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How to determine the time for temperature equalisation in batteries and supercaps for reliable laboratory measurements

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ABSTRACT

Temperature is an important impact factor for both battery performance and lifetime. As lifetime of a battery is typically smaller than that of the application it is used in and performance decreases significantly with ageing, lifetime and performance predictions are of great importance for almost all battery-powered applications. To achieve a good and reliable prediction, comprehensive ageing tests with a significant number of different operating conditions are necessary. From time to time, ageing tests are interrupted for capacity and resistance checkups. For comparable results, these checkups have to be performed under the same ambient conditions, typically room temperature. Thus, before the checkup is started, temperature equalisation is needed. The same is true for performance tests or parameterisation measurements for electrical models. Typically, they are not only performed at room temperature, but also at other temperatures to identify the influence of temperature on performance or electrical impedance. For this reason, a homogeneous temperature within the cell is essential for the test results as well. Therefore, a certain waiting time has to be inserted before starting the test, that on the one hand has to be long enough to assure that all parts of the battery have the same temperature, but on the other hand is as short as possible to prevent an unnecessary prolongation of the test, especially for already time consuming ageing tests. Temperature measurements within cells are typically impossible for commercial cells without destroying the cell. However, this paper shows that it is sufficient to measure the outside temperature to find out the necessary waiting time.

1. Introduction

Energy storage devices such as batteries or double layer capacitors (also called supercaps) play an important role in many mobile and stationary applications, e.g. electric vehicles or in combination with renewable energy sources. Typically, the lifetime of the storage device is less than the expected lifetime of the application and additionally, performance of all batteries and supercaps decreases noticeably with ageing. Examples for ageing tests and simulations (among many others) are [1–4] for lithium-ion batteries, [5–9] for supercaps and [10–12] for lead-acid batteries. Additionally, the performance of batteries and supercaps depends strongly on temperature [13–15].

Since batteries represent an important share of the total cost, prediction of both the achievable lifetime and the evolution of capacity and resistance (influencing the performance) over time is needed. Lifetime prediction needs reliable ageing tests used as a parameterisation of ageing models. Such ageing tests are typically performed as accelerated ageing tests, where Arrhenius' law is applied as a rule of thumb that lifetime halves with a temperature increase of 10 K if the main ageing mechanism is a chemical reaction. There are in principle two kinds of ageing tests: storage/calendaric and cycle tests [4]. Both are typically performed at a constant surrounding temperature. During a storage test, the battery is stored either at a fixed state of charge with open circuit condition ("storage") or with a connected voltage source with a fixed voltage ("float"), while during a cycle test the battery is charged and discharged additionally. Different influence factors such as temperature, voltage or state of charge, current rate, cycle depth etc. are varied, so that a large number of tests is performed.

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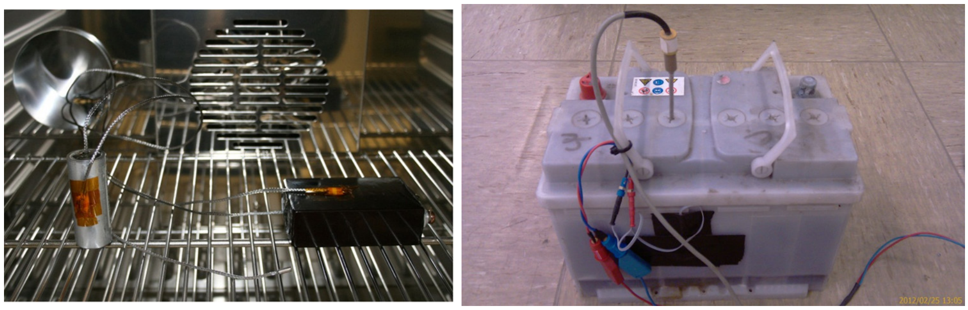

Fig. 1. Batteries used in this study, left: cylindrical lithium-ion battery and prismatic supercap, right: lead–acid battery.

To detect and record the changes in capacity and resistance with ageing, the tests are interrupted regularly for so-called check-up tests. Both capacity and resistance are strongly dependent on temperature [14,15], thus it is crucial to perform the check-up tests under the same conditions for all tests. This is typically done at room temperature so the battery has to be cooled down – or heated up – before starting the check-up. It is important to wait long enough to assure a homogeneous temperature within the complete battery. However, to not unnecessarily prolong the already time consuming ageing tests any further, the waiting time should be kept as short as possible.

Also for performance tests, which are done at different temperatures to determine the temperature dependency of energy content, power, capacitance, resistance or other values, it is essential to have a homogeneous temperature within the cell before starting the test.

There are several ways to determine the needed time span, e.g. measurement or calculation of heat capacity C_{th} and thermal resistance R_{th} of the battery [16], which together determine the time constant of equalisation $\tau_{th} = C_{th}\ R_{th}$. For the total time constant τ_{total} of the system, also the thermal resistance of convection and radiation, e.g. the heat exchange with the environment, have to be determined. After 4–5 times τ_{total}, the equalisation can be considered as finished. Such measurements, especially of the thermal resistances, can be difficult to perform and for a precise calculation, all internal dimensions of the battery and used materials with their thermal properties have to be known as well as the parameters for convection and radiation. Often, only a rough estimation can be achieved. Another method is to measure the temperature in different locations of the battery. However, for many batteries it is impossible to measure the inside temperature without destroying the battery. Thus, very often, a too long time is used to be sure that all transients have disappeared.

In this paper, temperature is measured inside and outside different batteries and supercaps to detect the necessary waiting time. Two small cells, a lithium-ion cylindrical cell and a prismatic supercap, and a much larger lead-acid SLI battery are investigated. Besides investigating the equalisation time for these three types, the overall aim is to find a method to measure or estimate the equilibrium without opening the cells that ideally works for different battery technologies and different sizes.

2. Experimental setup

The three batteries/cells used here are shown in Fig. 1. The lead-acid battery is a standard 12 V 60 Ah SLI flooded battery, the lithium-ion battery is a 26,650 size, $LiFePO_4$-based with 2.5 Ah and the supercap is a prismatic 600 F cell carbon-based electrodes with acetonitrile electrolyte. The three types were mainly chosen because of their size and geometry and to have three different technologies. A flooded lead–acid battery was chosen because it was easier (and less damage) to prepare for the experiment than a VRLA battery. VRLA batteries could have different results because heat transport is less good than in flooded batteries.

Lithium-ion and supercap cell are slowly discharged to 0 V with a large resistance and then a hole is drilled for inserting a PT100 temperature sensor with a cap resistant to the organic electrolyte. The hole is sealed again with resin. This procedure makes clear that both cells should not be charged again and operated afterwards. However, for the tests in the following, this is not necessary. Flooded lead-acid batteries typically have plugs that can be opened for refilling distilled water, so the temperature

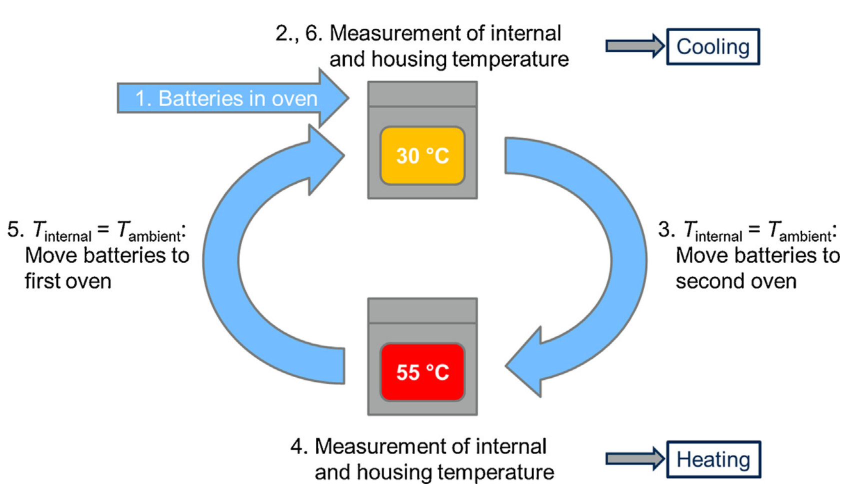

Fig. 2. Sequence of measurements.