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EXPERIMENTAL STUDY ON PHOTOVOLTAIC PANEL COOLING USING PHASE CHANGE MATERIALS

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ABSTRACT:

The electrical output of a photovoltaic (PV) panel falls as its operating temperature rises, which makes passive thermal management attractive for outdoor installations. This work compares three 20 W PV panels exposed to natural sunlight: a reference panel with no cooling, a panel backed by 800 g of stearic acid acting as a single phase change material (PCM), and a panel backed by 800 g of a ternary fatty-acid PCM prepared from 20 % stearic, 30 % myristic and 50 % palmitic acid. Panel temperature was read with digital thermometers, and voltage and current were measured with a multimeter. The ternary PCM was characterised by differential scanning calorimetry (DSC), thermogravimetric analysis (TGA) and Fourier transform infrared spectroscopy (FTIR). DSC gave a melting onset of 48.64 °C, a peak at 53.92 °C and a latent heat of 148.03 J/g; TGA showed 99.931 % of the mass retained at 152.99 °C with degradation starting at 248.45 °C; and FTIR showed bands typical of long-chain carboxylic acids. In the recorded observation set the panel temperature was 56 °C without PCM, 52.8 °C with stearic acid and 53 °C with the ternary PCM, and the calculated operating power ($P = V \times I$) was 21.84 W, 22.25 W and 23.83 W respectively. Irradiance, reading time and load were not recorded, and the calculated power exceeds the 20 W nameplate rating, so these results are preliminary and no panel efficiency is claimed. Both PCMs coincided with a temperature about 3 °C lower than the reference, and the melting range of the ternary PCM lies close to the recorded panel temperature. Validated, time-resolved measurements with measured irradiance are needed to confirm the benefit.

Keywords: Solar energy, photovoltaic panel, phase change material, stearic acid, ternary PCM, thermal management, passive cooling.

1. INTRODUCTION:

Solar photovoltaic conversion is one of the quickest-growing routes to renewable electricity, and regions with high insolation, such as Andhra Pradesh, are well suited to it. A crystalline silicon panel, however, converts only a part of the radiation it absorbs into electricity; the remainder appears as heat and raises the cell temperature well above that of the surrounding air. The open-circuit voltage of a cell falls as its temperature increases, so the power and conversion efficiency of the panel decline during the hottest part of the day. The dependence is usually expressed through a linear power–temperature relation, Eq. (7) in Section 4, and has been reviewed extensively [3]. Long periods at high temperature may also accelerate the ageing of the module.

Fans, pumps and water circulation can remove a great deal of heat, but they consume part of the electricity that the panel produces and add maintenance and complexity, which is a drawback for small or remote installations. Passive approaches avoid these penalties. Among them, a phase change material fixed to the rear of the panel absorbs heat as it melts, so that its temperature, and therefore that of the panel, rises more slowly while the material is changing phase. The stored heat is returned to the surroundings when the panel cools in the evening. Early work on PCMs for limiting the temperature rise of building-integrated photovoltaics [1], [2] and general reviews of PCM thermal storage [4] addressed the concept, and a number of experimental studies have since confirmed temperature reductions and power gains with PCM-backed panels (Section 2).

Most published PCM-based PV studies use a single commercial paraffin or a single-component material, sometimes enhanced with fins or nanoparticles. Fatty acids such as myristic, palmitic and stearic acid are organic, chemically stable and melt in a temperature range relevant to PV operation, and mixing them is a straightforward way to obtain a different melting range from that of any one component. Comparative outdoor experiments that place a single fatty-acid PCM and a ternary fatty-acid mixture on identical panels beside a reference panel are, in the literature reviewed here, scarce. This study addresses that gap on a small scale.

The aim is to investigate experimentally how a single PCM and a ternary PCM affect the temperature and electrical output of PV panels. The specific objectives are:

- to prepare a ternary PCM from myristic, palmitic and stearic acids and to characterise it by DSC, TGA and FTIR;
- to build an outdoor arrangement with three identical 20 W panels: a reference panel, a stearic-acid panel and a ternary-PCM panel;
- to record panel temperature, voltage and current and to compute the operating power and its change relative to the reference panel; and
- to relate the measured melting behaviour of the ternary PCM to the panel temperatures, and to state clearly which conclusions the present data

can and cannot support.

The contribution of this work is (i) a side-by-side comparison of a single fatty-acid PCM and a ternary fatty-acid PCM on identical panels in one experimental arrangement, (ii) measured DSC, TGA and FTIR data for a ternary PCM of fixed composition (20 % stearic, 30 % myristic, 50 % palmitic acid), and (iii) a transparent account of data quality, in which measured, calculated and literature values are kept separate and missing data are declared instead of estimated.

2. LITERATURE REVIEW:

Cooling methods are commonly grouped as active and passive. Active methods circulate air or water over or behind the panel and can extract a large amount of heat, but they require pumping or fan power. Passive methods rely on heat sinks, fins or phase change materials and have no moving parts. The temperature sensitivity that motivates all of them has been correlated and reviewed by Skoplaki and Palyvos [3], and hybrid concepts combining PV, thermoelectric generators and PCM have also been reported [14].

Huang et al. [1] and Hasan et al. [2] examined PCMs for limiting the temperature rise and regulating the thermal behaviour of building-integrated photovoltaics, and Sharma et al. [4] reviewed PCM thermal storage and its applications. More recent experiments confirm the benefit under outdoor conditions. Maghrabie et al. [12] compared two identical 40 W panels with RT-42 paraffin of 1, 2 and 3 cm thickness at tilts of 15–30° and reported a 15.8 % gain in power output and a 14.4 % gain in efficiency for 3 cm of PCM at 30° tilt. Sarabi and Hekmat [8] studied a concentrated PV system with a PCM tank and found that a PCM of higher latent heat performed better, with paraffin C38 raising power by 280 % and C20 by 144 % relative to no PCM. Adibpour et al. [16] used PCM on a sun-tracking panel and measured an average temperature reduction of 9.1 °C and an average efficiency gain of 4.6 %.

Because most PCMs have low thermal conductivity, many studies add conductive fillers or extended surfaces. Jamil et al. [6] added graphene nanoplatelets, multi-walled carbon nanotubes and MgO to PT-58 PCM and obtained a maximum temperature reduction of 9.94 °C against 5.01 °C for plain PV/PCM at 0.5 wt% graphene. Pu et al. [10] simulated PCM heat sinks with T-shaped fins and reported an average cell temperature reduction of up to 15.1 K, and Ibrahim et al. [17] found that PCM with internal and external fins under forced convection gave the highest relative efficiency increase (20.36 %) among four cooling techniques. Siahkamari et al. [18] reported 24.6–26.2 % more maximum power than uncooled operation with a sheep-fat PCM containing CuO nanoparticles. Coupled systems include a pulsating heat pipe with PCM [5], an air-based photovoltaic–thermal collector with PCM storage [7], natural water circulation with OM 35 PCM [15] (average temperature reduction 5.4 °C, power enhancement 13.54 %), and a PV–thermoelectric–PCM hybrid [14] whose temperature was 2.4 °C lower than that of a stand-alone PV panel.

Organic PCMs such as paraffins and fatty acids are generally chemically stable and show little supercooling, but their thermal conductivity is low [4]. A single-component PCM has one characteristic melting temperature, whereas a mixture can melt over a different range from its constituents. The use of more than one PCM has been explored numerically for layered PCM systems [11] and for dual PCMs with different melting points in a building-heating application [19]; Kazemian et al. [13] showed that the choice of melting temperature strongly changes how much of the PCM actually melts (a rise from 40 °C to 65 °C reduced the melted fraction from 82.7 % to 9.6 %).

The studies above show that PCM cooling can lower panel temperature and raise output, but they concentrate on commercial paraffins, nano-additives, fins and coupled systems. Experimental evidence for a ternary fatty-acid mixture compared directly with its single-component constituent under the same outdoor conditions, supported by thermal characterisation of the mixture, is limited. The present work contributes a first, small-scale data set of this kind.

3. EXPERIMENTAL MATERIALS AND METHODOLOGY:

Three identical monocrystalline PV panels (Waaree WS-20/12V, rated maximum power 20 W, open-circuit voltage 21.17 V, current at maximum power 1.17 A, from the nameplate) were mounted side by side on a black-painted steel frame in open sunlight at Rajam, Andhra Pradesh, in the horizontal position (Fig. 1). The active area used for the efficiency calculation is 0.485 m × 0.35 m = 0.16975 m². The panels were arranged as follows: Panel 1 is the reference without PCM, Panel 2 carries stearic acid as the single PCM, and Panel 3 carries the ternary PCM (Table 2, Fig. 3). The assignment of the three physical panels in Fig. 1 to Panels 1–3 is A fourth panel of a different make stands at the end of the frame and is not part of the comparison, and additional thermoelectric modules visible on one panel in Fig. 2 are not part of the comparison either; their role .

Table 2. Panel configuration and PCM loading.

Panel	Configuration	PCM content	Mass in container (report)
1	Reference, no PCM	–	–
2	Single PCM	Stearic acid, 100 %	800 g
3	Ternary PCM	Stearic 20 % + myristic 30 % + palmitic 50 %	800 g



Fig. 1. Outdoor experimental arrangement (top view) with a temperature probe and a digital thermometer for each panel.



Fig. 2. Rear view of the panels showing the sealed PCM containers.

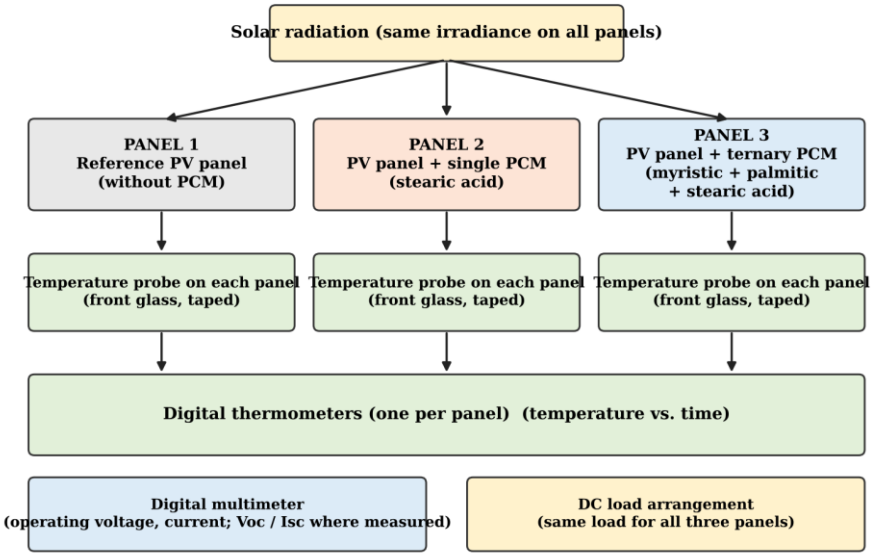
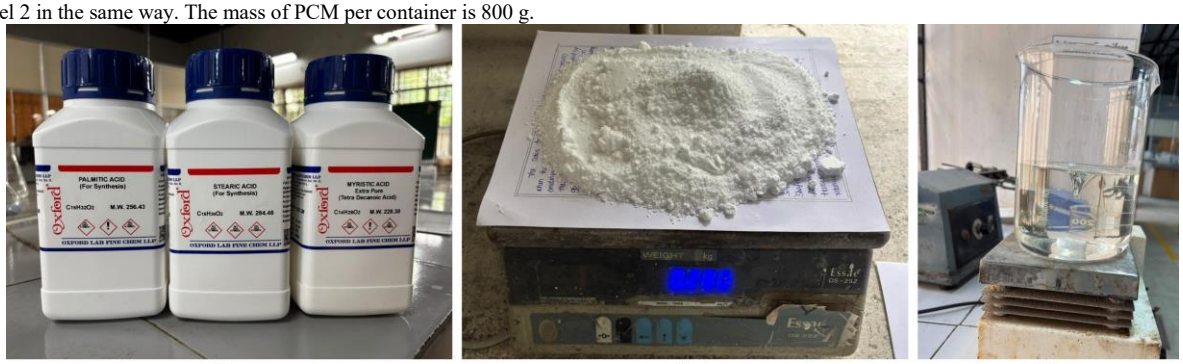


Fig. 3. Block diagram of the three-panel experiment.

The three figures show, respectively, the panels as installed, the PCM containers fixed at the rear of two panels, and the logic of the measurement: all panels receive the same radiation, each panel temperature is read by its own probe and thermometer, and a common multimeter measures voltage and current.

Myristic acid (extra pure, $C_{14}H_{28}O_2$, M = 228.38), palmitic acid (for synthesis, $C_{16}H_{32}O_2$, M = 256.43) and stearic acid (for synthesis, $C_{18}H_{36}O_2$, M = 284.48), all supplied by Oxford Lab Fine Chem LLP, were used (Fig. 4a). The ternary composition is 20 % stearic acid, 30 % myristic acid and 50 % palmitic acid; whether these percentages are by mass or by mole is The acids were weighed on an Essae DS-252 balance (Fig. 4b), then melted and stirred together on a hot plate with a magnetic stirrer in a 2000 mL glass beaker until a clear, uniform liquid was obtained (Fig. 4c). The hot-plate temperature and heating time the molten mixture was poured into the container of Panel 3 and left to solidify; stearic acid was filled into the container of Panel 2 in the same way. The mass of PCM per container is 800 g.



(a) (b) (c)

Fig. 4. PCM preparation: (a) myristic, palmitic and stearic acid; (b) weighing on the balance; (c) melting and stirring on the hot plate.

Each PCM is held in a sealed zinc container fixed to the rear surface of its panel so that the PCM stays in thermal contact with the module and cannot leak when molten (Fig. 2). The container dimensions and wall thickness are Compatibility of zinc with fatty acids at the operating temperature was not examined in this work and should be checked in future tests.

The temperature of each panel was measured with a probe taped to the front glass near the centre of the panel and read on an individual LCD digital thermometer; the probe type and the thermometer resolution and accuracy the PCM temperature and the ambient temperature were not recorded in the available data. Voltage and current were measured with a handheld digital multimeter under a resistive DC load; the load value solar charge controller display was also used to check the panel voltage. The solar irradiance during the recorded readings was not measured, and no satellite-derived value was supplied

The panels were placed horizontally in the same unshaded location, the temperature probes were fixed in the same position on each panel, and the same type of load was connected to each. For each test condition (no PCM, stearic acid, ternary PCM) the panel temperature, voltage and current were recorded. The report states that outdoor testing was scheduled for 25 October 2026; the date, time window and number of readings of the observation set analysed .

4.FUTURE SCOPE:

- Repeat the three-panel test over complete days with simultaneous, time-resolved readings of panel temperature, voltage and current, and with measured irradiance and ambient temperature.
- Locate the maximum power point for each panel (for example by sweeping the load) so that efficiency can be reported correctly.
- Measure the temperature inside the PCM and at the panel rear, in addition to the front surface, to show when melting and solidification occur.
- Study thermal cycling and long-term stability, container material compatibility, and the effect of fins or conductive additives on heat transfer.
- Extend the study to different tilt angles, seasons and an economic assessment.

CONCLUSION:

A ternary fatty-acid PCM (20 % stearic, 30 % myristic, 50 % palmitic acid) was prepared and compared with stearic acid and with an uncooled reference on 20 W PV panels showed a single melting peak with an onset of 48.64 °C, a maximum at 53.92 °C .

In the recorded observation set the panel temperature was 3.2 °C lower with stearic acid and 3.0 °C lower with the ternary PCM than without PCM, and the calculated operating power was 1.9 % and 9.1 % higher. Because irradiance, reading time and load were not recorded, the power calculated from the readings exceeds the nameplate rating, and the current rather than the voltage accounts for most of the power change, the results are preliminary. A cooling benefit of the order of 3 °C is suggested, but the superiority of either PCM is not established by the present data.

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