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DESIGN, DEVELOPMENT, AND ANALYTICAL STUDY OF SOLAR DRYERS FOR AGRICULTURAL PRODUCTS

Girish L. Allampallewar[1*], Swapnil N. Kakade[2], Prakash V. Saruk[3], Tushar G. Thokal[4], Mangesh R. Walekar[5]

[1,2,3,4,5]Marathwada Mitra Mandal's Institute of Technology, Pune: 411 047

Abstract

Solar drying technology stands as an eco-friendly and sustainable approach to the drying of various products. This abstract provides a brief overview of the key components and principles of solar dryers while addressing pertinent challenges in the field. The primary objective of this solar dryer project is to design, develop, and implement an efficient and sustainable solar drying system. This system aims to address the inefficiencies of traditional drying methods, reduce dependence on non-renewable energy, and provide an accessible solution for farmers and communities. By doing so, the project seeks to contribute to the reduction of post-harvest losses, promote sustainable agricultural practices, and mitigate the environmental impact of drying processes. The solar dryer represents a crucial advancement in sustainable and eco-friendly drying technology. By harnessing solar energy, this innovative system addresses the inefficiencies of traditional drying methods, significantly reducing post-harvest losses and promoting resource conservation. The integration of modern components such as efficient solar collectors, controlled drying chambers, and smart control systems enhances overall performance and adaptability. While challenges like initial costs and weather dependence exist, ongoing research and development are poised to overcome these hurdles. The solar dryer stands at the forefront of environmentally conscious drying solutions,

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*Corresponding author name and email: Girish L. Allampallewar, girish.allampallewar@mmit.edu.in

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offering a scalable and accessible alternative that aligns with global efforts towards greener and more sustainable agricultural practices.

1. Introduction

In the realm of sustainable agricultural practices, the utilization of solar energy has gained significant attention. One noteworthy application is the use of solar dryers, which offer an eco-friendly and cost-effective solution for preserving agricultural products. Traditional drying methods often rely on non-renewable energy sources and can be inefficient, leading to quality degradation of the harvested produce. In contrast, solar dryers harness the abundant and renewable energy from the sun to facilitate the drying process. Solar dryers function by capturing sunlight and converting it into heat, which is then used to remove moisture from agricultural products. This innovative approach not only minimizes the environmental impact but also addresses the challenges associated with conventional drying techniques, such as dependence on fossil fuels and susceptibility to weather conditions. The advantages of solar dryers extend beyond environmental considerations. They provide farmers and communities with a reliable and affordable means of extending the shelf life of perishable crops, reducing post-harvest losses, and improving overall food security. Moreover, solar drying contributes to the production of high-quality dried products, as the controlled temperature and gradual drying process helps preserve the nutritional content, flavor, and color of agricultural goods. This project aims to explore the design, construction, and performance evaluation of a solar dryer tailored for agricultural products. By harnessing the power of the sun, this initiative seeks to empower local farmers with a sustainable and efficient method for preserving their harvest. The integration of solar drying technology aligns with the global push towards clean energy solutions and sustainable agricultural practices, offering a promising avenue for enhancing food security and promoting economic resilience in agricultural communities.

2. Literature Review

The necessity of a solar dryer for efficient crop drying is paramount in addressing the critical issues of food security, post-harvest losses, and environmental sustainability. With a growing global population and increasing concerns about food availability, solar dryers play a pivotal role in extending the shelf life of agricultural produce, ensuring food remains accessible for longer periods with reduced post-harvest losses for food safety and economic stability. The paper investigated the design and development of a drying chamber and, the integration of automation for the regulation of humidity and temperature. The key aspects of solar dryers are:

a. Energy Efficiency: Traditional drying methods often rely on non-renewable energy sources, contributing to environmental degradation and escalating energy costs. Solar dryers harness the abundant and renewable energy of the sun, mitigating the reliance on conventional energy sources

b. Environmental Sustainability: Solar dryers operate with minimal environmental impact, producing significantly lower carbon emissions compared to conventional drying methods powered by fossil fuels that aligns with global efforts to mitigate climate change and promote sustainable practices in agriculture

c. Economic Viability: Solar drying systems, once installed, operate at minimal ongoing costs as they primarily rely on free solar energy. The cost-effectiveness can contribute to the economic sustainability of small-scale farmers and rural communities by reducing expenditure on energy-intensive drying methods

d. Post-Harvest Loss Reduction: Solar dryers facilitate efficient and uniform drying, reducing the moisture content in agricultural products that extends the shelf life of perishable commodities, minimizing post-harvest losses and ensuring a more sustainable food supply chain

e. Improved Product Quality: Solar drying, when controlled and optimized, preserves the nutritional quality of dried products. The gentle and natural drying process helps retain essential vitamins and minerals, contributing to higher-quality end products

f. Accessibility and Versatility: Solar dryers are well-suited for deployment in rural and remote areas where access to conventional energy sources may be limited. Their simplicity and adaptability make them accessible to smallholder farmers, supporting decentralized agricultural processing

g. Climate Resilience: Solar dryers are particularly effective in regions with abundant sunlight, providing a reliable and consistent drying solution even in arid or semi-arid climates. This resilience makes them well-suited for use in various geographical locations

h. Technological Advancements: Ongoing advancements in solar dryer design, control systems, and materials contribute to improved efficiency and usability. These innovations enhance the appeal of solar dryers as viable alternatives to traditional drying methods

i. Sustainable Development Goals (SDGs): The adoption of solar dryers aligns with several United Nations Sustainable Development Goals, including goals related to clean energy (SDG 7), zero hunger (SDG 2), and climate action (SDG 13), highlighting the broader societal benefits

3. Solar Dryer

The abundant radiation energy enables solar drying an effective and accessible method. It gives an effective and practical form of protection that can minimize postharvest losses and balance the quantity deficiencies. The best method for dehydrating is by utilizing sun radiation in the form of solar thermal energy, making it an alternate energy source for drying, especially fruits and other agricultural products. This method performs especially well in areas with high levels of radiation from the sun and prolonged sunshine. It is expected that considerable post-harvest losses of agricultural products happen in developing nations such as Nigeria. Fruits are rich in nutrients and appreciated agricultural products that the body significantly desires.

However, postharvest losses are exacerbated by its perishability because of the products' moisture content. Lowering the product's moisture content is required for tackling the risk it poses, as this will eventually limit the growth of microorganisms. A product can be stored when its moisture content has decreased to a specific, at where the metabolic processes stop or cease and microorganisms cannot flourish. Drying can be employed for improved quality, ease of handling, further processing, and hygiene in addition to prolonging storage life. Therefore, the aim of drying agricultural products is to decrease their weight or volume and retain their moisture for preservation.

A great deal of dried agricultural products may be classified as coarse, porous, or solid substances in a loose bulk structure. Much research has been undertaken over the years to better understand some of the chemical and biological changes taking place after dehydration and to develop methods of minimizing negative quality losses imposed due to humankind's customs. This is because of the fact because drying used to be primarily done in the sun (see plate 1), which exposed the products to multiple diseases. To avoid or decrease the risks of postharvest losses, numerous techniques have been utilized by companies to preserve agricultural products. Drying is an easily preserved approach among numerous preservative methods, including canning, freezing, and dehydration, among many.

This study explores the innovative concept of a hybrid photovoltaic-thermal (PV-T) solar collector and its practical application in the context of solar drying for agricultural products. The conventional paradigm involves separate systems for solar thermal collectors, primarily generating heat, and photovoltaic (PV) panels, dedicated to electricity generation. The hybrid PV-T collector, introduced in this research, combines both functionalities within a single system, aiming to enhance overall energy efficiency and versatility. The research begins with an extensive literature review, providing a comprehensive understanding of existing knowledge and advancements in hybrid PV-T applications, particularly focusing on their potential in solar drying. The review underscores the significant advantages of integrating heat and electricity generation within a unified collector, presenting a promising avenue for more efficient energy harvesting and utilization in various applications. Practical implementation of the hybrid PV-T concept involves the design, construction, and testing of a small-scale solar dryer system. This collector is designed to function seamlessly as both a solar thermal and electricity generator. Preliminary tests, conducted without a load, yield valuable insights into the system's performance. The outlet air temperature ranges between 35 to 50 °C, correlating with varying solar irradiation levels of 300–1000 W/m^2. Simultaneously, the electricity output from the PV-T collector fluctuates between 4 to 25 Watts, showcasing the adaptability of the system to changing solar conditions. The choice of amorphous PV cells is justified in the study for their cost-effectiveness, despite their relatively lower efficiency compared to other PV cell types. The study concludes with the affirmation that the hybrid PV-T collector, specifically utilizing amorphous-type PV cells, effectively meets the requirements of solar drying applications. The collector's ability to concurrently generate heat and electricity positions it as a promising and versatile solution for sustainable agricultural post-harvest processing.

4. Main Components of Solar Dryer

4.1 Drying Chamber

The drying chamber is a key component of a solar dryer, providing an enclosed space where materials are placed to undergo the drying process using solar energy.

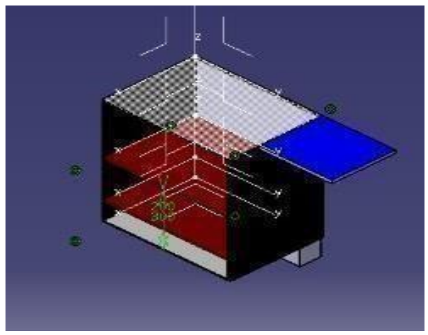


Figure 1. Drying Chamber

4.2 Glass

Glass is a commonly chosen material for the transparent cover of solar dryers, playing a crucial role in the efficiency of the collector. Typically, tempered, or toughened glass is employed due to its enhanced strength and resistance to breakage, achieved through a heat-treatment process. The primary function of the glass is to permit high transparency, allowing maximum penetration of sunlight into the collector. This transparency enables the creation of a greenhouse effect within the collector, where absorbed solar radiation transforms into heat, establishing an optimal environment for the drying process. UV-coated glass may be used to resist ultraviolet radiation, prolonging the life of the glass. Additionally, the smooth surface of the glass facilitates easy cleaning, essential for removing dust and dirt that can accumulate over time, potentially diminishing transparency, and collector efficiency.

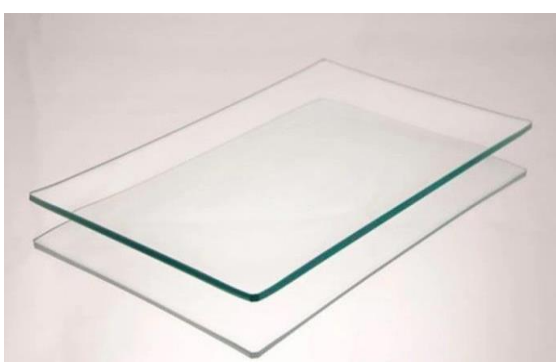


Figure 2. Transparent Glass

The size and thickness of the glass depend on the dimensions and design of the solar collector, with thicker glass often used for larger collectors to ensure structural integrity. As a critical component of solar dryers, the choice of glass is influenced by factors such as durability, thermal stress resistance, insulation, cost, and environmental considerations, contributing to the overall effectiveness of the solar drying system.

4.3 Ventilation System

The ventilation system in a solar dryer is a critical component responsible for maintaining optimal conditions within the drying chamber. Its primary function is to facilitate the removal of moisture-laden air generated during the drying process. There are two types of convection systems.

a. Natural Convection: In some solar dryers, natural convection is relied upon to move air. Warm, moisture-laden air rises, creating a natural airflow that draws in cooler, drier air to replace it. This natural convection process aids in the drying of materials

b. Forced Air Systems: In more advanced solar dryers, especially larger or industrial-scale ones, forced air systems may be incorporated. These systems use fans or blowers to actively circulate air within the drying chamber, enhancing t drying efficiency.

4.4 Control System

The control system in a solar dryer is a crucial element that monitors and regulates various parameters to ensure optimal drying conditions. This system helps maintain efficiency, control temperature, and humidity, and automate processes. Here are key aspects of the control system in a solar dryer:

4.4.1 Temperature Control: The control system monitors and regulates the temperature within the drying chamber. It may include sensors that measure the temperature and mechanisms to adjust heat sources or airflow to maintain the desired temperature. A temperature control sensor, also known as a temperature sensor or thermostat, is a device designed to measure and monitor the temperature of a specific environment and provide feedback to a control system to regulate temperature. These sensors play a crucial role in various applications, including climate control in buildings, industrial processes, automotive systems, and electronic devices. Here is some information on temperature control sensors:

Figure 3. Temperature Control Sensor

Types of Temperature Control Sensors:

a. Thermocouples: These sensors consist of two different metals joined at one end. The temperature difference between the ends generates a voltage, which is used to measure the temperature

b. RTDs (Resistance Temperature Detectors): RTDs are temperature sensors that operate on the principle that the electrical resistance of a metal increases with temperature. Common materials used are platinum, nickel, and copper

c. Thermistors: Thermistors are temperature-sensitive resistors. They exhibit a significant change in resistance with a small temperature change. There are two main types: NTC (negative temperature coefficient) and PTC (positive temperature coefficient)

d. Infrared Sensors: Infrared sensors detect the infrared radiation emitted by an object to determine its temperature. They are commonly used in non-contact temperature measurement

e. Bimetallic Temperature Sensors: These sensors use the differential expansion of two metals to bend and actuate a switch or control device based on temperature changes.

4.4.2 Humidity Detection Sensor: Monitoring and controlling humidity levels are essential for effective drying. The control system helps prevent over-drying or insufficient drying by adjusting ventilation rates or other factors. A humidity control sensor, also known as a hygrometer or humidity sensor, is a device designed to measure and monitor the moisture content or humidity levels in the air. These sensors are crucial in various applications, including climate control, industrial processes, agriculture, and manufacturing.

Figure 4. Humidity Detection Sensor

In modern solar dryers, automation features can be integrated into the control system. Automated processes may include starting or stopping the drying process, adjusting temperature and ventilation based on predetermined conditions, and optimizing overall system performance. Various sensors are employed to collect data on environmental conditions inside the drying chamber. These sensors may measure temperature, humidity, and other relevant parameters.

4.4.3 Insulation

Insulation in a solar dryer is a critical component designed to minimize heat loss and maintain a stable internal temperature within the drying chamber. Proper insulation enhances the efficiency of the solar drying process by preventing external temperature fluctuations from affecting the materials being dried. Using aluminum foil paper as insulation for a solar dryer can be an effective way to enhance the thermal efficiency of the system. In addition to its reflective properties, aluminum foil also provides thermal insulation. It can act as a barrier to reduce heat transfer by conduction, helping to maintain a higher temperature within the drying chamber. This is especially beneficial during periods of low solar radiation or at night when insulation becomes crucial to prevent heat loss.

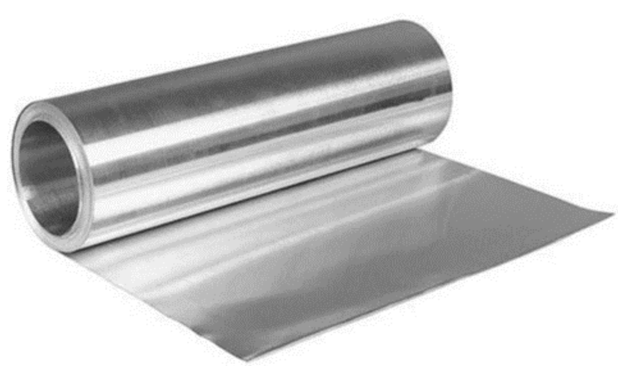


Figure 5. Aluminium Foil Paper

Aluminum foil has excellent reflective properties, meaning it can reflect a significant amount of solar radiation. When placed strategically in a solar dryer, it can help direct and concentrate sunlight onto the drying chamber, improving the overall efficiency of the system.

4.4.4 Solar Panel

Using solar panels in a solar dryer is a sustainable and energy-efficient approach to harnessing solar energy for the drying process.

Figure 6. Solar Panel

Solar panels convert sunlight into electricity, providing a clean and renewable energy source for the solar dryer. Photovoltaic (PV) cells within the solar panels generate electrical current when exposed to sunlight. Photovoltaic panels are typically mounted on the roof or an elevated structure to capture maximum sunlight. The ventilation system helps to regulate air circulation within the drying chamber. Materials that trap heat to improve the efficiency of the drying process. Solar energy is a clean and sustainable solution, reducing greenhouse gas emissions. Storage system (batteries) allows the solar dryer to operate during non-daylight hours or cloudy days. The size and number of solar panels depend on the energy requirements of the drying system and the available sunlight. Solar panels are integrated into the overall design of the solar dryer, ensuring they are positioned to capture sunlight effectively. The electrical components, such as fans and controllers, are connected to the solar panels to utilize the generated electricity. Solar dryers with panels are used in various sectors, including agriculture (for drying crops), food processing, and industrial drying processes. Solar panels in a solar dryer contribute to sustainable and eco-friendly drying practices, reducing the carbon footprint associated with conventional drying methods

5. System Model Development

Developing a solar dryer model involves creating a theoretical framework that describes the principles and processes behind solar drying. Solar dryers are devices that use solar energy to remove moisture from various materials, such as food, and crops. Here's a basic outline of the theoretical framework for developing a solar dryer model. Design calculation based on quantity to be stored as 20 kg, size of the box is 0.6× 0.6× 0.9 m, volume of the box is 0.324 m^3, length of 0.5 m, width as 0.5 m, height as 0.7 m (Total internal volume = 0.5 × 0.5 × 0.7 = 0.175 m^3).

The design is based on a storage temperature of 35 – 40 ºC. Humidity is below 60%. The climatic conditions of Pune are characterized by a tropical climate. In winter, there is much less rainfall in Pune than in summer. The climate is classified as Aw according to Koppen and Geiger. The mean yearly temperature recorded in Pune is 24.3 °C | 75.7 °F, as per the available data. Approximately 1200 mm | 47.2 inches of rainfall occurs every year with solar radiations of 1361 W/m^2. Drying time is calculated as Equation (1). Where M is the mass of the product, M (initial) is the initial moisture of the product, M (final) is the final moisture of the product, A is the drying area and I is solar radiation (W/m^2)

$$\mathrm{T} = \frac{\mathrm{M}}{AI}(M_{initial} - M_{\mathrm{final}}) \tag{1}$$

Fiberglass panels are semi-transparent and are usually a composite of glass fibers and plastic resin. PVC panels are typically less transparent than glass and fiberglass. Cost-effective and lightweight. Easy to work with and install. For our solar dryer project, we have selected glass panels as the primary material due to their high transparency, durability, and excellent insulation properties. The use of glass panels ensures maximum solar energy absorption, contributing to the efficiency of the dryer. We will focus on proper maintenance and UV resistance to ensure long-term durability. The project's timeline and budget account for the procurement and installation of these glass panels and safety precautions will be implemented for their handling. Our choice of glass panels aligns with our goal of creating an efficient and long-lasting solar dryer.

5.1 CAD and Actual Model

CAD model is developed using CATIA. Figure 6 shows the solar panel and Figure 7 shows the structural analysis of the storage model.

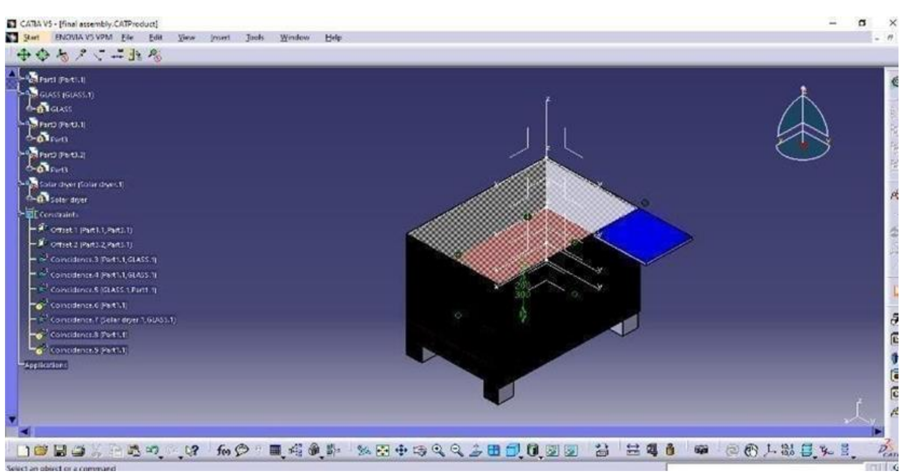


Figure 6. Solar Panel

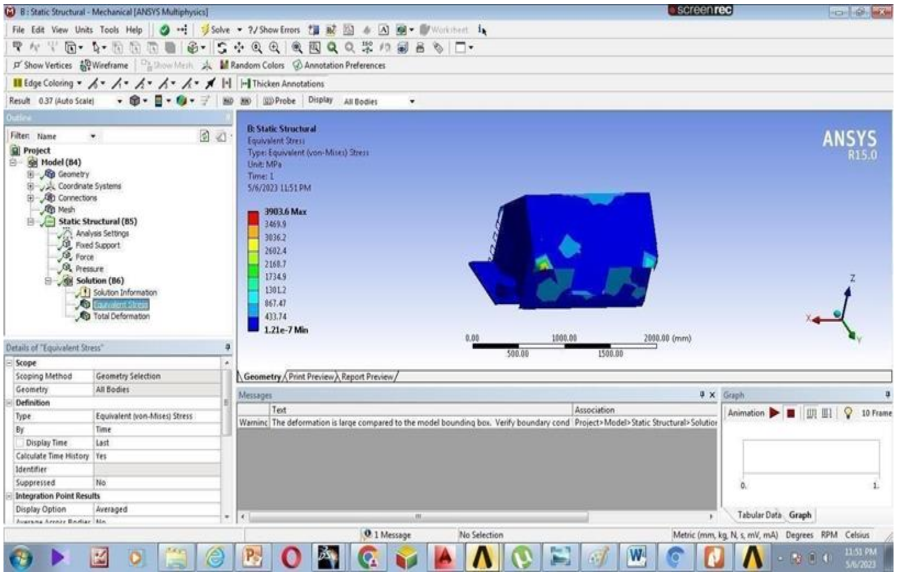


Figure 7. Structural model

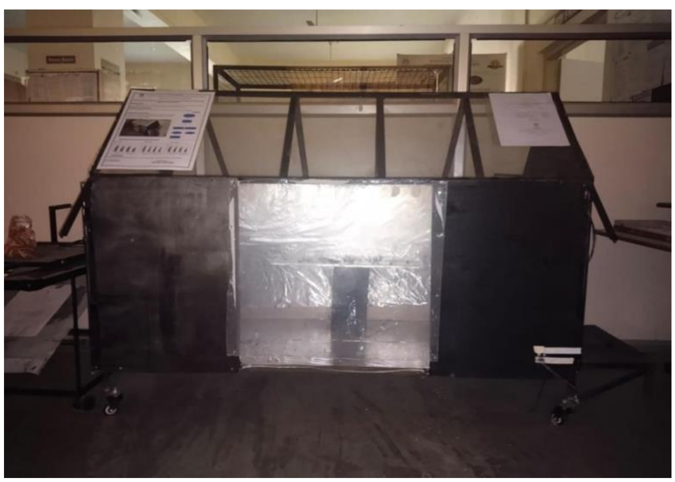


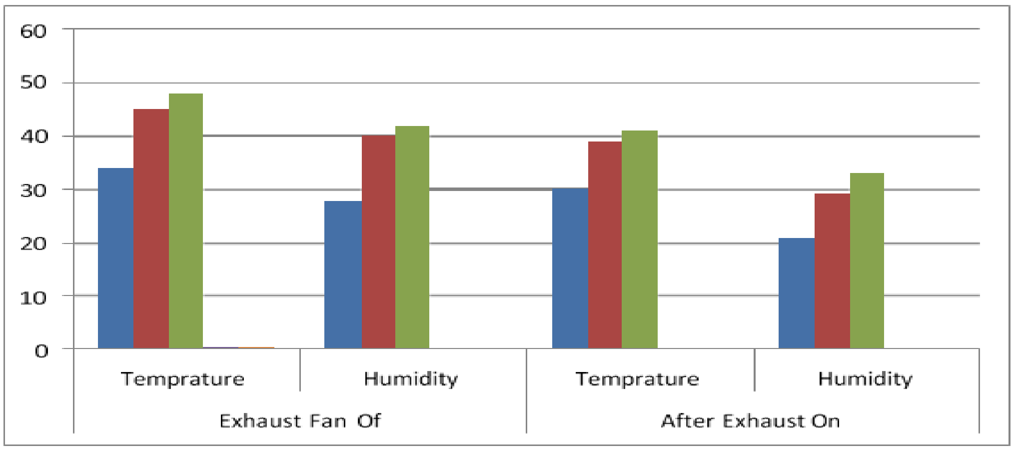
Figure 8. Actual model of storage system

6. Results and Discussions

The experiments are performed for Grapes.

Date: 1/3/24

	Exhaust Fan off		After Exhaust on	
Time	Temperature	Humidity	Temperature	Humidity
10:00 AM	34	28	30	21
12:00 PM	45	40	39	29
1:00 PM	48	42	41	33



The data provided illustrates the significant advantages of employing the exhaust fan in the solar dryer. With the fan off, the internal temperature and humidity levels rise steadily, potentially leading to overheating and inefficient drying. However, upon activating the exhaust fan, a noticeable reduction in both temperature and humidity occurs, indicating effective moisture removal and temperature regulation. This improvement suggests that utilizing the exhaust fan enhances the overall efficiency of the drying process. Not only does it facilitate faster drying by expelling moist air, but it also aids in preserving the quality of the dried product by controlling temperature and humidity levels. Additionally, the exhaust fan's operation aligns with principles of energy efficiency, as it helps optimize the drying process and reduce reliance on the solar heating system. Thus, based on the observed data, utilizing the exhaust fan in the solar dryer is essential for achieving optimal drying performance and producing high-quality dried products.

Calculated the time efficiency; we compare the drying time achieved with the solar dryer to the drying time without it. If we assume that grapes would typically take 20 days to dry without the solar dryer, the time efficiency can be calculated as.

Time efficiency = (Time without solar dryer - Time with solar dryer) / Time without solar dryer

* 100% Time efficiency = (20 days - 15 days) / 20 days * 100%

= (5 days / 20 days) * 100% = 0.25 * 100% = 25%

7. Conclusions

In conclusion, solar dryers offer a sustainable and energy-efficient alternative to traditional drying methods, harnessing the power of the sun to facilitate the drying of various products. The key points in concluding the discussion on solar dryers include: Solar dryers contribute to environmental sustainability by utilizing clean and renewable solar energy, reducing reliance on conventional energy sources, and minimizing carbon emissions. The use of solar energy for drying purposes is energy-efficient and cost-effective in the long run. Solar dryers can be particularly beneficial in regions with abundant sunlight. The use of solar energy for drying purposes is energy-efficient and cost-effective in the long run. Solar dryers can be particularly beneficial in regions with abundant sunlight. Solar dryers are versatile and can be adapted for various applications, including agriculture (crop drying), food processing, and industrial drying processes. The technology is accessible and suitable for both small-scale and larger industrial applications, making it inclusive and adaptable to diverse settings. Solar dryers play a crucial role in reducing post-harvest losses by providing a controlled and efficient environment for drying agricultural products. Ongoing technological advancements, including the integration of temperature and humidity control systems, enhance the efficiency and reliability of solar dryers.

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