Thermal Energy Storage for Short and Long Term

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WP 2: Storage of thermal energy

Thermal energy storage for building applications: sorption-based and sensible/latent heat storage
Three examples for seasonal storages

1. TCM: Thermal chemical storage based on NaOH + H₂O

2. PCM: water-ice storage

3. Sensible heat: large water pit storages for district heating systems in Denmark

4. Economic Evaluation of Thermal Energy Storages
Example TCM:

- **Thermo-chemical process**
  \[
  \text{NaOH}^*n\text{H}_2\text{O}(l) + m\text{H}_2\text{O}(v) \leftrightarrow \text{NaOH}^*(n+m)\text{H}_2\text{O}(l) + \text{heat}
  \]

- **Development of compact seasonal heat storage system with a higher energy density than water (factor 3 to 4 in volume).**

- **Use of renewable energy (60°C ... 90°C) by applying**
  - Solar collectors & other renewable heat (i.e. CHP) or energy sources

- **Technical challenge: development of compact components**
  - Thermal process operating at diurnal (or intermitting) power variation.
  - Material properties (NaOH!) are setting the boundary conditions.
  - Combined heat & mass transport in the reaction zones.
Charging of storage system during summer time

- Liquid sodium lye sorption energy storage concept:
  - Seasonal storage with low thermal losses and high volumetric energy density
  - Thermochemical storage based on water absorption/desorption in sodium hydroxide (NaOH)
  - High renewable energy fraction by using solar collectors and environmental heat

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Discharging of storage system during winter time

- **Liquid sodium lye sorption energy storage concept:**
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![Diagram of liquid sodium lye sorption energy storage system](image-url)
Development of A/D and E/C units

- Reaction zone design:

  - inside view of the E/C unit manifold (yellow) and tube bundle
  - Drawing of the reaction zone with both A/D (left) and E/C unit (right)

  - E/C manifold and tube bundle

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Container with mit solar collectors

Reaction zone units, storage tanks and all other components are installed inside the container.
Charging (desorption of water vapour from diluted sodium lye)

- Experiments with tube bundle falling film desorber / condenser: charging
  - Tube bundle surface wetting

Desorber flow rate:
0.4 l(NaOH-H₂O)/min @ wt=30 %, T=50 °C

Condenser maximum flow rate:
12 l(H₂O)/min @ T=20 °C

flow modes - from literature -
Discharging (adsorption of water vapour by concentrated sodium lye)

- Experiments with tube bundle falling film absorber / evaporator: discharging
  - Tube bundle surface wetting

Absorber flow rate: 0.4 l(NaOH-H₂O)/min @ wt=50 %, T=22 °C before and after full wetting

Evaporator flow rate: 6.0 l(H₂O)/min @ T=16 °C
Conclusions from experimental results

Heat and mass transfer zone design concept:

- Easy access to the tube bundles and their accessories (→ easy maintenance)
- Good sight on the process (→ fluid distribution / surface wetting & control)
- Reduced number of gaskets (→ low air leakage rate)

Experimental results & assessments:

- No heat transfer limitations due to the E & C unit
- Heat and mass exchanger design complies with the desorption process (charging)
  - Absorption process has to be improved (low exchanged power; improve numerical model)

Photo: A/D and E/C units.
Development of water-ice latent heat storage systems

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Properties of water-ice latent heat storages

- melting heat of ice: 334 kJ/kg
- High storage capacity (compared to sensible heat storages)
- Regeneration (charging) possible by low temperature heat (for example waste heat, heat from CHP systems or solar collectors)
Hydraulics of the demo-system Säntisweg, Rapperswil

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Innovation: de-icing of heat exchanger plates

View into the experimental water-ice storage tank in the SPF laboratory

- Floating ice layers already detached
- Heat exchanger plate without ice layer
- Heat exchanger layer with ice layer

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Demonstration system with water-ice storage

- Building from 1960’s with 35 MWh heating demand per year, 360 m² floor heating area
- Radiators requiring high feed-line temperatures
Demonstration system: installed solar collectors

- 50 m² flat-plate collectors
- These collectors are hermetically sealed in order to operate them below condensation temperatures
- 17 m² of uncovered collectors are installed on the facade
Demonstration system: water-ice latent heat storage

- Concrete storage container with 75 m³ volume
- Storage dug into the ground without heat insulation at lower half

- The system is operated successfully since 2012
- Measured seasonal system performance figure $JAZ_{Sys}: 5.2$

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Solar collector field with seasonal storage, Dronninglund DK

37'600 m² flat-plate collectors

Source: IEA-SHCTask 45
SUNSTORE 3: 60,000 m³ water pit storage in Dronninglund, DK

91 m x 91 m

61'700 m³

Source: IEA-SHCTask 45
Dronninglund water pit storage with floating cover

Floating insulated lid
Polymer liner
No insulation to earth!

Figure 5. Cross section of the edge of a floating cover based on flexible insulation mats. The specific design is from the 60,000 m³ SUNSTORE 3 storage in Dronninglund.

Source: IEA-SHCTask 45
Marstal: 33’000 m² collectors and 75’000 m³ water pit storage

Source: IEA-SHCTask 45
Under construction (Vojens): 200’000 m³ and 71’000 m² collectors

Source: IEA-SHCTask 45
Compact Thermal Energy Storage

Overview

Task 42 is a joint Task with the IEA Energy Conservation through Energy Storage (ECES) Programme Task 29.

Thermal energy storage is an important technology for renewable energy systems and energy efficiency. By improving the effectiveness of thermal storage, the effectiveness of all renewable energy technologies that supply heat can be improved.

Particularly for solar thermal systems, thermal energy storage is essential. To reach high solar fractions, it is necessary to store heat (or cold) efficiently for longer periods of time. Until now, no cost-effective compact storage technologies are available to do this. For high solar fraction systems, hot water stores are expensive and require very large volumes of space. Alternative storage technologies, such as phase change materials (PCMs) and thermochemical materials (TCMs) are available on a laboratory scale.
Economic Evaluation of Thermal Energy Storages via Top-down and Bottom-up Approach

Christoph Rathgeber *, Stefan Hiebler, Eberhard Lävemann, Andreas Hauer

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Figure 2. Maximum acceptable storage capacity costs $SCC_{acc}$ calculated via Eq. (2) for three user classes as a function of storage cycles per year $N_{cycle}$: enthusiast high/low case (green solid/dashed line), building high/low case (blue solid/dashed line), and industry high/low case (red solid/dashed line). Economic boundary conditions for high/low cases are given in Table 1.

Annuity Factors: (industry $i = 10\%$, building, $i = 5\%$ and enthusiast $i = 1\%$)
Figure 5. Maximum acceptable storage capacity costs ($SCC_{acc}$) and realised storage capacity costs ($SCC_{real}$) for short-term storages.
Evaluation for hot water storages up to 30 m$^3$

Figure 4. Maximum acceptable storage capacity costs ($SCC_{acc}$) and realised storage capacity costs ($SCC_{real}$) for hot water storages up to 30 m$^3$ storage volume.
Evaluation for long-term storages

Figure 3. Maximum acceptable storage capacity costs (SCC_{acc}) and realised storage capacity costs (SCC_{real}) for long-term storages.

1: NaOH + H$_2$O

5: Sunstore 4, 75’000 m$^3$ DK
Conclusions

- Development of seasonal storage systems is the most challenging task to be solved. Water storages only work if very large.

- Thermochemical materials (TCM) and Phase Change Materials (PCM) offer good development possibilities for compact heat storage systems.

- But further research work is necessary on the materials side as well as on the system engineering side.
Thank you for your attention!