A Review on Performance Enhancement of Solar Drying Systems

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Abstract

Solar thermal technology is emerging as a promising alternative in fulfilling the global energy requirement. Solar dryers, utilising the power of solar energy, are rapidly gaining global acceptance in the drying of agricultural products as a potential substitute for natural and fossil fuels. Fluctuation and non-availability of solar irradiation is the major challenge faced by solar dryers. This setback can be alleviated by capturing the sun’s energy during peak radiation time and later using it during inadequate radiation times or during night times. Solar dryers with thermal energy storage systems offer optimum steady state temperature (45 - 75°C) for drying of agricultural produces. Besides exhibiting reduced drying rate, these storage units extend the drying time of the solar dryer system during late evening hours. As PCM plays a vital role in enhancing the performance of solar drying systems, this paper attempts to present a summary of investigations of solar drying systems integrated with phase changing materials as latent heat storage for drying of agricultural products.

1. Introduction

Drying is an essential process in the preservation of agro produces. It greatly minimizes post-harvest losses as it brings down the moisture contained in the product to a safe level, thereby extending its shelf life and improving its quality. Traditionally crops were dried either under open sun or by burning of natural or fossil fuels. As they impose severe negative impacts on the environment and considering their rapid rate of depletion, the world is inclined towards an alternative reliant source of power, solar energy, as a key solution for a clean and green energy future. Solar drying is rapidly gaining global acceptance because of its significant potential in the preservation of agricultural products. Solar drying is an emerging technology, involving the use of solar energy, for a wide range of applications. Solar drying technology offers a highly effective and practical means of crop preservation system.

Drying of agricultural products under controlled temperature and humidity ensures eminent quality of the products that are dried. Many agricultural products, in particular fruits and vegetables, need temperatures ranging between 45-75°C to be dried safely. Suitably designed solar dryers is a promising
choice for solar drying of agricultural produces, especially in the tropical and sub-tropical countries, which have adequate sunshine almost throughout the year. The intermittent nature of sun’s energy can as well be nearly compensated by capturing the excess solar energy during high radiation times and using it later on during inadequate availability or when the sun goes down.

2. Solar Dryers

Solar energy is a sustainable and free source of energy that is inexhaustible, non-polluting, and renewable. Solar energy is a blessing for farmers and agri-based industries as it can supplement their different energy requirements with one solution in the form of renewable energy. With the advent of technology, solar-assisted drying is becoming the most promising, cost-effective, and environmentally friendly application of solar energy. Solar power, an indirect form of solar energy, in the form of solar dryers is used for drying immensely in food and agricultural industries. With solar dryers, it is possible to protect crops, grains, fruits and vegetables, dry them faster and more evenly and deliver quality products than conventional drying methods. Solar dryers heat air to a constant temperature with solar energy and extract moisture from the products to be dried. Solar dryers are categorised as natural convention type and forced convection type. Figure 1 shows the classification of solar dryers.

![Figure 1 Classification of Solar Dryers](image)

2.1 Natural Convection Type:

In natural type, no external factor is required to deliver heat for dehydration of the product. Natural convection type solar dryers maybe direct, indirect or mixed mode type.

2.1.1 Direct Solar Dryer:

Direct solar dryers are stand alone units in which both collection of solar energy and drying of the product take place in a single unit, the drying chamber, where the product gets directly exposed to solar radiation. The roof of the dryer is painted black to take in more incident solar radiation. The rays of the sun pass through the roof and heat the air inside the dryer chamber. The product to be dried directly absorbs the radiations of the sun, gets heated up and release moisture by evaporation which goes out by natural convection due to difference in vapour pressure.
These dryers are small, cost-friendly and easy to operate and are used by both small and large scale farmers. The main disadvantage is that heat absorbed by the product cannot be controlled and sometimes the products may undergo undue changes in quality because of being directly exposed to sunlight.

2.1.2 Indirect Solar Dryer:

In indirect solar dryer collection of solar energy and drying of the product take place in separate units. These dryers have two parts of an air heater which is usually a black flat plate and a drying chamber. The flat plate air heater heats up the incoming air and with the help of a blower this hot air is circulated inside the drying chamber. Upon absorbing moisture released by the wet product by convective heat transfer, the hot air finds its way out through a chimney. Drying temperature varies according to the crop to be dried. The main advantage of these dryers is that high and controlled temperatures can be achieved. As cost and complexity is involved in construction, these dryers are usually used by large scale farmers.

2.1.3 Mixed Mode Dryer:

A mixed mode dryer blends the key features of both direct and indirect solar dryers. In a mixed mode dryer, collection of solar energy takes place in both flat plate air heater and the drying unit and drying happens only in the drying chamber. Here the product is dried simultaneously by both hot air from the solar collector and by direct solar insulation absorbed by the walls or roof of drying chamber. Drying is achieved at a faster and improved rate with controllable drying temperature. Better quality of dried products is seen. As construction involves complexity, it is affordable only by large scale farmers.

2.2 Forced Convection Type

Operation and types of these dryers are identical to natural convection dryers, but with an additional fan/blower that blows hot air continuously over the products to be dried, resulting in much faster and more efficient drying. Relatively these dryers are thermodynamically competent and could be used to dry a wide range of agricultural products.

3. Thermal Energy Storage

In order to compensate the huge gap between energy supply and required demand, storage of energy is emerging as a prominent issue to be addressed. Solar dryers provide hot air only during sunshine hours. As solar radiation availability is intermittent at times and season dependent, its unreliability is the greatest challenge faced when it comes to solar energy usage by large. Many of the agro produces require steady temperature, continuously for few days to be dried right. Therefore, energy storage has become indispensable where steady use of solar energy is required. The possibility of continuous drying during intermittent solar radiations and also during late evening hours can be achieved by integrating a thermal storage unit in the solar dryers. These storage units can be charged during peak radiation hours. The stored charge can later be used during off sunshine hours to enhance continuous drying. Thermal energy can be collected or stored in the form of sensible heat storage or latent heat storage in thoroughly insulated solid form or liquid form as a result of changes in the internal energy of the storage material. Figure 2 depicts the classification of thermal energy storage.

3.1 Sensible Heat Storage
Thermal energy is retained by changes in temperatures of the sensible heat storage materials which may be solid or liquid. The material’s heat capacity and changes in its temperature during the course of heating and subsequent cooling is used to store energy in the storage materials. Usually these materials are cost friendly and available extensively.

3.2 Latent Heat Storage

In latent heat storage, the energy storage material stores heat energy during phase transition. Phase change Materials (PCM) are widely preferred as storage materials because of their property of high energy storage and constant temperature operation. PCM store and release sufficient heat energy during phase transition. Heating up of a material induces phase shift owing to which energy is stored in latent heat form, generally referred as latent heat storage process.

3.3 Thermal Chemical Heat storage

In thermo chemical systems, energy is absorbed and released during the breaking and subsequent reforming of molecular bonds in a chemical reaction that is completely reversible.

Amongst the three storage methods, latent heat is most preferred because of its capability of high energy-storage density.

4. Literature review on performance enhancement of solar dryers with latent heat storage medium

Many researchers have investigated performance enhancement of solar dryers by attempting to extend the system’s availability after sunset by incorporating thermal energy storage medium.

Rabha and Muthukumar[1] investigated a solar drying unit with a shell and tube paraffin wax LHS. Twenty kilograms of red chilli were dried both under open sun and in the dryer. The LHS was reported to maintain higher temperature with minimum fluctuations during the afternoon hours. It also extended the usage of the system for a few hours after sunset. With a saving in drying time by 122.8% against open sun drying, the exergy and average efficiency of the system were reported as 24.2 – 98.9% and 52.2% respectively. Sivakumar [2] analysed the moisture removal rate of tender coconut using a solar dryer.
having paraffin wax and brick as thermal storage medium. Efficiency of the system in terms enhancement of drying rate was studied. The moisture removal rate during peak insolation time and the one after an hour of reduction in insolation was reported to be nearly the same. Jain and Tewari [3] studied drying of mint leaves experimentally. The fabricated solar crop dryer consisted of packed bed PCM of 48 cylindrical tubes which was stacked with 48 kg of paraffin wax. The mass flow rate was maintained in the range 0.2 – 0.4 kg/s and 10 kg of mint leaves were loaded for drying. PCM maintained the dryer temperature between 40 - 45°C after sun down and extended the working of the system by 5 – 6 hours. Shalaby and Bek [4] conducted performance investigation of an indirect solar dryer with PCM loaded in two plastic cylindrical containers fixed at the underneath of the drying chamber. Thirty two copper tubes were inserted were inserted vertically inside the PCM box for heat transfer between hot air and PCM. The dryer was analysed for its efficiency with no load, with and without PCM thermal storage. From the observational results, the dryer with PCM rendered drying air at 42.5 ± 2.5°C after reduction in sunshine for seven consecutive hours. Reyes et al. [5] studied drying characteristics of mushroom using a hybrid solar dryer with paraffin wax as PCM. The storage unit had 100 copper pipes loaded with 14 kg of paraffin wax and aluminum fins located externally facilitated heat transfer of drying air. PCM extended the working of the system by 2 hours.

Bharadwaj et al. [6] investigated the drying behavior of medicinal herb, Valeriana Jatamansi, using an indirect solar dryer with paraffin RT-42 and PCM. Additional thermal storage, as a mixture of gravel and iron scalp with engine oil was also used. PCM and additional thermal storage enhanced the performance of the system. Also, PCM extended the working of the system by 7h after sunset, maintaining the temperature upto 10°C above ambient. Baniasadi et al. [7] investigated drying characteristics of fresh plums and apricot slices using a forced convection mixed-mode solar dryer without and with thermal energy storage. Copper coils containing granulated paraffin were placed at the bottom plate of the dryer chamber and used as the thermal energy collector. Use of paraffin based thermal energy collector reduced drying time by 50% and improved the overall thermal efficiency and pick-up reliability of the system. Sivaraman and Krishnan [8] constructed a solar dryer with paraffin-kerosene in the ratio 2:1 as thermal storage. The dryer was analysed for difference in temperature with and without thermal storage. Based on the observations, thermal storage improved the system’s average efficiency by 50%. It also helped maintain higher cabinet temperature for 3h after fall in solar radiation intensity. El-Khadraoui et al [9] investigated experimentally using PCM (paraffin wax) in a forced convective type indirect solar dryer for the number of hours it can be made available during night time. The dryer was tested with and without PCM for no load condition. When operated with PCM, the system exhibited 16°C higher temperature compared to ambient. The relative humidity of the dryer chamber was lower by 17 - 34.5% compared to relative humidity of ambient. Aggarwal and Sarviya [10] evaluated performance effectiveness of a simple and cost effective LHS unit containing paraffin wax by studying drying characteristics of potato slices during the discharging time. The LHS unit effectively reduced the moisture content of the potato slices to the desired value. It also helped maintain the drying air temperature 5 - 19°C above ambient and extended the system’s working by 10h during the night time. Arun et al. [11] studied uniform drying of unripe banana flakes inside a multi-tray mixed mode solar cabinet dryer with paraffin wax as the heat storage medium. PCM enhanced the drying rate rapidly. Uniformly dried and good quality of banana slices was achieved by the system. Also, the system was reported to dry 5 times as many banana samples as it did under the open sun. Lakshmi et. al. [12] investigated a forced convection mixed mode solar dryer incorporated with latent heat storage to study the drying behavior of black turmeric. A latent heat storage system in the form of shell and tube was used with paraffin wax installed in the shell. The devised system took 18.5 hours to dry product whereas under open sun it took nearly 46.5 hours to dry. The solar dryer's overall efficiency was reported as 12.0%.
5. Conclusion

The key to green energy future is the effective use of solar energy, which is a reliable and non-exhaustive energy source. This paper reviews investigations on solar dryers with phase changing materials to improve the performance of drying of agricultural products. It can be concluded that in many of the recent investigations, PCM is being focused as a prime medium for storing thermal energy, owing of its high density energy storage capacity. PCM helps to reduce heat losses and improves the heat conductivity of the system. Also, PCM narrows the gap between energy demand and supply by efficiently utilising solar energy source, thereby leading to energy conservation. Using PCM in solar dryers enhances the system’s reliability and also ensures continuous drying of agricultural products even beyond sunshine hours. PCM ensures that the products are dried faster in lesser time and are of higher quality with regard to its texture, colour and nutritional value.

6. References

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