Journal of Mechanical Engineering Research and Developments
ISSN: 1024-1752
CODEN: JERDFO
Vol. 44, No. 7, pp. 131-140
Published Year 2021

A review of the indirect solar dryer with sensible heat storage mediums

Tan Sang Le[†], Tri Hieu Le[‡] *, Minh Tuan Pham[‡†*]

[†] Institute of Engineering, Ho Chi Minh City University of Technology (HUTECH), Ho Chi Minh city, Vietnam
[‡] Institute of Maritime, Ho Chi Minh City University of Transport, Ho Chi Minh city, Vietnam
[‡†] School of Transportation Engineering, Hanoi University of Science and Technology, Hanoi, Vietnam

*Corresponding author email: lehieumttvimaru@gmail.com; tuan.phamminh@hust.edu.vn

ABSTRACT

The quality of agricultural products will have deteriorated as the preserved technology is inadequate and the storage process is not guaranteed. postharvest losses have been overcome with advanced techniques in production processes. Drying is applied to preserve food as well as agricultural goods. Utilizing the sun's energy for drying has been performed historically. Different designs of solar dryers with a variety of capacities are available in the agricultural sector. Among them, an Indirect solar dryer (ISD) is potential for food products however its drawback is unable to work after sunset. Techniques extend its operation at off sunshine hours for performance enhancement have not been reviewed in detail. This review aims to assess the features along with the advantages of sensible heat storage material (SHSM) in ISD. Common types of ISD with SHSM are presented and the review, discussion, and tabulation of obtained findings on ISD with various sensible heat material have been carried out. It is potential to develop a solar dryer system that employed thermal energy storage materials which have high thermal efficiency and appropriate cost and substitute possibly to fossil fuel in both the developing and developed countries. The storage unit usage, Drying process in ISD for agricultural food can be conducted at off sunshine hours, which was impossible with a conventional solar dryer. As a result, solar drying agricultural products with sensible heat storage materials benefit the energy conservation as well as the performance of solar systems.

KEYWORDS

solar energy, indirect type solar dryer, heat storage material, food preservation.

INTRODUCTION

The drying process is important to preserve products of the agriculture field. The safe temperature of high-temperature air for drying fruits or vegetables ranges from 45 to 60°C. Managing well temperature along with humidity will make food products reach quickly targeted moisture content and guarantee their superior quality [1]. In practice, almost all industrial drying processes are controlled. In industrial drying, increment of air temperature is usually conducted with the support of fossil fuel usage. It is a fact that the majority of fuels are utilized globally for this aim [2]. However, recently, many nations plan to reduce the dependence on fossil fuel due to high costs, depletion of its reserve as well as issues related to the environment [3, 4]. It is also noted that in developing nations, electricity shortage in most rural causes the usage of non-renewable energy sources for agricultural works to be unreliable and expensive [5]. As a result, it is inappropriate to apply electrical-based fans or heaters for crop-drying systems and unreasonable for small farmers due to the high capitalization and operating expense of fossil fuel-based dryers.

In developing countries, energy spending on drying is a major component of the total energy consumption, including commercial and non-commercial energy sources [6]. Quality drying is the benefit of industrial drying while high operation cost and environmental concerns limit its usage Solar energy is available, environmentally friendly, which is considered attractive alternative energy for sustainable future development. As a result, solar energy systems will be introduced on a large scale [7]. Moreover, solar energy is applied for a variety of purposes such as electrical generation (solar photovoltaic cell), maritime transportation, the distillation of water, air and water heating, and ventilation [8-13]. Open-sun drying is an ancient technique to preserve food, which has cost-effective but the quality is not ensured. Harnessing the energy of the sun in agricultural products dryer is considerable promising, which can address not only the disadvantages of open-sun drying but the environmental issue of fossil fuels used in industrial drying also. Different from the internal combustion engine and power plants, the solar dryer is not released greenhouse emissions such as CO, CO_2, NO_x, or other hazardous smokes [15].

Additionally, the stability of the product is enhanced, packaging problems are minimized, and the weight and cost of transportation can be optimized [16]. Nevertheless, the commercialization of solar energy dryers is not popular due to high initial investment, limitation of solar irradiation and operation time, not much-skilled manpower, and difficulty to maintain equipment [17]. Different agricultural products for example grains, fruits, vegetables even medicinal plants can be dried by open and direct solar drying (DSD) [18]. However, the drying quality, performance, and efficiency of the indirect solar dryer (ISD) are greater compared to such two techniques [19]. The other benefits of ISD are: better management as appearing over-drying, remain the color of products which are sensitive with ultraviolet radiation such as lemon, papaya, tomatoes, etc, no damage from heat for crops, and higher moisture removal [20]. Besides that, a mix mode solar dryer has been designed to utilize the advantages of DSD and ISD [21]. A review on the different types of solar dryers was conducted in the study of Singh et al. [22] and the techno-economic of hybrid solar electric dryers was analyzed by Nwakuba et al. [23]. Air was supplied into the solar collector by either natural convection or forced convection.

Improvement of natural convection heat transfer in enclosed engineering applications was reviewed by Ayed et al. [24]. But, a large area of the collector's surface is requested due to the low energy density of solar radiation. In addition, the large variation temperature of hot air can be gained by the solar devices only as there is sunshine. Many studied have been carried out experimentally and theoretically to improve the performance of solar air heater [25][26]. Whereas, the temperature for drying agricultural products (for example foods or vegetables) is steady and moderate [27]. Therefore, the drying process is performed in several days [28]. As a consequence, a solar air heater needs to store heat for drying when the weather is cloudy or in off sunshine times. Therefore, the solar dryers can be improved the utility along with reliability with the storage system [29]. In thermal storage, the charged process is carried out at the high solar radiation and the discharged process is utilized to remain warm air at off sunshine times [30] [31]. The simulation, designs, experimental investigation of solar air heaters for drying crops have been conducted by a variety of researches [32]. It is important to choose the appropriate dryer agricultural products in especially, tropical countries, where has a rainy season. In spite of certain literature on ITDs, no specific studies have contributed to references of ITDs with sensible heat storage approaches. This study fulfills the above gaps and extensively reviews the researches on ITD to draw considerable contributions. Reviews ISDs with SHSM based on various designs, influence parameters, and heat storage techniques.

WORKING PRINCIPLE OF INDIRECT SOLAR DRYER

Two main parts of the ITSD are the drying cabinet and solar collector and they are integrated. The former consists of trays to keep materials while the latter normally is a solar flat plate air heater. A simple solar air heater comprises a flat plate absorber and a glass or plastic cover, which inclines an angle similar to the latitude of the drying place. Black color is the best choice to pain the absorber because it absorbs the highest solar intensity compared to other colors. As solar intensity reaches the solar air heater, a small part of solar intensity is reflected and absorbed by glass, while the absorber plate absorbs the rest. The temperature of the absorber rises and simultaneously transfers convection heat to the air. After flowing through a solar heater, air with high temperature dried the food and remove its moisture.

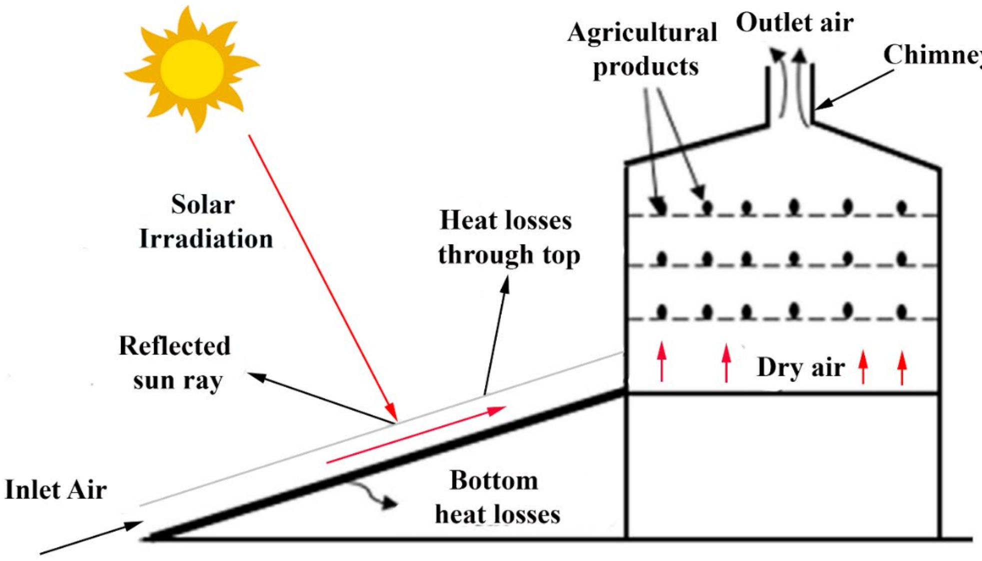

Figure 1. Schematic view of the indirect type solar dryer (ISD) [1].

SENSIBLE HEAT STORAGE

Utilizing intermittent energy sources to meet global energy needs can be solved by applying energy storage, especially renewable resources like solar. Energy can be stored in terms of mechanical, electrical as well as thermal energy by various techniques [33]. The charging and discharging process in the sensible heat storage system is performed due to utilizing the heat capacity of solid or liquid for a temperature change of the material. The parameters affect how much heat is stored including the specific heat, the temperature change, and storage mediums [34]. The sensible heat storage capacity of some commonly selected materials is shown in Table 1. Water is well known as the best SHS liquid due to its low cost and high specific heat. However for temperature is more than 100ºC, molten salts, oils, and liquid metals, etc. are used above. Rocks are employed for applications to increase air temperature.

Table 1. Properties of sensible heat storage material (SHSM) [35][36].

Phase type	Storage material	Range of Temperature	ρ (kg/m^3)	C_p (J/kg K)
Solid	Rock	20	2560	879
	Sand	200-300		1.3
	Bricks	200-800	1600	840
	Granite		2400	790
	Pebble stones	-	1920	835
	Concrete	200-400	1900-2300	850
Liquid	Water	0 - 100	1000	4190
	Caloriea HT43	12 - 260	867	2200
	Glycerin	17 - 290	1260	2420
	Liquid Paraffin	0 - 200	900	2130
	Molten salt	0 - 400	1950	1570
	Engine oil	0 -160	888	1880
Organic liquid	Ethanol	0 -78	790	2400
	Proponal	0 - 97	800	2500
	Butanol	0 -118	809	2400
	Isobutanol	0 - 100	808	3000
	Isopentanol	0 - 148	831	2200
	Octane	0 - 126	704	2400

*Note: ρ: density, C_p: Specific heat

Water, as well as thermal oil, are the most popular for both heating and cooling aim among liquid sensible heat storage. Moreover, the best storage media also belongs to water because of its advantages [36]. First of all, water is a cheap, harmless, nonflammable, and available element in the world. Secondly, it is easy to handle and manage without heat exchanger requirements. High density, specific heat capacity along thermal diffusivity are the third benefit. Fourthly, it is able to perform the charging and discharging process simultaneously. Finally, all types of the tank can store water which is easy to blend with additives. Besides, the usage of water for storage purposes has disadvantages: Limitation of operation temperature (0°C to the boiling temperature of 100°C), high pressure of water vapor at high temperature (above 5 bar); cause of corrosion and not easy to get stratification. Meanwhile, the application operates under low-temperature can use either ethanol or propanol. However, high flammability is their drawback for solar drying systems, which require complex handling leading to increment of cost.

By contrast, solid sensible heat storage can tackle the high vapor pressure of water and the drawbacks of liquids sensible heat storage. the most popular used storage solids are soil and rock piles because they are inexpensive and available. Generally, The advantages of solid storage mediums consist of not chemically reactive, have better energy storage ability comparing to liquids, and low pressure of vapor. Thereby, they can work without pressure-containing container. Their nature requires to circulate of drying fluid (air) for heat transfer in the charging process as well as discharging process. Thereby, the drying air constant direct contact between and the solid material needs to be maintained which has negative effects on thermal efficiency [37].

INDIRECT SOLAR DRIER (ISD) WITH SENSIBLE HEAT STORAGE MATERIALS (SHSM)

The usage of a thermal storage system help ITSD operate possibly in off sunshine hours. The devices that can store solar energy in terms of sensible and latent heat are described in Figure 2 (a) to (c). TES medium can be fabricated under the absorber plate which directly transfers conductive heat to them which is described in Figure 2a (Type A). In Figure 2b (Type B), TES material is set up at the lowest tray in the chamber. In the daytime, hot air dry agricultural products, and a part of the heat is stored by TES material which will be utilized in the evening time. Different from the above designs, a model in Figure 2(c) (Type C) uses the heat exchanger or storage tank. Water is used and heated up by a solar water heater. This high-temperature water transfers heat to TES medium in the storage tank which then increases the temperature of the drying air.

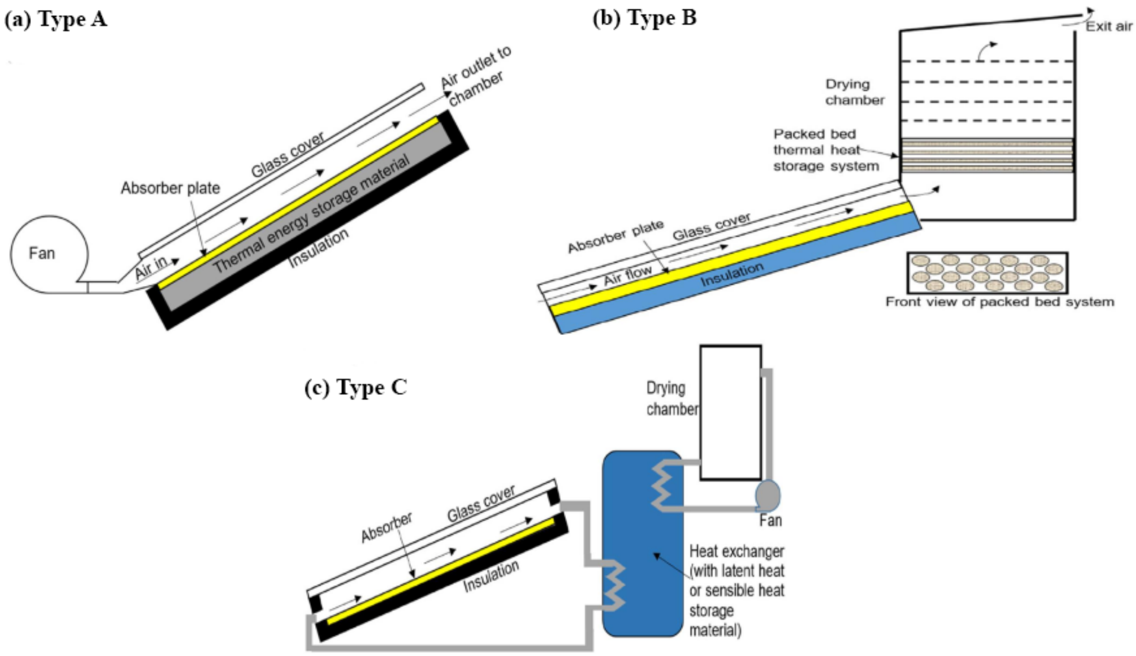

Figure 2. Different types of indirect solar dryers with heat storage material. [1]

Mohanraj and Chandrasekar [38] analyzed the performance of a solar dryer under force convection air to dry copra in India. The solar dryer included a drying chamber, solar air heater, and centrifugal fan. The sand was a sensible heat medium fabricated in the gap of 100 mm between the insulating layer and copper absorber plate of the solar air heater. The inclined angle of the solar air heater was 25^{o}C and faced the South direction. There were

3 trays in the drying chamber which is made of mild steel and insulated by glass wool. After 82 hours, the average moisture content of coconut was declined from 51.8% to 7.8% (wb) and 9.7% for the bottom tray and top tray respectively. The average thermal efficiency of their solar drier was 24%.

A dryer system applied heat storage system was proposed by Nabnean [39] for dehydrated cherry tomatoes. The main parts of such a system were a solar water heater, a water storage tank, and a drying cabinet in which a heat exchanger, blower, and 18 trays were arranged. This system dried 100 kg of tomatoes in 4 days under an air-drying temperature of 30 to 65 °C. The effect of bird, dust, and rain was prevented as drying. The Moisture content reduced from 62% to 15%, which is quicker than open sun drying. Estimation of payback time showed 1.37 years for their system. It is acceptable for the color change of dehydrated cherry tomatoes. Type A was studied in [40] to enhance the drying time along with the quality of chilies and fenugreek leaves. Instead of a flat plate, the absorber of the solar air heater was modified into a thin box and thermic oil was filled in such box as the sensible heat medium. Two kilograms of chilies and 1 kilogram of fenugreek leaves were dried in 4 days and 1 day respectively, which is improved compared to open sun drying, detachable dryer, and foldable dryer. Drying efficiency ranged between 8.35 and 21% for chilies, and 13.4 to 15.2% for fenugreek leaves. They suggested that their system was suitable for chilies, fenugreek leaves, mint, onion, and grapes which were sensitive as drying directly with solar irradiation. The cost of such dryer raised by 10% due to usage of thermic oil however drying time reduced 40%.

Shanmugam and Natarajan [41] built and tested an ITSD applied desiccant as a storage material. the construction of the dryer arranged a desiccant bed, which was installed at the top of the dryer. The desiccant medium consisted of bentonite (60%), vermiculite (20%), calcium chloride 10%, and cement, which was molded in copper cylinders. The system's performance was investigated by drying pineapple slices along with green peas with a total mass of 20 kg. The thickness of the pineapple slice was 10 mm. The mass flow rate of air through the solar heater was 0.01 kg/m^2 s and change to 0.035 kg/s during the off sunshine period. Finding in their work obtained that with reflective mirror, the time for drying pineapple declined by 4 hours while reduced by 2 hours for green peas. The drying efficiency ranged from 43 to 55% and the pick-up efficiency ranged between 20 and 60%. Vlachos et al. [42] used 125 liters of water for storing heat, which was kept in 25 sealed metallic boxes under a drying cabinet. Their experiment was conducted under full and without load, and various weather conditions. The drying process for materials dried was completed at a satisfactory rate. The estimation of drying efficiency was 45%.

An analytical model was developed by Jain and Jain [43] to analyze the performance of a deep-bed dryer for grain with SHS material integrated with a multipass solar air heater. The moisture content went down from 0.28 to 0.11 in 24 hours. Their research showed that the mass flow rate of drying air was proportional to its temperature. The temperature of grain increased with the rise of collector length. Heating the drying fluid in the off-sunshine period was supported by TES. Their work observed that increment of grain bed depth leads to grow up of the drying rate and humidity of drying air. Jain [44] presented a solar dryer for 95 kg onions with two absorber plates placed on top and bottom of the drying cabinet. Under the inclined top absorber plate, a triangular cavity was set up and fulfilled with granite grits that act as sensible heat storage while the bottom absorber received solar energy with the support of the reflected system below. The effect of airflow and height of the packed bed on the crop temperature was estimated. This system took 1 day to reductant of the moisture content from 6.14 to 0.27.

A force convective multi-pass solar air collector was investigated experimentally and theoretically by Kareem et al. [45] for drying Roselle. The sensible heat storage material was used in their study was granite. According to their results, the thermal efficiency of the solar air heater, moisture removal, drying process were 64.08%, 67%, and 36.22%, respectively. It took 14 hours to dried roselle from 85.6 of initial moisture content to 9.2%, which is 21 hours less than that taken by opening the solar dryer. The development of a theoretical model was proposed by Aboul-Enein et al. [46] for performance estimation of a solar dryer augmented with a solar air heater in case of with and without the sensible heat storage system. The weather of Tanta, Egypt was selected for their study. Sand, water, and granite were studied to investigate the effect of design parameters of the solar air heater. Obtained results revealed that the different temperatures between exit air and ambient air with sand, water, and granite, was 32.7°C, 21.8°C, and 29.0°C, respectively. A remarkable finding observed that 0.12 m was the optimized thickness as designing the heat storage material, which is convenient for various agriculture products

El-Sebaii et al. [47] designed and studied an ISD under natural convection with and without sand medium placed under the absorber for heat storage. The agricultural products were dried including apples, figs, seedless grapes, onions, tomatoes, and green peas. According to their results, the use of sand reduced the drying process by 12 hours. Furthermore, 8 hours was reduced more as the products were pretreated chemically in 60 seconds in boiling water consisting of olive oil (0.4%)and NaOH (0.3%). They concluded that chemical pre-treatment and storage material are the main causes of drying time improvement. Vijayan et al. [48] carried out a study with the same design but under forced convection conditions for bitter gourd drying. Pebbles were applied below the absorber as a sensible energy storage medium. It took 7 hours to remove moisture content from 92% to 9%. The collector and dryer have an efficiency of 22% and 19% respectively.

The integration between ISD and pebble medium for camel meat was design, constructed, and analyzed by Chaouch et al. [49]. Two positions were set up for solar air heaters. A conventional solar air heater was linked to the under of the drying chamber whereas, a triangular solar air heater was installed on top of the drying chamber. Pebble was installed under two absorbers which improved thermal efficiency up to 28% and 11.8% for solar air collector and chamber dryer. The moisture content reduced from 4% to 0.3% in 41 hours in July and 65 hours in November. It is obtained that the thermal efficiencies in July and November were 18.34% and 15.52%, respectively. They remarked that the desired quality could be maintained by using salt to pre-treat meat. Ayyappan et al. experimented to dry coconuts by solar greenhouse drier under natural convection conditions and they improve its performance with three sensible heat storage materials: concrete, sand, and rock bed [50]. Their findings revealed 4 inches was the optimum thickness for both sand and rock bed, which provided the highest temperature of drying air. Further interesting in their work obtained that rock bed usage has the lowest drying time (53 hours) for reducing the moisture content of coconut from 52% to 7%, following by sand (66 hours) and concrete (78 hours).

Kumar et al. [51] investigated experimentally an ISD that applied sensible heat storage material and/or latent heat storage material in the Himalayas. A solar collector in which gravel mixed iron scraps were placed and copper tubes with engine oil inside play a role as sensible storage materials. Valeriana rhizomes are drying products to dry in their study. They experimented till the moisture content of rhizomes reach 9 %, which was taken completely in 150 hours with the support of sensible heat storage material and in 120 hours in case of including phase change material. The energy efficiency with SHSM was 26.1% while the exergy efficiency was 0.81%. Several natural substances in term of solid (such as granite, rock, sand, dry brick, fire brick, waste concrete, pebbles) and liquid medium as water were employed as sensible heat (SH) materials in the indirect solar dryer while other interesting chemical liquid for drying food (or low-temperature devices) is used including thermic oil and desiccants.

The storing heat energy ability of the material depends on their heat capacity (multiple between specific heat and density). Hence, as collecting material for storage heat system for solar dryer, the heat capacity is suggested to be high. The usage of solid thermal energy storage leads to less complexity in design and fabrication than liquid material. Table 2 presents the performance parameters of ISD with various energy storage mediums. Thank sensible heat mediums, Compared to opening solar drying, There was a reduction of drying time by 50% for fenugreek leaves and chilies, copra, and 60% for Roselle. Meanwhile, time for drying pineapple slices with SH storage saved up 14.28%, for green peas by 10.5%, and for bitter gourd by 42.8%. The drying efficiency (ηd) ranges from 13.4 to 35% as shown in Table 2. Double pass solar dryers have an increment of ηd from 13% to 47.5% while solar dryers with heat storage mediums achieve 13.5%–55% of drying efficiency. It is revealed that the TES system is essential in solar food dryers.

Table 2. performance of different ISD with various sensible heat storage materials.

Product	M (kg)	Ref.	SHM	m_a (g/s)	T_a	MC		Time for drying			η (%)	
						initial	final	OSD	No SH	SHM	η_{sah}	η_d
Copra	60	[38]	Sand	-	43	51.8	7.8	168h	-	84h	24	-
Hydrated cherry tomatoes	100	[39]	water	-	30-65	62	15	-	-	4d	21-69	-

Chilies	2	[40]	Thermic oil	-	-	-	-	2 d	-	1d	34	21
Fenugreek leaves	1	[40]	Thermic oil	35	-	-	-	15 d	-	4d	34	13.4-15.2
Green peas	20	[41]	Desiccant	-	-	80	5	-	21h	19h	-	43-55
Pineapple slices	-	[41]	Desiccant	-	-	-	-	-	32h	28h	-	-
Roselle	75.2	[45]	Granite	20-70	57	85.6	9.2	35 h	-	14h	64	36.2
Onion	-	[44]	Granit grits	32-46	70	57.84	21.26	-	-	-	-	-
Bitter gourd	4	[48]	sand	63.6	40-50	92	9	10 h	7h	-	22	19
Orange slices	-	[52]	Pebbles	-	45	93.5	10.76	-	7h	7.2h	-	34.36
Coconuts	-	[48]	Concrete	-	20-70	52	7	174 h	-	78h	-	9.5
Coconuts	-	[48]	Sand	-	25-63	52	7	174 h	-	66h	-	11
Coconuts	-	[48]	Rock bed	-	25-58	52	7	174 h	-	53h	-	11.6

*Note: M: mass; SHM: sensible heat materials; OSD: open sun drying; m_a: mass flow rate of drying air; T_a: temperature of drying air; MC: moisture content; $\eta_{sah:}$ thermal efficiency of solar air heater; η_d: Efficiency of drying system

CONCLUSIONS

Indirect type solar dryers with sensible heat storage were provided in this work through a review of designs and performance estimation of the different models for a variety of agricultural products. Designing an efficient solar dryer needs be considered solar radiation, the temperature of the surrounding air, the mass flow rate of drying air, relative humidity, moisture content, kind and mass of drying products, etc. Different types of products require different periods of time for drying to reach standard moisture content. Drying time for meat normally requests more time than fruit and vegetable. The drying quality of the product is affected by temperature and velocity drying fluid. A sensible heat storage system improves the indirect solar dryer in drying time as well as the quality of the product after drying, especially color quality. The application of sensible heat materials helps solar dryers to possibly operate in the nighttime. At off sunshine hours, non-uniform drying rate as drying crops by indirect solar dryer can happen in case of without TES system. As a result, TES is very necessary for solar devices for drying crops. Solar energy is one of the most important alternative energy for global non-carbon aims in the future, the effective utilization of solar may pay back soon for an initial expensive investment of a solar dryer system.

REFERENCES

[1] A.B. Lingayat, V.P. Chandramohan, V.R.K. Raju, and V. Meda, “A review on indirect type solar dryers for agricultural crops – Dryer setup, its performance, energy storage and important highlights,” Appl. Energy, vol. 258, no. May 2019, p. 114005, 2020, doi: 10.1016/j.apenergy.2019.114005.

[2] A.T. Hoang, “Combustion behavior, performance and emission characteristics of diesel engine fuelled with biodiesel containing cerium oxide nanoparticles: A review,” Fuel Process. Technol., vol. 218, p. 106840, 2021.

[3] N.K. Vinayagam et al., “Smart control strategy for effective Hydrocarbon and Carbon monoxide emission reduction on a conventional diesel engine using the pooled impact of pre-and post-combustion techniques,” J. Clean. Prod., p. 127310, 2021.

[4] A.T. Hoang, “Waste heat recovery from diesel engines based on Organic Rankine Cycle,” Appl. Energy, vol. 231, pp. 138–166, 2018.

[5] H.T. Hashim, F.L. Rashid, and M.J. Kadham, "Concentration solar thermoelectric generator (CSTEG): Review paper," J. Mech. Eng. Res. Dev., vol. 44, no. 1, pp. 435–447, 2021.

[6] A.N. Olimat, "Study of fabricated solar dryer of tomato slices under Jordan climate condition," Int. J. Renew. Energy Dev., vol. 6, no. 2, pp. 93–101, 2017, doi: 10.14710/ijred.6.2.93-101.

[7] A.T. Hoang, V.V. Pham, and X.P. Nguyen, "Integrating renewable sources into energy system for smart city as a sagacious strategy towards clean and sustainable process," J. Clean. Prod., vol. 305, p. 127161, 2021, doi: 10.1016/j.jclepro.2021.127161.

[8] J. Ajayan, D. Nirmal, P. Mohankumar, M. Saravanan, M. Jagadesh, and L. Arivazhagan, "A review of photovoltaic performance of organic/inorganic solar cells for future renewable and sustainable energy technologies," Superlattices Microstruct., vol. 143, Pp. 106549, 2020, doi: https://doi.org/10.1016/j.spmi.2020.106549.

[9] A.T. Hoang et al., "Impacts of COVID-19 pandemic on the global energy system and the shift progress to renewable energy: Opportunities, challenges, and policy implications," Energy Policy, vol. 154, p. 112322, 2021.

[10] A. A. Salem and I. S. Seddiek, "Techno-Economic Approach to Solar Energy Systems Onboard Marine Vehicles," Polish Maritime Research. 2016, doi: 10.1515/pomr-2016-0033.

[11] Y. Shi and W. Luo, "Application of solar photovoltaic power generation system in maritime vessels and development of maritime tourism," Polish Marit. Res., vol. 25, pp. 176–181, 2018, doi: 10.2478/pomr-2018-0090.

[12] H. Tri Le, T. Chitsomboon, and A. Koonsrisuk, "Development of a Solar Water Distiller with a Receiver and Condenser," IOP Conf. Ser. Mater. Sci. Eng., vol. 886, no. 1, 2020, doi: 10.1088/1757-899X/886/1/012042.

[13] S. Faisal Ahmed et al., "Recent progress in solar water heaters and solar collectors: A comprehensive review," Therm. Sci. Eng. Prog., p. 100981, 2021, doi: https://doi.org/10.1016/j.tsep.2021.100981.

[14] Z. Ma, H. Ren, and W. Lin, "A review of heating, ventilation and air conditioning technologies and innovations used in solar-powered net zero energy Solar Decathlon houses," J. Clean. Prod., vol. 240, p. 118158, 2019, doi: https://doi.org/10.1016/j.jclepro.2019.118158.

[15] S. Ould Amrouche, D. Rekioua, T. Rekioua, and S. Bacha, "Overview of energy storage in renewable energy systems," Int. J. Hydrogen Energy, vol. 41, no. 45, pp. 20914–20927, 2016, doi: https://doi.org/10.1016/j.ijhydene.2016.06.243.

[16] D. G. Desisa and G. D. Shekata, "Performance analysis of flat-plate and v-groove solar air heater through cfd simulation," Int. J. Renew. Energy Dev., vol. 9, no. 3, pp. 369–381, 2020, doi: 10.14710/ijred.2020.30091.

[17] S. Suherman, H. Widuri, S. Patricia, E. E. Susanto, and R. J. Sutrisna, "Energy analysis of a hybrid solar dryer for drying coffee beans," Int. J. Renew. Energy Dev., vol. 9, no. 1, pp. 131–139, 2020, doi: 10.14710/ijred.9.1.131-139.

[18] G. P. Arul, S. Shanmugam, A. Veerappan, and P. Kumar, "Performance analysis of double-pass oscillating bed solar dryer for drying of non-parboiled paddy grains," Energy Sources, Part A Recover. Util. Environ. Eff., vol. 41, no. 4, pp. 418–426, 2019, doi: 10.1080/15567036.2018.1520326.

[19] D. Singh and P. Mall, "Experimental investigation of thermal performance of indirect mode solar dryer with phase change material for banana slices," Energy Sources, Part A Recover. Util. Environ. Eff., 2020, doi: 10.1080/15567036.2020.1810825.

[20] M. E. A. Slimani, M. Amirat, S. Bahria, I. Kurucz, M. Aouli, and R. Sellami, "Study and modeling of energy performance of a hybrid photovoltaic/thermal solar collector: Configuration suitable for an indirect solar dryer," Energy Convers. Manag., vol. 125, pp. 209–221, 2016, doi: 10.1016/j.enconman.2016.03.059.

[21] D. Aydin, S. E. Ezenwali, M. Y. Alibar, and X. Chen, "Novel modular mixed-mode dryer for enhanced solar energy utilization in agricultural crop drying applications," Energy Sources, Part A Recover. Util. Environ. Eff., vol. 43, no. 16, pp. 1958–1974, 2021, doi: 10.1080/15567036.2019.1663306.

[22] P. Singh and M. K. Gaur, "Review on development, recent advancement and applications of various types of solar dryers," Energy Sources, Part A Recover. Util. Environ. Eff., vol. 00, no. 00, pp. 1–21, 2020, doi: 10.1080/15567036.2020.1806951.

[23] N. Nwakuba, V. C. Okafor, and O. O. Okorafor, "Techno-economic analysis of a hybrid solar-electric dryer," Energy Sources, Part A Recover. Util. Environ. Eff., vol. 00, no. 00, pp. 1–25, 2020, doi: 10.1080/15567036.2020.1782537.

[24] S. K. Ayed, A. R. Al Guboori, H. M. Hussain, and L. J. Habeeb, "Review on enhancement of natural convection heat transfer inside enclosure," J. Mech. Eng. Res. Dev., vol. 44, no. 1, pp. 123–134, 2020.

[25] M. Aktaş, A. Sözen, A. D. Tuncer, E. Arslan, M. Koşan, and O. Çürük, "Energy-exergy analysis of a novel multi-pass solar air collector with perforated fins," Int. J. Renew. Energy Dev., vol. 8, no. 1, pp. 47–55, 2019, doi: 10.14710/ijred.8.1.47-55.

[26] T. Alam and M.-H. Kim, "Performance improvement of double-pass solar air heater–A state of art of review," Renew. Sustain. Energy Rev., vol. 79, pp. 779–793, 2017.

[27] S. OM, L. MT, and M. LT, "Performance Evolution Of An Improved Solar Thermal Hot Air Heating System For Drying Ground-Nut," J. Mech. Eng. Res. Dev., vol. 42, no. 3, pp. 1–5, 2019.

[28] X. Zhou and S. Wang, "Recent developments in radio frequency drying of food and agricultural products: A review," Dry. Technol., vol. 37, no. 3, pp. 271–286, 2019.

[29] H. Zhang, J. Baeyens, G. Caceres, J. Degreve, and Y. Lv, "Thermal energy storage: Recent developments and practical aspects," Prog. Energy Combust. Sci., vol. 53, pp. 1–40, 2016.

[30] S. Nižetić, M. Jurčević, D. Čoko, M. Arıcı, and A. T. Hoang, "Implementation of phase change materials for thermal regulation of photovoltaic thermal systems: Comprehensive analysis of design approaches," Energy, vol. 228, p. 120546, 2021, doi: 10.1016/j.energy.2021.120546.

[31] M. A. Theeb, M. H. Alhamdo, and R. S. Fahad, "Thermal effects of using various metal disks inside liquid-PCM thermal storage system," J. Mech. Eng. Res. Dev., vol. 43, no. 5, pp. 218–230, 2020.

[32] A. Buonomano, F. Calise, and A. Palombo, "Solar heating and cooling systems by absorption and adsorption chillers driven by stationary and concentrating photovoltaic/thermal solar collectors: Modelling and simulation," Renew. Sustain. Energy Rev., vol. 82, no. xxxx, pp. 1874–1908, 2018, doi: 10.1016/j.rser.2017.10.059.

[33] G. Alva, L. Liu, X. Huang, and G. Fang, "Thermal energy storage materials and systems for solar energy applications," Renew. Sustain. Energy Rev., vol. 68, no. February 2016, pp. 693–706, 2017, doi: 10.1016/j.rser.2016.10.021.

[34] K. Kant, A. Shukla, A. Sharma, A. Kumar, and A. Jain, "Thermal energy storage based solar drying systems: A review," Innov. Food Sci. Emerg. Technol., vol. 34, pp. 86–99, 2016, doi: 10.1016/j.ifset.2016.01.007.

[35] J. P. Angula and F. L. Inambao, "Optimization of solar dryers through thermal energy storage: Two concepts," Int. J. Eng. Res. Technol., vol. 13, no. 10, pp. 2803–2813, 2020, doi: 10.37624/IJERT/13.10.2020.2803-2813.

[36] M. Ebrahimi and A. Keshavarz, "8 - CCHP Thermal Energy Storage," M. Ebrahimi and A. B. T.-C. C. Keshavarz Heating and Power, Eds. Boston: Elsevier, 2015, pp. 183–188.

[37] V. P. Chandramohan, "Numerical Prediction and Analysis of Surface Transfer Coefficients on Moist Object During Heat and Mass Transfer Application," Heat Transf. Eng., vol. 37, no. 1, pp. 53–63, Jan. 2016, doi: 10.1080/01457632.2015.1042341.

[38] M. Mohanraj and P. Chandrasekar, "Drying of copra in a forced convection solar drier," Biosyst. Eng., vol. 99, no. 4, pp. 604–607, 2008, doi: 10.1016/j.biosystemseng.2007.12.004.

[39] S. Nabnean, S. Janjai, S. Thepa, K. Sudaprasert, R. Songprakorp, and B. K. Bala, "Experimental performance of a new design of solar dryer for drying osmotically dehydrated cherry tomatoes," Renew. Energy, vol. 94, pp. 147–156, 2016, doi: 10.1016/j.renene.2016.03.013.

[40] P. A. Potdukhe and S. B. Yhombre, "Development of a new type of solar dryer: Its mathematical modelling and experimental evaluation," Int. J. Energy Res., vol. 32, no. 4, pp. 765–782, 2008, doi: 10.1002/er.1387.

[41] V. Shanmugam and E. Natarajan, "Experimental study of regenerative desiccant integrated solar dryer with and without reflective mirror," Appl. Therm. Eng., vol. 27, no. 8–9, pp. 1543–1551, 2007, doi: 10.1016/j.applthermaleng.2006.09.018.

[42] N. A. Vlachos, T. D. Karapantsios, A. I. Balouktsis, and D. Chassapis, "Design and testing of a new solar tray dryer," vol. 20, no. 6, pp. 1243–1271, 2013.

[43] D. Jain and R. K. Jain, "Performance evaluation of an inclined multi-pass solar air heater with in-built thermal storage on deep-bed drying application," J. Food Eng., vol. 65, no. 4, pp. 497–509, 2004, doi: 10.1016/j.jfoodeng.2004.02.013.

[44] D. Jain, "Modeling the performance of the reversed absorber with packed bed thermal storage natural convection solar crop dryer," J. Food Eng., vol. 78, no. 2, pp. 637–647, 2007, doi: 10.1016/j.jfoodeng.2005.10.035.

[45] M. W. Kareem, K. Habib, M. H. Ruslan, and B. B. Saha, "Thermal performance study of a multi-pass solar air heating collector system for drying of Roselle (Hibiscus sabdariffa)," Renew. Energy, vol. 113, pp. 281–292, 2017, doi: 10.1016/j.renene.2016.12.099.

[46] S. Aboul-Enein, A. A. El-Sebaii, M. R. I. Ramadan, and H. G. El-Gohary, "Parametric study of a solar air heater with and without thermal storage for solar drying applications," Renew. Energy, vol. 21, no. 3–4, pp. 505–522, 2000, doi: 10.1016/S0960-1481(00)00092-6.

[47] A. A. El-Sebaii, S. Aboul-Enein, M. R. I. Ramadan, and H. G. El-Gohary, "Experimental investigation of an indirect type natural convection solar dryer," Energy Convers. Manag., vol. 43, no. 16, pp. 2251–2266, 2002, doi: 10.1016/S0196-8904(01)00152-2.

[48] S. Vijayan, T. V. Arjunan, and A. Kumar, "Mathematical modeling and performance analysis of thin layer drying of bitter gourd in sensible storage based indirect solar dryer," Innov. Food Sci. Emerg. Technol., vol. 36, pp. 59–67, 2016, doi: 10.1016/j.ifset.2016.05.014.

[49] W. B. Chaouch, A. Khellaf, A. Mediani, M. E. A. Slimani, A. Loumani, and A. Hamid, "Experimental investigation of an active direct and indirect solar dryer with sensible heat storage for camel meat drying in Saharan environment," Sol. Energy, vol. 174, no. April, pp. 328–341, 2018, doi: 10.1016/j.solener.2018.09.037.

[50] S. Ayyappan, K. Mayilsamy, and V. V. Sreenarayanan, "Performance improvement studies in a solar greenhouse drier using sensible heat storage materials," Heat Mass Transf. und Stoffuebertragung, vol. 52, no. 3, pp. 459–467, 2016, doi: 10.1007/s00231-015-1568-5.

[51] A. K. Bhardwaj, R. Kumar, and R. Chauhan, "Experimental investigation of the performance of a novel solar dryer for drying medicinal plants in Western Himalayan region," Sol. Energy, vol. 177, no. October 2018, pp. 395–407, 2019, doi: 10.1016/j.solener.2018.11.007.

[52] S. Vijayan, T. V. Arjunan, and A. Kumar, "Exergo-environmental analysis of an indirect forced convection solar dryer for drying bitter gourd slices," Renew. Energy, vol. 146, pp. 2210–2223, 2020, doi: 10.1016/j.renene.2019.08.066.