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Experimental Investigation Hemispherical Solar Dryer

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Abstract

The present study focuses on the design, development, and performance evaluation of a hemispherical solar dryer for agricultural applications**.** ***Drying*** is an essential process for preserving food materials by reducing their moisture content, thereby extending shelf life and minimizing post-harvest losses. Conventional open sun drying methods are associated with several limitations such as contamination, uneven ***drying,*** and dependence on climatic conditions. To overcome these challenges, a ***hemispherical solar dryer*** was developed using a dome-shaped transparent structure that enhances heat retention through the ***greenhouse effect***. The system consists of an absorber surface, drying chamber with trays, and a controlled airflow mechanism. Additionally, an ***IoT-based monitoring system*** incorporating a microcontroller and temperature-humidity sensor is implemented to observe and regulate internal conditions. Experimental results indicate that the dryer achieves higher internal temperatures compared to ambient conditions, leading to faster moisture removal. Approximately 0.643 kg of moisture was removed within 6 hours under favorable solar radiation. The system demonstrates improved drying efficiency, better product quality, and reduced contamination compared to traditional methods. ***The hemispherical solar dryer*** offers a cost-effective, energy-efficient, and environmentally sustainable solution for ***agricultural drying***, making it suitable for rural and small-scale applications.

Keywords

Hemispherical Solar Dryer, Solar Drying, Agricultural Drying, Greenhouse Effect, Moisture Removal, IoT Monitoring, Renewable Energy, Drying Efficiency

1.INTRODUCTION

Drying is one of the oldest and most widely used techniques for the preservation of agricultural products. It involves the removal of moisture from food materials to a level that inhibits microbial growth and minimizes chemical deterioration. This process not only extends the shelf life of food but also reduces its weight and volume, thereby facilitating easier handling, storage, and transportation. In many developing regions, drying remains a crucial method for ensuring food security and minimizing post-harvest losses.

Traditional open sun drying is commonly practiced due to its simplicity and low cost. However, this method has several limitations, including exposure to dust, insects, and adverse weather conditions such as rain and high humidity. Additionally, direct exposure to solar radiation can lead to degradation in product quality, affecting attributes such as color, flavor, and nutritional value. The process is also time-consuming and requires large open spaces, making it inefficient and unreliable under varying climatic conditions.

To overcome these drawbacks, solar drying technology has been developed as an improved alternative. Solar dryers utilize solar energy in a controlled environment to enhance drying efficiency and maintain product quality. Unlike traditional methods, these systems operate within enclosed structures, which protect the material from contamination and allow better control of temperature and airflow. Solar dryers can be broadly classified into passive and active types, depending on the mode of air circulation. Passive systems rely on natural convection, while active systems use external devices such as fans or blowers to improve airflow and drying rate.

The hemispherical solar dryer represents a modified design aimed at improving thermal performance and drying uniformity. Its dome-shaped structure enhances heat absorption and retention through the greenhouse effect, resulting in elevated internal temperatures compared to ambient conditions. This leads to faster moisture removal and improved drying efficiency. Furthermore, the enclosed configuration reduces contamination risks and allows better monitoring of the drying process.

In addition to structural improvements, recent advancements have incorporated automation and monitoring systems into solar dryers. The integration of sensors and microcontrollers enables real-time measurement of temperature and humidity, allowing for better control of drying conditions and improved system performance. Such developments make solar dryers more reliable and suitable for modern agricultural applications.

Therefore, the hemispherical solar dryer provides a sustainable, energy-efficient, and cost-effective solution for drying agricultural products, addressing the limitations of traditional methods while supporting environmental and economic benefits.

2 Literature Review

The concept of solar drying has been extensively studied as an alternative to conventional drying techniques, particularly for agricultural applications. Traditional open sun drying, although widely used, suffers from several limitations such as contamination, weather dependency, and uneven drying. These drawbacks have led researchers to explore improved solar drying technologies that provide controlled conditions and enhanced efficiency.

Early research on solar dryers focused on cabinet-type and direct solar drying systems, where air is heated using solar radiation and passed over the product. Lawand (1960) introduced one of the earliest solar cabinet dryers, demonstrating the feasibility of using solar energy for food preservation. Later, Bhatia and Gupta investigated solar drying of fruits like apricots and highlighted improvements in product quality and drying rate compared to traditional methods.

Further developments classified solar dryers into two major categories: passive (natural convection) and active (forced convection) systems. Passive dryers rely on natural air circulation, while active systems use external devices such as fans or blowers to enhance airflow. Studies have shown that active system

s provide faster drying but at higher cost and energy requirements. In contrast, passive systems are simpler, cost-effective, and more suitable for rural applications.

Recent studies have focused on improving dryer design to increase thermal efficiency and product quality. Bala and

Mondal (2001) conducted experimental investigations on solar drying of fish using tunnel dryers and reported significant reduction in drying time along with improved hygiene. Similarly, Nahar (2009) studied solar drying in arid regions and emphasized its importance in reducing post-harvest losses and enhancing food security.

In addition to structural improvements, modern research has incorporated automation and monitoring systems into solar dryers. The integration of sensors and microcontrollers allows real-time measurement of temperature and humidity, leading to better control over drying conditions. As observed in the present project, the use of IoT-based systems such as Node MCU and digital sensors enables efficient monitoring and data collection, improving overall system performance and reliability.

The hemispherical solar dryer represents a further advancement in solar drying technology. Its dome-shaped structure enhances heat retention through the greenhouse effect and ensures uniform distribution of thermal energy inside the chamber. Experimental observations indicate that such designs can achieve higher internal temperatures compared to ambient conditions, thereby increasing drying efficiency and reducing processing time.

Overall, the literature indicates that solar drying technology has evolved from simple open drying methods to advanced, controlled systems incorporating modern design and automation. Among these, hemispherical solar dryers offer a promising solution due to their improved thermal performance, protection from environmental factors, and suitability for small-scale agricultural applications.

3 Methodology

The development of the hemispherical solar dryer involved systematic design, fabrication, and performance evaluation. The methodology adopted for this study is divided into three major stages: system design, hardware implementation, and experimental analysis.

1. System Design

The hemispherical solar dryer was designed based on the principle of solar thermal energy utilization. The structure consists of a dome-shaped transparent enclosure, which allows maximum solar radiation to enter and creates a greenhouse effect inside the chamber. This leads to an increase in internal temperature, which facilitates moisture removal from the agricultural products placed on trays.

The design also includes air inlet and outlet provisions to ensure proper circulation of air. Ambient air enters through the lower vents, gets heated inside the chamber, and exits through the upper vents carrying moisture. The geometry of the hemispherical structure enhances uniform heat distribution and improves drying efficiency.

The system incorporates both mechanical and electronic components to improve performance and monitoring. The major components used include:

- **Hemispherical drying chamber** with absorber surface
- **Blower system** for controlled air circulation
- **Node MCU microcontroller** for system control
- **AHT10 temperature and humidity sensor** for real-time data acquisition
- **16×2 LCD display** for parameter monitoring

- **Buck converter and transistor circuit** for power regulation

The temperature and humidity sensor is placed inside the drying chamber to measure internal conditions. These readings are processed by the NodeMCU using I2C communication. Based on the measured parameters, the microcontroller controls the blower to regulate airflow and maintain suitable drying conditions.

2. Hardware Implementation

The system also enables wireless data transmission, allowing monitoring through internet-based platforms. This integration of IoT technology enhances accuracy, control, and data analysis capabilities.

3. Software Implementation

The programming of the microcontroller was carried out using an open-source development platform. The software was designed to read sensor data, display values on the LCD screen, and control the blower operation. Additionally, the system transmits temperature and humidity data to a cloud platform for storage and analysis.

4. Experimental Procedure

The performance of the hemispherical solar dryer was evaluated under natural sunlight conditions. Agricultural products were placed inside the drying chamber, and parameters such as temperature, humidity, and solar radiation were monitored at regular intervals.

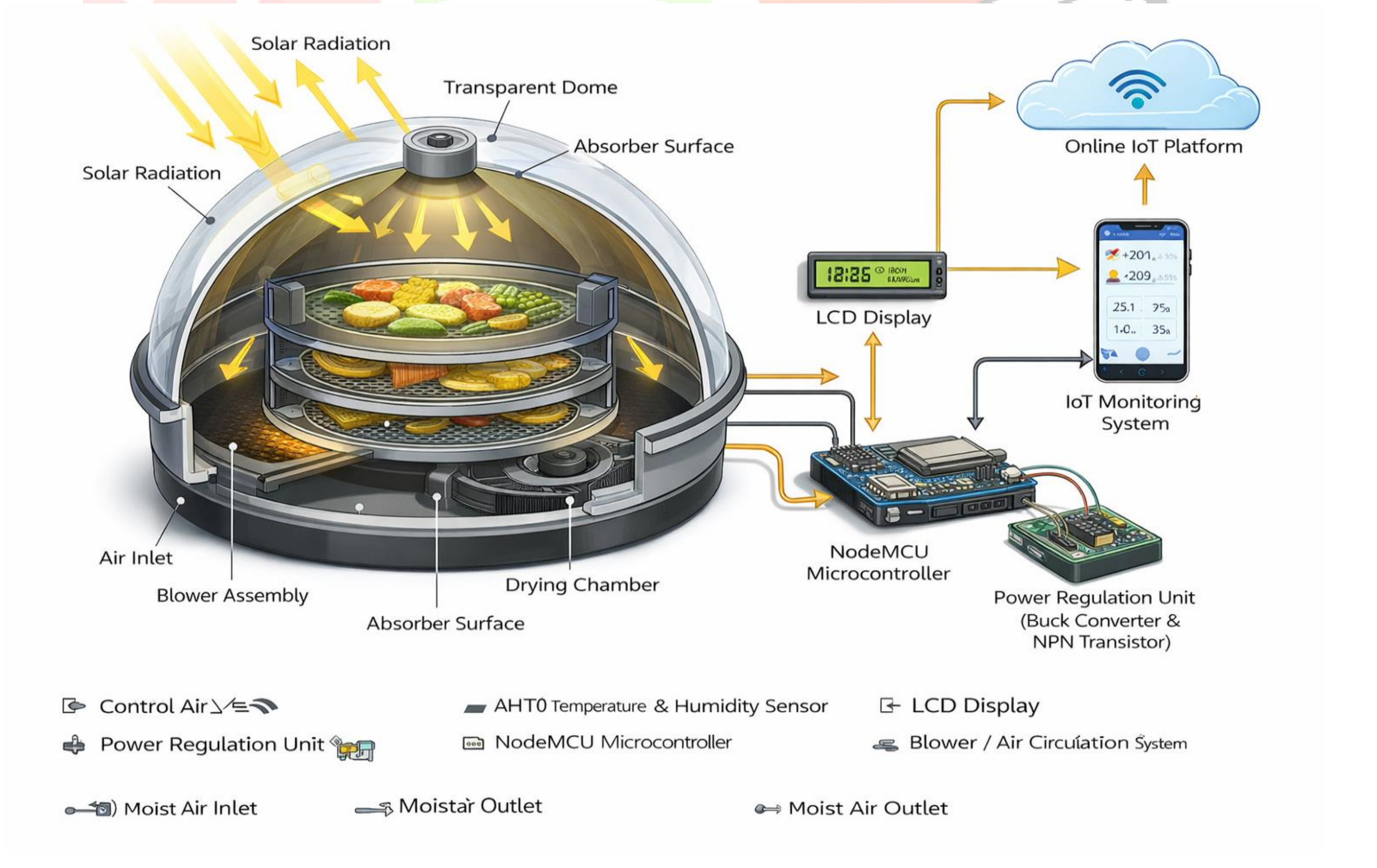
The variation of solar radiation with time was observed, and the corresponding changes in internal temperature were recorded. The drying process was continued for several hours, and the reduction in weight of the sample was measured to determine moisture removal.

5. Data Analysis

The collected data was analyzed to evaluate the efficiency of the dryer. Parameters such as drying rate, temperature variation, and humidity levels were studied. The results indicated that the internal temperature of the dryer was significantly higher than ambient conditions, which improved the drying rate.

The system also demonstrated better performance compared to traditional open sun drying in terms of drying time, product quality, and protection from environmental factors.

The adopted methodology integrates solar thermal principles with modern monitoring techniques to develop an efficient drying system. The combination of optimized design, controlled airflow, and real-time data monitoring ensures improved performance and reliability of the hemispherical solar dryer.



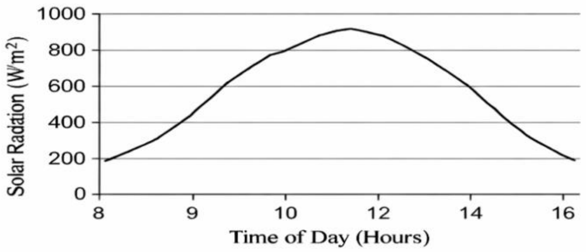


Fig. 3.2: Solar Radiation vs Time.

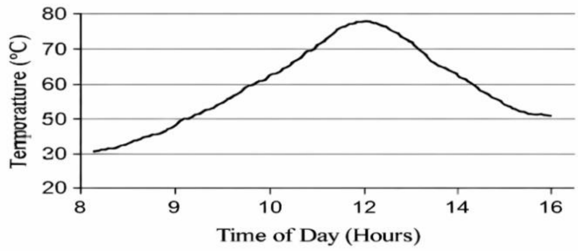


Fig. 3.3: Temperature Variation.

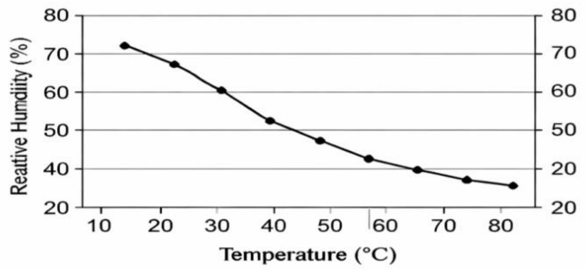


Fig. 3.4: Temperature vs Humidity.

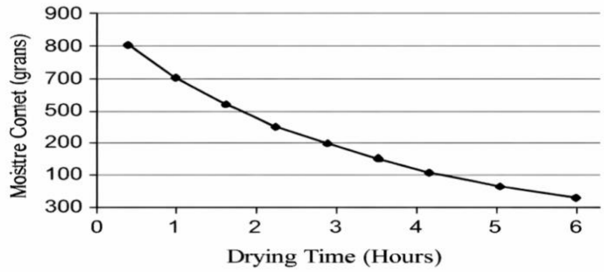


Fig. 3.5: Moisture Reduction Over Time.

4 Design & Calculations

The hemispherical solar dryer is designed to utilize solar thermal energy efficiently for drying agricultural products under controlled conditions. The system integrates a dome-shaped structure with thermal and electronic components to enhance heat retention, airflow, and monitoring.

1. Structural Design

The dryer consists of a **hemispherical dome-shaped enclosure**, which acts as a transparent cover. This geometry allows maximum solar radiation to enter the system from multiple angles throughout the day. The dome structure creates a **greenhouse effect**, trapping heat inside the chamber and increasing the internal temperature.

The lower portion of the dryer forms the **base and drying chamber**, where agricultural products are placed on trays. The compact design ensures uniform heat distribution and minimizes heat losses to the surroundings.

2. Solar Energy Absorption System

An **absorber surface**, typically coated with a dark material, is provided inside the dryer to maximize heat absorption. When solar radiation falls on this surface, it converts solar energy into thermal energy, which heats the surrounding air.

This heated air increases the temperature within the chamber, facilitating the evaporation of moisture from the product. The efficiency of the system depends on the effective absorption and retention of this thermal energy.

Moisture Removal Calculation

Moisture removed is calculated as:

Moisture Removed (Wm) = Initial Weight (Wi) – Final Weight (Wf)

From experiment:

Moisture Removed (Wm) = 0.643 kg

3. Airflow and Ventilation Design

The dryer operates on the principle of **natural and forced convection**. Ambient air enters through **inlet vents** located at the lower section of the dryer. As the air gets heated, its density decreases, causing it to rise and move through the drying chamber.

The **moist air exits through upper vents**, ensuring continuous airflow. Additionally, a **blower system** is incorporated to enhance air circulation and maintain uniform drying conditions. This controlled airflow improves drying efficiency and reduces drying time.

Air circulation works as follows:

- Cool air enters from bottom inlet
- Air gets heated inside dryer
- Hot air rises and absorbs moisture
- Moist air exits through top outlet
- Blower improves airflow

4. Drying Chamber and Tray Arrangement

The drying chamber contains **multiple trays** arranged in a vertical manner. These trays provide sufficient surface area for placing agricultural products such as fruits, vegetables, and tubers.

The design ensures that heated air flows uniformly across all trays, allowing even drying. The enclosed chamber also protects the products from contamination by dust, insects, and external environmental conditions.

Drying Rate

Drying rate is calculated by:

Drying Rate (DR) = Moisture Removed / Time

DR = 0.643 / 6 DR = 0.107 kg/hr

Heat Energy Required

Heat required for moisture removal:

$Q = m \times L$

Where:
m = 0.643 kg L = 2257 kJ/kg

$Q = 0.643 \times 225$ Q = 1451.25 kJ

5. Electronic Control and Monitoring System

The system incorporates an **IoT-based monitoring setup** to enhance performance and control. The main components include:

- **Node MCU microcontroller** for processing and control
- **AHT10 sensor** for temperature and humidity measurement
- **16×2 LCD display** for real-time data visualization

The sensor continuously measures internal conditions, and the data is processed by the microcontroller. Based on these readings, the blower operation is controlled to maintain optimal drying conditions.

The system also enables **wireless data transmission**, allowing remote monitoring and analysis of drying parameters.

6. Power and Control Circuit

A **buck converter** is used to regulate voltage according to the requirements of different components. Since the microcontroller cannot directly drive high-power devices, an **NPN transistor** is used as a switching element to operate the blower.

This arrangement ensures efficient power utilization and reliable system operation.

7. Working Principle

When solar radiation enters the hemispherical dome, it is absorbed by the internal surfaces and converted into heat. The air inside the chamber gets heated and flows over the product placed on trays.

This heated air absorbs moisture from the product and carries it out through the exhaust vents. The continuous circulation of air, combined with elevated temperature and reduced humidity, results in efficient drying.

The integration of sensors and control systems further improves the process by maintaining optimal environmental conditions inside the dryer.

The hemispherical solar dryer combines optimized structural design, efficient heat absorption, controlled airflow, and modern monitoring systems. This integrated approach enhances drying performance, reduces energy consumption, and ensures better product quality, making it suitable for sustainable agricultural applications.

Solar Energy Input

Solar energy received: $Q_s = I \times A \times t$

Where:
I = 980 W/m² A = 0.5 m², t = 6 hours = 21600 seconds

$Q_s = 980 \times 0.5 \times 21600$, Qs = 10584000 J, Qs = 10584 kJ

Thermal Efficiency

Efficiency is calculated as: Efficiency = (Useful Heat Output / Solar Energy Input) × 100

Efficiency = (1451.25 / 10584) × 100 Efficiency = 13.7 %

Temperature Rise

Temperature difference inside dryer:

Delta T = Inside Temperature – Ambient Temperature

Delta T = 75 – 30 Delta T = 45°C

5 Conclusion

Applications of Hemispherical Solar Dryer

The hemispherical solar dryer can be considered a sustainable and practical approach for addressing issues related to food preservation and energy consumption. Drying is one of the most effective methods for extending the storage life of agricultural commodities, and the integration of solar energy significantly enhances this process by reducing dependency on non-renewable resource

This type of dryer finds application across various sectors due to its adaptability and efficiency. Its major uses include:

• Preservation of agricultural produce through controlled drying
• Dehydration processes in fruit and vegetable industries
• Drying of fish and meat products for storage and transport
• Use in dairy sectors for powdered product preparation
• Moisture removal in wood and timber processing
• Drying applications in textile industries

Hence, solar dryers contribute to efficient resource utilization and support sustainable agricultural practices. However, economic considerations such as system cost and affordability remain key factors influencing large-scale adoption.

The hemispherical solar dryer offers several significant benefits, including:

1. Enhanced quality of dried materials with better retention of properties
2. Reduction in post-harvest losses, leading to improved economic returns
3. Protection of products from external contaminants like dust, insects, and rainfall
4. Decreased reliance on conventional fuels, thereby reducing environmental impact
5. Higher operational efficiency with comparatively lower running costs

These advantages make it a suitable and environmentally friendly alternative to traditional drying techniques.

Despite its advantages, certain challenges are associated with this system:

1. Inconsistent product quality may occur under unfavourable conditions
2. Performance is highly dependent on availability of sufficient solar radiation
3. Initial investment cost can be relatively higher, and drying duration may be longer compared to mechanical systems

Such limitations indicate the need for proper system design and consideration of climatic factors for optimal performance.

The hemispherical solar dryer effectively reduces moisture content in agricultural products while maintaining important quality parameters such as color, aroma, and taste. Since the system minimizes direct exposure to harsh solar radiation, it ensures better preservation compared to conventional open sun drying methods.

Experimental evaluation shows that the dryer is capable of increasing internal air temperature, which enhances the rate of moisture removal and improves drying efficiency. Additionally, the enclosed structure provides protection against environmental factors and reduces the need for continuous supervision.

The system is also versatile and can be used for drying a variety of agricultural products, including tuber crops. Its design allows easier monitoring and handling when compared to traditional drying practices.

From an economic perspective, the construction cost of a solar dryer is generally lower than that of mechanical dryers, making it suitable for small-scale and rural applications.

Overall, the hemispherical solar dryer represents an efficient, eco-friendly, and cost-effective solution for agricultural drying, with strong potential for widespread adoption in sustainable development practice

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