HSLU Lucerne University of Applied Sciences and Arts

Engineering and Architecture
B.Sc.. Energy and Environmental Systems Engineering
Bachelor-Thesis

Crystallization of PCM under Space Conditions

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1. Introduction, Goals and Research Questions

Inorganic salt hydrate PCMs① offer high energy density for space thermal energy storage. On Earth, their crystallization is strongly influenced by gravity-driven convection and phase segregation. In microgravity, these effects are suppressed, enabling more homogeneous solidification. Supercooling, typically undesirable in terrestrial systems, can therefore be exploited as a controllable state. However, experimental data under space-relevant conditions are limited. This project investigates sodium acetate trihydrate through laboratory experiments to support the design of a sounding-rocket microgravity experiment.

Research Question: How can supercooling and crystallization of SAT② be controlled for reliable microgravity experiments?

2. Method Overview and Materials

The experimental approach is structured around the phase-change behavior of sodium acetate trihydrate (SAT), illustrated in the phase diagram shown below. The diagram highlights the melting temperature, the metastable supercooled liquid region, and the transition to crystallization, which form the basis of the experimental design.

First, SAT was selected over calcium chloride hexahydrate using a structured decision framework focusing on supercooling behavior, stability, and experimental feasibility. The hydration state was then controlled through precise water content analysis to ensure reproducible phase-change conditions.
Mechanical stability of molten and supercooled SAT was investigated using analytical centrifugation to simulate launch-relevant accelerations. Finally, controlled thermal cycling experiments were conducted to probe supercooling depth, temperature response, and crystallization behavior under space-relevant boundary conditions.

Together, these methods characterize how SAT moves through the phase diagram under thermal and mechanical loading and provide experimental input for the design of a microgravity crystallization experiment.

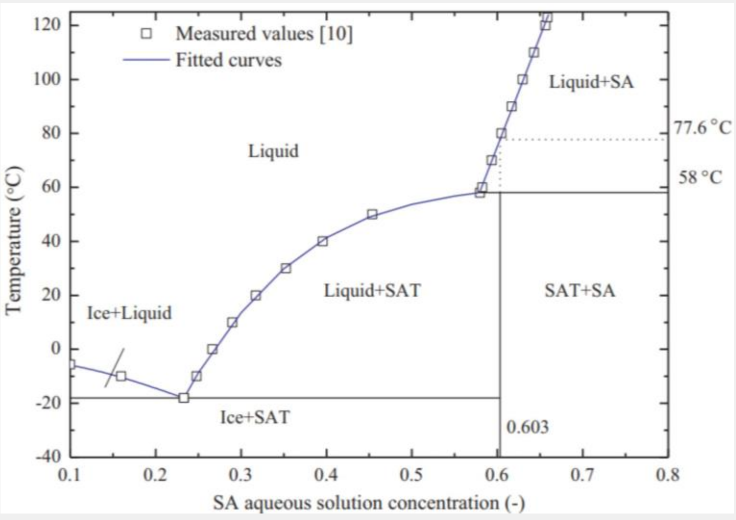

Figure 1: Phase diagram of sodium acetate aqueous solution

① PCM = Phase Change Material, ② SAT = Sodium Acetate Trihydrate

3. Results and Discussion

The experiment was conducted using an EasyMax reaction calorimeter, which provides precise control of the jacket temperature (Tj) and continuous measurement of the sample temperature (Tr) during thermal cycling. The graph shows that Tr follows Tj with a clear thermal delay during heating and cooling. During deep cooling to sub-zero temperatures, the sample enters a supercooled state below the melting temperature of sodium acetate trihydrate. A short temperature spike is observed, indicating incipient crystallization, which is abruptly terminated when reheating begins, preventing full crystallization and sustained latent heat release.
For this thesis, the graph demonstrates that deep cooling alone is sufficient to induce supercooling but not sufficient to reliably trigger complete crystallization within short time windows. This directly supports the selection of a supercooling-based operational strategy and shows that future microgravity experiments must incorporate active triggering mechanisms to achieve controlled crystallization.

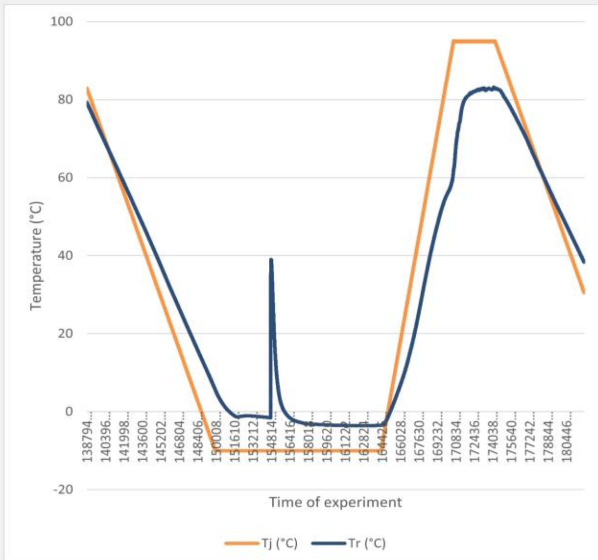

Figure 2: Temperature evolution of Tj and Tr, showing supercooling spikes

4. Conclusion and Recommendations

Sodium acetate trihydrate can be stably supercooled under space-relevant conditions, but deep cooling alone does not reliably trigger full crystallization. A supercooling-based approach with active triggering is therefore recommended for microgravity experiments. Precise water content control and minimized thermal coupling are essential to achieve reproducible crystallization in sounding-rocket missions.

References

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2. Ma, Z., Bao, H., & Roskilly, A. P. (2017). Study on solidification process of sodium acetate trihydrate for seasonal solar thermal energy storage. Solar Energy Materials and Solar Cells, 172, 99–107. https://doi.org/10.1016/j.solmat.2017.07.024

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