



ISSN Print: 2664-844X
 ISSN Online: 2664-8458
 NAAS Rating: 4.97
 IJAFA 2025; 7(5): 357-359
www.agriculturaljournals.com
 Received: 13-03-2025
 Accepted: 14-04-2025

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A brief review on novel applications of phase change materials

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DOI: <https://www.doi.org/10.33545/2664844X.2025.v7.i5f.424>

Abstract

Solar dryers have potential to preserve various agricultural commodities. All the existing dryer has a common limitation of constant energy production and distribution in plenum chamber. The optimum temperature required for drying a commodity with superior quality is 70°C. Depending upon the availability of solar radiation (Global and Beam, W/m²), relative humidity (ϕ ,%) and air flow rate (m³.s⁻¹), the area of heat collecting source is determined. This technology is one of the prime and green renewable sources of energy. It is abundantly available over the surface of the earth with maximum day length in summer and minimum day length in winter seasons. Due to intermittent nature of solar availability, the energy produced is non-uniform and irregular, hence introduction of Phase Change Material (PCM) in the field of solar dryers helped to produce uniform temperature throughout the drying period. Organic PCMs are observed to be non-corrosive, chemically stable and exhibit little or no sub-cooling. Inorganic PCMs have the advantageous of high latent heat per unit volume, high thermal conductivity and are non-inflammable. Among various available PCM, Neo-pentyl-glycol (NPG) and Tris (hydroxymethyl) Amino-Methane (TRIS) are promising PCMs for heat storage system applications. The major fringe benefit of applying PCM is that drying time could be extended to off sunshine hours which help in performance enhancement of the developed solar dryer. Hence, the present review was focused on the novel application of thermal storage system using Phase Change Material (PCM) integrated solar air heater for drying of agricultural commodities with consistent heat generation and distribution inside the drying chamber.

Keywords: PCM, solar, dryer, evacuated tubes, phase change material, thermal storage

1. Introduction

Solar energy is the most promising source of energy for drying. Phase Change Material (PCM) plays a pivotal role in optimizing indirect forced convection solar dryers, revolutionizing the efficiency and reliability of these systems (Abi Mathew & Thangavel, 2021) ^[1]. With the help of phase change material, available solar energy can give constant drying air temperature (Shringi *et al.*, 2014) ^[9]. These dryers represent a significant advancement in drying technology, particularly for food, industrial and agricultural applications where effective drying is necessary (Mukherjee *et al.*, 2023) ^[5]. By associating solar energy and PCM, these dryers offer a sustainable and cost-effective solution for drying various products while minimizing energy consumption and environmental impact. These dryers operate by utilizing solar radiation to heat up heat transfer fluid generally air or any other which is then circulated through the plenum chamber to remove moisture from the commodity being dried. PCM, in this context, acts as a thermal energy storage medium, absorbing and releasing heat energy during its phase change process. The integration of PCM into these dryers enhances their thermal performance and operational flexibility (Elarem *et al.*, 2021) ^[3]. Figure 1 represents all the keywords of the research articles which were reviewed for drafting this paper.

2. Phase Change Material

Firstly, PCM effectively absorbs heat energy from the hot air passing over it during high solar radiation. As the heat is absorbed, it undergoes change in phase solid to liquid, thereby maintaining a relatively constant temperature within the drying unit. This mitigates temperature fluctuations and maintains uniform drying temperature irrespective of changes occurring in solar radiation, which can adversely affect the quality of the dried product.

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Also, PCM enables the extension of drying hours beyond day length, allowing for continuous drying even during periods of limited solar availability. This is particularly advantageous in regions with variable weather patterns or seasonal changes in solar radiation. Storage of solar energy during peak sunshine hours facilitates continuous drying during bad weather or at night, maximizing drying time and capacity (Akeiber *et al.*, 2016) [2].

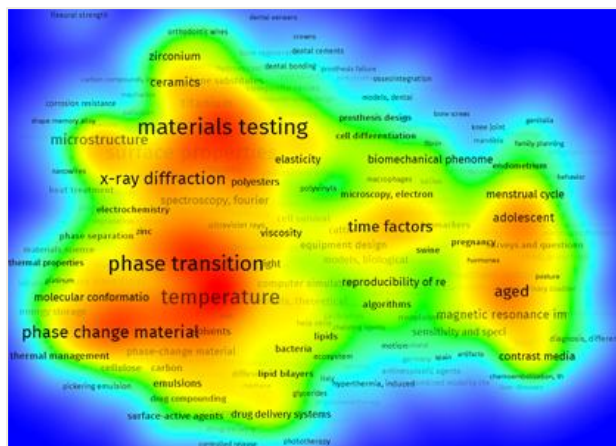


Fig 1: Network Visualization of PCM keywords

3. PCM Mould

Generally, PCM facilitates temperature regulation within the drying chamber, which helps drying sensitive products like leafy, spice, and aromatic commodities that are susceptible to thermal degradation (Rehman *et al.*, 2023) [8]. Hence, it helps in preserving the quality, nutritional value, and shelf life. This is especially important in industries where product quality and consistency are paramount. PCM minimizes the reliance on auxiliary heating sources such as electric heaters or fossil fuels, thereby lowering operational costs and carbon emissions. This aligns with the growing demand for sustainable and eco-friendly drying solutions that prioritize energy conservation. Figure 2 represents the container which holds the PCM material intact (Krishna *et al.*, 2024) [4].

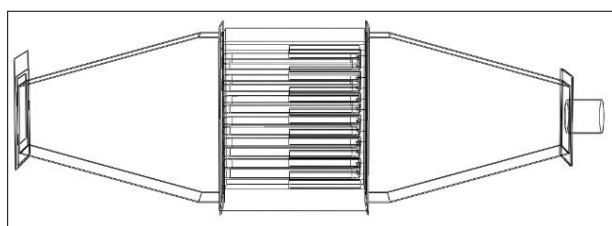


Fig 2: PCM container

4. Types of PCM

Commonly used PCM materials include organic, inorganic, and eutectic mixtures, each offering unique properties and performance characteristics suitable for specific drying applications (Mehla & Kumar, 2021) [7]. Organic PCMs are observed to be non-corrosive, chemically stable and exhibit little or no sub-cooling. Inorganic PCMs have the advantageous of high latent heat per unit volume, high thermal conductivity and are non-inflammable. Among various available PCM, Neo-Pentyl-Glycol (NPG) and Tris (hydroxymethyl) Amino-Methane (TRIS) are promising PCMs for heat storage system applications. The major fringe benefit of applying PCM is that drying time could be

extended to off sunshine hours which help in performance enhancement of the developed solar dryer. (Akeiber *et al.*, 2016) [2]. Figure 3 illustrates the latent heat and melting point of few PCMs.

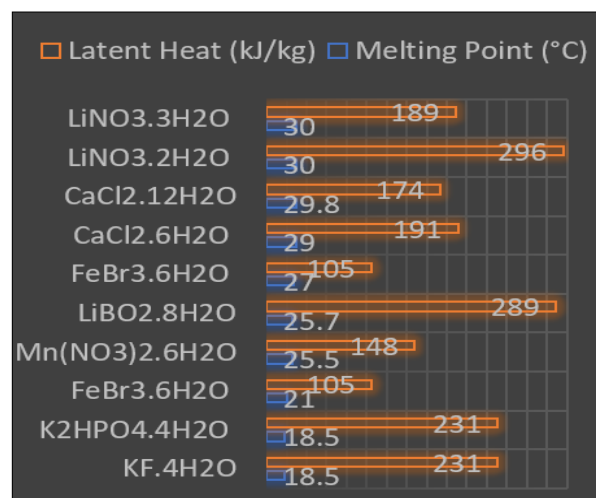


Fig 3: Thermal Properties of PCM (Krishna *et al.*, 2024)

Hence, drying of agricultural commodities with consistent heat generation and distribution inside the drying chamber is possible by incorporating the novel application of thermal storage system using phase change material (PCM) in convective solar dryers (Elarem *et al.*, 2021) [3]. The benefits from the installation and operation of solar energy systems can be divided into three categories: energy saving, generation of job opportunities and a decrease in environmental pollution (Krishna and Mathew, 2018) [13].

5. Conclusion

In conclusion, PCM plays a vital role in solar dryers by optimizing thermal performance, extending drying hours, regulating temperature fluctuations, preserving product quality, and enhancing energy efficiency. The integration of PCM into these dryers represents a sustainable and innovative approach to drying technology, offering numerous benefits for agricultural, industrial, and commercial applications. As research and development efforts continue to advance PCM technology and its applications, dryers equipped with PCM are poised to become increasingly prevalent in the quest for efficient, cost-effective, and environmentally friendly drying solutions.

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