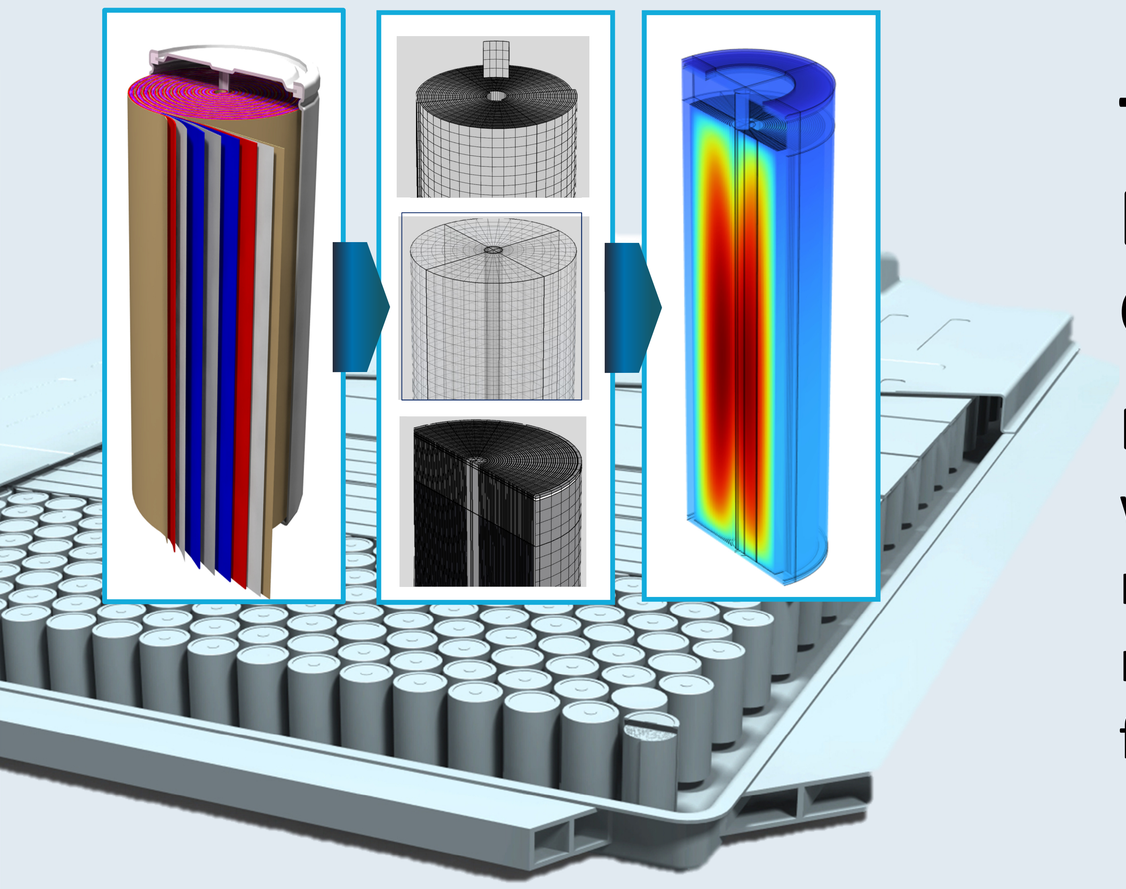

Thermal Battery Simulation Models: Evaluating Levels of Abstraction and Geometric Resolution

Different thermal simulation model approaches were developed and compared to each other. To manage the high effort of parameter calculation, modeling and simulation a specific workflow with focus on automation was developed.

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Abstract

The accurate modeling and simulation of battery cells are crucial for the optimization and design of efficient energy storage systems. The choice of an appropriate battery simulation model heavily depends on the specific problem being investigated. This poster presents a comparative analysis of battery simulation models with varying levels of abstraction and geometric resolution, employing the COMSOL Multiphysics® software. Specifically, the Heat Transfer Module and Equivalent Electrical Circuit (ECM) modeling within COMSOL® are utilized for the simulation and analysis of battery behavior.

Battery simulation models with different levels of abstraction provide varying degrees of detail and computational efficiency. In this study we compare different 3D battery cylindrical cell models which differ significantly in the geometric representation and especially in the Jelly Roll. Each model is implemented and simulated using COMSOL®, and their respective advantages and limitations are explored. The most detailed 3D model represents the battery with high fidelity, capturing high resolution geometrical features and thermal distributions, which is also useful for tab-design.

However, this level of detail comes at the cost of increased computational resources and simulation time. The most simplified geometry comes with the shortest calculation time. At the same time, however, accuracy differs. The goal is to find a simplified 3D geometric model that strikes a balance between accuracy and computational efficiency, allowing for faster simulations while still capturing important thermal battery effects. To evaluate and compare these models, key performance metrics such as temperature distribution, current distribution, and cell voltage are analyzed and compared across the different simulation approaches.

The results from this work highlight the importance of selecting an appropriate battery simulation model based on the specific problem and available computational resources. Overall, this study provides valuable insights into the selection and application of battery simulation models, which enables researchers and engineers to develop efficient and optimized energy storage systems.

Methodology

For this study six different model approaches with different geometric representations were developed. The models (S0, S1, J0, J1, F0, F1) are illustrated on the left side.

Above the developed workflow is shown which includes both steps in COMSOL® and MATLAB using LiveLink™ for MATLAB®. To calculate thermal and physical parameters a MATLAB® -Tool was written. Starting point is a parameter set from a in-situ investigated Samsung INR18650-35E cell, which is transfered and homogenized to the other model approaches.

A LiveLink™ for MATLAB® script automates the simulations using the calculated parameters and pre-defined COMSOL® models of every approach. To accelerate computational effort a constant heat source of 1,5W is used.

Finally, the simulation results were reimported into MATLAB® for visualization and comparison.

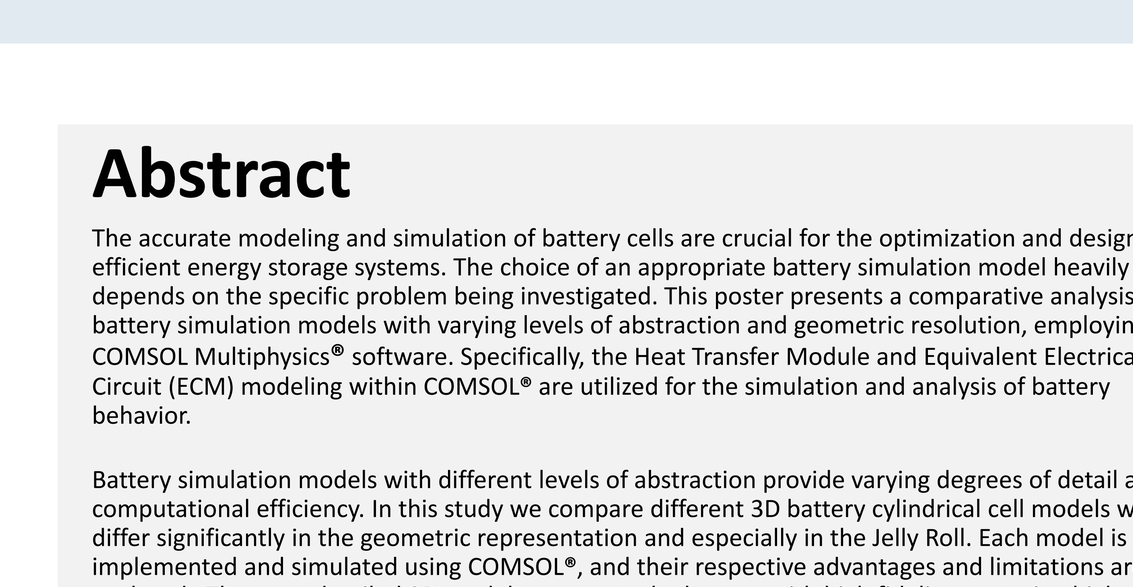


FIGURE 1. Top: Workflow of this study Bottom: Overview of different model approaches used in this study

Results

The maximum temperature of active material differs significantly (ΔT_max=8,2°C) across the different model approaches which shows the importance of a proper model choice. Most accurate model F1 shows temperature differences within the active material from about 2°C(T_{max}-T_{avg}) respectively 3°C(T_{max}-T_{min}) which is also significant and justifies a geometrically detailed model approach.

The Jelly Roll-only models have lower average temperature than the full assembly models due to the more direct convectional cooling and the absence of isolating hollow spaces in the top and bottom of the cell assembly.

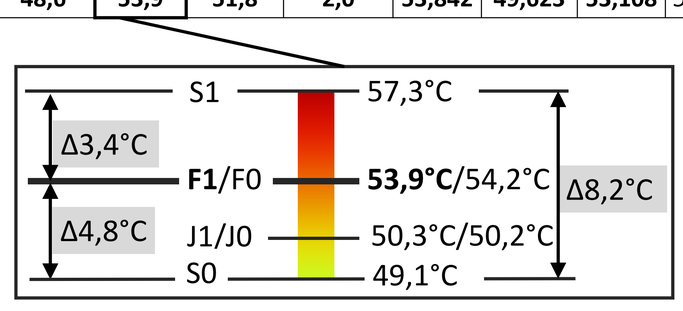
Comparison of model F0 and F1 shows a slightly lower average temperature for the spiral Jelly Roll model due the better heat tranfer in peripheral direction. As the temperature difference is very low but the computational time for F0 much smaller, F0 is the better choice. However T_{avg} of J1 is about 0,1°C higher than T_{avg} of J0 which means an opposite effect. As 0,1°C difference is neglectable no further investigation on this was made.

When comparing model F0/F1 with S1 a deviation in T_{max} of about 3,4°C is observed with higher temperatures in the simplified model. This means an estimation on the safe side. Depending on the purpose of the simulation model you could argue that S1 is the better compromise of accuracy to computational effort than model F0/F1. However the big difference in maximum temperature of S1 in comparison with S0 is noticable and should be further investigated.

As expected the computational effort rises with more accurate model approaches and varies significantly from roughly 1 to 30 minutes.

A validation with temperature sensors on a tested cell should be performed to further interpretate the simulation results. This could help to clarify the caused questions. Further studies on the impact of simplifications like absence or thickness of gaps within the cell could also help to make reliable conclusions. This study shows that detailed thermal 3D-models detect significant temperature deviations within the active material and also across different model approaches which are crucial aspects for designing battery systems with high performance requirements like fast charging.

Model	Active material temperatures in °C							Computational effort	
	T_{min}	T_{max}	T_{avg}	T_{max}-T_{avg}	T_{bottom}	T_{middle}	T_{top}	*Number of FEs*	*Comp. Time [s]*
S0	**48,5**	**49,1**	**48,9**	**0,2**	**48,861**	**48,746**	**49,000**	*10.920*	*80*
S1	**51,9**	**57,3**	**55,1**	**2,2**	**57,315**	**53,179**	**56,526**	*26.100*	*111*
J0	**47,8**	**50,2**	**49,4**	**0,9**	**49,689**	**48,486**	**50,182**	*72.212*	*58*
J1	**47,7**	**50,3**	**49,5**	**0,8**	**49,772**	**48,588**	**50,304**	*576.76*	*68*
F0	**48,7**	**54,2**	**52,0**	**2,2**	**54,181**	**50,033**	**53,319**	*100.900*	*343*
F1	**48,6**	**53,9**	**51,8**	**2,0**	**53,842**	**49,623**	**53,108**	*574.425*	*1879*



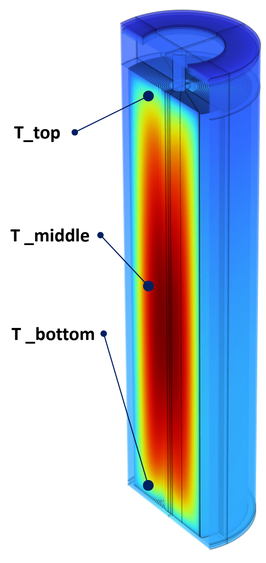


FIGURE 2. Top: Overview of activematerial temperatures and computational effort. Right: Position of temperature measurement points in the cell. Bottom: Variations of maximal activematerial temperatures of the different models approaches.

REFERENCES

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Excerpt from the Proceedings of the COMSOL Conference 2023 Munich