Thermal Energy Storage

• WP3.1 Compact Chemical Heat Storage
• WP3.2 Compact Latent Heat Storage
• WP4.3 Process Heat Storage

Dan Zhou, Jose Pereira-da-Cunha, Daniel Mahon, Philip Eames
CREST
Loughborough University
• WP3.1 Compact Chemical Heat Storage
Aim to produce a high energy density thermal store with minimal degradation of energy stored

• WP3.2 Compact Latent Heat Storage
Aim to produce a phase change energy storage system with good charge and discharge rates and medium energy density at temperatures up to 140°C

• WP4.3 Process Heat Storage
Aim to produce a phase change energy storage system with good charge and discharge rates and medium energy density at temperatures up to 220°C
Investigation of the Potential of MgSO$_4$ for Inter-Seasonal Thermochemical Energy Storage

Daniel Mahon

CREST
Loughborough University
Activities Undertaken

• Analysis of MgSO$_4$ composite material dehydration heating rate effects
• Nitrogen Vapour sorption testing of composite samples
• 100g scale hydration tests
• 2 Sample preparation methods trialled
• Design, and construction of a new larger (adjustable) size all-in-one de/hydration chamber ongoing
• MgSO₄ shown to be affected by high heating rates
  • Material “damage”
  • Slow Kinetics
• Zeolite appears to be unaffected by heating rates
  • No sign of slow kinetics
• For these reasons heat rate affects on the composite materials (Zeolite-Y+MgSO₄ 15, 25 & 35wt%) were tested.
• All composites have similar peak dehydration Temp.
• Zeolite impregnation appears to neutralize the heating rate affects of the MgSO₄
• Promising for practical applications of the composites
• Lower desorption temperature possible for higher dehydration enthalpy composites (i.e. 35wt%) (corresponds to energy density)
Nitrogen Vapour Sorption Testing

• To assess the changing surface area and porosity of each sample, nitrogen vapour sorption testing was conducted.
• Higher surface area and pore volume (Micro or Mesopores) is beneficial – Enhances vapour transportation.
• Each sample degassed at 170°C for 3h using N₂ as a purge gas.
Nitrogen Vapour Sorption Testing Cont.

• BET surface area decreases with increasing wt%  
• Majority of Zeolites pore volume is from 5nm pores (i.e. Mesopores)  
• Hydration tests required to assess the effect the results have.
A new, variable volume, hydration chamber has been designed and built to test ~100g of different TCES materials.

The experimental setup allows for assessment of the hydration heat of samples.

Chamber hosts inlet, outlet and temperature sensors within material as well as humidity output sensor.

All samples dehydrated to 150°C and held isothermally for 3h, heating rate 1°C/min.

Hydrated with 60%RH @20°C (pH₂O=~1.3kPa) for 24 hours, this is an achievable condition in winter times (only first 12h shown on next slide).
• Composite Beads show minimal peak $\Delta C$ however, temperature held for relatively long.

• $\text{MgSO}_4$ beads very poor. The density of material was very low resulting in poor energy density.
Sample Preparation Techniques

100g hydration tests show powder samples (especially zeolite) have poor permeability. Need for sample preparation investigations to enhance permeability.

Two Methods are under investigation

- **Agglomeration** – Uses frictional and gravitational forces applied, to moist powder, on an inclined rotating disc to create small beads.

- **“Rolled” Beads** – Creation of a “paste” by using water to moist powder. Paste then rolled into beads.
Design of Larger (0.4-2.5L) Fixed Volume Reactor

- Ability to de/hydrate material without transportation of material.
- Larger scale Setup
- Tracks mass change with de/hydration
- Cycle time much shorter.
- Better insulated than previous design.
- Should allow for more practical scale hydration heat results.

Diagram:

Key:
- Ball Valve
- Flow Control Valve
- RTD Temperature Sensor
- Humidity Sensor

Base of Experimental Setup

All sensors and load cell connected to Datataker for data logging.
Future Work

• Assess the affect each sample preparation method has on energy density, peak power output and vapour transportation.
  • N₂ Vapour sorption measurements for porosity + BET surface area
  • TGA/DSC tests for dehydration enthalpy
  • Undertake further 100g scale hydration tests.
• Test materials within the new de/hydration chamber.
Thermal Energy Storage for Medium Temperature Industrial Process Heating

Dan Zhou

CREST
Loughborough University
• **Materials Characterisation:**
Molten salt mixtures of lithium nitrate and sodium nitrate were characterised with the DSC and TGA.

• **System Development:**
The experimental system design has been finalised and main components have been ordered.

• **Thermal performance simulation**
A simple thermal model of the experimental system was developed and analysis of some of the factors influencing performance undertaken.
Heat storage media selection

- Molten salt mixtures with lithium nitrate are being investigated as the potential heat storage media.
- The thermal properties (from the literature) of the selected mixtures are shown below.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Melting temperature (°C)</th>
<th>Latent heat (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiNO$_3$+NaNO$_3$ 0.57+0.43</td>
<td>193</td>
<td>248</td>
</tr>
<tr>
<td>LiNO$_3$+NaNO$_3$ 0.49+0.51</td>
<td>194</td>
<td>265</td>
</tr>
<tr>
<td>LiNO$_3$+NaCl 0.87+0.13</td>
<td>208</td>
<td>360</td>
</tr>
<tr>
<td>LiNO$_3$+NaNO$_3$ +Sr(NO$_3$)$_2$ 0.45+0.47+0.08</td>
<td>200</td>
<td>199</td>
</tr>
<tr>
<td>LiNO$_3$+NaNO$_3$ +LiCl 0.479+0.507+0.014</td>
<td>180</td>
<td>267</td>
</tr>
</tbody>
</table>

- The long-term thermal stability of the binary salt system of LiNO$_3$+NaNO$_3$ (0.49:0.51) was assessed using the TGA.
Thermal stability and repeatability

- The sample is heated from 30°C to 300°C then cooled down to 30°C at a constant heating/cooling rate of 15°C/min of 30 times.
- The weight loss in the first cycle is 2.06% (this is due to the salts water-soluble character)
- The weight loss in the following cycles are small, 0.31% for cycle 2.
The sample was heated from 30°C and equalised at 50°C, then heated up at a heating rate of 10°C/min. The sample was then held at 100°C, 150°C, 200°C, 250°C, 300°C and 350°C for 2 hours.

The sample showed good thermal stability until the temperature was increased to 350°C.
Heat Storage System

Experimental heat storage system

Heat storage tank with helical coiled tube (proposed to use single, double and other configurations): stainless steel 316.
Heat Storage System components

**High temperature heat exchanger:** tube-in-tube heat exchanger ½” NPT male inner tube connections and 1” NPT female outer tube boss.

**Pump:** M pumps CM MAG-M series magnetically coupled centrifugal pump. Differential head: 6m; capacity: 2-15 L/min; working temperature: up to 300°C.

**Turbine flowmeter with a Rate/Totalizer indicator:** flow range: 1.8-18 L/min; repeatability: 0.05%; temperature range: -265°C to 350°C.

**Highly dynamic temperature control system:** Julabo
Phase Change Materials for Thermal Energy Storage

Jose Cunha
j.pereira-da-cunha@lboro.ac.uk

CREST
Loughborough University
• Material Analysis:
Eutectic mixture (LiNO3-KCl) good stability and good latent heat. TGA analysis showed that organics work only when encapsulated;
Corrosion tests showed that Aluminium is suitable to store the eutectic compound.

• Lab scale experiments:
Compact and encapsulated latent heat storage systems have been constructed and initial tests will commence shortly.
TGA analysis + Mass Spec

- Organics sublime around their melting point;
- Adipic Acid seemed suitable, but TGA indicated sublimation at its melting point;
Corrosion tests

- Metal samples were prepared and initial mass was measured;
  - A SEM analysis was made for further comparison;
- The compounds were inserted in a oven at 200°C with common air atmosphere;
  - A daily mass measure and SEM analysis was performed for further comparison.

**LiNO$_3$-KCl eutectic**

- Organics only lasted 24h due to:
  - Severe Oxidation (brownish color);
  - Partial Sublimation (adipic and 2-Chlorobenzoic acid);
Corrosion tests

- Copper reacted with every compound;
- Aluminium was the most stable;
- Initial mass samples [mg];
  - Copper [480-485];
  - Aluminium (160-165);
  - Galv Steel (400-405);
Heat storage media

• Inorganic eutectics proved to have better stability than other compounds;
  ▪ Nitrite mixture is the only non-hygroscopic compound;

• From DSC analysis; most promising compounds are:

<table>
<thead>
<tr>
<th>Inorganic Eutectics</th>
<th>Mass Ratio</th>
<th>$T_{\text{melt}}$ °C</th>
<th>$\Delta H_{\text{fusion}}$ kJ/kg</th>
<th>$E_{\text{density}}$ kWh/m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiNO$_3$-KNO$_3$</td>
<td>33-67</td>
<td>128</td>
<td>135</td>
<td>82</td>
</tr>
<tr>
<td>LiNO$_3$-NaNO$_3$-KNO$_3$</td>
<td>30-18-52</td>
<td>127</td>
<td>167</td>
<td>90</td>
</tr>
<tr>
<td>KNO$_3$-NaNO$_2$</td>
<td>56-44</td>
<td>142</td>
<td>45</td>
<td>33</td>
</tr>
<tr>
<td>+ 7% NaNO$_3$</td>
<td>58-7-35</td>
<td>141</td>
<td>76</td>
<td>46</td>
</tr>
<tr>
<td>LiNO$_3$-KCl</td>
<td>44-56</td>
<td>169</td>
<td>141</td>
<td>76</td>
</tr>
<tr>
<td>+5% NaNO$_3$</td>
<td>53-5-42</td>
<td>167</td>
<td>152</td>
<td>82</td>
</tr>
<tr>
<td>LiNO$_3$-NaNO$_3$</td>
<td>48-52</td>
<td>195</td>
<td>142</td>
<td>85</td>
</tr>
<tr>
<td>+3% LiCl</td>
<td>48-1-51</td>
<td>193</td>
<td>118</td>
<td>73</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Organics</th>
<th>$T_{\text{melt}}$ °C</th>
<th>$\Delta H_{\text{fusion}}$ kJ/kg</th>
<th>$E_{\text{density}}$ kWh/m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adipic acid</td>
<td>153</td>
<td>219</td>
<td>90</td>
</tr>
<tr>
<td>2-Chlorobenzoic acid</td>
<td>142</td>
<td>127</td>
<td>53</td>
</tr>
<tr>
<td>d-Mannitol</td>
<td>165</td>
<td>269</td>
<td>120</td>
</tr>
</tbody>
</table>

• Organic compounds need encapsulation for thermal storage;
  ▪ Organics crystallization demonstrated high endothermic peak with large subcooling;

• Corrosion testing with common metals proved that Aluminium was suitable for use with the selected materials
• Compact Storage:
  • Higher PCM volumetric Ratios;
    • Larger isothermal power output possible;
  • Higher sensitivity to PCM’s thermal conductivity;

• Encapsulated storage:
  • Lower PCM volumetric Ratios;
    • More sensible heat behaviour;
  • Higher power outputs;
  • Lower sensitivity to PCM’s thermal conductivity;
Laboratory Heat Storage System

Schematic of experimental apparatus

Aim to determine the most effective solution in terms of charge/discharge rates and energy storage density.
Questions