



Impact of High Temperature and High Humidity on Battery Materials

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This application note describes the sorption behaviour of several lithium battery materials—lithium (Li), manganese (Mn), iron (Fe), aluminium (Al), lithium cobalt oxide (LiCoO₂), lithium manganese oxide (LiMn₂O₄), and lithium iron phosphate (LiFePO₄)—under varying relative humidities (RH's) and temperature conditions using DVS.

Introduction

Standard battery testing overlooks critical environmental factors. Real-world humidity and temperature variations significantly degrade a battery's capacity, discharge capability, and structural integrity compared to idealised lab conditions. Understanding how lithium and metal oxide cathode materials respond to environmental stress is essential for reliable battery design.

This research uses DVS to examine the environmental stability of key battery components including elemental lithium, aluminum, manganese, and common cathode materials—lithium cobalt oxide (LiCoO₂), lithium manganese oxide (LiMn₂O₄), and lithium iron phosphate (LiFePO₄).

Dynamic Vapour Sorption (DVS) is a gravimetric technique that determines sorption and desorption profiles of samples by precisely measuring the uptake and loss of water or organic solvent vapours. A carrier gas at controlled relative humidities flows over samples as an ultra balance (SMS) measures mass changes. The resulting data is a kinetic and isotherm plot, which can then be used to

characterise a sample's properties such as water uptake or the diffusion coefficient.¹

DVS is employed in this project to evaluate battery material cycling stability under demanding environmental parameters to provide insights into real-world material performance and durability.

Methods

The DVS method employed in this study is illustrated in Figure 1. The experiments were performed at 30, 50 and 80°C, varying the relative humidity (RH) from 0 to 90% (sorption) and then from 90 to 0% (desorption) using 10% RH increments (full cycle). The percentage mass change per minute (dm/dt) was set at 0.002%, allowing the mass of the material to equilibrate at each humidity level. The kinetic data and the adsorption/desorption isotherm plots for the materials were studied.

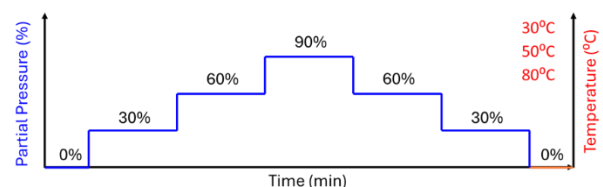


Figure 1: Experimental Method



Results and Discussion

The first experiment analysed the impact of temperature and humidity on the behaviour of lithium.

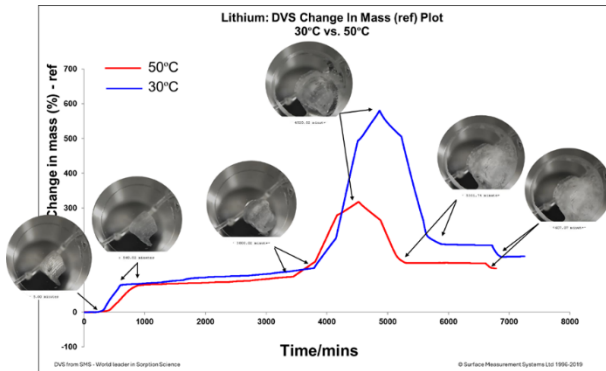


Figure 2: Influence of temperature on lithium at 30°C and 50°C coupled with a camera – DVS change in mass plot

Figure 2 illustrates the kinetic plot of lithium at 30°C and 50°C, displaying the % mass change at different RH's and the corresponding camera images at each phase. Results indicate significant water uptake for lithium and the formation of LiOH, particularly at high RH's and temperatures, with the camera images verifying LiOH formation on the granule surfaces.² A second cycle performed after this experiment confirmed an irreversible lithium to LiOH reaction at these conditions. Figure 3 shows the chemical mechanism of this irreversible reaction, illustrating how RH influences the reaction mechanisms in lithium-air batteries.

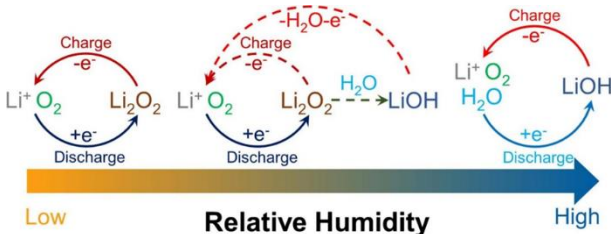


Figure 3: Reactions in non-aqueous lithium-air batteries during discharge and charge depending on the relative humidity.²

Both Figure 2 and 3 illustrate how temperature and humidity have a significant impact on the behaviour of lithium, especially at high humidities.

The same experimental method was carried out on Fe, Al and Mn at 30°C. The kinetic plot in Figure 4 shows a very low uptake for all three materials, where Fe and Al show a percentage change in mass of ~0.05%, and ~0.1% for Mn.

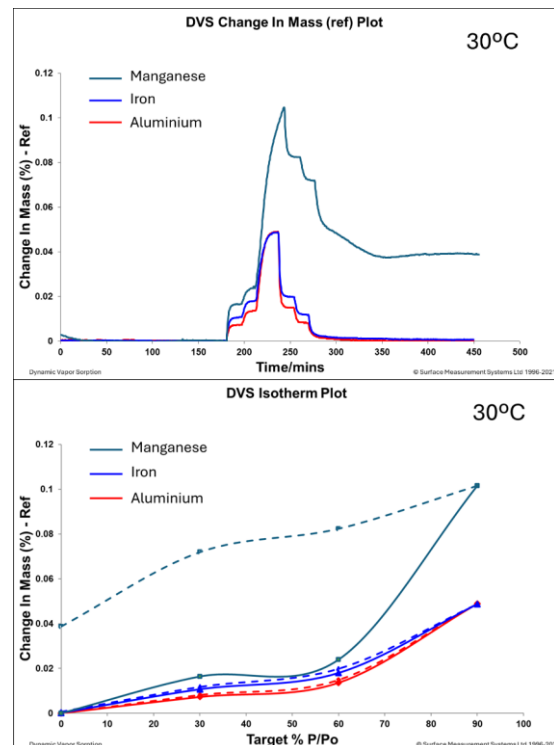


Figure 4: Comparison of raw materials Mn, Fe and Al at 30°C – DVS Change in Mass Plot and Isotherm Plot.

This isotherm plot in Figure 4 shows that there is reversible sorption for Fe and Al, indicating no change in chemical structure. The shape of the isotherm, coupled with the low water uptake, indicates that only a surface sorption mechanism is taking place for Fe and Al. In contrast, the isotherm plot for Mn does not return to zero, therefore the reaction for the Mn sorption process is irreversible.

The water sorption method was then carried out on LiCo₂, LiFePO₄ and LiMn₂O₄ cathode materials at 30°C and 80°C (Figure 5).

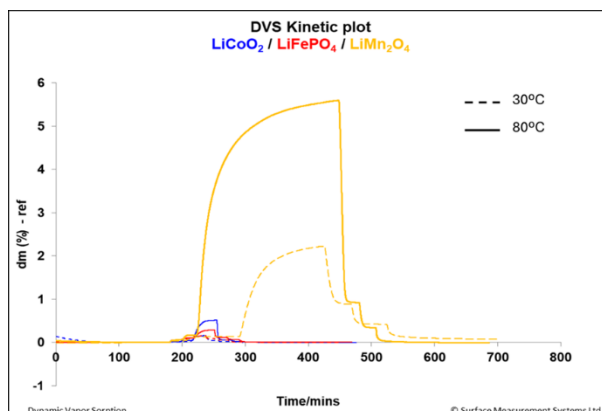


Figure 5: Comparison of LiCoO₂, LiFePO₄ and LiMn₂O₄ at 30°C and 80°C – DVS Change in Mass Plot

Figure 5 illustrates that the metal oxides exhibit both humidity- and temperature-dependent sorption behavior. The kinetic plot displays an increase in water uptake with increasing RH and temperature for all three cathode materials. Additionally, the data demonstrates fast sorption and desorption kinetics across all materials.

Conclusion

In this study, DVS analysis of non-aqueous lithium battery materials revealed minimal water uptake in all materials except lithium, which formed increasing amounts of LiOH with rising humidity and temperature. The materials showed fast sorption kinetics and good reversibility, with lithium and manganese being exceptions. These findings contribute to a deeper understanding of how battery materials behave under real-world environmental conditions, highlighting the importance of humidity control in improving stability and performance. Additional high-temperature studies and research on a wider range of battery materials are ongoing.

References

1. Hunter, N. Dynamic Vapour Sorption. in *Principles of Thermal Analysis and Calorimetry* 47–66 (The Royal Society of Chemistry, 2016). doi:10.1039/BK9781782620518-00047.
2. Tan, P., Shyy, W., Zhao, T. S., Zhang, R. H. & Zhu, X. B. Effects of moist air on the cycling performance of non-aqueous lithium-air batteries. *Appl Energy* **182**, 569–575 (2016).