



Physics-based models

FACTSHEET #4 ON KER 3

As a key enabler of the physics-based modelling approaches explored in the NEMO project, an extended Pseudo-Two-Dimensional (P2D) battery model allows ageing and mechanical swelling to be predicted under realistic operating conditions. Learn how coupling the P2D framework with EIS-based experimental data and pressure-dependent parameters enables sensor-free swelling prediction, supports a digital twin operating alongside the BMS, and helps balance performance and lifespan in next-generation battery module design.



Discover more at:

→ NEMOPROJECT.EU

OR CONTACT US AT:

→ INFO@NEMOPROJECT.EU



Co-funded by
the European Union

Swiss participant Centre Suisse d'Electronique et de Microtechnique SA - Recherche et Developpement (CSEM) has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

Research approaches

In order to develop precise battery ageing prediction under various conditions, a standard P2D battery model will be adjusted, incorporating specific ageing processes and a model-experimental coupling to the EIS technique, commonly used to evaluate battery performance over time. This will lead to a digital twin framework, where live data from the battery management system is used to feed the predictive model and battery ageing and performance data is fed back to the BMS.

The NEMO project demonstrates that accurate battery swelling prediction under mechanical constraints requires extending standard P2D models with pressure-dependent parameters to reflect real operating conditions, enabling sensor-free swelling prediction and safer module design.

The TUG modelling framework combines constrained swelling experiments and mechanical calibration of commercial lithium-ion prismatic cells to couple electrochemical and mechanical behaviour within the P2D model.

Findings

Usage of the P2D-based electrochemical ageing and mechanical swelling models:

- ◆ Predict battery ageing parameters, SoH evolution, and reversible cell thickness changes under different cycling conditions and externally applied mechanical pressure.
- ◆ Integrate battery cycling, EIS data, and pressure-dependent parameters into the P2D electrochemical framework.
- ◆ Support digital twin operation coupled with the BMS and enable swelling prediction without real-time force and displacement sensors.
- ◆ Implemented in COMSOL Multiphysics® (connected to the NEMO cloud and accessible to users) and in the open-source PyBaMM framework for reproducible simulations.

Contribution to advanced battery management system:

- ◆ Provides a physics-grounded ageing and mechanical state estimator that can be integrated into BMS and digital twin frameworks.
- ◆ Supports battery SoX assessment by prediction of battery ageing characteristics to be coupled with other models.
- ◆ Supports safety assessment by enabling prediction of structural degradation risk over the battery lifecycle.
- ◆ Enables live feedback of battery performance to BMS systems.
- ◆ Enables optimisation of preload force in battery modules to balance performance and lifespan.

Integration perspective:

- ◆ Complements the standard P2D model, adding mechanical and electrochemical contributions within the NEMO system to make it meaningful.
- ◆ Highlights that external pressure should be directly coupled with transport properties in predictive models.
- ◆ Open-access publication and public dataset support FAIR data principles and research reuse.