

Detailed Characterization of Emissions from Li-ion Battery Fires

SOUTHWEST RESEARCH INSTITUTE®

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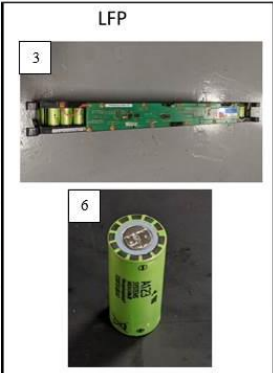
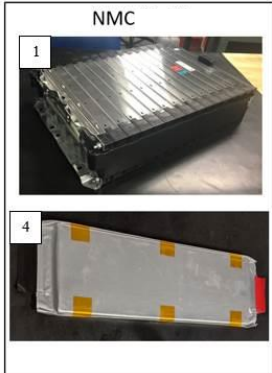
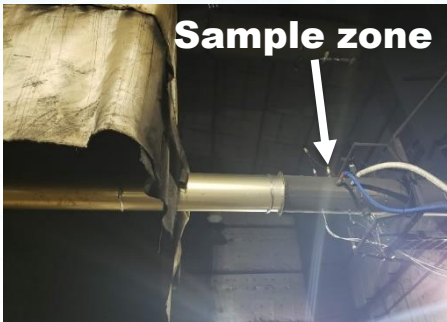
Vinay Premnath, Lead Engineer



Overview

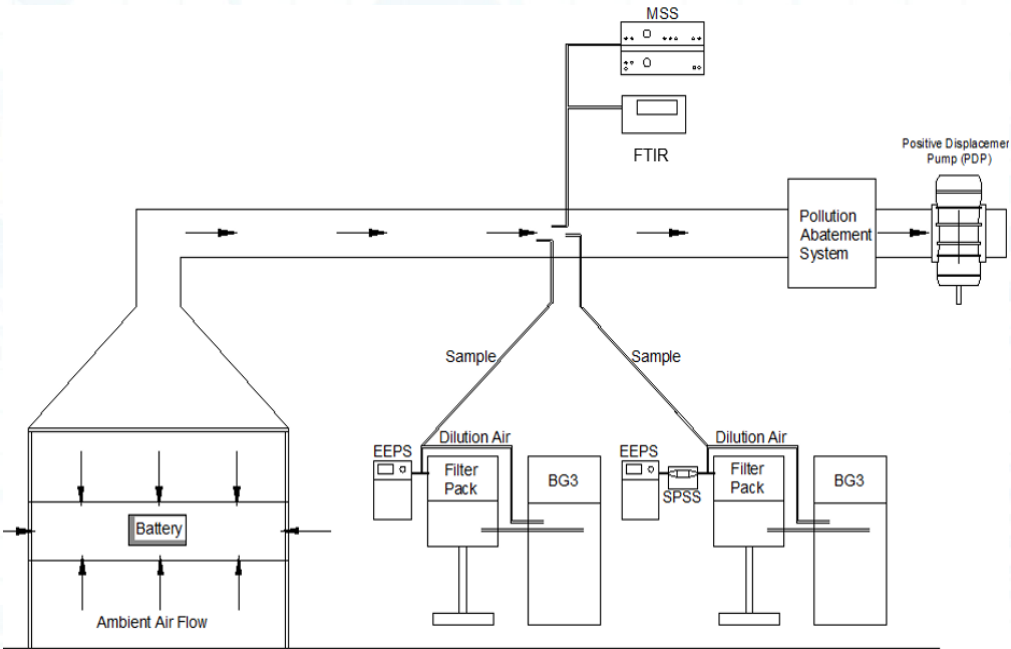
- Objectives:
 - To investigate emissions from Li-ion battery fires triggered by thermal runaway
 - Focus was primarily on ‘fine’ particle emissions ($<2.5\ \mu\text{m}$)
 - Develop a robust process to capture such emissions
 - Conducted detailed characterization of particle emissions from Li-ion battery fires triggered by thermal runaway
 - Lithium nickel manganese cobalt (NMC) oxide and Lithium iron phosphate (LFP) chemistries were evaluated
 - Five tests were conducted to gain information on repeatability, impact of battery chemistry, and initiation mechanism on emissions
 - Test 1 – LFP via nail penetration
 - Test 2 – LFP via nail penetration
 - Test 3 – LFP via overcharging
 - Test 4 – LFP via overcharging
 - Test 5 – NMC via nail penetration
 - All modules charged to full SOC
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- The diagram uses brackets to categorize the five tests listed above. A red bracket groups Test 1 and Test 2, labeled 'Variability'. A green bracket groups Test 3 and Test 4, labeled 'Initiation mechanism'. A blue bracket groups all five tests (Test 1 through Test 5), labeled 'Battery chemistry'. Additionally, a red bracket groups Test 5, also labeled 'Variability'.

Experimental Methods



	LFP	NMC
Cell chemistry		
Battery type	Cylindrical	Pouch
Capacity, Ah	2.5	60
Cutoff voltage, V	3.6	4.2
Maximum cont. charge rate, A	10	60
Maximum cont. discharge rate, A	60	120
Dimensions, mm	26 ϕ , 66.5 height	16.5 x 100 x 330
Weight, g	70	820
Module configuration	8P12S	3P10S
Module Energy, kWh	0.864	7.56

Modules were instrumented with temperature and voltage sensors



- Test article placed inside the enclosure
- Particle/gaseous emissions sampled from inception to completion – no control systems were engaged
- Sufficient oxygen was always present to simulate fire incidents occurring at ambient conditions

Emissions Instrumentation

Soot – AVL micro-soot sensor



Total Particle Sizer – PN/size (volatile + solid)

Solid Particle Sampling System (SPSS)



+



Solid Particle Sizer – PN/size (metallic + soot, no volatiles)

PM measurement – Sierra BG-3



+

Heat-Pak



PM filter

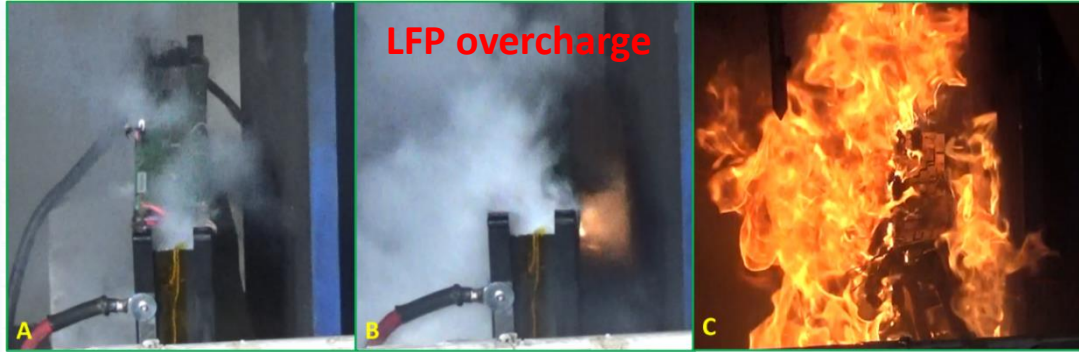
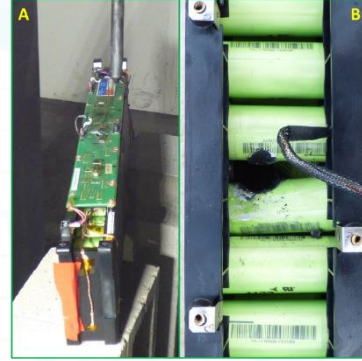


- Particle measurements included
 - Real-time soot concentration
 - Real-time total particle number/size
 - Includes volatile + solid particles
 - 5.6 nm to 560 nm
 - Real-time solid particle number/size
 - Includes metallic + soot particles (no volatiles)
 - 5.6 nm to 560 nm
 - Particulate Matter mass (PM2.5)
 - Regulated air quality metric
- Gas measurements were conducted using an FTIR
 - CO, CO₂, NO, NO₂, HCN, HCl, HF, CH₂O, CH₄ and C₃H₈

Results-I Physical Observations



LFP nail
penetration



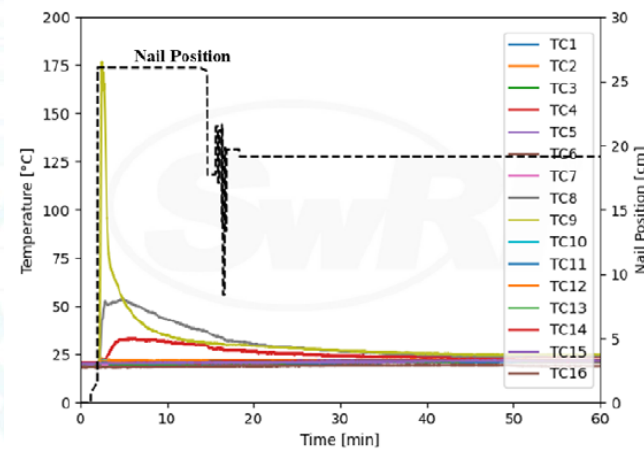
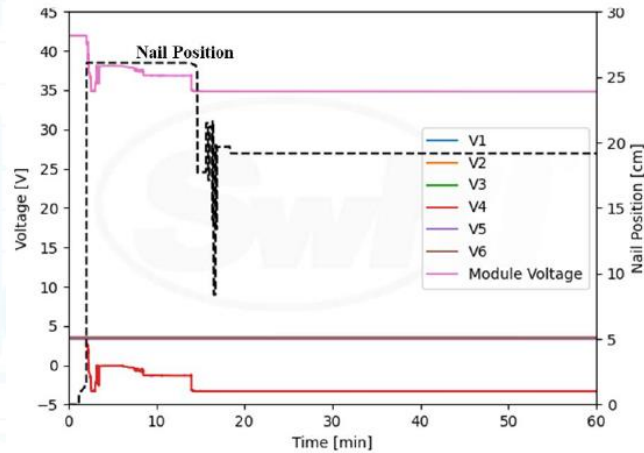
NMC nail
penetration



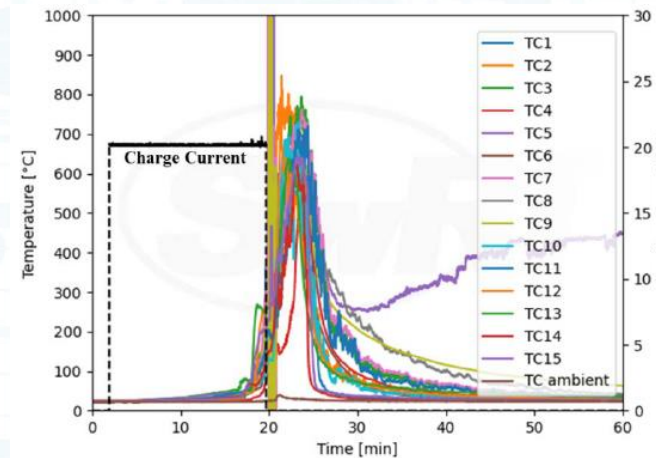
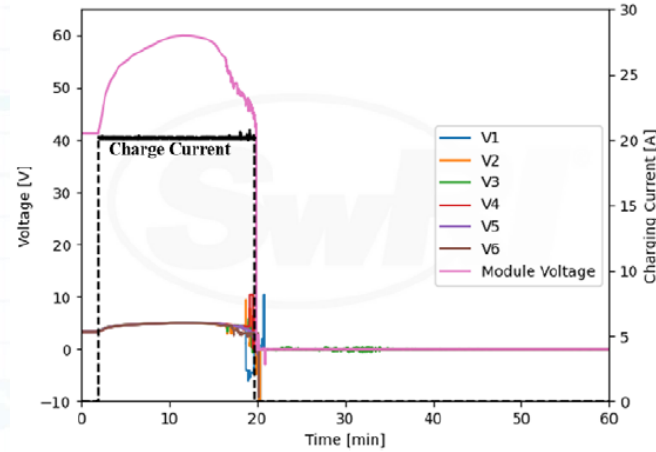
- LFP nail-penetration tests
 - Only cells in the path of the nail experienced thermal runaway
- LFP overcharge tests
 - All cells in the module experienced thermal runaway
 - Significant smoke and fire was observed
- NMC nail-penetration tests
 - All cells in the module experienced thermal runaway
 - Thermal runaway propagation was observed cell-to-cell
 - Significant smoke and fire was observed

Results-2 Battery Parameters

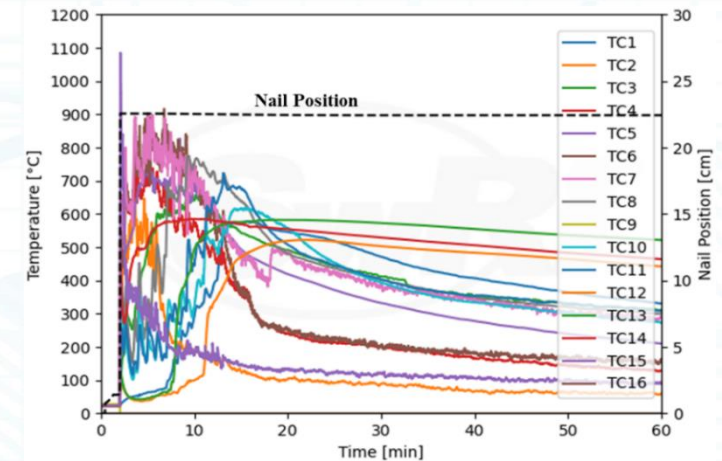
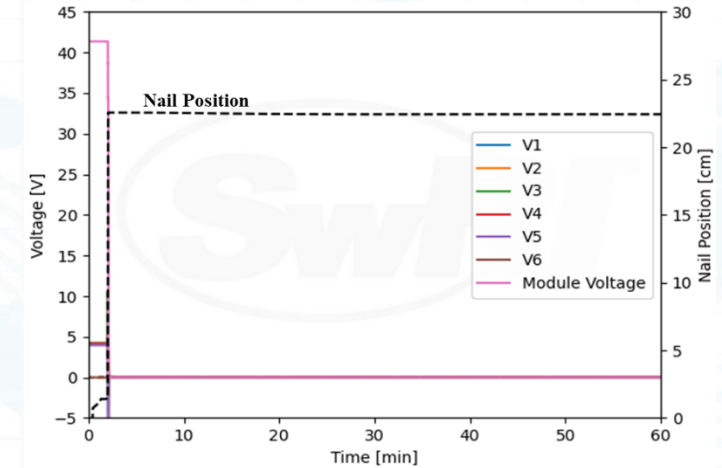
LFP via nail-penetration



LFP via overcharging



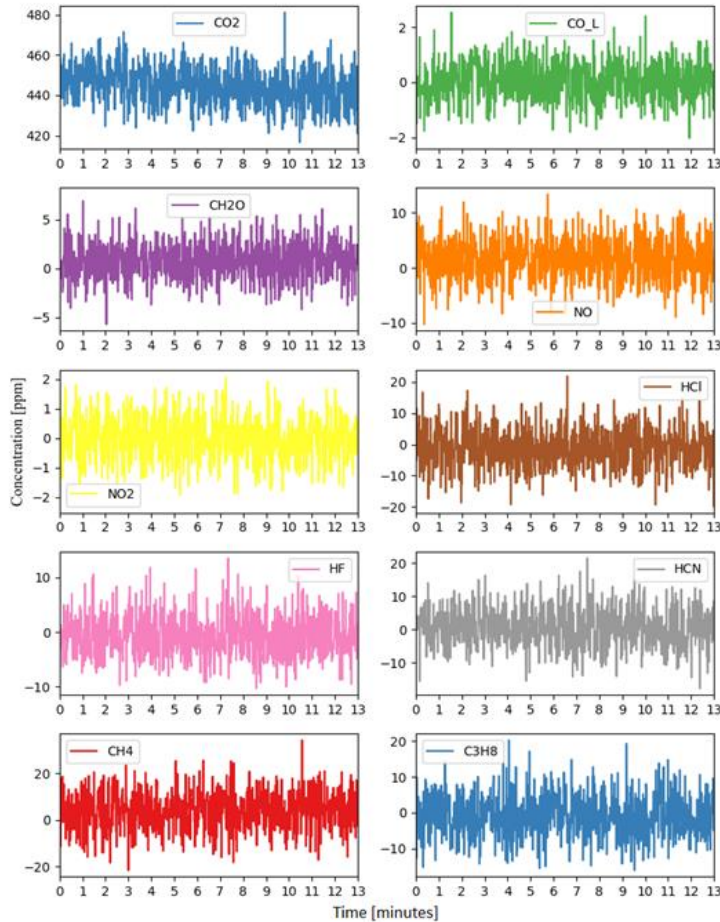
NMC via nail-penetration



- All modules were charged to full state-of-charge
- LFP modules entered thermal runaway after about 15 minutes of overcharging

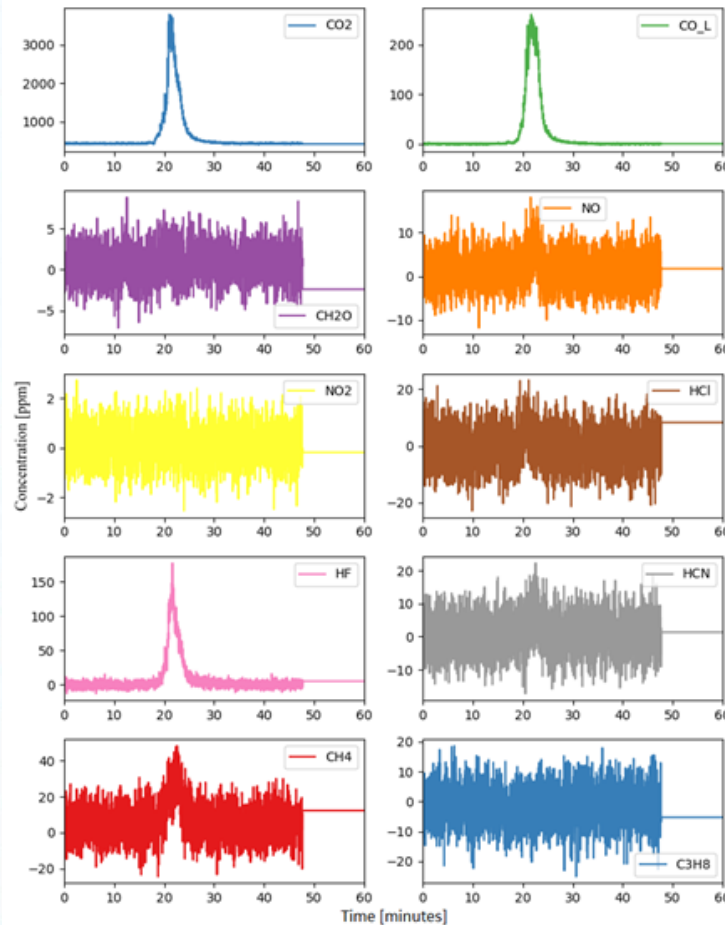
Results-3 Gaseous Emissions

LFP via nail-penetration



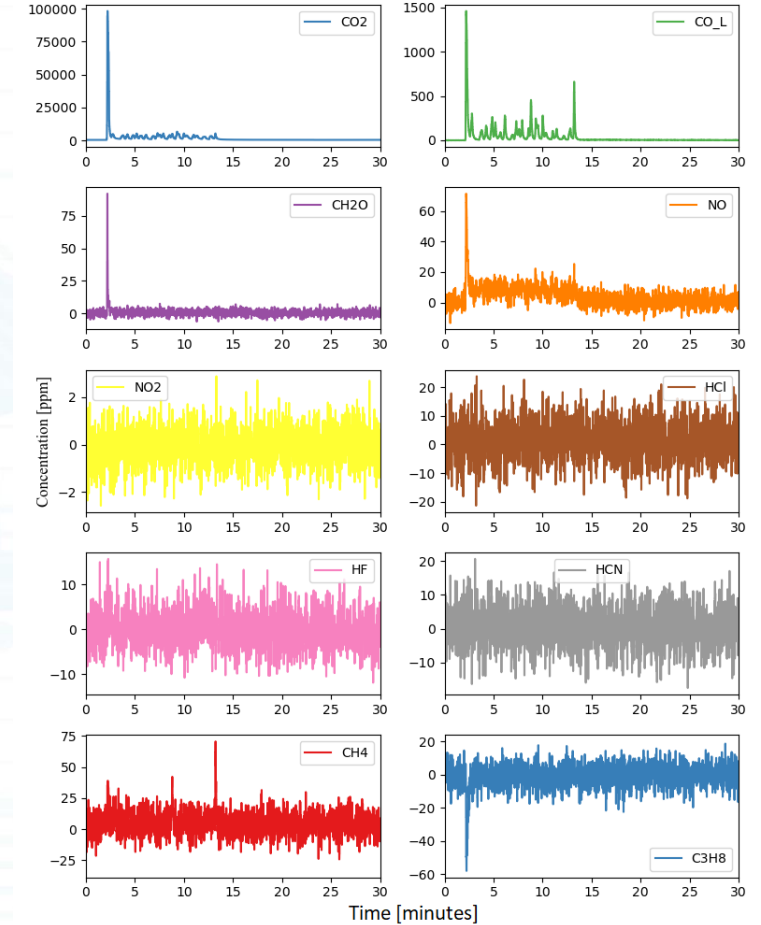
- LFP via nail-penetration (no significant emissions)

LFP via overcharging



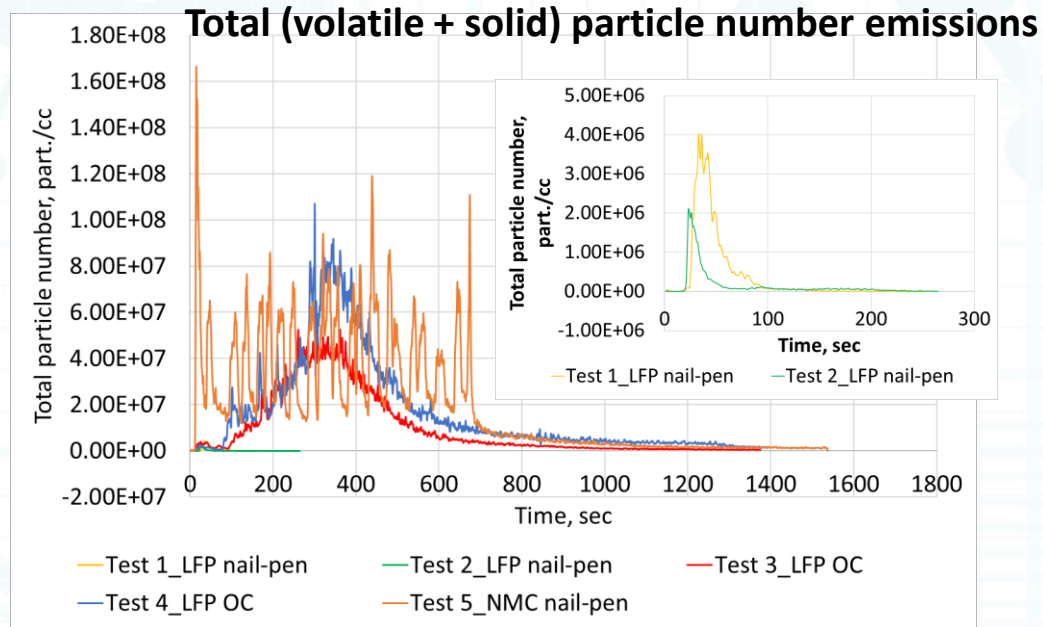
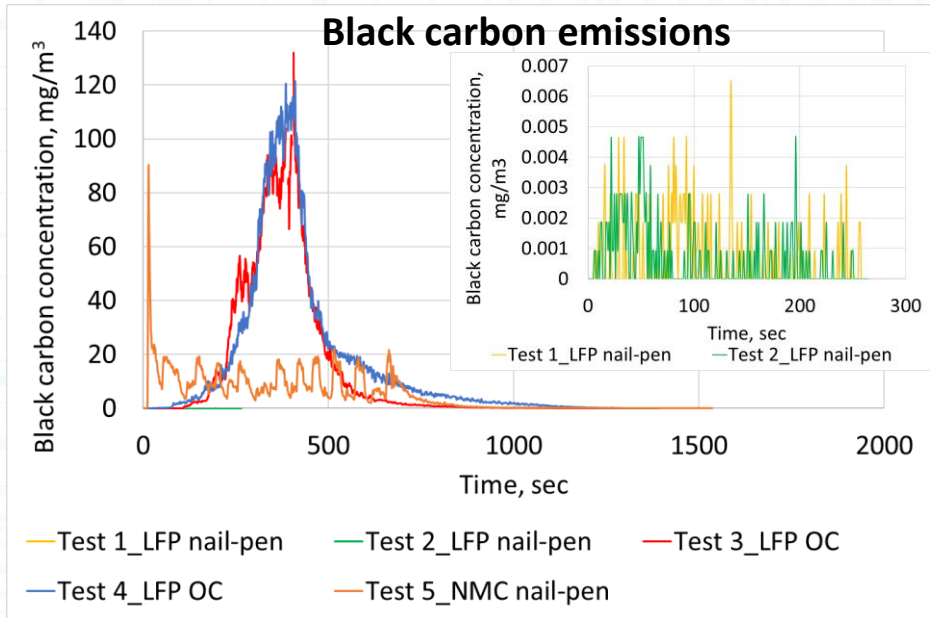
- High emissions observed for multiple gases
- HF exceeded immediately dangerous to life or health (IDLH) limit of 30 ppm

NMC via nail-penetration



- CO₂ peak 20 times higher than LFP
- Formaldehyde above IDLH limit of 20 ppm

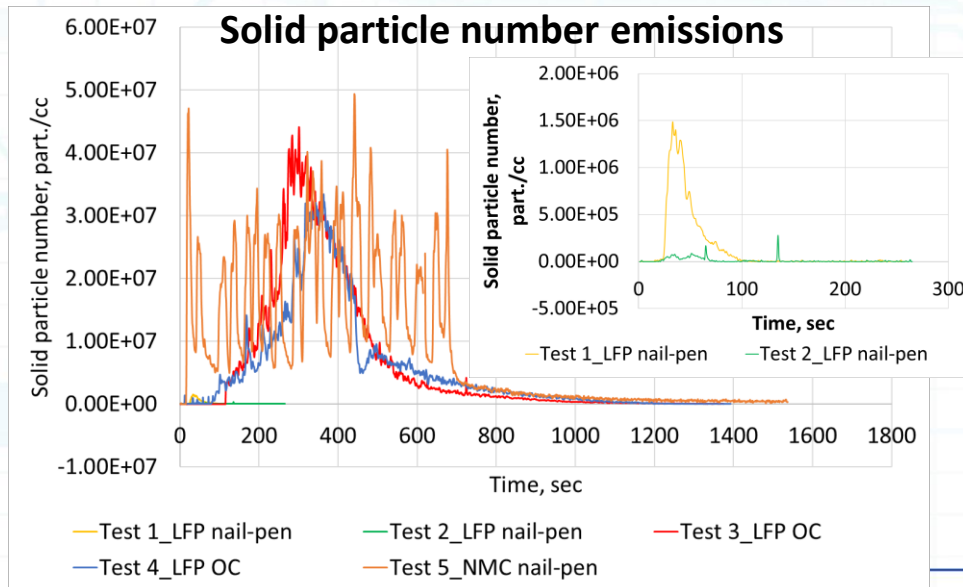
Results-4 Particle Emissions (Real-time)



Background PM filter



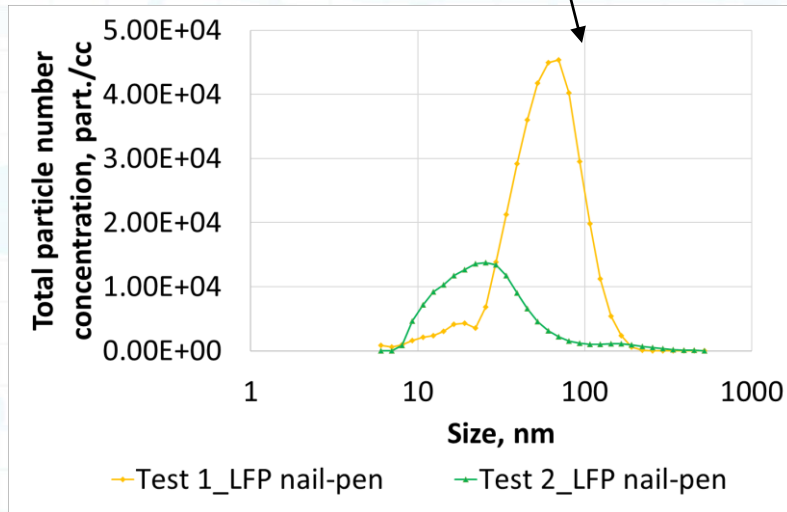
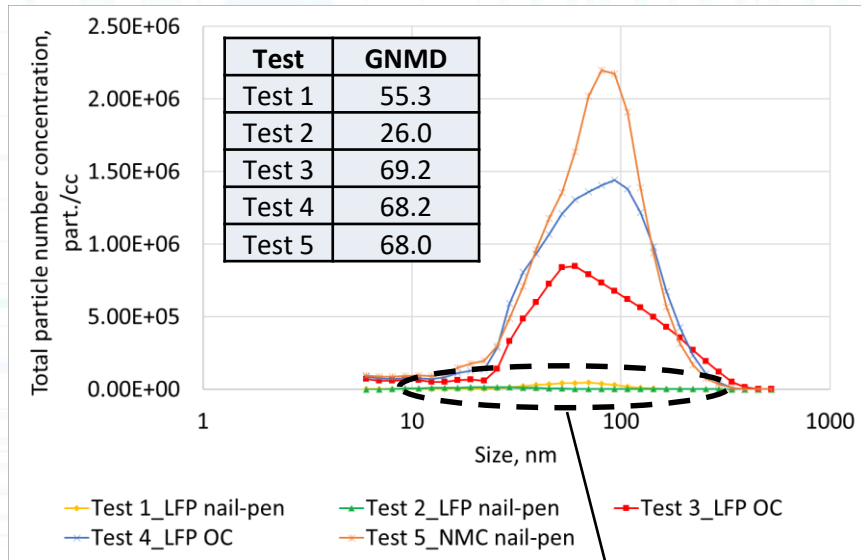
PM Filter for Test 4



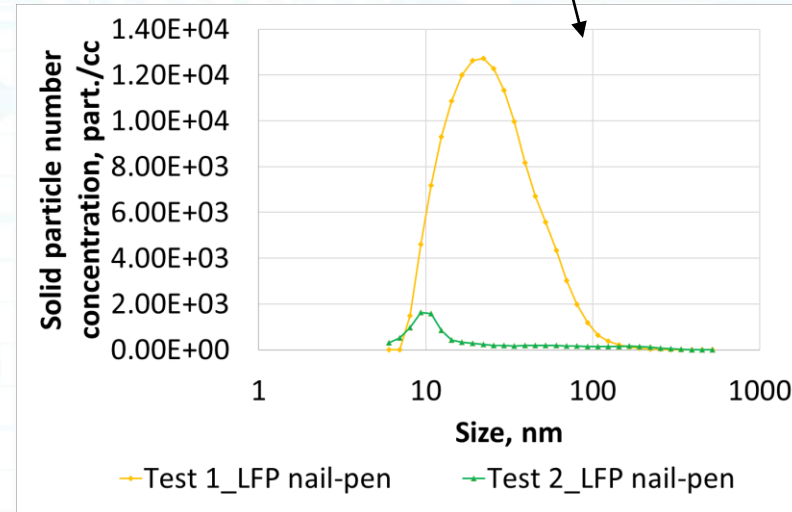
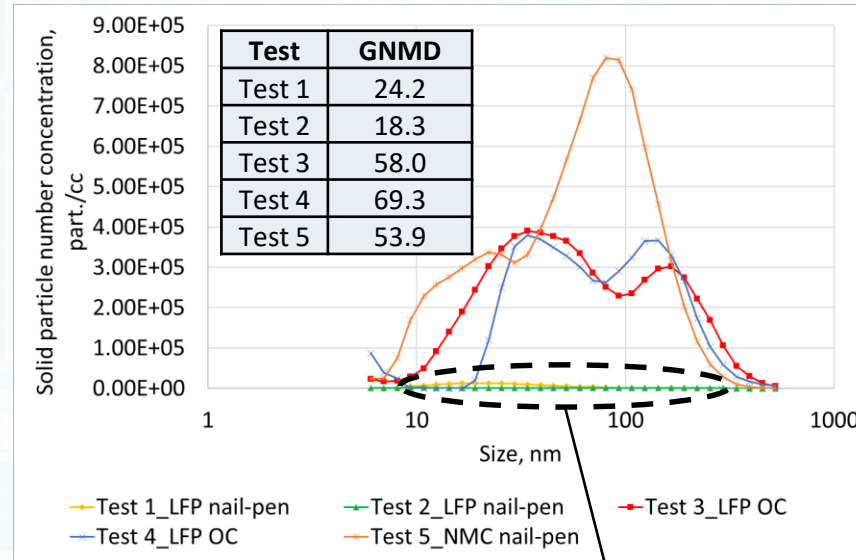
Test	Test duration, sec	PM2.5 emissions, g/hr	Black carbon emissions, g/hr	Solid PN emissions, part./hr	Total PN emissions, part./hr
Test 1_LFP nail-pen	260	1.81	0.00	1.56E+15	4.24E+15
Test 2_LFP nail-pen	266	0.00	0.00	1.12E+14	1.61E+15
Test 3_LFP OC	1376	386.09	149.90	8.89E+16	1.13E+17
Test 4_LFP OC	1392	375.97	185.78	6.11E+16	1.83E+17
Test 5_NMC nail-pen	1535	551.03	66.52	1.06E+17	2.08E+17

Results-5 Particle Size Distributions

Total particle size distribution



Solid particle size distribution



- Particles were observed to be in the respirable size range
- Peak of the distributions were in the sub 100 nm size range
 - Also called ultrafine particles that are known to be more harmful to human health
- All five tests exhibited unique size signatures, both, for solid and total particles

Summary

- Emissions from battery thermal runaway events can result in significant particle and gaseous emissions
- Initiation mechanism could play an important role in the scale of the thermal runaway event
- Battery chemistry coupled with initiation mechanism influences magnitude of emissions, along with release profile
- Physical dimensions and arrangement of cells within a module could influence the severity of the runaway event
- Emissions from thermal runaway events of identical modules induced into runaway via the same mechanism could be highly variable

Thank you for your attention!



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