Thermal High Performance Storages for vehicle applications

2. ETA - Tagung
Energie- und Thermomanagement, Klimatisierung, Abwärmenutzung

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Motivation and approach
Motivation and approach
Thermal management in battery electric vehicles

• High heating capacity for vehicles interior at low ambient temperatures

• High efficiency of drive train, little waste heat

• Use of electric heaters for interior heating

→ Essential loss of range
Motivation and approach
Use of Thermal Energy Storage for Heating

Battery
- High-value electric energy for traction
- High cost (≈ 200 €/kWh)
- High mass and volume
  (≈ 100 – 150 Wh/kg, 150 – 250 Wh/l)
- Use of critical materials (Li, Co)
- Limited recyclability

Thermal Energy Storage
- Needed form of energy
- Potentially lower cost (≈ 50 €/kWh)
- Potentially lower mass and volume
  (≈ 200 – 230 Wh/kg, 300 – 350 Wh/l @ $T_{\text{max}} \approx 600 \, ^\circ\text{C}$)
- No use of critical materials
- High recyclability

Metallic Phase Change Materials (mPCM)
**Metallic Phase Change Materials**  
*Basic principles heat storage*

**Sensible heat storage**  
Change of the temperature

\[ Q = c_p \cdot m \cdot (\vartheta_1 - \vartheta_2) \]

**Latente heat storage**  
Change of the aggregate state

\[ Q = c_p \cdot m \cdot (\vartheta_1 - \vartheta_2) + m \cdot h_f \]

**Thermochemical heat storage**  
Reaction enthalpy of a chemical process

\[ Q = \Delta H_R \]

Metallic Phase Change Materials
Sensible + Latent heat storage

- **Sensible heat**
  - Use of sensible heat in solid and liquid state
  - Used temperature range approx. 100 °C to 600 °C

- **Latent heat**

\[
\lambda = \sim 160 \text{ W/mK} \\
\lambda = \sim 0.5 \text{ W/mK}
\]

Vol. energy density storage material [kWh/m^3]
Metallic Phase Change Materials
Beneficial properties

- High thermal conductivity → High thermal output
- Eutectic alloys → High cycling stability
  - High long-term stability
- High maximum temperature level → High energy density
  - Low mass
  - Low volume
Metallic Phase Change Materials

Challenges

Potential reactivity in liquid state  ➔  Suitable housing material

Volume expansion  ➔  Compensation method

Unique for vehicle application (TRL 4)  ➔  Demonstration in real vehicle

Storage concept
Storage concept
MonoTherm – High Performance Thermal Energy Storage

- small
- lightweight
- powerful

Technologie
metallic Phase Change Material (mPCM)

Charging: Electric resistance heater
Discharging: Indirectly on cooling fluid (evaporation of working fluid, e.g. water, alcohol)

Working temperature: ca. 100 °C – 600 °C
Reference scenario
Reference scenario
Basic setting

- Design of MonoTherm Storage for winter term conditions -10 °C and -20 °C
- Realistic long range driving scenario (e.g. Skiing Holidays, Christmas Travelling, etc.)

<table>
<thead>
<tr>
<th>Time</th>
<th>Phase</th>
<th>Vehicle</th>
<th>THS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Charging of the battery</td>
<td>Charging Battery (11 kW)</td>
<td>Charging (11 kW)</td>
<td></td>
</tr>
<tr>
<td>2: Charging of the Thermal Energy Storage</td>
<td>PreCon Interior (by THS)</td>
<td>Charging (11 kW)</td>
<td></td>
</tr>
<tr>
<td>3: Pre-Conditioning of the interior</td>
<td>Driving Maximum Range Motorway</td>
<td>Discharging for Interior Heating</td>
<td></td>
</tr>
<tr>
<td>4: Driving maximum Range (motorway cycle)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reference scenario
Procedure

Boundary Conditions

<table>
<thead>
<tr>
<th>Phase</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>Charging Battery (45 kW)</td>
<td>PreCool</td>
<td>Interior Heating (35 kW)</td>
<td>Driving Motor</td>
</tr>
<tr>
<td>Time</td>
<td>ca. 4.5 h</td>
<td>ca. 5.5 h</td>
<td>ca. 2.5 h</td>
<td></td>
</tr>
</tbody>
</table>

- **Battery Capacity:** 45 kWh
- **Heating demand:** 3.4 kW (@ -10 °C), 5.1 kW (@ -20 °C)
- **Energy usage:** 19.3 kWh / 100 km (Motorway)
- **Charging power:** 11 kW

Designing Tool

Results

- **Volume**
- **Mass**
- **Dimensions**
- **Range**
- **SOC**
Reference scenario

Results

**MonoTherm Storage (@ -10 °C / @ -20 °C)**

Storage Material: AI$\text{Si}_{12}$

- Capacity: 8,9 kWh / 13,2 kWh
- Mass: 35 kg / 50 kg
- Volume: 25 l / 36 l
- Height (Diameter): 317 mm / 359 mm

Effect. grav. energy density: 222 / 227 Wh/kg
Effect. vol. energy density: 311 / 325 Wh/l

- Working Temperature: 110 °C – 610 °C
- Thermal output: 3,4 kW / 5,1 kW
- Installed el. charging power: 11 kW

- Increase of range: **36,3 km** resp. **18,4 %** @ -10 °C
- Increase of range: **48 km** resp. **26,7 %** @ -20 °C
Reference scenario
Comparison

**Battery + PTC - Heater**
- Grav. energy density: 150 Wh/kg
- Vol. energy density: 250 Wh/kg
- Overall efficiency: 90 %
- Specific cost battery: 200 €/kWh
- Cost PTC - Heater: 150 €

- Battery capacity to enable same range increase as MonoTherm Storage

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**MonoTherm vs. Battery + PTC - Heater (@ -10 °C)**

<table>
<thead>
<tr>
<th></th>
<th>MonoTherm</th>
<th>Battery + PTC - Heater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>35 kg</td>
<td>57.5 kg</td>
</tr>
<tr>
<td>Volume</td>
<td>25 l</td>
<td>34.5 l</td>
</tr>
<tr>
<td>Estimated Cost</td>
<td>445 €</td>
<td>1876 €</td>
</tr>
</tbody>
</table>

**Additional potential benefits MonoTherm**
- No use of critical raw materials (e.g. Lithium, Cobalt)
- Use of recycled raw materials (e.g. AlSi$_{12}$)
- High recyclability
- Lower energy effort for manufacturing
- Long term stability

Thermal High Performance Storages (THS) in electric buses
THS in electric buses
Boundary Conditions

State of the art

- Fuel heaters using Diesel
  - Local emissions
  - Already ban of Diesel driven cars from cities

- Heat pump with R134a or CO₂
  - Additional electric heater for low temperatures necessary
  - Loss of range at low temperatures not solved
  - Battery prices $> 500 \text{ €/kWh}$

Necessity for alternative heating solutions even more relevant!

### THS in electric buses

**Potentials and Challenges**

#### Challenges

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long operating times</td>
<td>Long term stability</td>
</tr>
<tr>
<td>Various defined scenarios</td>
<td>Modular storage design</td>
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<tr>
<td>High amount of mPCM</td>
<td>Questions regarding safety</td>
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#### Potentials

<table>
<thead>
<tr>
<th>Potential</th>
<th>Benefit</th>
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<tbody>
<tr>
<td>High prices for batteries</td>
<td>THS even more economic</td>
</tr>
<tr>
<td>High energy demand</td>
<td>Positive scaling effects</td>
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<tr>
<td>Defined scenarios</td>
<td>Custom design possible</td>
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THS in electric buses
Current project

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