An Investigation for the Performance of the Solar Dryer from Several Perspectives

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Abstract- Solar dryers use the sun's energy to produce hot air, which they then use to dry a variety of foods and agricultural products. Solar dryers have the limitation that they cannot operate constantly in the absence of sunlight. Solar dryers are coupled with thermal energy storage technologies to achieve continuous drying. A solar collector and a place to lay sliced potatoes are the two basic parts of indirect type solar dryers. The quality of the finished product would also rise due to its rapid moisture removal. In the current study, a single-pass indirect type forced convection solar dryer was built. To improve the solar dryer's performance during the times when the sun isn't shining, paraffin was added to the solar collector as a phase-changing material.Thermal energy can be stored in solar dryers as sensible, latent, or a mixture of the two. The numerous sensible and latent storage units, materials, and direct, indirect, and mixed-mode forced convection dryer types are all thoroughly described on this page. We go into great depth on various dryer types, dried commodities, working conditions, materials utilized for sensible and latent heat storage, and their results. The essay goes into great length on the use of thermal storage units in solar dryers. The upcoming difficulties and suggestions for the choice, use, and testing of the thermal storage unit for various solar dryers are also covered. This review study aims to provide an overview of past and present research on materials used as sensible and latent heat storage in solar dryers for drying agricultural food items. Agricultural food items may now be dried in the late afternoon with the storage unit; this was previously impossible with a traditional sun dryer. A solar dryer with a storage container is therefore excellent for preserving energy and assisting people.

Keywords Potato slice dryer, Greenhouse effect, Thermal energy storage, Phase changing materials, Renewable energy, Adsorbents.

1. Introduction

Our energy needs are met by renewable energy, which also helps to mitigate the greenhouse effect by reducing carbon dioxide emissions. All renewable energy is derived from the sun, and by properly harnessing its power, the world can end its current energy crisis. The energy needed for drying is provided from a variety of sources, including the sun, natural gas, and fossil fuels. Solar energy is anticipated to become a widespread source for drying due to the quick depletion of natural fuel supplies, rising fossil fuel prices, and the environmental impact caused by fossil fuels. Rural Indians employ the open sun drying method to dry their agricultural goods, but it has a number of disadvantages, including dust contamination, pollution, damage from insects, animals, and birds, etc.

By removing moisture from edible things like cereals, vegetables, fish, etc., solar dryers play a crucial role in the food sectors for their preservation. They gain from open-air drying because it shields the food from contaminants like dust and insects. They are also credited with increasing energy savings and preventing the deterioration of the environment. A solar collector and a place to lay sliced potatoes are the two primary components of indirect type solar dryers. Their high rate of moisture removal would enhance the final product's quality. India comes in third place behind China and Russia in terms of global potato production. Numerous studies looked at passive solar dyers' inferior performance to those that also used heat storage system. Therefore, more research is required to develop solar dryers that combine heat storage technologies to retain more heat that may be used when the sun is not actively shining.

A forced solar convection drier of the indirect kind will be constructed in the current work. To enhance the accountability of the solar dryer during the non-sunshine hours, three different phase changing materials will be integrated with the solar collector. For drying sliced potatoes, process variables including moisture removal rate, dryer efficiency and drying time were examined.

In India, a tropical country that is quickly developing, over 58 percent of the rural population still earns the majority of their income from agriculture. India ranks among the world's top producers, consumers, and exporters of agricultural goods. According to recent agricultural figures, the rise in gross income from agriculture and fisheries is expected to be around INR 19 billion [1]. In terms of commercial benefits, potatoes are the fourth most significant crop farmed globally, behind maize, wheat, and rice. They have a big impact on the world economy [2]. They are used or consumed in many different contexts, such as snacks, starch flours, and substantial meals. They have a moisture level that varies between 75% and 85% [3]. Squeezing the moisture content out of potatoes during processing is necessary in order to produce a wide range of value-added items from it. In the open sun, potatoes lose quality and develop burns on their surface [4]. For drying potatoes, the sun drier is a preferable solution since it keeps expenses down, the environment safe, and quality requirements high[5].The moist atmosphere around food makes it easier for bacteria to scavenge the food. The moisture is subsequently reduced to the ideal amount, prolonging the edible life and storage options [6]. Removing moisture from agricultural products and herbs is a frequent practice in tropical countries. Drying or dehydration is a typical post-harvest operation and a crucial technique for food preservation all over the world [7].

2. Solar Dryer

Sun dryers dry things in a drying cabinet or tent where drying air is circulated at temperatures ranging from 30 to 80 degrees Celsius. At high temperatures, the moisture carrying capacity of air rises due to a drop in relative humidity and an increase in the drying rate. External drying parameters can be controlled using blowers, exhaust fans, solar air heaters, thermal energy storage devices, extra auxiliary heating sources (such as grid electricity, fossil fuels, and biogas), and sun dryers (inlet air temperature, flow rate of air, relative humidity, and heat input).Solar dryers achieve good quality dried products more quickly than traditional drying procedures because of the little space and clean atmosphere. Following are the classifications of solar dryer.

2.1 Direct Type Solar Dryer

Materials are put in a drying cabinet in a direct type solar dryer, where sunlight penetrates through a transparent sheet cover and instantly warms the items as shown in fig.1 The drying cabinet is made to seem like a greenhouse and includes several racks. To dry products continuously, these direct type solar dryers use a thermal energy storage unit and an additional heat source. Natural convection undergoes air movement as a result of the various densities present throughout the drying chamber. The air is pumped through the drying cabinet using an exhaust fan or blower unit operated by the grid or solar photovoltaic panels in forced convection.

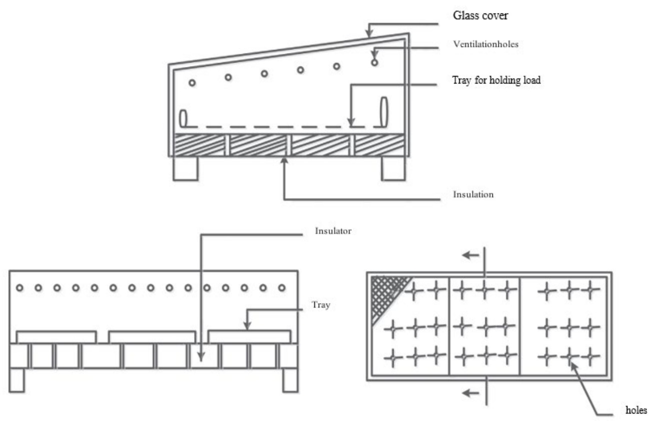

Fig. 1. Direct type solar dryer

2.2 Indirect type solar dryer

The product is dried in an opaque drying chamber away from the sun in an indirect solar drier as shown in fig 2 [21]. Solar air collectors or heaters supply the hot, dry air needed to dry items[8].

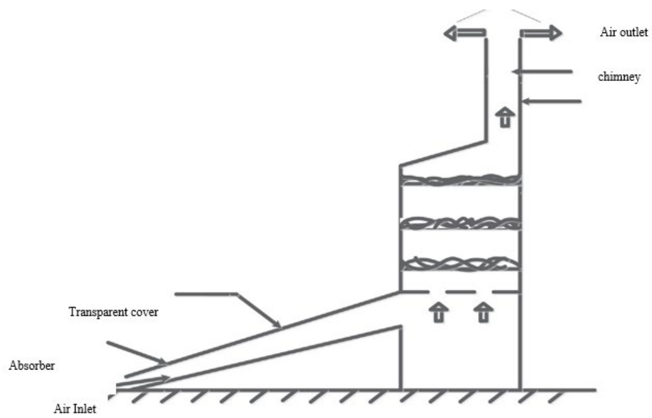

Fig. 2. Indirect type solar dryer

2.3 Mixed Mode Type Solar Dryer

The mixed-mode type combines direct and indirect type solar dryers as shown in fig 3[7]. The product is heated by sun radiation as well as hot air generated by the product's maximum permissible drying temperature and moisture content [9].

Fig. 3 Mixed mode type solar dryer

3. Importance

The quality, financial, environmental, and social elements of the solar dryer are covered in this section.

3.1 Quality Aspect

Food's physical, chemical, and nutritional qualities are changed by mass and heat transfers during drying[10].When compared to sun drying, researchers observed that solar drying with air recycling reduced color changes and volume loss in dried pistachios [11]. According to some research, complementary solar drying of dried lemon samples results in a brighter color than hot air drying at 60 degrees Celsius [12].

3.2 Economic Aspect

Since such investments are typically predicated on deemed economic and technical feasibility, determining the economic sustainability of solar dryer investments demands thorough financial and economic analyses. Comparing the solar dryer to other commercial dryers, it is well known that it is a capital-intensive technology[13].Compared to traditional sun drying method solar dryers provide a variety of economic benefits, including lower costs for fossil fuel and combustion equipment. Additionally, they deliver top-notch results that increase market value and ensure steady and high revenue in a variety of climatic conditions.

3.3 Environmental Aspect

The majority of drying systems use fossil fuels and electricity as energy sources, which has negative effects on the environment due to higher greenhouse gas emissions and high running costs [14]. One of the most effective ways to store thermal energy for greenhouse applications is through the use of phase-changing materials for latent heat storage [24]. As a result, food producers are now relying more on sustainable energy-based technologies including direct and indirect thermal energy from the sun. To estimate the energy consumption of the solar dryer, a researcher suggested using metrics such as embodied energy, time to energy recompense, CO_2 emission, and carbon avoidance [15]. It was demonstrated that a solar dryer system with a 40% efficiency level could reduce the use of conventional energy by 27 to 80 percent. The fan in the forceful circulation greenhouse dryer, according to Liu et al. (2015), utilizes 5% of the total energy used [16]. The solar system's nighttime recovered heat provided 31% of the greenhouse system's total heating needs [27].

3.4 Social Aspect

The Earth is under serious threat from global warming, especially given how much greenhouse gas emissions are now at. By switching from energy based on fossil fuels to energy based on solar energy, governments and industries from all over the world have attempted to minimize emissions [17].The majority of governments implement energy policies to address the issue, which often involve legislation, international agreements, and financial incentives for investment[18].Tax credits have been offered as a means of reducing emissions, however it has been noted that "one-size-fits-all" rewards are unlikely to be effective because energy regulations are often nation-specific. Some nations, like China, Germany, France, Spain, Canada, and Malaysia, promote the use of clean, renewable energy sources like solar power [19].

4. Summary

It offers a thorough overview of the various arrangements of sensible and latent heat storage components utilized in various classes of solar dryers, such as direct-type, indirect-type, and mixed-mode dryers that work in both forced and natural convection modes. There are extensive reports on the several sun dryer types employed, the dry products, operating conditions, and the materials for latent and sensible heat storage used [20].This article offers some recommendations for creating low cost heat storage systems for solar dryers. Below is a summary of some of this review's key points.

- Incorporating solar dryers with sensible and latent heat storage devices enables the continual drying of a range of agricultural and food goods. Temperature changes in the drying room are managed and avoided by the thermal energy storage unit. During the gloomy period, the energy storage decreased temperature swings [25].
- Water, rocks, pebbles, sand, and bricks are the sensible heat storage components utilized in solar dryers most frequently [13]. Sensible heat storage materials range in size from 1 to 5 cm. To prevent unnecessary use, the ideal thickness and volume of sensitive storage material should be carefully assessed beforehand. In solar dryers, water is the only liquid that is used as sensible heat storage liquid. Sensible heat storage materials have the benefits of being readily available, having a larger specific heat capacity, and being inexpensive.

- Desiccants (adsorbents) have not been extensively studied as materials for sensible heat storage. The desiccant is left in the drying chamber overnight to continue drying after being deposited outside during the day. The desiccant unit's exothermic reaction produces sensible heat, which causes the temperature to rise. Additionally, the desiccant system dehumidifies the moist air in the drying cabinet before returning it to the drying chamber or solar air heater.

- With a melting point range of 35 to 80 degrees Celsius, paraffin wax is a frequently utilized substance for latent heat storage. Standard paraffin wax is chemically stable, it is a choice for heat storage in sun dryers, affordable, and non-toxic. The melting point is in accordance with the required temperature for the solar dryer application.

- The phase-changing materials were directly charged in the tubes and microcapsules by either solar light or a working liquid (water, air, glycol, etc.).The solar air heater unit heated the hydraulic fluid while the phase-changing material unit was operating in indirect charge mode. To obtain the appropriate temperature in indirect load mode, a second heater linked to the dryer and control unit regulates the temperature. The low heat transfer coefficient of phase-changing materials from the storage medium to the fluid promotes heat transfer is a drawback. Another drawback is the low charge/discharge rate brought on by the air's poor thermal conductivity. Ribs, metal dies, and encapsulations are just a few of the components employed to boost the system's performance. Recently, nanoparticles have been introduced to phase change materials to increase heat transfer coefficient. If reflectors and materials that store latent heat are combined, the temperature on the collector plate will rise [28].The efficiency of solar systems is also increased by phase-changing materials with high conductivity inserts [26]. Here are some measurable and scalable comparison between different phase changing materials are given below [22]:

S.No	Name of PCM	Melting Temperature (°C)	Thermal conductivity (kJ/kg K)	Latent heat (kJ/kg)
1	Paraffin wax	56	0.24	226
2	Lauric acid	40–43.90	0.16	180
3	Capric-palmitic acid	22.50	0.14	173

- Most dryers operated by solar energy with latent heat storage have intricate characteristics and numerous parts (solar water heaters, solar air heaters, auxiliary heaters, heat exchangers, latent storage and drying chambers). This results in a substantial capital investment. All-weather operational flexibility is provided by integrating the thermal energy storage unit (sensible heat storage and latent heat storage), supplementary heating unit, and heat pump within the dryer. When latent heat storage is used with a solar dryer, the drying period is increased past the time of day. It was found that the latent heat storage unit lessened the temperature swing at the collector exit, causing the drying to be more consistent. In addition, the temperature remained maintained for a brief period of time even when the sun energy changed.

- Due to the fact that aflatoxins are typically linked to most common staples including corn, rice, fruits, and nuts, aflatoxins contamination in foods and feeds is a hazard for human health on a global scale. Aflatoxin-contaminated diets have an impact on animal productivity and health as well. Aflatoxin contamination leads in a high percentage of agricultural product rejection, which consequently generates very significant economic losses and harms the country of origin's reputation. In the agricultural and food industries, hot air drying is perhaps the most popular technology. This process uses hot air as a medium to give heat and remove the evaporated moisture. When compared to sun and solar drying, hot air drying helps shorten the drying period and thereby inhibits the growth of mould. Additionally, this drying method offers a more hygienic production environment [23]. When there is less sunlight, the performance of the solar air heater is improved by the employment of various phase-changing materials. Therefore, a combination of pre-treatment and carefully monitored drying during times of low sunlight may be utilised as efficient strategies to lower the generation of aflatoxins.

It has been noted that using dryers operated by solar energy to dry agricultural products boosts the agricultural community's income because the dryers may be made with locally available materials. Solar dryers effectively preserve the excellent quality and sustainability of a variety of products (fruits, vegetables, and grains).

5. Conclusion

In our experimentation, we must get over the solar dryer's typical flaw, which is that it stops functioning when there isn't sunlight. Because of this, our idea uses phase-changing or latent heat storage materials to store solar heat energy and release it when sunlight isn't available. On the basis of drying efficiency, drying time, and moisture removal rate, we examine paraffin wax,lauric acid and palmitic acid as phase-changing materials or a latent heat storage material in solar dryers. Finally, we must draw a conclusion regarding the amount by which heat transfer rates in horizontal phase-changing material tubes will improve in comparison to vertical phase-changing tubes.

6. Challenges And Future Recommendations

The sensible and latent heat storage components utilized in various sun dryer models intended to dry various produce have been the subject of an unexpectedly large amount of research. Future difficulties and suggestions for the choice, application, and testing of units for storing thermal energy integrated into solar dryers are discussed below based on data which is published.

• Solar air heater and drying chambers use heat storage, both sensible and latent components, making use of both types of heat storage materials (sensible heat storage-availability, economy, latent heat storage-higher specific heat capacity).

• Desiccants (adsorbents) appropriate for the drying process need to be thoroughly investigated. To choose the best desiccant, information is required, particularly regarding drying times and speeds for various types of desiccants.

• Appropriate heat transfer enhancement approaches, including nanomaterials, must be used to address low heat transmission from the phase change materials unit to the hydraulic fluid.

• In order for the dryer to run continuously in all-weather situations, more research is required to incorporate heat pumps, booster heaters, solar panels, and latent and practical heat storage devices. To continually dry products out of the sun, sensitive units, latent heat storage units, biogas units, and desiccants (adsorbents) can be used in combination.

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