Effect of SA-LA Composite PCM Volume on PV/PCM Thermal Control Properties

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Abstract. SA-LA binary composite phase change material was prepared by mixing stearic acid (SA) and lauric acid (LA) in different mass fractions, and tested for thermal properties. The results indicate that composite PCM has a lowest peak melting point of 42.9℃, thus suitable for application in solar cell thermal control system. In addition, PV/PCM solar cell thermal control prototypes with different PCM thicknesses were designed and tested for thermal and electrical properties. The effects of different PCM volume on solar cell thermal control properties were studied, showing that compared with non-PCM systems, solar cell temperature in the PV/PCM system was reduced by more than 20℃, with output power increased by more than 11%. The research results provide experimental references for the preparation of SA-LA composite phase change materials and their application in thermal control of solar cells.

1. Introduction

With its advantages of huge reserves, cleanliness and environmental protection, solar energy enjoys wide applications in solar photovoltaic power generation, solar thermal power generation, solar thermal utilization, solar drying and building integrated photovoltaics (BIPV) [1-3]. In solar photovoltaic power generation, solar cells only convert less than 17% of solar energy into electrical energy, while most of the incident solar energy is converted into thermal energy, thus increasing the temperature of solar cells. For crystalline silicon solar cells, the photovoltaic conversion efficiency decreases by 0.45% for every 1℃ increase in temperature [4,5]. In the practical photovoltaic power generation system, temperature of solar cells can reach up to 80℃. Hence, how to achieve thermal control management of solar cells and reduce its operating temperature has become one of the research hotspots in the field of increasing efficiency and improving performance of photovoltaic power generation systems. Where, phase change materials with the characteristics of unchanged temperature despite heat absorption during the phase change have been widely studied in thermal control of solar cells [6-8]. For example, Huang et al. analyzed thermal and electrical characteristics of PV/PCM systems using finite element analysis methods [9,10]. By establishing a PV/T-PCM system model, Fayaz H et al. carried out numerical simulation analysis and experimental research under sunlight intensity of 200W/m² to 1000W/m² [11]. Stropnik and Strith studied the impact of PCM application in photovoltaic/thermal systems (PV/T) on electrical efficiency of solar cells by numerical simulation [12]. Studies have shown that the use of PCM for thermal control management of solar cells can theoretically lower solar cell temperature and increase power generation efficiency, demonstrating huge application potential. In this paper, based on the thermophysical properties of stearic acid (SA) and lauric acid (LA), SA-LA binary composite phase change materials with different mass fractions
were prepared and tested for properties to explore phase diagram characteristics of composite phase change materials and provide a basis for the selection of solar cell thermal control materials. In addition, a PV/PCM prototype was designed using composite phase change material with a peak melting point of 42.9°C. Moreover, experimental testing and analysis were carried out to provide experimental basis for PV/PCM.

2. Preparation and property test of SA-LA composite PCM

According to temperature characteristics of solar cells in photovoltaic power generation, SA and LA were used as raw materials to prepare composite phase change materials for detection of thermophysical properties. Lauric acid: Jiangyin Chuanglin Chemical Ltd., melting point 55°C, stearic acid: Shanghai Zhenyi Industrial Co., Ltd., melting point 67°C.

2.1. Preparation of composite PCM

SA and LA at different mass fractions were selected as shown in Table 1. The two phase change materials were mixed at a certain mass ratio (10g in total), placed in a collector-type constant temperature heating magnetic stirrer for heating and melting according to constant temperature water bath heating method. Stir for 10 minutes to make the mixture uniform, pour it out for natural cooling and solidification, and grind it in a ceramic crucible to obtain SA-LA composite phase change material. The preparation process is shown in Figure 1.

![Figure 1. Preparation process of SA-LA binary composite PCM](image)

2.2. SA-LA composite PCM melting point test

Using a BEDS200 differential scanning calorimeter, weigh 10 mg of SA-LA binary mixed PCM sample and place it into an aluminum crucible. Set the differential scanner to an air atmosphere environment with heating rate is 15°C/min and the maximum temperature of 120°C. By testing DSC chart of composite PCM with different mass fractions, its peak melting point temperature is obtained as shown in Table 1.

| Stearic acid (SA) % | Lauric acid (LA) % | Peak melting point /°C | Stearic acid (SA) % | Lauric acid (LA) % | Peak melting point /°C |
|-------------------|-------------------|------------------------|-------------------|-------------------|------------------------|
| 100               | 0                 | 67.00                  | 37                | 63                | 43.70                  |
| 90                | 10                | 62.20                  | 35                | 65                | 42.90                  |
| 80                | 20                | 58.10                  | 32                | 68                | 43.40                  |
| 70                | 30                | 54.90                  | 30                | 70                | 43.80                  |
| 60                | 40                | 51.80                  | 25                | 75                | 45.10                  |
| 50                | 50                | 44.90                  | 20                | 80                | 46.70                  |
| 45                | 55                | 44.20                  | 10                | 90                | 49.90                  |
| 40                | 60                | 43.90                  | 0                 | 100               | 55.10                  |

From Table 1, the peak melting point change map of SA-LA binary composite phase change material with different mass fractions can be obtained as shown in Figure 2.
It can be known from Figure 2 that SA-LA composite phase change material has the lowest peak melting point temperature at a stearic acid mass fraction of 35%, and the lowest peak melting point temperature of SA-LA is 42.9°C. The results show that by changing SA mass fraction, it is possible to obtain SA-LA composite phase change material with a wide variation range of melting point, thus helping expand the application range of composite phase change material.

**2.3. Thermal stability test of composite PCM**

10 mg of SA-LA binary composite PCM samples with 20%, 35% and 80% SA mass fractions were selected and placed in a HTG-1 thermogravimetric analyzer. The initial temperature was set at 25°C, the termination temperature was 450°C and heating rate was 15°C/min. The measured TG curve is shown in Figure 3. The sample mass change law and its thermal stability amid temperature rise were analyzed.

It can be seen from the Figure 3 that within 180°C, composite PCM shows good stability and is suitable for use in middle-and-low-temperature solar cell temperature control system.

**2.4. Infrared spectrum of composite PCM**

SA, LA and binary mixed PCM were tested by infrared Fourier spectrum tester. The test spectrum is shown in Figure 4.
Figure 4. Infrared spectrum of composite PCM

It can be seen from Figure 4 that binary mixed PCM has obvious SA and LA characteristic peaks. Where, absorption peaks at 2950 cm\(^{-1}\) and 2850 cm\(^{-1}\) are ascribed to the stretching vibration absorption of CH bond of methyl group and methylene group; that at 1700 cm\(^{-1}\) is attributed to the stretching vibration of C=O, that at 1471.6 cm\(^{-1}\) is ascribed to -CH shear vibration, and that at 1355.9 cm\(^{-1}\) is attributed to swing vibrations of -CH and -CH2. The results show that the physical and chemical properties of SA and LA remain unchanged during the preparation, and no new substances are generated in the binary mixed PCM.

3. PV/PCM prototype preparation and experiment

A SA/LA binary composite PCM with a SA mass fraction of 35% and peak melting point of 42.9\(^\circ\)C was selected to design a PV/PCM thermal control solar photovoltaic power generation test prototype. In the designed PV/PCM photovoltaic thermal control prototype, SA-LA composite PCM was installed in aluminum boxes with a volume of 0.8L (No. 3), 0.96L (No. 4), and 1.12L (No. 5), respectively. Using thermally conductive silicon grease, the aluminum box was pasted on the back of the solar cell, as shown in Figure 5. The characteristic parameters of the used solar cell are shown in Table 2.

![Test prototype](image)

Figure 5. Test prototype

| Parameter name | Voc (V) | Isc (A) | Pmax (W) |
|----------------|---------|---------|----------|
| Parameter value | 17.75   | 0.15    | 2.59     |

In the simulated solar light source system, irradiance was set at 600W/m\(^2\), and a data measurement system was established by using Pt100, temperature transmitter and Altai data acquisition card to test PV/PCM phase change material temperature, solar cell back temperature, solar irradiance, solar cell output voltage and current parameters. Solar cell temperature and solar cell output power test results are shown in Figure 6(a)(b).
 According to the test results, the main parameters of the test system are obtained as shown in Table 3.

| PCM No. | Maximum back temperature (°C) | Average output power (W) |
|---------|-------------------------------|--------------------------|
| No-PCM  | 63.62                         | 1.26                     |
| PCM No. 3 | 43.41                        | 1.14                     |
| PCM No. 4 | 42.00                        | 1.161                    |
| PCM No. 5 | 40.98                        | 1.181                    |

As can be seen from the above table, use of PCM can effectively reduce the operating temperature of solar cells. Compared with non-PCM thermal control system, the three PV/PCM systems with different PCM thermal control unit volumes have a reduction in the maximum solar cell back temperature by at least about 20.21°C, 21.62°C, and 22.64°C, respectively. It also indicates that the volume of the phase change material thermal control unit also directly affects PV/PCM thermal control effect. The thermal control effect is better under a larger volume. In addition, compared to solar cells without PCM thermal control units, the output power of solar cells in PV/PCM system is increased by approximately 11.4%, 13.5%, and 15.5%, respectively. It suggests that the use of PCM can effectively control solar cell temperature and increase solar cell output power.

4. Conclusion
According to the thermophysical properties of stearic acid and lauric acid, SA-LA composite phase change materials with different mass fractions were prepared for thermophysical property test. The results show that mixing SA and LA at different mass fractions can produce binary composite phase change material with peak melting points in the range of 42.9°C-67°C. The phase change material has a stable structure and good thermal stability, thus suitable as a thermal control material for solar cells. In addition, three PV/PCM prototypes with different thicknesses were designed using SA-LA composite phase change material with a melting point of 42.9°C, and tested and analyzed for thermal control properties. It can be known that in the PV/PCM thermal control system, SA-LA binary composite phase change material has a significant effect on temperature control of solar cells. Compared with independent solar cells, temperature of solar cells in phase change material thermal control PV/PCM can reduce by more than 20°C. In addition, in the PV/PCM thermal control system, PCM mass (volume of thermal control unit) is a major factor that directly affects thermal control characteristics of the system. Under the same volume, solar cell thermal control properties are better with greater solar cell output power when the mass is higher.

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