Estimation of Heat Flux From Gases Released During Thermal Runaway of Lithium-Ion Batteries

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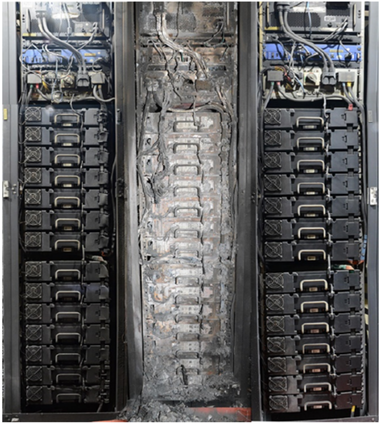
Motivation: Thermal Runaway

- Thermal runaway occurs due to abusive conditions
- Cell temperature increases significantly in a short time
- Thermal runaway can propagate to other cells and modules
- Lithium-ion battery failures have resulted in serious injuries and considerable financial losses
- Conduction propagation has a local effect to adjacent cells
- Conduction propagation has been intensively investigated



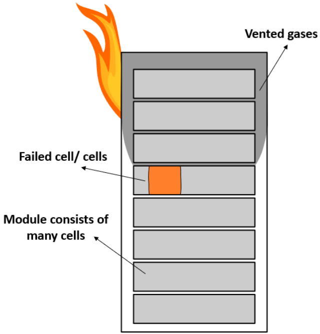
Arizona Explosion[1]

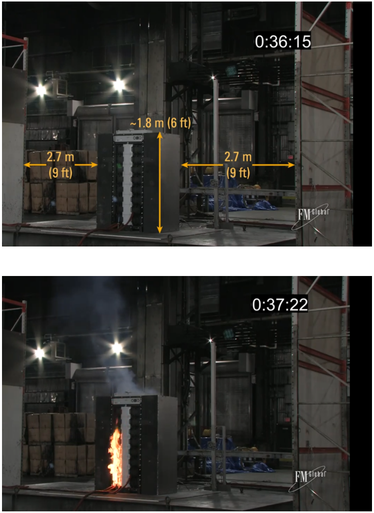
(Image credit: Arizona Public Services)

[1] Hill, D., 2020. McMicken Battery Energy Storage System Event: Technical Analysis and Recommendations. DNV GL Energy Insights USA, Incorporated.

Motivation:
Energy Storage System Failures And Vented Gas

- Convection Thermal Runaway Mode:
  - Vented gases contain high thermal energy
  - Spread through entire energy storage system





Energy Storage System Fire[2]

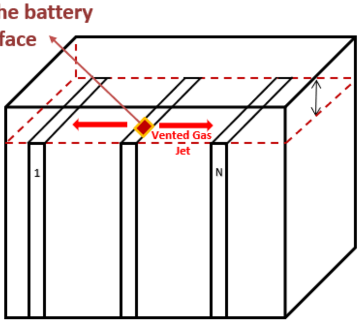
[2] https://www.youtube.com/watch?v=uLzPSN8iagk: FM Global Fire.

Characterization of Vented Gas Predictions
Important Vented Gas Characteristics of Heat Transfer

- Venting time
- Venting speed
- Vented gas temperature
- Total vented moles
- Vented gases species

- Why they are important?
  - $\overline{Nu}$ is related to Re
  - The average heat flux

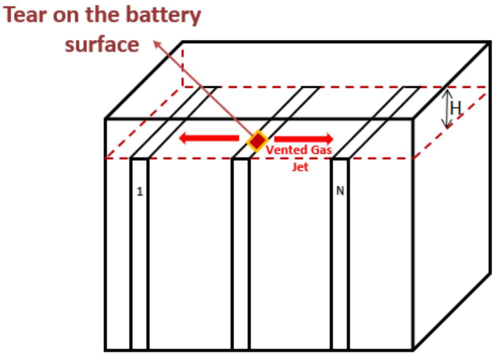
- Understanding the heat transfer mechanism and estimating the heat flux are major keys to predicting the temperature of other cells and the hazard posed by vent gases

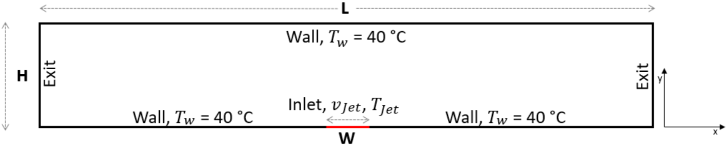


* The vent gas characteristics were estimated from LIM1TR[3]

[3]Kurzawski, A., and Shurtz, R., 2019. LIM1TR: Lithium-ion Modeling with 1-D Thermal Runaway v1.0. Tech. Rep. SAND2021-12281, Sandia National Lab, (SNL-NM), Albuquerque, NM (United States)

Vent Gas Heat Flux Estimation
Impinging Jet





Vent Gas Impinging Jet Nusselt Number Correlation and Simulation

$$\frac{\overline{Nu}}{\mathrm{Pr}^{0.42}} = \frac{3.06}{0.5/A_r + H/W + 2.78}\mathrm{Re}^m$$

$$m = 0.695 - \left[\left(\frac{1}{A_r}\right) + \left(\frac{H}{2W}\right)^{1.33} 3.06\right]^{-1}$$

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

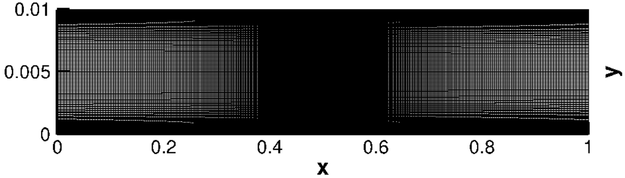
- The impinging correlation is the closest available to the simulated case
- Only used as a point of reference

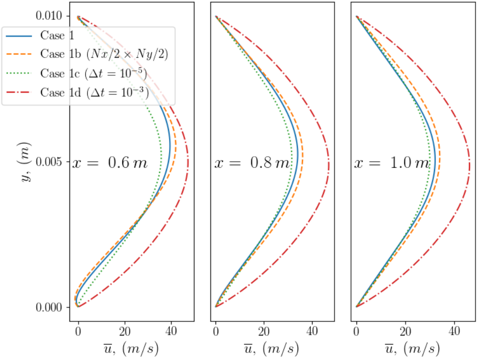
- 2-D compressible flow simulation
- 2^{nd} implicit dual time stepping
- DNS resolved mesh
- Uniform vent gas inflow

- Mesh and simulation parameters:

Nx	750
Ny	150
Δt	1×10^{-4} s
Jet velocities	58.5 and 7.0 m/s
Simulation time	2.5 s

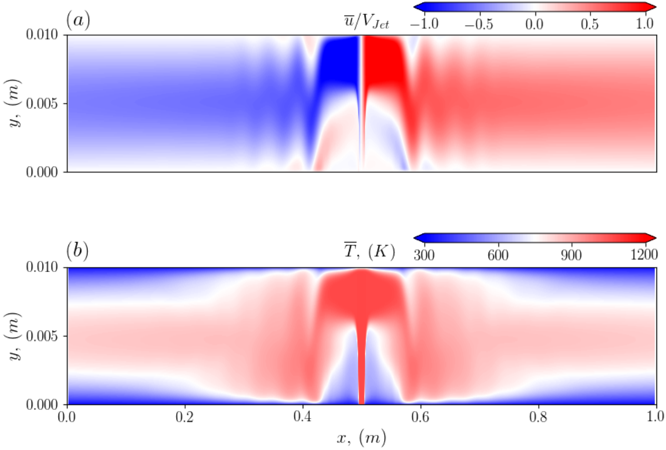
Grid Independence Study





Venting Jet Evolution

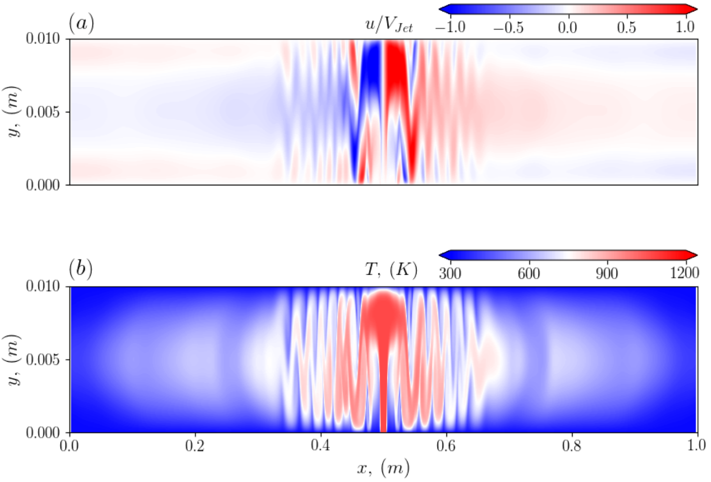
- Case 1: $v = 58.5\ m/s,\ H = 1\ cm$



* Note that: The aspect ration $(L/H) = 100$

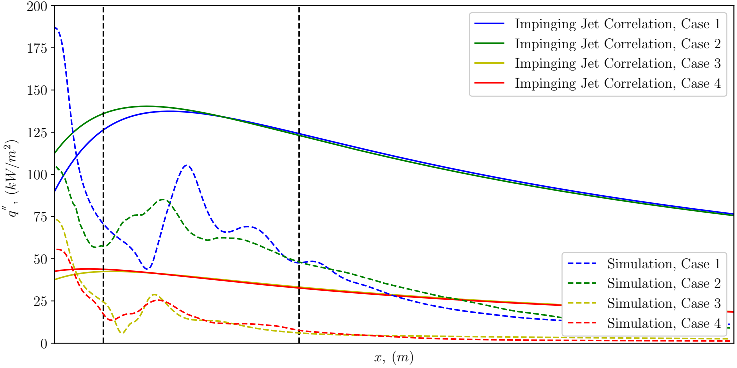
Venting Jet Evolution

- Case 2: $v = 7\ m/s,\ H = 1\ cm$



Heat Flux Estimation: Correlation VS Simulation

- For case 1: $v = 58.5\ m/s,\ H = 1\ cm$
- For case 2: $v = 7\ m/s,\ H = 1\ cm$
- For case 3: $v = 58.5\ m/s,\ H = 2\ cm$
- For case 4: $v = 7\ m/s,\ H = 2\ cm$

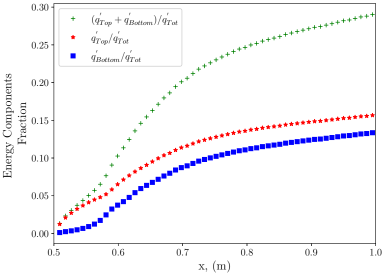


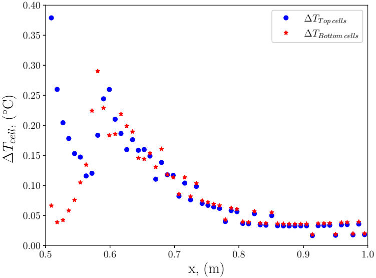
Heat Transfer Assessment of Thermal Hazards

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

$$q' = \int_{x=x_1}^{x=x_2} q''\,dx;$$

$$q'' = -k(dT/dy)$$





- ΔT_{cell} is averaged over the cell during the venting only (Local temperatures will be higher)
- ΔT_{cell} is an indication of the energy deposited in the top/bottom cells
- Multiple sequential cells failures are required to provide sufficient energy to initiate thermal runaway in the adjacent module

Conclusion And Future Work

Summary:

- 40% to about 70% of venting gases energy can leave the module gap
- Multiple and sequential failures of cells are needed to induce thermal runaway in cells in other modules

Future Work:

- Adding a suitable turbulence model
- Performing 3D simulations to study the effect of module geometry on the heat flux

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THANK YOU!
Questions?

https://github.com/sandialabs/lim1tr/

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