Influences of geometry on vent gas propagation in lithium-ion battery energy storage systems

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BACKGROUND

Large-scale energy storage systems (ESSs) are becoming an integral part of maintaining a stable grid with renewable energy. Battery cells, however, are prone to degradation and inevitable failure, leading to thermal runaway and hot volatile gas being ejected through venting. If thermal runaway occurs, vent gases and flames are the important driver of heat transfer to other modules, potentially causing additional modules in the battery rack to go into thermal runaway. Examining vent gas propagation is an important first step to develop strategies to mitigate potential harm.

MODELING CHALLENGES

Modeling the heat transport via convection is very challenging because of:

- The nonlinear coupling between turbulence, buoyancy, and combustion;
- 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

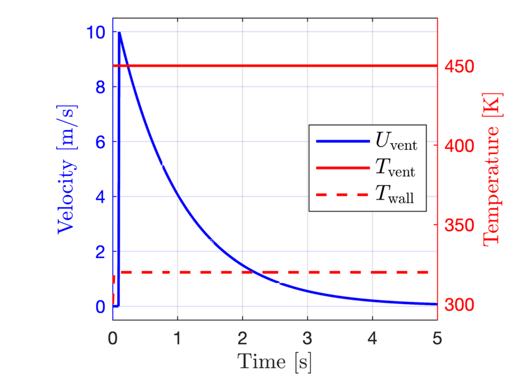
OBJECTIVE

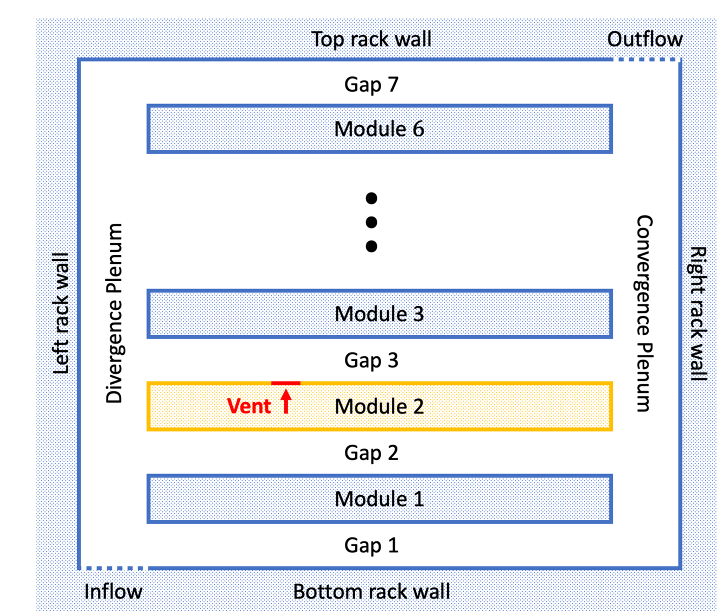
To examine the role of rack geometry and initial failure location on the flow of hot gases and subsequent heat transfer to surrounding modules

APPROACH

Simplified computational domain:

- Inflow and outflow are modeled as open boundary conditions
- Remaining boundaries are modeled as isothermal, no-slip walls
- Six modules represented as rectangles are stacked vertically
- Small slit on selected module represents vent port
  - Vent velocity/temperature profile is provided to the right
- Geometry (not drawn to scale):
  - 10 cm inflow/outflow width
  - 80 cm module width
  - 2 cm gap height
  - 10 cm module height
  - 2 cm vent width



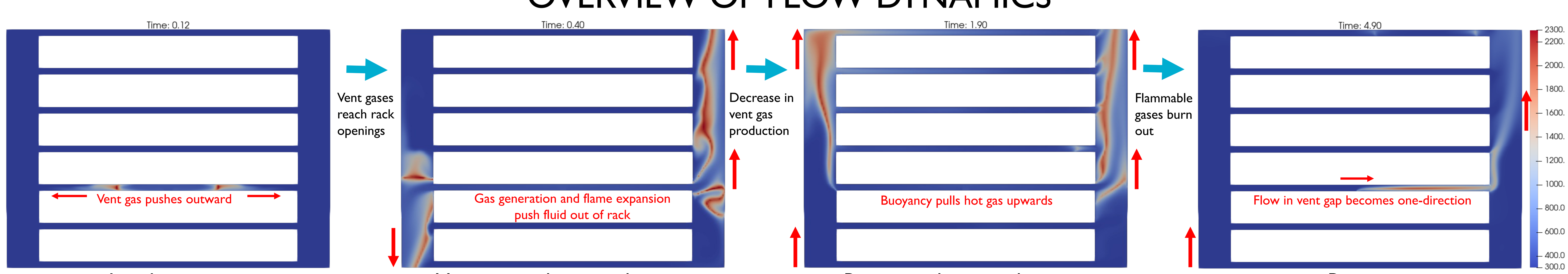


Numerical simulations:

- Second-order finite element control volume approach (Sierra/Fuego)
- Reynolds-averaged Navier-Stokes simulations using $k-\epsilon$ model
- Radiative transport using Thurgood quadrature type of 4th order

OVERVIEW OF FLOW DYNAMICS

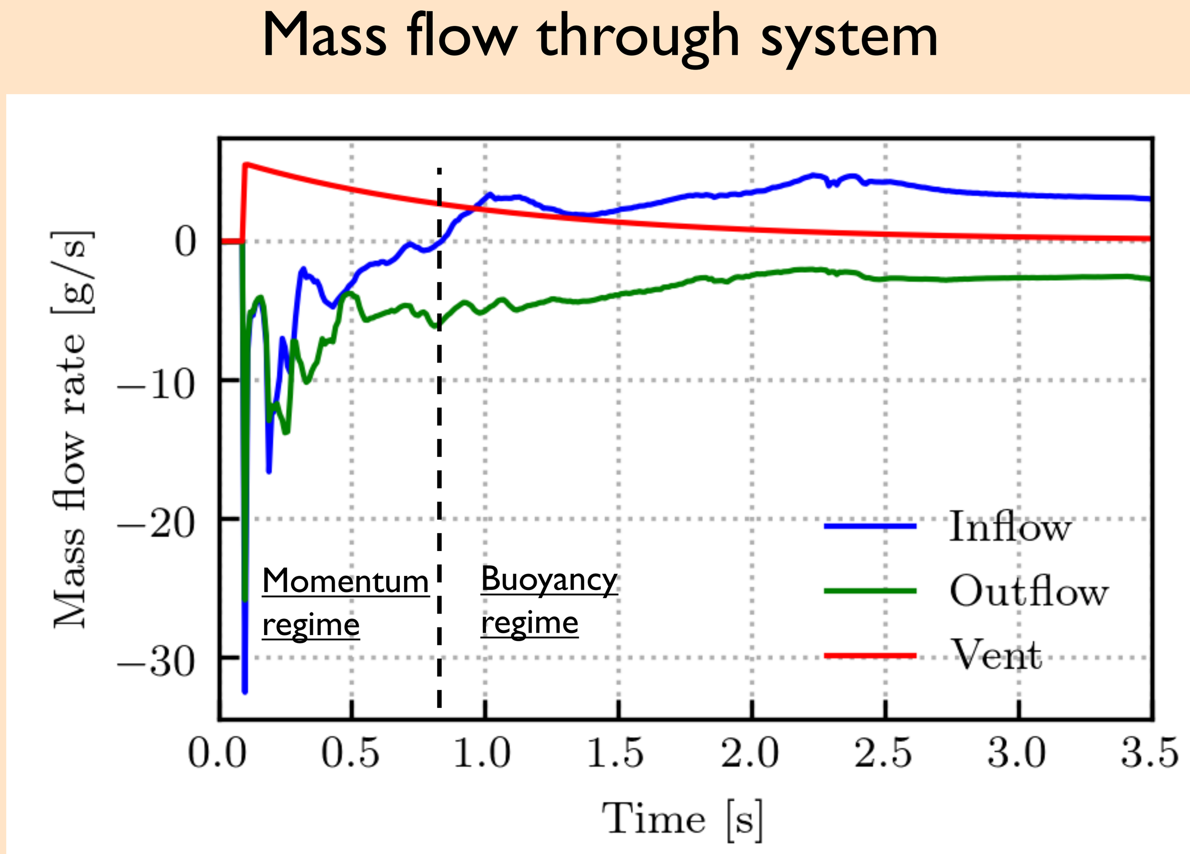
*indicates flow direction



Initial venting — Momentum-dominated regime — Buoyancy-dominated regime — Burn out

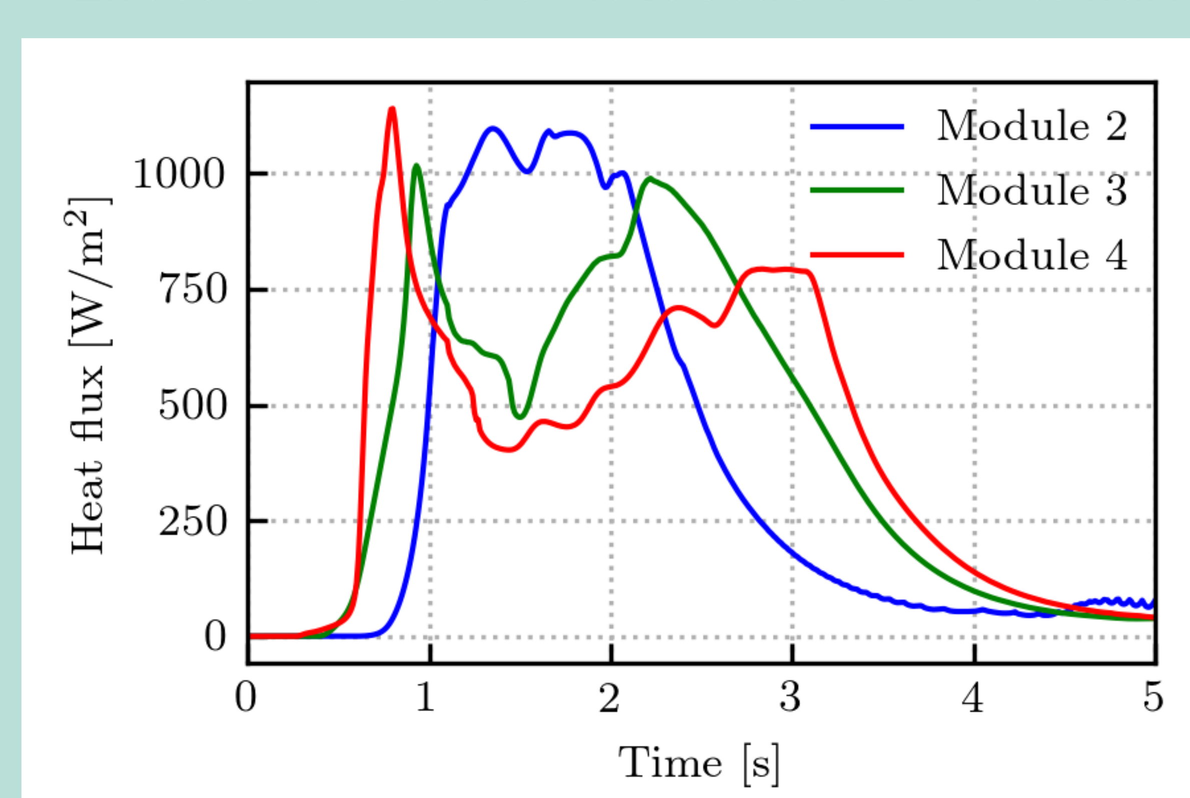
RESULTS

Mass flow through system



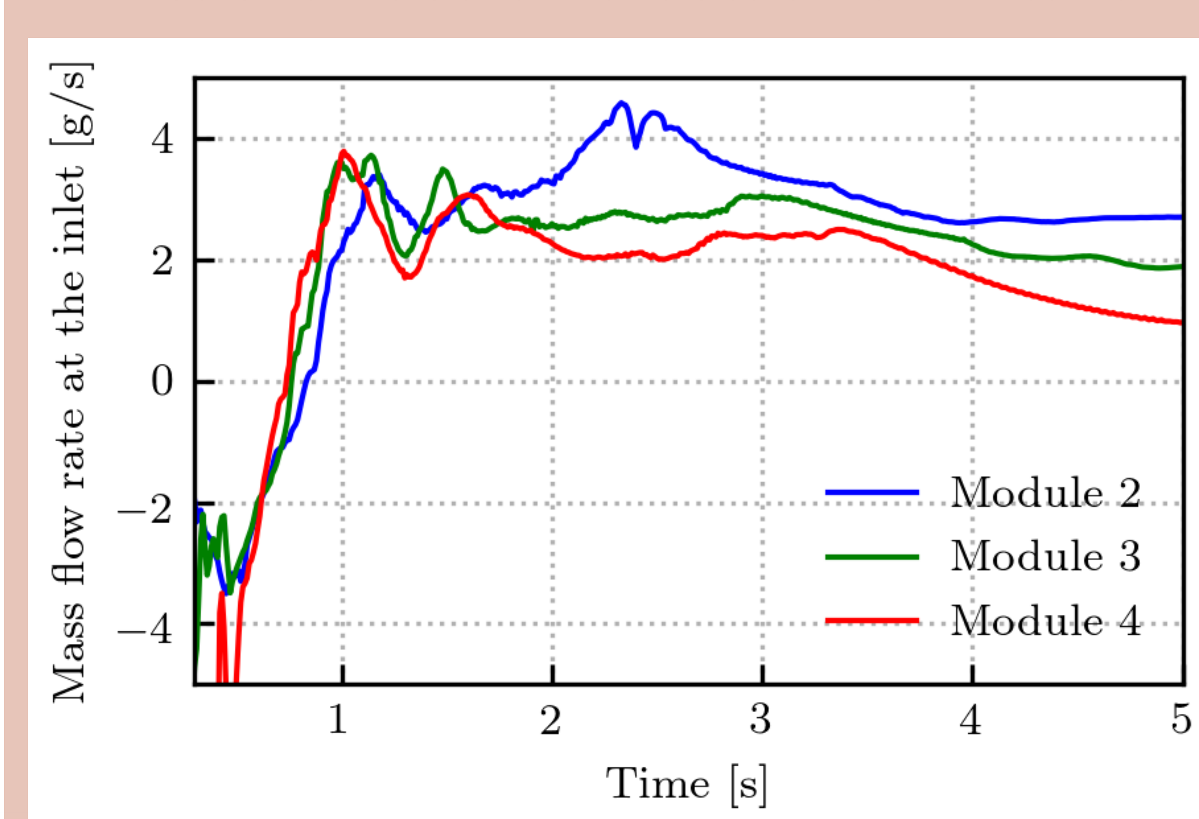
- Initial venting and burning results in a symmetric ejection of hot gases through the inflow and outflow openings
- Buoyancy generated from hot gases eventually (approx. 0.8 sec) causes entrainment of fresh air through the inflow

Effect of vertical vent location on heat flux



- Plotted: average heat flux on the top of module 6 with the vent positioned on different modules
- The duration of large heat flux increases but magnitude decreases as vertical vent location increases

Effect of vertical vent location on heat flux



- Plotted: mass flow rate at the inlet with the vent positioned on different modules
- Buoyancy causes lower vertical vent position to increase in the amount of entrained air (after approx. 2 sec)

SUMMARY

- Numerical simulations of vent gas ejection were conducted to explore how vent position affects subsequent flow propagation
- Momentum and buoyancy-dominated regimes are identified
- Horizontal vent position was varied but does not affect heat or flow
- Lower vertical vent position increases the amount of entrained air and the amount of heat flux on the top surface of module 6

FUTURE WORK

- Improve subgrid-modeling and mesh resolution requirements
- Incorporate three-dimensional effects by including gaps in the front and back of the rack
- Explore larger parameter space with various openings in the rack

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