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Measurement of 18650 format lithium ion battery vent mechanism flow parameters

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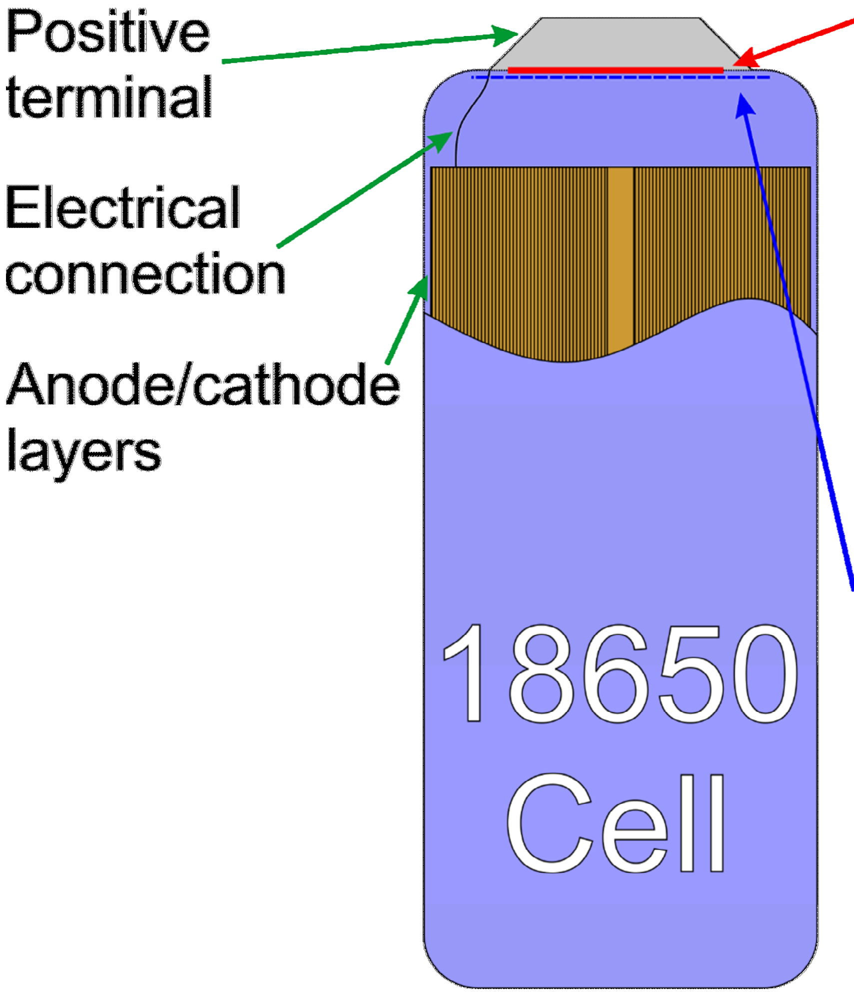
Quantifying vent mechanism opening parameters to describe venting

- Most cells have a vent to relieve pressure during thermal runaway
- Avoids case rupture but still presents safety concerns including flammability
- Burst pressure, opening area, and discharge coefficient assist gas and liquid flow description
  - Flow rates
  - Atomization patterns
  - Velocity fields

- LG MG1 (NMC)
- Overcharge and heating
- Elapsed time: 160 ms
- Frame rate: 5 kHz

Direct measurements with vent caps removed from 18650 cells



Scored burst disk:

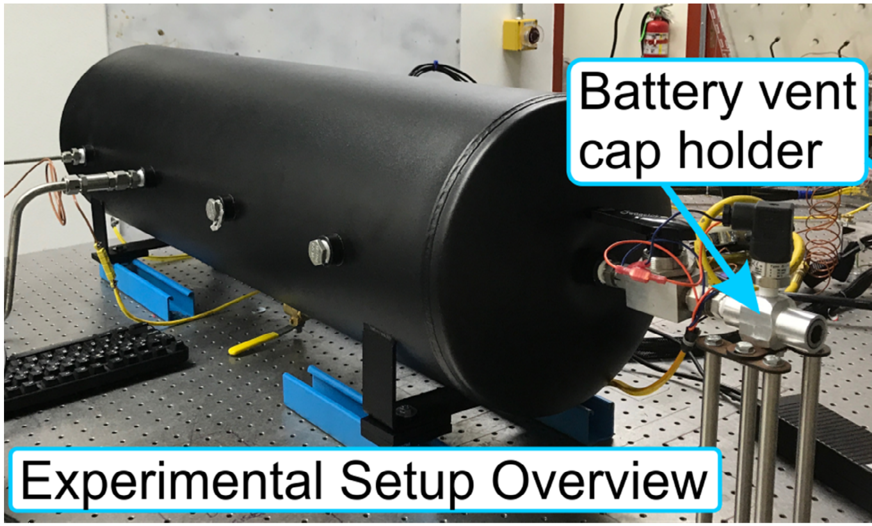
Intact:

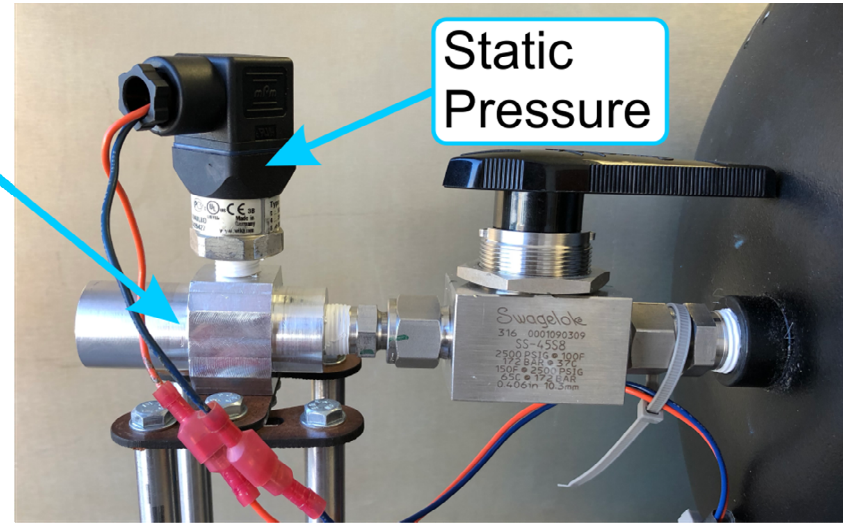
Open:

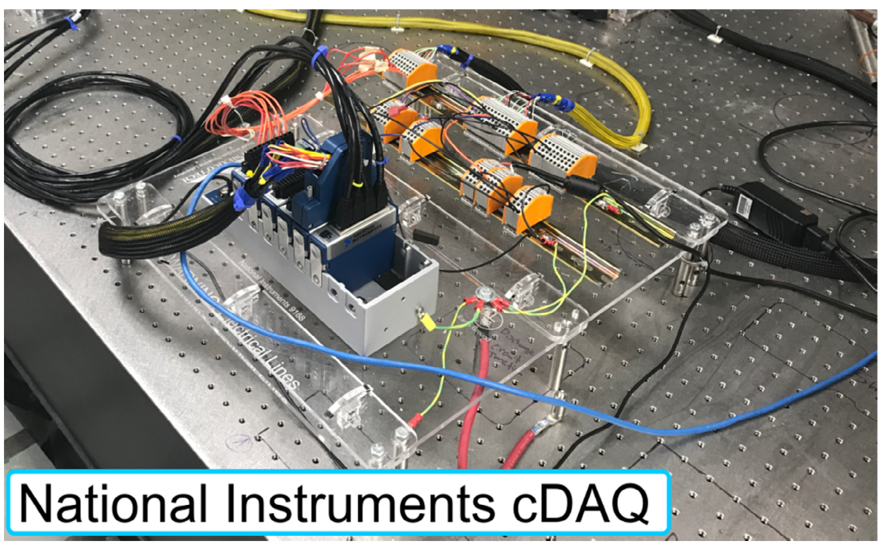
Perforated plate:

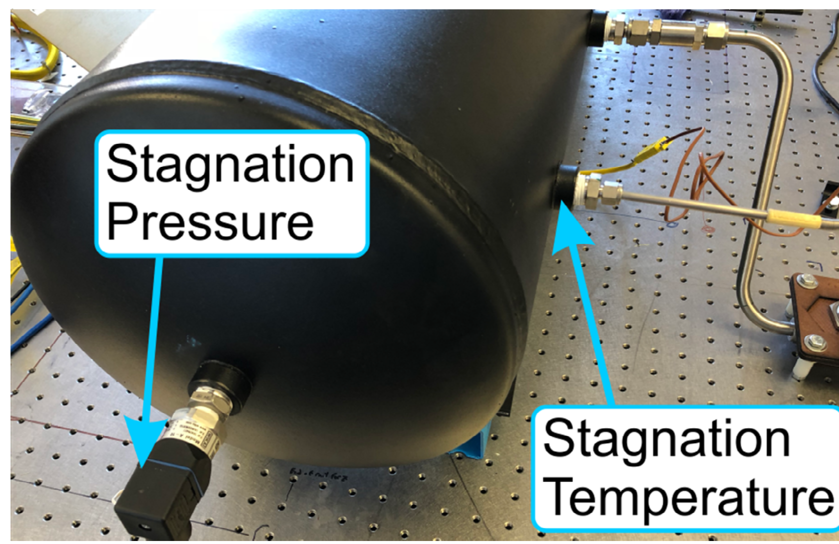
- Different geometries from various manufacturers

Development of a vent cap pressurization test apparatus



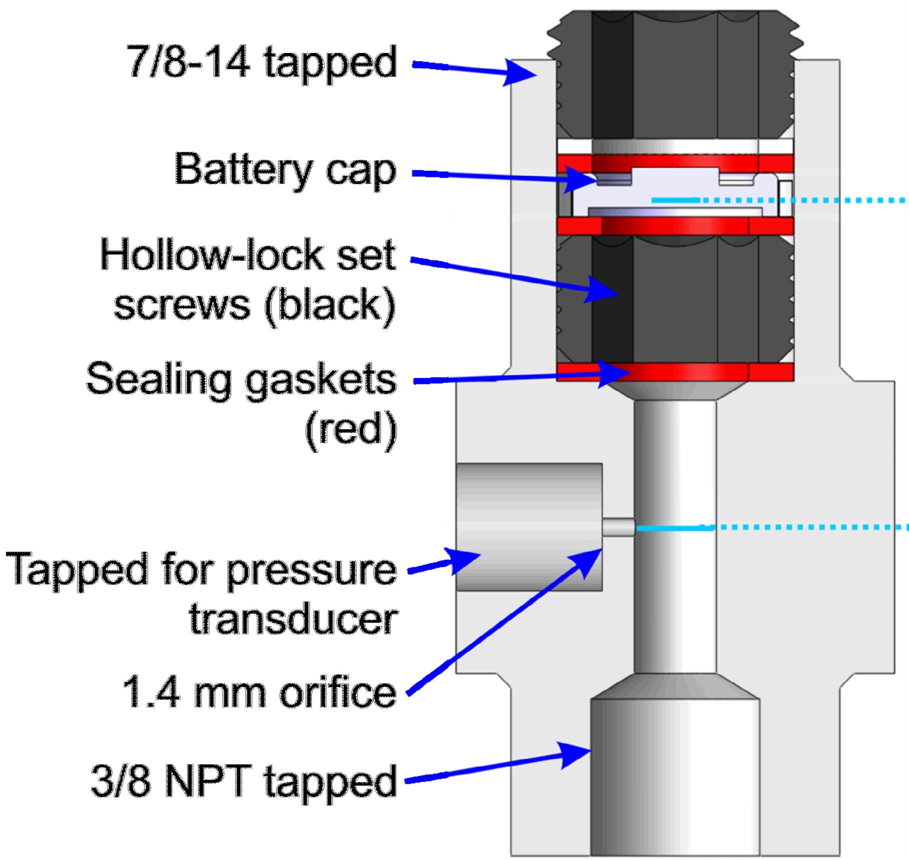




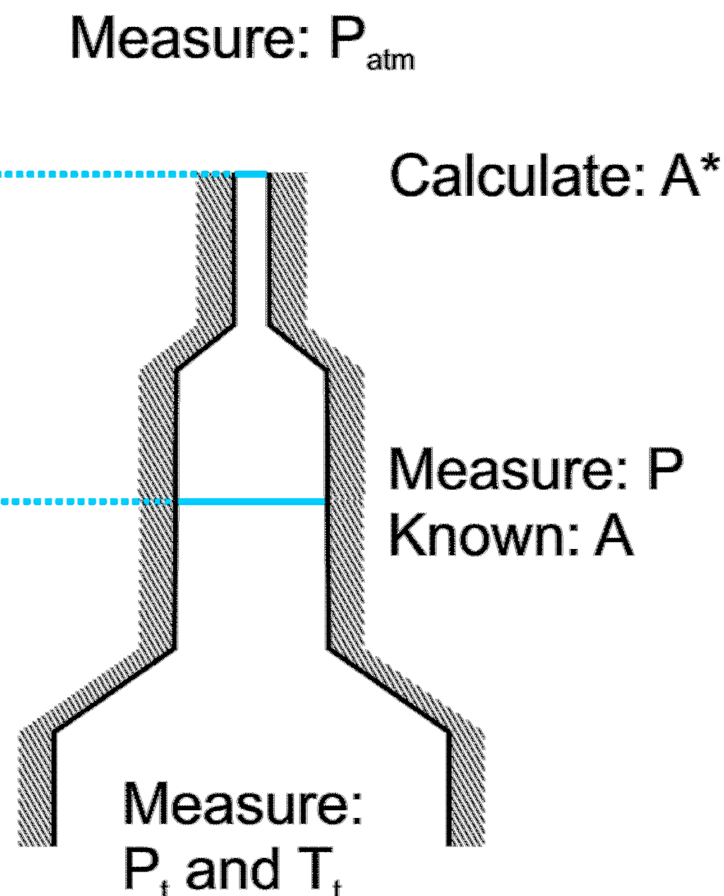


The vent cap pressurization apparatus is a choked nozzle

<u>Vent Cap Holder:</u>



<u>1-D Nozzle:</u>



Opening area calculation from isentropic flow relationships

- Mach number at the flow constriction via pressure ratio:

$$\frac{P_t}{P} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma-1}}$$

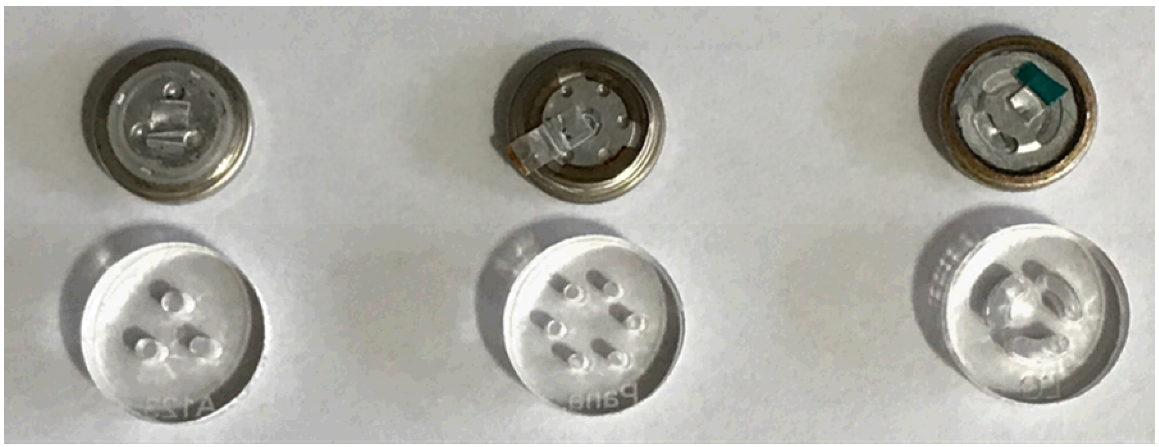
- Vent area is the sonic condition (*A**) for choked flow:
  - Area (*A*) and Mach number (*M*) reference constriction

$$\frac{A}{A^*} = \frac{1}{M}\left(\frac{\frac{\gamma+1}{2}}{1 + \frac{\gamma-1}{2} M^2}\right)^{\frac{\gamma+1}{2-2\gamma}}$$

- Similar calculation made when flow is not choked
  - Define an arbitrary sonic cross section (*A**)
  - Assume static pressure at the vent is atmospheric

Opening area validation tests with known orifices

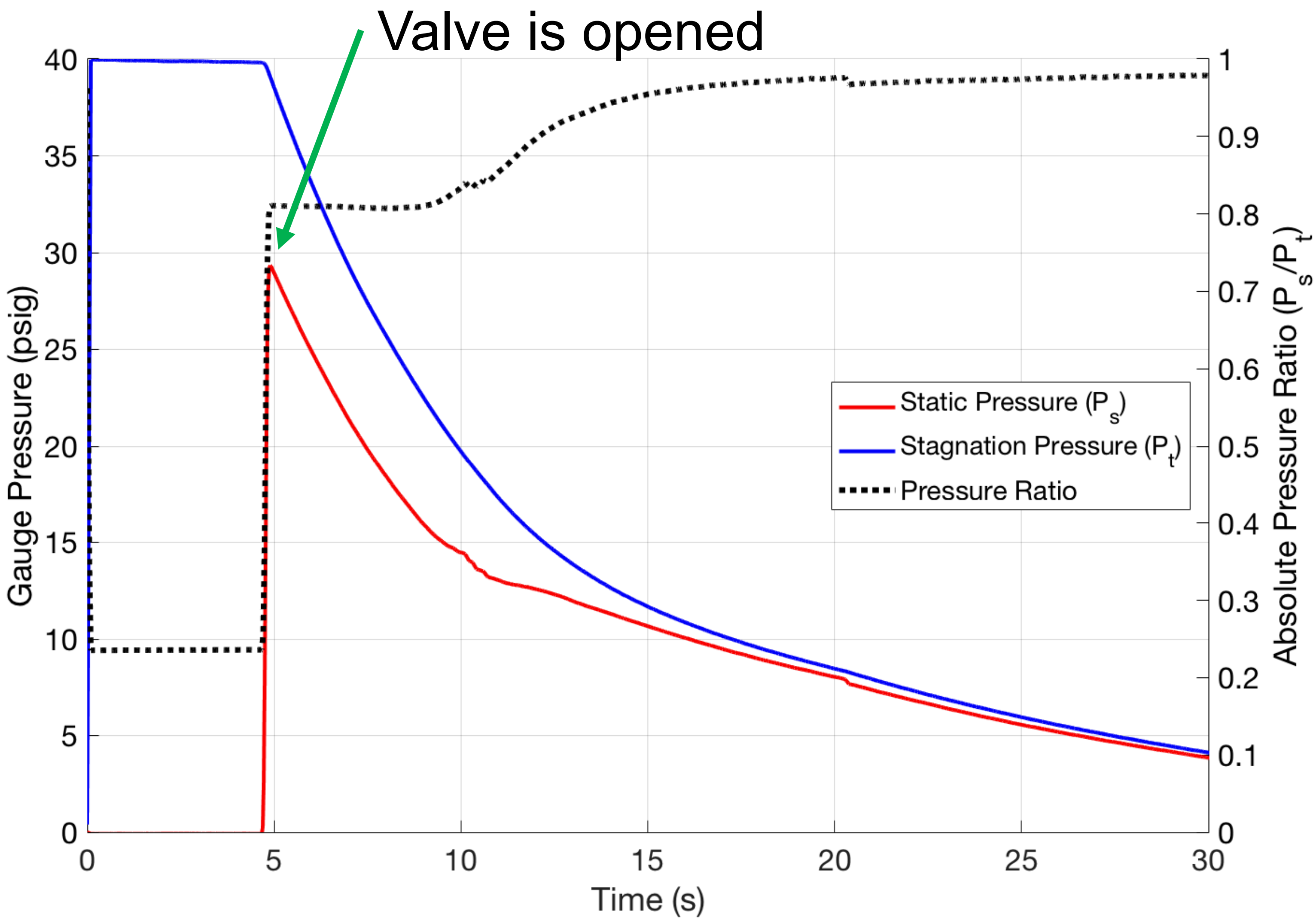
- Laser cut acrylic orifice plates to replace battery cap
  - Twenty individual circular orifices plates
  - Three mock 18650 vent caps



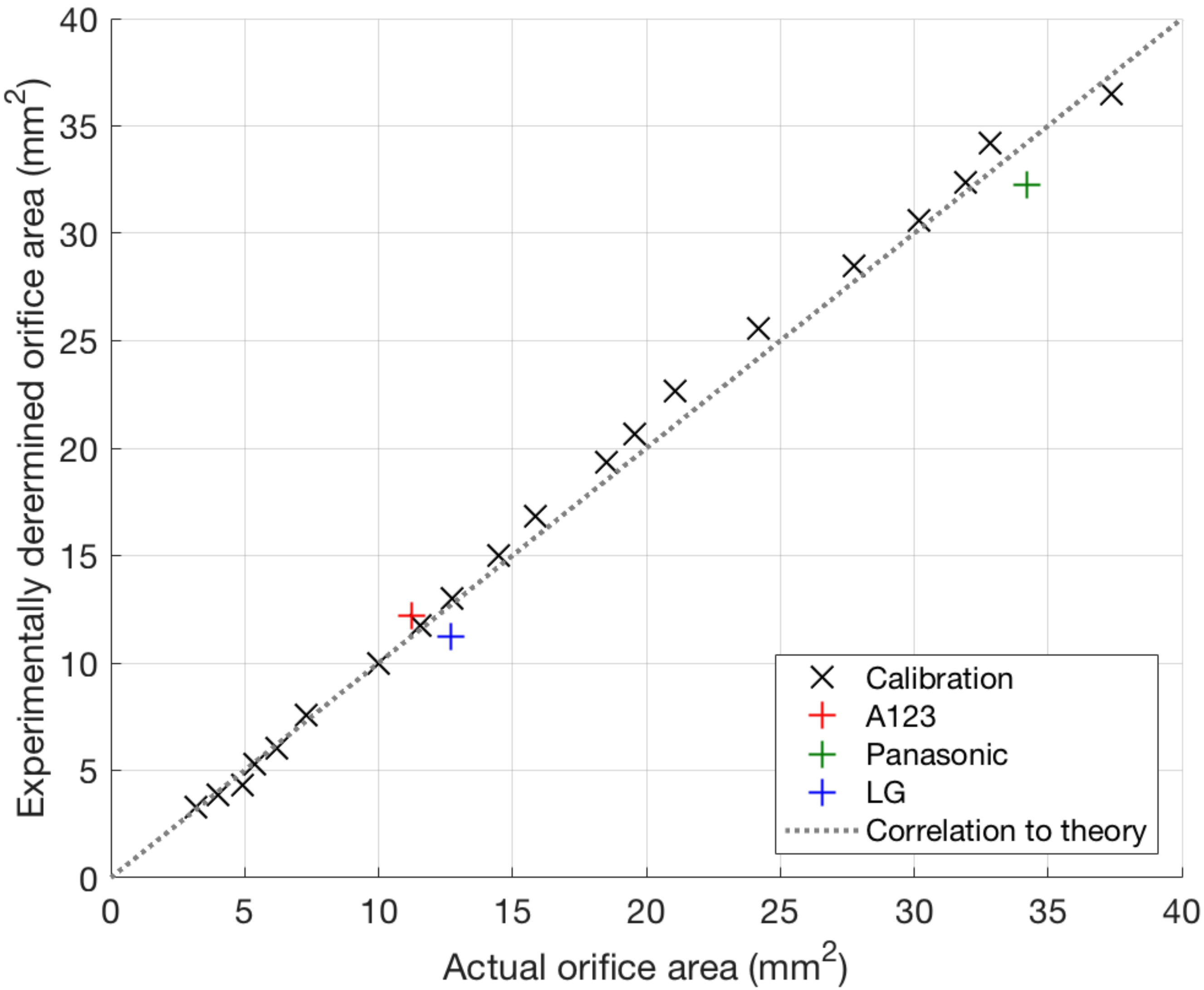
A123 LG Panasonic

- Accumulator tank pressurized to 40 psig for each test
- Manually operated ball valve to simulate vent opening

Sample of data recorded during a single validation test (mock Panasonic)



Validation test results with orifice plates



Initial testing attempts with vent caps from LG HE2 (LCO) cells

Trial	Burst Pressure (kPa)	Opening area (mm^2)
1	1,940.9	7.3
2	1,823.7	7.1
3	1,992.6	6.5

- Maximum possible opening area: 12.7 mm^2

Vent opening

Calculating discharge coefficient (C_d)

- Discharge coefficient is defined as the ratio of actual (*a*) mass flow to theoretical (*t*):

$$C_d = \frac{\dot{m}_a}{\dot{m}_t}$$

- Where theoretical flow rate can be calculated from stagnation properties (P_t and T_t) and choked cross sectional area (A^*):

$$\dot{m}_t = \frac{P_t}{\sqrt{RT_t}} A^* \sqrt{\gamma} \left(1 + \frac{\gamma - 1}{2}\right)^{\frac{\gamma+1}{2-2\gamma}}$$

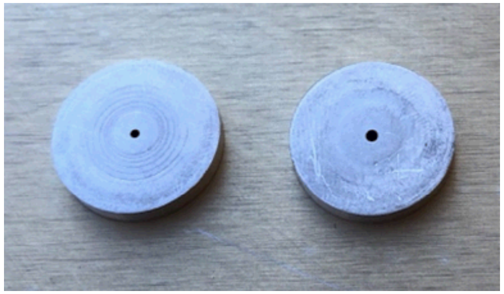
- With no inlet during venting, the actual flow rate can be calculated from conservation of mass for an Ideal Gas:

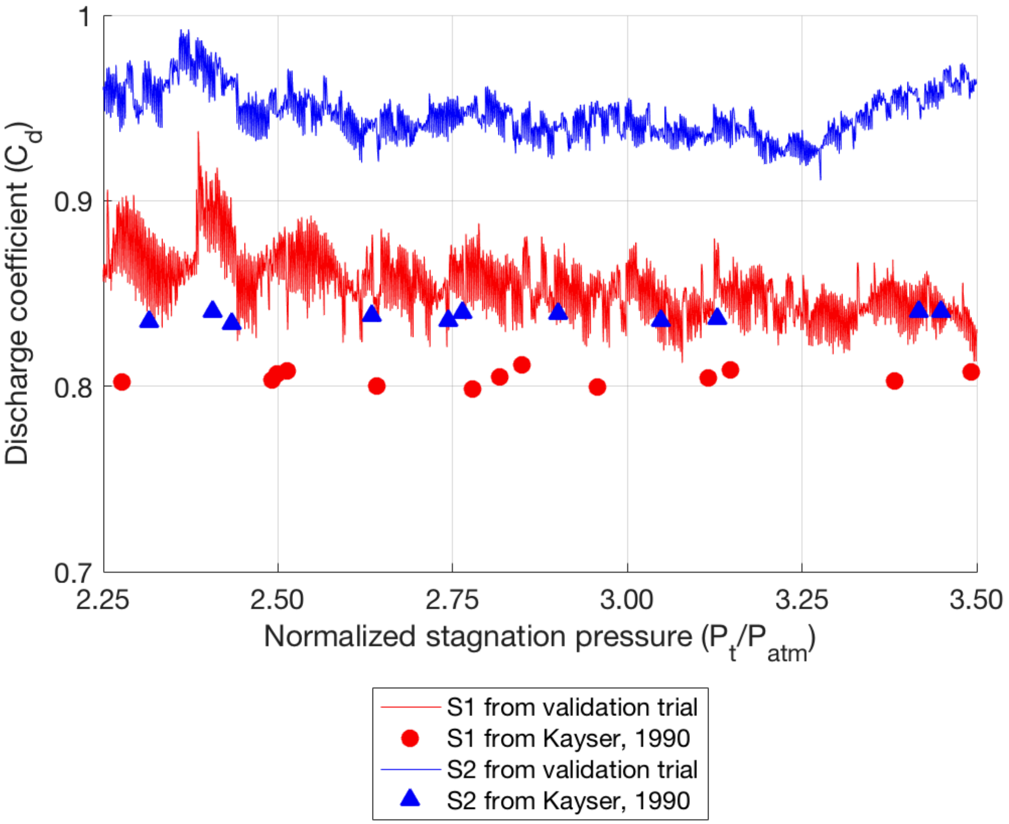
$$\dot{m}_a = -\frac{V}{R} \cdot \frac{d}{dt}\left(\frac{P}{T}\right)$$

Discharge coefficient calculation comparison to literature

- Machined straight bore orifices with diameters of 1.13 mm (S1) and 1.41 mm (S2)
- C_d values are constant between pressure ratios of ~2.25 to ~3.5

S1: S2:





Progress and expected outcomes from direct pressurization testing

- Designed and validated test apparatus to measure the burst pressure and opening area of vent caps from 18650 cells

- Initial exploration into calculating the discharge coefficient on machined straight bore orifices.

- Direct pressurization tests describe when vent caps can be expected to open and how subsequent flow of gases and liquids will occur

Questions?

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