Extended Abstract

Design, Optimization, Development, and Experimental Evaluation of a Solar Cooker Integrated with Phase Change Material for Thermal Energy Storage

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Scope of the Thesis

Solar energy harnesses the power of sunlight to produce electricity, heat, and other forms of energy, with the potential to significantly reduce dependence on traditional energy sources. This highlights the overarching motivation for exploring solar cooking solutions. Solar cookers offer numerous benefits in the context of global energy challenges. These benefits are particularly relevant in developing countries, where access to affordable and clean energy is often limited.

The research focused on the design, modelling, and simulation of solar cookers integrated with phase change materials (PCMs) using COMSOL Multiphysics. Results demonstrated that PCM-integrated systems maintained more stable operating temperatures and exhibited prolonged heat retention after sunset compared to non-PCM configurations. The solar cooker geometry was developed in Siemens NX and subsequently imported into COMSOL Multiphysics for performance assessment under varying design parameters. Optimization was conducted by evaluating the influence of glass thickness variation, pot vessel material selection, absorber plate thickness modification, and the use of different PCMs. Comparative analysis of melt fraction and energy storage capacity facilitated the identification of optimal design configurations.

Traditional box-type solar cookers are constrained by their reliance on direct solar radiation. The integration of phase change materials (PCMs) into box-type solar cookers is proposed as an effective strategy to enhance thermal energy storage and release capabilities. In this work, the thermal conductivity and structural stability of o-dihydroxybenzene (C) were improved through the incorporation of thermally expanded graphite (TEG). A composite containing 2 wt% TEG exhibited a 159.92% increase in thermal conductivity relative to the pure PCM, representing a substantial performance enhancement. Comprehensive material characterization was performed to elucidate the mechanisms underlying the improved performance of the TEG-enhanced o-dihydroxybenzene composites.

In addition to simulation and characterisation, the thesis encompasses experimental investigations of two solar cooker, one with and another without PCM. The experiments have been carried out under standalone and loading conditions wherein data retrieved in analysed numerically. The comparative analysis of a reference Solar cooker with PCM cooker gives understanding and insight into variation of Temperature of Absorber area for its domestic usage.

Key Findings and Highlights from the study are:

- Design and Modelling of a Simple Box-type Solar Cooker in NX and its design optimisation by simulating different geometrical dimensions and materials.
- Development of a novel composite phase change material (PCM) using o-dihydroxybenzene and thermally expanded graphite (TEG).
- Characterisation of various samples of PCM with different ratio of thermally expanded graphite (TEG) its characterisation and evaluation of performance enhancement.
- Numerical simulations using COMSOL Multiphysics showed that PCM-integrated solar cookers maintained more stable temperatures and retained heat longer after sunset compared to cookers without PCM
- Experiments with two similar solar cookers, one as a reference and another PCM-enabled for comparative analysis and insights on domestic cooking usage.

Thesis is Structured as Follows:

Chapter 1: Introduction

This chapter provides a comprehensive overview of the global energy landscape and the rationale for investigating and utilizing green and clean solar energy. It elaborates on the challenges and opportunities associated with harnessing solar energy, particularly in light of advancements in technology. Additionally, the various types of solar cookers, their performance metrics, and the economic analysis criteria for solar cookers are defined, alongside an energy and exergy analysis. The necessity for optimizing solar cookers is established, along with the need for the development of phase change material (PCM) composites for domestic cooking.

Chapter 2: Fundamentals and Literature Review

This chapter aims to provide an in-depth examination of the literature concerning the history, varieties, and technologies associated with solar cookers. It offers a thorough overview of solar cookers employed for both research purposes and practical applications, with and without the inclusion of Thermal Energy Storage materials. The innovative and distinctive design enhancements implemented have been organized chronologically, accompanied by references, fundamental principles, and notable performance improvements that have been validated.

Chapter 3: Development and characterization of Thermally expanded Graphite reinforced enhanced PCM

This chapter discusses the development and characterization of an innovative composite phase change material (PCM), specifically o-dihydroxybenzene infused with thermally expanded graphite (TEG). The research emphasizes the enhancement of thermal efficiency in box-type solar cookers through the creation and analysis of a composite PCM composed of o-dihydroxybenzene and TEG. The findings reveal that the addition of TEG markedly enhances the thermal conductivity and leakage resistance of the PCM, resulting in improved stability and prolonged cooking performance, even when direct sunlight is not available.

Chapter 4: Design, Modelling, Simulation and Optimization of Solar Cooker Design

This chapter begins the design of a straightforward of a box-type cooker, including its modelling in NX and subsequent importation of the model into COMSOL Multiphysics software for analysis. The variations in the geometrical dimensions of the glass cover, absorber plate, pot thickness, and pot material have been optimized in relation to the temperature of the absorber wall and the performance evaluation metrics. A temperature profile for both optimized and unoptimized solar cookers has been developed for various phase change materials (PCMs).

Chapter 5: Performance evaluation of Solar Cooker by Experimentation and data analysis

This chapter examines an experiment conducted concurrently using two comparable solar cookers, one serving as a standard reference solar cooker and the other equipped with a vessel containing Phase Change Material (PCM). The testing was performed in standalone mode, with water, and with a cooking load. The PCM was placed between the cylindrical walls of a concentric cylindrical pot vessel. An analysis of the cooking times across the different solar cookers is presented.

Chapter 6: Conclusion and Future Scope

This chapter encapsulates the principal findings of the thesis and underscores the importance of optimizing the design of the Solar Cooker. The model employed can be further investigated and analysed with various phase change materials (PCMs). The Solar Cooker has been crafted to facilitate the use of different PCMs for experimentation and future research. Prospective research avenues encompass the optimization of PCM material composition, the development of advanced composites PCM systems in Domestic Cooking applications.