

Solar Drying Technology: Recent Innovations and Future Perspective

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ABSTRACT: The increasing demand for sustainable and energy-efficient technologies has led to the development of solar drying systems as an alternative to conventional drying methods. This project focuses on the design, construction, and performance evaluation of a solar dryer for agricultural products. Traditional drying techniques, such as open sun drying, are often associated with contamination, uneven drying, and dependence on weather conditions, while conventional dryers consume significant fossil fuel energy.

This study demonstrates that solar drying is a cost-effective, eco-friendly, and sustainable solution for agricultural processing, especially in regions with abundant solar radiation. The findings highlight the potential of solar dryers in promoting renewable energy utilization and supporting rural development.

KEYWORDS: Solar Dryer, sustainable, energy-efficient, cost-effective, eco-friendly, agriculture.

I. INTRODUCTION

A solar dryer is a system designed to use solar energy efficiently for removing moisture from various agricultural and food products. It is an improved and scientific method of drying that overcomes the limitations of traditional open sun drying. By providing a controlled environment, a solar dryer ensures better product quality, hygiene, and faster drying rates. The working of a solar dryer is based on the greenhouse effect, where solar radiation enters through a transparent cover and gets converted into heat energy inside the system. This heat increases the temperature of air within the dryer, reducing its humidity and enhancing its ability to absorb moisture from the materials placed inside. In conclusion, a solar dryer is a simple, cost-effective, and eco-friendly solution for drying and preserving food products. It not only improves the quality and shelf life of dried materials but also promotes the use of clean energy. Therefore, solar dryers are an important technology for sustainable development and rural advancement.

II. OBJECTIVES OF SOLAR DRYER

The main objective of this project is to design, develop, and analyze an efficient solar dryer system that utilizes renewable solar energy for drying agricultural and food products. The system aims to reduce moisture content in materials in a cost-effective, eco-friendly, and energy-efficient manner while maintaining product quality. The objectives of this solar dryer project focus on developing a sustainable, efficient, and economical drying system that benefits both users and the environment. This project not only enhances technical knowledge but also contributes to solving real-world agricultural and energy-related problems.

III. LITERATURE REVIEW

3.1. Overview of recent solar drying technologies

Many improvements were made to solar drying systems to increase efficiency, integrate renewables, add storage, and address design issues between 2020 and 2026. Because of these systems, drying methods are now active and intelligent, using alternative strategies to improve drying and product quality. Recent studies are used to compile Table 1, which provides an organised view of a range of systems and their performance factors.

Table.1. Solar Drying Technologies and Key Features

Dryer Type	Configuration / Description	Enhancement / Technology Used	Performance Indicators
Direct Solar Dryer	Transparent cover with absorber plate for natural or forced convection drying	Basic passive solar radiation use	30–45 % energy efficiency; drying time reduced by 25–35 %
Indirect Solar Dryer	Separated solar collector and drying chamber for controlled air flow	Collector optimisation; forced convection fans	45–60 % energy efficiency; 35–50 % faster drying
Hybrid Solar–Biomass Dryer	Solar collector integrated with biomass backup for night operation	Air recirculation; thermal heat exchangers	55–75 % energy efficiency; operational continuity for 24 h
Solar–PV Hybrid Dryer	Photovoltaic panels power fans and sensors	PV-assisted automation and IoT control	50–70 % efficiency; drying time reduced up to 60 %
PCM-Integrated Dryer	Phase change materials incorporated for heat storage	Paraffin, stearic acid, and nanoparticle additives	60–80 % thermal efficiency; 3–4 h extended drying
CFD/ANN Optimised Dryer	Model-based performance optimisation	CFD simulation; ANN prediction; RSM modelling	>95 % predictive accuracy; reduced energy loss
Indirect Solar Dryer	parabolic trough collector assisted with air recycling system, nanofluid and energy storage system	CFD, MATLAB, nanofluid Al ₂ O ₃ PCM (paraffin) integrate with PTSC	The thermal efficiency of the system is considerably reduced (15.6–76.9 %)
Indirect Solar Dryer	PV-assisted solar dryer using a sun tracking system	A digital camera (Canon A3200IS, for shooting pictures, data logger thermometer (DL-9601A, Lutron)	The drying time decreased about 16.6 %e36.6 % using the sun tracking system.
Hybrid solar dryer	Forced convective SD system	Firebrick heat storage materials (FTSM)	Reduction of moisture
Hybrid solar dryers	Thermal Chimney Effect	Thermal Chimney Effect	40–70 % faster compare to open sun
Indirect solar Dryer	Natural Convection, mode semi-theoretical model.	Pebbles sensible thermal storage material	Reduction of moisture took from 56 % w.b. to 10.62 and 15.20 % w.b

IV. SCOPE OF THE PROJECT

The scope of the "Design and Development of Solar Dryer" project defines the boundaries, objectives, deliverables, and limitations for creating a cost-effective, solar-powered drying system suitable for agricultural produce in rural and semi-urban settings. This engineering project targets small-scale implementation using locally available materials, focusing on natural convection indirect drying technology to preserve fruits, vegetables, herbs, and spices while minimizing post-harvest losses.

The system aims to achieve 70-90% moisture reduction in 6-12 hours under typical solar insolation of 5-6 kWh/m/day, outperforming traditional open-sun drying by 2-4 times in speed and quality retention.

The technical scope encompasses conceptual design using solar collector theory (Hottel-Willier-Bliss model), material selection (galvanized iron sheets, polycarbonate glazing, wooden frame), and fabrication of a 1m x 0.8m x 0.6m indirect dryer with 4-6 trays (capacity 10-15 kg fresh produce). Key components include blackened absorber plate (area 0.8 m²), chimney for natural convection (height 0.5m), and optional reflectors boosting insolation by 20-30%. Testing involves drying trials with thermocouples (0-100°C range), anemometer, and moisture analyzer, comparing against open drying baselines. Software scope is limited to basic Excel-based data logging and efficiency calculations, excluding IoT or automation.

V. DETAILS OF DESIGNS, WORKING AND PROCESS

The solar dryer is designed as a simple, low-cost, indirect natural convection system for drying agricultural products such as fruits, vegetables, spices, and herbs. In this design, the product is not exposed directly to sunlight, which helps improve quality, hygiene, and color retention. The system mainly consists of a solar collector, drying chamber, trays, air inlet, outlet chimney, transparent cover, absorber plate, and supporting frame. The collector converts solar radiation into heat, and the heated air is then sent into the drying chamber for moisture removal. The design is suitable for small-scale use and can be fabricated using locally available materials.

The main structure is generally rectangular in shape for easy fabrication and better arrangement of trays. A sloped transparent cover is provided on the collector so that maximum solar radiation enters the system. Beneath the cover, a black absorber plate is used to absorb sunlight and convert it into thermal energy. The drying chamber is attached to the collector so that hot air flows naturally from the collector to the chamber. A chimney or exhaust outlet is placed at the top end to allow moist air to escape continuously. This arrangement creates natural airflow without the need for an external fan.

The drying trays are placed inside the chamber at proper spacing to allow uniform airflow around the product. The trays are usually made of wire mesh so that hot air can pass through them easily. The chamber walls are insulated or made with materials that reduce heat loss to the surroundings. The entire unit is mounted on a frame that provides strength, stability, and the required tilt angle for the collector. The tilt angle is normally selected according to the local latitude so that the solar radiation is received efficiently throughout the day.

5.1 Working Principle

The working principle of the solar dryer is based on the greenhouse effect and natural convection. Solar radiation enters through the transparent cover and strikes the absorber plate. The absorber plate heats up and transfers heat to the air flowing inside the collector. This heated air moves into the drying chamber due to the difference in density between hot and cool air. As the air passes over the wet material, it absorbs moisture from the product surface and removes it through the exhaust opening.

5.2 Advantages of the Design

The design is simple and can be built with low-cost materials. It requires no electricity or fuel for basic operation. The system gives better product quality than open drying because it reduces contamination from dust, insects, and animals. It also provides more uniform drying and faster moisture removal. Because of its small size and simple operation, it is suitable for farmers, small businesses, and household use.

5.3 Limitations of the Design

The performance of the solar dryer depends on weather conditions and sunlight availability. On cloudy or rainy days, drying efficiency may reduce. The system usually works best during daytime, so additional storage or backup heat may be needed for round-the-clock operation. Drying capacity is also limited in small prototypes. If the tray loading is not uniform, some parts of the material may dry faster than others. Proper design and operation are therefore important for achieving good results.

5.4 Conclusion of Process

The solar dryer works by converting solar energy into heat, passing the heated air through the drying chamber, and removing moisture from the agricultural product through natural airflow. Its design is simple, economical, and suitable for small-scale food preservation. The process improves product quality and reduces post-harvest losses compared to traditional open sun drying. For an engineering project, this system is a practical example of renewable energy application in agriculture.

5.5 Block / Diagram of Project

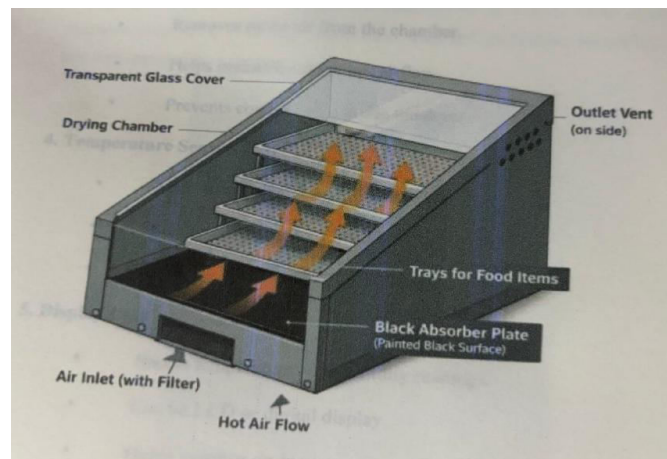


Fig -1: Solar Dryer

Solar drying is one of the most effective methods of preserving agricultural products using renewable energy. A solar dryer is a device that uses heat energy from sunlight to remove moisture from food materials like fruits, vegetables, grains, and spices.

Compared to traditional open sun drying, solar dryers provide faster drying, better quality, and protection from dust, insects, and rain.

The construction of a solar dryer is simple and cost-effective. It mainly consists of a solar collector, drying chamber, trays, and airflow system. The system is designed in such a way that sunlight is absorbed, converted into heat, and circulated inside the dryer to remove moisture.

This project focuses on the design and construction of solar dryer using locally available materials. It is widely used in rural areas and small-scale industries due to its low cost and eco-friendly nature.

VI. RESULTS

The performance of the solar dryer is generally judged by temperature increase, humidity reduction, drying time, and final moisture content. During operation, the temperature inside the drying chamber becomes higher than the surrounding air, which creates the required condition for moisture evaporation. As the hot air passes over the product, the moisture slowly leaves the material and escapes through the outlet. This continuous movement of warm air improves the drying rate.

VII. APPLICATIONS

The solar dryer has many practical applications in agriculture, food processing, and small-scale industries. It is mainly used for drying fruits such as mango, banana, papaya, and grapes. It is also suitable for vegetables like onion, tomato, chilli, and leafy vegetables. Spices such as turmeric, coriander, cumin, and ginger can also be dried using this system. Herbs and medicinal plants benefit as well because the dryer helps preserve color, aroma, and quality.

In rural and farming communities, the solar dryer can be used by individual farmers or self-help groups to preserve surplus produce. This helps them sell products later when market prices are better. It also supports value addition because dried products can be packed and sold as semi-processed goods. This creates additional income opportunities for small growers.

The project can also be used in fish drying, seed drying, and other agricultural preservation tasks. In small food industries, the dryer can help in drying raw materials before packaging or storage. It can even be adapted for non-food applications where low-temperature drying is required. The flexibility of the system makes it useful across different sectors.

VIII. CONCLUSION

The final outcome of the project is a working solar-powered drying system that can be used for small-scale preservation of agricultural products. It proves that solar energy can be successfully applied for food drying in a simple and practical way. The project also shows that a low-cost design can provide meaningful benefits to farmers and small businesses.

The solar dryer project has successfully demonstrated a simple, low-cost, and eco-friendly method for drying agricultural products using solar energy. It provides an effective alternative to open sun drying by improving hygiene, reducing drying time, and protecting the material from dust, insects, and weather disturbances. The project also helps in preserving the color, quality, and shelf life of the dried product, which makes it more suitable for storage and sale.

IX. FUTURE SCOPE

The future scope of the solar dryer project is very promising because the basic design can be improved in many ways to increase efficiency, capacity, and usability. One major improvement can be the addition of a fan system for forced convection, which would increase airflow inside the dryer and reduce drying time further. Another useful upgrade is the use of temperature and humidity control so that the drying process becomes more accurate and consistent. The system can also be made more advanced by adding a solar panel, battery, and controller to create a hybrid solar dryer. In this arrangement, the dryer can work even when sunlight is weak, and small electrical parts such as fans, sensors, or a digital display can be powered easily. This would make the dryer more suitable for day-and-night operation and improve performance during cloudy weather.

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