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Model-based safety evaluation of thermal runaway risk for lithium-ion batteries in aerospace applications

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Motivation

- Lithium-ion batteries with high energy densities are used in various aerospace applications, such as drones and satellites, under extreme ambient conditions.
- In aerospace, the safety of the single battery cells is even more critical than for other applications, such as electric vehicles, stationary energy storages, or portable electronic devices.
- Fully parameterized and validated models can evaluate the thermal runaway risk for batteries under different conditions and limit the required amount of expensive safety tests [1].

Methodology

Thermophysical properties of the jelly roll

- Specific heat capacity and SOH-depending through-plane thermal conductivity on full-cell level determined by variant convective cooling method in a wind tunnel
- Thermal diffusivity on electrode-level measured with a laser flash apparatus

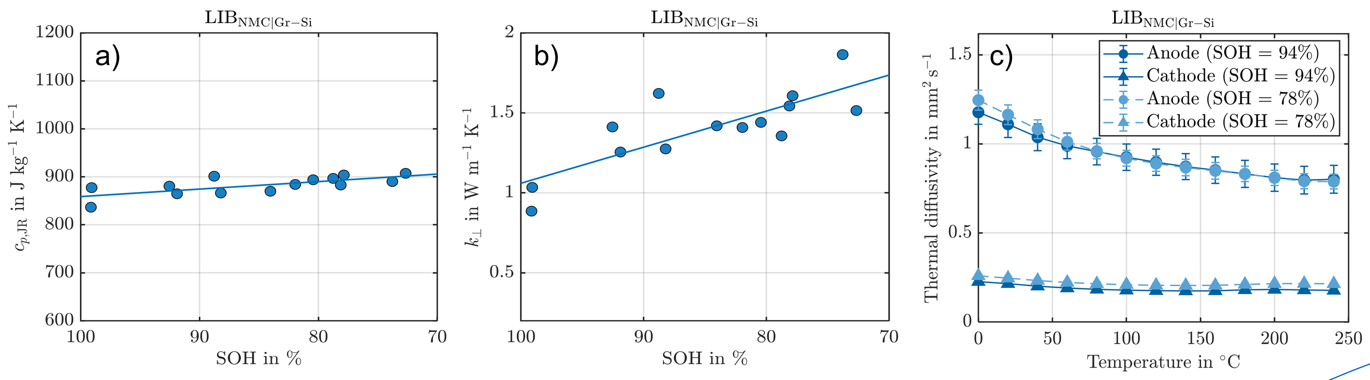

Figure 1 – Thermophysical properties: (a) specific heat capacity over SOH, (b) through-plane thermal conductivity over SOH, and (c) thermal diffusivity over temperature

Venting gas characteristics

- Custom venting test bench to measure gas temperatures up to 1400 °C and record venting dynamics using a high-speed camera with a resolution of 10,000 fps [2]
- Venting gas velocity calculated based on high-speed video image analysis
- Determination of venting duration for model validation

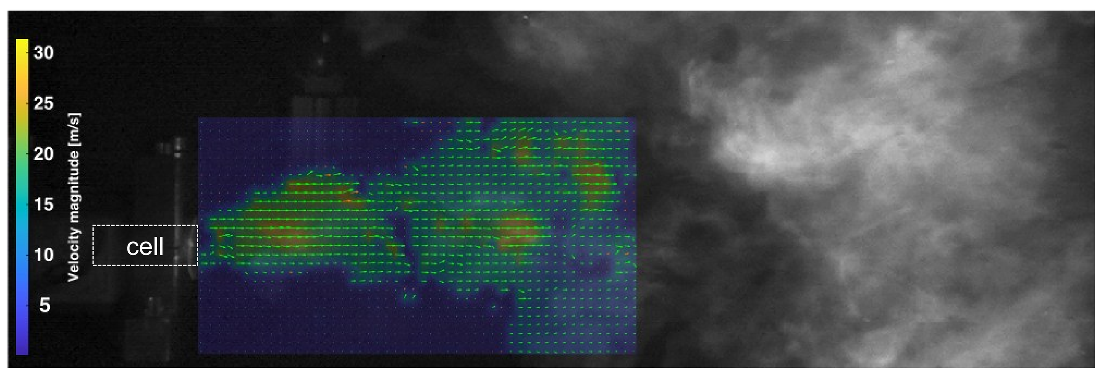

Figure 2 – Exemplary snippet of venting gas velocity estimation at the end of the venting phase using a fast fourier transformation algorithm in PIVlab

Thermal stability

- Accelerating rate calorimetry (ARC) to determine Arrhenius-based reaction rates [1]
- Better thermal stability of LFP compared to NMC-811 regardless of the cell format

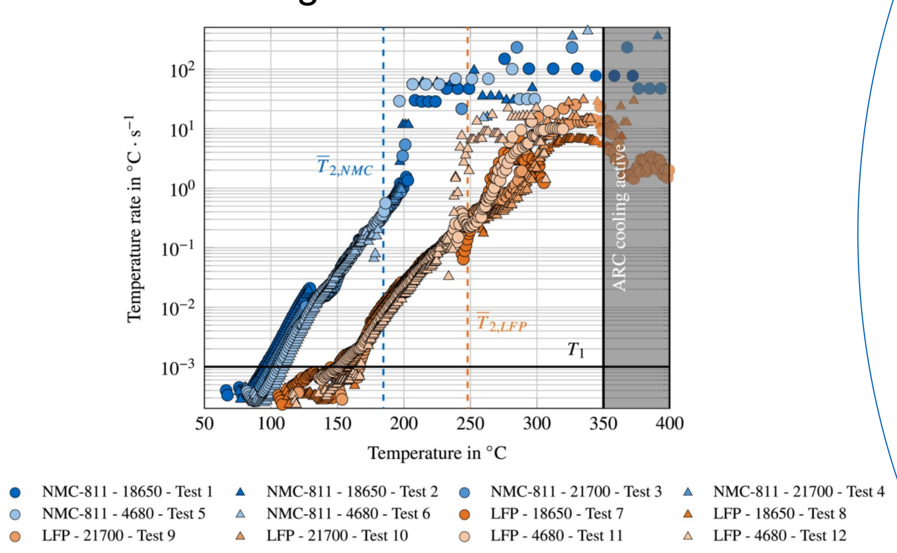

Figure 3 – Temperature rates from ARC measurements [3]

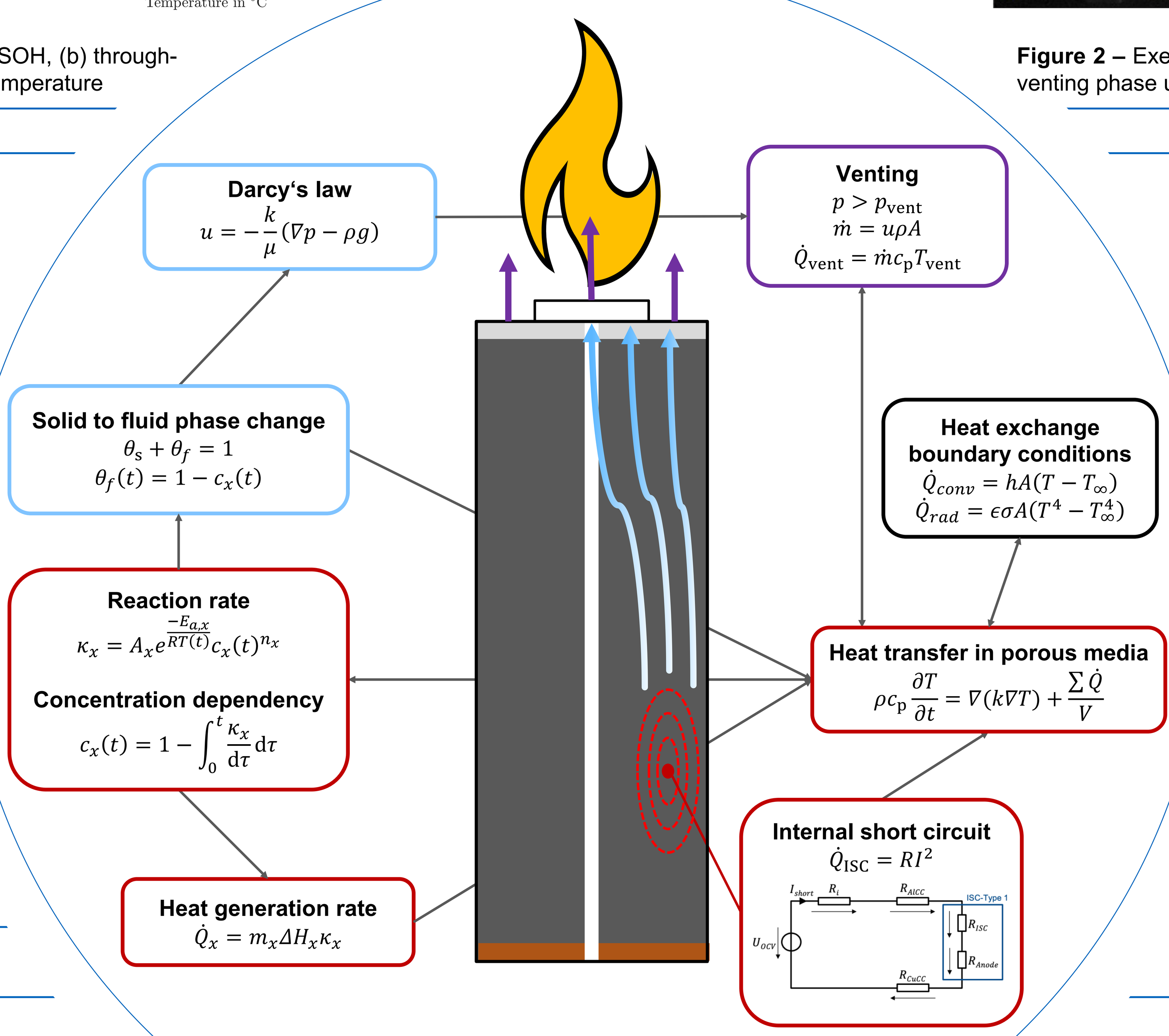

Figure 5 – Coupled thermal runaway modeling framework

Heat release

- Fractional thermal runaway calorimetry (FTRC) to decouple heat retained in the cell body from heat expelled via ejection of gases and particles
  - Ca. 3x more total heat release and higher gas and ejecta heat fraction for NMC-811 compared to LFP

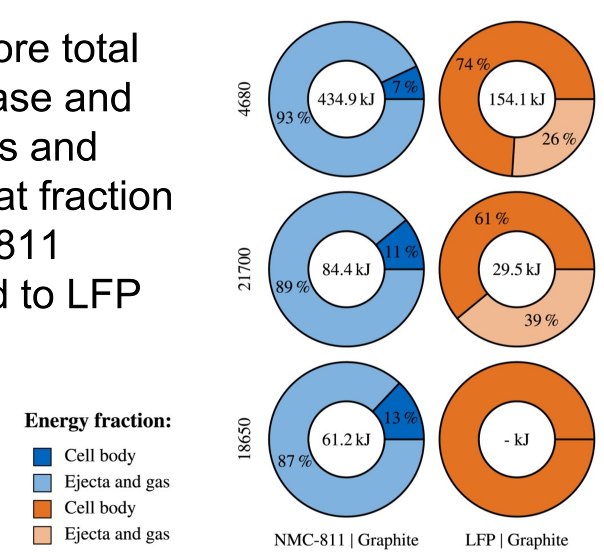

Figure 4 – Heat release and fractions from FTRC measurements [3]

Results

- Exemplary simulation of thermal runaway initiation and intra-cell propagation after an internal short circuit (ISC) for an 18650 NMC-811 cell in COMSOL Multiphysics
- ISC diameter of 3.18 mm based on the ISC device developed by NASA and NREL

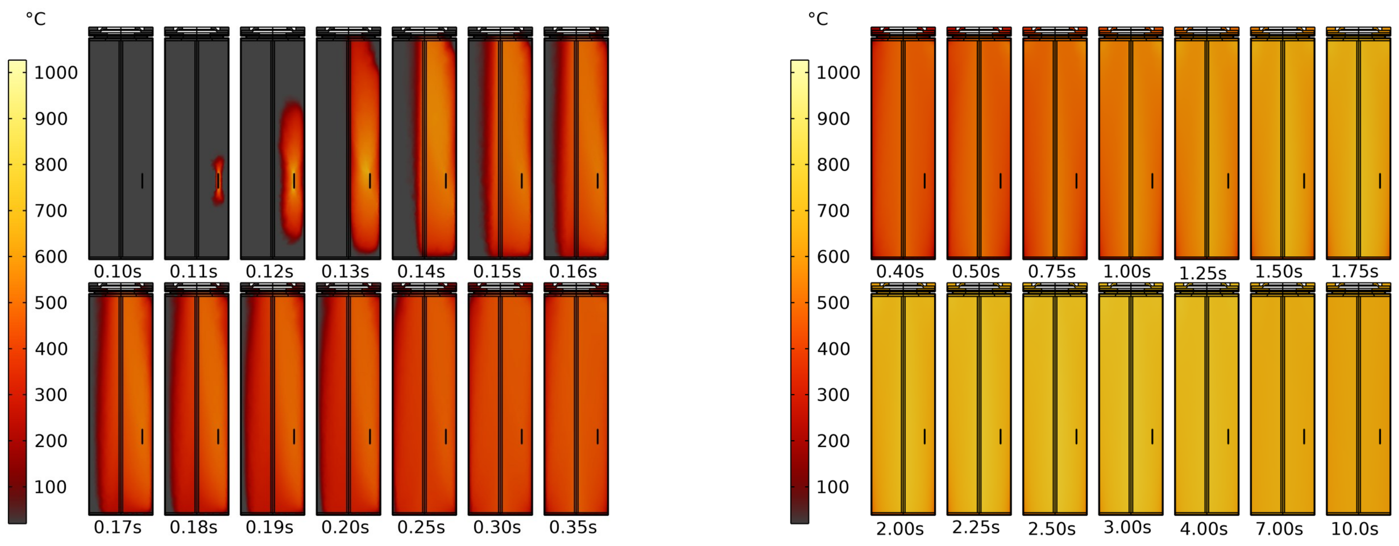

Figure 6 – Illustration of the intra-cell thermal runaway propagation after an internal short circuit

- Parameterization for three cell chemistries and cell formats
- Reduced computation time compared to CFD simulations
- Evaluation of extreme ambient conditions relevant for aerospace applications (e.g. -20 °C, 0.689 kPa)

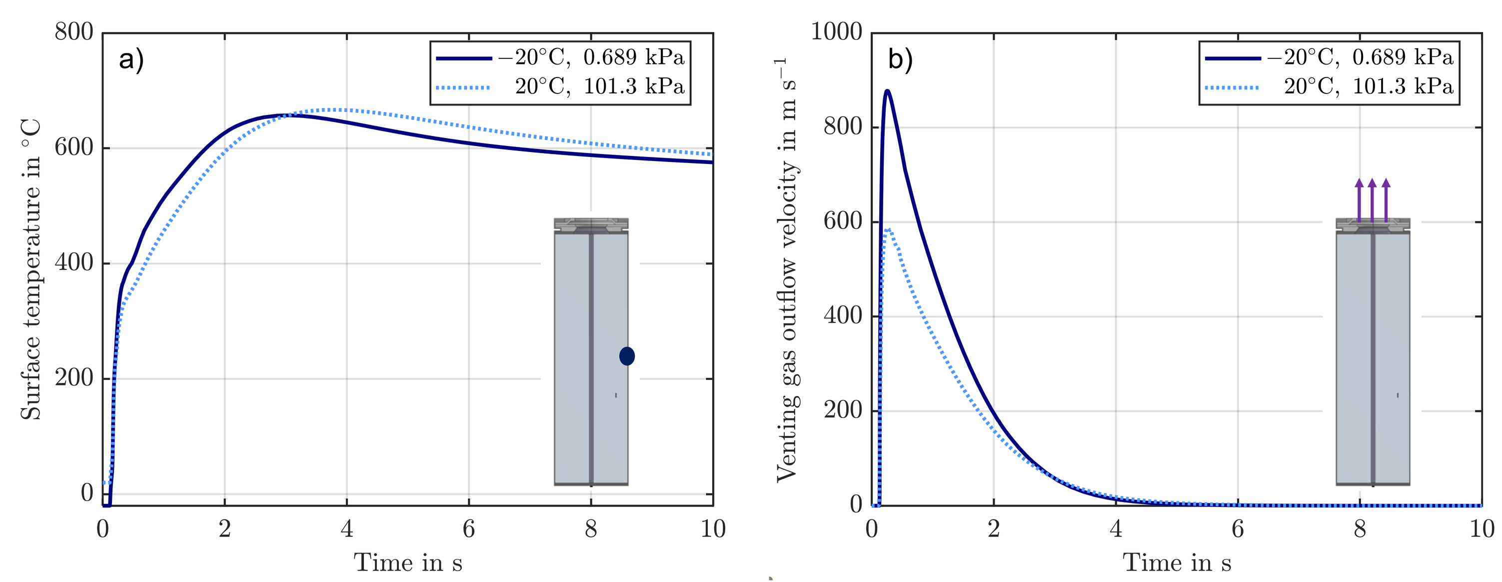

Figure 7 – Comparison of (a) surface temperature and (b) venting gas outflow velocity for aerospace and standard conditions

Conclusion

- A fully parameterized thermal runaway reaction and heat release model with a coupled ISC model and simplified venting dynamics, enabling reduced computation time, is presented.
- Simulations under low-temperature and low-pressure aerospace conditions show higher venting gas velocity and similar maximum temperatures compared to standard conditions.
- In the future, cell-to-cell propagation for aerospace conditions will be investigated, and different combustion characteristics of venting gas without ambient oxygen must be considered.

References

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[3] J. Schöberl, S. Ohneseit, S. Schaeffler, D. Förstermann, L. Grahl, A. Jossen, C. Ziebert, and M. Lienkamp, "Thermal runaway characterization of cylindrical lithium-ion and sodium-ion batteries with various sizes and energy contents," J. Power Sources, 648, 237240, 2025.

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