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Performance of Solar Collector Using Recycled Aluminum Cans for Drying

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Abstract

This study highlights the crucial role of flat plate collectors in solar dryer applications for drying agricultural produce. The aim is to develop a solar collector from discarded aluminium beverage cans, following the IS 1933, 2003 standard. The performance is evaluated at three different mass flow rates to dry 12 kg of green chillies. The cylindrical curved surfaces of the tubes are coated with a mixture of activated charcoal and blackboard paint to meet insulation standards. The total efficiency of the collector is determined by measuring the incoming and outgoing air temperatures at various mass flow rates. Additionally, the weight and moisture content removed from the 12 kg green chillies is monitored every 30 minutes throughout the day. The results show that efficiency decreases with increasing mass flow rates, with the solar collector achieving its highest efficiency of 67.89% at a mass flow rate of 0.005 kg/s, effectively removing 88% of the moisture content from the green chillies. This underscores the importance of optimising mass flow rates to maximize the efficiency of solar dryers using recycled materials. The use of activated charcoal and blackboard paint coatings on the aluminium cans enhances heat absorption and retention, contributing to the overall efficiency of the solar dryer. Future research could explore the application of this technology to other types of agricultural produce and further refine the coating materials to improve thermal performance.

Keywords: *Critical Radius of Insulation, Flat Plate Collector, Heat Transfer, Selective Coating, Solar Drying*

1.0 Introduction

Solar power, recognized as a cost-free and environmentally friendly energy source, stands out as a highly promising alternative. In the realm of agriculture, solar drying plays

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an important function in the prolonged preservation of food. C. N. Deepak *et al.*[1] explain, in specific situations, this approach may result in notable reductions in both the quantity (additional weight) and quality of the dehydrated products, certain commonly utilized food items, particularly fruits and vegetables, necessitate a temperature range of 45-60 °C for secure drying. To ensure the extended storage and preservation of perishable agricultural produce, it is imperative to achieve effective drying, reducing the moisture content to a range of 5% to 8%[2]. Maintaining optimal humidity and temperature levels is consistently beneficial in preserving the superior quality of the items[3]. Indirect solar dryers involve utilizing externally pre-heated air for the drying process, while mixed-type solar dryers employ a combination of direct and indirect methods. Numerous investigations have been documented regarding solar drying systems of both direct and indirect types[4,5]. Fudholi *et al.*[6] conducted a study on a straightforward wooden hot box solar cabinet, which is a type of direct solar dryer. The upper side of the dryer featured a transparent polyethene cover, while the bottom was composed of wood and a metal sheet. Sharma *et al.*[7] reached a maximum plate temperature of 80-85 °C without any load and 45-50 °C when drying a 20 kg load of wheat. Various studies have delved into indirect solar drying systems. Early research on using solar energy for drying agricultural products involved thermal storage beds and box-shaped collectors. In 1986, Maroulis and Saravacos designed a system that utilized air heated by a flat plate collector to dry products[8]. Meanwhile, Bolaji investigated a box-type collector with a black absorber plate to maximize heat absorption[9]. This box-type collector achieved a maximum efficiency of 60.5%, with an average temperature of 64°C inside the collector and a peak average temperature of 57°C within the drying chamber. Researchers have investigated methods to improve solar air dryers for efficient product drying. Pangavhane *et al.* proposed a design with fins on the absorber plate to increase heat absorption[10]. Fudholi *et al.* tested a double-pass dryer for palm oil fronds, achieving a collector efficiency between 9% and 48% and extracting 0.29 kg of moisture per kWh of energy used[11]. In general, increasing the surface area and heat transfer of the absorber plate is crucial for dryer efficiency. Studies have explored various techniques like fins, corrugations, V-grooves, and truncated cones to achieve this[12-15]. Anant *et al.*[16-19,20] explain the material selections towards thermal cooling. Shital *et al.*[21-23] explains critical reviews on heat transfer enhancement in heat exchangers. Pachaivannan Partheeban *et al.*[24] proves efficient (drying efficiency of 30%) and results in high-quality geopolymer bricks compared to conventional drying methods. Hussein A. Kazem *et al.*[25] explain the use of photovoltaic thermal air collectors (PV-T) and integrated greenhouse drying systems for PV-T air collectors as a means to reduce fossil fuel consumption and reduce global warming. Azim Doğuş Tuncer *et al.*[26,27] explained the effect of integrating recyclable aluminium cans as tubular fins to a Triple-Flow Solar Air Collector (TFSAC) has been numerically and experimentally investigated. Khanlari A *et al.*[28] explained CFD simulation for determining appropriate aluminium cans configuration.

The review of research indicates that advancements in solar collector technology can greatly enhance the efficiency of solar dryer systems. Improving solar dryer technology, especially solar collectors, is essential for consistent and efficient drying while preserving the quality of agricultural products. This investigation aims to evaluate the effectiveness of a newly designed flat-plate solar collector made from recycled aluminium beverage cans.

The design adheres to the IS 1933, 2003 standard for solar collectors in the following ways[29]:

Material Specifications: Uses discarded aluminium beverage cans, meeting durability and efficiency requirements.

Selective Coating: Applies a mixture of activated charcoal and blackboard paint, enhancing heat absorption and minimizing heat loss.

Thermal Insulation: Coated cylindrical curved surfaces of the tubes ensure effective insulation and minimal thermal energy loss.

Construction and Durability: Recycled aluminium cans provide a robust, stable framework that withstands long-term sunlight and varying weather conditions.

Performance Testing: Comprehensive evaluation at mass flow rates of 0.005, 0.007, and 0.01 kg/s, including measurement of inlet and outlet air temperatures to assess overall efficiency.

Thermal Efficiency Measurement: Efficiency is determined by measuring incoming and outgoing air temperatures, ensuring compliance with the standard.

2.0 Materials and Setup for Experiments

2.1 Flat Plate Collector

A flat plate solar collector was ingeniously fashioned using discarded aluminium cans typically used for soft drinks. By repurposing these cans, the upper and side sections were skillfully cut to create a pipe with a diameter of 55 mm and a thickness of 0.4 mm, effectively minimizing thermal resistance. These cans were then interconnected to form a pipeline for airflow, as depicted in Figure 1. The unique U-shaped corrugated design of the cans induced turbulence, thereby improving airflow within the system. This circular hollow pipe configuration significantly increased the surface area of the Flat Plate Collector (FPC), thus enhancing its overall efficiency. The specific thermal properties of the activated charcoal and blackboard paint material, combined with the application of selective coating, contribute to the enhanced performance and efficiency of solar collectors in capturing and utilizing solar energy. The black paint acts like a solar sponge, soaking up sunlight and turning it into heat that warms the aluminium tubes. The charcoal then helps trap some of this heat inside the collector, like a cosy blanket, minimizing heat loss to the environment. The reason behind using these cans is due to the following parameters. Eco-friendly: Repurposes used cans, minimizing waste. Affordable: Uses readily available aluminium cans. Efficient heat transfer: Aluminum's conductivity boosts performance. Light and strong: Easy to handle and lasts long.

To significantly improve the dryer's performance, the researchers coated the absorber pipe with a special layer called Selective Coating (SC). Activated charcoal and blackboard paint make an effective SC for solar collectors due to their specific thermal properties. They have high absorptivity in the solar spectrum, allowing them to absorb significant solar radiation and maximize energy capture. Activated charcoal's low emissivity helps retain absorbed heat, while its good thermal conductivity ensures efficient heat transfer. Blackboard paint provides a stable and durable coating that withstands environmental conditions, ensuring the longevity of the SC. These properties enhance the heat absorption capacity and overall efficiency of solar collectors by maximizing absorptivity, minimizing emissivity, and optimizing energy utilization. This leads to more efficient drying processes, reduced drying times, and improved product quality. Additionally, using readily available materials like activated charcoal and blackboard paint makes SC applications cost-effective while significantly improving performance, resulting in more effective and efficient solar drying systems. This coating, made by mixing activated charcoal with blackboard paint paste, offered exceptional properties for heat absorption (80%)

Figure 1. Solar collectors by using waste cans.

and minimized heat loss (20% emissivity). These qualities are essential for efficiently transferring heat from the absorber to the drying air used for agricultural products. The researchers also carefully considered factors like the thermal conductivity of both the coating and the pipe itself to further optimize heat transfer. Finally, they implemented the concept of Critical Radius of Insulation (CRI), which proved to be another key factor in boosting heat transfer efficiency.

2.2 Experimental Setup and Procedure

Figure 2 depicts the experimental setup, which includes a flat plate collector made from a repurposed aluminium can, an insulated wooden cabin designed for drying agricultural products, an air blower, a pyrometer, and various measuring instruments. The flat plate collector is positioned southward with a 31.54°C inclination angle. Solar radiation data is recorded every 30 minutes using a pyrometer. Six Copper-Constantine (K-type) thermocouples, accurate to ±0.1 °C, record temperatures. A bottom-connected air blower ensures forced circulation within the collector. Air velocity, measured with an anemometer (accuracy±0.01 m/s), and a variable mass flow rate blower at the flat plate collector inlet determines the air mass flow rate. Rock wool insulation is applied to the collector's bottom and sides.

Before running the experiments, the researchers recorded the initial surrounding conditions (ambient temperature, etc.) and set a specific airflow rate for each test. They tracked solar radiation intensity every 30 minutes, starting at 8:00 AM. The intensity began at 334 W/m² and peaked at 781 W/m² by noon. The average intensity over the 10.5-hour test period with a mass flow rate of 0.01 kg/s was 577.72 W/m². In total, they conducted experiments with three different airflow rates: 0.005 kg/s, 0.006 kg/s, and 0.01 kg/s to analyze the solar collector's thermal performance.

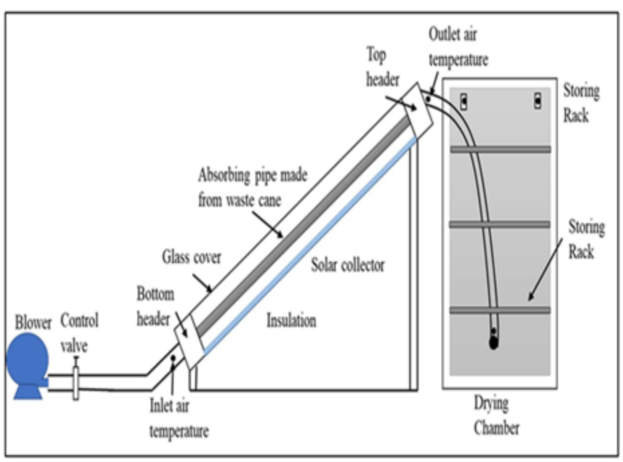

Figure 2. Test setup.

3.0 System Analysis

3.1 Critical Radius of Insulation

From the conduction thermal electrical analogy,

$$Q = \frac{\Delta T}{\sum R}$$

Assuming the constancy of all outer surfaces (r3), given that only r3 depends on the provided selective coating,

$$\sum R = \frac{1}{Q\, 2\pi r_1 l\, h_1} + \frac{\ln\left(\frac{r_2}{r_1}\right)}{Q\, 2\pi l\, k_1} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{Q\, 2\pi l\, k_2} + \frac{1}{Q\, 2\pi r_3 l\, h_2}$$

ΣR is at a maximum or minimum, the second derivative,

$$\frac{d^2 \sum R}{dr_3} = \frac{h_2^2}{2\pi k_2^2} > 0$$

r3 for the selective coating, is used in the fabrication of the experimental setup for the Flat Plate Collector

Thermal Performance Evaluation

Total heat received

$$Q_u = m\, c_p\, (T_{out} - T_{in})$$

$$\text{Thermal Efficiency} = \frac{\text{Total Heat Gain}(Q_u)}{\text{Radiation Collected on Surface}}$$

Thermal Performance Evaluation

% moisture removed,

$$M_{removed} = \left(\frac{M_w - M_d}{M_w}\right) x\, 100$$

4.0 Results and Discussion

We built and tested a unique solar collector design using recycled aluminium cans. They investigated how different

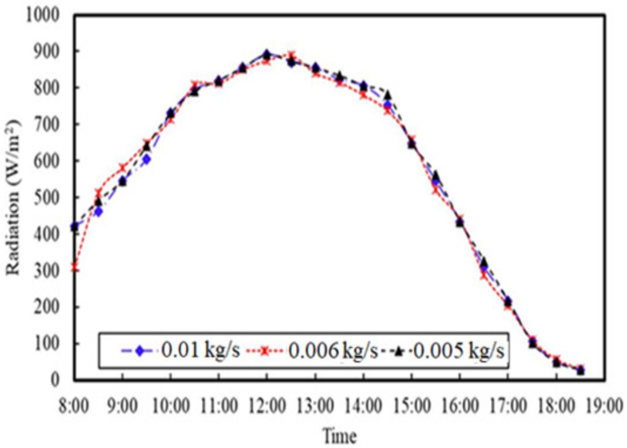

Figure 3. Solar radiation in W/m^2.

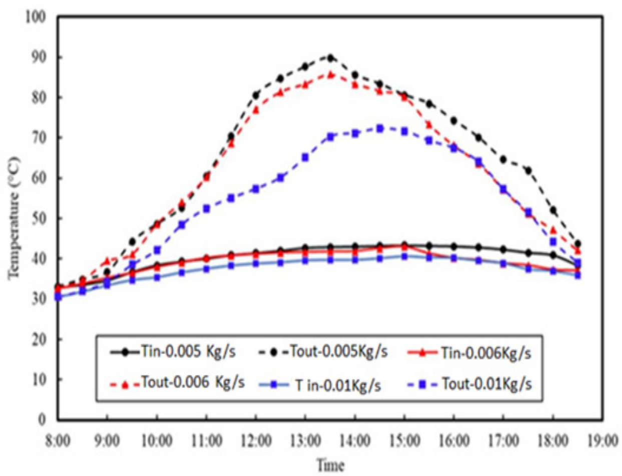

Figure 4. Graph of in and out temperature vs time.

airflow rates (0.005 kg/s, 0.006 kg/s, and 0.01 kg/s) affected the collector's thermal performance. Figure 3 shows the daily outlet air temperature at each flow rate.

The key takeaway is that lower airflow rates resulted in higher outlet air temperatures. This is because the collector's design, made from corrugated recycled cans, creates turbulence at slower airflows. This turbulence increases heat transfer, leading to higher temperatures. For example, at the lowest flow rate (0.005 kg/s), the peak outlet temperature reached 77.6°C, with an average of 54.39°C. Figure 4 further demonstrates this trend over three days. The lowest flow rate (0.005 kg/s) also showed the greatest temperature difference (45.78°C) compared to the ambient temperature, while the highest flow rate (0.01 kg/s) had the smallest difference (31.2°C).

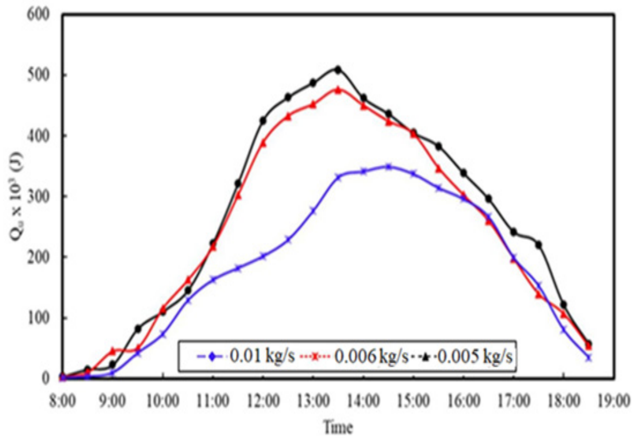

Figure 5. Plot of heat gain from different mass flow rates with time.

Figure 5 highlights the significant heat gain achieved by the FPC, making it a promising option for drying applications. At a low airflow rate of 0.005 kg/s, the collector captured a maximum of 526.42 kJ of usable heat at 1:30 PM and a total of 258.205 kJ for the entire day. The average heat gain decreased with increasing airflow rates, reaching 234.22 kJ and 172.31 kJ for 0.006 kg/s and 0.01 kg/s respectively. Lower airflow rates also resulted in higher collector efficiency. This is because the design retained heat throughout the day, especially at the lowest flow rate (0.005 kg/s). With lower airflow, the collector reached a peak thermal efficiency of 49.52% at the end of the day. This efficiency benefit stems from the stored heat within the recycled aluminium cans, which continued to warm the air even as solar radiation declined. The average daily thermal efficiency also peaked at 16.27% for the lowest airflow rate, dropping to 9.23% for the highest flow rate (0.01 kg/s).

5.0 Conclusion

The solar dryer, constructed from waste aluminium cans, effectively dries green chillies, demonstrating the benefits of using recycled materials to promote sustainability and provide an affordable solution for farmers to preserve produce. A solar collector made from discarded aluminium beverage cans was successfully built and tested in a laboratory-scale setup following the IS 1933, 2003 standard. Experiments at mass flow rates of 0.01, 0.006, and 0.005 kg/s involved measuring inlet and outlet air temperatures to evaluate the system's overall performance. Future research should aim to optimize drying parameters to enhance the dryer's efficiency for a broader range of agricultural products.

Conclusions from the experiments include:

- Recycled corrugated tubes can increase the air temperature within the solar collector.
- The corrugated shape improves heat transfer by creating turbulence in the airflow.
- The largest temperature difference between inlet and outlet was at a mass flow rate of 0.005 kg/s.
- Mass flow rate variations slightly impact the collector outlet temperature, with a decrease of 4-7 %.
- The solar collector's thermal efficiency reached a peak of 49.52% by the end of the day, with the highest average efficiency of 16.27% at a mass flow rate of 0.005 kg/s.

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