Safety Hazards Associated with Heat Transfer from Li-ion Battery Thermal Runaway Vent Gases

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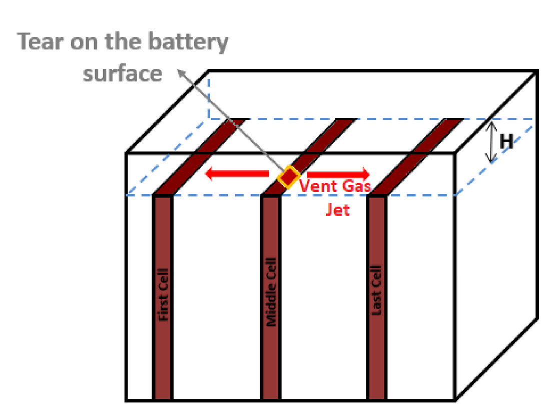
Motivations and Objectives

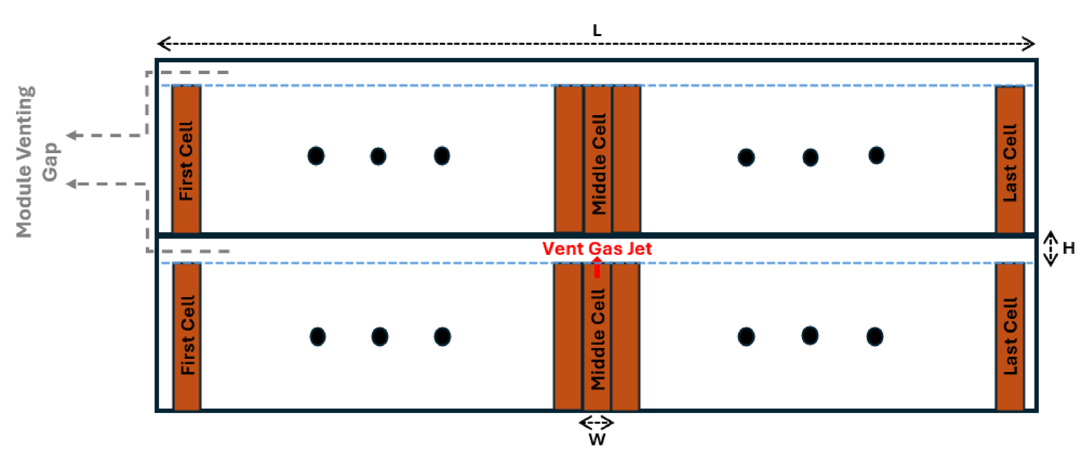
- Li-ion batteries can fail catastrophically at high temperatures in a process called thermal runaway.
- Serious safety issues are associated with thermal runaway propagation.
- Li-ion batteries vent high-temperature, combustible gases during thermal runaway.
- Objective: Estimate heat flux from impinging vent gases for different module geometries and venting speeds.
- Objective: Test the effect of protecting cells from direct vent gas impingement by passive mitigation.

Vent Gas Thermal Hazards

- During thermal runaway gases are ejected from a Li-ion cell at high temperature and speed which can pose safety issues.
- These gases are ejected from the cell through a tear in the cell packaging as in pouch cells or a manufactured venting orifice in the case of prismatic and cylindrical cells.



A Simple representation of module of pouch cells with tear facing a gap characterized by height "H".



A Simple representation of two modules of pouch cells showing a jet of gas leaving the failing cell and impinging on the top wall of the bottom module.

Simulations and Convection Coefficients Estimations

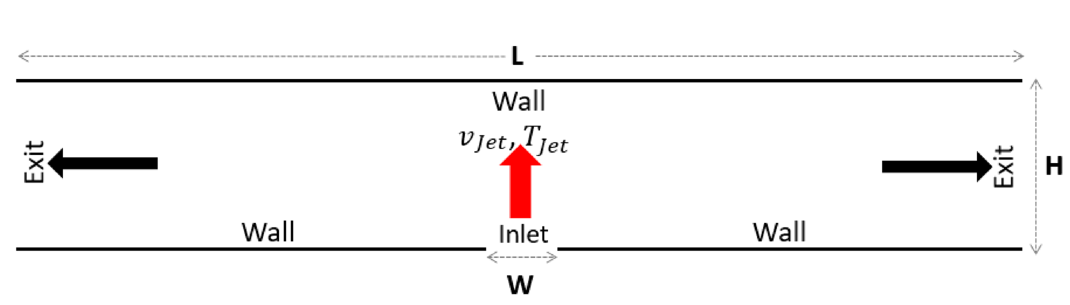
- The goal is to estimate the convection heat transfer coefficients at the wall.
- 2-D compressible flow simulation of uniform vent gas inflow velocity (v_{Jet}) and temperature (T_{Jet}) to a narrow channel with constant temperature wall condition[1].
- k-w Shear-Stress Transport (SST) RANS model[2] is employed.
- Simulations were verified with DNS results[3].
- Thermal runaway model, LIM1TR (Lithium-ion Modeling with 1-D Thermal Runaway), is used to study the potential of thermal runaway initiation in a Li-ion cell due to vent gas[4].

Case Study

Simulations of four thermal runaway scenarios of two venting velocities, v_{Jet}, and two gap heights, H,:

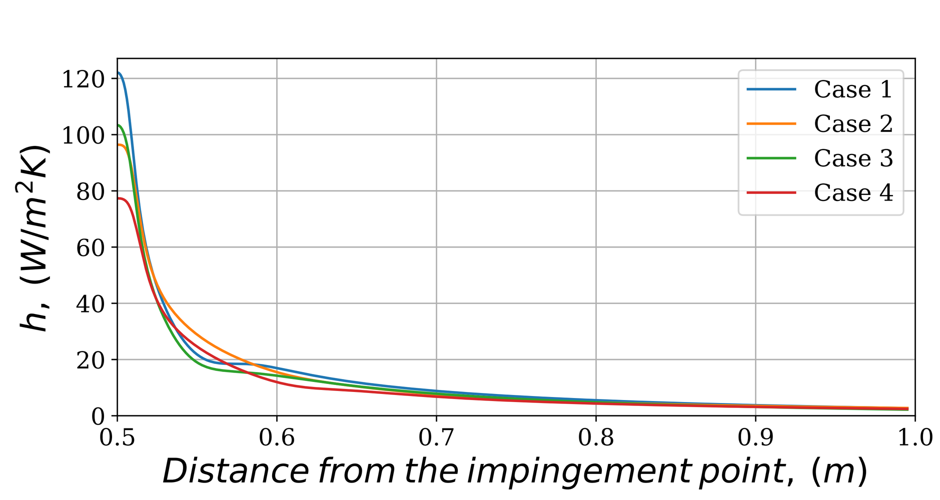
- Case 1 (5 Ah): $v_{Jet} = 7\ m/s, H = 1\ cm$
- Case 2 (5 Ah): $v_{Jet} = 7\ m/s, H = 2\ cm$
- Case 3 (10 Ah): $v_{Jet} = 5\ m/s, H = 1\ cm$
- Case 4 (10 Ah): $v_{Jet} = 5\ m/s, H = 2\ cm$

The cases are for 5 Ah and 10 Ah pouch cells of dimensions of 67.4 mm×62.1 mm×8.8 mm and 150.4 mm×57.8 mm×10.4 mm[5], respectively. The temperature of vent gas is assumed to be 800 °C. **Gap heights, H, are selected based on estimates from a deployed system.**

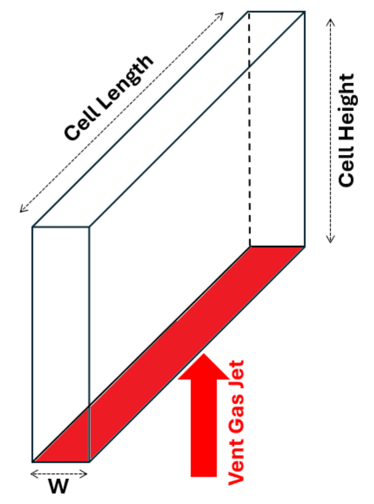


Module venting gap.

Convection heat transfer coefficients at the gap top wall



Vent gas jet impinges on a cell bottom surface



- The case with the lowest H and highest v_{Jet} (Case 1) corresponds to the highest convection coefficient.

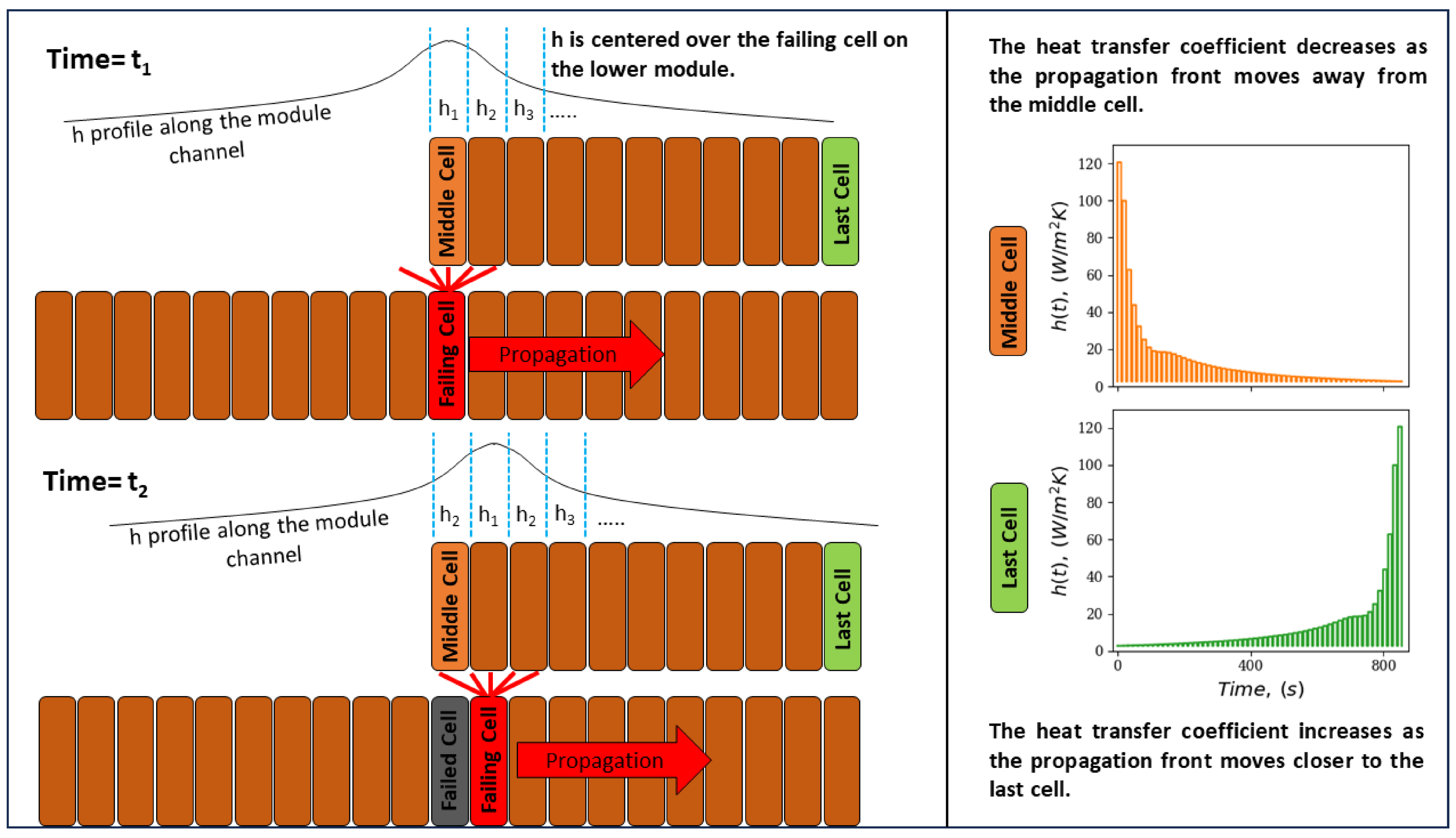
[1]https://www.openfoam.com/documentation/guides/latest/doc/guide-applications-solvers-heat-transfer-buoyantPimpleFoam.html.
[2]F. R. Menter, M. Kuntz, R. Langtry, et al., Ten years of industrial experience with the sst turbulence model, Turbulence, heat and mass transfer 4 (1) (2003) 625–632.
[3]Jaramillo, J. E., et al. "DNS and RANS modelling of a turbulent plane impinging jet." International Journal of Heat and Mass Transfer 55.4 (2012): 789-801.
[4]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).
[5]R. W. Kennedy, K. C. Marr, O. A. Ezekoye, Gas release rates and properties from lithium cobalt oxide lithium ion battery arrays, Journal of Power Sources 487 (2021) 229388.

Potential of Thermal runaway Initiation by Vent Gas and Mitigation by Plates of Different Materials

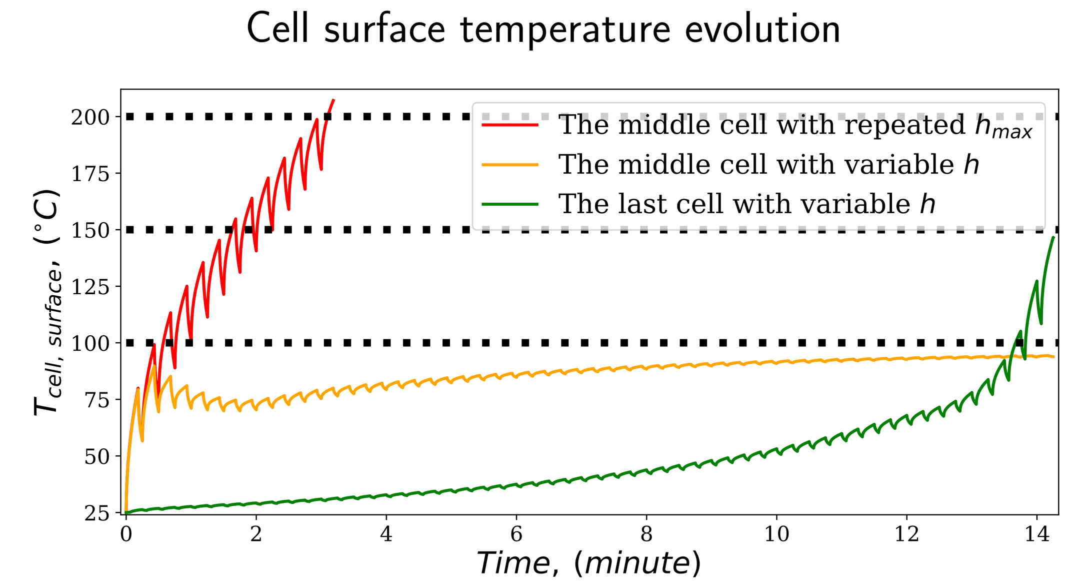
Does vent gas represent a serious safety issue?

- The goal here is to evaluate the potential of driving a Li-ion cell into thermal runaway due to exposure to a vent gas jet.
- Thermal runaway is assumed to occur when the cell surface temperature is 200 °C.
- The cells under interest are the middle and last cells in the top module due to the failure of the middle cell in the bottom module as show in the figure below. Case 1 (The highest h) is under interest in this analysis.

Spacial distribution effect of convection coefficient on cells at different locations in the channel



Cell surface temperature evolution

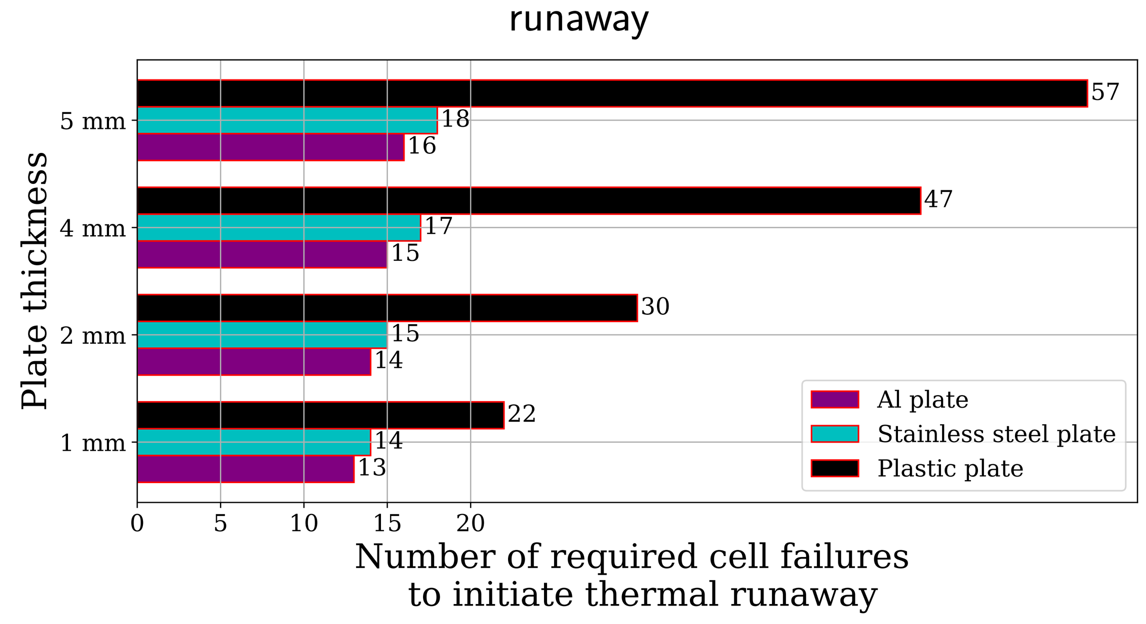


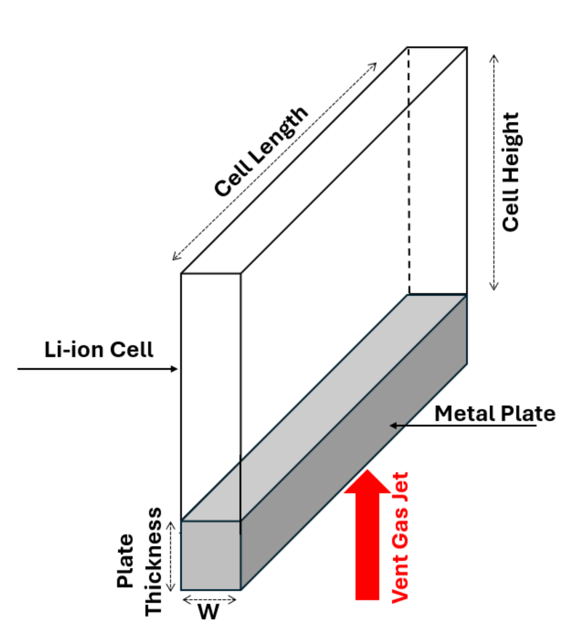
- It takes 13 sequential cell failures to initiate thermal runaway in the cell subjected to an impinging vent gas jet of h_{max}. Where 3 failures raise the surface temperature to 100 °C.
- Cells at different locations are affected differently, where gradual heating shown in the last cell has remarkable effect in increasing the cell temperature significantly.

Mitigation by metal and plastic plates

- Plates with certain thicknesses can be inserted between the cell and jet stream as mitigation method. Practically, these plates could be a component of the module casing or thermal management design. The figure below represents a cell sitting on a plate of some thickness in the module above the venting module.

Aluminum (Al), stainless steel, and plastic plates thicknesses and their corresponding number of the cell failures until thermal runaway





- By inserting Al and stainless steel plates with a small thickness of 5 mm, the number of failing cells required to initiate thermal runaway in the cell subjected to the gas jet increases by approximately 23% and 38%, respectively.
- With a 5 mm thickness of polypropylene used as a plastic plate, the number of failing cells increases significantly. However, using plastic plates may increase the risk of fire.

Summary

1. Li-ion batteries vent gases can play a vital role in pre-heating of cells. This pre-heating is crucial for module-to-module thermal runaway propagation.
2. Designing cells with relatively large venting tears (or orifices) and modules with small gap heights reduces the heating due to direct impingement.
3. Inserting metal plates with sufficient heat capacity is a way of propagation mitigation.

Contact and Acknowledgement

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