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A Comprehensive Study On The Design, Development & Performance Analysis Of A Portable Multipurpose Solar Dryer

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ABSTRACT

Agricultural produce drying is a critical step in preserving food and reducing post-harvest losses. The drying methods often rely on fossil fuels, making them costly and environmentally harmful. To address these issues, a multipurpose solar dryer is designed specifically for agricultural purposes. This innovative system utilizes solar energy to efficiently dry various agricultural products, including fruits, vegetables, grains, and herbs. The design incorporates solar collectors, a heat exchanger, and a drying chamber, all powered by renewable energy sources. This solar dryer offers significant advantages such as reduced operating costs, minimal environmental impact, and improved product quality. Its versatility and adaptability make it a valuable tool for farmers in diverse geographical regions, aiding in the reduction of food waste and enhancing the sustainability of agricultural practices.

Experimental testing and performance evaluation demonstrate the effectiveness of the multipurpose solar dryer in reducing moisture content, preserving nutritional quality, and extending the shelf life of dried products. The results highlight the potential of solar drying technologies in sustainable agriculture and food processing industries, contributing to food security and economic development in rural communities. This paper underscores the potential of solar drying technologies in addressing food security challenges, especially in rural areas where post-harvest losses are prevalent. By harnessing renewable energy sources like solar power, the solar dryer not only contributes to sustainable agricultural practices but also aligns with global efforts to mitigate climate change. Overall, the multipurpose solar dryer offers a viable solution for improving food preservation, reducing waste, and promoting economic resilience in agricultural sector.
Keywords: Solar Dryer, Multipurpose, Portable, Design, Drying, Collector & Heat exchanger.

1. INTRODUCTION

The construction of a solar dryer offers nutmeg and other food crops dryers a cutting-edge and environmentally friendly substitute. With the help of solar dryers, you can create a controlled drying atmosphere using the sun's abundant energy. These sun-powered dryers can efficiently dry nutmeg while reducing the hazards connected with conventional drying techniques. The greatly shortened drying period is one of the main benefits of food crops drying using a solar dryer. Solar dryers can speed up the drying process in comparison to sun drying, which can take several days. This means that production can happen more efficiently and with faster turnaround times.

These constraints are addressed by the development of portable solar dryers, which use solar energy that is renewable to provide a regulated drying atmosphere. Typically, these dryers are made up of a drying chamber, ventilation system, solar collector, and control systems that maximize humidity, temperature, and airflow for effective drying. They are more affordable and environmentally friendly than traditional energy sources since they make use of solar radiation to lessen their dependency on it.

The applications of portable solar dryers span various sectors, including agriculture, food processing, and small-scale industries. Farmers can use them to dry crops like fruits, vegetables, grains, and herbs, thereby reducing post-harvest losses and increasing marketable yield. Food processors can maintain product quality during drying, ensuring consistency and meeting industry standards. Additionally, in remote or off-grid areas, these dryers offer self-sufficiency in food preservation, promoting food security and economic stability. The greatly shortened drying period is one of the main benefits of nutmeg drying using a solar dryer. Solar dryers can speed up the drying process in comparison to sun drying, which can take several days. This means that production can happen more efficiently and with faster turnaround times. Additionally, sun dryers help to raise the general standard of dried nutmeg. The carefully regulated temperature and humidity levels in the controlled environment are essential for maintaining the spice's flavor, fragrance, and nutritional value. As a result, the finished product is of a higher caliber and satisfies customer and industry standards.

2. LITERATURE SURVEY

In order to improve the utilization of solar energy for food drying, this paper uses solar dryers to address the shortcomings of open sun drying. It highlights how popular Thermal Energy Storage (TES) systems are for enhancing dryer performance, particularly when combined with readily available and moderately priced naturally occurring energy storage materials [1]. Inadequate preservation techniques and storage provisions can degrade agricultural product quality, leading to postharvest losses. Advanced methods, such as solar drying, combat this issue. Solar dryers, including the Indirect Type (ITSD), offer diverse capacities and designs for agricultural drying. This study aims to explore ITSD's features, types, and performance-enhancing techniques. It provides a classification of solar dryers, discusses heat transfer enhancement, pre-treatment's impact, and evaluates ITSD's payback period and cost. Key findings emphasize parameters influencing drying rates, with air temperature and velocity being most significant. Passive solar dryers are simpler to construct, and pre-treated foods exhibit high drying rates with preserved quality [2].This paper focus on improving the performance of a portable greenhouse solar dryer for drying onion slices. Four modes were tested: AGHSD, AGHSD with recirculating fans (AGHSD @ circulating fans), AGHSD with recirculating fans and an Evacuated Tube-type solar Air Heater (AGHSD @ circulating fans+ ETAH), and AGHSD with recirculating fans, Evacuated Tube-type solar Air Heater, and an air flow distribution system (AGHSD@ circulating fans + ETAH + air flow system). The last mode showed the best results, reducing moisture ratio to 5.32% in one day, with higher heat utilization factor, coefficient of energy, heat gain, and thermal efficiency compared to other modes [3]. Traditional drying methods, such as burning wood and fossil fuels, are costly and environmentally harmful. With fossil fuels in short supply, researchers have turned to solar drying as a faster, more efficient, and eco friendly alternative. This paper provides an overview of recent developments in solar dryer technology, including those equipped with thermal storage for enhanced efficiency during offsunshine hours and solar thermal reservoirs to address sunshine irregularity. It reviews various types of solar dryers according to product, such as chili, turmeric, peanut, grapes, copra, and fish, and discusses potential future improvements. Performance evaluation parameters include moisture reduction, moisture removal rate, and efficiency. Despite its benefits, solar dryers have not seen widespread commercial use due to high initial investment, long payback periods, and intermittent application. Nevertheless, solar dryers offer significant advantages, including reduced fossil fuel usage, improved product quality, and minimal environmental impact, making them ideal for food preservation in rural areas. This study serves as a valuable resource for farmers and researchers interested in designing new types of solar dryers for various products. [4} Maize (zea-mays) falls into the cereal group of food crops, used for food by both humans and animals. At harvest, maize usually contains too much moisture (about 20%-25%) which is a favourable environment for the growth of moulds (fungi) and insects that normally cause grain damage. In order to avoid this, drying of the maize must be done to reduce the moisture content to about (11.8%-13%) for safe year-round storage. Research carried out on open sun drying method found out that the existing method was very tedious, time wasting, wastage, in terms of produce and consequently having a very low hygienic level. The direct exposure to sunlight, or more precisely .ultraviolet radiation, can greatly reduce the level of nutrients such as vitamins in the dried product. As a solution to these problems, an idea was created and a Distribution Passive Solar Energy Maize Dryer was designed, fabricated, and tested. The aim of this research work therefore, is to design, construct and test an Azimuth Probe Maize solar Dryer to dry at least 20kg of maize [5].Drying, particularly of crops, is an important human activity and globally the use of dried products is widespread. For preservation, quality improvement and processing purposes, moisture must often be removed from both organic and inorganic materials. Sun drying and mechanical dehydration using fossil fuels are the most common technologies used. Sun drying is a low-cost drying method but the final quality is variable, while mechanical dehydration is an energy intensive process and contributes substantially to energy use and greenhouse gas emissions. Multipurpose dryer and heater, we introduce through our project is useful for drying grounds and cardamom wherever moisture contents. This is also used as a room heater. Now a day, rain fall occurs at any time. At that time, the dryer is used to remove the moisture contents in the ground. In our project, the Multi-purpose dryer and heater consists of two main parts such as heating element and blower. The blower is used to passing the hot air to the ground, so that the moisture contents in the ground was removed. The size of our project is also portable [6]. This paper gives an overview of different types of solar dryers used for drying agricultural products [7]. The idea underlying the design of type of solar rice dryer described in this paper is to heat a body of air in sun and then let this air pass through a flat bed of rice by natural convection [8]. A low cost solar dryer (LCSD) is designed for drying fish and its advantages are listed when compared to existing mechanical dryers [9]. This paper presents developments and potentials 1 of solar drying technologies for drying of fruits, vegetables, spices, medicinal plants, and fish. [10]

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3. METHODOLOGY

3.1 Design

3.1.1 Research & Development

A comprehensive research on existing solar dryer technologies, including their design, fabrication and its limitations was conducted.. This helped to identify key areas for improvement and innovation. Research and development on portable solar dryers is a multifaceted endeavor encompassing various aspects to enhance efficiency, durability, and affordability. This involves optimizing the design of solar collectors to efficiently capture and convert sunlight into heat energy, while also focusing on airflow management within the drying chamber to ensure uniform drying and prevent moisture-related issues.

Material selection is crucial for constructing durable and cost-effective dryers, often involving lightweight yet robust materials resistant to outdoor conditions. Integration of automated controls enables precise regulation of drying parameters, reducing the need for constant monitoring. Additionally, the incorporation of energy storage systems and mobile connectivity features enhances flexibility and reliability, allowing for operation even in areas with intermittent sunlight and facilitating remote monitoring and control.

Collaboration with stakeholders in agriculture, food processing, and renewable energy sectors ensures that portable solar dryers meet the practical needs of end-users while contributing to sustainable development goals. In a portable solar dryer with a recirculation mechanism, airflow management is crucial for efficient drying. The process begins with fresh air entering through the inlet fan to drying chamber. As this air flows into the system, it passes through a heat exchanger or collector, where it absorbs solar energy. This heating stage elevates the temperature of the air, enhancing its capacity to absorb moisture from the material within the drying chamber. Once heated, the air is directed into the drying chamber, where it interacts with the material undergoing drying. During this phase, the warm air extracts moisture from the material, facilitating the drying process. Instead of being expelled from the system, the moist air is re circulated back into the drying chamber. This recirculation can be facilitated by fans or through natural convection, ensuring a continuous flow of air throughout the drying process. As the moist air cycles through the drying chamber, it continues to absorb moisture from the material, gradually reducing its moisture content. Depending on the dryer's design, the moisture may be removed from the air through desorption using a desiccant or condensed and collected for disposal. This recirculation mechanism allows for a continuous drying process, maintaining a controlled environment within the dryer and maximizing efficiency. By integrating a recirculation mechanism, portable solar dryers can achieve optimal drying outcomes while conserving energy. This approach ensures that the drying process is both effective and sustainable, making it suitable for various applications where portable drying solutions are needed.

3.1.2 Humidity control:

The dryer has mechanisms to detect and to regulate humidity levels inside the drying chamber to prevent over-drying or spoilage of the product. Research and development on portable solar dryers is a multifaceted endeavor encompassing various aspects to enhance efficiency, durability, and affordability. This involves optimizing the design of solar collectors to efficiently capture and convert sunlight into heat energy, while also focusing on airflow management within the drying chamber to ensure uniform drying and prevent moisture-related issues. Material selection is crucial for constructing durable and cost-effective dryers, often involving lightweight yet robust materials resistant to outdoor conditions. Integration of automated controls enables precise regulation of drying parameters, reducing the need for constant monitoring. Additionally, the incorporation of energy storage systems and mobile connectivity features enhances flexibility and reliability, allowing for operation even in areas with intermittent sunlight and facilitating remote monitoring and control. Collaboration with stakeholders in agriculture, food processing, and renewable energy sectors ensures that portable solar dryers meet the practical needs of end- users while contributing to sustainable development goals. Insulation is another method that recirculating solar dryers may use to regulate humidity in addition to the previously stated ones. Insulation lowers the chance of condensation and moisture buildup by assisting in the stabilization of temperature inside the drying chamber. Insulation helps keep the drying environment stable and prevents heat loss, which is especially crucial at night or during high humidity times. Moreover, some sophisticated recirculation-style solar dryers combine energy recovery techniques with humidity control systems. By capturing and reusing the heat and moisture released during the drying process, these systems save energy usage and maximize drying effectiveness. Heat exchangers have the capability to retrieve heat from exhaust air and transmit it to incoming air, so preheating it prior to its entry into the drying chamber. In a similar vein, moisture condensation systems reduce water waste and improve sustainability by collecting water vapor from exhaust air and recycling it for irrigation or other uses. Furthermore, humidity control in recirculation-type solar dryers can be influenced by the architecture of the drying chamber itself. Designers can ensure consistent drying throughout the drying cycle by promoting efficient moisture removal and distribution through the optimization of chamber geometry and airflow patterns. Recirculation-type solar dryers with numerous humidity control mechanisms enable for exact manipulation of drying conditions, maximizing quality, productivity, and energy efficiency. This all-encompassing strategy guarantees that the dryer can adjust to different environmental circumstances and efficiently treat a variety of materials with little assistance from the user.

3.1.3 Flow of air required:

Flow rate of air can be determined by assuming the expected time in which drying must be completed t and the volume of air as calculated above V and Flow Rate $Q=V/t$. The size of the drying chamber, the kind of material being dried, and the intended drying rate are some of the variables that determine how much airflow is needed in a recirculation-type solar dryer. In general, there should be enough airflow to effectively remove moisture from the drying chamber and keep the drying conditions constant. Engineers usually take into account the moisture content of the item being dried, the moisture content of the incoming air, and the intended ultimate moisture content when calculating the airflow rate. In order to prevent over drying or quality deterioration, the airflow rate needs to be high enough to remove the moisture released from the drying material. In actuality, recirculation-type solar dryers' airflow speeds might vary from several hundred to several thousand cubic feet per minute (CFM), depending on the specific application. For example, delicate products may require lower airflow rates to prevent damage, while bulkier or denser materials may require higher airflow rates to ensure thorough drying.

3.1.4 Area of the solar heater/collector:.

A computer-aided model (CAD) was created based on the preliminary design calculation, illustrating the fundamental mechanism. The frame of solar dryer is made up of PVC laminated sheets and is made into a box type and a glass covers the top of the box which then traps the heat radiation that has entered the drying chamber .There are trays inside the drying chamber where the food crops can be spread to dry .To ensure moisture content from the food crops is removed a forced recirculating mechanism is installed in our solar dryer .We need to know the mass m of water to evaporate from the mass of the product, the specific latent heat L of vaporization of this water, and the amount Q needed to gather enough solar energy to dry the product.

3.2 MATERIALS USED

Table-1

COMPONENTS	**QUANTITY**
Solar panel	1
PVC Laminated sheet	1
Transparent glass	1
Wheel	4
Fan	2
Sawdust/Glass wool	3kg
Thermocouple	2
Pvc Pipe	4 joints
Aluminium channel	3kg

3.3 FABRICATION

Workshop tools such as table saw, drill machine, file, hammer, spray gun, hacksaw etc. were used in the fabrication process of the solar dryer. The wiring of the electric components was done as per the instructions of each manufacturer. The controls and humidity monitor are placed on the outer side of the solar dryer in a compact form to make our solar dryer user friendly. Exhaust fan and blowing fan are connected to solar panel placed on the outer side of the solar dryer which utilizes the solar energy for its working. The humidity sensor and monitor are powered by a lithium ion battery. Fabricating a recirculation type solar dryer involves several key steps to ensure its effectiveness and efficiency:

Design Planning: The design of the solar dryer is done considering factors such as the intended application, material to be dried, available space, and environmental conditions. Further the size, shape, and airflow system of the dryer is decided. A CAD model of the body of the drying chamber is then made.

Material Selection: Choose appropriate materials for the construction of the dryer. The materials should be durable, weather-resistant, and have good thermal properties to maximize heat absorption and retention. PVC laminated sheets are chosen for this, which have good thermal properties and are of low cost.

Construction of Drying Chamber: The drying chamber is constructed using insulating materials such as PVC laminated sheets and aluminum channels to minimize heat loss.

Installation of Airflow System: A recirculation airflow system comprising fans or natural convection channels to circulate air is installed within the dryer. Integrate ducts or channels to guide airflow efficiently through the drying chamber. Choose a recirculation system that fits the size and design of your portable solar dryer. This system typically includes a pump, pipes, and possibly a filter. Determine where you want to place the recirculation pipe. It should ideally be positioned to distribute heated air evenly throughout the dryer. If necessary, drill holes in the dryer to accommodate the recirculation pipe. Make sure these holes are appropriately sized and positioned to ensure smooth airflow. If the recirculation system includes filters, install them as directed to ensure the air circulating through the dryer remains clean and free of debris. Before using the solar dryer with the recirculation pipe, test the system to ensure everything is working correctly. Check for any leaks, and make adjustments as needed. Regularly monitor the recirculation system to ensure it's functioning properly. Clean or replace filters as necessary, and address any issues promptly to keep the solar dryer operating efficiently

Incorporation of Solar Collectors: A solar collectors or heat exchanger is installed to harness solar energy for heating the air. Position the collectors optimally to maximize sunlight exposure throughout the day. Choose solar panels that can generate enough power to run the blower fan and exhaust fan. The factors such as the fan's power requirements and the amount of sunlight available in the location where it will be used should be considered. The mounting of the solar panels onto the blower fan and exhaust fan is then performed. This could involve attaching them to the fan housing or creating a separate mounting system that positions the panels for optimal sunlight exposure. The wiring is done to connect the solar panels to the both fan's power supply. This may involve routing the wires through the fan housing and connecting them to the fan motor or controller. To prevent overcharging and damage to the fan's electrical components, a charge controller may be installed between the solar panels and the fan. This device regulates the voltage and current from the solar panels to ensure safe operation. Clean the solar panels regularly to ensure maximum sunlight absorption. The wiring and connections are checked periodically for signs of wear or damage, and make any necessary repairs or replacements as needed.

Integration of Moisture Removal Mechanism: A mechanism for removing moisture from the re circulated air, such as desiccant beds or condensation traps, to maintain low humidity levels within the dryer. Integrating a moisture removal mechanism into the re circulating pipe of a solar dryer can significantly enhance its efficiency in drying various materials. The moisture removal system is placed in the designated location along the re circulating pipe. Ensure it is securely mounted and properly connected to the pipe to prevent air leaks. Silica or charcoal can be placed inside the mesh attached to the re circulating pipe which absorbs the moisture from the air passing through it. This constitutes a moisture removal mechanism.

Testing and Optimization: Tests should be conducted to evaluate the performance of the solar dryer under various conditions. Optimize airflow rates, temperature settings, and other parameters to achieve efficient drying

Monitoring and Maintenance: Regularly monitor the operation of the solar dryer to ensure optimal performance. Clean the ducts, collectors, and drying chamber periodically to prevent blockages and maintain efficiency.

Scaling Up if Necessary: Depending on the intended scale of operation, consider scaling up the fabrication process to build multiple units or larger dryers to meet demand. By following these steps and paying attention to detail during the fabrication process, you can create a functional and efficient recirculation type solar dryer suitable for various drying applications

3.4 COMPONENTS

Components include Solar panel, Lithium Ion battery, Transparent glass, Exhaust and blower Fan,PVC laminated sheets, PVC pipe (Recirculating pipe), DHT 11, LCD display, 12E module, Arduino UNO

3.4.1 Solar Panel

A 20-watt solar panel represents a compact yet efficient solution for generating renewable energy. With advancements in photovoltaic technology, these panels are increasingly lightweight, portable, and cost-effective, making them suitable for a variety of applications. Whether used in off-grid settings for charging small electronic devices like smartphones and tablets, powering outdoor lighting systems, or supporting remote monitoring equipment, a 20-watt solar panel provides a reliable source of clean energy. Its modest size makes it ideal for installations where space is limited, such as on RVs, boats, or small residential rooftops. Additionally, these panels can be combined with energy storage systems like batteries to provide continuous power even when sunlight is unavailable, further enhancing their versatility and usability. As the demand for sustainable energy solutions continues to grow, 20-watt solar panels offer an accessible and eco- friendly option for individuals and businesses seeking to reduce their carbon footprint and reliance on traditional fossil fuels.

3.4.2 Lithium Ion Battery

A lithium-ion battery is a rechargeable energy storage device that utilizes lithium ions as the main carrier of electrical charge. It is widely used in various applications ranging from consumer electronics to electric vehicles due to its high energy density, long cycle life, and relatively low self-discharge rate. The basic structure of a lithium-ion battery consists of positive and negative electrodes (anode and cathode) separated by an electrolyte solution, typically a lithium salt dissolved in an organic solvent. During charging, lithium ions move from the positive electrode (cathode) to the negative electrode (anode) through the electrolyte, where they are stored in the anode material (usually graphite). During discharging, the ions flow back from the anode to the cathode, generating electrical energy that can power devices or vehicles. The use of lithium-ion batteries has revolutionized portable electronics and transportation by providing lightweight, high-performance energy storage solutions with reduced environmental impact compared to traditional battery chemistries. Ongoing research and development efforts continue to improve the performance, safety, and cost-effectiveness of lithium-ion batteries, making them an essential component of modern technology and clean energy initiatives

3.4.3 Transparent Glass

Transparent glass is used to trap solar radiation inside the solar dryer. This helps in increasing internal temperature inside the solar dryer. Solar radiation can enter the drying room through transparent glass. Light and heat are two forms of energy that are carried by solar radiation. The sun's rays are absorbed by the chamber's floor, walls, and drying objects once inside. They get heated as a result of this absorption. The heated surfaces within the chamber emit heat energy known as infrared radiation, which is repelled by transparent glass. This means that while solar radiation can enter the chamber easily, the heat generated inside is effectively trapped, creating a greenhouse effect. The trapped heat accelerates the drying process by maintaining a consistently warm environment within the dryer. This helps to remove moisture from the materials being dried more efficiently. Even on chilly days or in periods of indirect sunshine, solar dryers can function efficiently because they use clear glass to trap heat. This can drastically cut down on drying time and energy consumption while also improving the process' overall efficiency. While retaining heat helps with drying, it's crucial to have enough airflow to avoid overheating and preserve ideal drying conditions. It is possible to include ventilation systems in the design to control airflow and stop the accumulation of moisture. All things considered, using transparent glass in solar dryers is a straightforward but efficient method of utilizing solar energy for drying while increasing productivity and lowering dependency on outside energy sources.

3.4.4 Exhaust Blower Fan

In a solar dryer, a blower fan facilitates air circulation, hastening the drying process. This is how it usually operates. The sun's heat is absorbed by the solar dryer, raising the inside temperature of the dryer chamber. The dryer chamber’s interior or outside ambient air is drawn in by the blower fan. The temperature of the solar-heated chamber rises when heat is absorbed by the entering air. As the substance (such as fruits, vegetables, or grains) dries out, the warm air takes up the moisture and carries it away the dryer's ducts or vents are used to release the moist air

An exhaust fan in a solar dryer facilitates air circulation throughout the dryer, which drives moisture out of the drying chamber. Dryer air can replace the damp air and carry on the drying process as it is expelled outside by the exhaust fan. The constant circulation inside the dryer creates a uniform environment, which helps to expedite the drying process. The exhaust fan plays a crucial role in this mechanism. It helps to draw the moisture air from the drying chamber and expel it out of the system. By doing so, it creates a pressure gradient within the chamber, encouraging hot fresh air to enter. This moisture air gets heated by the solar radiation absorbed by the transparent glass or other heat-absorbing materials such as silica gel or charcoal used in the recirculation pipe of the dryer.

3.4.5 PVC Laminated Sheet

This is a useful and economical way to use solar dryer chambers made of PVC laminated sheets. It is made of a sturdy, lightweight material that is resistant to weather. Furthermore, PVC laminated sheets are simple to construct and modify to the precise measurements required for the solar dryer chamber. Additionally, they act as insulation, which aids in preserving the chamber's ideal temperature for the effective drying of other materials or agricultural products. In general, building solar dryer chambers with this option is a wise decision. This makes them suitable for outdoor applications like solar dryers, where they will be exposed to the elements. The lamination process adds a protective waterproof layer to the PVC sheets, helping to prevent water ingress into the solar dryer. This is crucial for maintaining the integrity of the dryer and protecting the products being dried from moisture-related damage. PVC laminated sheets are lightweight, making them ideal for portable solar dryers. Their low weight makes transportation and setup easier, allowing for greater mobility and flexibility in deploying the dryer in different locations as needed. PVC laminated sheets are generally more affordable compared to other materials used for constructing solar dryers, such as glass or polycarbonate. This can help reduce the overall cost of manufacturing portable solar dryers, making them more accessible to small-scale farmers or communities with limited resources. PVC laminated sheets can be easily cut and shaped to fit the specific design requirements of the solar dryer. This flexibility allows for customization based on factors such as size, shape, and configuration, ensuring optimal performance and efficiency.

3.4.6 PVC Pipe (Re circulating Pipe)

A popular and useful method for air recirculation in solar dryers is the use of PVC pipes. PVC pipes are appropriate for outdoor application since they are robust, lightweight, and corrosion- resistant. You can establish a system for circulating air inside the solar dryer chamber by adding PVC pipes. This will help to disperse heat evenly and encourage effective drying of the materials inside. Furthermore, PVC pipes are easy to work with and reasonably priced, providing versatile design possibilities to maximize airflow within the solar dryer. PVC pipes are generally more affordable compared to other materials like metal or copper. This makes them a cost-effective option, especially for small-scale solar dryer setups or in areas with budget constraints. PVC pipes are highly resistant to corrosion, even in humid or moist environments. This quality ensures the longevity of the recirculation system, especially when it's exposed to the moisture generated during the drying process.

Using moisture-absorbing materials inside recirculating PVC pipes of a solar dryer can enhance its performance by helping to control humidity levels within the drying chamber. Moisture-absorbing materials placed inside the PVC pipes can help remove excess moisture from the air circulating within the solar dryer's system. This is particularly useful in humid conditions where moisture removal is critical for efficient drying. The moisture-absorbing materials can be placed strategically inside the PVC pipes along the recirculation path. For example, silica gel or charcoal can be inserted into the pipes at intervals to ensure uniform moisture absorption throughout the system. Over time, the moisture-absorbing materials will become saturated with moisture. It's essential to periodically regenerate or replace these materials to maintain their effectiveness. This moisture absorbing materials have to be changed or replaced at regular intervals of time.

3.4.7 DHT 11 Temperature Sensor

A thermistor is used to detect temperature, and a humidity sensing component powers of the DHT11 temperature sensor. A moisture-absorbing polymer that is included in the sensor modifies its electrical resistance in response to variations in humidity levels. An internal heater periodically heats this humidity sensing device to remove any absorbed moisture. Relative humidity can be determined simultaneously by measuring the capacitance shift brought on by the evaporated moisture using a capacitive humidity sensor. The combination of the humidity sensing component and the thermistor enables accurate measurements of both temperature and humidity. It's fascinating how it utilizes different elements to achieve this functionality.

3.4.8 LCD Display

LCD display attached to the chamber shows the temperature and humidity inside the drying chamber. Users may quickly view the humidity and temperature within the drying chamber thanks to the LCD display. They can keep an eye on the drying process's development and adjust as needed thanks to this real-time input. Users may make sure that the drying conditions stay within the ideal range for the particular object being dried by taking precise measurements of the temperature and humidity. This contributes to the production of higher-quality dried goods by preventing over- or under-drying and enables modifications to be made as needed. The information shown on the LCD can be used by users to maximize the solar dryer's performance. For instance, they can modify ventilation or circulation to encourage moisture removal if the humidity is too high. Similarly, if the temperature is too low, they can take steps to increase heat input for faster drying. LCD displays provide a user-friendly interface for accessing information about drying conditions. They can be equipped with buttons or touch screens for easy navigation and configuration of settings.

3.4.9 Arduino UNO

The Arduino Uno is a popular microcontroller board widely used for prototyping and DIY electronics. Microcontroller: The Arduino Uno is based on the ATmega328P microcontroller, which is the brain of the board. This microcontroller has built-in memory, input/output pins, timers,and other features.

Input/Output Pins: The Uno has a set of digital and analog input/output pins that can be used to connect various sensors, actuators, and other components. These pins can be programmed to read digital or analog signals and to output digital signals to control external devices.

USB Interface: It has a built-in USB interface that allows it to be easily connected to a computer for programming and communication.

Power Supply: The Uno can be powered via USB connection or an external power supply (e.g., battery or DC adapter). It also has a built-in voltage regulator to provide stable power to the board and connected components.

Programming Environment: Arduino Uno is programmed using the Arduino IDE (Integrated Development Environment), which is based on the C and C++ programming languages. It has a simple and easy-to-use interface, making it accessible for beginners and experienced developers alike.

Open Source: Arduino Uno is part of the Arduino ecosystem, which is open-source hardware and software. This means the design files, schematics, and software are freely available for anyone to use, modify, and distribute.

Overall, the Arduino Uno is a versatile and beginner-friendly platform that allows users to create a wide range of electronic projects, from simple blinking LED experiments to complex robotics and IOT applications.

4. EXPERIMENTAL SETUP

4.1 Working Principle

A solar dryer operates by harnessing solar energy to heat the air within a drying chamber. This process begins with the absorption of sunlight by a collector, typically made of glass, which converts the sunlight into heat energy. The heated air is then circulated throughout the drying chamber, with the assistance of fans, there will be an blower fan and an exhaust fan. n a solar dryer with a recirculating mechanism, both exhaust and blower fans play crucial roles in ensuring efficient airflow and temperature regulation within the drying chamber. The combination of the blower fan and exhaust fan creates a recirculating airflow pattern within the solar dryer. This recirculating mechanism ensures uniform drying conditions throughout the chamber and prevents the buildup of humidity, enhancing the efficiency and effectiveness of the drying process. Agricultural products to be dried are placed on trays or racks inside the chamber, allowing the heated air to pass over and absorb moisture from the products. And then this air containing moisture content is passed through a recirculating pipe which contains moisture absorbing materials like charcoal/silica gel absorbs the moisture content. And the conditioned dry air then enters into the drying chamber with the help of blowing fan. And this cycle of process continues till the required level of dryness is achieved. This solar dryer has a mechanism to monitor the humidity and temperature level inside the drying chamber which gives the value of humidity and temperature inside the drying chamber in regular intervals. Once the desired moisture content is removed and dryness is obtained, the dried products can be removed for storage or further processing. Overall, solar dryers provide a sustainable and eco-friendly method for preserving agricultural products by utilizing renewable solar energy.

The working principle of a portable solar dryer with recirculation type mechanism involves harnessing solar energy to create a controlled environment for drying agricultural products or other materials. Here's how it typically operates:

Solar Energy Absorption: The solar dryer consists of a transparent cover or surface, often made of transparent glass, which allows sunlight to enter the drying chamber. This transparent cover absorbs solar radiation, converting it into heat energy. There will be a solar collector/panel attached to the drying chamber to absorb the solar energy and convert it into mechanical energy and stored to a battery for the working of exhaust and blower fans which constitutes the recirculation mechanism inside the drying chamber. Heat Generation: As sunlight enters the drying chamber through the transparent glass, it heats up the air and surfaces inside. This solar energy absorption raises the temperature within the chamber, creating a warm environment conducive to drying. Solar panel which is attached to drying chamber absorbs the solar energy and convert it into mechanical energy and for the workingof fans.

Air Circulation: The fresh air is typically heated by the solar radiation absorbed by the chamber's surfaces, blower fan further increasing its temperature. An exhaust fan or which is fixed at downside of the drying chamber expels the moisture-laden air from the drying chamber to the inlet fan which is the blower fan. Then the moisture-laden air sucked out by the exhaust fan is passed through the recirculation pipe. The moisture is absorbed by the moisture absorbing particles such as silica gel /charcoal present inside the recirculation pipe and straightly given to blower fan. By removing moist air from the drying chamber, the exhaust mechanism helps maintain low humidity levels inside the chamber, which is essential for efficient drying.
Recirculation System: Inside the drying chamber, a recirculation system is employed to absorb the moisture content from the air and also to maintain a continuous flow of heated air. This system typically consists of recirculating pipe or channels through which the moisture-ladent air is circulated and fresh hot air is released. The recirculating air helps distribute heat evenly throughout the chamber and promotes the drying process

5. RESULT & DISUSSION

5.1 Testing of humidity and temperature of air at drying chamber

Moisture content in the air within the drying chamber is tested in regular interval with the help of DHT 11 sensor which displays humidity within the air in a LCD monitor. Here we use DHT 11 sensor for measuring both humidity and temperature. Ensuring that the sensors are accurate and calibrated, start the testing process and monitor the humidity and temperature readings displayed by the sensors in real-time in the LCD monitor. Record the data at regular intervals to track any fluctuations or trends over time.. Analysis of the collected data reveals trends and fluctuations, aiding in the identification of potential issues and adjustments needed for optimization. Adjustments may involve modifying airflow, insulation, or solar collector settings. Subsequent validation testing verifies the effectiveness of adjustments, with ongoing monitoring to maintain consistent performance. Comprehensive documentation of testing procedures, results, and adjustments serves as a valuable resource for troubleshooting and future optimization efforts. Through this systematic approach, one can ensure that the recirculating type solar dryer operates efficiently, facilitating effective drying processes. Fluctuations in humidity and temperature may indicate inefficiencies or areas for improvement, prompting adjustments to various parameters such as airflow, insulation, or solar collector positioning. Subsequent validation testing ensures that these adjustments yield the desired results, confirming the dryer's optimized performance. Moreover, ongoing monitoring and documentation of testing procedures, results, and adjustments are paramount for maintaining consistency and reliability in drying operations. By adhering to this meticulous testing process, manufacturers and operators can fine-tune their recirculation type solar dryers to achieve optimal drying conditions, thereby enhancing product quality, reduce energy consumption, and maximizing overall efficiency. The solar energy stored in the battery is used to provide power for the working of exhaust and blower fans.

5.2 Testing the Battery charging system

A 2v SLA battery in conjunction with a 20 watt solar panel is used. The solar panel provides around 22v at peak solar radiation. The fluctuating solar voltage is made constant to the battery and the fans run properly without reducing the battery voltage. This system makes it totally passive. Once it's confirmed that the solar panels are generating adequate power, attention can turn to the battery charging system itself. Testing should involve monitoring the charging voltage and current to ensure they are within safe and optimal ranges for the batteries being used. Additionally, it's important to check the charging system's efficiency, ensuring that the batteries are being charged as quickly and efficiently as possible.Testing the power supply to the blower and exhaust fan comes next, once the batteries have been verified to be charged appropriately. This entails attaching the batteries to the proper parts and keeping an eye on the voltage and current to make sure the parts are getting the power they need to function. Simulating a range of operational situations, such as variable sunshine levels and demands on the blower and exhaust fan, is essential during testing for the solar dryer. This makes it possible for the battery charging mechanism to adjust to shifting circumstances and keep the dryer's internal parts powered reliably. Throughout the testing process, data should be carefully recorded and analyzed to identify any issues or inefficiencies in the battery charging system. Any problems that arise should be addressed promptly to ensure the reliable operation of the portable solar dryer in real-world conditions. By thoroughly testing the battery charging system, manufacturers can ensure that their portable solar dryers are capable of providing consistent and efficient performance, even in remote or off-grid locations.Throughout the testing process, meticulous data collection and analysis are essential. Detailed records of voltage, current, and performance metrics should be logged to identify any anomalies or inefficiencies in the battery charging and power delivery systems. Any issues detected during testing should be promptly addressed through adjustments or optimization to ensure optimal performance and reliability of the portable solar dryer. Moreover, it's crucial to conduct field testing under real-world conditions to validate the system's performance in practical applications. Field testing provides valuable insights into the system's behavior in diverse environments and helps identify any operational challenges that may arise.By rigorously testing the battery charging system

6. CONCLUSION

A recognizable saving in drying time was obtained for the solar dryer compared with that of the natural sun drying. In addition, the food was completely protected from insects, dust and rain, and dried products were of good quality. They harness renewable solar energy, reducing reliance on conventional energy sources like electricity or gas, making themenvironmentally friendly.

A budget friendly solar drier was developed which is affordable to small scale farmers. Who cannot afford large scale dryer which utilizes fossil fuels for its function. That has the all the qualities of a large scale solar dryer. Once purchased, the operational costs are minimal since they utilize free solar energy. This can be particularly advantageous for small-scale farmers or individuals in remote areas with limited access to electricity.

Large variety of food crops can be dried using this solar dryer. And this solar dryer is not a single product specific solar dryer. This solar dryer has attached wheels which help to move this solar dryer anywhere. A re circulating mechanism is incorporated to maximize heat consumption, speed up the drying process, and reduce energy loss.The efficacy of the recirculating type portable solar dryer in expediting the drying process has been proved by its ability to remove moisture from a variety of materials with significant efficiency. Utilizing recirculating mechanisms and solar energy, it maximizes drying conditions, resulting in shorter drying times and higher-quality products.

This type of solar dryer offers several advantages, including its portability, which enables deployment in remote or off-grid locations where traditional drying methods may not be feasible. Additionally, its reliance on renewable solar energy makes it environmentally friendly and cost-effective in the long term. The recirculation feature enhances efficiency bymaximizing heat retention and airflow within the drying chamber.

Despite its strengths, there are areas where the portable recirculation type solar dryer can be further enhanced. For instance, optimizing the recirculation system to ensure uniform airflow distribution and heat transfer throughout the drying chamber could improve drying efficiency further.

7. REFERENCES

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