Colloidal Routes to Thermoregulating Coatings from Phase Change Materials Polymer Nanocapsules

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Phase change materials (PCMs) regulate heat flows by storing and releasing latent heat during phase transitions, enabling passive thermoregulation [1–3]. Confinement within polymer shells prevents leakage upon solid–liquid PCMs. In this context, the integration of encapsulated PCMs (ePCMs) into coatings relies on precise control over capsule morphology, encapsulation efficiency, colloidal stability, and processability during film formation. Reducing capsule size to the nanoscale facilitates their incorporation into coatings while tuning heat storage dynamics and thermoregulating performance [2].

Polymer nanocapsules of organic PCMs were prepared by miniemulsion techniques, in which PCM-containing droplets act as nanoreactors for shell formation. Two strategies were employed to induce polymer growth at the droplet interface: conventional miniemulsion polymerization and interfacial polymerization. In the former, polymerization proceeds within monomer-swollen droplets, leading to shell formation through phase separation, whereas in the latter, the reaction is confined at the droplet boundary by the interaction of complementary precursors across the interface. The resulting colloidal dispersions were used to fabricate coatings via casting–solvent evaporation, preserving capsule integrity.

The influence of encapsulation on particle size and morphology was assessed, reflecting the interplay between interfacial stabilization and polymerization kinetics. Differential scanning calorimetry and thermogravimetric analysis confirmed successful PCM confinement, with encapsulation efficiencies above 90%. Thermoregulating performance was evaluated using a semi-adiabatic two-chamber setup, where heat transfer across the sample is governed by conduction and latent heat contributions. The incorporation of nanocapsules results in a measurable temperature-damping response, attributed to the presence of the ePCM and its effect on heat transport across the film.

Keywords:
Nanoencapsulation, Miniemulsion polymerization, Phase change materials, Heat storage, Thermal regulation

References:

[1] O. Álvarez-Bermúdez, I. Adam-Cervera, A. Aguado-Hernándiz, K. Landfester, and R. Muñoz-Espí, ACS Sustain Chem Eng, 2020, 17956–17966.
[2] I. Adam-Cervera, J. Huerta-Recasens, C. M. Gómez, M. Culebras, and R. Muñoz-Espí, Polymers, 2024, 100.
[3] F. Lafta Rashid et al., Buildings, 2024, 1582.

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