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Passive Indirect Solar Dryer Integrated with Perforated Baffles and Thermal Storage for Drying Coconut Briquettes

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The sustainability and low carbon footprint of coconut briquettes make them a popular renewable energy source. In contrast to conventional charcoal and wood fuel sources, coconut briquettes have been found to produce reduced levels of smoke and exhibit greater environmental sustainability. Manufacturing coconut briquettes can pose a challenging task, as it necessitates husks drying to an exact moisture level prior to compression. This study explores the potential of a passive indirect solar dryer (PISD) equipped with perforated baffles and thermal storage for drying coconut briquettes in Brgy. Bambang, Calaca, Batangas. The research highlights the significance of combining baffles and thermal storage in solar dryer designs to achieve enhanced drying efficiency, better briquette quality, and reduced drying time compared to conventional sun-drying methods. This configuration demonstrated optimal heat distribution and moisture removal efficiency, underlined by statistical analysis of temperature stability across the drying trays. It was found that the PISD significantly decreased the drying time by two-thirds that of the traditional sun drying ($p<0.05$). It was also shown that there is a significant difference in drying temperature when utilizing both thermal storage and baffles during the drying ($p=0.03$). The study also analyzed the temperature variations experienced by the trays in which tray 3 has the least standard deviation. The solar collector and dryer efficiencies are 88.88 % and 80.29 %.

1. Introduction

The Philippines possesses a significant amount of biomass waste, underscoring the importance of adopting sustainable waste management strategies that can adequately tackle the environmental consequences of such waste while simultaneously offering economic advantages by utilizing it as a form of sustainable energy. It is relevant to mention that coconuts, a crop frequently cultivated in the region, are recognized for producing a significant quantity of waste such as coconut shells, coconut husks, and copras (Debrah et al., 2021). Hence, it is crucial to investigate novel and effective approaches for the management of this waste and its conversion into a valuable resource that can aid in fulfilling the energy requirements of the nation while diminishing its reliance on non-renewable energy sources. Through this approach, the Philippines has the potential to not only advance environmental sustainability but also generate creative possibilities for economic growth and progress.
The sustainability and low carbon footprint of coconut briquettes make them a popular choice as a renewable energy source. The briquettes are composed of compacted coconut husks, which are a residual material of the coconut sector (Haryadi et al., 2019). In contrast to conventional charcoal and wood fuel sources, coconut briquettes have been found to produce reduced levels of smoke and exhibit greater environmental sustainability. The process of manufacturing coconut briquettes can pose a challenging task, as it necessitates the drying of husks to an exact moisture level prior to compression. Traditionally, coconut husks are dried using the sun, which can be a time-consuming process and is highly dependent on weather conditions. In open sun drying, the products are displayed directly to sunlight, and considered cheap, but the products can easily be contaminated by dust, pollution, and damage from animals, birds, or insects (Maia et al., 2021). Alternatively, mechanical dryers can be used, but they are costly and require a significant amount of energy. Therefore, there is a need for a more sustainable and cost-effective drying method for coconut husks to produce coconut briquettes. To

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address this need, a proposed study aims to investigate the feasibility of using natural convection solar drying mechanisms for drying coconut husks. Natural convection solar drying is a practical and effective approach of drying commodities (Akter et al., 2025). This method is not only environmentally friendly but also cost-effective, making it an ideal solution to produce coconut briquettes.

Traditional drying methods often rely on non-renewable energy sources, leading to the reduction of limited resources and the emission of harmful greenhouse gases (Kumar et al., 2022). The environmental impact of these methods has raised concerns regarding their sustainability over time. Considering the present circumstances, there is a pressing need to devise sustainable methods of drying that can mitigate energy usage and environmental impacts while concurrently maintaining or improving drying efficiency. The present study aims to address this need through the implementation of a solar air-drying mechanism that utilizes biomass briquettes for energy production. The solar air dryer being evaluated is designed to take advantage of the abundant radiation from the sun present in many different areas. The utilization of biomass briquettes along with renewable energy sources has been integrated into the design of the dryer, resulting in a more effective and ecologically sustainable option for drying. Some innovations in general solar dryers have been explored like employing V-corrugated absorber to increase energy efficiency compared to traditional solar air collectors by the study of Kumar et al. (2022), utilizing perforated baffles with evacuated tube collectors by the study of Kandukuri et al. (2024) and thermal storage (Muthaiyan et al., 2021). The proposed methodology entails the integration of natural convection, a V-corrugated absorber, perforated baffles in the drying chamber and thermal storage in the solar collector. The inclusion of these features aims to enhance heat transfer and air circulation, resulting in faster drying time and increased efficiency. The studied system demonstrates the ability to provide sustainable and financially feasible drying options, specifically in regions with restricted access to electricity and sufficient exposure to sunlight. The sun-drying method of materials can cause ergonomic problems for workers, and the current design of solar air dryers using natural convection has limitations in terms of efficiency and drying rate (Susana, 2018). However, the heating of air using solar collectors has the drawback of a low heat capacity in comparison to water (Goel et al., 2021). An addition of thermal storage will aid in sustainable drying of the briquettes (Muthaiyan et al., 2021). This research sought to address the need for more efficient and sustainable drying methods that can reduce energy consumption and environmental impact, especially in regions with abundant solar radiation.

2. Materials and Method

This section entails the utilization of a solar air dryer to desiccate diverse materials, with a specific emphasis on the dehydration of biomass briquettes derived from coconut shells. The solar air dryer prototype will undergo monitoring and optimization of its operating parameters to establish potential correlations between said parameters and factors that may impact on the efficacy and quality of drying. These considerations include the period of the drying procedure, and the amount of moisture removed.

2.1 Site Selection

Given the growing demand for coconut briquette products in the Philippine market, the selected site is a small-scale coconut briquette business as the beneficiary of the study’s advantages in Barangay Bambang, Calaca, Batangas. Problems like inherent unpredictability of the weather and unforeseen rainfall disrupted the drying process, resulting in inefficiencies and a yield decrease of up to 40 % compared to ideal sunny conditions. Furthermore, a lack of consistent good weather negatively impacted the ability to accurately estimate and maximize production. Drying the briquettes outside could also lead to the development of physical flaws like cracks, deformation, and mold, thereby decreasing their value for consumers. The exposure of biomass resources to environmental factors without any form of protection naturally resulted in these flaws.

2.2 Material Selection

The material selection of components in a solar air dryer was a critical aspect that directly impacted the cost, availability, durability, efficiency, and overall performance of the system. Proper material selection ensured that the components could withstand the specific operational requirements and environmental conditions associated with solar drying applications. However, the selection of materials prioritized availability and affordability. Given the beneficiary’s location, it was critical that the materials be available locally in their area. Since their briquetting business was new, the beneficiary requested that the materials be as affordable as possible. There were several types of materials that could be used for parts of the solar cabinet dryer; each material had different properties to consider and needed to be appropriate to the proposed design. To ensure the process of selecting materials, the Weighted Property Method developed by Farag (2014) was applied. This methodical approach was implemented to address various performance needs and minimize the possibility of overlooking any alternate options. The drying chamber consisted of insulation, perforated trays, perforated baffles, and exhaust. The collector and drying chamber both used the same materials for insulation. Thermal and strength properties were the most important considerations, but availability and cost could influence the selection factors. Low-carbon steel was selected as the material for the casing and drying chamber. Perforated drying racks were used to support and protect briquettes throughout the drying process, preventing them from being deformed or damaged. The material under consideration was stainless steel. Due to its exceptional corrosion resistance, stainless steel was recommended for drying racks expected to meet moisture or corrosive substances. Jianchun et al. (2023) found that the material demonstrated durability and elasticity, allowing it to maintain its structural integrity even under high temperatures and heavy loads. A thermal energy storage system was required to extend the duration of heating at low levels of sunlight. Fernandes and Tavares (2024) stated that the use of thermal storage could effectively prevent the dried product from rehydrating. Rehydration not only reduced the drying process's effectiveness but also caused product damage. The locality indicated that their briquettes frequently developed mold. This natural solar dryer employed a sensible heat storage technique. Fernandes and Tavares (2024) also identified some common materials used for sensible heat storage such as sand, gravel, rocks and concrete. The selection of gravel as a potential medium for thermal storage was based on its accessibility, affordability, and ease of use.

2.3 PISD Design

Figure 1 details an exploded view of the PISD showcasing its components to enhance understanding of its design and function. The PISD is 1,500 mm long, 500 mm wide and 690 mm high. The system featured a drying chamber with an exhaust at the top to aid in moisture release. Trays with perforations beneath the chamber held the material for drying. A significant challenge encountered by solar dryers is the distortion of drying trays. As a result, the load calculations were primarily centered around the perforated drying trays, with forces applied along the vertical axis. Additionally, strategically positioned baffles with perforations distributed airflow evenly throughout the trays. At the bottom, the solar collector supported the entire structure, equipped with wheels for mobility. The solar collector casing, complete with insulation and a V-corrugated absorber, stood next to the drying chamber. A glazing cover had been placed over the thermal storage unit to trap solar energy, which was then used to heat the air that flowed into the drying chamber, making the drying process efficient and sustainable.

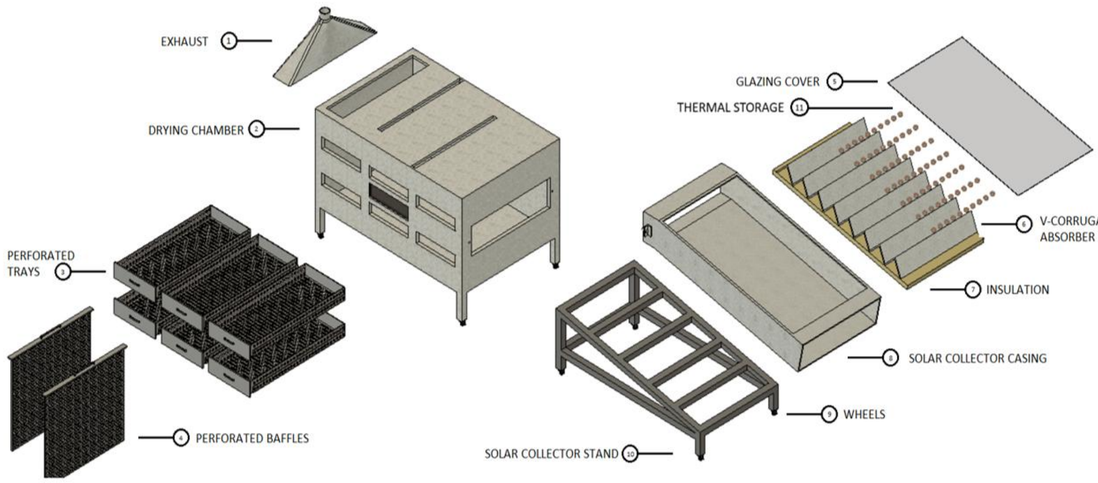

Figure 1: PISD Design in exploded view

2.4 Energy Analysis

An important parameter in assessing the dryer performance would be its efficiency (Atienza et al., 2024). Using the formula from the study of Adelaja and Babatope (2013), the efficiencies of the collector and dryer were evaluated as well as the drying time. The solar collector efficiency $\eta_{collector}$ is described by Eq(1) in which the ratio of the collector's beneficial heat is $Q_{u,collector}$ and heat take up by radiation in the collector $Q_{rad,in,collector}$. The dryer efficiency η_{dryer}, on the other hand, is presented in Eq(2) in which the cabinet's useful heat is $Q_{u,cab}$. heat transfer into the chamber $Q_{dc,in}$ and heat take up by radiation in the cabinet $Q_{rad,in,cab}$.

$$\eta_{collector} = \frac{Q_{u,collector}}{Q_{rad,in,\ collector}} \tag{1}$$

$$\eta_{dryer}=\frac{Q_{u,cab}}{Q_{rad,in,\ cab}+Q_{dc,in}} \tag{2}$$

2.5 Tray Location Analysis

The study also analyzed the tray locations as seen in Figure 2 with the most stable temperature in the dryer with baffles and thermal storage configurations, and without baffles and thermal storage configurations. In order to assess this, the standard deviation σ of the temperatures in the trays were calculated using Eq(3) where T_i and T_{i+1} are the temperatures at the beginning and end of the third minute interval with n being the number of observations. The tray with the lowest standard deviation was considered the most stable, indicating the least temperature variation over time and a more uniform absorption of heat. Monitoring temperature stability was important for enhancing the efficiency and effectiveness of the solar drying process, specifically for drying coconut briquettes, which were prone to changes in environmental conditions.

$$\sigma^2=\frac{\sum(T_{i+1}-T_i)^2}{n-1} \tag{3}$$

Figure 2: PISD with Tray Location Labels

2.6 Experimentation

The testing involves the following configurations such as no load, with baffle and thermal storage, with baffle and without thermal storage, and no baffle and thermal storage. Throughout the testing phase, the crucial parameters were monitored including wind speed, ambient temperature, relative humidity, temperature and drying time. The temperatures were carefully documented at five-minute intervals. The solar dryer had been equipped with a digital hygrometer thermometer tolerance of 1 ºC for temperature and 10 % RH for relative humidity. and a mechanical analog weighing scale, which were essential for monitoring the ambient conditions and the mass of the briquettes, respectively. Also, the initial moisture content of the briquettes has been obtained using the study of Enerio et al. (2024) for the oven test procedures. Aransiola et al. (2019) have noted that the production of high-quality briquettes is contingent upon maintaining a final moisture content of approximately 5 % – 10 %. This ensures that the briquettes can ignite effectively and do not exhibit any tendency to disintegrate during combustion.

3. Results and Discussion

As seen in Figure 3, incorporating baffles and thermal storage showed that Tray 3 had the lowest standard deviation, indicating the most consistent temperature conditions. This indicated that the strategic positioning of baffles and the implementation of thermal storage were successful in establishing a uniform drying atmosphere. The smaller temperature deviation for Tray 3, compared to the other trays, suggested a more consistent drying environment. Consistency was essential for the drying process of materials such as coconut briquettes, as steady conditions were necessary to ensure high quality. The strategic positioning of Tray 3 facilitated effective heat transfer and indicated well-distributed airflow, both important considerations in the design of solar dryers. Experimental studies had shown that the location of trays within drying apparatuses was crucial, impacting both the effectiveness of heat transfer and the uniformity of the drying process The findings indicated that trays located in central and lower positions, such as Tray 3, might experience improved results when exposed to stable thermal conditions (Lobatón-García et al., 2023). The steady temperature observed in Tray 3 in with baffle and thermal storage configuration. indicated that the strategic positioning of the baffles surrounding it effectively preserved a stable environment. Given that baffles enclosed Tray 3 and positioned it centrally at the bottom, it was likely that the baffles effectively directed airflow and regulated heat retention, thereby contributing to its consistent stability, emphasizing the significance of including them in the system's design to achieve optimal drying efficiency. During the test when baffles and thermal storage were not present, all trays exhibited greater fluctuations in temperature. Tray 4 displayed the largest standard deviation, indicating the least stable conditions. Tray 2 exhibited a higher level of stability compared to the other trays. However, Tray 3 was even more stable than Tray 2 on the previous test. Ultimately, the use of baffles and thermal storage had a beneficial effect on the consistency of the drying conditions. The strategic location of trays near the center, surrounded by baffles, highlighted the importance of positioning components in the solar dryer to achieve the best possible drying performance. It was also examined that there is a substantial distinction in drying temperature when utilizing both thermal storage and baffles during the drying ($p=0.03$) compared without the features.

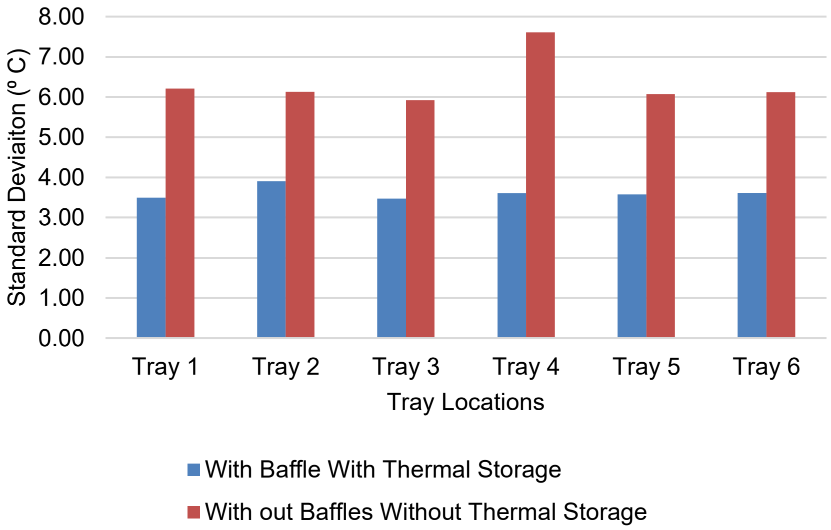

Figure 3: Temperature Standard Deviation per Tray Location

The initial moisture content of the briquettes was 41.24 %. The solar collector recorded an average temperature of approximately 58.30 °C and a relative humidity of 60.52 %. The drying chamber has a temperature of 46.12 °C and a relative humidity of 61.57 %. Despite the high temperature, drying could still occur with a high relative humidity. The relative humidity indicated the air's ability to retain moisture. Reducing humidity accelerated the drying process because it increased the air's capacity to absorb moisture from the briquettes. The solar drying had a significantly shorter drying time compared to the sun-dried method ($p < 0.05$). The accurate values from the graph suggested that the sun-dried approach required approximately 24 h while the solar-dried method needed just over 8 h. This visually and statistically indicated that the solar-dried method substantially reduced the drying time, cutting it by approximately two-thirds. The solar collector efficiency was estimated at 88.88 % while drying efficiency is 80.29 % which is higher compared to the study of Prabhu et al. (2025) on coconut biomass. The evaluation of the solar dryer's efficacy, based on the thermal measurements taken during operation, had a substantial impact on its thermal energy intake. This resulted in a performance that was considerably more efficient, thereby illustrating its suitability for solar-powered drying. The higher temperatures attained throughout the experiment demonstrated how effectively the dryer absorbed and utilized solar heat. The net income of the proposed design is at least four times of the proposed design with the same number of dried briquettes.

4. Conclusion

Adding baffles and thermal storage to a solar dryer system had made the drying process much more efficient by ensuring that the temperature was evenly distributed across all trays. This was shown by a careful analysis of the experimental data and the design considerations of their study. Effective insulation had further enhanced the horizontal orientation of the drying chamber, ensuring a stable internal setting conducive to efficient drying The strategic design of the horizontal chamber and insulation utilization had been impossible to emphasize enough. Insulation had enabled a more controlled and efficient drying process by reducing heat loss, while the design had ensured even heat distribution by maximizing natural convection flows.

Nomenclature

$Q_{dc,in}$ – heat absorbed by radiation in the chamber, W
$Q_{rad,in,cab}$ – heat take up by radiation in the cabinet, W
$Q_{rad,in,collector}$ – heat take up by radiation in the collector, W
$Q_{u,cab}$ – cabinet's useful heat, W
$Q_{u,collector}$ – collector's beneficial heat, W
$\eta_{collector}$ – collector efficiency, %
η_{dryer} – dryer efficiency, %

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