Convective Thermal Runaway Propagation via Vented Gases from Failing Li-ion Batteries

Ala' E. Qatramez[1], Andrew Kurzawski[2], John Hewson[2], Daniel Foti[1], and Alexander J. Headley[1]

[1]Department of Mechanical Engineering, University of Memphis,
[2]Fire Science and Technology Department, Sandia National Laboratories

THE UNIVERSITY OF MEMPHIS

SAND2023-10230C

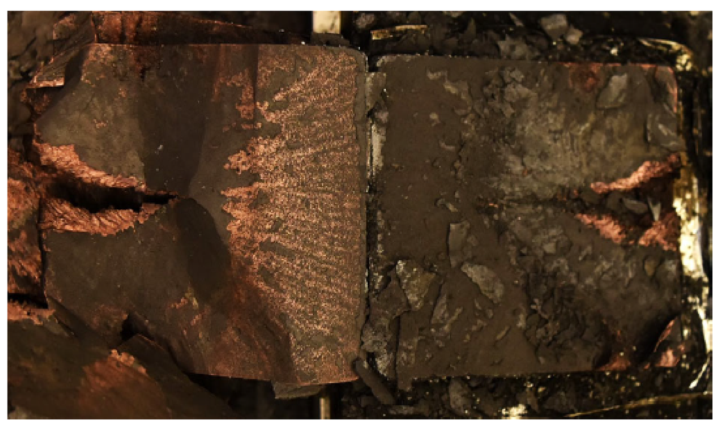
Motivations and Objectives

- Li-ion batteries have failure modes that cause safety hazards and financial losses.
- Vented gases expelled during thermal runaway contain high thermal energy.
- Objective: Estimate heat flux from impinging vent gases for different thermal runaway scenarios.
- Objective: Investigate the effects of module geometry on heat transfer via simulations and correlations.

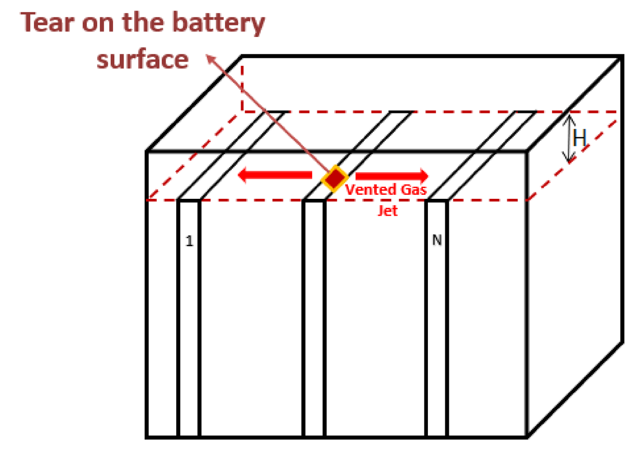
Convective Thermal Runaway Propagation

Thermal Runaway Propagation via Vent Gas:

- Hot vented gases spread heat through an energy storage system.
- Understanding the heat transfer mechanism and estimating the heat flux are major keys to predicting the temperature of other cells and the hazard posed by vent gases.
- The value of the heat flux the cell is exposed to has a significant effect on the thermal runaway initiation ($t \sim \frac{1}{q''^2}$).
- Vented gases are ejected from the cell through a tear in the cell packaging (pouch cells) or a manufactured venting orifice (prismatic and cylindrical cells). Metal cell casing can also fail along seams providing another vent opening.



Erosion of the electrode shows the effect of vented products moving towards a tear[1].



Representation of module of pouch or prismatic cells with tear facing a gap characterized by height "H".

Parameters Relevant to Heat Transfer:

- Venting duration
- Vent gas speed
- Vent gas temperature
- Total vented moles

- Why are they important?
  - Venting speed is related to Re.
  - $\overline{Nu}$ for impinging jet is directly related to Re.
  - $\overline{Nu}$ describes the convective heat transfer.

Impinging Jet Correlations and Simulations

Heat Transfer Correlations:

- Used as a point of reference due to limits on Re range and geometry shown below:

$$\begin{bmatrix} 3000 \leq Re \leq 90,000 \\ 2 \leq H/W \leq 10 \\ 0.025 \leq A_r \leq 0.125 \end{bmatrix}$$

- H is the module gap height and W is the tear width (See the above module figure).
- Correlations[2] are used to calculate $\overline{Nu}$ from impinging jets.
- The impinging jet correlations are the closest fit to actual battery module scenarios.

Simulations:

- Employed to validate/assess heat transfer correlations.
- Laminar and modified k-w RANS turbulence modeling[3].

Case Study

Simulations emulate thermal runaway scenarios with different gap sizes H and inflow (Re):

- Case 1: $v = 58.5\ m/s\ (Re \approx 26,000)$, $H = 1\ cm\ (H/W = 1.1)$
- Case 2: $v = 7\ m/s\ (Re \approx 3,000)$, $H = 1\ cm\ (H/W = 1.1)$
- Case 3: $v = 58.5\ m/s$, $H = 2\ cm\ (H/W = 2.2)$
- Case 4: $v = 7\ m/s$, $H = 2\ cm\ (H/W = 2.2)$

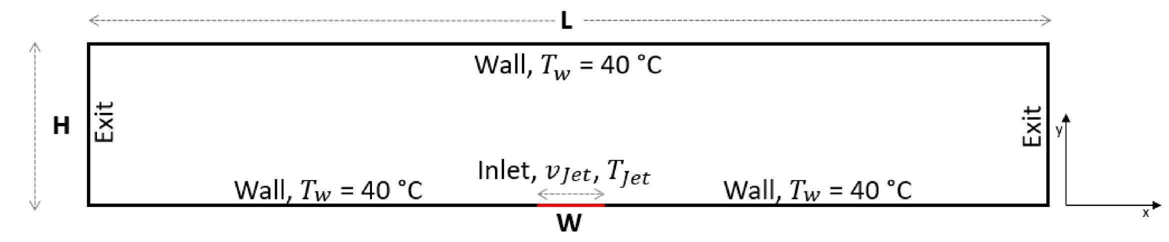
The cases are for pouch cell of 5 Ah and dimensions of 75.5 mm ×64.5 mm ×9 mm[1]. **Gap heights are selected based on estimates from a deployed system.**

Contact and Acknowledgement

For questions:
Dr. Alexander Headley, jheadley@memphis.edu. Ala' Qatramez, qatramez@memphis.edu.

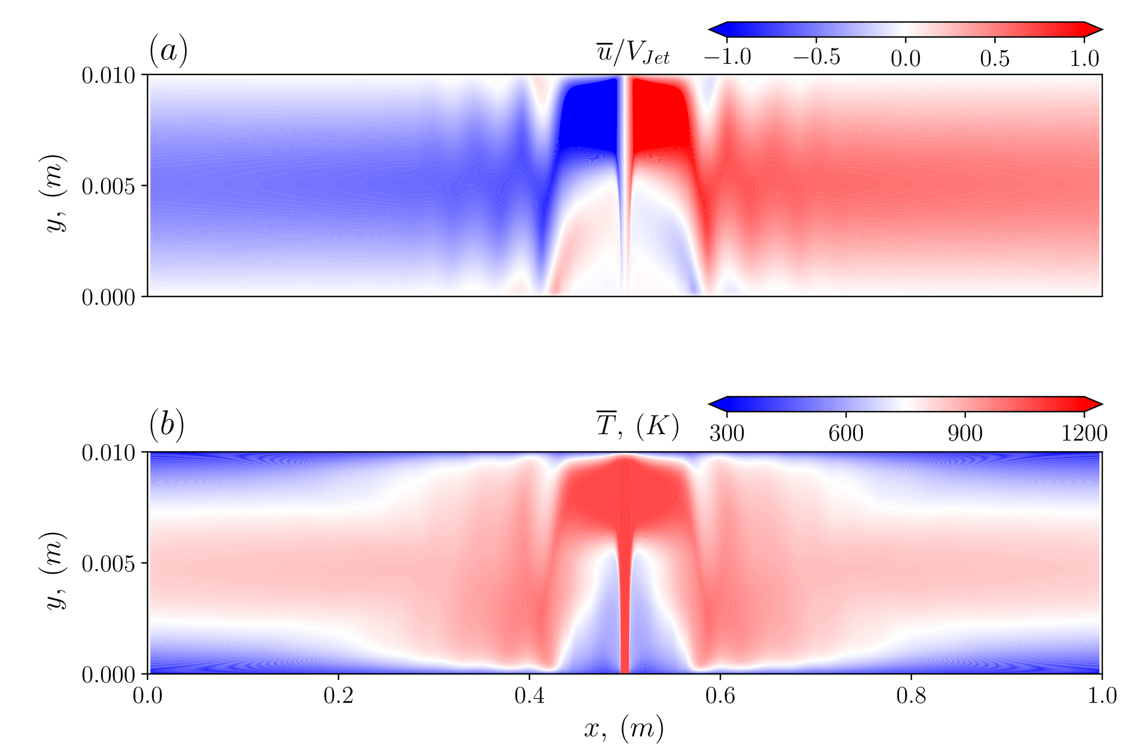
This work is funded by Dr. Imre Gyuk through the U.S. Department of Energy; Office of Electricity.

Vent Gas Heat Flux Estimation



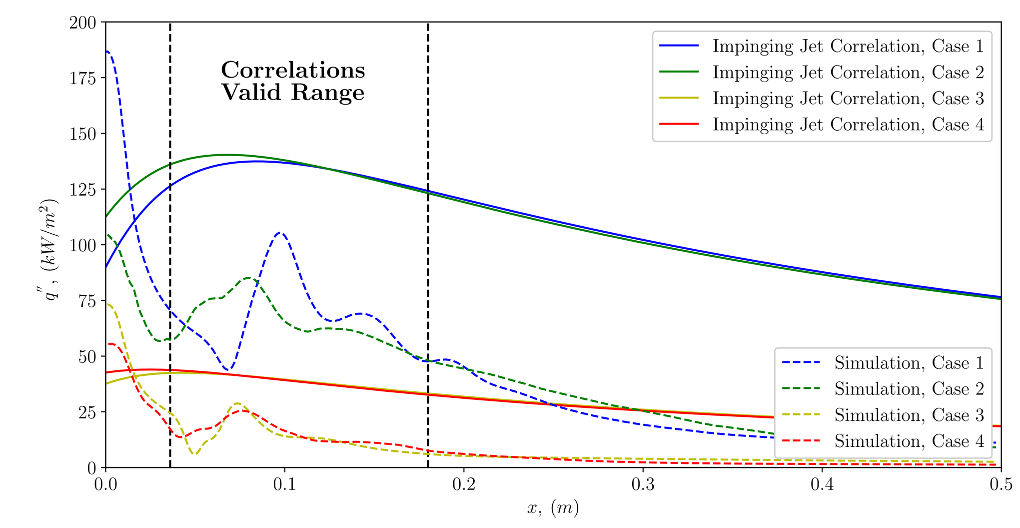
Module venting gap[4].

Venting Jet Evolution[4]



Contour plots of the average a) axial velocity $\overline{u}$ and b) temperature $\overline{T}$ of vent gas for Case 1. The aspect ration $(L/H) = 100$.

Heat Flux at the Gap Top Wall



Average heat flux at the top wall for all cases calculated from the simulations and correlations.

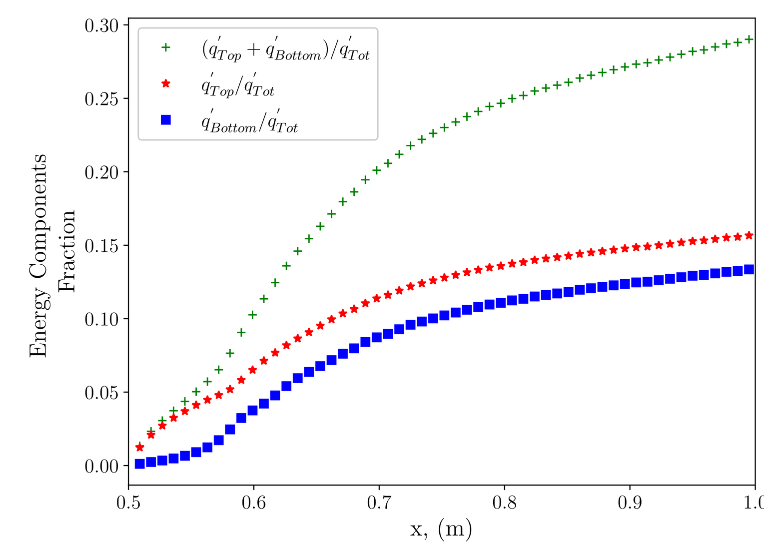
- The case of highest v and lowest H (Case 1) is corresponding to the highest heat flux.
- Cells above the impinging point are subjected to the highest heat flux.
- Another peak appears at about $10\ cm$ from the impinging point.

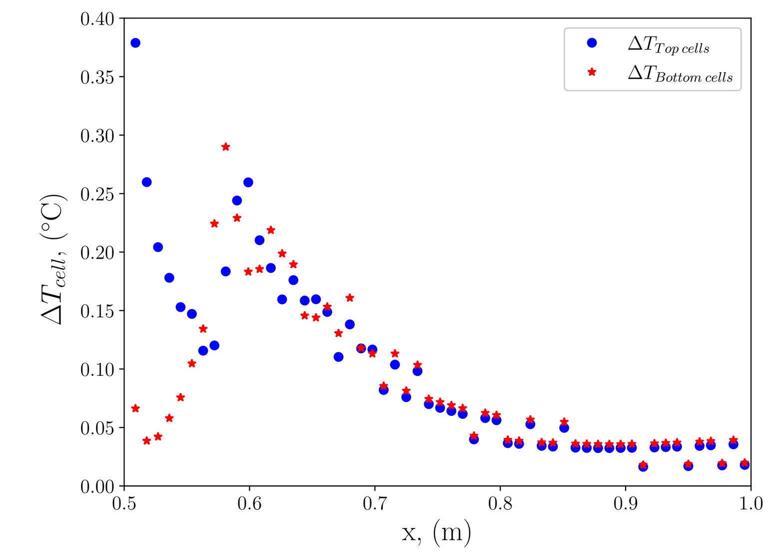
Thermal Hazards Assessment

$$q' = \int_{x=x_1}^{x=x_2} q''\, dx; \quad q'' = -k(dT/dy)$$

$$\Delta T_{cell} = \frac{q'_{cell}\, t_{vent}\, L_{cell}}{m_{cell}\, cp_{cell}}$$

For case 1 ($v = 58.5\ m/s$, $H = 1\ cm$):





- ΔT_{cell} is the average temperature rise of the cells in contact with the top and the bottom walls.
- ΔT_{cell} is an indication of the energy deposited in the top/bottom cells.
- About 40 to 70% of the energy advected by the vented gases will leave the module.
- Multiple and sequential failures of cells are needed to induce thermal runaway in cells in other modules.

[1]Archibald, Erik, et al. "Characterization of thermally induced runaway in pouch cells for propagation." Fire Technology 56.6 (2020): 2467-2490.
[2]Incropera, Frank P., et al., 2012. Principles of Heat and Mass Transfer. John Wiley Sons.
[3]R. Abid, C. Rumsey, T.B. Gatski, Prediction of nonequilibrium turbulent flows with explicit algebraic stress models, AIAA J. 33 (11) (1995) 2026–2031.
[4]Qatramez, Ala'E., et al. "Estimation of Heat Flux From Gases Released During Thermal Runaway of Lithium-Ion Batteries." Proceedings of the ASME 2023 Heat Transfer Summer Conference. ASME 2023 Heat Transfer Summer Conference, 2023.