



# Characterization of phase change materials for thermal control of photovoltaics using Differential Scanning Calorimetry and Temperature History Method



A. Hasan<sup>a,\*</sup>, S.J. McCormack<sup>b</sup>, M.J. Huang<sup>c</sup>, B. Norton<sup>d</sup>

<sup>a</sup> Department of Architectural Engineering, College of Engineering, United Arab Emirates University, P.O. Box 15551, Al Ain, UAE

<sup>b</sup> Department of Civil, Structure and Environmental Engineering, University of Dublin, Trinity College, Dublin 2, Ireland

<sup>c</sup> Centre for Sustainable Technologies, University of Ulster, Newtownabbey, N. Ireland BT370QB, UK

<sup>d</sup> Dublin Energy Lab., Focas Institute, School of Physics, Dublin Institute of Technology, Kevin St., Dublin 8, Ireland

## ARTICLE INFO

### Article history:

Received 7 November 2013

Accepted 19 February 2014

Available online 15 March 2014

### Keywords:

Phase change materials

Thermal control

Photovoltaics

Temperature History Method

## ABSTRACT

Five solid–liquid phase change materials comprising three basic classes, paraffin waxes, salt hydrates and mixtures of fatty acids were thermophysically characterized for thermal regulation applications in photovoltaics. The PCM were investigated using Differential Scanning Calorimetry and Temperature History Method to find their thermophysical properties of interest. The relationship between thermophysical properties of the PCM and their choice as temperature regulators in photovoltaics is discussed in relation to the ambient conditions under which PV systems operate.

© 2014 Elsevier Ltd. All rights reserved.

## 1. Introduction

Silicon photovoltaics (PV) show a power drop of  $-0.3\%/K$  up to  $-0.65\%/K$  [1,2] above  $25\text{ }^\circ\text{C}$  panel temperature depending on type of the PV cell and the manufacturing technology [3]. Various mathematical correlations have been developed to describe dependence of PV operating temperature on climatic conditions and PV materials [4]. The operating temperature reached by PV panels and associated power drop largely depends on the climate of the site. In Germany 50% of the solar radiation incident on a PV panel is above  $600\text{ W/m}^2$  while in Sudan this value reaches 80% resulting different operating temperatures and associated power drop [5,6]. A maximum PV operating temperature of  $125\text{ }^\circ\text{C}$  has been reported in southern Libya (27.6 N and 14.2 E) resulting in a 69% reduction in the nominal power [7]. The advisable operating temperature limit for PV ranges from  $-40$  to  $85\text{ }^\circ\text{C}$  [8] however in hot and arid climates, PV temperature frequently rises above this temperature

range [7], which results in temperature induced power failure as well as PV cell delamination and rapid degradation [9] urging a strong need for PV temperature regulation to maximize both panel power output and lifetime.

In an attempt to avoid temperature dependant PV power loss, passive cooling of PV with paraffin wax based solid–liquid phase change materials (PCMs) was evaluated both experimentally and numerically. The PCM was contained in a rectangular aluminium container with internal dimension of  $(300\text{ mm} \times 132\text{ mm} \times 40\text{ mm})$  and front surface of the container was selectively coated to mimic a PV cell attached to the surface [9]. Temperature distributions on the front surface and inside the PCM were measured and validated through a 2D as well as a 3D finite volume heat transfer model [10,11]. Building on this work, Hasan et al. 2010, replaced the selective coating meant to mimic the PV cell with an actual PV cell encapsulated in perspex sheet and evaluated 5 PCMs under various solar radiation intensities to mimic different weather conditions. Two PCMs, a eutectic mixture of capric acid–palmitic acid and a salt hydrate  $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$  achieved relatively higher temperature regulation at all solar radiation intensities [12]. A temperature regulation of  $18\text{ }^\circ\text{C}$  was recorded for 30 min and  $10\text{ }^\circ\text{C}$  for 5 h at  $1000\text{ W/m}^2$  insulation and  $23\text{ }^\circ\text{C}$  ambient temperature. Huang et al. [13] evaluated the insertion of metallic fins in the PV-PCM systems previously investigated [10,11] and reported an improvement in temperature regulation due to increased natural convection. A simulation study was conducted

*Abbreviations:* CL, eutectic mixture of capric–lauric acid; CP, eutectic mixture of capric–palmitic acid; DSC, Differential Scanning Calorimetry; EG, expanded graphite; LDPE, low-density polyethylene; (P(BMA-co-MAA)), p(n-butyl methacrylate-co-methacrylic acid); PCM, phase change material; PEG, polyethylene glycol; PGMA, polyethylene glycol poly (glycidyl methacrylate); PUs, polyurethane polymers; RT20, a commercial paraffin wax; SP22, a commercial blend of salt hydrate and paraffin wax; THM, Temperature History Method.

\* Corresponding author. Tel.: +971 555454069.

E-mail address: [ahmed.hassan@uaeu.ac.ae](mailto:ahmed.hassan@uaeu.ac.ae) (A. Hasan).

## Nomenclature

### Symbols

|           |   |
|-----------|---|
| $A_c$     | convective heat transfer area             |
| $B_i$     | biot number                               |
| $c_{p,l}$ | mean specific heat capacity of liquid PCM |
| $c_{p,s}$ | mean specific heat capacity of solid PCM  |
| $c_{p,t}$ | specific heat capacity of test tube       |
| $c_{p,w}$ | mean specific heat capacity of water      |
| $H_m$     | latent heat of fusion of PCM              |
| $h_c$     | convective heat loss coefficient          |

|                |                                     |
|----------------|-------------------------------------|
| $m_p$          | mass of PCM                         |
| $m_t$          | mass of test tube                   |
| $m_w$          | mass of water                       |
| $t_1$          | start of solidification time        |
| $t_2$          | end of solidification time          |
| $T_o$          | cooling curve start point           |
| $T_r$          | reference fluid (water) temperature |
| $T_s$          | start of solidification temperature |
| $T_{\infty,a}$ | ambient temperature                 |

[14] for temperature regulation performance of BIPV containing microencapsulated PCM with a melting point of 26 °C attached at back of PV showed very low temperature drop from 49 to 47 °C in summer and from 35 to 30.5 °C in winter. The low performance can be attributed to lower thermal conductivity of encapsulation materials and the lower mass ratio of PCM contained in microencapsulation. Biwole et al. [15] modelled heat and mass transfer of a PCM layer at the back of PV and reported a time lag of 75 min compared to bare PV panel to reach 40 °C which shows thermal mass effect of adding PCM layer into PV. Author observed that the previous research focussed on incorporating the PCM into PV systems with least attention to characterizing PCM thermo-physical properties in relation to PV temperature regulation.

On another front most of the PCM characterization has been conducted on determination of the thermophysical properties of PCM [16] with no reported characterization for PCM as temperature regulators in PV systems. Polyethylene glycol (PEG10000)/poly (glycidyl methacrylate) (PGMA) crosslinked copolymer was prepared as solid–solid phase change material and it was found that the PCM reversibly stores heat from 25 to 60 °C and maintains the solid structure as high as 100 °C [17]. Polyurethane polymers (PUs) have been synthesized as solid–solid phase change materials using three different kinds of diisocyanate molecules and polyethylene glycols (PEGs) through the condensation reaction of PEGs with diisocyanates. The solid–solid PCM possessed phase change enthalpy of 179 kJ/kg and phase transition temperature of 60 °C [18]. Expanded graphite (EG) was used in Sodium nitrate, potassium nitrate and their mixture to enhance PCM thermal conductivity. It was reported that by addition of 10 % by weight EG increased the thermal conductivity of PCM by about 30–40% [19]. Composite PCM by impregnating 65% paraffin into halloysite nanotube was prepared and tested for leakage with a melting point of 57.16 °C and heat storage capacity of 106.54 kJ/kg. Melting and freezing time were reported to decrease by 60.78% and 71.52% respectively with the addition of graphite [20]. Polyethylene glycol (PEG)/silicon dioxide (SiO<sub>2</sub>) composite form-stable phase change materials (PCMs) without co-solvent and surfactant with 80% PEG weight percentage. The PCM possessed enthalpy value of (102.8–111.1 J/g) and phase transition temperature of up to 56.5 °C and showed very little change in phase change enthalpy and temperature with 50 thermal cycles [21].

Form-stable paraffin/PUPCMs composites (*n*-octadecane/PUPCM, *n*-eicosane/PUPCM and paraffin wax/PUPCM) were prepared with phase transition temperature range (20–65 °C) and enthalpy range of up to 141.2 J/g. An inexpensive process of preparation via bulk polymerization was introduced and the PCM was reported to be stable at higher temperature [22]. Low-density polyethylene (LDPE) with paraffin waxes was prepared by melt-mixing method with a Brabender-Plastograph and were tested for leakage. It was found that the wax remained compact during melting cycle showing no leakage [23].

Microencapsulated PCM was prepared by containing *n*-alkane in p(*n*-butyl methacrylate-co-methacrylic acid) shell (P(BMA-co-MAA)) with phase change enthalpies of melting (130.3 J/g or 123.9 J/g) and freezing (125.8 J/g or 118.4 J/g). The PCM was subjected to thermal cycles and phase change enthalpies varied with thermal cycles [24]. polystyrene/*n*-tetradecane composite nanoencapsulated phase change material were prepared via ultrasonic-assistant miniemulsion in situ polymerization with melting and freezing temperatures of 4.04 °C and –3.43 °C and latent heats of 98.71 J g<sup>-1</sup> and 91.27 J g<sup>-1</sup>, respectively. Mechanical structural stability was reported through freeze–thaw cycle test [25].

The properties desired for a suitable PCM are summarized in Table 1. A systematic PCM choice is difficult as a particular PCM may only have some of the desired characteristics, but may not possess the others. The current work relates PCM properties of melting point, latent heat of fusion, specific heat capacity, thermal conductivity, density and under-cooling in relation to PV temperature and night time ambient temperature to regenerate PCM to achieve better temperature regulation effect.

## 2. Methodology

PCMs were characterized using (i) Differential Scanning Calorimetry (DSC) and (ii) Temperature History Method (THM) to determine their thermophysical properties and compare them

**Table 1**  
Properties of a PCM desired for photovoltaic thermal regulation.

|                   | Requirement   | Reason for requirement  |
|-------------------|---|---|
| <i>Properties</i> |   |   |
| Thermal           | High latent heat<br>High heat capacity<br>Good thermal conductivity<br>Reversible phase change<br>Fixed melting point | Maximum heat absorption<br>Minimum sensible heating<br>Efficient heat removal<br>Diurnal response<br>Consistent behaviour |
| Physical          | Congruent melting<br>Low volume expansion<br>High density   | Minimum thermal gradient<br>No overdesign<br>Low containment requirement  |
| Kinetic           | No supercooling<br>Good crystallisation rate  | Easy to freeze<br>Faster solidification   |
| Chemical          | Chemical stability<br>Non-corrosive<br>Non-flammable<br>Non explosive<br>Non-toxic                                    | Long life<br>Long container life<br>Comply building safety codes<br>Environment friendly                                  |
| Economic          | Abundant<br>Cheap and cost effective  | Market competitiveness<br>Economic viability and market penetration   |
| Environmental     | Recyclable/reusable<br>Odour free   | Ease to dispose of<br>Comfortable to apply in dwellings environment   |

Download English Version:

<https://daneshyari.com/en/article/763965>

Download Persian Version:

<https://daneshyari.com/article/763965>

[Daneshyari.com](https://daneshyari.com)