# Energy Nanocapsules for Thermo-Regulating Paints and Textiles

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# Advances of Phase Change Materials (PCMs) encapsulation

1. Confine liquid phase during the Solid-Liquid transition and vice-versa – particular important for crystallohydrates.

2. Prevent degradation of the PCMs in contact with the external environment.

3. Heat transfer improvement via increasing the surface/volume ratio (for capsules with heat-transfer elements in the shell).

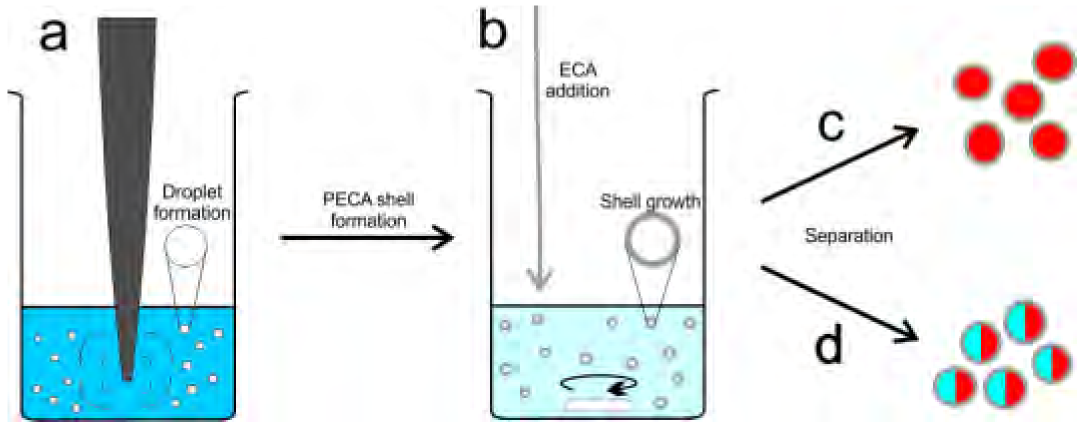
4. Supercooling problems in inorganic PCMs are neglected after encapsulation.

5. Flexibility of incorporation of PCM capsules in the application macrosystems.

# Encapsulation of salt hydrate mixtures

**-Selected $Mg(NO_3)_2$*$6H_2O$ and $Na_2SO_4$*$10H_2O$** as crystallohydrate PCM

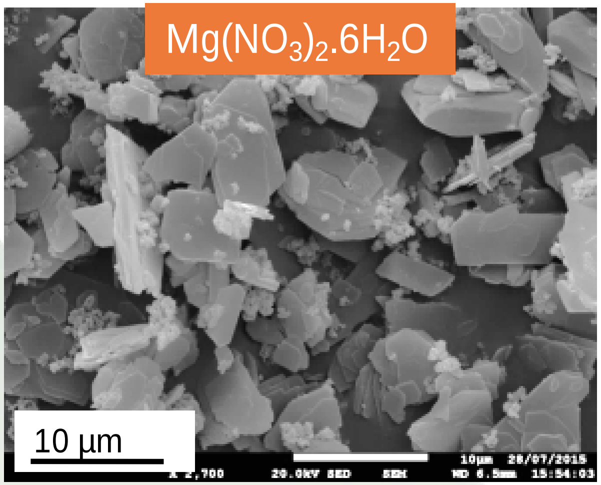
-poly(ethyl-2-cyanoacrylate) (PECA) shell

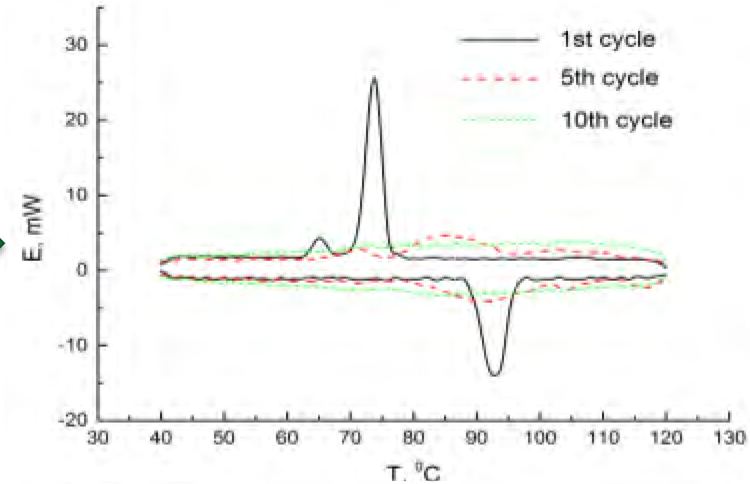



(a) macroemulsion sheared by sonication to form inverse miniemulsion. (b) ECA dissolved in chloroform dropped in to form the PECA shell around aqueous phase. Depending on aqueous phase, nanocapsules are fabricated with (c) single salt hydrate core or (d) salt hydrate mixture core.

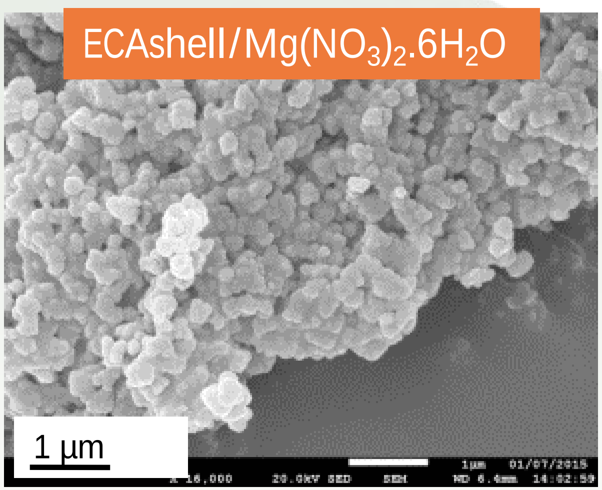
M. Graham, E. Shchukina, D. G. Shchukin. *J. Mater. Chem. A* **2017**, *5*, 13683-13691.

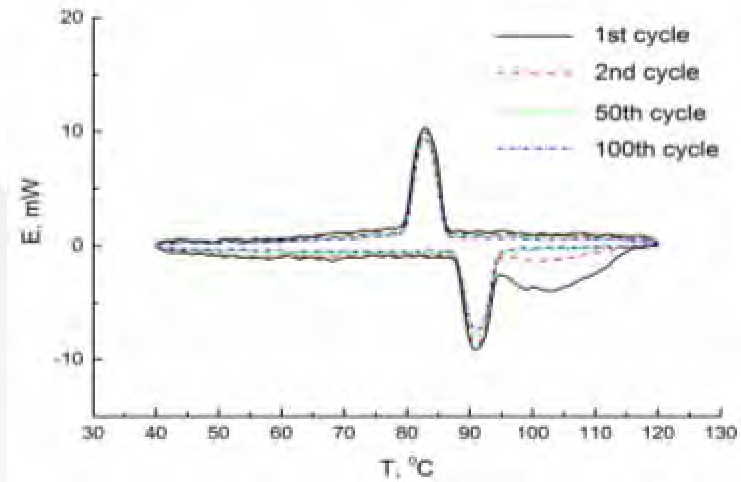
# DSC stability of nanoencapsulated salt hydrates




Degradation occurs after a few cycles




No degradation of the salt

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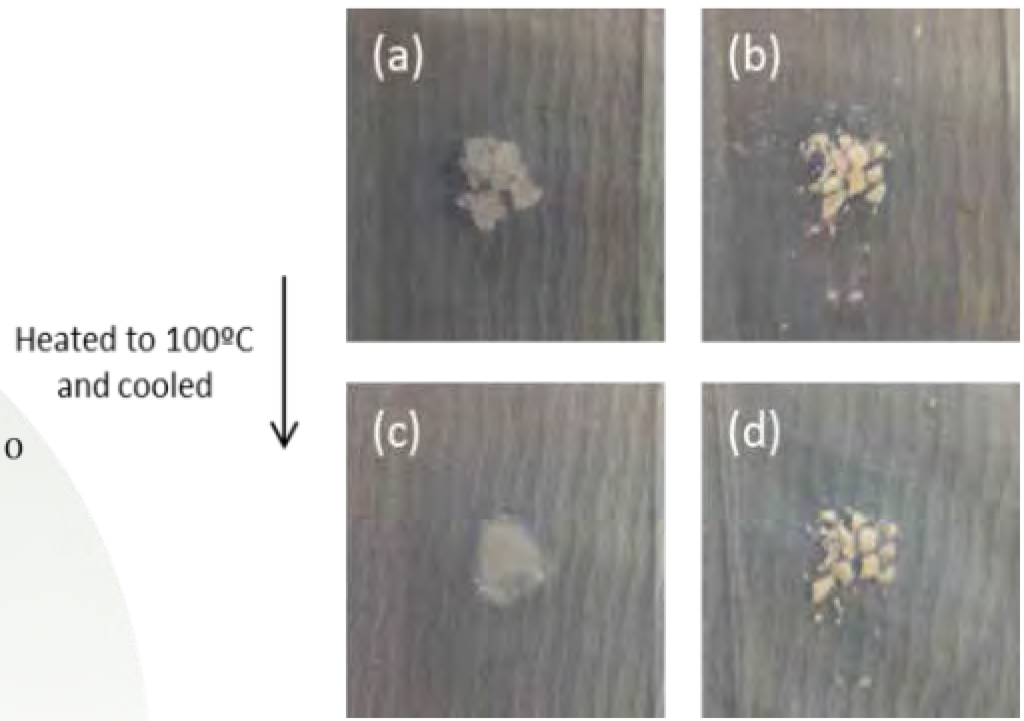
# Macroscale stability of nanoencapsulated crystallohydrates

Free $Mg(NO_3)_2*6H_2O$ (a & c) and nanoencapsulated salt hydrate (b & d) before heating to 100 $^0C$ (top), and after cooling back to room temperature (bottom)

$$Mg(NO_3)_2.6H_2O \underset{<90^oC}{\overset{90^oC}{\rightleftharpoons}} Mg(NO_3)_2 + 6H_2O$$

Congruent melting



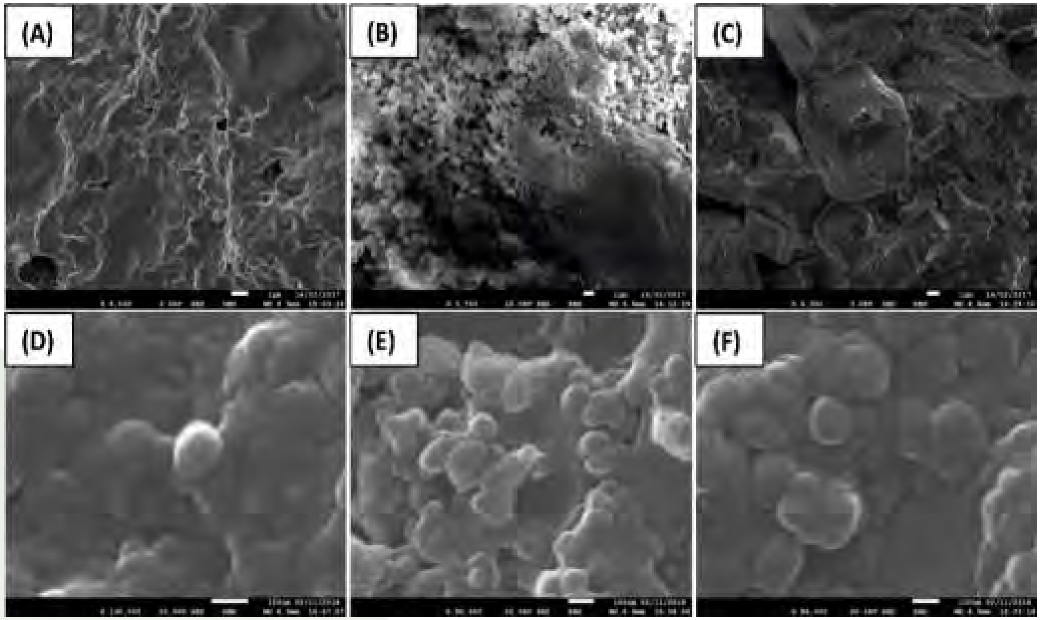

$$1.\ Mg(NO_3)_2.6H_2O \xrightarrow{90^oC} Mg(NO_3)_2.2H_2O + 4H_2O$$

$$2.\ Mg(NO_3)_2.2H_2O \underset{<129^oC}{\overset{129^oC}{\rightleftharpoons}} Mg(NO_3)_2 + 2H_2O$$

Incongruent melting

M. Graham, E. Shchukina, D. G. Shchukin. *J. Mater. Chem. A* **2016**, *4*, 16906-16916.

# SEM of encapsulated salt hydrate mixtures

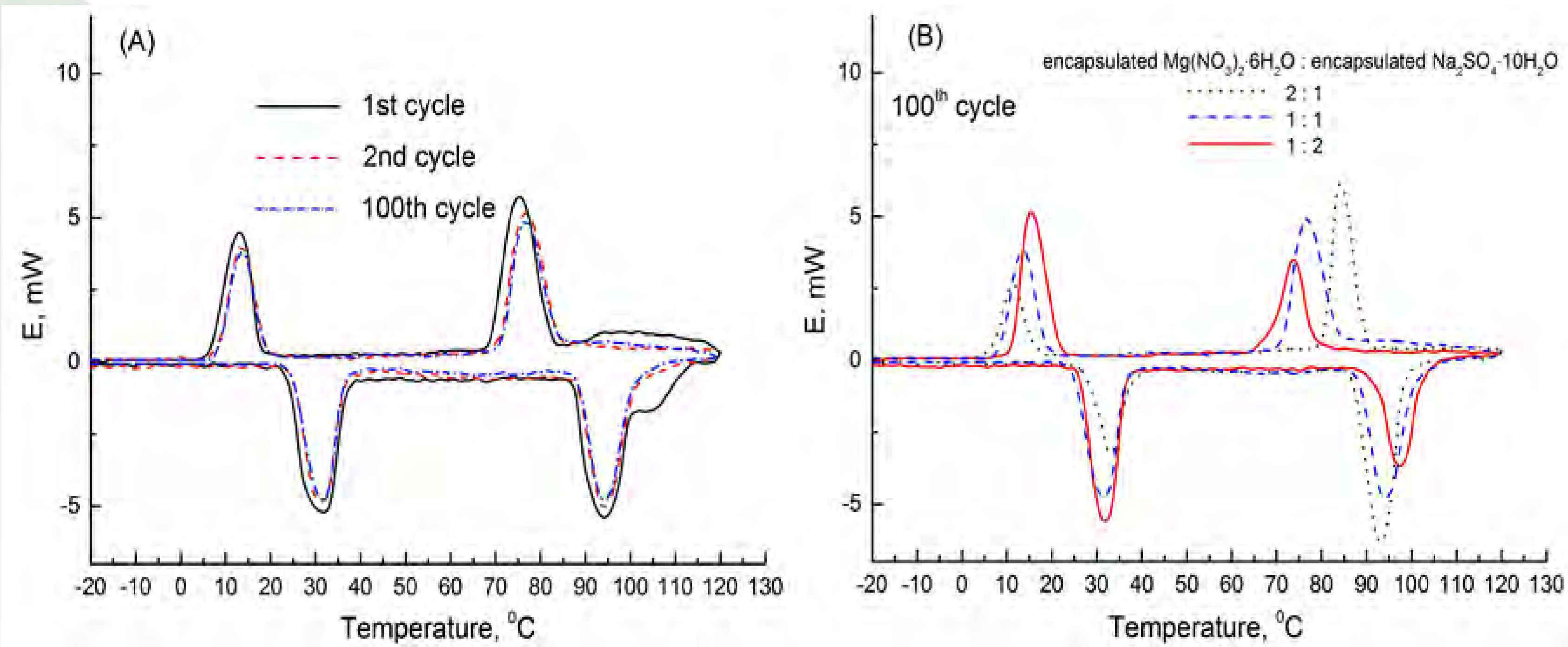



SEM images of bulk $Mg(NO_3)_2*6H_2O$ (A), $Na_2SO_4*10H_2O$ (B) and 1:1 $Mg(NO_3)_2*6H_2O:Na_2SO_4\cdot10H_2O$ mixture (C). (D), (E), (F) demonstrate energy nanocapsules with $Mg(NO_3)_2*6H_2O$, $Na_2SO_4*10H_2O$ and 1:1 $Mg(NO_3)_2*6H_2O:Na_2SO_4\cdot10H_2O$ core, respectively. Scale bar for (A)-(C) images is 1 µm; for (D)-(F) images is 100nm.

# Encapsulated salt hydrate mixtures

## Additive mixtures (of capsules containing single crystallohydrate as a core)

DSC thermograms for (A) 1:1 ratio of poly(cyanoacrylate) encapsulated $Mg(NO_3)_2{*}6H_2O$ to poly(cyanoacrylate) encapsulated $Na_2SO_4{*}10H_2O$, different cycles, (B) different encapsulated $Mg(NO_3)_2{*}6H_2O$ to encapsulated $Na_2SO_4{*}10H_2O$ ratios on 100$^{th}$ heat uptake/release cycle

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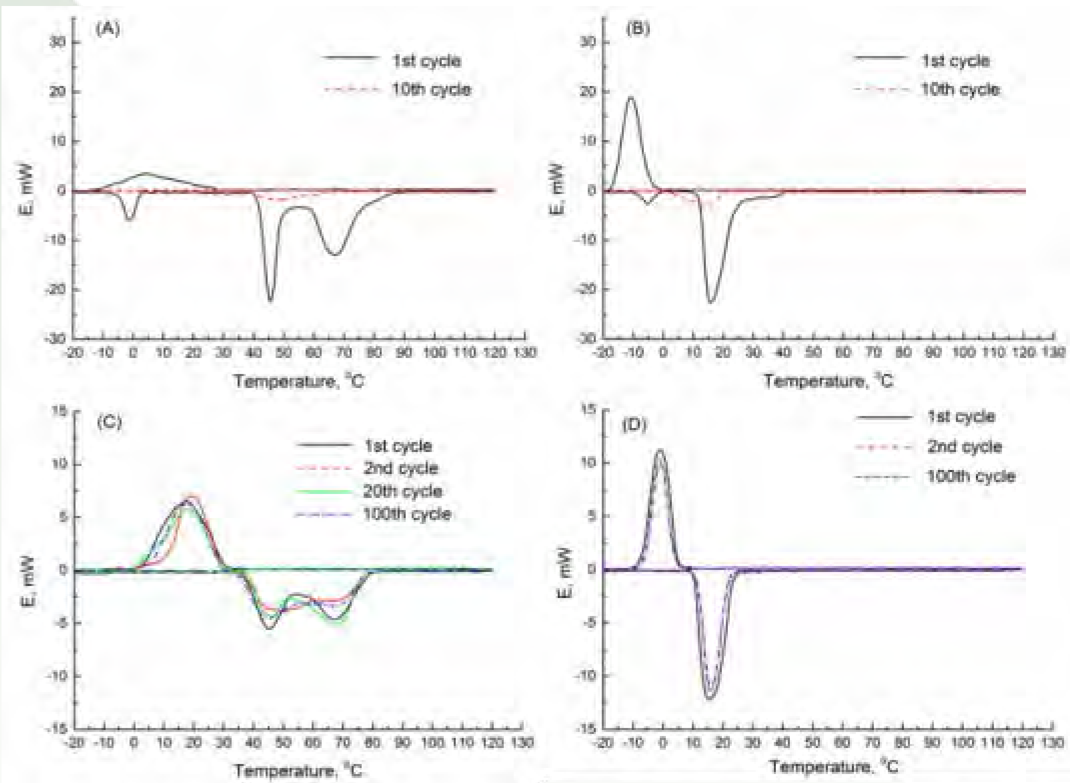
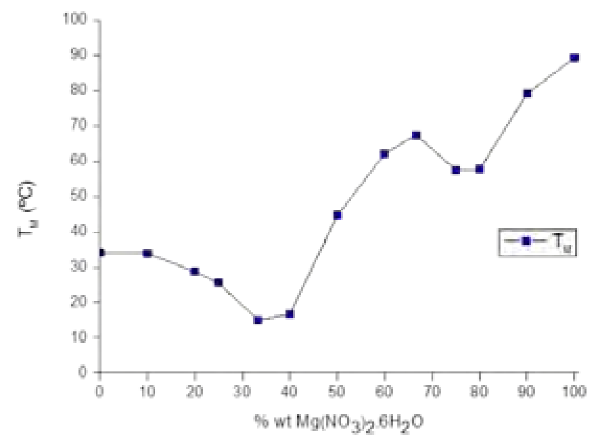
# Encapsulated salt hydrate mixtures

## Nanoencapsulated crystallohydrate eutectics

DSC thermograms for (A) 1:1 wt.% $Mg(NO_3)_2*6H_2O:Na_2SO_4*10H_2O$ bulk mixture, (B) 1:2 wt.% $Mg(NO_3)_2*6H_2O:Na_2SO_4*10H_2O$ bulk mixture, encapsulated 1:1 wt.% $Mg(NO_3)_2*6H_2O:Na_2SO_4*10H_2O$ (C) and encapsulated 1:2 wt.% $Mg(NO_3)_2*6H_2O:Na_2SO_4*10H_2O$ (D)




$Mg(NO_3)_2*6H_2O:Na_2SO_4*10H_2O$ wt.% ratio

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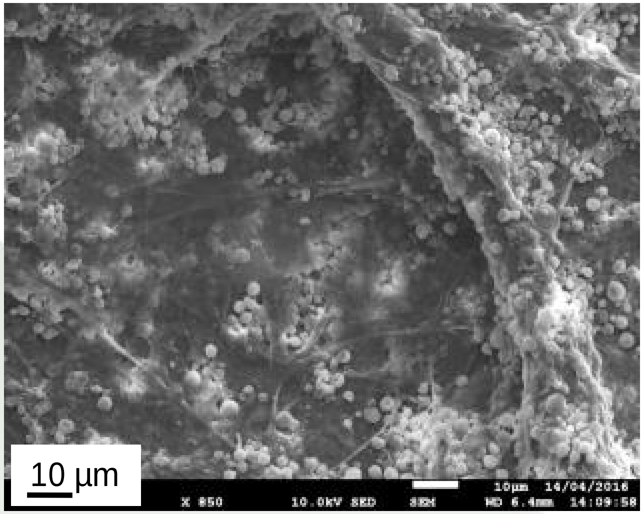
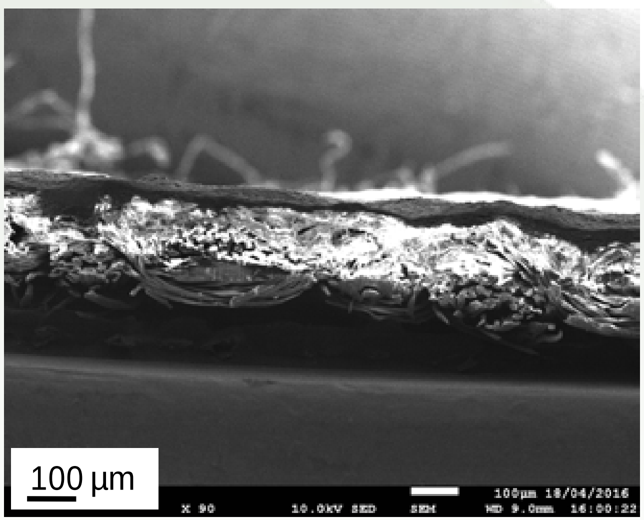
# Application of encapsulated PCMs

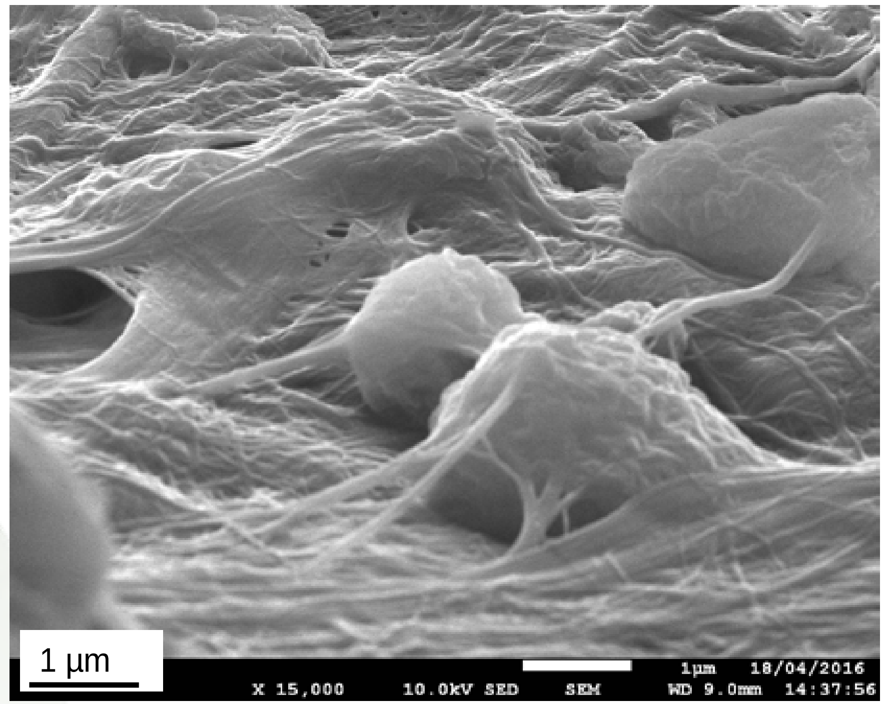
## Incorporation of mPCMs into textiles by Nanofibrillated Cellulose (NFC) coating

**SEM images**




Capsules coated
on the surface of textile with NFC

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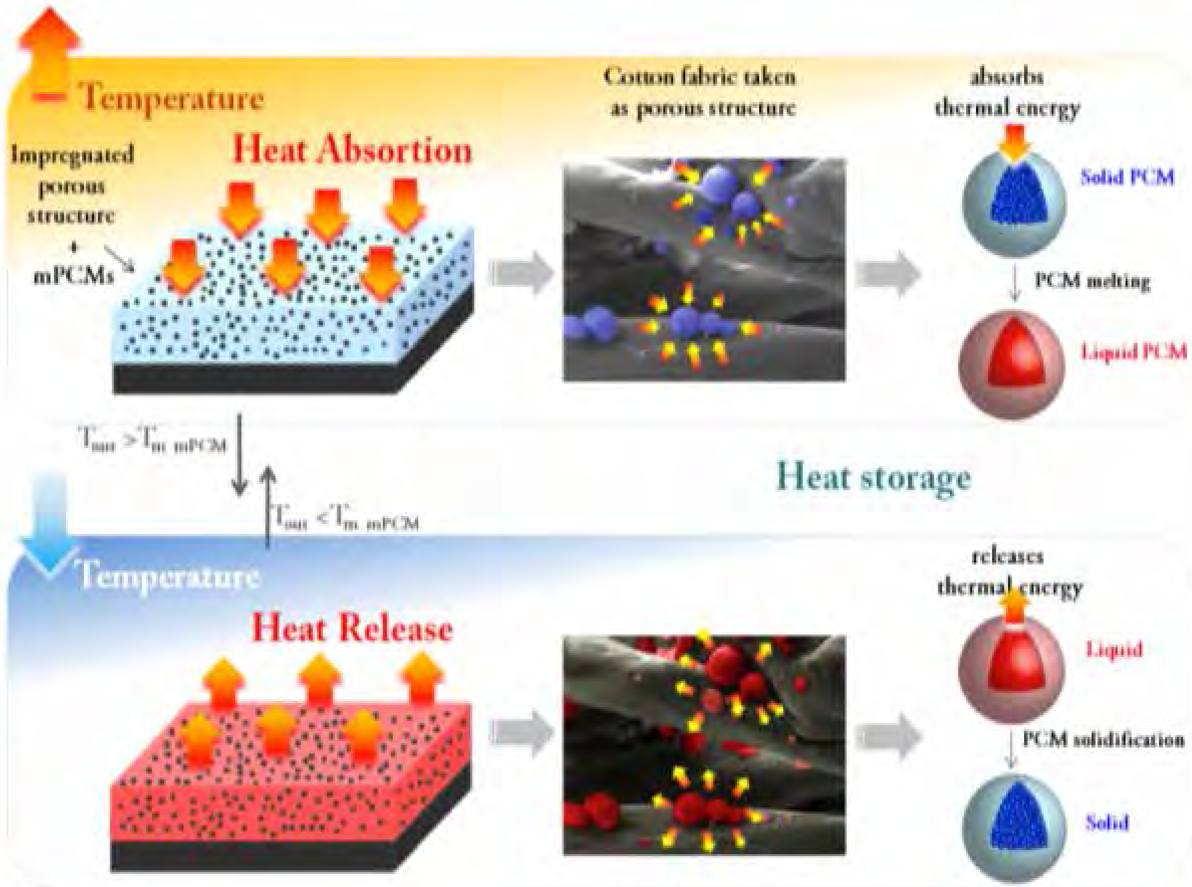
***Collaboration Project** with University of Georgia (USA), Prof. Sergiy Minko*

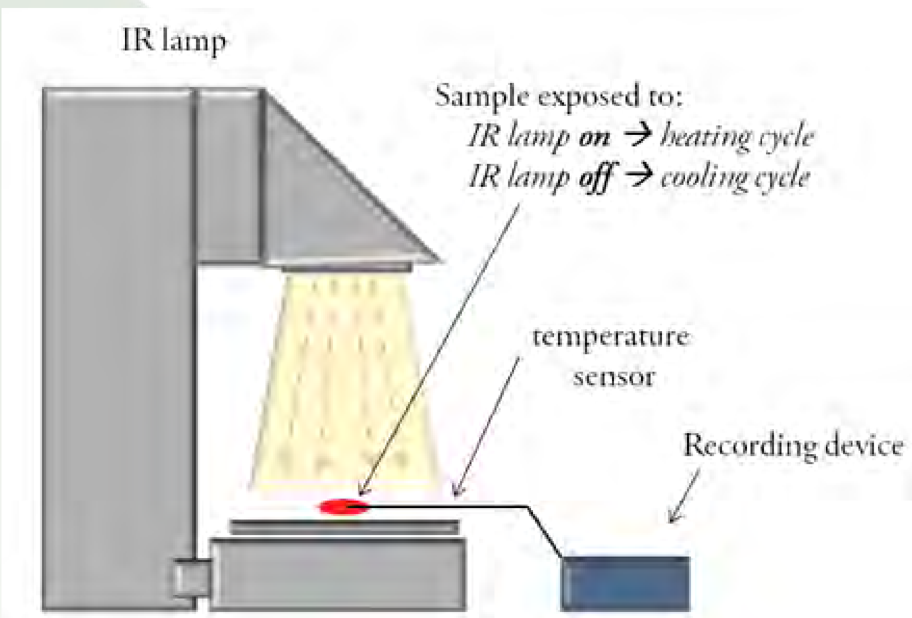
# Overall operation scheme

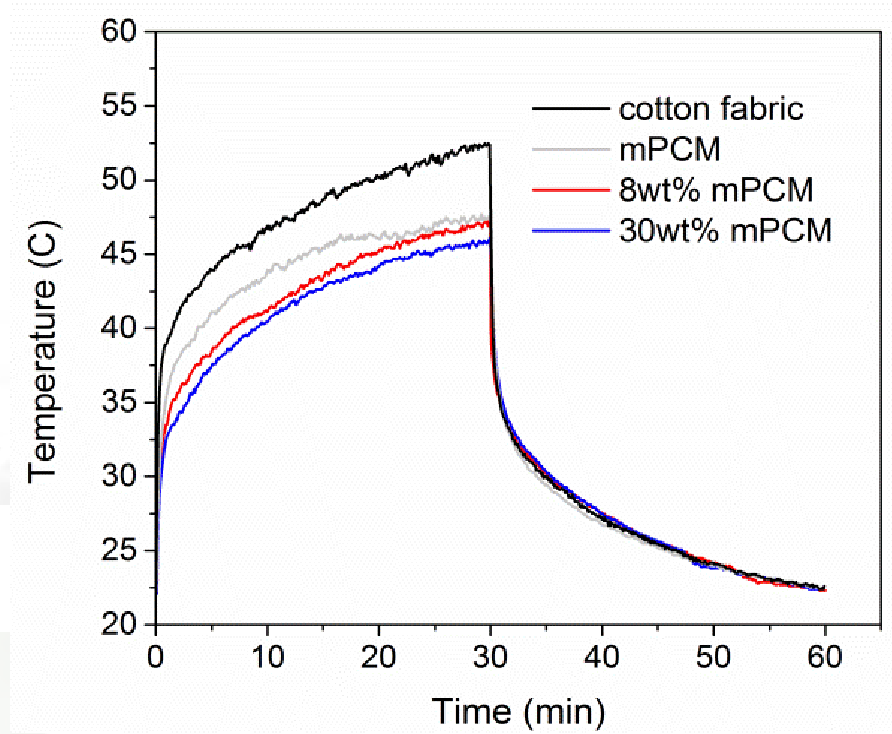
Scheme illustrating thermal energy intake and release process of the impregnated textile structure with mPCMs when the environment temperature increases and drops over the phase change temperature of the encapsulated PCM



# Thermo-regulating properties of mPCM-loaded textiles

Dynamic heat storage measurements for: untreated cotton fabric and treated cotton fabric with 8 wt.% and 30 wt.% of mPCMs



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- ENERCAPSULE Consolidator
- ERC Proof-of-Concept

- NanoBarrier
- Byefouling
- SonoBarrier


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# Thank you very much for your attention