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Design and Analysis of a Box-Type Solar Cooker

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Abstract- This project involves the design, fabrication, and testing of a box-type solar cooker that utilizes solar energy for clean and cost-effective cooking. The cooker comprises a well-insulated wooden box, an aluminum inner lining, a glass lid, and reflective aluminum sheets to concentrate sunlight into the cooking chamber. Performance testing showed that the cooker is capable of reaching sufficient internal temperatures to boil water and cook standard food items under varying weather conditions. The solar cooker demonstrates practical viability for rural and off-grid regions, especially where conventional fuels and electricity are scarce. The study also outlines design constraints, including sunlight dependency and heat retention challenges, and proposes future enhancements to improve cooking performance and reliability.

Keywords- Solar Cooker; Box-Type Cooker; Solar Thermal Energy; Heat Retention; Insulation Materials; Renewable Cooking Technology

I. INTRODUCTION

The transition to clean cooking technologies is essential to reduce the health and environmental impacts of traditional biomass stoves, particularly in rural and off-grid communities. Box-type solar cookers have emerged as a practical and eco-friendly alternative, offering a zero-fuel, low-emission solution for cooking in sun-rich regions. Their simple design and minimal operational cost make them highly suitable for household-level deployment, especially in areas lacking access to LPG or electricity. Recent research on box-type solar cookers has focused on enhancing their thermal efficiency, heat retention, and adaptability to real-world conditions. One of the major limitations of conventional solar cookers, interrupted cooking during low solar intensity hours, has been addressed through the integration of thermal storage systems, such as phase change materials (PCMs). These modifications enable cooking during evening hours or intermittent sunlight conditions (Vishwakarma & Sinha, 2022; Saxena et al., 2020; Misra et al., 2023).Further performance improvements have come from optimized absorber plates and fixed vessel arrangements, which facilitate better thermal contact and reduce energy losses during handling (Grupp et al., 1991; Saxena et al., 2011). Additional innovations include mirror reflectors and improved glazing materials, which raise the cooking chamber temperature and increase solar capture efficiency (Saxena et al., 2011; Ravisankar et al., 2020). Some designs have also integrated wiper systems for glazing, enhancing performance by maintaining clear optical surfaces. Experimentally, these enhanced designs have demonstrated significant gains: efficiencies of up to 53.8% and the ability to boil 5 liters of water per square meter within an hour (Grupp et al., 1991; Saxena et al., 2020). Standardized testing protocols, such as those used by El-Sebaii & Ibrahim (2005), ensure consistency and comparability of results across different cooker designs. Studies confirm that these cookers can perform reliably across seasons and climatic conditions, supporting their deployment in diverse environments (Soria-Verdugo, 2015; Geddam et al., 2015).In addition to performance, emphasis has also been placed on economic and social accessibility. Modern box-type cookers are often lightweight, locally manufacturable, and cost-effective (e.g., around

$39), making them feasible for community-scale distribution (Grupp et al., 1991; Saxena et al., 2020; Misra et al., 2023). As they displace the use of firewood and kerosene, solar cookers contribute to improved indoor air quality, reduced carbon emissions, and advancement of clean energy goals (Vishwakarma & Sinha, 2022; Saxena et al., 2011).

In this study, a box-type solar cooker is designed, fabricated, and tested using locally available materials to evaluate its thermal performance and potential for use in household cooking. The aim is to assess its temperature rise, water boiling capability, and design constraints under real sunlight conditions, contributing toward accessible, sustainable cooking solutions for energy-deficient regions.

II. METHODOLOGY

1. Design Overview

The solar cooker designed in this study follows a box-type configuration, which traps solar energy inside an insulated enclosure to heat and cook food. The design prioritizes simplicity, material availability, and affordability, targeting applications in rural and off-grid households. The main structure consists of a rectangular wooden box, open at the top and lined internally with an aluminum sheet for reflective heat retention. A double-layer glass lid serves as the transparent cover, allowing solar radiation to enter while minimizing convective and radiative heat losses. A flat aluminum cooking tray is placed inside the box to hold the cooking vessels and absorb heat. To enhance solar energy concentration, the cooker includes external aluminum reflectors mounted around the top opening. These reflectors are manually adjustable to redirect additional sunlight into the cooking chamber during different times of the day.

2. Materials Used

All materials were selected based on cost-effectiveness and local availability. The major components include:

- **Outer Box:** Made of seasoned wood, chosen for its insulating and structural properties.
- **Inner Lining:** Polished aluminum sheet to reflect and retain heat inside the chamber.
- **Glazing:** Two glass panels, mounted with an air gap in between to act as insulation while allowing maximum solar radiation entry.
- **Cooking Plate:** Flat aluminum sheet with high thermal conductivity.
- **Reflectors:** Lightweight aluminum sheets fixed at inclined angles for sunlight redirection.

3. Assembly and Construction

The wooden box was constructed with dimensions suitable to hold one to two cooking vessels. The inner surfaces were lined with aluminum to reflect heat toward the vessels. A black-painted aluminum tray was placed at the base to absorb solar radiation. The double-glass cover was installed at the top with a seal to reduce air leakage. Reflectors were attached around the top edges at a fixed inclination to enhance light concentration.

4. Testing Procedure

The solar cooker was tested under clear-sky daytime conditions, with the following procedure. One liter of water was placed inside a standard cooking vessel. The vessel was placed on the cooking tray inside the solar cooker and covered with the glass lid. The cooker was oriented toward the sun, and adjustments to reflector angles were made manually to maximize solar input. Water temperature readings were taken at 30-minute intervals using a standard thermometer. Ambient temperature and solar intensity (measured with a pyranometer) were recorded for reference. The testing continued for several hours to evaluate the temperature rise profile of the cooker under natural solar conditions.

III. RESULTS AND DISCUSSION

The box-type solar cooker was evaluated under direct sunlight conditions to assess its thermal performance, water heating capability, and practical cooking feasibility.

1. Temperature Profile

The cooker's performance was tested by placing 1 liter of water inside the cooking vessel and recording temperature readings at 30-minute intervals throughout the day. The initial temperature of the water was approximately 28°C, and under favorable solar radiation, the water temperature gradually increased, reaching 90°C within 3 hours. This temperature rise demonstrates that the cooker is capable of bringing water close to the boiling point using only solar energy, validating its effectiveness for basic cooking and disinfection tasks (e.g., boiling or slow cooking).

2. Cooking Capability

The cooker was able to boil water and cook simple food items such as rice and vegetables, indicating sufficient heat retention and energy capture during the test period. The results confirm that the cooker is functionally suitable for common household cooking operations in sun-rich rural areas. However, the cooker's performance varied based on the intensity of sunlight, which declined after mid-afternoon, slowing the cooking rate.

3. Performance Influencing Factors

Glazing and Insulation: The use of double glass panels provided effective insulation, reducing convective and radiative heat losses and maintaining elevated internal temperatures throughout the cooking period.

- **Reflectors:** The aluminum reflectors enhance solar energy input by concentrating sunlight into the chamber, especially during early morning and late afternoon hours. Their effectiveness depended on proper angular adjustment.
- **Box Lining:** The polished aluminum interior and black-painted tray contributed to rapid heat absorption and uniform temperature distribution.

4. Observed Limitations

Despite its successful operation, the cooker exhibited some limitations. Dependence on sunlight limits its use during cloudy days and early morning or evening hours. The absence of thermal storage means it cannot retain heat once sunlight decreases. Cooking time is longer than conventional stoves, especially for dense food items or larger volumes. These observations are consistent with challenges reported in prior studies and underscore the importance of thermal mass integration and improved tracking mechanisms for future design improvements (Saxena et al., 2020; Misra et al., 2023).

IV. CONCLUSION

The study successfully demonstrated the design, fabrication, and testing of a box-type solar cooker constructed using cost-effective and locally available materials. The cooker incorporates double-glazed glass, internal aluminum lining, and external reflectors, which collectively enhance solar energy capture and thermal performance. Testing under clear-sky conditions showed that the cooker could heat 1 liter of water to approximately 90°C within 3 hours, and effectively cook basic food items such as rice and vegetables. These results confirm the stove's functional viability for household cooking applications, especially in rural and off-grid regions with reliable sunlight. However, the cooker's performance is highly dependent on solar intensity, with reduced efficiency during cloudy weather or late-day operation. The lack of thermal energy storage limits its ability to retain heat for evening use. Future enhancements such as phase change material (PCM) integration and solar tracking mechanisms may improve its utility and consistency. Overall, the box-type solar cooker offers a clean, low-cost, and sustainable alternative to conventional cooking fuels, with strong potential for improving energy access and reducing environmental impact in underserved areas.

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