Development of a Metal Foam based Latent Heat Cooling System in the Field of Solar Power Generation

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Photovoltaics, electric current transformation, standard cooling system
Air flow channels and PCM-heat storage system
Development of single latent heat storage modules

Facts:

Heat conductivity of paraffin is very low (0.2 W/m/K).

Metal foam with open porosities is filled with paraffin.

This way the effective thermal conductivity of the composition can be increased.

The melting point of paraffin: 29°C.

As long as paraffin is available for melting the temperature in the building can be damped.
Influence of metal foam on heat conductivity and melting process

TIME: 0.333333 (min)
ANTEIL: 0.498301
Influence of metal foam surrounded by air on heat conductivity

Aluminium
Air

yz, x=0-boundary, T=600K

3 mm

Tets, 0.15 mm
Cells: 1 920 000

Prism Layer
Calculated Temperature Distribution for different time stamps

\[
\begin{align*}
  t &= 0.15s, \quad T_{av,metal} = 533.1K \\
  t &= 0.35s, \quad T_{av,metal} = 585.3K
\end{align*}
\]
Influence of metal foam on the convective heat transfer

$T_{fluid,av} = 483.5K$

$T_{struk,av} = 566.2K$

$T_E = 300.0K$

$T_H = 600.0K$

$T_A = 536.3K$

Origin [0,0,0] mm
Inlet, $T = 300K$, $u = 1m/s$
Outlet
Tests, $x=0$-boundary, $T = 600K$

Temperature (K)

300.00 360.00 420.00 480.00 540.00 600.00

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Facts

- The combination of metal foam and paraffin helps increasing the heat transfer
- Even if metal foam is surrounded by air (which has a very bad heat conductivity) the heat transfer can be increased
- If convection is added also air can be heated quite well.

→ **Metal foam is the right answer for a latent heat storage modul**
Dimensioning of the LHS

Five inverters placed in each building

- **5 Inverters**
  - Power: \( P = 5 \times 105 \text{ kW} \)
  - Efficiency: \( h = 0.98 \)

Power loss is released as heat into environment \( 7,875 \text{ kW} \)

Power loss about \( 10.5 \text{ kW} \)

into building \( 2,625 \text{ kW} \)

- **5 hours of maximum power**
  - Released energy:
    - \( E = 5h \times 2.625 \text{ kW} \)
    - \( E = 47.25 \text{ MJ} \)
  - Mass of PCM
    - \( M = E/C \)
    - \( M = 47.25 \text{ MJ}/169 \text{ kJ/kg} \)
    - \( M = 280 \text{ kg} \)

**Procedure:**
- Mass defined → Volume needed for the storage modules clarified
- Place for the LHS-System is only in the cellar of the building available
- Installation requirements (maximum channel size) and the dimension of the cellar leaded to a LHS configuration which consists of
  - 15 cylinders (Single Storage Modules, Metal foam and Paraffin)
  - Dimension: \( D = 0.2 \text{ m}, H = 0.7 \text{ m} \)
Possible ordering schemes within the given geometrical dimensions of the LHS
Pressure loss and Heat flux for selected ordering scheme → operation condition

variable heat flux and pressure loss

- Pressure loss [Pa]
  - 200 Pa

- Heat flux [W]
  - 3300 W

- Flow rate [m³/h]
  - Volume rate: 2500 m³/h

Flow rate vs. Pressure loss and Heat flux graph.
Results of CFD-Simulation
Computational Model

- inlet
- outlet
- single storage module
- flow channel
- bend + guiding plate
Results of CFD-Simulation
Computed velocities

The flow at the final row of cylinders shows vortexes which result by the flow expansion.

Highest velocities can be observed in the gaps between the cylinders.

Guiding plate
Results of CFD-Simulation
Computed temperature distribution

During the solidification process of paraffin the first row and last row of the cylinders are dragged behind the other cylinders.

During the melting process the cylinders in the first and last row do melt slower as the other cylinders.
Calculated air temperature and melting process for a day cycle

Time: 30 (min)  
Fluessigkeitsanteil: 100  
Temperature_outlet: 26.8731 (C)
Latent heat storage system installed in Spain (2009 / 2010)

Installed measurements:

- Ambient temperature
- Room temperature
- Flow temperature (after entering LHS)
- Flow temperature (before entering LHS)

Temperature measurements installed in the SSM's for ventilator control
Control Mode

The control mode is based on different temperatures
- environment
- building
- paraffin

Cooling mode
→ Reduce temperature inside the building

Discharging mode (during the night)
→ Release stored heat
Measured temperatures
(One day)

Temperature in a building without additional cooling system

Temperature in the building with LHS cooling system

Temperature inside the SSM

Ambient temperature

dT=10°C

Temperaturverläufe im Vergleich LWS EWT OKS 30 Juni 2010

Temperatur [°C]

Zeit beginnend bei 0 Uhr in [min]

Innenraum EWT
Innenraum OKS
Innenraum LWS
Paraffin 1 LWS
Paraffin 2 LWS
Umgebung
Measured temperatures (three days)
Summary

• **Requirements**
  – Development of a Cooling System for buildings with inverters for electric current transformation
  – Cooling System must be compact and mostly passive
  – Cooling System must damp temperatures inside the building

• **Solution**
  – A Latent Heat Cooling System has been developed
  – Single Storage Modules consist of metal foam and paraffin
  – The Cooling System can store 5 hours of released heat during a day cycle

• **Development and Installation**
  – Lay out of the system by numerical and analytical simulations (24 hours)
  – Successful installation in Nov. 2009, Operation started in April 2010
  – Measures show that the cooling is successful

• **CFD-Methods (StarCCM+)**
  – Using the Volume of Fluid Method the melting and solidification process can be simulated
  – The ordering scheme has been selected by parametrical studies according to the correlations given by VDI
Thank you for your attention