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THE APPLICATION OF PHASE CHANGE MATERIALS IN FOOD PRESERVATION USING INDIRECT TYPE SOLAR DRYER (ITSD)

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1. ABSTRACT

Traditional food storage methods often lead to problems such as energy waste and the inability to maintain food quality over the long term. Phase change materials (PCM) have the advantages of high energy storage density, energy saving, and environmental protection. This article provides a recent overview on the use of PCMs in indirect solar drying. This study details the working principles, materials, equipment, and main findings of ITSD. Paraffin wax became the most prevalent PCM, and PCM demonstrated a remarkable ability to significantly extend drying duration.

2. INTRODUCTION

In the past few decades, the problem of agricultural waste has received widespread attention due to its adverse effects on human society, economic trade, and environmental protection. The main reason for the waste of resources is that vegetables, fruits, wood and other agricultural products have high moisture content and are easy to rot and deteriorate. The main purpose of drying is to reduce water activity and ensure long-term safe storage of dried products. Incorporating thermal energy storage (TES) modules into the food preservation process is considered an effective solution to this problem. PCM has the advantages of high energy storage density, high latent heat value, non-corrosiveness, and strong temperature maintenance ability. In the food drying process, integrating PCM modules into solar dryers can not only achieve energy saving, but also improve the quality of dried products by effectively controlling moisture content.

In this paper, in terms of the utilization of phase change materials in ITSD. The energy storage principle, classification and characteristics of PCMs are explained first. Subsequently, the application of PCMs in the drying process is comprehensively discussed, including the working principle of dryers and optimization effects. Finally, future research directions and existing challenges are outlined. The article aims to provide a theoretical basis for the advancement of PCM applications in the field of food preservation.

3. Classification and analysis of PCMs

Latent heat storage (LHS) involves the storage or release of heat within a medium that changes physical state (phase change) during charge/discharge. PCMs can be divided into four types: liquid-solid, solid-liquid, solid-gas, and liquid-gas; however, only transitions between liquid-solid and solid-liquid states are feasible. During the melting process, the material absorbs heat, allowing it to accumulate thermal energy at a constant temperature, while during solidification it releases heat. The storage capacity of LHS with PCM can be calculated using the following formula[1, 2].

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$$Q = \int_{t_i}^{t_m} mc_p dt + mf\Delta q + \int_{t_m}^{t_f} mc_p dt \tag{1}$$

$$Q = m\left[C_{SP}(t_m - t_i) + f\Delta q + C_{IP}(t_f - t_m)\right] \tag{2}$$

According to the previous study, PCMs can be basically divided into three groups: organic, inorganic, and eutectic materials which can be seen from Fig.1. Additionally, substances of the organic type are separated into paraffin and non-paraffin types. Metallics and salt hydrates are the two additional branches into which inorganics can be divided[3]. Inorganic-inorganic, organic-organic, and inorganic-organic type pairings are examples of eutectic types.

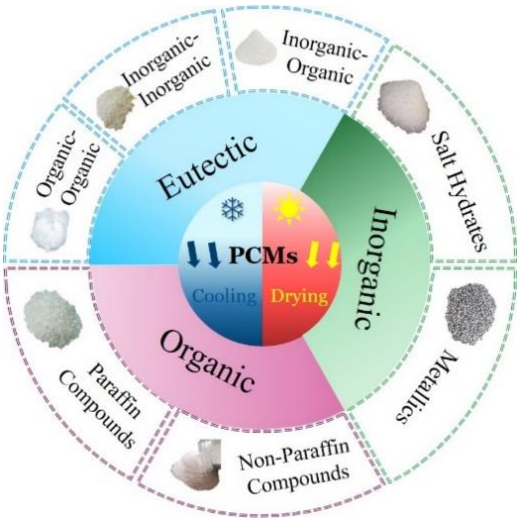

Fig.1 Classification of PCMs

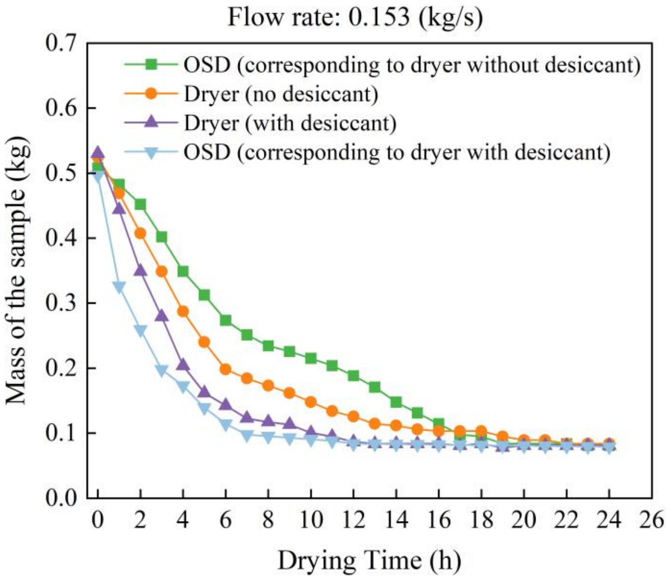

Fig.2 Variation of mass of the sample with time in different modes of drying (flow rate: 0.153 kg/s).[4]

4. Application of PCMs in the indirect type of solar dryer (ITSD)

The ITSD consists of two main components: a drying cabinet (used to hold the material on the pallet) and a solar collector unit (consisting of glass and absorber panels). Solar radiation incident on a glass cover causes partial reflection, some of which passes through the glass. The absorber plates capture some of the energy, while the rest is converted into heat, heating the air entering the chamber. Food in the drying cabinet absorbs heat and loses moisture, promoting product drying.

The thin-layer drying equation is the main method of drying simulation and represents the moisture exchange between the thin layer of the dried product and its surrounding air. El-Sebaii et al.[5] compared 11 thin-layer drying models and determined that the four-parameter logistic model was the most suitable for predicting the moisture transport process during the drying of the thymus leaves. Furthermore, drying time can be significantly reduced by up to 50% using PCM with ITSD. In the context of PCM-integrated ITSD drying processes, the Midilli model was found suitable for predicting the drying behaviours of garlic cloves and blood fruit, while the Henderson and Pabis model and parabolic fit offered optimal mathematical predictions for oleaster fruit and ginger drying, respectively.

The primary aim of integrating PCMs as heat storage units with ITSD is to reduce drying time and enhance energy efficiency. Sabareesh et al.[4] proposed a novel technique for indirect solar drying of ginger, utilizing liquid desiccant (liquid calcium chloride) and paraffin wax for thermal energy storage. Results illustrated in

Fig. 2 demonstrate that ginger requires 13 hours less drying time with desiccant usage compared to open sun drying and 9 hours less time without desiccant, at a flow rate of 0.153 kg/s. Some other investigations about the application of PCMs in ITSD to improve drying efficiency have been concluded in Table 1.

Table 1 Previous research summary of PCM incorporated in ITSD

Authors	Type of study	Drying items	PCM	Findings
S.M. Shalaby et al. (2020)	Experimental	Basil leaf	Paraffin wax	The indirect solar dryer can save 48.3% of the time when using PCMs.
Mulatu C. Gilago et al. (2022)	Experimental	Ivy gourd	Paraffin wax	Drying efficiencies were 13.15 and 15.2% for passive/active indirect-type solar dryer, respectively
Reyes et al. (2018)	Experimental	Kiwifruit	Paraffin wax	Drying system with phase change material fuzzy logic control systems can saved 33% energy
Mohadeseh Ahmadi et al. (2023)	Experimental	Oleaster fruit	Paraffin wax	Using air recirculation and PCMs can significantly improve drying and thermal efficiency which was about 43.42% and 16.75%, respectively.
Thaker et al. (2023)	Numercial	Banana	Paraffin wax	The system achieved a maximum predicted efficiency of 67.40% when operated at a temperature range of 60-65℃.

5. CONCLUSIONS

The latest progress of PCMs as energy storage materials in food storage processes is summarised. Paraffin wax was found to be the most used PCM. The application of PCM in solar drying has shown significant effects in drying efficiency, reducing costs, extending effective drying time, and improving the quality of dried products.

PCM indeed holds significant promise for enhancing food storage processes, and researchers have made considerable strides in advancing its application in the food industry. However, there are notable challenges that warrant attention: The current research landscape in PCM application for drying processes predominantly focuses on paraffin wax, with limited exploration of eutectics and salt hydrates. To enhance drying efficiency and exercise better control over product quality, researchers must expand the range of PCM types considered for such applications. Conducting comparative studies across different PCM types can facilitate the identification of the most suitable PCM for specific drying processes.

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