Charge State Sensor for Thermal Energy Storages Based on Phase Change Slurries

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Motivation & Methods

Performance of thermal storages can be improved by utilising phase change material (PCM). According to [1], dispersing PCM in a continuous phase creates a new class of functional fluids. The so called phase change slurries (PCS) exhibit the following particularities:

Enhanced heat conduction. ⇒	+ Higher charge and discharge rates than PCM.
Always pumpable. ⇒	+ Usable in distribution networks.
Isothermal heat transfer. ⇒	+ Exergetically efficient. – Temperature not related to charge state.
Other heat capacity than water. ⇒	+ Increased in phase transition range. – Decreased in the single-phase range.
Supercooling effects occur. ⇒	– Charge and discharge at different temperatures. – Temperature not related to charge state.

Following the above, temperature alone is not suitable to monitor and control a PCS system. As proposed by [2], the state of aggregation is directly linked to the latent charge state via the heat of fusion. The authors investigate three methods to determine the solid content of a PCS containing 21 wt.% paraffin.

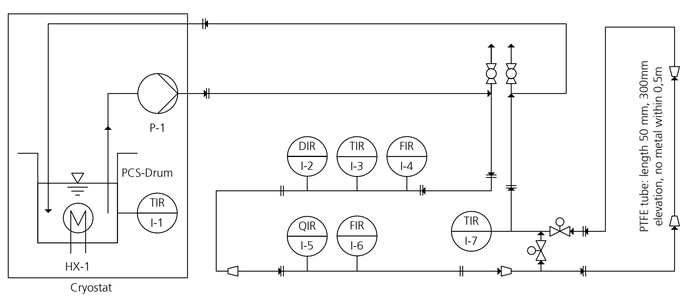

Figure 1: Schematic of the test rig.

A test rig was equipped with standard sensing technology for density and speed of sound as well as a custom-built portable Halbach magnet from [3] for nuclear magnetic resonance (NMR) relaxation measurements. A schematic of sensors and piping is shown in Figure 1.

- Heating from 5 °C to 35 °C at 0.25 K min^{-1} ⇒ equilibrium is assured.
- Density and sound velocity are recorded at a sampling rate of 1 Hz.
- NMR data is acquired every 10 s from alternating procedures. Amplitude of free induction decay (FID) is used for temperature calibration and Carr, Purcell, Meiboom, Gill (CPMG) acquires transverse (T_2) relaxation spectra.

Experimental Results

Paraffin droplet density is calculated from bulk density. Comparing the curves in Figure 2 reveals that there is molten paraffin at 5 °C already. At 22 °C, the measured data meets the liquid line, this indicates that the phase change is completed.

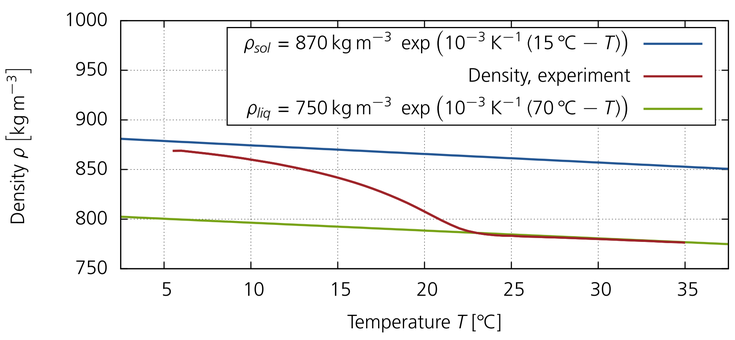

Figure 2: Paraffin droplet density and pure substance properties.

As explained in [4], thermal and visco-inertial scattering attenuate the signal. Here, sound velocity can hardly be measured for more than 17 wt.% paraffin. However, in dilute PCS, phase change can be followed by ultrasonic velocimetry.

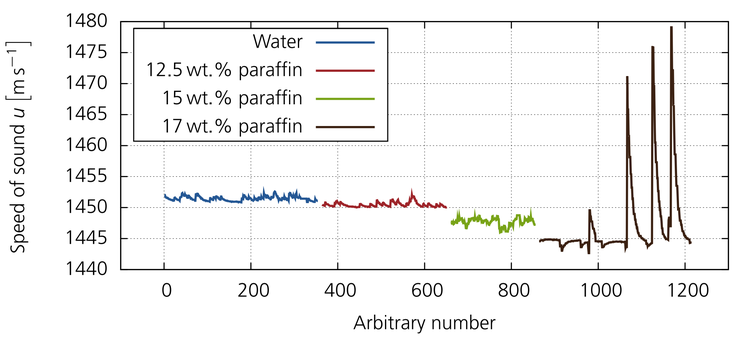

Figure 3: Sound velocities in different PCS, recorded at constant temperatures.

Since the raw T_2 amplitude is given in arbitrary units (a.u.), an interpretation of Figure 4 is complex.

- Solids exhibit a T_2 in the microsecond domain ⇒ invisible to chosen CPMG procedure.
- T_2 times below 200 ms are ascribed to melting paraffin.
- Completely liquid wax cannot be distinguished from water, T_2 around 0.7 s.

Summing up amplitudes below and above T_2 = 200 ms gives Figure 5. Solid wax melts and becomes visible and thus, the sum of the overall amplitude increases.

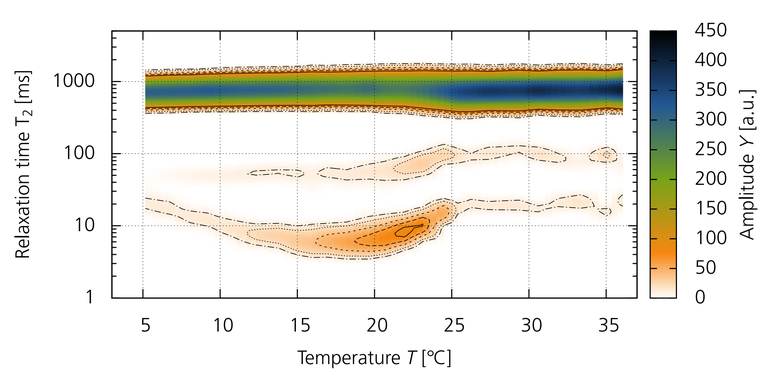

Figure 4: T_2 relaxation spectra of the PCS during a temperature run, contour lines are drawn at 10, 20, 40, 60 and 80 a.u. to enhance visibility.

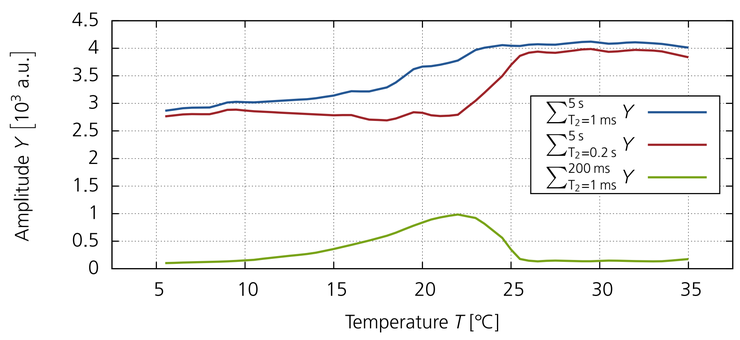

Figure 5: Cumulated amplitudes of the T_2 fractions depicted in Figure 4.

Conclusion

Advancing phase transition could be followed with all sensors. A first approach of solid content determination by means of density and NMR data is shown in Figure 6.

- Density of droplets gives solid content directly.
- NMR relaxometry needs minimum and maximum amplitudes as reference points.
- Sound velocity sensors and data processing need to be improved.

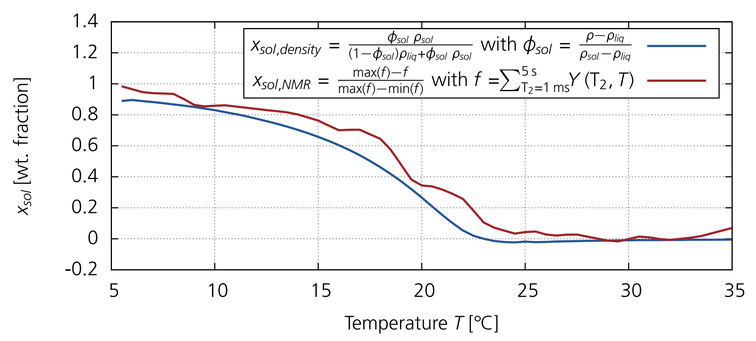

Figure 6: Solid content of the dispersion as estimated from density and NMR data.

Standard density monitoring equipment can be used to estimate the solid content of a dispersion based on the pure substance characteristics. Achieving the same by means of NMR relaxometry requires a compulsory calibration to quantify the total amounts of liquid, melting and thereby solid matter. However, since NMR is able to spot melting paraffin, it is a promising candidate which delivers deeper insight into PCS phase transition behaviour.

Acknowledgement & References

The authors thank the German Federal Ministry of Economics and Technology for funding the project »EnEff: Emulsionen aus Paraffinen und Wasser für Anwendungen in Versorgungssystemen der Gebäudetechnik« (FKZ 0327471A).

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