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A Review Paper on CFD Analysis of Solar Dehydration System

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Abstract: This study presents a comprehensive analysis of a solar dehydration system using Computational Fluid Dynamics (CFD).Solar dehydration systems offer a sustainable method for preserving agricultural produce by utilizing solar energy. This review delves into the advancements and applications of Computational Fluid Dynamics (CFD) in the design, analysis, and optimization of solar dehydration systems. CFD has emerged as a powerful tool, providing detailed insights into the thermal and fluid dynamics processes within these systems. By simulating various design configurations and operating conditions, CFD helps in enhancing the efficiency and performance of solar dryers. This review compiles and analyzes recent studies, highlighting the methodologies employed, key findings, and the challenges faced in CFD Modelling of solar dehydration systems. It also discusses the future prospects and potential improvements in CFD techniques to further optimize solar drying processes, aiming for increased energy efficiency, reduced drying times, and better product quality.

Keyword: Solar energy, Energy efficiency, CFD, CFD analysis, Modelling

I. INTRODUCATION

Solar dryer is a product that we need vegetables and fruit and they are dried by the rays of sun with the help of use solar collector they are dried there are many types of dryers. A solar dryer is an innovation device used to dry agricultural product using solar energy it harnesses the power of crops such as fruit vegetables, grains and herbs. Solar dryers provide an eco friendly and cost-effective solution for drying agricultural produce compared to traditional method like un drying or mechanical drying. Solar energy to create a warm and dry environment for drying various crops food and material. Solar dehydration is unique compared to other types because direct exposure to sunlight provides enough radiant heat to the surface that is likely to occur, which contributes to floating effect needed to achieve the desired effect. The rate of moisture loss represents the impact of a process that involves large calculations to establish relationships between influencing variables under different conditions. Multiple sensors are used to attach to different locations on the dryer to check air flow. CFD provides a larger working space to perform various simulations to estimate the air speed in the drying chamber, which is expensive and difficult to do in real experiments. Developing relationships between numerical and experimental results obtained leads to the development of new theories and new knowledge in this field. The following sections aim to explain various experimental and numerical research methods by different researchers.

II. LITERATURE REVIEW

C.V. Papade [1] The use of solar dryers is limited in research because drying is not possible due to frequent clouds during the day or evening. If solar energy storage is ensured in the solar dryer, the product can be dried in the evening. Therefore, energy can be stored in latent or sensible heat storage materials. In this document, all design parameters of indirect type solar dryers are taken into account, such as the volume of water evaporated, the energy required to evaporate the water content, the amount of heat obtained through air, the required drying time. Speed, average drying speed, heat loss and insulation thickness. The analysis of 2D converging and diverging sections is performed using CFD. The analysis is done to know which geometry is correct to use in indirect type solar dryer piping system for air flow as shown in Figure 1 and Figure 2.. He concluded that solar dryer design, design considerations, design calculations and material selection are very important parameters.

Energy storage in latent heat storage materials is useful as it stores the maximum amount of energy compared to materials that store sensible heat with equivalent amounts of material. Phase change materials (PCMs) are practical for solar energy storage. Observing the results, the convergence part gives correct results, because the inlet wind speed in both cases is the same, but in the convergence part, the exit wind speed is almost double the inlet wind speed and at the divergence part is almost reduced by an amount. The third day.

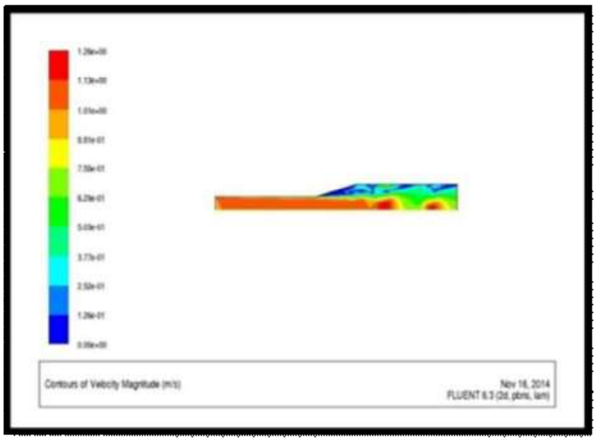

Fig.1 Contours of the velocity of divergent section

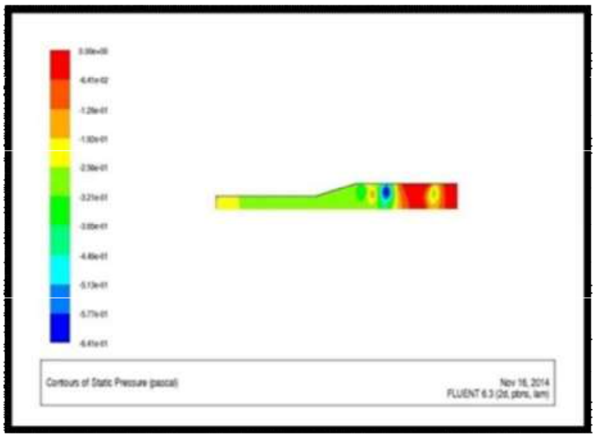

Fig.2 Contours of pressure of divergent section

Babagana Gutti. et. al. [2] worked on this article, they designed and built a conventional forced/natural solar dehydration system, and they used heat storage material for fruits and vegetables. The system is built using locally available materials such as wood and hardware materials. They observed that forced convection was more efficient than natural convection; Their system operates for six hours at night through the use of thermal storage materials. Nourelislam Siabdallah.et. al. [3] In this article, experimental results of growing spinach using forced convection are presented, reducing the humidity of spinach from 93% to 2%. Drying time is reduced from 3 to 4 hours by forced convection. They recycle 90% of the air. Bukke. et. al. [4] When researching this article, the author believes that drying removes water from a substance, which is an energy-intensive activity, mainly done by outdoor sun drying. The objective of this research paper is to design an integrated solar tunnel dehydration system with a solar air heater and heat storage material for drying orange peel under Vellore measurement conditions, in India. Here in this project, you have used gravel base, sand, gravel, etc. Elamin Akoy. et. al. [5]Working on this paper to design and build a solar mango slice dryer, they dried 100 kg of mango slices in 20 hours. They require a collection surface of 16.8 m^2. The initial and final moisture content of the mango slices were 81.4% and 10% wet basis. Maundu Musembi. et. al. [6] researched an indirect natural convection solar dehydration system designed and manufactured with the objectives: suitable for mid-latitude applications, determine its performance, Analyze air properties using humidity measurement tables and evaluate the quality of dry products. The results show higher overall efficiency even with a higher number of drying batches than the initially designed batch size. Ragul Kumar. et al. [7] A large-scale solar greenhouse dehydration system was developed and field tested. An experimental study was conducted in a dehydration system to dry 250 kg of red peppers in two time periods. Most agricultural products require drying temperatures of 50-60°C to produce good quality dried products, greenhouse-type dehydration systems using solar energy are most suitable for that application. Lalita Balakrishnan. et. al. [8] researched this solar dewatering system and tested it at four locations in India. The activists are led by All India Women Conferences, a nonprofit non-profit organization with 150,000 members in more than 500 branches. Solar dehydration systems can dry fruits and vegetables in quantities sufficient to make a living for one person. Dried fruits and vegetables are of good quality and can replace vegetables dried by electricity or gas. The goal of the project is to apply solar energy as a value-added device for the fruit and vegetable processing industry at the micro level. And save large quantities of fruits and vegetables that are spoiling in all rural areas due to lack of storage, processing and marketing facilities. Umayal Sundari. et. al. [9] have worked toward the goal of this research, which was to study the system's performance on the bitter ground and design and develop a forced convection solar dehydration system using an evacuated tube air collector. The components of this system are a drying chamber, an evacuated tube air collector, a blower, and a chimney. The system's performance is evaluated by calculating the drying parameter, moisture ratio, and drying rate in comparison to sun drying. According to the study's findings, the forced convection dehydration system is more effective; in just six hours, the moisture content of bitter ground is lowered from 91% to 6.25%. Lokesh Dhumne. et. al. [10] have attempted to explore the necessity of drying agricultural products as well as the different techniques employed in this process in this paper. Drying is among the most traditional ways to preserve agricultural goods. The drying process needs, on average, 2.4 MJ of energy to evaporate one litre of water. For long-term storage, the majority of the 80–90% water content in many of our food crops must be removed. Because the majority of the dehydration systems in use operate at less than 50% efficiency in real-world scenarios, a considerable amount of energy is required for this postharvest activity. The traditional method used in the majority of developing countries for sun-drying agricultural products is open air. A commodity that has been exposed to both direct solar radiation and the convective force of the natural wind is referred to as "sun-dried.". The most affordable and widely used technique for preserving and storing agricultural products is drying. Qianjun Mao. et. al. [11]

The efficient solution to the conflict between unstable input energy and steady output energy in concentrating solar power plants is to work on solar thermal energy storage or TES. Using phase change materials (PCMs), the latent heat thermal energy storage (LHTES) system is the primary means of storing thermal energy. Key PCM parameters for the TES system are their thermal properties, namely their melting points and latent heat. This paper divides PCMs based on their chemical composition into two categories: inorganic and organic. The inorganic PCMs can be further classified into three categories based on their melting point: low-temperature heat storage (below 120°C), medium-temperature heat storage (between 120-300°C), and high-temperature heat storage (above 300°C). This paper mostly discusses the most recent DSC setup studies conducted in solar TES systems to determine the melting point and latent heat of PCMs. Regarding PCM selection and use in solar TES systems, the results can serve as a useful guide. Shripad Chopade.et. al. [12] contributed to this article, which describes how to store solar thermal energy through phase change. The development of efficient and affordable energy storage technologies is as important as the creation of new energy sources. Energy storage is essential for energy conservation because it can reduce the time lag between energy supply and demand. By smoothing performance and increasing reliability, it improves the energy system. The topic of this article is the storage of solar thermal energy in phase change materials. We are talking about PCMs, which include hydrated, paraffinic, non-paraffinic and inorganic eutectic salts. Phase change materials (PCMs) offer the advantage of compressibility and provide heat at a constant temperature for thermal storage. Nagendra Babu. et. al. [13] The dehydration system operates on the principle that hot air rises in altitude because it is lighter than cool air. As a result of the warm air rising, food slices come into contact with it and lose moisture. this process's iterative cycle. Murat Kenisarin. et. al. [14] have worked on this paper, which examines the state of research in this specific area with the primary goal of making it an inexpensive, highly beneficial long-term investment. Typically, the sun's heat is utilized to remove the fruits' or vegetables' moisture content. The percentage of moisture removed from various food products is the subject of this paper. Suraj Rokade. et. al. [15] To improve the efficiency of solar air dehydration systems, research has been done on the various phase change materials (PCM) that can be used as thermal storage. To maximize the system's operating hours and maintain a constant temperature of the heating air, PCM integration can be very important. As PCM undergoes phase transitions from solid to liquid and vice versa, heat is either absorbed or released, functioning as a latent heat storage system. The study provided an overview of several popular PCM thermal storage media and how they can raise solar heating systems' thermal efficiency.

Joshi Santosh. et. al. [16] have worked on this paper, which modifies the current natural grape drying process with an appropriate enclosure that includes IR radiators and related systems. Parameters like humidity, temperature, and sample weight are measured with the proper sensors. The grapes are uniformly dried with the aid of infrared radiation, according to experimental analysis carried out with the use of a dehydration system. Because the drying process occurs at a low temperature, the original colour of the grapes is better preserved. Comparing the drying process to a natural one, a significant amount of time is saved. on the evaluation of different PCMs' thermal qualities, techniques for improving heat transfer, and designs of heat storage facilities for use in solar-powered greenhouses, solar-powered cooking, and passive and active space heating systems. Shalaby. et. al. [17] The previous research on solar drying systems that used phase-change materials as an energy-storage medium is reviewed in this paper. It is concluded that using a PCM in a solar dehydration system lowers heat losses and boosts system efficiency. In addition, since paraffin wax is frequently utilized as a storage medium in solar drying systems, this review paper provides an overview of the prior techniques applied to enhance the thermal conductivity of the phase change material in use. Graphite foam, carbon fibers, expanded graphite, and highly thermally conductive particles are hypothesized to enhance the thermal efficiency of solar energy devices that use paraffin waxes as thermal energy storage media. Kathiravan Krishnamurthy. et. al. [18] have worked on this article, which discusses various facets of infrared heating and offers a theoretical framework for processing food materials in this manner as well as how infrared radiation interacts with food ingredients. In the context of samples and process parameters, the impact of IR on food quality attributes is examined. Future research opportunities and applications of infrared heating in food processing operations are also discussed. Pravin Gupta. et. al. [19] have contributed to this paper, which details the planning and building of a solar dehydration system for the purpose of drying agricultural products. The Nagpur location served as the basis for the design, and meteorological data were gathered to ensure appropriate design specifications. If appropriate planning is done, solar radiation can be used very effectively to dry agricultural products in our environment. The efficiency of the current solar food dehydration system can still be enhanced, particularly in terms of shortening the drying period and perhaps storing thermal energy inside the apparatus. Mithat Akgun. et. al. [20] have labored in Turkey's Black Sea Region, which is too wet and humid for naturally drying fruits and vegetables during the fruit and vegetable harvest season. This means that more energy is required in the area to dry out. It was discovered that the drying times using three different LED temperatures were less than those using an electric heater and the sun. It was determined that LED drying had higher energy efficiency than traditional methods. Amedorme K. et. al. [21] have worked on developing and building the solar crop dyer with an indirect forced convention to dry moringa leaves. Using resources that were readily available to them, they built a dehydration system. A batch of moringa leaves weighing 2 kg by mass was taken, and it had an initial moisture content of 80%. To get it dried to the required moisture content of 10%, they had to remove 1,556 kg of water. At first, they projected a drying time of 24 to 30 hours for the planned test site, Kumasi, which is located at a latitude angle of 6.7 N. They also anticipated average solar intensity of 320 W/m^2 and ambient temperatures of 25 °C and 77 % relative humidity.

As per their design, a solar collection area of at least 0.62 m^2 is necessary to achieve a drying efficiency of 25%. Ogheneruona E. et. al. [22] have designed and constructed a solar dehydration system using direct natural convection to dry tapioca in rural regions. A batch of 100 kg of tapioca was dried in 20 hours (two days of drying time) using a 7.56 m^2 solar collector area. 10% and 79% of the total moisture content were taken into consideration at the beginning and end, respectively. They received 13 MJ/m^2/day from the solar radiation incident. Bolaji O. et. al. [23] have worked on the solar wind ventilated cabinet dehydration system design, construction, and testing in Nigeria at latitude 7.5 N. They found that open-air drying performed less well than drying using the solar cabinet dehydration system. During the testing phase, they measured an average air velocity of 1.62 m/sec through the solar dehydration system. Inside the dehydration system, they discovered that the maximum drying air temperature was 64°C.Gaeta A. et. al. [24] have designed and examined a solar drying system with a cylindrical section. His system, which he designed to dry 70 kg of bean crop, consists of a solar flat plate collector with an area of 1.21 m^2. He had used three air flow rates to test the solar air collector's performance. He measured the air flow rate at 2.43 kg/hr and the solar radiation intensity at 750 W/m^2 while conducting the test. At an air flow rate of 4.05 kg/hr, he obtained the maximum value of average thermal efficiency of 25.64 percent of the solar air collector; at an air flow rate of 2.43 kg/hr, the minimum value of average thermal efficiency was obtained. When the air flow rate was 2.43 kg/hr, the beans' initial moisture content was 70% and their final moisture content was 14% at the time of testing. Forson K. et. al. [25]have developed a system for drying crops, including cassava, using mixed-mode natural convection solar energy. They started with a 160 kg batch of cassava by mass, and after extracting 100 kg of water, the batch's initial moisture content of 67 percent wet basis was reduced to 17 percent wet basis. At first, they projected a drying time of thirty to thirty-six hours, 400 W/m^2 of average solar radiation, and 25 °C and 77 % relative humidity as the ambient conditions. They came to the conclusion after their test that, in accordance with the design, an expected minimum of 42.4 m^2 of solar collector area is needed [52-53].

Evan Eduard Susanto. et. al. [26] have studied solar dehydration, and vermicelli is one of the many foods that utilize this abundant source of water in Indonesia. Local farmers still use open-sun drying for vermicelli production, which lowers the product's quality, takes a lot of time, and cannot be done in inclement weather. Thus, a hybrid solar dehydration technique— which combines solar dehydration with an additional heater driven by liquefied natural gas—is presented in this study as a novel vermicelli drying method. At 40, 60, 80, and 100°C, hybrid solar dehydration is carried out. The final moisture contents of vermicelli dried by hybrid solar dehydration met the standard limit after two hours of drying, whereas open-sun drying and natural solar dehydration did not; this suggests that hybrid solar dehydration is quicker and more efficient. Valentin Silvera Diaz. et. al. [27] have worked on designing an indirect solar dehydration system that presents watersensitive heater storage and a vacuum solar collector. A model load of 80 kg with an initial water content of 75% w was created based on references found in the literature to analyze the system's performance. final of 10% w and b. b, for drying times of four hours and three hours, respectively, and air velocities of one point one and seven m/s. Surendra Poonia.et. al. [28]have studied the economic assessment of hybrid photovoltaic/thermal (PV/T) solar dehydration systems made with locally accessible materials, as well as the drying kinetics of ber (Zizyphus mauritiana) fruit. g. Fan, PV panel, glass, and galvanized iron sheet. Ber fruits were dried for 240 hours with an 18 kg drying load to reach the safe moisture content of 20 percent. A solar dehydration system uses solar energy efficiently to produce higher-quality products faster. M. Nithis Kumar. et. al. [29]have experience in the field of agriculture. An agricultural product like seeds, onions, tomatoes, tea, coconuts, turmeric, etc. can be dried using solar dehydration. A solar drying system helps preserve agricultural products by using solar energy to heat the air and dry the food materials inside. This reduces the amount of agricultural waste that occurs. To maintain the drying time and temperature, temperature and time are essential for solar dehydration. With solar dehydration, IoT is used to minimize human labour. One of IoT's main goals is to deliver intelligent, uninterrupted services directly to the user. Saravanan. et. al. [30] have researched solar energy, a cheap, accessible, and limitless source of power. Traditionally, drying and heating applications have made use of solar energy. Life on Earth is maintained by it. The demand for solar energy increased in 1973 as a result of the world oil crisis, and all research focused on solar appliances. The depletion of fissile fuel reserves, air pollution, and global warming have all contributed to an increase in the use of solar energy in recent years. Utilizing the most solar energy possible for product solar dehydration is the subject of extensive research. Swapnil Kawale. et. al. [31] study solar energy and other renewable energy sources because of their seemingly endless potential. Grain dehydration has long been a focus of direct solar energy applications. Corn in the field, windrow, or stack is dried by the sun and wind. To enhance harvest rate in bad weather or reduce field losses, artificial dehydration has been added to this process. Sunlight grain dehydration is one alternative that is examined in this article. Referred to as shortwave radiation, solar radiation, solar energy, or isolation, is the radiant energy that leaves the sun and reaches the surface of the earth. All of the radiation can come from the sun directly, diffusely, scattered by the atmosphere, or reflected off of nearby surfaces. Patchimaporn Udomkun.et. al. [32] Solar dehydration is the most productive, economical, sustainable, and renewable technology for preserving agricultural products in Asian and Sub-Saharan African (SSA) nations. The various forms of solar dehydration that are commonly employed in Asia and Africa are presented in this review paper. Furthermore, the impact they have on product quality is paramount, and their effects on the economy, environment, and society are also emphasized. This paper also examines the influence of structural, external, and financial factors on the efficacy of solar dehydration technologies in a few selected Asian and SSA countries, since these factors are crucial to the adoption and scaling of solar dehydration. Jyoti Singh.et. al. [33]

she is working on various solar dehydration systems, and the main goal of this experiment is to create dehydration that satisfies the fundamental requirements of dehydration and is enhanced by altering the indirect forced solar dehydration system's design. The idea behind building a dehydration unit is to preserve food and save energy through solar dehydration's moisture removal process. Karunaraja Natarajan. et. al. [34] have worked with chillies, one of the most valuable and widely grown commercial crops in India. Dehydration under the open sun is a common method used, but it has many negative effects and produces chillies of poor quality. As an alternative to open sun drying, there is a technology called solar tunnel dehydration. Field testing and development were done on a large-scale natural convection solar greenhouse dehydration system. 250 kg of red chillies were dehydrated throughout two intervals in an experimental study. The red chilli's moisture content dropped from 79% (w.) due to solar dehydration. b. from roughly 10 percent (w. b.) in 55 hours as opposed to the 124 hours needed for open-sun dehydration, saving 56% of the time. For chilli dehydration, the thermal efficiency was determined to be 16.25 percent, with a specific energy consumption of 6.06 kWh/kg. The dehydration process in the solar greenhouse yielded high-quality dried chili. It has been discovered that the solar tunnel dehydration method produces clearly higher-quality products than open-air dehydration.

Samyukth Kumar. et. al. [35] have worked on the studies that were done to dry banana slices and examine the dehydration properties of those bananas, such as the rate of dehydration and the flavor, colour, and form of the dried banana. The dehydration process includes the following features: two distinct airflow configurations (referred to as the top flow between the glass cover and absorber plate and the bottom flow between the absorber plate and the bottom insulation of the solar collector), forced flow with variable flow rates ranging from 0 to 3 m/s, and two distinct mounting strategies (wooden skewers and conventional trays). The crop selected for the experiment is the banana because it has a high yield and significant losses in India. Dried bananas are also a necessary part of a diet because of their high nutritional value. Abhay Lingayat. et. al. [36] have been made on how inadequate preservation methods and inadequate storage facilities cause agricultural products' quality to decline. Agricultural products' postharvest losses have been decreased by the application of advanced processing techniques. One processing method for preserving food products is dehydration. Solar energy dehydration is an old method of food preservation. For agricultural industries, solar dehydration systems come in a range of sizes, capacities, and designs. One popular method for dehydrating food products is indirect-type solar dehydration (ITSD), which has not yet undergone extensive research despite having several distinct types, characteristics, and techniques used to enhance its effectiveness. Shraddha B. et. al. [37] have worked on solar dehydration, which improves energy conservation and is very environmentally friendly. Nonetheless, a primary drawback of solar energy systems is the issue of the sporadic nature of solar radiation and the low solar radiation intensities in solar thermal systems. The process of dehydrating nutmeg in the sun. For dehydration, the Solar Dehydration Chamber was created. The 660×1250×500mm solar dehydration system, which includes an exhaust fan, aluminium trays, Plunum chamber, and other subsystems, was designed and built for dehydrating nutmeg. Anupam Tiwari. et. al. [38] have worked on the traditional dehydration system, which uses solar dehydration, a free and renewable energy source, to preserve fruits, vegetables, grains, fish, meat, wood, and other agricultural products. Nevertheless, several recognized restrictions on sun dehydration apply to large-scale production, such as contamination by dirt, dust, or debris, damage to crops from animals, birds, and rodents, and quality deterioration from direct sun exposure, dew, or rain. Additionally, this system requires a lot of labour and time because crops need to be covered at night and during inclement weather to prevent domestic animal attacks. Hadiyanto.et. al. [39] have worked on the sugar palm (Arenga pinnata), which is primarily found in Malaysia and Indonesia but is also known as are in Indonesia. According to the Indonesian Ministry of Agriculture (2014), the country's sugar palm production area spanned nearly all of its provinces, from Papua to Sumatra, and reached approximately 70,000 hectares in 2014. The starch found at the base of the sugar palm tree is typically transformed into sugar when the tree flowers. The starch from the trunk of a sugar palm can be extracted and used for different purposes when the palm is not producing (Sanyang, Sapuan, Jawaid, Ishak, and Sahari, 2016).Sebastian Romuli. et. al. [40] Solar dehydration is one of the most successful, economical, ecological, renewable, and eco-friendly methods for preserving agricultural produce in Asian and Sub-Saharan African (SSA) nations. The many forms of sun dehydration that are often employed in Asia and Africa are presented in this review paper. Furthermore, the impact of their use on product quality is paramount, and their implications on the economy, environment, and society are also emphasized. this paper is explains in new technologies in solar dryers and selected Asian 0r SSA nations, since these factors are crucial to the acceptance and scaling of solar dehydration. Petros Demissie [41] have worked on solar-powered indirect food drying is designed and developed. They are design a drying chamber with two columns of four rack shelves chimney in exhaust air and a solar power fan. The dryer's output is made to reduce condensed water precipitation and allow for additional drying air heating at the exit. They are developed and manufactured dryer. The air flow distribution in the vicinity of the rack shelves showed that the mean flow velocity is 0.14 m/sec for the lowest shelf and 0.12 m/sec for the other shelves due to cooling of the air. The flow of as compere to frist shelves airflow distribution is observed on the top three shelves compared to the bottom shelf. the drying chamber calculated temperture is 315K. food dried in 35 minute. And they maximum average temperature of CFD is 4.3 °C. they have working in CFD air flow in chamber with in temperature as shown Figure 3. Rupanshu Singh el.at.2021[42] CFD analysis and result in an indirect solar dryer. The temperature and flow velocity variations at different mass flow rates (0.0872, 0.0636 and 0.0447 kg/s) were predicted and compared with experimental data. The velocity curves and straight lines were obtained and the results showed that the average velocity at the collector outlet was 2.89 m/s from a flow mass is 0.0872 kg/s, from a flow mass is 0.0447 kg/s and it 1.36 m/s

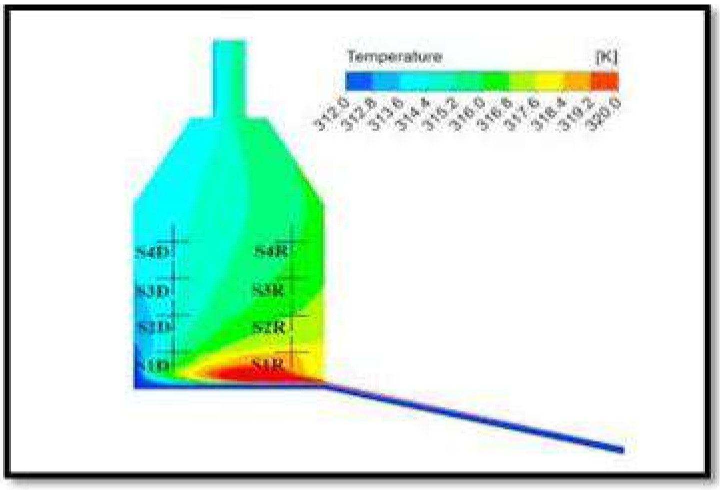

Fig 3: Temperature distribution on the symmetry plane dividing the two halves of the drying chamber

Table 1: Comparison of temperature distributions from the experiment and CFD modelling on the symmetric plane

Location	S1R	S1D	S2R	S2D	S3R	S4R	S4D
Experiment	314.2	314.4	313.9	313.6	313.9	313.4	313.7
Simulation	318.0	315.0	316.8	314.3	314.3	315.9	314.2
Difference	3.9	0.6	2.9	0.7	0.4	2.5	0.5
% Deviation	1.2	0.2	0.9	0.2	0.1	0.8	0.2

The maximum collector outlet temperature was 44.6 °C and the maximum absorber plate temperature was 69.57 °C for the mass flow rate of 0.0872 kg/s. The average difference in temperature increase is about 4°C for the two flow rates (0.0872 and 0.0447 kg/s). The temperature curves in the trays were analyzed and it was found that the lowest tray reached the maximum temperature, while the highest tray had the lowest temperature. CFD simulations provide interesting insight into the temperature distribution and velocity characteristics in solar dryers. Table 1 gives a comparison of temperature distributions from the experiment and CFD modelling on the symmetric plane. Oluwasanmi Lyiola Alonge [43] worked on the numerical modelling, fabrication, and performance evaluation of a direct solar dryer for fish. Computational Fluid Dynamics code was used for the modelling, which involved simulating various dryer dimensions at different fan speeds. Using the desirability function method, the best uniform airflow distribution and optimal temperature are obtained with a (70 x 60 x 40 cm3) drying chamber positioned 25 cm from the base for the tray location. Without a load, the performance of the constructed dryer was experimentally assessed during the year's dry and wet seasons utilizing the findings of the numerical model. During both seasons, a maximum temperature elevation of 26°C and collector efficiency of 77.2% were recorded at natural convection (0 m s-1 fan speed). At the fan speeds taken into consideration, the statistical t-test ($p \leq 0.05$) revealed no significant differences between the experimental and numerically predicted values. Predictions using root mean square error and mean bias error were within an acceptable limit (10 %). numerically predicted values by statistical t-test ($p \leq 0.05$) at fan speeds considered. Dixit. D. Patel [44] proposed researching grain drying using solar energy as an alternative solution. Radiant energy from the sun reaching the earth's surface is called shortwave radiation, solar radiation, solar energy or insulation. total radiation directly from the sun and atmosphere diffusion from the surface in adjected. The drying temperature and drying speed were found to be higher than the natural sun drying method. The results show significant advantages of solar dryers over traditional sun drying methods in terms of drying speed and lower risk of damage. Solar energy is the most promising renewable energy source with its seemingly unlimited potential. Direct solar energy has been applied to grain drying for many years. Sun and wind dry crops in the field, on piles or in front of windows. Artificial drying perfects this process to increase harvest yields in bad weather or minimize losses in the fluid. Material properties are shown in Table 2.

Table 2: Material Properties

Properties	**Laminated Sheet**
Thickness, t	3.00 mm (±0.1)
Resistance to Surface wear	≥350 (revolutions)
Resistance to immersion in boiling water mass increase (%)	10.0%(Max)
Resistance to immersion in boiling water thickness increase (%)	1.7894×10^{-5}
Resistance to dry heat	180 °C

Shantanu S. Kulkarni [45] have worked on a paper analysis of a solar drying chamber for the drying of agricultural products. Design and analysis were done in ANSYS fluent.

The CFD analysis was carried out to analyze temperature and velocity distribution. Temperature and velocity is the most important parameters for drying products. CFD is a good quantitative and qualitative technique for the analysing effect of variation of temperature and velocity on the dryer there are analyses of drying chamber temperature and velocity, variation in ansys with Modelling. Senay Teshome Sileshi [46] solar dryer's airflow was not uniform with the airflow inside the drying chamber. The airflow in the drying chamber is analyzed using the CFD method. Due to radiation, species transport and k-omega SST models were used. A comparison of the numerical temperature distribution results with the experiment shows a reasonable agreement. Between the upper and lower panels, a velocity change of 0.015 m/s and a relative humidity of 2% were observed. The dryer provides the necessary air temperature for solar drying. The results show that using a vertical air distribution channel can improve the drying process by increasing the uniformity of drying air distribution. Mixed-type dryers can be modified to natural beliefs by combining CFD with experimental studies. A.I. Ambesange [47] The CFD flow study that is being worked on in this paper includes, when appropriate, the design, testing, and optimization of flow conditioning devices to direct the gas flow through the duct. In this case, the CFD code FLUENT VERSION 14.5 was used to carry out a two-dimensional numerical simulation of heat transfer, Nussult number, velocity, and temperature. The conservation equations for mass, momentum, and energy have numerical solutions included in the CFD model. With the following presumptions, the convective heat transfer process is modeled using these three equations: (a) The flow is two-dimensional, turbulent, smooth, and fully developed. (b) It is impossible to compress the fluid or flow. (c) The roughening material, absorber plate, and duct wall are isotropic and homogeneous. find through a result in CFD with speed and temperature to heat transfer solar dryer.

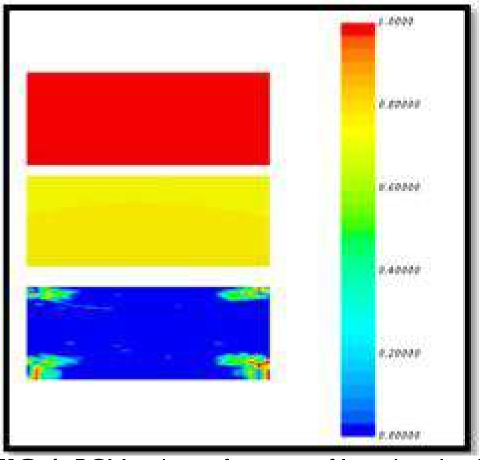

FIG 4: PCM volume fraction of liquid and solid

S. P. Salve. et. al.[48] have worked on comparing the drying cabinet's experimental and CFD temperatures, and it is found that there is a difference of about 5°C between the temperatures found in the experiments and the CFD calculations. The temperature plots of the drying cabinet show that starting at 9:00 a.m. up until 25:00 hours. the air temperature was recorded with a PCM case at a temperature higher than 40°C at 9:00 hrs. until 18:00 hours. not using a PCM case. The use of PCM allowed the dryer to maintain the necessary drying temperature (above 40°C) for an additional 7 hours. Designed and developed for drying chillies using thermal energy storage, the portable forced convection solar dryer is functional. This air heating system, which uses a flat plate collector and thermal energy storage, has a 15 kg capacity. Phase change material (PCM) is made of paraffin wax. Swarup R. Joshi. et. al. [49] have worked on this paper solar dryer for drying chamber with agricultural product. solar drying chamber for dry the agricultural product and evaluate their performance. In this article we are constructing up the model of sun oriented drying chamber using ANSYS FLUENT R15.0. A simulation is run in CFD tool for drying chamber.

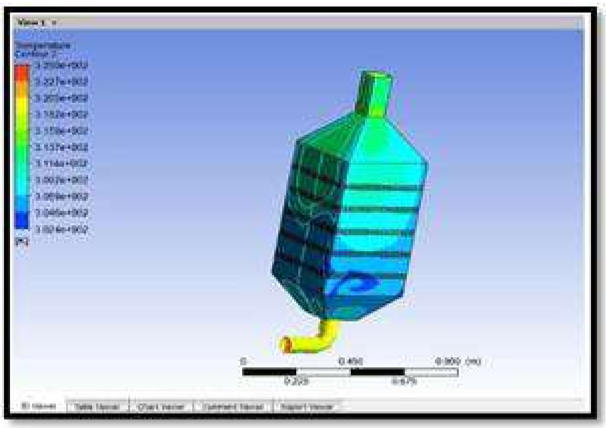

Fig 5: Temperature Distribution of Drying Chamber

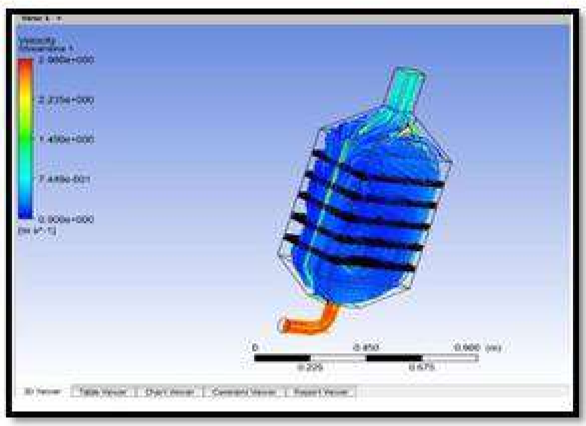

Fig 6: Velocity Distribution of Drying Chamber

The evaluation of temperature and velocity at outlet of drying chamber for agricultural products, the temperature is decreases up to 6-10℃ and velocity also reduce. Figure 5 and Figure 6 shows results of temperature and velocity distribution. Nicolás-Iván Román-Roldán [50]. The turbulent kinetic energy, temperature and velocity distribution of the humid air inside the greenhouse solar dryer (GHSD) were numerically modeled in the ANSYS FLUENT CFD code. The numerical simulations were based on two geometric models: a real model and a reduced height model, the solutions of which agreed well with the experimental temperature data. The real model results showed that the TKE ranged from 1.27 m2/s2 to 6 m2/s2 with an average of about 1.6 m2/s2 for the entire greenhouse solar dryer (GHD). The maximum intensity in the diffuser path, resulting temperature of drop 2 K in the regions near the walls. Thus, a nearly uniform temperature distribution was achieved throughout the GHD volume, although the average temperature was 315 K and the slope relative to ambient temperature was 14 K, i.e. suitable for drying. the average air speed and height of 1 m is 0.71 m/s, and value close is lowest limit (0.6 m/s) in forced convection drying. The improvement in GHD by reducing the mass by 36.5% allows to increase the average TKE to 3.8 m2/s2 (2.4 times more than before) located in the middle of the greenhouse; The average temperature reaches 316.5 K with a slope of 15.5 K, an increase of 1.5 K (11%) compared to the real geometric model. The air velocity at a height of 1 m increases to 0.9 m/s in the improved geometry (35.7% increase compared to the previous geometry). More than 95% of the enhanced GHD volume of uniform temperature, is suitable for good quality drying at higher speeds. Taiwo Aduewa[51] have worked on this paper. For Akure, Nigeria (5.304° Latitude, 7.258° Longitude), a simulation of a hot-air supplemented solar dryer (HSSD) built for this purpose is presented for temperature distribution based on direct solar irradiation of 1423 W/m^2. Computational fluid dynamics (CFD) was used to simulate the airflow, temperature, radiative heat flux, and other system parameters. The simulation result is compared calculated to determine in estimated values of the HSSD parameters. The drying chamber's temperature distribution and airflow pattern were examined, and the findings showed that the drying air condition was spatially homogeneous. Due to a buildup of hot air at the outlet vent, there is a higher velocity profile there. The drying chamber experienced a comparatively low level of external temperature interference. They work with CFD air flow through a chamber and compute the drying chamber's temperature and velocity. and determining the CFD result.

III. METHODS OF SOLAR DRYING TECHNOLOGIES

Various agricultural products can be dried using solar dryers, which come in a variety of sizes and designs. According to the needs of farmers, a variety of dryer types are offered in the market. The main way that drying systems are categorized is by the temperature ranges in which they operate: high temperature solar dryers and low temperature solar dryers. The techniques and pictures for solar drying technologies are displayed below. The traditional method of product drying is direct solar drying. With this approach.

1) The outdoor open air solar drying as shown in Figure 7

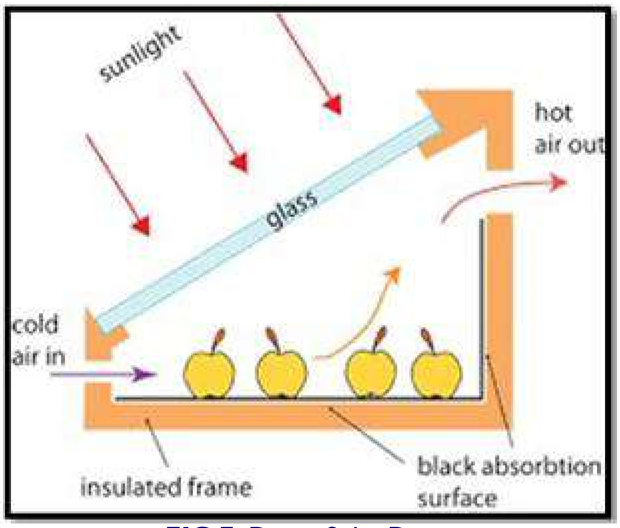

FIG 7: Direct Solar Drying

The products are subjected to direct solar radiation, which lowers the amount of moisture in the air. The variation in density is what causes the air movement. It falls into one of two general categories: (2) With a transparent cover that partially shields the food from rain and other environmental factors. E. a technique for passive solar drying. In order to expose a thin layer of product to solar radiation, it is spread out over a large area. The products will need a considerable amount of time to dry through this process. Concrete or a specific patch of soil used as the surface makes it suitable for outdoor direct sun drying. Grain can benefit from this kind of drying technique. Material is kept outside for an extended period of time typically 10 to 30 days.

The simplest method for product drying has the following drawbacks, though:

1. It requires a large surface and prolonged sun exposure, and it depends on the climate.
2. The final product is dependent on the observations of an inexperienced person.
3. A dried product's final state will never be under scientific control.

4. A product's quantity may be lost due to rodent, animal, or bird attacks.
5. Product may be subject to a wide range of weather variations.
6. For direct solar drying, the drying rate is extremely low.
7. Direct sunlight exposure can significantly lower the amount of vitamins and other nutrients in the dehydrated product.

The new method of product drying is called convective solar drying, or indirect solar drying as shown in Figure 8.. Compared to direct solar drying, this method is much more efficient. This method uses a concentrated solar collector or a flat plate collector to heat the ambient air. Either passive or active heating occurs. The cabin that houses the products then receives this heated air flow. Because of convection and diffusion, moisture from the product may be lost there. This drying technique is employed to prevent direct exposure to solar radiation. The main drawbacks of direct solar drying are mitigated by this technique. A drying chamber is equipped with an air circulation system that allows hot air to circulate through vegetables and exhaust, thereby eliminating moisture from the produce.

Systems for ventilation: let out air that is damp. Some designs for thermal storage tanks incorporate mechanical attributes.

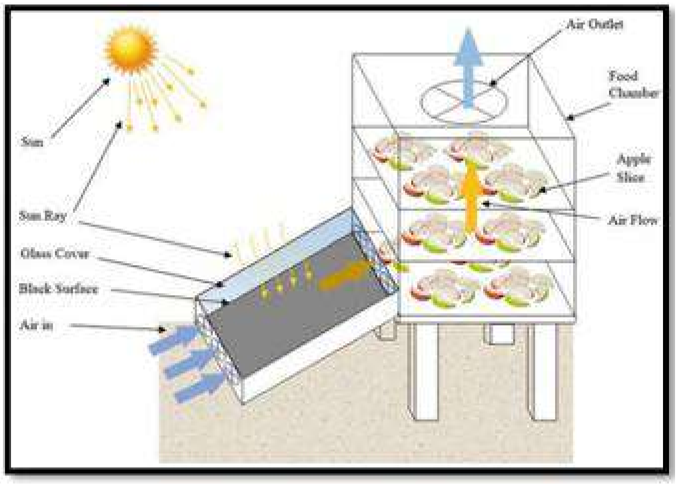

FIG 8. Indirect Solar Drying

An Indirect solar dryer with air recirculation in this solar dryer, a duct is provided from the motor to the drying chamber to recirculate the hot air, reducing losses and cutting down on drying time compared to standard indirect dryers. Additionally, based on experimental results, the moisture removal rate is increased relative to previous levels, increasing from about 80% to 10% instead of 13%. Therefore, an indirect solar dryer with air recirculation is preferable to others in terms of food preservation, time and energy efficiency. They use solar energy to dry food and vegetables by forcing hot air through a drying chamber.

Solar dryer with forced convection: This type of dryer has a fan fixed on one side. As a result, the dryer's temperature controls are maintained and more outside air can enter the dryer. The most moisture and humidity is absorbed in this manner. Rapid heat recovery and temperature uniformity are both provided by the forced air circulation system.

Natural convection solar dryer: He natural convection solar dryer operates on the principle of atmospheric temperature passing over a substance and absorbing its moisture. The product's moisture will be removed by this air and released into the surrounding atmosphere. These are techniques for solar drying technologies.

IV. FLOW DIAGRAM AND EXPLANATIONS CFD ANALYSIS PROCESS

The detailed steps of CFD analysis as shown in the flow process in Figure 9.

1. **Problem Definition:** Identify the objectives of the CFD analysis (e.g., optimizing airflow, heat transfer). Define the scope and goals of the study, including specific parameters to be analyzed.
2. **Geometry Creation:** Develop the 2D or 3D model of the solar dehydration system. Use CAD software to create a detailed and accurate representation of the system components.
3. **Mesh Generation:** Divide the geometry into smaller, discrete elements (mesh) to enable numerical analysis. Ensure the mesh is fine enough to capture important details while balancing computational resources.
4. **Boundary Conditions:** Define the physical conditions at the boundaries of the model (e.g., inlet air velocity, outlet pressure). Set up thermal conditions, solar radiation inputs, and material properties.
5. **Solver Setup:** Select appropriate CFD solver settings, including the type of flow model (e.g., laminar, turbulent). Configure solver parameters such as convergence criteria and time stepping.
6. **Simulation Run:** Execute the CFD simulation using the configured solver. Monitor the simulation for convergence and stability, making adjustments as needed.
7. **Post-Processing:** Analyze the simulation results using visualization tools (e.g., temperature and velocity contours, streamlines). Extract quantitative data such as heat transfer rates, moisture content, and drying time.

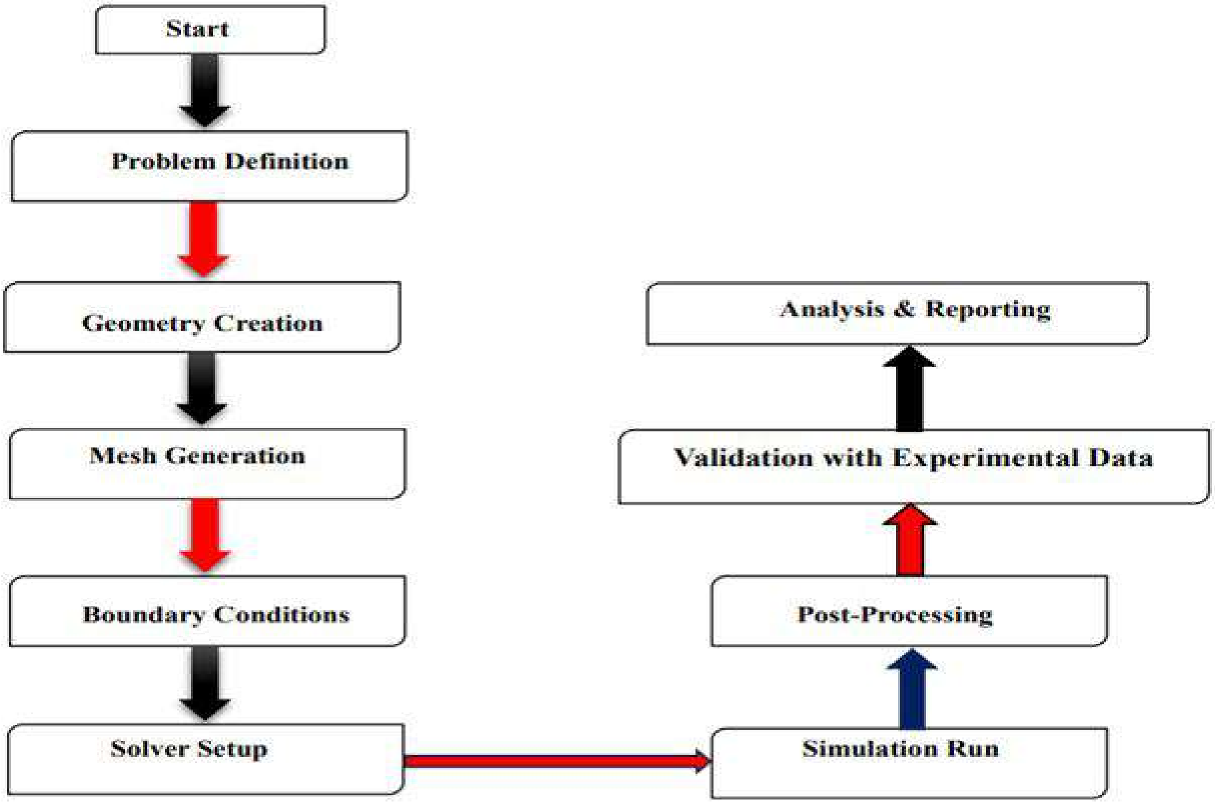

FIG 9. Flow Diagram CFD Analysis Process

8. **Validation with Experimental Data:** Compare CFD results with experimental measurements to validate the accuracy of the model. Adjust the model and re-run simulations if discrepancies are found.
9. **Analysis & Reporting:** Interpret the results to draw meaningful conclusions about the performance and optimization of the solar dehydration system. Prepare a comprehensive report detailing the methodology, findings, and recommendations for future work. This flow diagram and accompanying explanations provide a structured overview of the CFD analysis process for solar dehydration systems, ensuring a thorough and systematic approach to the study.

V. CONCLUSION

The application of Computational Fluid Dynamics (CFD) in the analysis and optimization of solar dehydration systems has significantly advanced the understanding and efficiency of these sustainable technologies. This review has highlighted the diverse methodologies and approaches employed in CFD studies, illustrating how simulation tools can provide deep insights into the thermal and fluid dynamics of solar dryers. Through CFD analysis, researchers have been able to identify optimal design configurations, improve air flow distribution, enhance heat transfer mechanisms, and ultimately increase the efficiency of solar dehydration processes. However, challenges remain, particularly in the accurate modeling of complex physical phenomena such as moisture transport, phase change, and the impact of varying climatic conditions. Addressing these challenges will require continuous advancements in CFD techniques, including the integration of more sophisticated models and the validation of simulation results with experimental data. Future research should focus on developing more comprehensive and user-friendly CFD models that can be readily applied by engineers and practitioners in the field. Additionally, interdisciplinary collaboration between CFD experts, agricultural scientists, and solar energy engineers will be crucial in driving innovations and achieving practical, scalable solutions. In conclusion, CFD analysis holds immense potential for transforming solar dehydration systems, making them more efficient, cost-effective, and environmentally friendly. Continued research and development in this area will play a vital role in promoting sustainable food preservation methods and supporting global efforts towards energy conservation and climate change mitigate

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