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INDUSTRIAL AND SOCIAL APPLICATION OF SOLAR DRYER FOR DRYING THE AGRICULTURAL PRODUCT

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Abstract
The Solar drying system utilizes solar energy and biomass energy to heat up air and to dry any food substance. Drying reduces wastage of agricultural produce and helps in preservation of agricultural produce. Based on the limitations of the natural sun drying such as exposure to direct sunlight, liability to pests and rodents lack of proper monitoring, and the escalated cost of the mechanical dryers, a solar-biomass hybrid dryer was therefore developed to cater for these limitations. This project presents the design and construction of a portable hybrid dryer, the dryer is composed of a solar drying chamber containing rack of three trays and biomass combustion chamber both being integrated together. Air is allowed through air inlet and is heated up in the solar chamber where it is utilized in drying (removing the moisture content from the food substance or agricultural product loaded). Drying is further continued using biomass energy in case of absence of solar energy and hence it is a solar and biomass-based hybrid dryer. The design was based on the geographical location which is Pune and meteorological data were obtained for proper design specification. Locally available materials were used for the construction, namely glass, mild steel metal bars, Acrylic sheets and Aluminum foil, Aluminum fabrication material for the trays.

Keywords: Solar dryer, forced circulation, thermal analysis, CFD analysis, IoT Circuit

I. Introduction

The purpose of this paper is to spotlight the issue of depleting conventional sources of energy and the importance of using nonconventional energy sources in the form of solar energy. It also provides the explanation for the key components used in the manufacture of the Forced Circulation Solar Dryer. At last, it explains the thermal analysis of collector along with the thermal losses occurred from the collector.

Need of Renewable Energy

The available resources of fossil fuels on the globe are fast depleting and there is every possibility of energy starvation to occur in coming future. The use of these resources is continuously adding hazardous pollutants to the environment, causing environmental pollution and almost made the ecological balance fragile. This situation has urged the search for alternative recourses which are environmentally friendly. Thus, renewable energy resources received prominent attention in recent years, as it is proven to be a viable alternative of conventional energy sources. Renewable energy can contribute to global climate change mitigation if it is produced in a sustainable manner. It is also assumed to play a critical role in nurturing the Indian economy as India has a large amount of renewable resources such as solar, wind, hydro and biomass. Solar energy is an infinite resource on the earth. Solar energy, which is available for free of cost in almost all parts of the world, is a non-polluting reservoir of fuel. According to Anandarajah and Gambhir, India receives solar energy equivalent to over 5000 trillion kWh/ year, which is far more than the total energy consumption of the country. The solar radiation reaches the earth's surface at a maximum flux density of about 1.0 kW/m^2 in a wavelength band between 0.3 and 2.5 μm which is a short-wave radiation in the visible spectrum. The direct irradiance received in a plane normal to the sun over the total solar spectrum is defined as direct normal irradiance (DNI). DNI represents the solar resource that can be used in various forms of concentrating solar technologies (CST), such as concentrating solar power (CSP) systems and concentrating photovoltaic (CPV) systems. Based on the data of National Renewable Energy Laboratory (NREL)

Solar Energy:

Solar energy is the energy derived from the sun through the form of solar radiation. Radiant light and heat from the sun, has been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar energy technologies include solar heating, solar photovoltaics, solar thermal electricity and solar architecture, which can make considerable contributions to solving some of the most urgent problems the world now faces. Solar energy is available in abundance and considered as the easiest and cleanest means of tapping renewable energy. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

Solar Dryer

Solar drying technology indeed emerged as a solution to address the challenges associated with open sun drying. While the exact timeline of its invention may vary, solar drying gained significant attention and development following the oil crisis in 1973. The crisis heightened interest in finding sustainable energy sources for various applications, including grain and fish drying, which led to the development of solar drying systems.

Direct Solar Dryers: Direct solar dryers are the simplest and most common type of solar dryers. They consist of an enclosed chamber with a transparent cover, which allows sunlight to enter and heat the drying material directly. The heated air inside the chamber removes moisture from the material, drying it. Direct solar dryers are suitable for drying crops, fruits, vegetables, and other agricultural products.

II. Literature

The information obtained from literature review papers is very helpful for designing, finalizing and specializing the sonal panel. The source of the review is collected or studied from journals, websites, and books.

Masnaji R. Nukulwar, Vinod B. Tungikar (2021)-This paper explores various types of solar dryers, their design, development, and performance for different products. It emphasizes the need for different drying environments based on the specific product. From this research paper we got an idea about how dryer should be work. By taking reference of this research paper, we covered inner area of Air collector and drying chamber by aluminum sheets which purpose is to reduce loss of heat. This will affect the efficiency of drying process. Here for maintenance of constant temperature electric heater and solar energy used simultaneously similarly we used this theory for our dryer by automate it by IOT circuit for maintaining same or constant temperature.[1]

Om Prakash, Anil Kumar (2014) Greenhouse dryers using forced convection are best for high moisture content crops, while natural convection is ideal for low moisture content crops. They produce superior quality and colored crops compared to open sun drying. PV-integrated solar greenhouse dryers are well-suited for large-scale dried crop production in Southeast Asian countries. They can be used in remote areas without grid-connected electricity. Simulation models are proposed to aid in selecting the optimal dryer design. By using this concept of greenhouse effect, similarly in our project generation of part of heat is done by greenhouse effect where sun rays refract through glass and falls on reflecting aluminium sheet surface. It will be reflecting inside, and heating environment will be there that is greenhouse effect. Which helps to increase temperature inside our collector.[2]

Sendhil Kumar Natarajan and Elavarasan (2019) A double slope solar dryer appropriate has been developed and inspected have been directed to assess the rate decrease of wetness fraction for potato. For double slope sun powered dryer with natural convection, sun-based dryer was 10.32% more effective when contrasted with open sun drying in case of potato on first day. During second day solar dryer was 14.21% more effective when compared with open drying. In this research study they have done the experiment and comparison between open sun drying and indirect sun drying by drying potatoes as product. After that they got an idea that after drying weight of product will be less in case of indirect drying method compared to direct drying. We got an idea It's reported that drying time basically depends on mass flow rate of dehydration air, global solar radiation and temperature of air. [3]

Salah A. Eltief, M.H. Ruslan, B. Yatim (2007) The study aimed to assess the performance of the drying chamber in a forced convective solar-assisted drying system. The choice of materials for the chamber's structure is crucial, as a well-constructed and well-insulated chamber improves system efficiency. The paper presents equations based on heat transfer analysis to determine temperature changes in the drying chamber. These equations utilize the concepts of thermal effectiveness and the number of transfer units, providing general equations applicable to solar drying systems' drying chambers. In this research paper we take idea about design and insulation, if the drying chamber is well constructed and provided with good insulation the efficiency of the system is increased. [4]

Petros Demissie et.al. (2019) The research paper provided valuable insights into the design and computational fluid dynamics (CFD) analysis of solar dryers. It discussed different types of solar dryers, examining their unique characteristics and applications. The paper covered the design aspects, emphasizing the importance of efficient drying systems with considerations for airflow, insulation, and heat transfer. The CFD analysis focused on optimizing airflow patterns and heat distribution within the dryers. Overall, the research paper provided a comprehensive understanding of the design, CFD analysis, types, characteristics, and applications of solar dryers, offering valuable information for further advancements and implementation in various industries. [5]

Redha Rebhi et.al. (2022)

The research study provides a concise summary of a comprehensive literature review on solar collectors and heat exchangers. The review incorporates experimental and numerical studies with different geometries and hypotheses. Traditional and innovative approaches to forced thermal transfer are explored, specifically in solar receivers and heat exchangers. The analysis considers parameters like wind speed, solar radiation intensity, and wall types. The study reveals suboptimal thermal performance due to low convective heat transfer, but the introduction of rib roughness improves heat transfer coefficients. The document highlights diverse applications for solar collectors and heat exchangers, including cooling electronic components, house heating/cooling, transpiration cooling, food drying, and cold storage, showcasing their versatility and potential benefits across various industries. [6]

Melike Sultan Karasu Asnaz et.al. (2021)

Solar drying is an effective method for preserving food, providing high-quality dried products regardless of seasonal variations. A study investigated the effects of slice thickness and pretreatment on mushroom drying using different solar dryers. Key findings include the reduced drying time with pretreatment in natural and forced convection dryers, while heat pump dryers showed no significant difference. [7]

Emetere, M. E., T. Osunlola et.al. (2019)

Through the examination of this research, we have gained valuable insights into the design of a drying chamber and air collector. As a result, we propose an alternative approach by utilizing aluminium foil instead of aluminium plates to cover the inner surface. This substitution aims to enhance the efficiency and effectiveness of the drying process. Aluminum foil offers advantages

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such as increased heat transfer, improved surface area coverage, and ease of installation. This modification has the potential to optimize the performance of the drying chamber and air collector, providing a more efficient and reliable system for the intended purpose. [8]

Suresh Bade Venkata et.al (2023)

The paper provides valuable insights into the design and manufacturing of a fruit solar dryer. Through a comprehensive study, the challenges, risks, and recommendations associated with its production have been identified. Manufacturing a solar dryer poses challenges such as intricate design considerations, material selection, and ensuring optimal energy efficiency. Risks can include equipment malfunctions, quality control issues, and potential cost overruns. To address these, recommendations encompass implementing robust safety measures, conducting thorough quality checks, and optimizing energy utilization. By heeding these insights during the manufacturing process, potential obstacles can be effectively tackled, risks mitigated, and the fruit solar dryer can be produced with enhanced performance, reliability, and sustainability.[9]

Lakshmi D. V. N., P. Muthukumar et.al. (2019)

This research as the foundation for our paper, which focuses on developing a mixed-type solar dryer. In line with the findings, we integrated an IoT-based data acquisition system into our design. This system enables us to accurately monitor temperature and humidity levels at various locations within the dryer. By utilizing IoT technology, we can collect real-time data and make informed decisions regarding the drying process. This integration enhances the efficiency and control of our project, allowing us to optimize the drying conditions and ensure the desired quality of the dried products. [10]

I. III. METHODOLOGY

Fig. 1 - Flow Process Chart of Project (Methodology**)**

Flow Process Chart of Project .Figure 1 show the flow chart of this paper

Construction Details of Forced Circulation Solar Dryer-

Forced circulation solar dryer form the foremost component of solar energy utilization system.

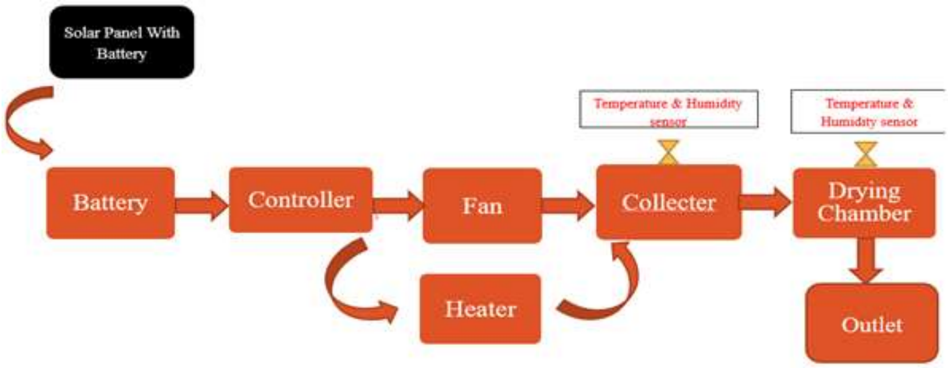

Fig. 2 Block Diagram of Force Circulation Solar Dryer

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This Forced circulation solar dryer absorb the irradiance and convert it into thermal energy at the absorbing surface and then transfer the energy to a fluid flowing through the collector. Forced circulation solar dryer are inexpensive and most used collection devices because of their inherent simplicity. Forced circulation solar dryer are used in several solar energy applications, especially for space heating, timber seasoning and agriculture drying. It has been observed that the key components of Forced circulation solar dryer such as a Collector, Drying chamber, Solar panel, blowers, Heater, controller, battery, IC, Diode, Sensors, Switcher have a significant effect on the thermal performance of the system. Figure 2 shows the major components of a Forced circulation solar dryer.

Fig 3-: 3D Model and Actual model of Force Circulation Solar Dryer

Major Components of Forced Circulation Solar Dryer-

Components	Description	Diagram
Collector	The solar dryer consists of a solar collector, typically made of a Reflection material, such as black metal or plastic, which absorbs solar radiat1ion and converts it into heat. The collector is designed to maximize solar absorption and minimize heat losses.	
Drying Chamber	The drying chamber is an enclosed space where the products to be dried are placed. It is designed to maximize the exposure of the products to the heated air and sunlight.	

Battery	While solar dryers typically do not require batteries for their basic operation, there are instances where batteries can be integrated into a solar dryer system for specific purposes	
Heater	In solar dryers, a heater can be used as an additional component to supplement the solar energy and provide a consistent heat source for the drying process. While the primary source of heat in a solar dryer is solar radiation, a heater can be incorporated to ensure drying conditions are maintained even during periods of low sunlight or at night and in rainy season.	
Blower	Blowers, also known as fans, are commonly used in solar dryers to enhance the airflow within the drying chamber and facilitate the drying process. Blowers help in distributing heat evenly, removing moisture from the drying material, and promoting faster drying. They play a crucial role in improving the efficiency and effectiveness of solar drying systems.	
Solar Plate	In a hybrid solar dryer, a solar panel can be integrated as a component of the system to generate electrical energy from solar radiation. This electrical energy can be used to power various components of the dryer, such as blowers, control systems, sensors, or even an electric heater, if necessary. The combination of solar energy and electrical energy from the solar panel allows for increased flexibility and reliability in the drying process	

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Sensor	Temperature and humidity sensors are essential components of a solar dryer system, as they provide crucial data for monitoring and controlling the drying process. These sensors help maintain optimal drying conditions, ensure product quality, and prevent issues such as over-drying or moisture retention. By incorporating temperature and humidity sensors in a solar dryer, operators can accurately monitor and control the drying conditions, making adjustments as needed to optimize the process. This allows for efficient drying, prevents spoilage, and ensures the production of high-quality dried products. We use Invento DHT 22 Temperature and Humidity Sensors. The DHT22 sensor, also known as the AM2302, is a popular temperature and humidity sensor manufactured by Invento. It is commonly used in various applications that require accurate monitoring of environmental conditions. Here's some information about the DHT22 temperature and humidity sensor:	
IoT circuit	The Internet of Things (IoT) can be leveraged in solar dryers to enhance their efficiency, control, and monitoring capabilities. By incorporating IoT technologies, solar dryers can become more intelligent, automated, and connected. Here are some ways IoT can be used in solar dryers:	

Table1-Various component of Forced Circulation Solar Dryer

- **Remote Monitoring and Control:** IoT-enabled solar dryers can be equipped with sensors and connectivity features that allow remote monitoring and control. Temperature sensors, humidity sensors, and other environmental sensors can provide real-time data on the drying conditions. This data can be transmitted to a central monitoring system or accessed through a mobile application, enabling users to monitor and control the drying process from anywhere.
- **Automation and Optimization:** IoT technology enables automated control and optimization of solar dryers. The data collected from sensors can be analyzed in real-time to make intelligent decisions. For example, based on temperature and humidity readings, an IoT-enabled system can

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automatically adjust the airflow rate, activate or deactivate the heater, or adjust ventilation to optimize the drying conditions and energy consumption.

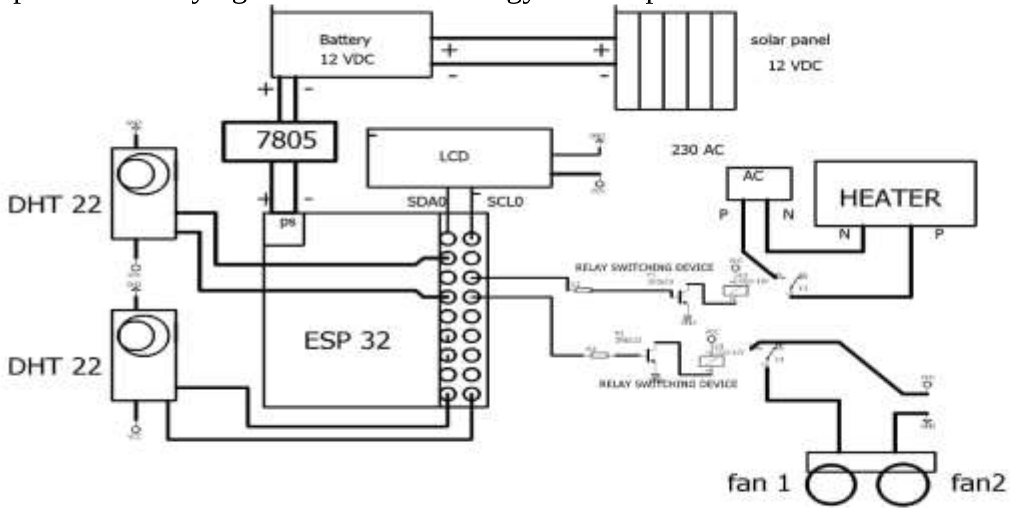

Fig. 4 IOT Circuit

Following are the main components of the IoT circuit: -

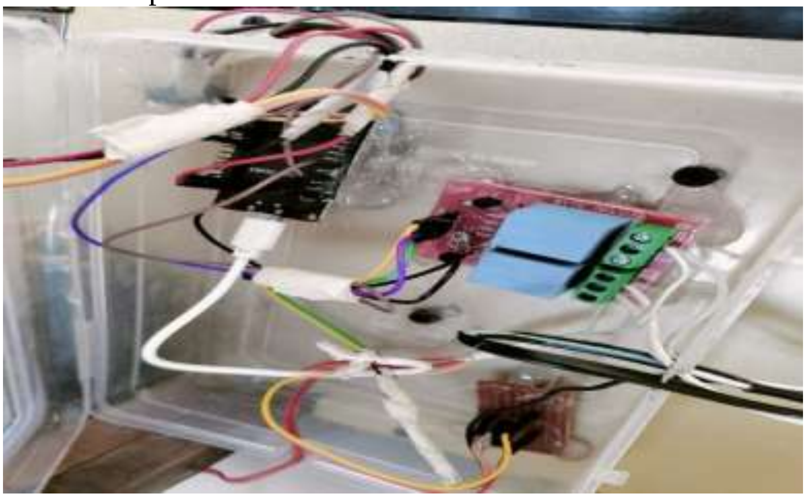

Fig.5 Components of IoT Circuit

Controller (ESP 32)

The ESP32 is a popular microcontroller and system-on-chip (SoC) that is widely used in IoT applications. It is developed by Esp if Systems and is known for its versatility, performance, and extensive connectivity options. Here are some key features and capabilities of the ESP32.Fig.5 shows various component of IoT circuit

Web Interface or Mobile App**: E**nvelop a web interface or mobile application that connects to the microcontroller board via Wi-Fi or Bluetooth. Users can view the temperature and humidity readings, control settings remotely.

Design Process: -

It seems like to provided a description of the fabrication process for your IoT-based force circulation solar dryer. Here is a summary of the steps you mentioned:

1. **Material Selection:** We chose a square bar of 20mm as the appropriate material for our dryer.
2. **Cutting:** We cut the bars into small, required pieces using a hacksaw blade.
3. **Base Frame Fabrication:** The base frame for the air collector and drying chamber was fabricated using the arc welding process.

4. **Finishing:** After fabrication, the frames were ground and excess material was removed using a hand grinder.
5. **Acrylic Sheet Installation:** Acrylic sheets were cut to the proper size for the collector and drying chamber frames, and then screwed onto the base frames.
6. **Chamber Assembly:** The collector and drying chambers were put together and positioned accordingly and three-hole passes were created for fastening purposes.
7. **Airflow Holes:** Seven holes (2 at the start for blowers, 3 on both the collector and drying chamber for air flow, and 2 on the top of the drying chamber for air outlet) were made on the acrylic sheets.
8. **Glass Fitting:** A separate frame for glass fitting was made for the air collector to capture sunlight and create a greenhouse effect. It was attached using door flag hinges.
9. **Heater Installation**: The heater was installed on the required side and position of the collector.
10. **Solar Plate Fixing:** A solar plate was fixed on the top of the drying chamber using screws.
11. **Net Attachment:** A net was attached to the two air outlet holes on the top of the drying chamber.
12. **Battery and IoT Circuit Placement**: A small, fixed frame was created and welded to the collector frame to hold the battery and IoT circuit.
13. **Wheels Addition:** Wheels were added to both frames to facilitate easy mobility.

Fig.6 Fabricated model of Forced circulation solar dryer

Thermal analysis Forced circulation solar dryer:

The thermal analysis of the Forced circulation solar dryer on Ansys. By put heater maximum temperature 90^{O}C and air outlet temperature of 40^{o}C.

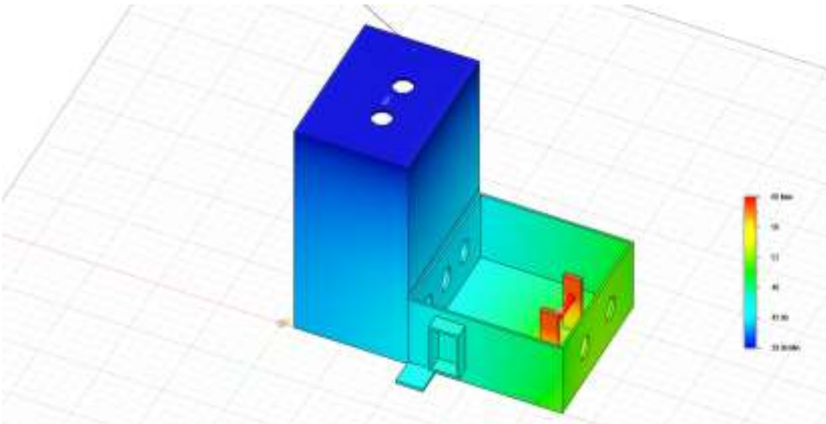

Fig.7 Thermal analysis Forced circulation solar dryer

CFD Analysis of Solar Dryer

Here we can see the air flow of air entering through collector.

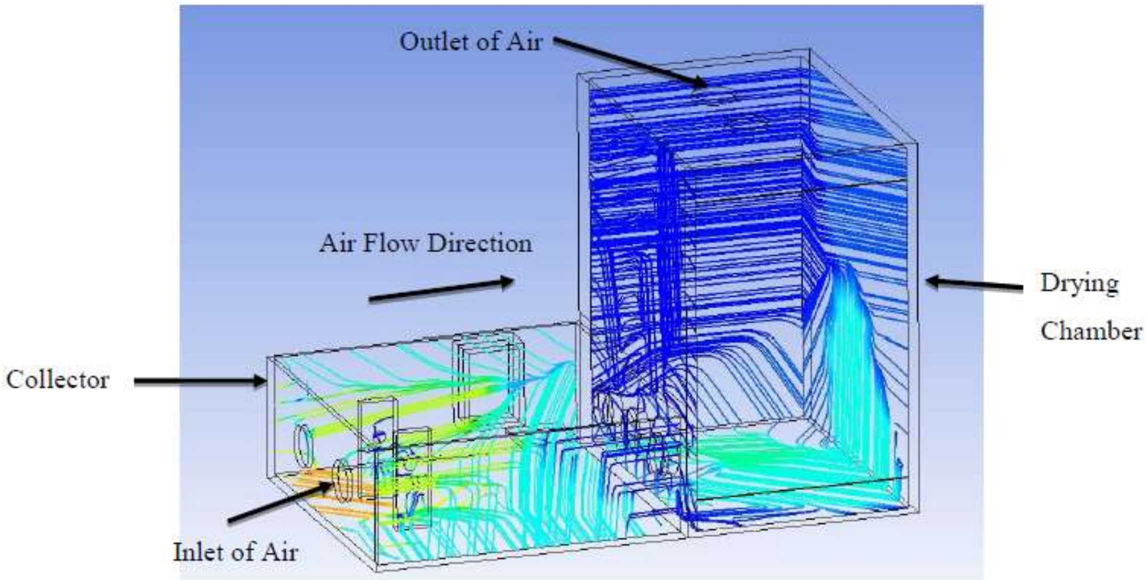

Fig.8 CFD Analysis of Solar Dryer

IV.Result

Drying Papad in a solar dryer can be an effective and sustainable method. Solar drying harnesses the sun's energy to remove moisture from the Papads, preserving them for longer periods.

Drying onions in the sun can be a traditional and cost-effective method for preserving them. Drying onions in the sun requires a consistent and favorable weather condition, such as hot and dry days. If the weather is humid or rainy, it can significantly prolong the drying process or even prevent it altogether.

Drying potato chips in the sun is a method commonly used in some regions to make homemade potato chips. Sun drying is highly dependent on weather conditions. It requires warm, dry, and sunny weather to facilitate the drying process. If the weather is cloudy, humid, or rainy, it can significantly prolong the drying time. Compared to other drying methods, such as using a Solar Dryer or dehydrator, sun drying generally takes longer. The duration can vary based on weather conditions, and it may take several days to a week for the chips to dry completely. Sun drying may result in uneven drying of the potato chips. Factors such as the sun's intensity, airflow, and placement of the chips can cause some chips to dry faster than others.

Drying food outdoors exposes it to the environment, making it susceptible to contamination from dust, insects, birds, or other animals. Solar dryers utilize renewable solar energy, which is abundant and freely available. By harnessing the power of the sun, you can dry potato chips without relying on conventional electricity, making it an environmentally friendly and cost-effective option. Properly dried and stored potato chips from a solar dryer can have an extended shelf life. The low moisture content achieved through solar drying inhibits microbial growth and helps prevent spoilage, allowing the chips to be stored for an extended period.

Solar dryers provide a gentle drying environment for potato chips. The low and consistent temperatures in a solar dryer can help preserve the natural flavors and colors of the chips while minimizing the risk of over-drying or burning. Drying potato chips in a solar dryer can result in high-quality products. The controlled drying environment helps retain the nutritional value of the potatoes while maintaining their texture and taste. Solar drying can also reduce the risk of chemical additives or preservatives, allowing for healthier snacks.

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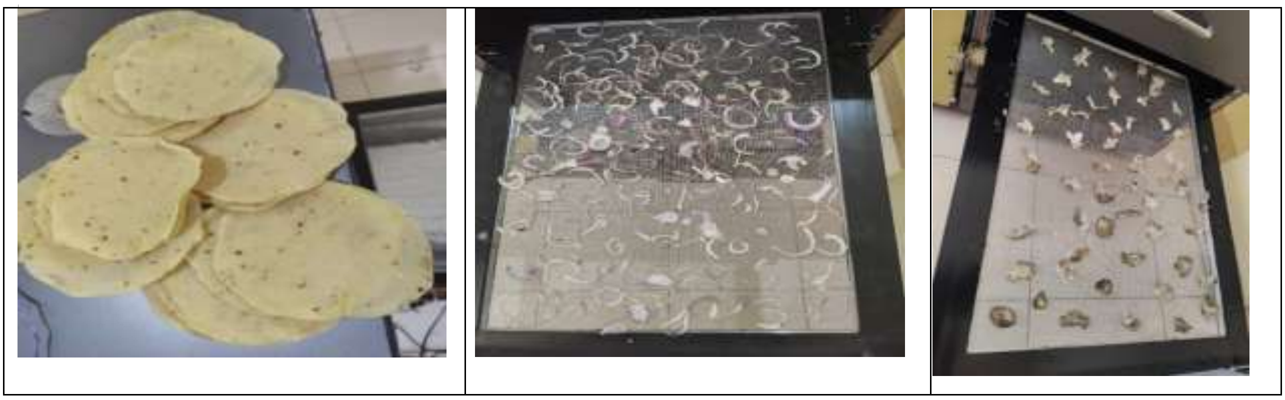

Fig.9 Sample dry products in solar dryer

V.Future Scope

IoT-based force circulation solar dryers can leverage cloud connectivity to store and analyse data. This facilitates data sharing among multiple stakeholders, such as farmers, researchers, and agricultural cooperatives. Collaborative data analysis can lead to collective insights, best practices, and continuous improvement in drying techniques.

Safety is an essential aspect of any technological advancement. Future solar dryers may include advanced safety features such as fire detection and prevention systems, emergency shut-off mechanisms, and fault diagnosis capabilities. These measures will ensure the protection of the drying system, surrounding environment, and personnel.

Future designs may incorporate intelligent control systems that utilize machine learning algorithms and artificial intelligence to optimize drying processes. These systems can analyse data from various sensors, weather forecasts, and historical patterns to automatically adjust parameters such as temperature, airflow, and drying duration. This level of automation can lead to more precise and consistent drying results.

VI. Conclusion

Forced convection solar dryers surpass conventional drying methods in terms of both drying rate and efficiency. The utilization of forced convection enables a significantly faster and more effective drying process compared to traditional methods. However, it is important to note that the specific duration of drying varies depending on the nature of the application and the product being dried.

The integration of IoT (Internet of Things) technology into our forced circulation solar dryer. This incorporation allows for precise control and maintenance of specific temperature parameters tailored to the requirements of the product undergoing drying. By leveraging IoT capabilities, we are able to monitor and adjust the drying process remotely, ensuring optimal conditions and enhancing overall efficiency.

One of the key advantages of our paper is its versatility. Our solar dryer can be employed for drying a wide range of products, making it a flexible and adaptable solution for various industries. This adaptability stems from the ability to customize drying parameters to suit the specific needs of different products, thus expanding its potential applications.

Moreover, our solar dryer is designed with portability and user-friendliness in mind. Its compact size and ease of handling make it convenient for transportation and setup in different locations. This accessibility facilitates its utilization in diverse settings, including remote areas where access to conventional drying methods may be limited.

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