC-MP modeling tools enable SOFC designers to numerically test changes in stack design, component materials, and operating conditions to meet program technical targets for performance and reliability. This poster demonstrates recent enhancements and studies using the 2D and 3D modules.

Recent Enhancements

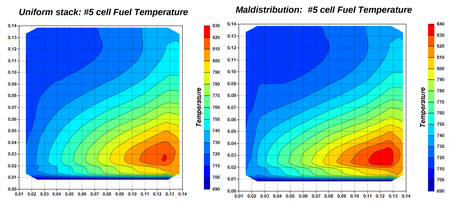
- 2D module: fuel/oxidant heat transfer in the inlet and outlet manifolds.
- 3D module: off-nominal cell variance, cell state variables for degradation calculations, integration with commercial FEM models.
- GUI: common interface for both 2D and 3D modules with pre-processing and post-processing capabilities.

Realistic Stack Performance Using 3D Tool

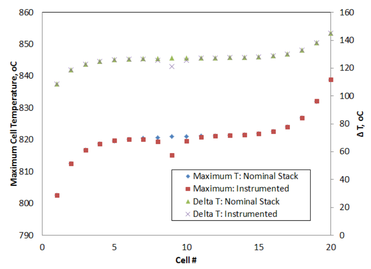
- Cell variance feature: allows cell-specific user assignment of fuel/air flow rates, inlet temperatures, and EC parameters to simulate potential off-nominal stack test conditions such as thermocouple plates, flow maldistribution, poor performing cells, etc.



- Effect of uneven fuel flow
  - Flow maldistribution with -12% fuel in cell #5 and +12% fuel in cell #15 for a 20-cell cross-flow stack.
  - Cell fuel utilizations and working voltages change accordingly, but overall stack EC performance is not drastically degraded.
  - Local cell temperatures affected by the different electrochemical performance which also impacts the maximum temperature and temperature difference for the next few adjacent cells in the stack.

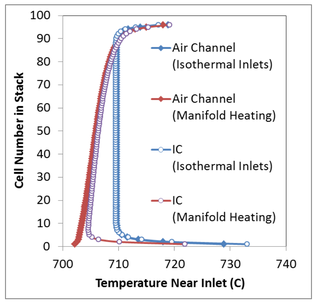


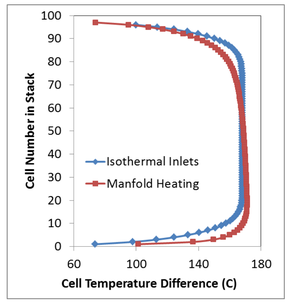
- Effect of measurement pates
  - Although overall temperature distribution remains unchanged, the actual maximum temperature of the cell without the thermocouple is 5ºC higher than that obtained for the same cell in a stack with the thermocouple measurement plates.



Effect of Gas Heating in Inlet and Outlet Manifolds

The SOFC-MP 2D module was enhanced to include fuel/oxidant heating in the manifolds of tall stacks. Although the overall electrochemical performance did not change dramatically for the 96-cell stack simulation, the inlet gas temperature rose gradually from the bottom of the stack to the top cell. This changes the profile of the cell temperature difference, which is a driver for the mechanical stresses on each individual cell.

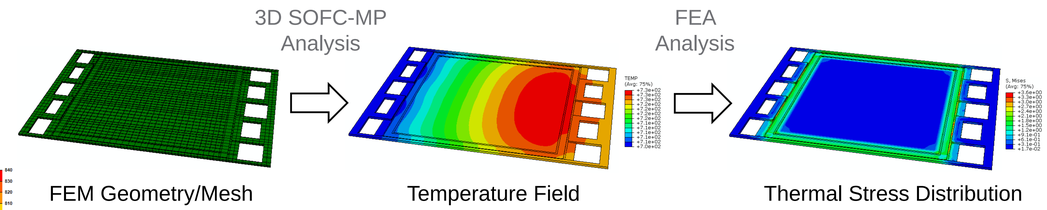




Increased lateral heat conduction provided by the thicker bottom and top load frame plates is the cause for the higher temperatures on the interconnect at the ends of the stacks. These end effects alter the temperature field for the adjacent 10 cells.

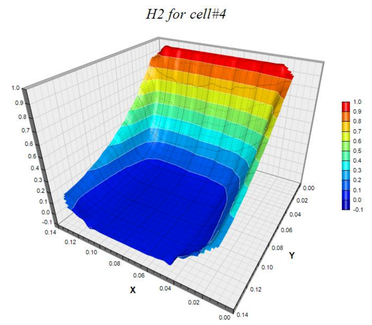
Stress and Reliability Analysis

- The main benefit of the 3D module is extraction of the full temperature profile for thermal-mechanical stress analysis. SOFC-MP has been modified to work with ABAQUS® and ANSYS® FEM models. The model geometry and mesh is first created in the commercial FEM package and exported, the mesh data file is read by SOFC-MP, the electrochemical model is set up and solved, the generated thermal distributions are exported, and the FEM model is solved for analysis of stresses and reliability.



Common User Interface for SOFC-MP Tools

- The common user interface performs pre- and post-processing functions for both the 2D and 3D modules. The tabular UI plots electrochemical results and works with commercial FEM packages (ABAQUS and ANSYS currently) to exchange 3D stack temperature loading for structural analysis in the user's preferred FEM software package.



Future Work

- Integration of the SOFC-MP 3D module with the SOFC-ROM tool.
- Addition of fuel and air recycling calculations in 2D and 3D modules to support system-level modeling.
- Integration of the 3D module with FEM tools to perform full-scale structural reliability analysis.
- Completion of parametric studies to characterize mechanical reliability and loss of contact for state of art SOFC stacks.
- Release of the SOFC-MP software tool suite which consists of the 2D module, 3D module, GUI, and SOFC-MP ROM.

Acknowledgement

This work was funded as part of the Solid-State Energy Conversion Alliance Core Technology Program by the U.S. Department of Energy's National Energy Technology Laboratory.

For more information, please contact:

Kevin Lai, Brian J. Koeppel
Pacific Northwest National Laboratory
Richland, WA 99352
Kevin.Lai@pnnl.gov
Brian.Koeppel@pnnl.gov

PNNL-SA-103919