PCM storage for industry

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RESEARCH & DEVELOPMENT

PCM storage for industry

PCM for cooling application:

- Find suitable PCM’s (melting point between 135 – 195°C)
- Determine thermal and cycling stability of the PCM’s and corrosion behaviour of possible container materials
- Project duration: 12.2015 – 12.2017
- Funded from company (contract research)

Considered boundary conditions:

- Industrial process under vacuum conditions
- Thermal energy must be stored in an cooling unit
- Heat flow between 2 and 4 W/cm²
- Exposure time 10 – 15 min
- Temperature level of the object to be cooled: in the range of 180°C up to 210°C
- Stability criteria > 1 year

PCM storage for industry

Main results of the project:

- Verification of the cooling concept in the Simulation
- Verification of the cooling concept storing the resulting thermal energy in an demonstrator (several cooling cycles carried out)
- Universal cycling unit (material testing in the range of -30 to 200 °C)
- First corrosion test kicked some material pairs out (Salt-eutectics/aluminium alloy, carboxylic acids/steel,…)
- Stability test of five PCM‘s up to 5000 cycles was carried out

Challenges/questions arising from the project:

- Simplify the handling of the material samples
- Influence of the container material to the cycling stability of the PCM’s
- Determine the state of charge and the quality of the PCM’s continuously

PCM – Material research

Material properties of about 40 PCM’s (135 – 195°C):

<u>Types of materials:</u>

- Salt eutectics (theoretical)
- Carboxylic acids and phenols
- Sugar alcohols
- Polymers
- Metals

A167 (167°C) = D-Mannitol (167°C) ?

KOH:NaOH (170°C)

Hydroquinone (172,5°C)

HDPE (~135°C)

Bi:Sn (138°C)

Galactitol (179,8°C)

H160 (~162°C)

10 promising PCM‘s chosen for further analysis!

Corrosion test

Tested materials with PCM's:

- copper
- steel
- brass
- aluminium
- stainless steel

<u>Lessons learned:</u>

- Do not use glass tubes as containment material (it cracks)
- Hydroxides produce in contact with aluminium hydrogen
- Propionic acid react with all metals (produce gas bubbles)
- Puretemp 151X react only with steel (produce gas bubbles)

Simulation of the cooling unit

First approach:

- Finite elemente simulation with MATLAB
- 2D copper block with100x100 mm
- PCM (D-Mannitol) in slots
- Heat flow from left to right

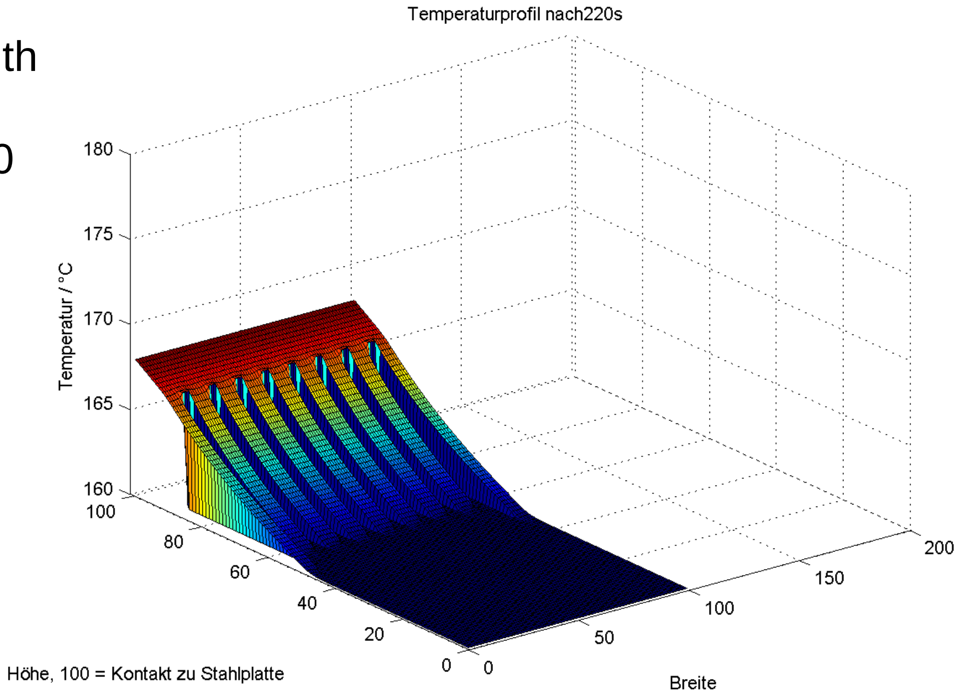


Fig. 1: Simulation of the cooling unit

Lab-scale demonstrator

- The parameter to find the best geometry was temperature rising per second (of the metal plate) during melting process (with D-Mannitol)
- 16 halogen floodlight used as heat source
- Best results shows copper block with Ø8mm holes

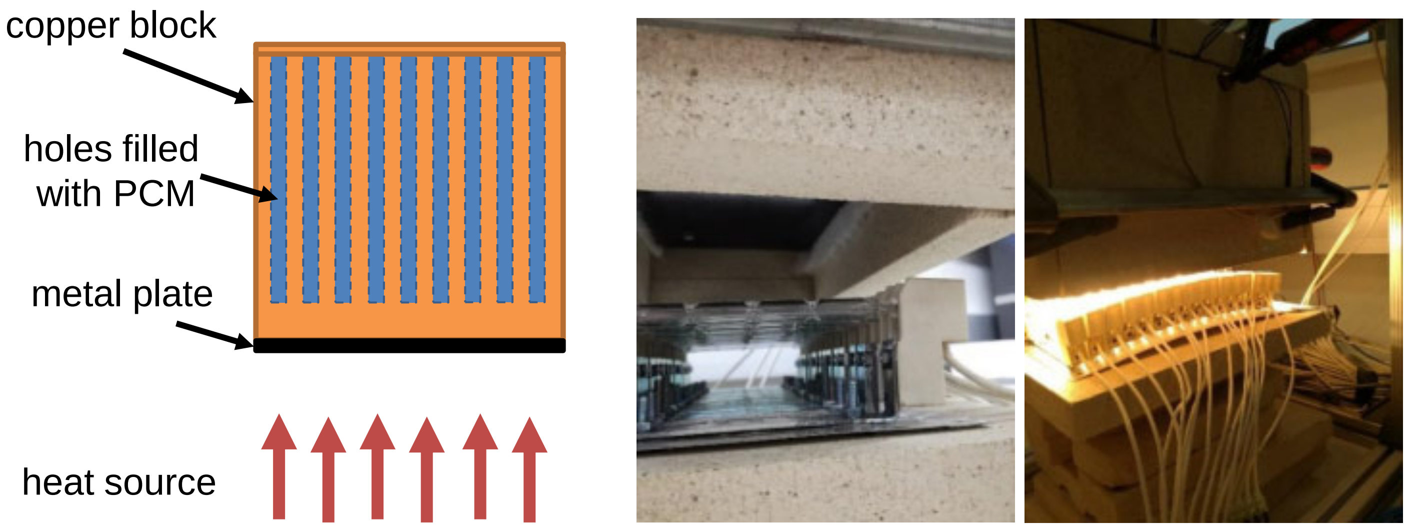
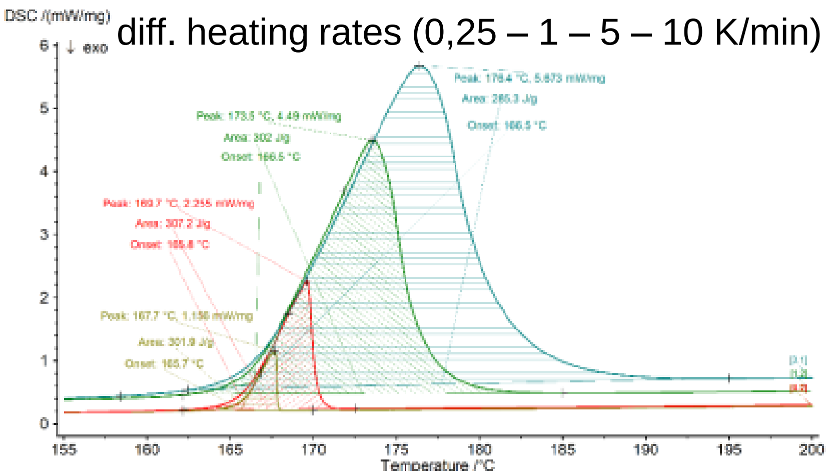


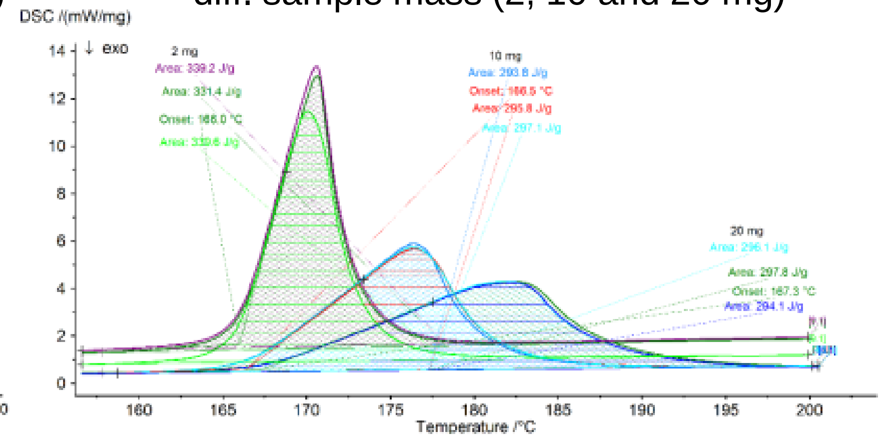
Fig. 2: set-up schema (left) and real set up (right)

DSC – accuracy and repeatability

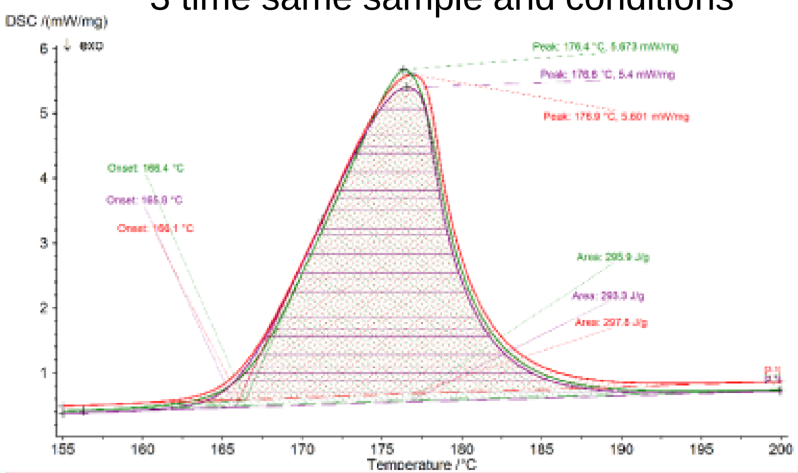
diff. heating rates (0,25 – 1 – 5 – 10 K/min)



diff. sample mass (2, 10 and 20 mg)



3 time same sample and conditions



Best results for D-Mannitol:

- 10 mg samples
- 10 K/min heating rate

Measuring error:

- +/- 0,5°C of melting temperature
- +/- 5 J/g of heat of fusion (< 2%)

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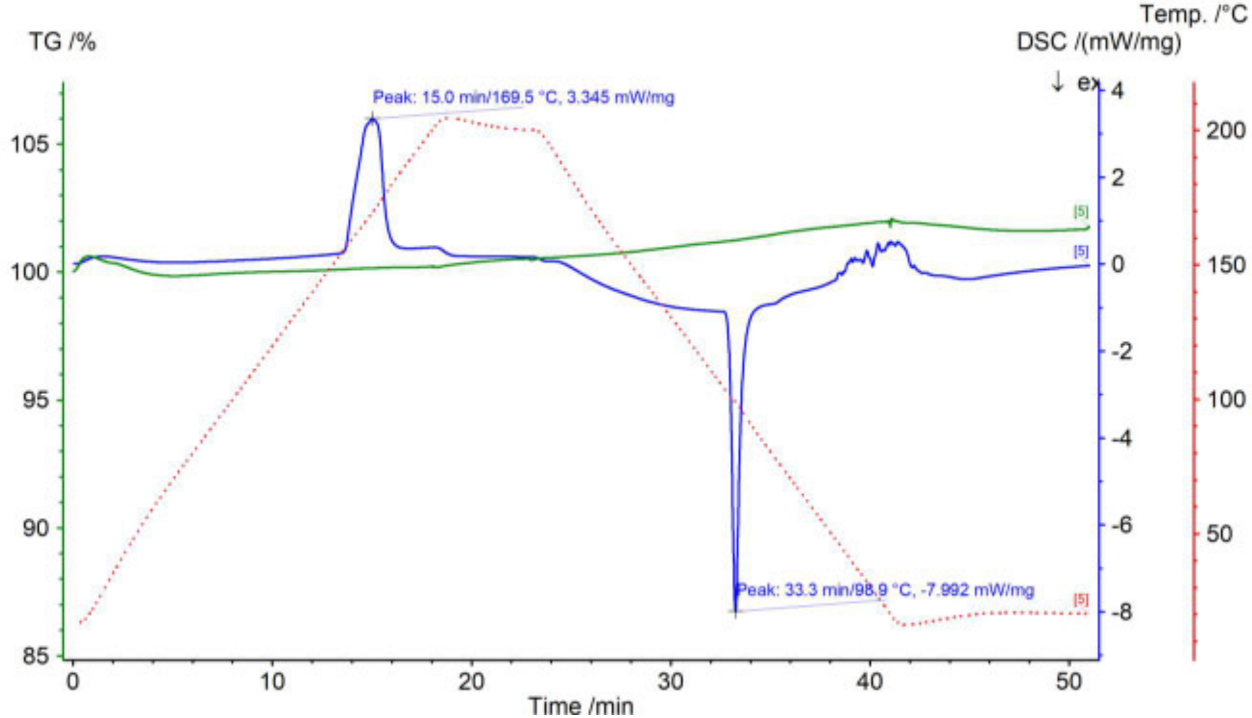
DSC - stability test (examples)

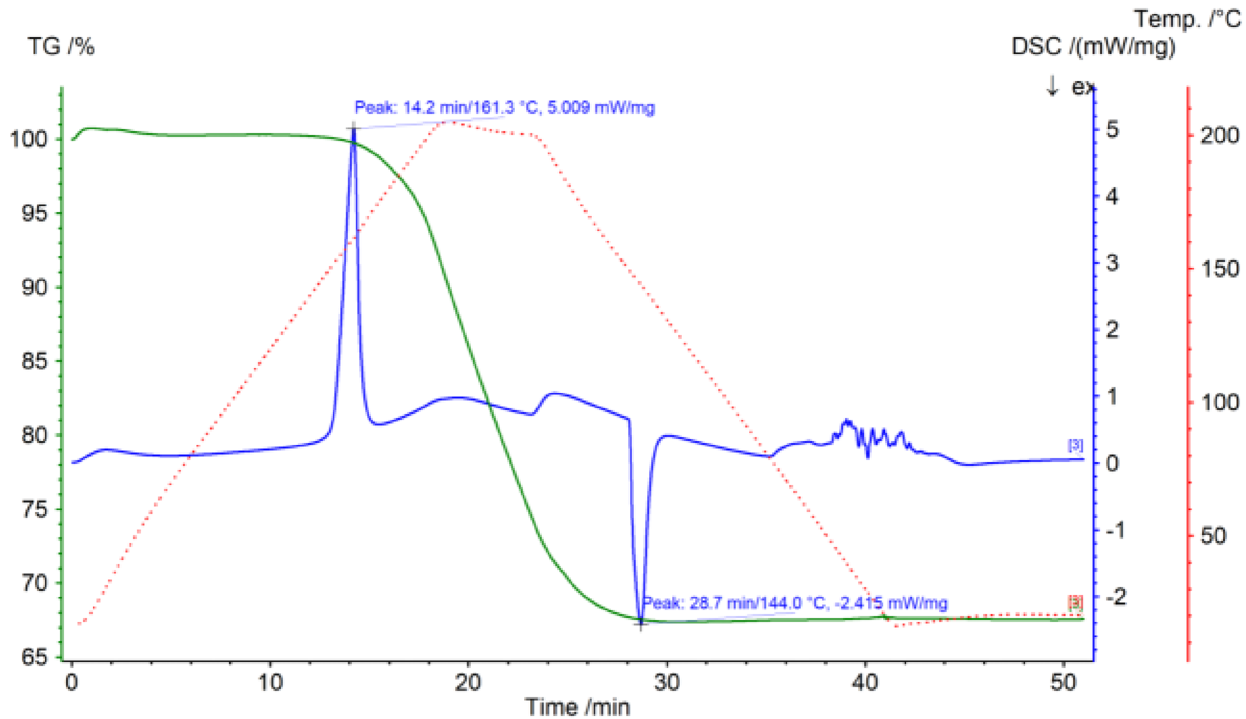
Mass signal during the DSC measurement up to 200°C – thermal stable



D-mannitol/dulcitol - after 5000 cycles

DSC - stability test (examples)

Mass signal during the DSC measurement up to 200°C – thermal unstable

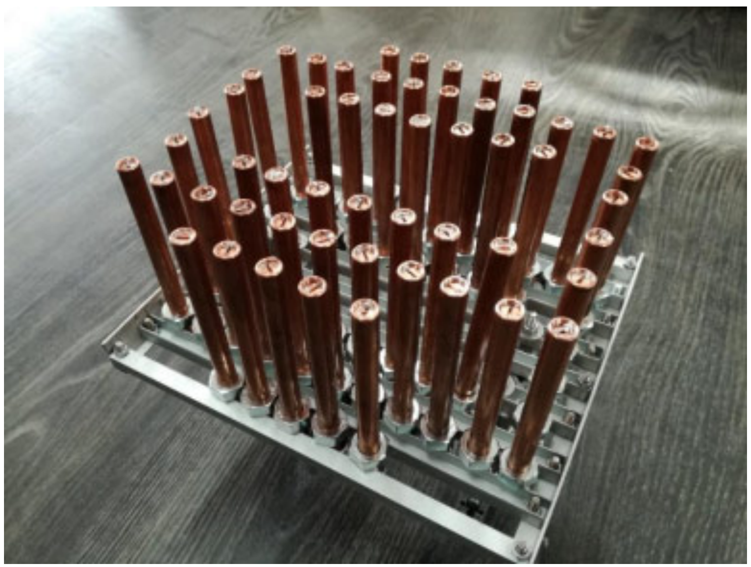


P-151X with paraffin oil - after 5000 cycles

Cycling stability test

Info's to the cycling test:

- Only a part of the PCM in the samples melts during a cycle (solid core)
- Sub cooling is only a problem, when the material is definitely damaged



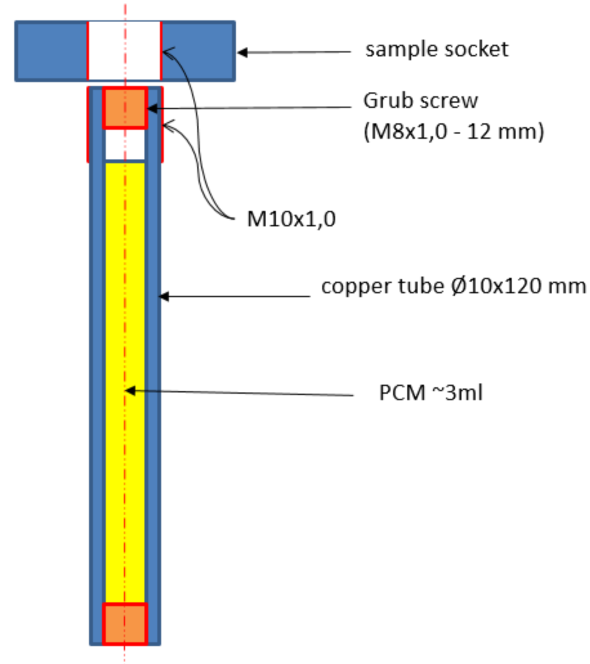


Fig. 3: sample socket (left) and schematic PCM with encapsulation (right)

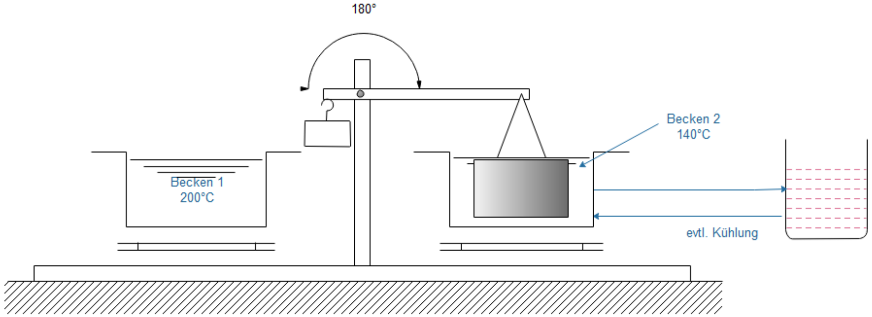
Cycling stability test

Development of the Cycling-Unit for accelerated cycling tests:

- Two temperature controlled oil baths
- Swivel arm
- Sample socket (for 60 samples)
- B&R controller

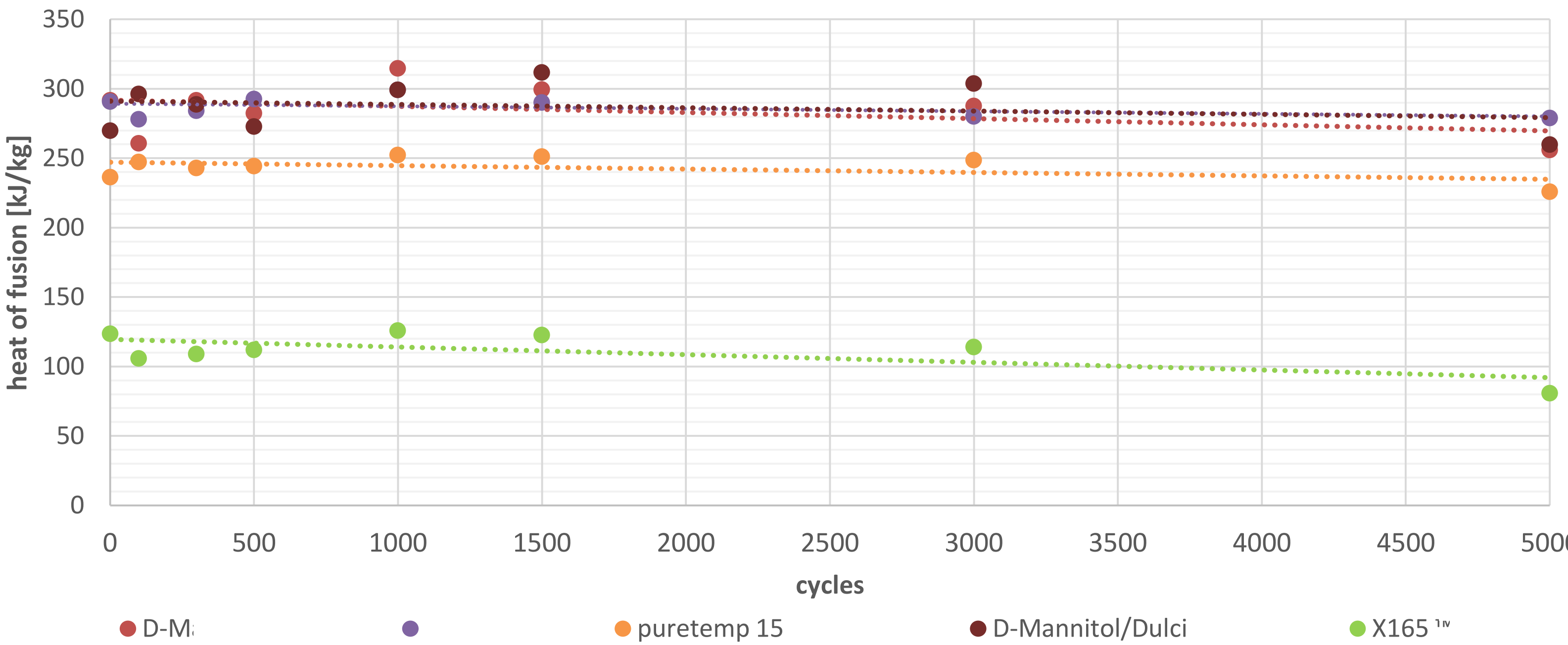
Target:

Partial melting of the PCM‘s controlled by the detention time up to 5000 cycles



Cycling stability test

PCM	Melting Point	Latent Heat Capacity
D-Mannitol	**167 °C**	**410,4 kJ/dm³ (270 kJ/kg)**
A167	**167 °C**	**435 kJ/dm³ (290 kJ/kg)**
Puretemp151X	**151 °C**	**323,3 kJ/dm³ (217 kJ/kg)**
D-Mannitol/Dulcitol	**153 °C**	**421,4 kJ/dm³ (280 kJ/kg)**
X165	**165°C**	**225 kJ/dm³ (172,5 kJ/kg)**



All materials shows after 5000 cycles degradation of about 5 – 10 % of the melting temperature and heat of fusion!

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Constant thermal stress test

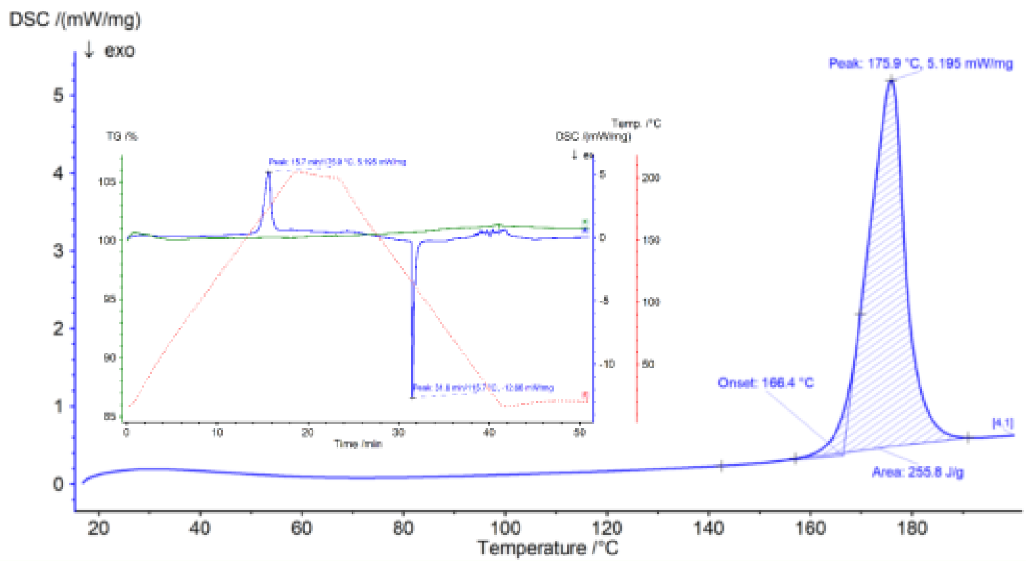
- Convection oven under 180°C up to 456h
- D-Mannitol samples in aluminium and copper encapsulation

	aluminium sample		**copper sample**	
PCM	Melting Point (Onset / Peak)	Latent Heat Capacity	Melting Point (Onset / Peak)	Latent Heat Capacity
D-Mannitol (theory)	**167 °C**	**270 kJ/kg (410,4 kJ/dm³)**	**167 °C**	**270 kJ/kg (410,4 kJ/dm³)**
pure material	164,7 / 176,0	291,6	164,7 / 176,0	291,6
first time melted	167,2 / 182,6	266,1	167,2 / 182,6	266,1
after 122 h	164,6 / 174	242,1	164,8 / 174,4	247,2
after 290 h	162,7 / 172,7	228,7	164,0 / 173,7	242,5
after 456 h	161,5 / 170.9	184	162,9 / 172,1	208,2

- After 456h, D-Mannitol lost about 1/3 of the initial heat of fusion (in comparison with the pure material)
- Decreasing tendency is more marked with aluminium than copper encapsulation

Conclusion

- Four PCM‘s showed after 5000 cycles good results
- The decrease of d-mannitol in constant thermal stress test (122 hours) is nearly the same like in the cycling test after 5000 cycles (around 110 hours)
- After 456 hours, d-mannitol has lost about 1/3 of the initial heat of fusion (from 291 kJ/kg to 208 kJ/kg) and the melting temperature decreased to 163 °C
- Four of the PCM‘s are promising candidates, which fulfill the requirements of the industrial batch process for a year



D-Mannitol - after 5000 cycles