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Simulated venting flow from 18650 format lithium ion batteries incorporating optical diagnostics

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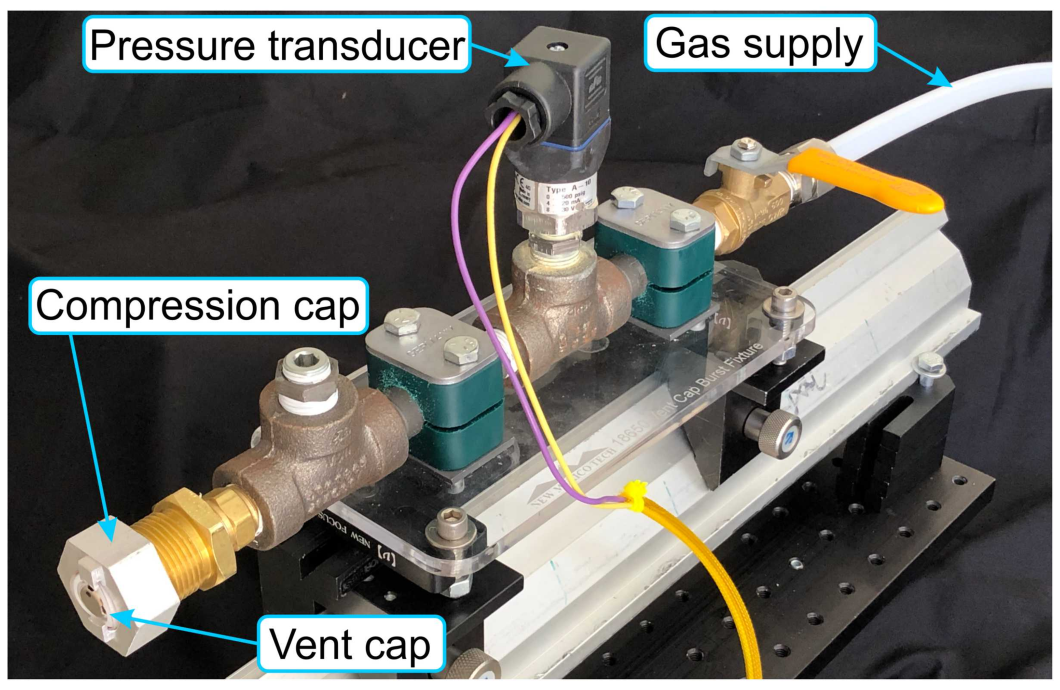
Introduction

- Stationary energy storage systems (ESS) are increasingly deployed to maintain a robust and resilient grid.
- As system size increases, financial and safety issues become important topics.
- Holistic approach: electrochemistry, materials, and whole-cell abuse will fill knowledge gaps.
- Vent mechanisms are integral to commercial battery designs to avoid case rupture under abuse conditions, but venting still presents safety concerns.
- Unique experiments are performed here on vents from common 18650 size cells to characterize the venting process.
- High-speed schlieren imaging is implemented to quantify the transient velocity field immediately after vent opening.

Custom experimental setups

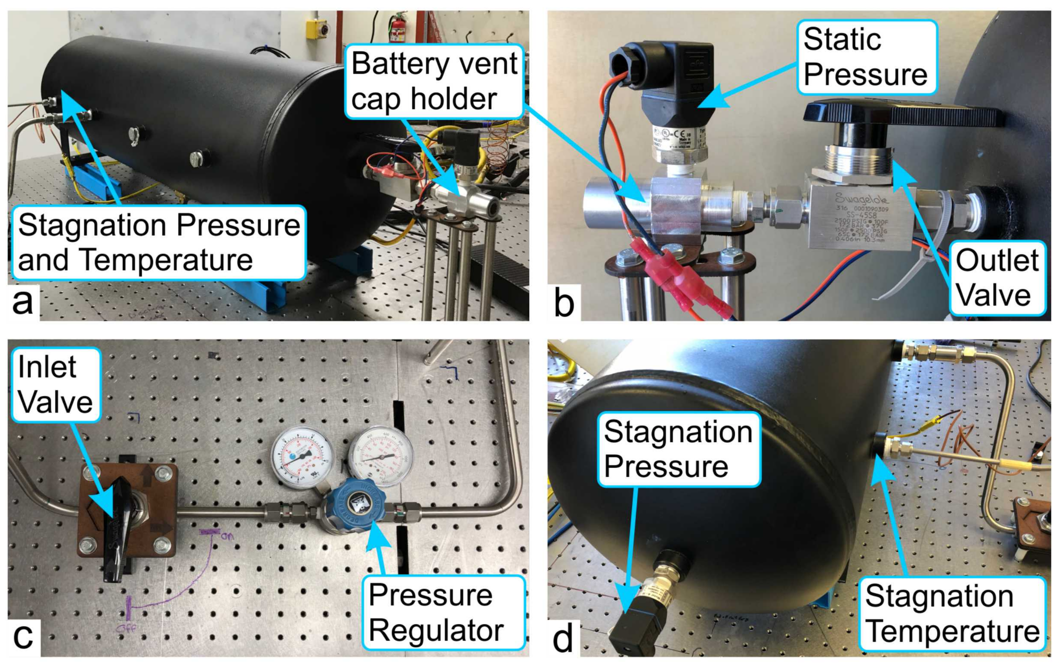
Vent cap burst fixture:

- Measure burst pressure with inert gas up to 3.45 MPa
- Accommodations for off-the-shelf construction or custom imaging



Choked orifice testing apparatus:

- Measure opening area and discharge coefficient from stagnation properties and vent holder geometry
- Tests are performed on vent caps after testing with vent cap burst fixture



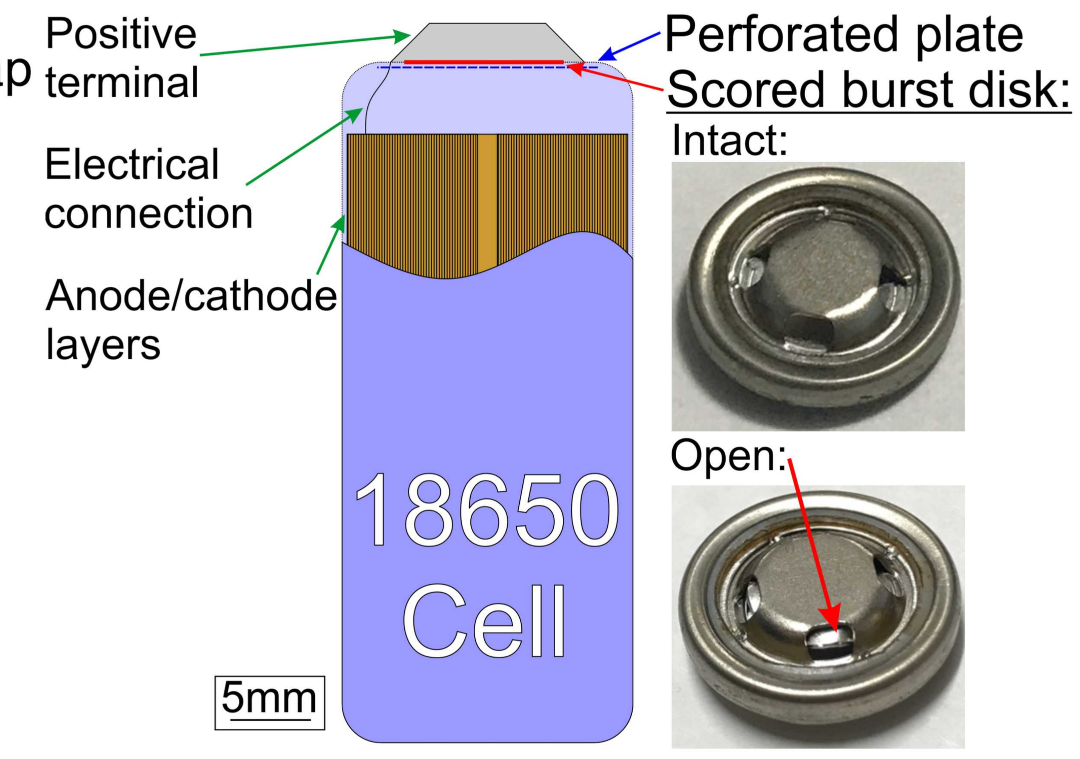
Measuring venting parameters from 18650 cells

Experiments were designed to measure the burst pressure, opening area, and discharge coefficient from 18650 cell vents regardless of manufacturer [1]. These parameters describe the the flow as it exits the cell. Vent caps tested can either be sourced as components or removed from live cells. As shown below, mean parameters can vary between cell manufacturers.

Vent brand	Burst pressure (MPa)	Opening area (mm^2)	Discharge coefficient at P_0/P_{atm} = 2.6
MTI	2.158	8.967	0.850
LG	1.906	7.025	0.814

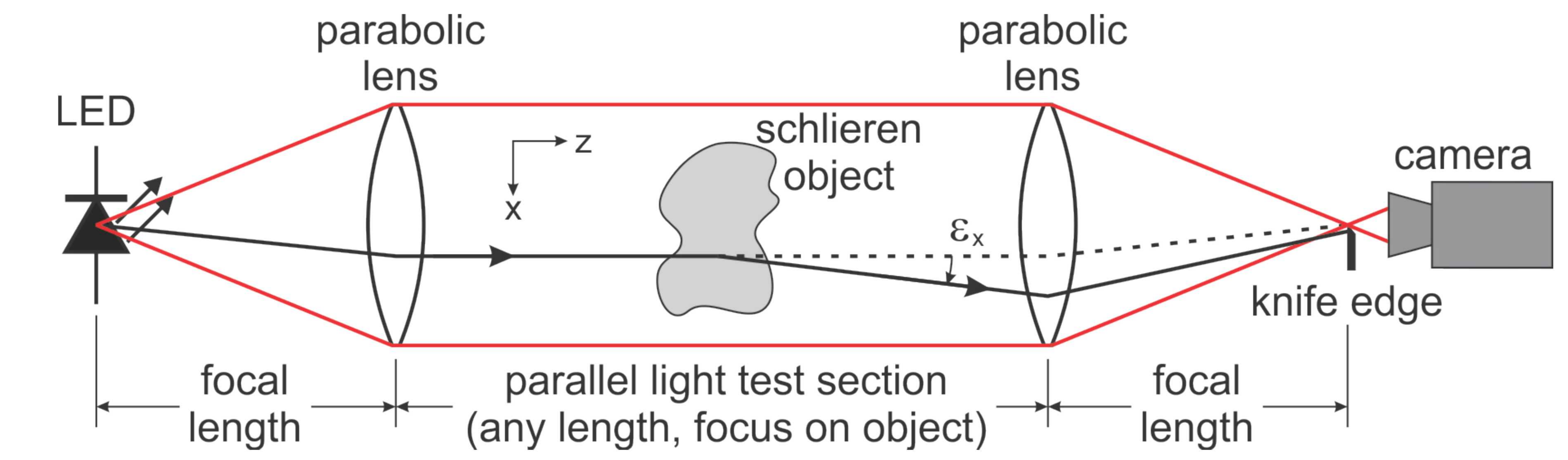
18650 battery anatomy

- Pressure relief vents on 18650 cells are built into a crimped cap which is also the positive terminal.
- Vent construction varies between manufacturers:
  - Differing flow paths and burst pressures.
  - Uniform experiments apply to all cell makes.
- Vents can only actuate once and remain open after burst.



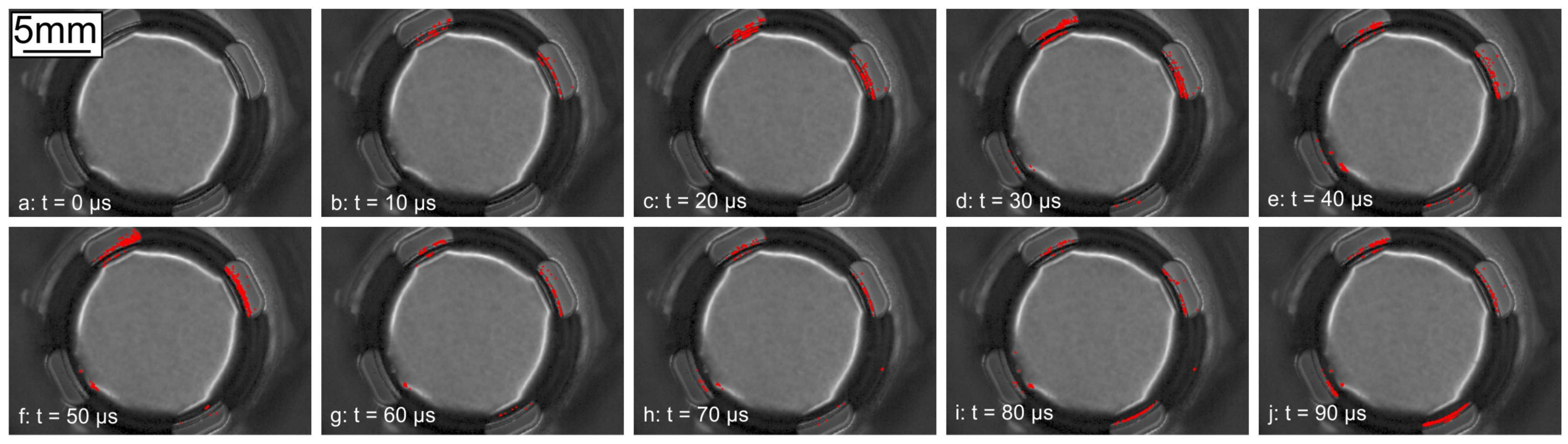
High-speed schlieren imaging

Schlieren imaging was performed to visualize the simulated gas flow field immediately after vent opening. Represented below, light from a point source is collimated through the test section by a parabolic lens, and a second parabolic lens refocuses the light onto a knife edge which evenly blocks a portion of the light throughout the image. Within the test section, variations in gas density and chemical species refract the light which refocuses in a new location either missing or being blocked by the knife edge. This causes the characteristic light-to-dark gradients within the image.



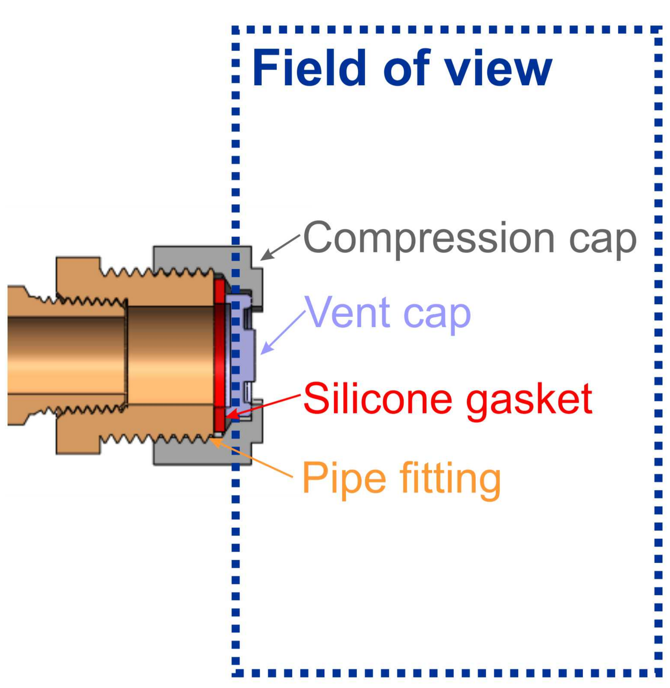
High-speed imaging of vent opening

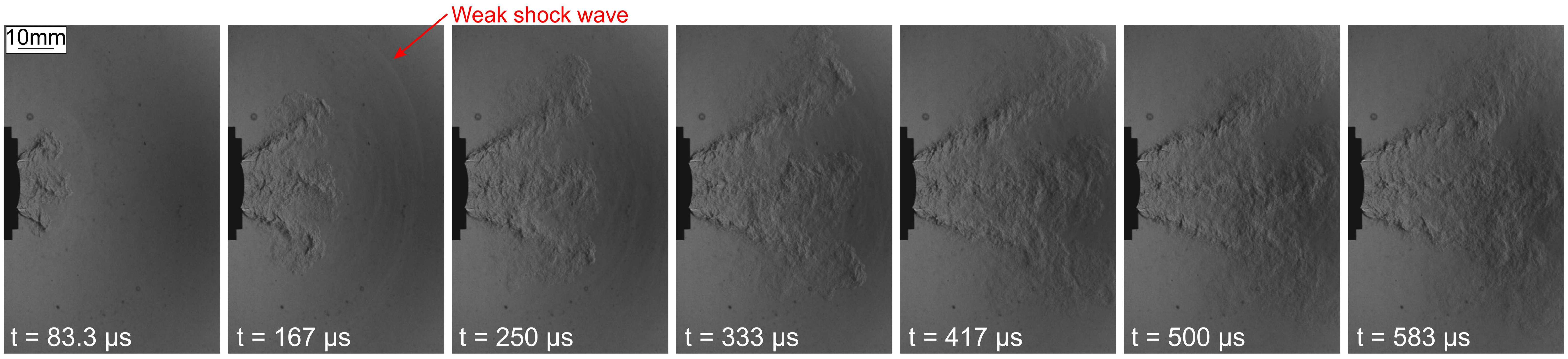
A vent cap was directly imaged with a frame rate of 100 kHz to show burst disk opening. An image processing routine was created to highlight open portions of the scored perimeter of the burst disk. As seen below, the opening starts from a single point which spreads around the perimeter before meeting on the opposite side of the scored burst disk. The vent was fully open within 90 *μs*.



Schlieren imaging test results

The vent cap burst fixture was configured to allow imaging of vented gas with minimal obstruction to the field of view. Carbon dioxide was used to mimic the fluid dynamics during failures of live cells and increase the gas visibility within the schlieren images as shown below. Images were recorded at a frame rate of 48 kHz, and time stamps correspond to the time elapsed since the first noted venting. Venting can be seen with the leading edge of the jet traveling approximately 150 m/s over the first 417 *μs* of venting. Individual jets correspond to each of the four openings in the positive terminal (where the central jet corresponds to two openings overlapping within the field of view). Jet propagation is fairly uniform between openings as the vent is approximately fully open by the *t = 83.3 μs* frame. Additionally, weak shock waves (approximately Mach 1) were seen at *t = 167 μs* as previously observed during failures of other cylindrical cells under thermal and overcharge abuse [2].





Conclusions

Understanding the gas flow field from a venting 18650 cells is key to evaluating the safety risks of batteries under abuse conditions. Testing with vent caps removed from cells has allowed unique measurements under a more controlled environment than a live cell failure. High-speed imaging has shown how the vent itself opens, and schlieren imaging provides information of the location and velocity of vented gases within a transient flow field.

References and Acknowledgements

- [1] Mier, F. A., 2018. “Measurement of 18650 format lithium ion battery vent mechanism flow parameters”. Master’s thesis, New Mexico Institute of Mining and Technology.
- [2] Mier et. al., Overcharge and thermal destructive testing of lithium metal oxide and lithium metal phosphate batteries incorporating optical diagnostics, J. of Energy Storage 13C (2017) pp. 378-386

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