IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology
Vol. 3, Issue 5, May 2016

Advancements in Solar Drying: A Comprehensive Review

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Abstract: India produces over 200 million tonnes of food grains annually. There is need of postproduction management system to match with the increasing production rate. Drying is the primary need of crop's postproduction system. Sun drying is a popular mode of crops drying in India. The use of mechanical dryers is almost nil. With ever growing population, the food grain production will increase to meet the demand of people. The crop drying cannot be dependent on sun drying. The produce has to be handled and managed properly to reduce losses. Drying of agriculture produce for safe preservation is one of the important post-harvest operations to save the grain from losses. There is not much facility of drying at farm level, though the losses due to the improper drying is over 10% in food grains and 20 to 40% in fruits and vegetables. Solar drying is a possible replacement for open sun drying. Sun drying is by no means a perfect process with problems arising due to potential contamination of the produce, variability in drying times, rain damage and so on. The present paper presents developments in solar dryer designs for different dryer classifications. Recommendations for energy-efficient design and measures for improvement in existing dryers are also discussed.

Keyword: Solar dryer, Sun drying, Post-harvest loss

I. INTRODUCTION

Drying is a fundamental process used to remove moisture from products and achieve the desired moisture content. It is an energy-intensive operation with various objectives, including extending the storage life of products, improving their quality, facilitating handling and further processing, and ensuring sanitation. Throughout history, drying has been one of the oldest methods employed by humans for preserving food. The drying process involves applying heat to vaporize moisture and subsequently removing the water vapor from the food product. It is a simultaneous operation of heat and mass transfer, where energy is required to facilitate the moisture removal. By eliminating moisture, the growth and reproduction of microorganisms such as bacteria, yeasts, and molds, which cause decay, are prevented. Additionally, many deteriorative reactions that depend on moisture are minimized. Drying also leads to a significant reduction in weight and volume, resulting in lower packaging, storage, and transportation costs. It enables products to be stored at ambient temperatures, which is particularly beneficial for developing countries, military feeding programs, and space food formulations.

Fudholi et al., (2013)designed a forced convection indirect dryer and conducted an exergy and drying analysis of red chilli. The study compared the drying time of red chilli using open sun drying and the forced convection indirect dryer system. The results showed that the dryer system reduced drying time by 49% compared to open sun drying. The average collector efficiency was approximately 28%, and the average exergy efficiency was around 57%. The study concluded that the forced convection dryer system outperformed the open sun drying system. Fudholi et al., (2014) designed a solar dryer and investigated the drying kinetics and exergy analysis of the system for red seaweed. The products were placed horizontally on trays within the dryer, oriented towards the air inlet. The study analyzed the moisture removal rate and drying time. The average collector efficiency was found to be 35%, while the drying efficiency reached 27.1%. The exergy efficiency ranged from 1% to 93%. Midilli, (2003) conducted an energy and exergy analysis of the drying process of shelled and unshelled pistachios using a solar drying cabinet. The study presented graphs depicting the variations of energy and exergy with respect to drying time and collector temperature. Medugu., (2010) Fabricated and studied the performance of a forced convection direct mode solar dryer. In addition to the basic components of a solar dryer, this design consisted of a chimney and a 40 W photovoltaic module used to power and run a dc fan. Drying 50 kg of tomato with an initial moisture content of 90% using this type of solar dryer was completed within 129 h which is about 55% of the time required to dry using natural sun drying. The author also evaluated the performance of the solar chimney dryer in comparison with solar cabinet dryer without a chimney which took about 138 h to dry the same quantities of tomato. Higher quality dried product in terms of its colour and flavour was obtained when using the solar chimney drier. Goyal & Tiwari, (1999)) worked on the new concept of reverse flat plate absorber non-concentrating collector which can collect solar energy at high temperature, unlike conventional non-concentrating collectors. The concept of a reverse flat plate collector has been used as a heating medium of air for drying agricultural products in a cabinet dryer. The thermal performance of the new proposed dryer was analyzed and compared with a conventional cabinet dryer. It was found that the reverse flat plate absorber dryer gives the better performance, and drying of crop was more uniform compared to the normal cabinet dryer because the crop is not directly exposed to solar radiation.

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II. CLASSIFICATION OF DRYERS

Direct solar dryers involve placing the material to be dried in an enclosure with a transparent cover. Solar radiation is absorbed by the product and the internal surfaces of the drying chamber to generate heat (Kreider SF, Kreith F, 1981). Brenndorfer et al. (1987) designed a simple dryer consisting of a tent-like framework covered with plastic sheeting. The ends and sun-facing sides are covered with white plastic sheeting, while the shaded side and ground within the tent are covered with black plastic sheeting. The drying tray is positioned centrally along the length of the tent.

Sharma et al. (1990) conducted a performance evaluation of a direct-type solar dryer. The predicted plate temperature reaches a maximum of 80-85°C during noon hours under no load conditions, while with a loaded condition, the maximum temperature is approximately 45-50°C. The decrease in plate temperature with a drying load is attributed to a significant portion of the heat being utilized for water evaporation, limiting temperature rise. The study also observed that the equilibrium moisture content is reached rapidly for small loads but takes longer for higher load values.

Ekechukwu and Norton (1997) designed and developed a natural circulation type solar dryer suitable for drying various crops. Experimental results demonstrated the superior drying characteristics of integral-type, natural-circulation solar-energy dryers compared to traditional open sun drying methods.

Medugu (2010) fabricated and studied the performance of a forced convection direct-mode solar dryer. This design included a chimney and a 40 W photovoltaic module to power a DC fan. Drying 50 kg of tomatoes with an initial moisture content of 90% using this solar dryer was completed within 129 hours, which is approximately 55% faster than natural sun drying. The author also compared the performance of the solar chimney dryer with a solar cabinet dryer without a chimney, which took about 138 hours to dry the same quantity of tomatoes. The solar chimney dryer resulted in a higher quality dried product in terms of color and flavour Fig . 1.

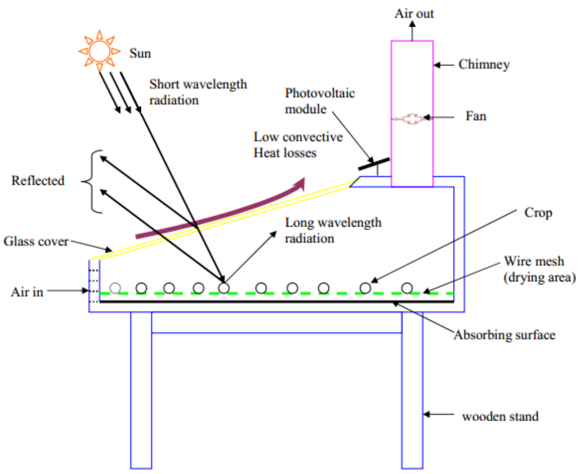

Figure1. Forced Convection Direct Mode Solar Dryer (Medugu, 2010)

James et al (2012) investigated the performance analysis between two mixed-mode solar dryers. The dryers were identically constructed, one of the dryers utilized mobile and easily adjustable flat concentrating solar panels to maximize incident solar energy on the dryer. Temperatures inside the dryer that utilized the concentrating solar panels were approx. 10 °C higher than those in the normal dryer. Test performed by drying tomato Fig.2. The concentrating solar panels increases drying rate, with a 27% decrease in total drying time as compared to the normal dryer. The faster drying rate achieved in the dryer utilizing solar concentrators, under both sunny and simulated cloudy conditions.

Figure 2. Solar dryer and two concentrating solar reflection panels (James et al 2012)

Cakmak and Yıldız (2011) a solar air collector with phase-change material (PCM) and drying room with swirl element.

An expanded-surface solar air collector has been used to achieve high heat transfer and turbulence effect whiles a solar air collector with PCM has been used to perform the drying process even after the sunset. In this system, the drying is uniform and the products dried by system with PCM in swirl flow media achieve lower moisture values in shorter time. The experiments have been conducted at three different air velocities.

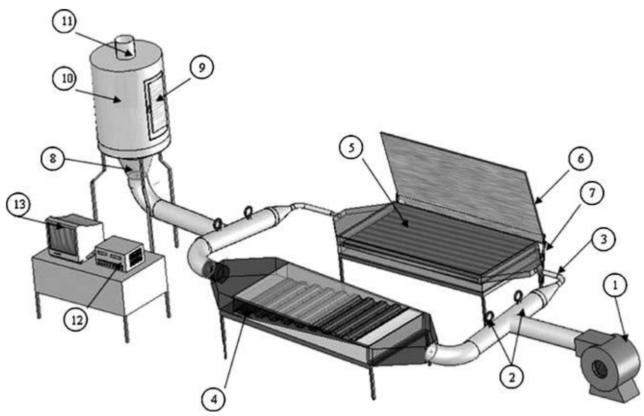

Figure 3. PCM integrated solar dryer system (Cakmak and Yıldız 2011)

In addition to using only solar energy, hybrid systems incorporate another means of heating the air for drying a produce (Brenndorfer et al., 1987). This enables the dryer to be operated during cloudy periods as well as at night.
Chauhan et al (1996). They studied the drying characteristics of coriander in a deep bed dryer coupled with a solar air heater and a rock bed storage unit. A rock bed storage device stores heat during sunshine hours and discharges the heat to ambient air during off-sunshine hours. The theoretical investigation was made by writing the energy and mass balance equations for different components of the dryer-cum-air-heater-cum-storage device and by adopting a finite difference approach for simulation. The drying performance with and without rock bed storage was compared. The results revealed that for reducing the moisture content from 28.2% (db) to 11.4% (db), the solar air heater takes 27 cumulative sunshine hours, i.e. about 3 sunshine days, whereas the solar air heater and the rock bed storage combined take 31 cumulative hours, i.e. about 2 days and 2 nights at an air flow velocity of 250 kg/hm2 , and recommended that the heat stored in the rock bed can be used effectively for heating the inlet (ambient) air for off-sunshine drying of agricultural produce.

III. CONCLUSIONS

Solar drying is a versatile and sustainable method for removing moisture from various products. It harnesses the power of the sun to generate heat, facilitating the evaporation of water and preserving the quality of the dried products. Through the use of direct and indirect solar dryers, significant advancements have been made in enhancing drying efficiency and reducing drying time. The classification of solar dryers, such as direct solar dryers, natural circulation dryers, and forced convection dryers, offers a range of options to suit different drying requirements. These dryers utilize innovative designs and technologies to optimize heat transfer and airflow, resulting in improved drying performance. Numerous studies have demonstrated the benefits of solar drying, including extended shelf life, quality enhancement, energy efficiency, and cost savings. Solar drying not only reduces dependence on fossil fuels but also minimizes environmental impact by utilizing renewable solar energy. Furthermore, solar drying has proven to be a viable solution for various applications, including food preservation, agricultural products, medicinal herbs, and even space food formulations. Its versatility and effectiveness make it an attractive option for both industrial and small-scale drying operations, particularly in areas with abundant sunlight and limited access to conventional drying methods.

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