EXPERIMENTAL HIGH-THROUGHPUT INFRARED THERMOGRAPHIC SCREENING OF FATTY ACID-FATTY ALCOHOL BINARY PHASE DIAGRAMS FOR TAILORED SOLAR PV/T OPERATING CONDITIONS

Summary

Organic eutectic phase change materials (PCMs) formulated by combining two or more organic compounds retain the favorable thermal stability, chemical compatibility, and high latent heat of their parent materials. Binary systems based on fatty acids and fatty alcohols can exhibit melting temperatures significantly lower than those of the individual components, making them attractive candidates for low-to medium-temperature thermal energy storage. In this study, three novel fatty acid-fatty alcohol binary systems (Palmitic acid/1-Tetradecanol, Palmitic acid/1-Octadecanol, and Stearic acid/1-Tetradecanol) were experimentally screened to determine their phase behavior and construct binary phase diagrams. A dynamic calorimetric methodology based on non-contact infrared thermography was employed to simultaneously monitor phase transitions of multiple compositions within approximately one hour, substantially reducing experimental time and cost compared with conventional differential scanning calorimetry (DSC). Across all experimentally tested compositions, melting temperatures were observed in the range of 33 to 68 °C, providing a broad and tunable operating window suitable for customized solar photovoltaic/thermal (PV/T) system conditions. Ensuring effective heat storage and consistent PV thermal performance requires a PV/T system with a tunable PCM working window that aligns the materials melting and solidification temperatures with changing solar and thermal loads. This temperature flexibility enables targeted selection of compositions adapted to specific thermal management and storage requirements. The most promising compositions will be further characterized by DSC to accurately quantify phase transition temperatures and latent heat values. Overall, infrared thermography demonstrates strong potential as a high-throughput experimental tool for rapid construction of binary phase diagrams and accelerated optimization of eutectic PCMs for solar PV/T Operating Conditions.

Keywords: Phase change materials, Infrared thermography, Phase diagram, Binary, Organic eutectics, PV/T

Field of application for the findings: Solar Thermal and PV/T Collectors

Addressed audience: Multidisciplinary international community of solar energy researchers, engineers, research students, industry professionals, policy-makers, and renewable-energy specialists

Introduction

Fatty acid–fatty alcohol eutectic mixtures are promising bio-based phase change materials (PCMs) for solar photovoltaic/thermal (PV/T) systems because their melting temperatures can be tailored to match module operating conditions while providing high latent heat and good cycling stability (Liu et al., 2021). However, conventional techniques for assessing phase diagrams and identifying optimal eutectic compositions, such as differential scanning calorimetry (DSC), are time-consuming and poorly suited to high-throughput screening across many binary systems and compositions (Mailhé et al., 2020). Infrared thermography has recently emerged as a dynamic calorimetric method capable of estimating complex solid–liquid phase diagrams in only a few hours by monitoring the melting of arrays of micro-droplets under controlled heating (Mailhé et al., 2019).

Materials and Methods

2.1. Materials

The materials used in this study are Palmitic acid, 1-Octadecanol and 1-Tetradecanol supplied by Sigma Aldrich; and Stearic acid from Merck Schuchardt OHG, Germany. The comparative property analysis of the utilized materials are listed in **Tab. 1**.

Tab. 1: Properties of materials

Material	CAS Number	Molecular weight(g/mol)	Melting Point (°C)	Purity
Palmitic Acid	57-10-3	256.42	62–66	≥98%
Stearic Acid	57-11-4	284.48	69–71	98%
1-Octadecanol	112-92-5	270.50	59–60	95%
1-Tetradecanol	112-72-1	214.39	35–39	≥99.0%

2.2. Binary Eutectic Preparation

Each binary mixture was prepared by beginning with the pure material, followed by stepwise reductions of 5 wt.% of that material and replacement with its paired component. The wt.% of the paired component increased progressively until it reached its pure form. A total of 21 samples were produced for each binary system. After weighing the required amount on a KERN 770-15 digital scale (accuracy ±0.20 mg), each sample was melted, cooled, and remelted to ensure homogeneity of the components.

2.3 Sample preparation and infrared thermography experiment

The samples were placed as droplets on an aluminium plate measuring 11 x 7.5 cm, with each droplet kept at a similar size and spaced far enough apart so that the heat transfer behaviour of one droplet remained independent from the others. After the samples were fully crystallised, the plate was subjected to a controlled heating ramp while surface temperature distributions were monitored using an infrared camera (FLIR X6580SC). Phase transitions were detected by interpreting emissivity-related contrast variations through a singular value decomposition (SVD) based image processing method (Mailhé et al., 2021). The extracted temperatures marking the onset and completion of melting for each composition were then used to construct solid–liquid phase diagrams and determine melting points for each composition.

Results and discussions

3.1 Phase diagram analysis

Figure 1 shows the solid–liquid phase behaviour of a binary mixture of palmitic acid with 1-Octadecanol, plotted as transition temperature versus molar fraction of 1-Octadecanol. The scattered black crosses correspond to the various phase-transition temperatures detected by infrared thermography for each mixture composition, while the red curve labelled “SLE” represents the solid–liquid equilibrium liquidus line, that is, the highest transition temperature attributed to melting for that composition. As the molar fraction of 1-Octadecanol increases from 0 to about 0.8, the liquidus temperature decreases gradually from the melting point of pure palmitic acid (around 60 °C) toward lower values around 50 °C, indicating a broad compositional region where eutectic-like melting occurs near the desired PV/T operating range. For mixtures richer in 1-Octadecanol (molar fraction above roughly 0.8), the liquidus temperature rises again and approaches the melting behaviour of pure 1-Octadecanol, with experimental points clustering near 45–50 °C at a molar fraction of 1.0. Overall, the agreement between the SLE curve and the upper envelope of the IRT data confirms that the binary system follows the expected melting-curve trend and that suitable eutectic compositions can be selected to place the melting temperature within targeted PV/T operating windows.

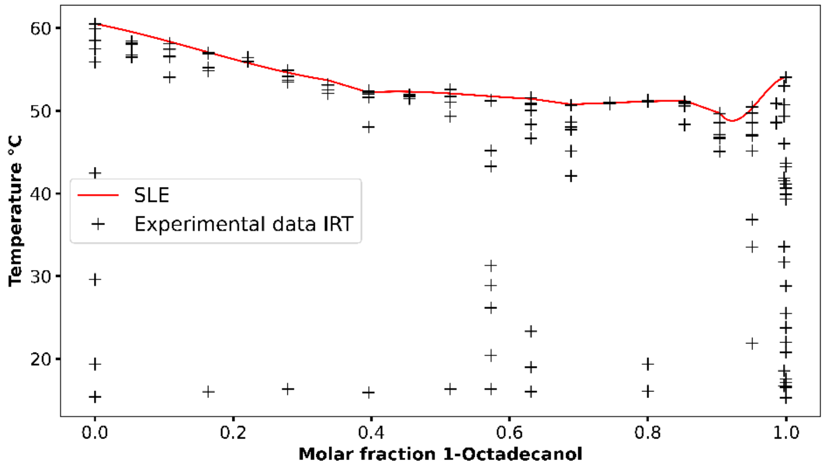

Fig. 1: Phase diagram of Palmitic acid/1-Octadecanol binary eutectic

3.2 Discussion

This study prepares three novel binary eutectic phase change materials and shows that, for each fatty acid–fatty alcohol system examined, the melting temperature range lies within the typical temperature range experienced by PV/T modules during operation (roughly 40–60 °C for flat-plate collectors) (Prasetyo et al., 2023). The infrared thermography method can yield eutectic phase diagrams that are approximate yet sufficiently accurate for rapid screening of candidate materials. Compared with DSC, its main advantage is the drastically reduced measurement time (Palomo Del Barrio et al., 2016). For studies targeting the development of new PCMs for PV/T, the method provides fast, useful guidance for initial screening of promising mixtures.

Conclusions

It can be concluded that experimental high-throughput infrared thermographic screening enables a rapid construction of fatty acid–fatty alcohol binary phase diagrams and efficient identification of eutectic PCMs tailored to solar PV/T operating conditions. By combining this fast preliminary phase boundary detection with targeted DSC validation, the approach provides a powerful workflow for narrowing down composition spaces, while shortening development time and focusing detailed testing on the most promising bio-based PCMs for solar energy applications.

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