Application of Phase Change Materials and PCM-Slurries for Thermal Energy Storage

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Outline

• Thermal energy storage with PCM
• PCM materials and their thermal properties
• PCM integration into TES
  – Macro – encapsulation
  – Micro – encapsulation, PCM slurries
  – PCM in tank, immersed heat exchanger
• Conclusions and outlook
Thermal energy storage with PCM

- High energy density with low temperature differences
- Temperature stability during phase change
- Possibility to
  - save storage volume
  - increase storage capacity
- Low thermal conductivity of the materials
  ⇒ Limitation of charge/discharge power
  ⇒ Need for: - small modules
            and/or
            - enhancement of thermal conductivity
Energy density of different PCM materials

per mass unit [kJ/kg]

per volume unit [kJ/dm³]

- water
- paraffin
- sodium acetate
- sodium acetate + graphite

temperature [°C]

enthalpy [kJ/kg]

0 200 400 600 800

0 20 40 60 80 100

enthalpy [kJ/dm³]
Volumetric storage capacity (compared to water)

- Sodium Acetate Trihydrate
- Sodium Acetate Trihydrate + Graphite
- Paraffin
Possibilities of PCM integration into TES

a) Macro-encapsulation
b) Micro-encapsulation, PCM slurries
c) PCM in tank, immersed heat exchanger
Macro-encapsulation

- Encapsulation of the material into suitable modules (e.g. spheres, cylinders)
- Module envelope serves as heat exchanger between water and PCM

- **advantages:**
  - easy integration into the tank (also into existing tanks)
  - possibility of using different PCMs in one tank

- **disadvantages:**
  - requirements for a high heat transfer rate:
    - the modules should be as small as possible
    - and / or
  - enhancement of the thermal conductivity
Macro-encapsulation

Experimental storage tank

- Volume: ~ 35 Liter
- 7 cylindrical PCM elements, ø 5 cm
  \[ \Rightarrow \text{PCM volume fraction} \sim 30\% \]
Sodium Acetate inside the modules

Storage tank: $T_{\text{start}} = 70°C$

- $T_{\text{return}}$
- $T_{\text{flow}}$
- $T_{\text{water}}$
- $T_{\text{PCM\_surface}}$
- $T_{\text{PCM\_center}}$
- discharge power

$T_{VL} = 50[°C]$

$\dot{V} = 100[\ell/h]$
Sodium Acetate + Graphite inside the modules

Storage tank: $T_{\text{start}} = 70^\circ \text{C}$

$T_{vl} = 50[^\circ \text{C}]$

$\hat{V} = 100[\text{l/h}]$
Discharge power for different materials inside the modules

Storage tank: $T_{\text{start}} = 70^\circ\text{C}$

Discharge power [kW] vs. time [min]

- **Water**

$T_{vl} = 50[^\circ\text{C}]$

$\dot{V} = 100[^\text{l/h}]$
Discharge power for different materials inside the modules

Storage tank: $T_{\text{start}} = 70^\circ\text{C}$

- **Paraffin**
  - $\lambda = 0.2 \,[\text{W/(m.K)}]$
  - $T_{VL} = 50^\circ\text{C}$
  - $\dot{V} = 100[\text{l/h}]$

- **Water**
Discharge power for different materials inside the modules

Storage tank: $T_{\text{start}} = 70^\circ\text{C}$

- Sodium Acetate
  - $\lambda = 0.4 \,[\text{W/(m.K)}]$
  - $T_{vl} = 50\,^\circ\text{C}$
  - $\dot{V} = 100\,[\text{l/h}]$

- Water

- Paraffin

- Sodium Acetate Trihydrate
Discharge power for different materials inside the modules

Storage tank: T_start = 70°C

Sodium Acetate + Graphite
\( \lambda = 4 \, [\text{W/(m.K)}] \)

\( T_{VL} = 50[\degree \text{C}] \)
\( \dot{V} = 100[\text{l/h}] \)
Micro-encapsulation, PCM slurries

Capsules with diameters of 5-10 µm:

⇒ high ratio of surface area to volume
⇒ thermal conductivity is no problem

When mixed with water ⇒ pumpable fluid

⇒ PCM slurry
⇒ heat storage- and transport-medium
Used material (BASF)

- Melting temperature range: 45-63°C
- Latent heat microcapsules: ~ 140 [kJ/kg]
- Sens. heat capacity microcapsules: ~ 2.7 [kJ/(kg.K)]
  ⇒ smaller than for water!
- Size of the capsules: 5-10 µm
  ⇒ slurry can be treated as a homogeneous fluid
- Viscosity of concentrations > 30% is very high!
  ⇒ high pressure losses
  ⇒ low heat transfer coefficients
Storage capacity (compared to water)

- Melting range
- Concentration of microcapsules:
  - 50%
  - 40%
  - 30%
  - 20%
  - 10%
Storage tank with internal heat exchanger

- Volume: 200 litres
- Spiral type internal heat exchanger
- Measurements with different storage fluids

Water
- Slurry 20%
- Slurry 30%
- Slurry 40%
- Slurry 50%
Heat transfer coefficient (natural convection) for different storage fluids

Conditions:

Heat exchanger fluid (water):
Flow rate 1000 liter/h, $T=70^\circ$C

Storage fluid:
$T_{\text{start}}=50^\circ$C
Heat transfer coefficient (natural convection) for different storage fluids

Conditions:

Heat exchanger fluid (water):
Flow rate 1000 liter/h, T=70°C

Storage fluid:
T_start=50°C
Heat transfer coefficient (natural convection) for different storage fluids

Conditions:
Heat exchanger fluid (water):
Flow rate 1000 liter/h, T=70°C
Storage fluid:
T_start=50°C

- water
- Slurry 20%
- Slurry 30%
- Slurry 40%
- Slurry 50%
Flat plate heat exchanger (counterflow): Determination of overall heat transfer coefficient

Side 1: Water
\[ \dot{m}_1, t_{h1} \]

Side 2: Water
\[ \dot{m}_2, t_{c1}, t_{c2} \]

The overall heat transfer coefficient is shown as a function of the flow rate secondary side [dm³/h].

\[ \text{flow rate secondary side [dm³/h]} \]

- [Graph showing the relationship between flow rate and overall heat transfer coefficient]

\[ \dot{m}_1, t_{h1} \]

\[ \dot{m}_2, t_{c1} \]
Flat plate heat exchanger (counterflow): Determination of overall heat transfer coefficient

Water
Slurry 20%
Slurry 30%
Slurry 40%

Side 1:
Water
$\dot{V} = 400 \ lm/h$

Side 2:
Water
Slurry 20%
Slurry 30%
Slurry 40%

$m_1, t_{h1}$
$t_{c2}$
$m_2, t_{c1}$

overall heat transfer coefficient [W/(m²·K)]

flow rate secondary side [dm³/h]

- Water
- Slurry 20%
- Slurry 30%
- Slurry 40%
PCM in tank, immersed heat exchanger

- PCM is filled directly into the tank
- Charging / discharging via a suitable heat exchanger

**Advantages:**
⇒ possibility of a high fraction of PCM
⇒ lower effort (no filling of modules)

**Disadvantages:**
⇒ special heat exchanger is necessary
⇒ storage envelope and heat exchanger have to be geometrically adjusted to each other
⇒ different PCMs in one tank are not possible
Heat exchanger

Water-to-air heat exchanger

**Advantages:**
- PCM fraction > 80%
- Very high heat transfer surface because of fins
- High charge/discharge power
- Mass product

**Disadvantages:**
- Material combination – corrosion?
Discharging the tank – measurement and simulation

volume of the tank : 45 litres

mass flow: 601 kg/h
T_inlet: 24 °C
T_storage_start: 70 °C
Conclusions and Outlook

• Different possibilities of PCM integration depending on the application

• Encapsulation of materials is a critical issue

• PCM Slurries are not suitable for solar applications

• Short term storage:
  
  high discharge powers in relation to storage size
  
  requirements:
  
  ⇒ small modules
  
  and / or
  
  ⇒ enhancement of thermal conductivity

• Long term storage:
  
  lower discharge powers in relation to storage size

• Simulation as an instrument for further work / optimisation
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