Seasonal Solar Thermal Energy Storage
Status and Envisioning Tomorrow

Webinar Heating and Cooling Research
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Thermal Energy Storage is a Key Enabling Technology
3 Main principles for Heat Storage

- **Sensible heat**
  - principle: heat capacity
  - reservoirs, aquifers, ground/soil

- **Latent heat**
  - principle: phase change (melting, evaporation)
  - water, organic and inorganic PCMs

- **Sorption heat and Chemical heat**
  - principle: physical (adhesion) or chemical bond (reaction enthalpy)
  - adsorption and absorption and chemical reactions
Seasonal storage of solar heat: compactness needed

Storage volume (m³) needed for a very energy efficient household

- Sensible: 120 m³
- Latent: 60 m³
- Chemical: 12 m³
Heat losses from sensible storage

Comparison solid sorption storage with water storage (ITW, Stuttgart)

For seasonal thermal storage, we need to slash the heat losses!
Reducing the heat losses

• Increase the volume
  • Stored heat proportional to volume
  • Heat losses proportional to surface area
    → Large pit storages

• Apply superinsulation
  • Cost reduction required

• With Phase Change Materials: use supercooling

• Thermochemical materials
  • Virtually no losses during storage period
Storage Density
Module level (all components needed to charge – store – discharge)

Dependent on which volume is considered
1. Only storage material → $S_{phys}$
2. Volume of the black box (always prismatic) → $S_{eff}$
3. Volume including service space → $S_{act}$

$$S_{phys} = \frac{Q_{storage \ capacity}}{V_{storage \ medium}}$$

$$S_{eff} = \frac{Q_{storage \ capacity}}{V_{storage \ (black \ box)}}$$

$$S_{act} = \frac{Q_{storage \ capacity}}{V_{storage \ (black \ box)} + V_{service}}$$
### Storage density comparison

<table>
<thead>
<tr>
<th>Storage Density [kWh/m³]</th>
<th>COMTES Line A (zeolite system)</th>
<th>Water storage (800 L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material, $S_{phys}$</td>
<td>180</td>
<td>82</td>
</tr>
<tr>
<td>Module, $S_{eff}$</td>
<td>30-40</td>
<td>36</td>
</tr>
<tr>
<td>$S_{eff}$, better packing</td>
<td>40-72</td>
<td></td>
</tr>
<tr>
<td>Service space included, $S_{act}$</td>
<td>36-65</td>
<td>30</td>
</tr>
</tbody>
</table>

Sorption storage density is factor 2 better than water storage, on storage system level.
Principles of sorption heat storage construction

**External reactor design / open cycle** (e.g. EnErchem project funded by the German federal minister of economics)
- Reaction zone and material storages area are separate
- Storage capacity and charging/discharging power are not coupled
- Process operates at ambient conditions and with process air

**Internal reactor design / close cycle process** (e.g. COMTES project funded by EU commission)
- Reaction zone and material storages area are the same
- Storage capacity and charging/discharging power are coupled
- Process operates at vacuum conditions

Source: Thomas Badenhop, Vaillant Group
Overview of sorption heat storage projects

<table>
<thead>
<tr>
<th>Reactor design</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process managament</td>
<td>Monosorp (ITW, DE) SolSpaces (ITW, DE) KoWaSS (ITW, DE) MobS (ZAE, DE)</td>
<td>EnErchem (ITW, DE) Sotherco (Besol, Be) STAID (CETHIL, Lyon)</td>
</tr>
<tr>
<td>Open-cycle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closed-cycle</td>
<td>COMTES (AEE, AT) CREATE (TNO, NL) Merits (TNO, NL) Modestore (AEE, AT)</td>
<td></td>
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</tbody>
</table>

Organisation name in brackets is the consortium coordinator
Project overview list makes no claim to be complete

Source: Thomas Badenhop, Vaillant Group
Open solid sorption for seasonal heat storage – ITW, Stuttgart University

- External reactor, transport of zeolite or composite grains
- Capacity and power uncoupled

FlowTCS system
ITW, University of Stuttgart, DE
Open solid sorption for heating peak power – CETHIL, University of Lyon

- Zeolite fixed bed with air flow

**Desorption (charge)**
- Air + water extracted
- Hot air
- Reactor
- Air + water
- Heat exchanger
- Air from outside

**Adsorption (discharge)**
- Air + water extracted
- Reactor
- Hot air
- Heat exchanger
- Air from outside

TESS system in STAID project, CETHIL, University of Lyon, FR
Main Results:

SG+CaCl$_2$  SG+MgCl$_2$

SG+SrBr$_2$  MIL-160(Al)

SG = Silicagel

Open solid sorption for seasonal storage – SOTHERCO project
Heat storage capacity of sodium acetate tri-hydrate

Supercooling

Activation of solidification

Melting point = 58 °C

Phase Change Material (PCM) with supercooling - DTU, Denmark
Supercooling: COMTES DevLine C

- Sodium Acetate Trihydrate; 58 DegC
- Development of 250 kg storage modules
- Controlled solidification
- 4-Module system tests
COMTES Line B: Operation Principle
Closed cycle, external reactor

NaOH x (m+n)H₂O + heat ⇔ NaOH x mH₂O + nH₂O
Concentration limited to 50% due to solidification
Liquid Sorption: Heat and mass transfer

- EMPA and SPF, Switzerland: Development and testing of a reaction zone for evaporation/condensation and generation/regeneration of sodium hydroxide adsorption technology
Line B system set-up and experiments

- Measured power of desorber was much lower than design value: Redesign of reaction zone needed
COMTES Line A: solid sorption
Closed cycle, internal reactor

- **Charging process** (desorption, drying of adsorbent)
- **Storage period**
- **Discharging process** (adsorption of working fluid on adsorbent)
Insertion of HEX into vessel
Top view of open vessel with header and zeolite beads
Energy density Desorption

Energy density [kWh/m³]

Regeneration temperature [°C]

- 100 °C: 33 kWh/m³
- 160 °C: 105 kWh/m³
- 180 °C: 137 kWh/m³
- Charge boosting: 171 kWh/m³
- Inclusive sensible: 197 kWh/m³
Results from past and present projects

- Several proof of concepts were delivered
- Material performance/cost ratio is still low
- Design and optimisation knowledge of key components to be improved
Task58/Annex33
Material and Component Development for Thermal Energy Storage

- 3-year duration, 2017-2019
- Materials and Application Experts (over 60 from 13 countries)
- Semi-annual experts meetings
- Work on common goals
Objectives

• The key objectives of the joint Annex/Task are:

• Development and characterisation of storage materials to enhance TES performance

• Development of materials testing and characterisation procedures, including material testing under application conditions

• Development of components for compact thermal energy storage systems

• Mapping and evaluating the TES application opportunities concerning the requirements for the storage material
Scope

- Advanced materials for latent (PCM) and chemical thermal energy storage (TCM) materials.

- Three different scales:
  - **Material properties**, behaviour from molecular to bulk scale, material synthesis, micro-scale mass transport and sorption reactions;
  - **Material performance** materials behaviour, also within the storage system; heat, mass, and vapour transport, wall-wall and wall-material interactions, reactor design;
  - **Storage system implementation** performance of a storage within a heating or cooling system, including e.g. economical feasibility studies, case studies, and system tests.
Subtask structure

**PCM**

**Subtask 1:** “Energy Relevant Applications for an Application-oriented Development of Improved Storage Materials”

Andreas Hauer (ZAE, DE) /Wim van Helden (AEE Intec, A)

**Subtask 2:** “Development and Characterization of Improved Materials”

Stefan Gschwander (ISE, DE) Alenka Ristic (NIC, SI)

**Subtask 3:** “Measuring Procedures and Testing under Application Conditions”

Christoph Rathgeber (ZAE, DE) Daniel Lager (AIT, A)

**Subtask 4:** “Component Design for innovative TES Materials”

Ana Lazaro, Uni Zaragoza, ES) Benjamin Fumey (EMPA, CH)
Envisioning Tomorrow

Target for 2025:
- Further increase of the system storage density
- Demonstration of systems
- First field experiments

What is needed:
- Programmed, international approach
- Virtual knowledge institute for compact thermal energy storage
- Materials research, components development, system development, system demonstration, industry development

Support through RHC ETIP, working on SET Plan, Mission Innovation, H2020, FP9, national programs