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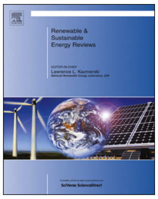

Review of solid–liquid phase change materials and their encapsulation technologies

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ABSTRACT

Various types of solid–liquid phase change materials (PCMs) have been reviewed for thermal energy storage applications. The review has shown that organic solid–liquid PCMs have much more advantages and capabilities than inorganic PCMs but do possess low thermal conductivity and density as well as being flammable. Inorganic PCMs possess higher heat storage capacities and conductivities, cheaper and readily available as well as being non-flammable, but do experience supercooling and phase segregation problems during phase change process. The review has also shown that eutectic PCMs have unique advantage since their melting points can be adjusted. In addition, they have relatively high thermal conductivity and density but they possess low latent and specific heat capacities. Encapsulation technologies and shell materials have also been examined and limitations established. The morphology of particles was identified as a key influencing factor on the thermal and chemical stability and the mechanical strength of encapsulated PCMs. In general, in-situ polymerization method appears to offer the best technological approach in terms of encapsulation efficiency and structural integrity of core material. There is however the need for the development of enhancement methods and standardization of testing procedures for microencapsulated PCMs.

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List of symbols

(OP)-10	polyethylene glycol octylphenyl ether
ABS	acrylonitrile–styrene–butadiene copolymer
AS	acrylonitrile–styrene copolymer
BDDA	1,4-butyleneglycol diacrylate
CAB	cellulose acetate butyrate
Cp	specific heat
DETA	diethylene triamine
DNS-86	ether sulfate
DSC	differential scanning calorimetry
DSP	sodium phosphate dodecahydrate
DVB	divinybenzene
DVB	divinyl benzene
EDA	ethylene diamine
EMT	effective medium theory
FT-IR	Fourier transform infrared
H	latent heat
HD	hexadecane
HSMA	hydrolyzed-styrene-alt-maleic anhydride
k	thermal conductivity
MDI	methylene diisocyanate
MEPCM	microencapsulated phase change material
MF	melamine formaldehyde
n.v.n.s.	non-volatile non-solvent
NEPCM	nanoencapsulated phase change material
O/W	oil/water
PA	palmitic acid
PC	polycarbonate
PCMs	phase change materials
PDVB	polydivinylbenzene
PEMA	polyethyl methacrylate
PETRA	pentaerythritol tetraacrylate
PFR	phenolic resin
PMMA	polymethylmethacrylate
PS	polystyrene
PSB	styrene-1,4-butylene glycol diacrylate copolymer
PSD	styrene–divinylbenzene copolymer
PSDB	styreneedivinylbenzenee 1,4-butylene glycol diacrylate copolymer
PVAc	polyvinyl acetate
SA	stearic acid
SDS	sodium dodecyl sulphate
SEM	scanning electron microscope
SEM	scanning electron microscopy
SMA	styrene–maleic anhydride-monomethyl
St	styrene
St-BA	styrene-butyl acrylate
St-MMA	styrene-methyl methacrylate
TA	sodium laureth sulfate
TDI	tolylene 2,4-diisocyanate
TEM	transmission electron microscope
TG	thermogravimetric
TGA	thermal gravimetric analysis
T_m	melting temperature
TMPTA	trimethylol propane triacrylate
TPGDA	tripropylene glycol diacrylate
TSC	two-step coacervation
UF	urea formaldehyde
v.s.	volatile solvent
WBPU	waterborne polyurethane
XRD	X-ray diffraction
ρ	density

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1. Introduction

Energy consumption in buildings continues to pose environmental problems to many countries and the world as a whole. Techniques such as thermal energy storage are being explored at different levels for reducing energy consumption in buildings which currently accounts for about 40% of total global energy consumption [1]. Phase change materials (PCMs) are capable of storing and releasing large amounts of energy during melting and solidification at specific temperatures. Thermal energy storage does not only reduce the mismatch between energy supply and demand but also improves the performance and reliability of energy systems and plays an important role in conserving energy resources. Current applications of PCMs in buildings include air conditioning, i.e., free cooling [1], cold thermal storage media and absorption refrigeration. Other integrated systems are PCM Trombe wall, PCM wallboards, PCM shutter, PCM concrete, PCM under-floor heating systems, PCM ceiling boards [2–4] as well as hot water supply and waste heat recovery systems [5]. For instance, Oro et al. [6] and Li et al. [7] reviewed PCMs melting point below 20 °C for cold thermal energy storage applications. Agyenim et al. [8] identified phase change materials of melting temperature within 0–65 °C to be suitable for domestic heating/cooling application. They also stated that PCMs of melting temperatures 80–120 °C could be used in absorption cooling system, whereas those types of melting temperatures above 150 °C could be applied in solar power plants systems coupled with parabolic trough collectors for direct steam generation. Furthermore, Cabeza et al. [9] stated more comprehensively that melting temperatures up to 21 °C are more suitable for cooling applications, 22–28 °C for thermal comfort applications, 29–60 °C for hot water supply and over 120 °C for waste heat recovery applications.

Depending on the type of PCM, energy storage process could be described as solid–solid, solid–liquid, liquid–gas or solid–gas as