Storage Technology for Process Heat Applications

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Introduction

Presentation directed to:

- Energy Storage for Process Heat
- Higher temperature than required for domestic heating
  Temperature range 100 – 300 °C
  Water (at low pressure) not applicable as TES material
  single phase or 2-phase flow fluids as HTF
- Emphasis on PCM storage
Survey - Industrial Process Applications

Anteil am Wärmebedarf in 2005

- Industrie und Bergbau (Gesamt)
- Maschinenbau
- Fahrzeugbau
- Gummi- und Kunststoffwaren
- Gewinnung Steine und Erden, sonst. Bergbau
- Ernährung und Tabak
- Sonstige Wirtschaftszweige
- Metallbearbeitung
- Papiergewerbe
- Grundstoffchemie
- Sonst. Chem. Industrie
- NE-Metalle, Gießereien
- Verarbeitung von Steinen und Erden
- Glas und Keramik
- Metallerzeugung

Quelle: Fraunhofer ISI

Process heat $T < 100 \, ^\circ C$

Process heat $100 \, ^\circ C < T < 300 \, ^\circ C$

Process heat $T > 400 \, ^\circ C$
Requirements

Generation of Solar Heat for Process Heat Applications

- Extension of solar heating to higher temperature range
- Concentrating collector elements needed

CPC Collector  
Fresnel Collector  
Trough Collector
Storage Integration Aspects

**Efficient and economic storage technology needed** to meet energy demand and required operation conditions of a specific process

Selection of storage concept depends on system aspects
Classification of storage systems

- **Direct storage of the primary working fluid:**
  - single phase fluid (thermal oil, pressurized water)
  - fluid with phase change (Steam accumulator)
- **Indirect storage: Thermal energy transferred to separate storage medium**
  - sensible heat storage medium (solid or liquid)
  - phase change material

<table>
<thead>
<tr>
<th>Storage Medium</th>
<th>Sensible Heat Storage</th>
<th>Latent Heat Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concrete</td>
<td>Salt (single component)</td>
</tr>
<tr>
<td></td>
<td>Thermal oil</td>
<td>Eutectic Mixtures</td>
</tr>
<tr>
<td></td>
<td>Molten Salt</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pressurized Water</td>
<td></td>
</tr>
<tr>
<td>HTF Medium</td>
<td>Single phase fluid</td>
<td>2-phase fluid / water-Steam</td>
</tr>
</tbody>
</table>
# Direct Storage – Sensible Heat

<table>
<thead>
<tr>
<th>Storage Concept</th>
<th>Temperature range [°C]</th>
<th>Pressure [bar]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Oil</td>
<td>100 - 300</td>
<td>1 - 5</td>
</tr>
<tr>
<td>Pressurized Water</td>
<td>100 - 200</td>
<td>5 - 10</td>
</tr>
</tbody>
</table>

**Diagram:**
- **2-tank storage**
- **Single tank storage**
Direct Storage - Steam Accumulator / Sensible Heat

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<tr>
<th>Storage Concept</th>
<th>Temperature range [°C]</th>
<th>Pressure [bar]</th>
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</thead>
<tbody>
<tr>
<td>Steam Accumulator</td>
<td>100 - 300</td>
<td>5 - 100</td>
</tr>
</tbody>
</table>

Charging process raising temperature in liquid water volume by condensating steam

Discharging process generation of steam by lowering pressure in saturated liquid water volume
Indirect Storage – Sensible Heat / Concrete

Test storage at Almeria
100 kW, 350 kWh

Test storage at Stuttgart
100 kW, 400 kWh

Max. Operation temperature: 400°C
Storage for Process Heat with Steam

Important AREA for process heat applications for the temperature range 100-250 °C

• Generation of process steam at low or intermediate pressure for isothermal processes
• Food processing
• Manufacturing of construction materials
• Production of paper, textile industry etc.
• Water purification, desalination
• Double effect sorption cooling
Potential for high effective cooling systems

Diagram showing a Dampfkreislauf system with storage and cooling components.
Characteristic Issues of Steam

93% Evaporation

4% Preheating

3% Superheating

10bar steam
T - range 160 to 200°C
evaporation temperature (10bar): 180°C
Correlation of storage medium and working fluid
Why using Phase Change Material (PCM) ?

Working fluid water/steam:
=> Evaporation phase (T=const)

Phase change storage medium
=> Melting phase (T=const)

Significant advantage of PCM technology in steam production due to constant temperature
Survey of potential PCM storage materials

- KNO₃
- NaNO₃
- NaNO₂
- KNO₃-NaNO₃
- LiNO₃-NaNO₃
- KNO₃-LiNO₃
- KNO₃-NaNO₂-NaNO₃
- LiNO₃
- Ca(NO₃)₂-KNO₃
- KSCN

Temperature [°C]

Enthalpy [J/g]
Flexible PCM`s with Binary Systems

Advantage to cover broad range of temperature and applications

<table>
<thead>
<tr>
<th></th>
<th>LiNO₃</th>
<th>NaNO₃</th>
<th>KNO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latent heat of fusion J/g</td>
<td>367</td>
<td>169</td>
<td>94</td>
</tr>
<tr>
<td>Specific heat capacity J/g·K</td>
<td>1.6</td>
<td>1.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Density kg/m³</td>
<td>1760</td>
<td>1880</td>
<td>1860</td>
</tr>
<tr>
<td>Volume change %</td>
<td>21.4</td>
<td>10.7</td>
<td>3.3</td>
</tr>
<tr>
<td>Heat conductivity W/m·K</td>
<td>1.38/</td>
<td>0.8/</td>
<td>0.9/</td>
</tr>
<tr>
<td></td>
<td>0.63</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Phase Diagram of Binary Nitrate Systems
Challenge for PCM: Heat Transfer

Heat transfer coefficient is dominated by the thermal conductivity of the solid PCM

→ Low thermal conductivity is bottle neck for PCM’s
Design Options für PCM Storage
Basic Concepts

**Increasing heat conductivity**
- Integrierter Wärmeübertrager
  - Wärmeübertragerrohre
- PCM - Composite Material

**Increasing specific heat transfer surface**
- Makroverkapselung
  - Druckbehälter mit gekapseltem PCM
- Kapsel mit PCM

- Ausgedehnte Wärmeübertragungsstruktur
  - zusätzliche Wärmeübertragungsflächen
Inceasing Thermal Conductivity
Composite material approach PCM/Graphit

1. Intercalation and exfoliation
2. Grinding
3. Compression

Manufactured by

Ground expanded graphite
Compressed expanded graphite plates

Infiltration
Extrusion + Compression
Achievements

Graph showing the relationship between graphite content [g/cm³] and thermal conductivity [W/mK].

- **EG Formkörper ohne Salz**
  - Graphite content: 1.6-1.8 g/cm³ (Route 1)

- **VM EG Formkörper (infiltrieren) pges=1,6-1,8 g/cm³ (Route 1)**

- **VM EG Pulver (verpressen) pges=1,9-2,0 g/cm³ (Route 2)**

- **VM NG Schüttung (infiltrieren) pges=2,1 g/cm³ (Route 3)**
300 kg Storage Module with composite Salt-Graphite

Heat exchanger tubes with first PCM/Graphite Segment without external containment (left)

Storage module during integration in the test facility (right)
Increasing specific heat transfer surface
High effective thermal conductivity through heat conducting elements

„Sandwich“ design

Graphite-foil
Steam pipe
10 mm

0.5 mm

PCM

Increasing specific heat transfer surface
High effective thermal conductivity through heat conducting elements

„Sandwich“ design

Graphite-foil
Steam pipe
10 mm

0.5 mm

PCM
Experimental Verification with Nitrate salts

before filling with PCM

Im beladenen Zustand

PCM liquid

Graphitfolie
400 kg “sandwich Design” Storage Module
## Status of PCM Storage at DLR for the range 120 - 250 °C

<table>
<thead>
<tr>
<th>Design Concept</th>
<th>Storage material</th>
<th>Size</th>
<th>Power range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandwich concept</td>
<td>KNO$_3$-NaNO$_3$</td>
<td>100 kg</td>
<td>2-4 kW 1)</td>
</tr>
<tr>
<td>Composite EG/salt</td>
<td>Compressed EG / KNO$_3$-NaNO$_3$</td>
<td>300 kg</td>
<td>10 kW 2)</td>
</tr>
<tr>
<td>Sandwich concept</td>
<td>NaNO$_2$-NaNO$_3$-KNO$_3$</td>
<td>400 kg</td>
<td>10 kW 1)</td>
</tr>
<tr>
<td>Sandwich concept</td>
<td>KNO$_3$-NaNO$_3$</td>
<td>2000 kg</td>
<td>100 kW 2)</td>
</tr>
</tbody>
</table>

1) national BMWi Project  
2) FP 6 Project
Comparison storage systems

**Example**

Containment and TES Material Volume
- 100 kWh, providing saturated steam at 140°C –
- Impact of exit temperature of the solar field during charging
- Impact of different HTF`s – oil, pressurised water, steam

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<tr>
<th>Storage System</th>
<th>Containment Volume</th>
<th>TES Material Volume</th>
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<tbody>
<tr>
<td>Solid Media</td>
<td>13.5 m³</td>
<td>0.8 m³</td>
</tr>
<tr>
<td>Heat Transfer Oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressurised Water</td>
<td>4.2 m³</td>
<td>0.7 m³</td>
</tr>
<tr>
<td>Steam Accumulator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCM</td>
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**Case 1: 160°C**

**Case 2: 200°C**
Conclusions

- large potential for heat storage in the process heat sector
- type of the selected collector/HTF has significant influence on the storage concept
- Significant potential for PCM storage in connection with water/steam systems
- New “sandwich design“ and/or new Salt/Graphite composite materials are solving the bottleneck of the low salt heat conductivity
- the Nitrate salt based PCM storage technique is ready for pilot scale demonstration
Further Information

http://www.dlr.de/tt/institut/abteilungen/thermischept

http://www.dlr.de/tt/institut/abteilungen/thermischept/DISTOR

http://www.iea-eces.org/

Joint IEA Annex19 / FP6 DISTOR Workshop in September in Spain