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Investigations into Nano-PCM Energy Storage for Solar Air Heater

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ABSTRACT

This work investigates the integration of nano-phase change materials (PCM) to enhance the heat storage capacity and for the performance enhancement of solar air heaters. Solar air heaters rely on direct solar radiation, and during non-sunshine hours, the efficiency drops regularly. Usually, PCMs are incorporated into solar systems to store heat, however, their performance is not significant due to their lower thermal conductivity. The thermal properties of the PCM are improved by adding nanomaterials such as aluminum oxide (Al_2O_3) and graphene oxide which leads to better heat absorption and retention. Highly stable Al_2O_3 nanoparticles with significant thermal conductivity have been utilized in this work, facilitating the PCM to absorb energy quickly during sunlight and release it efficiently during non-sunlight hours. The significant thermal and electrical properties of Graphene oxide further enhance the thermal performance of the nano-PCM. The inclusion of nano-PCM makes for more reliable performance even during non-sunshine hours for heating and drying requirements. This reduces the need for standby systems which is eco-friendly and retards the energy expenditure. This work makes solar air heaters suitable for capturing a variety of residential and business applications by providing a more efficient solution.

Keywords: Heat storage, heat storage applications, nano-PCM, solar air heater

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INTRODUCTION

Phase change materials (PCM) have the ability to absorb, store, and release large amounts of thermal energy when they change phases, either from a solid to a liquid or the other way around. Al-jarjary et al. (2024) examined solar air heaters by integrating PCM; the thermal energy that has been stored can be released during the hours when there is notany sunshine, maintaining

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a constant temperature and increasing overall efficiency. However, the research intends to utilize cutting-edge nano-PCM to further improve this system.

MATERIALS AND METHODS

Despite significant improvements in the thermal properties of nano-PCMs, their long-term thermal stability needs further studies (Ameri et al., 2023). Material fatigue, PCM leakage, or alterations in the structural integrity of nanomaterials can all cause PCM-nanomaterial composites' thermal performance to deteriorate during prolonged heating and cooling cycles. This deterioration may cause solar air heaters to lose their ability to store heat and become less efficient. In-depth research on the long-term thermal cycling stability of PCM-nanomaterial composites, particularly under actual operating conditions, is lacking.

Objectives of the Work

1. To improve the overall thermal efficiency of the solar air heaters by integrating Nano-PCM.
2. To integrate nano-PCM, which can absorb, store, and release substantial amounts of thermal energy during phase changes.
3. To improve thermal management through nano-PCM integration with enhanced heat retention.

Methodology

Selection of Material

PCM Selection. A Phase Change Material (PCM) with a high latent heat storage capacity, like paraffin wax, which is both cost-effective and has a high energy storage capacity, has been chosen for the work.

Nanomaterial Selection. Nanomaterials with exceptional heat conductivity, including graphene oxide and Al_2O_3 nanoparticles, are chosen. To select these nanomaterials, criteria such as thermal conductivity, particle size, dispersion stability, and cost are considered.

Surfactant Selection. A surfactant such as sodium oleate may be chosen to ensure uniform dispersion of nanoparticles within the PCM, preventing agglomeration.

Preparation of Composites

Composite Fabrication

The nano-PCM composite has been prepared by adding the nanomaterials to the base PCM (Paraffin) in the molten state at its phase transition temperature, as shown in Figure 1. The stability of the nano-PCM composite is being enhanced by the addition of a surfactant.

Figure 1. Preparation of nano PCM

Characterization

The performance standards of the prepared nano-PCM are confirmed by characterization which involves the study of thermal and physical characteristics.

RESULTS AND DISCUSSION

The primary goal of a solar air heating system using PCMs is to maximize thermal efficiency by taking advantage of the latent heat storage features of phase change materials. In this research, the thermal and structural features of nano-PCM with 10% weight and 15% weight of nanomaterials with paraffin wax were prepared in the proportions of sodium oleate, aluminum oxide, and graphene oxide in the molar ratio of 1:3:2.5.

The functional groups incorporated within the PCM samples were determined by FTIR spectroscopy that confirmed the incorporation of the paraffin wax, sodium oleate, aluminum oxide, and graphene oxide into the composite matrix.

The FTIR spectrum of the Nano Powder mixture sample shows significant peaks at 441.70, 837.11, 1425.40, and 3452.58 cm^{-1}, indicating the presence of key functional groups possibly involving C-H, O-H, or C=O bonds. The intensity values vary, with a prominent corrected intensity of 93.09 at 3012.81 cm^{-1} and a substantial corrected area of 11197.441 at 837.11 cm^{-1}, suggesting strong absorption by certain functional groups. In nano powder mixture with 10 wt.% of the PCM sample as shown in Figure 2, peaks are notably present at 447.49, 1126.43, 1465.90, and 3153.61 cm^{-1}, with an exceptionally high corrected intensity of 94.85 at 2021.40 cm^{-1}. This shows a large corrected area of

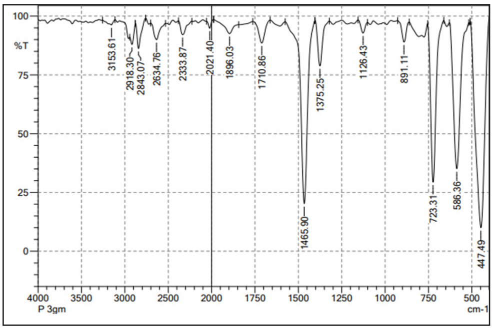

Figure 2. FTIR for nano-powder mixture with 10 wt.% of PCM

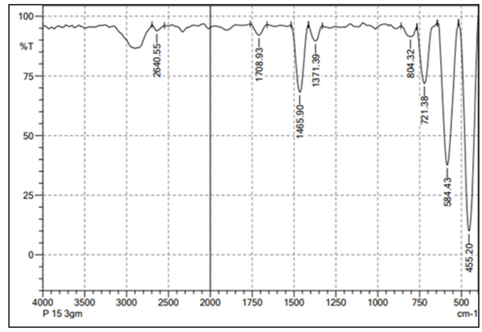

Figure 3. FTIR for nano-powder mixture with 15 wt.% of PCM

5094.627 at 447.49 cm⁻¹, highlighting the strong presence of specific functional groups, possibly associated with C-O or N-H bonds.

The Nano Powder mixture with 15 wt.% of sample shown in Figure 3 exhibits main peaks at 455.20, 584.43, 1371.39, and 2640.55 cm⁻¹, with high corrected intensity values, particularly at 2640.55 cm⁻¹ with an intensity of 93.86. Additionally, it has a large corrected area of 5332.327 at 455.20 cm⁻¹, pointing to substantial absorption in this region. Differential Scanning Calorimetry (DSC) was used to evaluate the thermal properties of the PCM samples, specifically focusing on melting temperature and latent heat capacity as shown in Figures 4 and 5. The ability of the PCM to absorb heat during phase transitions was verified by the DSC data with noticeable endothermic peaks corresponding to the melting temperatures of the paraffin waxes. The melting temperature of the 10 wt.% nano-PCM sample was found to be slightly lower than that of the 15 wt.% sample, attributed to the higher wax content that raises the thermal storage potential.

A series of significant diffraction peaks as shown in Figure 6 and 7 identifies the presence of discrete crystalline phases within the material, as demonstrated on the intensity

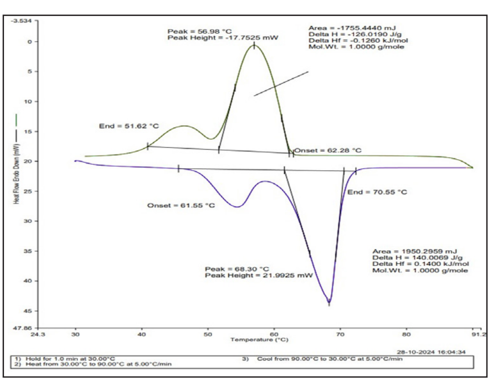

Figure 4. DSC-10 wt.% sample

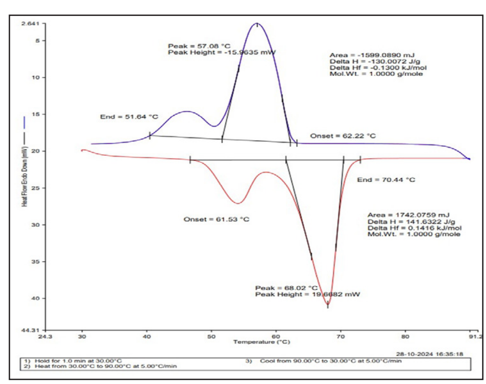

Figure 5. DSC-15 wt.% sample

vs. 2Theta plot arising from the X-ray diffraction (XRD) analysis of sample P-10% presented above. XRD analyzes the P-15% sample, which contains multiple varying intensity peaks corresponding to different crystal planes, confirming its polycrystalline character. Peak shape parameters such as full width at half maximum (FWHM) gives clues to crystallite size and lattice strain and the patterns of peaks suggest good crystallinity.

It is highly probable that the SEM images provided in Figures 8 and 9 illustrate the specific structural characteristics of the composite nanoparticles which are characterized by the use of sodium oleate as a surfactant to improve the dispersion and reduce the agglomeration of graphene oxide with Al_2O_3 particles. Al_2O_3 nanoparticles are generally found to be in the form of small nearly spherical particles, but their association with graphene oxide is expected to make their distribution uniform over the surfaces of the oxide sheets. The combination is expected to enhance the material's stability along with thermal conductivity.

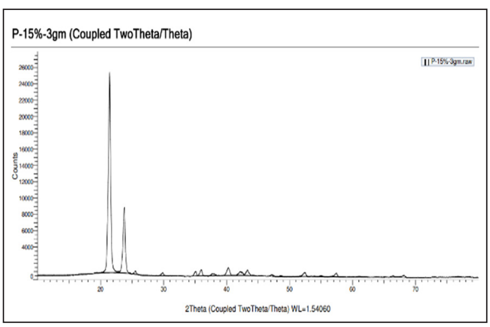

Figure 6. XRD for 15% PCM with nano Powder Mixture

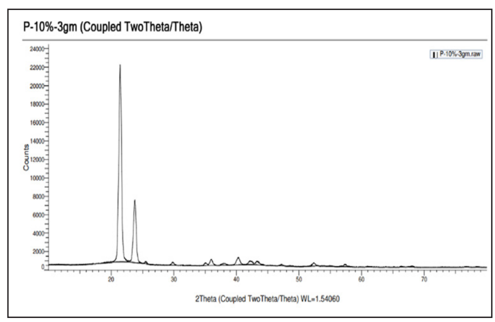

Figure 7. XRD for 10% PCM with Nano Powder Mixture

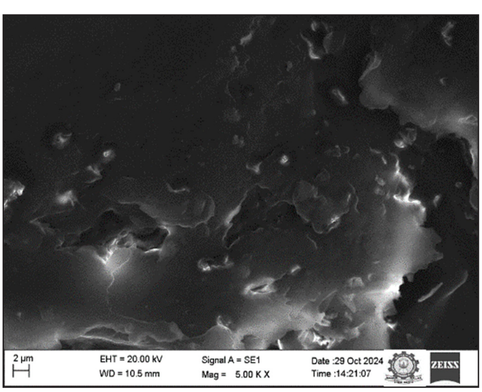

Figure 8. SEM image for 10% PCM with nano powder mixture

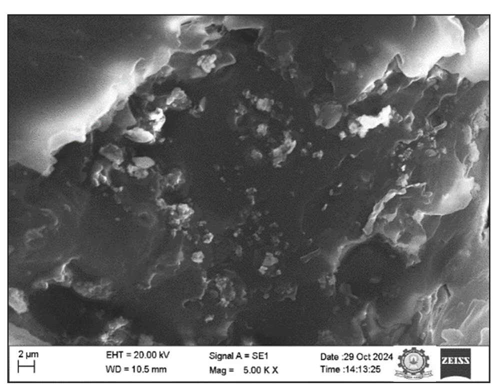

Figure 9. SEM image for 15% PCM with nano powder mixture

CONCLUSION

This research demonstrates that integrating Phase Change Materials (PCM) with nanomaterials significantly enhances the efficiency, reliability, and operational duration of solar air heaters by improving heat storage and minimizing losses. The PCM-nanomaterial composite stores thermal energy during sunlight hours and releases it when needed, ensuring stable performance even during non-sunlight periods. With increased thermal conductivity from nanomaterials like Al_2O_3 and graphene, the system offers faster heat transfer and greater energy efficiency, making it a viable solution for applications such as space heating and drying in various climates.

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