State of Charge Determination Utilizing Material Response in Compact Thermal Energy Storages

Report of intermediate results of work led by:
• Gerald Englmaier, DTU, Denmark (for PCM)
• Reda Djebbar, NRCan, Canada (for TCM)

Gerald Englmaier, PhD
Assistant Professor
Technical University of Denmark
Department of Civil and Mechanical Engineering (Construct)
Email: gereng@dtu.dk

“Thermal battery” - schematic
Why state of charge (SoC) determination?

Storage integration into (digitalized) energy systems requires interaction with advanced (predictive) controls.

→ Reliable SoC determination potentially enables flexibility (reserve market access) of heating and cooling systems

OUR DEFINITIONS:

**Thermal Battery**: A TES with instantaneous State of Charge determination

State of charge determination utilizes measurement techniques of **material bulk response**

State of charge is a **component level property** (analogy: electrical battery)

\[ \text{SoC} = \frac{E(t)}{E_{\text{max}}} \% \]
Survey on measurement techniques - Literature

Phase Change Materials (PCM)
- magnetic_resonance
- x-ray_imaging
- ultrasound
- temperature
- calorimetry
- pressure
- heat_flux
- infrared_imaging
- electrical_resistance
- uv-vis_spectroscopy
- acoustic_emission
- fibre_bragg_grating

Thermochemical Materials (TCM)
- volumetric_measurement
- fibre_bragg_grating
- electrical_resistance
- thermogravimetry
- calorimetry
- radiography
- temperature
- x-ray_imaging
- ph_value
- spectroscopy
- uv-vis_spectroscopy
- heat_flux
- vapour_pressure
- magnetic_resonance
- ultrasound
- ir_spectroscopy
- tcm_mass_vessel
# Survey on measurement techniques - Institutions

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... 21 contributors in total
Measurement techniques – applied by Task experts (weighted)

**PCM (25 studies)**
- Mainly PCM bulk temperature determination in labs for storage model development – component level.
- A couple of investigations in material labs

**TCM (17 studies)**
- Mainly investigations in the material labs
- A few component level investigations
SoC determination – research classification

1. Material laboratory:
   Material response with charging/discharging can be reproduced
   
   Source: FH Upper Austria

2. Pilot testing:
   Correlation of material response to heat flux → Calibration at test stand
   
   Source: Technical University of Denmark

3. Reliable, instantaneous SoC determination enables CTES operation in flexible systems
   
Exemplary proof of concepts

1. Material

2. Component (Storage)

3. System

PCM Material level – Chamber pressure

Discharge of storage – containing paraffin; $T_{\text{melting}} = 4^\circ C$

TCM material level – Capacitive sensor applied to Zeolite


Experts: Bernhard Zettl, Gayaney Issayan
Spectral comparison of solid \( \text{CuCl}_2 \) (blue line) and solid \( \text{CuCl}_2 \cdot x \text{NH}_3 \) (red line)

Measured in diffuse reflectance with a Perkin-Elmer Lambda 900 UV-vis-NIR spectrometer
The aqueous sodium hydroxide heat storage system is designed as a closed transported system consisting of the heat and mass exchanger and the tanks containing the charged and discharged sodium hydroxide and water.

By knowing how much concentrated sorbent is left (level in tank), the state of charge is known.

Correlation of PCM bulk temperature to SoC
– storage containing salt hydrate; $T_{\text{melting}} = 15 \, ^{\circ}\text{C}$


https://cool-data.dtu.dk/
System level: Data driven models (research)

Server room cooling model to develop a predictive system control algorithm


https://cool-data.dtu.dk/
System application:
PCM heat storage control based on SoC determination

Based on internal temperature distribution, the following operation states are determined:

- Full cell charge (100% SoC)
- Partial cell charge (50-100% SoC)
- Nucleation activation required (≤ 50%)
- Cell depleted (0% SoC)

Internal temperature sensors in selected locations
(result of control system development)

Storage containing salt hydrate composite; $T_{\text{melting}} = 58 \, ^\circ\text{C}$

Source: Neothermal energy storage Inc.; Further information available at https://neothermal.ca/

Expert: Louis Desgrosseillers
Preliminary conclusions

(State of charge determination utilizes measurement techniques of material bulk response)

State of charge is a component level property (analogy: electrical battery)

Its reliable determination in storages is a prerequisite for flexible system operation

PCM: The combination of bulk temperature and heat flux measurement is common in the lab.
→ Novel techniques are potentially less complex in their application (once developed)

TCM: Common: a) Adsorbate content of sorption material; b) Mass of reactants in closed vessels.
→ Novel techniques (non-intrusive) for large & high temperature solutions are important

Interdisciplinary, applied research is needed to bridge material science and system engineering

“Thermal Battery”