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Flow dynamics through simplified battery rack configurations

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BACKGROUND

Large-scale energy storage systems (ESSs) are becoming an integral part of maintaining a stable grid. In order to improve the performance and safety of ESSs, it is essential to *develop models* that accurately assess *system degradation*. An important component of this is the *convective heat transfer* inside the rack.

MODELING CHALLENGES

Modeling the heat transport via convection is very challenging because the combination of design requirements, buoyancy, and turbulence creates:

- An enormous disparity between largest and smallest physical scales;
- Transitional flow regimes, challenging classic subgrid-scale models;
- A vast parameter space unamenable to simple empirical correlations.

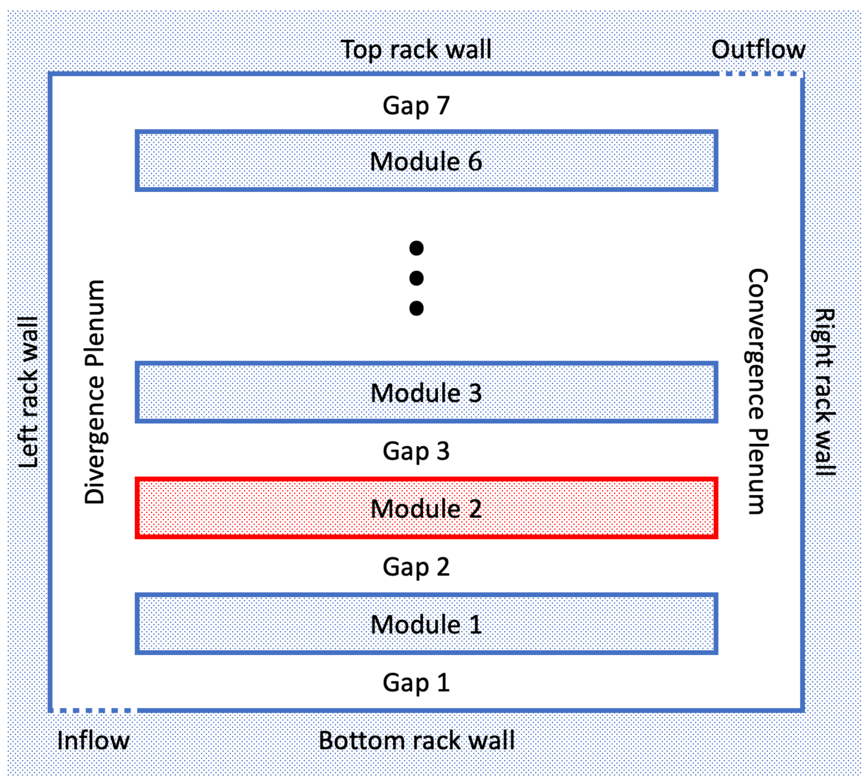
OBJECTIVE

To explore, assess, and understand how parameters in simplified battery rack configurations affect the flow development and the convective heat transfer

APPROACH

Simplified computational domain:

- Inflow and outflow are modeled as open boundary conditions
- Remaining boundaries are modeled as isothermal, no-slip walls
- Six modules are stacked vertically and the module second from the bottom is heated above ambient temperature of 300 K
- Rectangular geometry:
  - 10 cm inflow/outflow width
  - 80 cm module width
  - 2 cm gap height
  - 10 cm module height
  - 20 cm rack/module depth



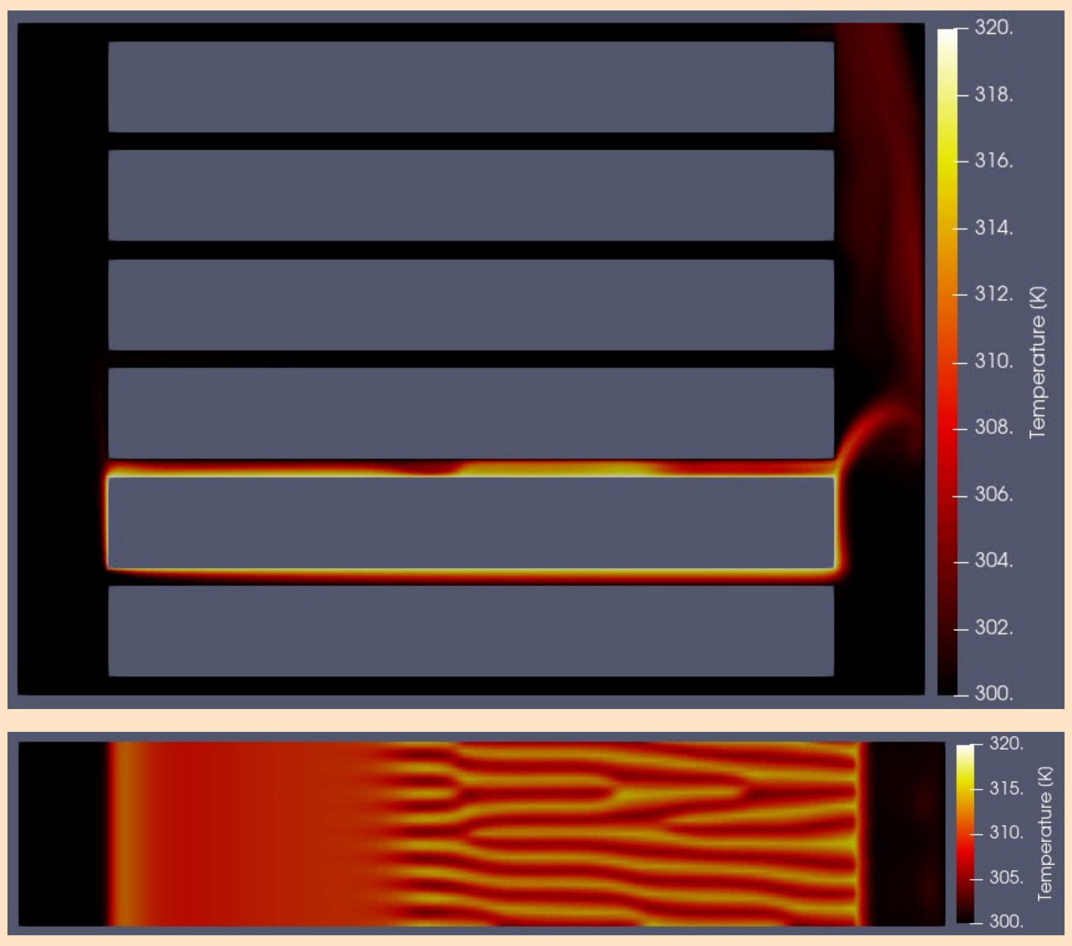
High-fidelity numerical simulations:

- Second-order finite element control volume approach (Sierra/Fuego)
- Highly-resolved numerical grid
- No subgrid-scale modeling

RESULTS

Qualitative overview

- A simulation was conducted with Module 2 heated to 320 K. Below are visualizations of the temperature field sliced at the center plane ($z = 0$ cm) and at the center of Gap 3 ($y = -12$ cm)

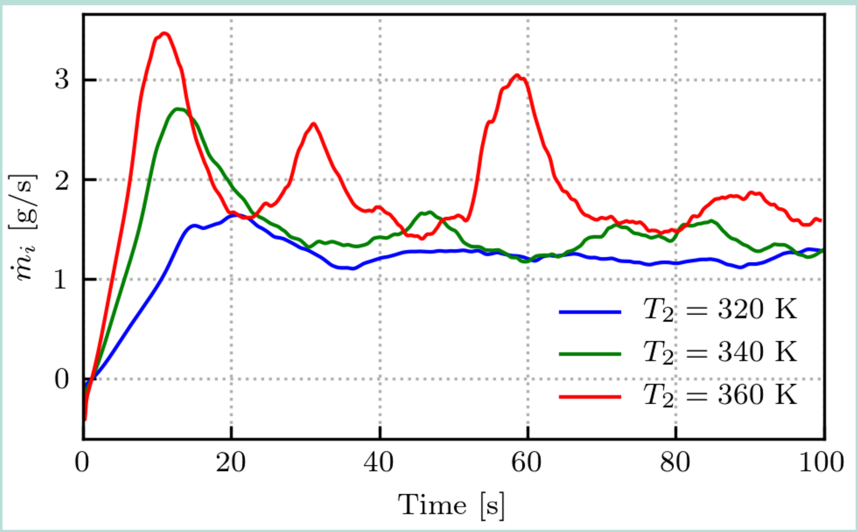


- The critical Rayleigh/Reynolds number for the onset of Rayleigh-Bénard-Pouiselle instability is met in Gap 3 creating large-scale vortices
- The behavior and scale of the vortices in the gap varies as a function of entrance length

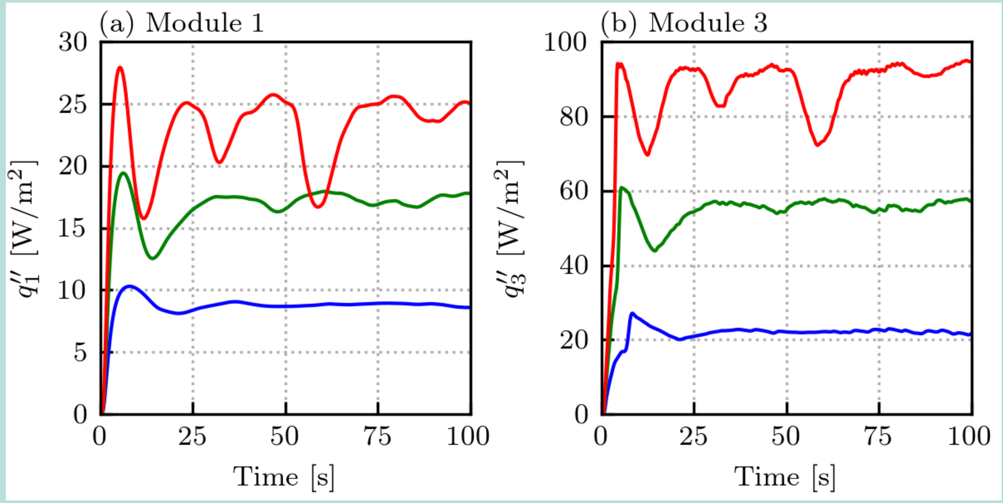
Effect of temperature

- Three simulations are compared with Module 2 heated to 320 K, 340 K and 360 K.

Mass flow rate measured at the inlet:



Average heat fluxes on neighboring modules:

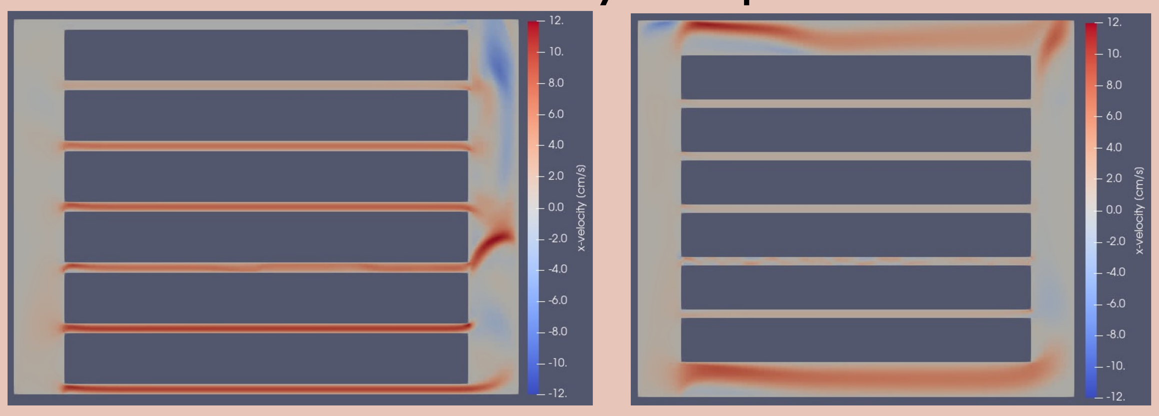


- Increasing module temperature only slightly increases mass flow due to buoyancy
- Measured heat flux is approximately linearly correlated with temperature difference

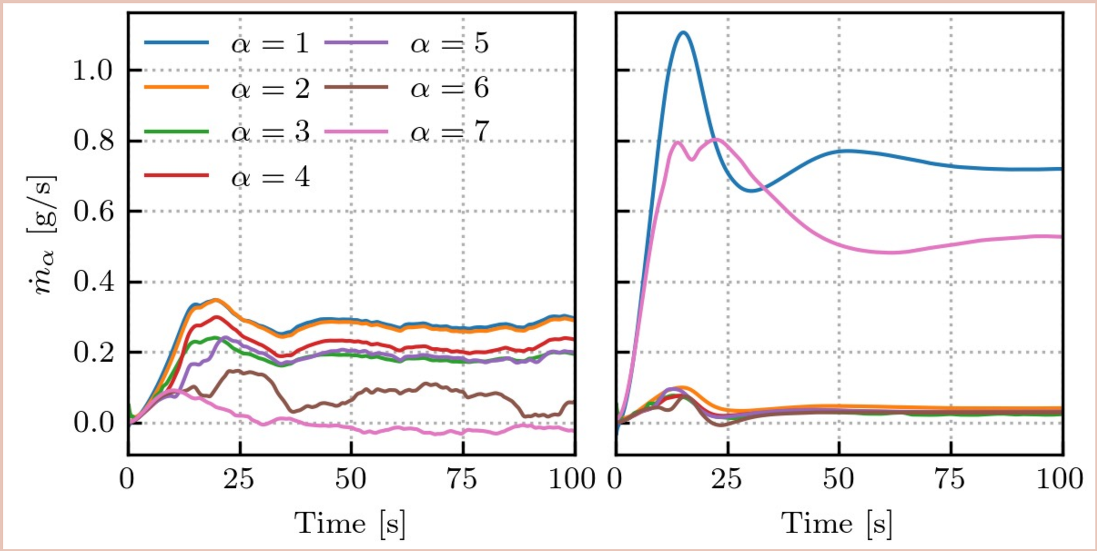
Effect of spacing

- Two simulations are compared with gap heights set to all 2 cm (left) and with gap 1 and 7 increased to 8 cm (right) with Module 2 being heated to 320 K

Visualizations of x velocity component:



Measurements of mass flow rate through each gap as a function of time:



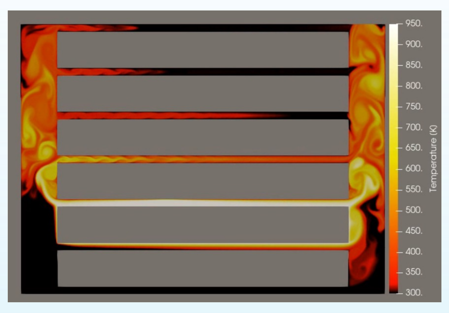
- Increasing the top and bottom gap heights decreases the flow around the heated module

SUMMARY

- High-fidelity numerical simulations were conducted to explore the flow dynamics through simplified battery racks
- Flow exhibits Rayleigh-Bénard-Pouiselle instability in Gap 3
- Variations in the heated module temperature and module spacing can affect flow rates and heat transfer in a non-obvious manner

FUTURE WORK

- Validate results with available experiments
- Develop network model
- Include effects of venting (preliminary work toright)



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