



Thermo - Physical Characterization of Shea Butter for Effective Thermal Energy Storage Application in Solar Dryers

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ABSTRACT

Traditional solar dryers often face inconsistent drying temperatures during times of low solar irradiation and after dark, negatively impacting drying efficiency and the quality of the dried products. To enhance solar drying methods, there has been a rising interest in integrating thermal energy storage (TES) systems that utilize phase change materials (PCMs). This research analyzed the thermo-physical characteristics of shea butter as a bio-based PCM suited for latent heat thermal energy storage in solar dryers. Differential Scanning Calorimetry (DSC) was used to assess the material's thermal properties under controlled conditions. Findings showed that shea butter has a latent heat of fusion of 50.36 J/g and a melting temperature ranging from 31.25°C to 40.16°C. Its thermal conductivity, density, and specific heat capacity were measured at 0.25 W/mK, 910 kg/m³, and 2090 J/kgK, respectively. These properties suggest that shea butter is well-suited for drying processes at low and medium temperatures, such as for fish and agricultural products. Additionally, the thermal stability of shea butter falls within the temperature range needed for solar drying. Its renewable, biodegradable, non-toxic nature, along with local availability, reinforces shea butter as an environmentally sustainable alternative to synthetic PCMs. This study uniquely focuses on the locally sourced shea butter, characterizing it using DSC for potential integration into solar dryer thermal energy storage systems in tropical regions, thus providing valuable foundational data for future research.

Keywords: Shea butter, phase change material, thermal energy storage, solar dryer, latent heat, DSC

INTRODUCTION

The rising global need for sustainable energy solutions has spurred research into renewable energy systems aimed at diminishing reliance on fossil fuels and enhancing energy efficiency. Among these, solar drying has gained popularity as an economical and ecologically sound method for preserving food products, particularly in developing countries where traditional energy sources may be scarce (Abubakar et al., 2024).

Despite its benefits, the efficiency of conventional solar dryers can be compromised by variations in solar radiation during cloudy days and at night, resulting in longer drying times and poorer product quality. In the specific case of fish preservation, fluctuating drying temperatures can lead to microbial growth and a decline in nutritional value and shelf life (Ibrahim et al., 2024).

To mitigate these issues, researchers have increasingly adopted thermal energy storage (TES) systems in solar dryers to help regulate drying temperatures during low solar radiation periods. PCMs are effective in these applications as they can absorb and release significant amounts of thermal energy during their phase changes (Sharma et al., 2024). Unlike sensible heat storage systems, latent heat storage with PCMs offers greater energy density and better thermal management in drying environments (Elmesbahi & Al-Kayiem, 2025).

Recent investigations have highlighted a shift towards bio-based PCMs in response to environmental concerns regarding synthetic materials. Natural fats and oils are preferable due to their biodegradability, renewability, non-toxicity, and

environmental sustainability (Pereira et al., 2024). Shea butter, derived from the nuts of the shea tree (*Vitellaria paradoxa*), contains high levels of stearic and oleic acids, enhancing its thermal properties.

Various studies have looked into the use of natural fatty materials in solar thermal systems. For instance, Gunawan et al. (2023) demonstrated that natural wax-based PCMs improved heat retention and dryer performance. Similarly, Bareen et al. (2024) noted enhanced temperature stability in PCM-supported solar drying systems compared to conventional setups, while Ndoumou et al. (2023) affirmed that natural fatty substances display suitable latent heat characteristics for thermal storage.

Despite the extensive research on different bio-based PCMs, there is a lack of detailed thermo-physical characterization of shea butter for solar drying. This study uniquely identifies the properties of locally sourced shea butter using DSC analysis for its potential as a thermal storage material in solar drying within tropical climates. Thus, the study's objective is to assess shea butter's thermo-physical characteristics to evaluate its viability as a PCM for thermal energy storage in solar dryers.

MATERIALS AND METHODS

Sample Collection

Shea butter samples for the study were sourced from various local markets in Bida Local Government Area, Niger State, Nigeria. These samples were mixed to form a representative sample for testing.

To ensure sample consistency, the cone and quartering method outlined by the American Society for Testing and Materials (ASTM) was utilized (Mason et al., 2020). This involved thoroughly mixing the samples, shaping them into a conical form, flattening that form, dividing it into four equal parts, and systematically selecting opposing quarters until the required quantity was achieved.

Differential Scanning Calorimetry (DSC) Analysis

The thermo-physical properties of shea butter were examined through DSC. About 6.4 mg of the sample was sealed in an aluminum crucible and subjected to a constant heating rate of 10°C/min under controlled laboratory conditions.

The DSC analysis was performed at the Central Laboratory of the Department of Physics at Umaru Musa Yar'adua University in Katsina State, Nigeria, adhering to ASTM's standard thermal analysis procedures to ascertain the onset melting temperature, end-set temperature, latent heat of fusion, and phase transition characteristics of the sample. The DSC technique gauges the heat absorbed or released during heating and cooling stages, revealing the thermal storage capability necessary for thermal energy applications.

Thermo-Physical Properties Determination

Thermo-physical properties analyzed in this study include:

- Latent heat of fusion
- Melting temperature range
- Thermal conductivity
- Density
- Specific heat capacity

These characteristics were assessed to determine the appropriateness of shea butter for low-temperature thermal energy storage applications in solar dryers.

RESULTS AND DISCUSSION

DSC Thermogram of Shea Butter

The DSC thermogram for shea butter indicated stable phase transition behavior suitable for thermal energy storage. An onset melting temperature at 31.25°C and an end-set temperature of 40.16°C were noted.

Initially, as the temperature rose from 25°C to 30°C, there was a slight upward trend, proceeded by a minor dip. A significant downward peak was observed between approximately 31°C and 41°C, denoting the material's melting range. Beyond 42°C, the curve stabilized and returned close to the baseline. This phase transition range aligns with typical temperature requirements for solar drying processes.

Thermo-Physical Properties of Shea Butter

Table 1: Thermo-Physical Properties of Shea Butter

Thermo-Physical Property	Value	Unit
Density	910	kg/m ³
Specific Heat Capacity	2090	J/kgK
Latent Heat of Fusion	50.36	J/g
Thermal Conductivity	0.25	W/mK
Energy Storage Density	45.8	MJ/m ³

Discussion

The DSC analysis established that shea butter has desirable thermal properties for low-temperature thermal energy storage. The melting range of 31.25°C–40.16°C fits within the temperature spectrum generally necessary for solar drying operations, particularly for fish and agriculture.

The latent heat of fusion value of 50.36 J/g indicates shea butter's ability to absorb and release significant amounts of thermal energy during phase changes, an essential attribute for maintaining thermal stability in solar dryers. Similar conclusions have been drawn by Ndoumou et al. (2023), who reported that natural fatty materials have adequate latent heat capacities for renewable energy applications.

The thermal conductivity measured at 0.25 W/mK is typical for organic and bio-based PCMs. Despite the potentially slower heat transfer rates due to low thermal conductivity, this value remains suitable for low-temperature thermal storage systems (Li et al., 2024).

The density and specific heat capacity metrics imply that shea butter can effectively store and retain thermal energy during heating, contributing to stable thermal behavior and a gradual release of heat during cooling.

In contrast to synthetic PCMs, shea butter presents environmental and economic benefits, being biodegradable, renewable, non-toxic, and available in many African regions. Such characteristics position shea butter as a viable option for sustainable thermal energy storage, especially in rural areas lacking access to costly synthetic materials.

The results align with previous studies on bio-based PCMs for solar thermal uses (Pereira et al., 2024; Gunawan et al., 2023), suggesting that shea butter has promising thermo-physical properties for incorporation into PCM-assisted solar dryers.

This study enhances knowledge by providing experimental data on the thermo-physical properties of shea butter as a bio-based PCM viable for thermal energy storage in solar dryers. It details the latent heat capacity, melting range, thermal conductivity, density, and specific heat capacity of shea butter via DSC analysis.

The findings also serve as a foundation for future studies comparing bio-based and synthetic PCMs in solar drying systems under tropical conditions.

CONCLUSION

This research assessed the thermo-physical properties of shea butter as a bio-based phase change material for thermal energy storage in solar dryers utilizing Differential Scanning Calorimetry (DSC). The results showed shea butter has a latent heat of fusion of 50.36 J/g and a melting range of 31.25°C to 40.16°C, indicating its suitability for low-temperature solar drying.

The thermal conductivity, density, and specific heat capacity suggest shea butter can efficiently absorb, store, and release the thermal energy necessary for drying agricultural and fish products. Additionally, its biodegradable, renewable, environmentally friendly, and locally obtainable qualities render it a sustainable substitute for synthetic PCMs.

Consequently, the study concludes that shea butter is a promising option for thermal energy storage in solar drying systems. However, it was limited to laboratory characterization and did not assess real-time performance in solar dryers. Future research should focus on enhancing the thermal conductivity of shea butter and evaluating its long-

term performance in practical PCM-assisted solar drying systems.

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