Experimental studies on natural convection open and closed solar drying using external reflector

Abd Elnaby Kabeel 1,2 · Paul Durai Leon Dharmadurai 3 · Sathiyaseelan Vasanthaseelan 4 · Ravishankar Sathyamurthy 1,4 · Bharathwaaj Raman 4 · Athikesavan Muthu Manokar 5 · Ali Chamkha 6,7

Received: 19 March 2021 / Accepted: 28 July 2021 / Published online: 5 August 2021 © The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2021

Abstract
For low temperature agricultural crop and meat drying, dryers utilizing the renewable energy source (solar energy) appear to be an efficient technique as it is ecofriendly, energy efficient, and available in free of cost. This work presents the experimental investigation on a solar food dryer equipped with external reflectors to enhance the rate of drying efficiency by removing the moisture content available in the anchovy fish. A comparison of conventional open solar drying is carried out to assess the parameters such as drying efficiency, moisture removal rate, and heat energy required for drying the anchovy fish using the modified solar dryer using the natural convection technique. From the experimental results it is observed that the relative humidity greatly influence the rate of drying. The average relative humidity during the experiments using open solar drying is found as 50–65% whereas, the using solar dryer the average relative humidity inside the chamber is found as 20–35%. The relative humidity of the fish using open solar drying is higher as compared to solar dryer drying as the drying products are kept in open atmosphere. The physical examination results on the dried products proved that using a modified solar dryer, the dried product is free from insects, and dust. Also, it is found that the loss of color from the product is a minimum while compared to conventional open solar drying. The results showed that the thermal efficiency of top tray (dryer 1) and bottom tray (dryer 2) is comparatively higher as compared to that of conventional open solar drying and found as 16.73 and 19.34 %, respectively. Results also showed that nearly 20.05% of the energy could be saved using the modified solar dryer as compared to the open solar drying technique.

Keywords Fish · Moisture · Drying · Solar · Hygiene

Introduction
The increase in global population and economic prosperity is followed by an increase in material demands and energy consumption. Since the Earth’s fossil fuel supplies are finite and will inevitably run out, the loss of these fuels is a danger to life in the world. Furthermore, the use of fossil fuels as a source of energy has had a variety of environmental implications. Following the heavy use of coal, oil, and natural gas over the past 150 years, many countries are now invested in renewable energy supplies. Globally, there is an increasing realization that expanded renewable energy adoption is vital for mit-
igating climate change, generating new economic prospects, and delivering energy coverage to the billions of people who already lack modern energy services. Solar energy has received a lot of interest among renewable energy options because of its availability, free connectivity, and commercial potential. Photovoltaic and solar thermal systems are two popular methods for using solar energy in use (Dharmadurai et al. (2020); Bal et al. (2010); Mustayen et al. (2014a, b)). The fish is washed cleanly with the water and made to dry for some time. The salt is applied to the layer of the fish to kill the micro-organism. Then the salted fish is exposed to sunlight as shown in Fig. 1. At present there are many methods for drying the fish namely the open drying method, using an electric dryer, and using a solar dryer. The salted fish is exposed to the sunlight till it attains 10% moisture level. The advantage of this process is that the capital cost is less and more products can be dried at the same time. The disadvantages of this method are that there is no hygiene and it takes more time to dry. The dry fish can’t be saved during the unexpected rain time.

For centuries, the drying of agricultural crops, vegetables, and fruits are carried out using the open solar drying technique (Fudholi et al. (2010); Mustayen et al. (2014a, b); Jairaj et al. (2009)). There are several drawbacks to the open solar drying technique as it requires large space, labor and the time required for drying is higher. The quality of products is also considered to be the main influential parameter in the open solar drying technique as it was affected by unexpected rain, and foreign bodies left by the animals and birds. To overcome these issues, a solar dryer was developed to create a hygiene food processing. The dryer can be classified into two major groups, namely: (a) passive solar-energy drying systems, (b) active solar-energy drying systems. Either passive or active solar dryer, it is further divided into (a) direct, (b) indirect, and (c) mixed type. Indirect solar dryers can be either forced circulation or natural circulation mode (Fig. 2) (Kumar et al. (2016); Ekechukwu and Norton (1999)). Mohana et al. (2020) made a comprehensive review on different concepts on solar dryer design for drying food.

The effect of absorber plate solar air collector on indirect solar drying was experimentally investigated by Essalhi et al. (2017). The absorber plate was fixed with cylindrical fins kept parallel to the absorber plate while the air flows over the cylindrical absorber of the solar collector to dry the food products available in the solar dryer. Results showed that the effect of cylindrical corrugations improved the drying chamber efficiency. On a 24-h operation, the mass of samples kept inside the dryer was reduced from 997.3 to 135.13 g.

Eltawil et al. (2018) studied the enhancement of a solar tunnel dryer by coupling a flat plate collector and a solar photovoltaic system to remove the moisture content available in peppermint effectively. The photovoltaic panel is incorporated for forced convection, while the direct solar radiation is avoided by providing curtains. A comparison of open solar drying was made to study the effect of tunnel dryers on single, double, and three layers of mint. With an energy payback time of 2 years, the dryer efficiency, overall efficiency, and photovoltaic efficiency were found as 30.7, 16.3, and 9.3%, respectively. Also, it was estimated that the CO2 mitigation for the entire lifetime was 31.8 tons. Nabnean et al. (2016) experimentally analyzed an innovative solar dryer to dry the osmotically dehydrated cherry tomatoes. A comparison was carried out to assess the performance of solar dryers over natural solar drying techniques. It was reported that there was a significant reduction in the time of drying while compared to that of natural drying. Similarly, the efficiency of the modified solar dryer was found in the range of 21–69%.

Fig. 1 Drying fish in Open Sunlight in India

Fig. 2 Types of solar dryer
Sengar et al. (2009) used a low-cost dryer to assess the performance, which was used for drying the salted and unsalted fish products. A comparison was also made between the solar dryer and open solar drying techniques. It was reported that the time taken to dry the fish using the proposed method was 8 h, while the open solar drying technique required 15 h to reach the same amount of moisture content. It was also found that the average drying efficiency using salted and unsalted fish was 14 and 11%, respectively, and the overall thermal efficiency of the system was found as 70.97%.

With a moisture content of 48.8–50.3% on a wet basis, Subarkah and Hendrarsakti (2013) experimented the effect of drying anchovy fish using the solar drying chamber technique. Even at a temperature of 70°C, it was found that there is no case-hardening. In order to optimize the results, the drying process is carried out in three different stages namely, drying the anchovy fish at 70°C for 150 min followed by drying the fish at 50°C for 100 min, and finally drying at 40°C to attain equilibrium moisture content. Koya et al. (2015) undergone research to find the most efficient angle and direction for the solar radiation when solar power is introduced by using Geographic Information System (GIS) in Kitakyushu city, Fukuoka Prefecture as an example. The results revealed that the south-facing angle of 25° is the most efficient angle on the solar power for Kitakyushu city, Fukuoka Prefecture, Japan. The results are promising and required for the best utilization of solar energy in Japan. The method is applicable anywhere in the world with the availability of GIS data access.

Subarkah and Hendrarsakti (2013) conducted experiments to determine if the drying rate interval of anchovy fish shifts from steady to dropping when the essential moisture content is between 48.8 and 50.3% (wet basis). Even at temperatures of 70°C, there is no case-hardening in these studies. To obtain the best results, the drying process should be done in three steps: drying at 70°C for 150 minutes, drying at 50°C for 100 minutes, and finally drying at 40°C before equilibrium moisture content is achieved.

Lingayat et al. (2017) designed and experimented an indirect solar dryer to dry agricultural products. Solar dryers are made up of a solar flat plate air collector with V-corrugated absorption plates, an enclosed drying cavity, and an exhaust air chimney. The collectors have a gross surface area of 2 m². The qualitative study for banana drying indicated that the moisture content of banana was decreased from 356 percent (db) to 16.32% in tray 1, whereas, from tray 2, tray 3, tray 4, and solar open drying the moisture content available was found as 19.47%, 21.15%, 31.15%, and 42.37%, respectively. From the results, it was found that the calculated overall thermal efficiency collected was 31.5% whereas, the chamber drying efficiency was found as 22.38%. The most critical and effective factor during drying is the temperature of the drying air. The humidity of the air, as well as the velocity of the air, are essential factors in improving the drying rate. An indirect solar dryer with forced circulation for drying the commodities utilizing a DC-powered fan was analyzed by Chandrasekar et al. (2018). The air from the solar collector was integrated into the drying chamber for improved kinetics of drying.

Swami et al. (2018) performed a comparative analysis on solar dryers using rock bed, pebbles as heat storage to increase the efficiency of the solar dryer with decreased drying time. To improve the overall system performance, Daghigh and Shafieian (2016) integrated a heat recovery system into the drying chamber. The hot water from the storage tank is integrated with the help of a heat exchanger and the air is blown into the dryer for improved efficiency. The hot air reaches the drying main chamber, which holds the drying materials to dry

---

Table 1  Specification of instruments used in the present study

| S. No | Name of instrument          | Range       | Error ( % ) |
|-------|-----------------------------|-------------|-------------|
| 1     | Solar power meter           | 0–2500 W/m² | ±3.5 %      |
| 2     | Anemometer                  | 0–45 m/s    | ±4 %        |
| 3     | Thermo hygrometer           | 0–100%      | ±2 %        |
| 4     | RTD sensors (PT-100 type)   | 0–1000°C    | ±1.5 %      |
| 5     | Electronic balance          | 0–2.500 kg  | ±1 %        |
completely. The mean outlet air temperature of the dryer was approximately 44.3°C at a volumetric flow rate of 0.0328 m$^3$/s. At the end of the day, the system’s exergetic performance reaching a peak, which was about 11.7%. Azam et al. (2020) compared the drying performance of PV and solar collector integrated greenhouse dryers. Pretreatments of the tomatoes were done before drying. Udomkun et al. (2020) reviewed the performance of different solar dryers for agricultural products in Asian and African regions. Murali et al. (2020) designed a dryer using a solar-LPG dryer in a hybrid mode for drying shrimps. The moisture content available in the fresh shrimps was reduced from the initial moisture content of 76.71% to the final moisture content of 15.38%. Spall and Sethi (2020) designed a multi-rack solar dryer with reflectors for concentrating solar radiation.

From the various literature reviewed, it was clear that the existing method of open drying system has no hygiene because there is a chance of external attack from the birds and animals, and then the dust will fall on the food product during drying. The products cannot be saved during heavy rainfall.

Fig. 4 Experimental photograph of solar dryer with modification

![Fig. 4 Experimental photograph of solar dryer with modification](image1)

Fig. 5 Hourly variation of wind velocity, ambient temperature, tray temperature, relative humidity, and solar intensity during a Day 1 b Day 2 c Day 3, and d Day 4 using a conventional open solar dryer

![Fig. 5 Hourly variation of wind velocity, ambient temperature, tray temperature, relative humidity, and solar intensity during a Day 1 b Day 2 c Day 3, and d Day 4 using a conventional open solar dryer](image2)
The drying period in the open sunlight is more. Even though there are several studies carried out in solar drying techniques, the use of external reflectors to focus the solar radiation on drying the food products is very limited to the knowledge. This study emphasizes a solar drying technique that uses external mirrors on the top of the solar dryer to dry the fish products collected from the local market. A comparative analysis is carried out to assess the performance of solar dryers over conventional open drying techniques.

Experimental setup and procedure

The conventional open solar drying is carried out by placing the required amount of anchovy fishes in the basket and kept in the outdoor condition of Coimbatore. In the modified solar drying, the dryer with an effective area of 0.152 m² with width and height of 0.48 and 0.32 m, respectively. The dryer is installed with a capacity of handling 3 kg of fish. Additionally, to improve the drying efficiency, a top reflector is used to focus the solar radiation. Two trays are placed inside the dryer namely tray 1 and tray 2. Tray 1 is placed at the top and tray 2 is placed below tray 1. The dryer is oriented east-west, and the reflector is oriented east-west. Two trays are placed inside the drying chamber and the product is placed to dry. The sun's rays would reach the glazing region and be reflected within the dryer. Since the black absorber is less reflective, heat is lost within the dryer. The trapped heat dries the put substance. The air difference will frequently expel moist air from the dryer and replace it with fresh air (Fig. 3). The experimental photograph used in the present investigation is shown in Fig. 4.

Experiments are carried out between 9:00 and 17:00 Hrs and the ambient temperature, dryer temperature (tray 1 and tray 2), basket temperature, relative humidity (ambient and dryer) are measured every hour. The wind velocity and solar intensity variations are measured using an anemometer and solar power meter respectively (Fig. 4). Temperature is measured using PT100 type RTD sensors. An electronic balance is used to measure the weight of the anchovy fish while the relative humidity is measured using a Thermo hygrometer. The specification of the instruments used in the present study is given in Table. 1.

Results and discussion

The effect of temperature and humidity has a vital part in drying. For perfect drying, the temperature should be high and the humidity should be less. It is observed that the temperature inside the dryer tends to be more than the open drying temperature. The humidity is less for dryer drying compared to open drying. The temperature changes from time to time according to the incident solar radiation. The high temperature and low humidity inside the dryer are responsible for the quick drying of products. But the temperature should not be so high because it will spoil the drying of the products.

The hourly variation of wind velocity, ambient temperature, tray temperature, relative humidity, and solar intensity during experimental days using a conventional open solar dryer is shown in Fig. 5. During the experimental days, it is observed that the relative humidity of the open basket and the ambient is almost equal and the temperature of the basket is increasing steadily with respect to the incident rays falling on
the fish. On increased solar intensity the relative humidity measured from the basket and ambient decreases. The relative humidity of day 2 is found to be in the ranges of 50–65%, while the relative humidity of day 3 and day 4 is found in the ranges of 35–55 and 37–56%, respectively. With lower humidity, the temperature of the basket reaches a peak value of 45 and 48°C during day 3 and day 4, respectively. With higher moisture content available in the basket, the peak temperature recorded during day 1 and day 2 is found as 44 and 40°C while the relative humidity recorded during the peak solar intensity for the days is found as 50 and 48%, respectively.

Similarly, the hourly variation of wind velocity, ambient temperature, tray temperature, relative humidity, and solar intensity during the experimental days using a modified solar dryer is shown in Fig. 6. It can be clearly seen from the experimental days that the influence of dryer configuration with reflectors increased the temperature of the tray to a maximum of 60, 58, and 65°C with peak solar intensity in tray 1 for day 1, day 2, and day 3, respectively. On increased drying condition of fishes in the tray, the relative humidity inside the dryer reduced with increased solar intensity and tray temperature. The relative humidity measured inside the dryer ranged from 35–65% during the day 1 operation while day 2 and day 3 showed 23–55 and 21–50%, respectively.

Figures 7 and 8 show the conventional open solar drying and modified solar drying of anchovy fish before and after drying, respectively. It is observed that the product which is opened dried has lost more color when compared to dryer drying. The color of the product will retain when it has indirect exposure to the sunlight for drying.

Moisture content

Moisture content lost during the drying process is defined as the ratio of the difference in moisture content before and after drying to the initial moisture content available in the product. Mathematically it is expressed as (Akoy et al. (2006); Khalifa et al. (2012); Panchal et al. (2013)),

\[
\text{Total moisture content loss} = \frac{M_1 - M_2}{M_1} \times 100\% \quad (1)
\]

where, \(M_1\) and \(M_2\) are the sample mass before and after drying (kg).

For every 2 h, the samples are weighed in the electronic balance and the mass of fish is recorded. The variation in the mass of fish during the drying process using conventional open solar drying and modified solar drying is plotted in Fig. 9. The amount of time required for drying the anchovy fish in an open solar drying is higher while comparing it with dryer drying. While drying with a different seasoning time period, the mass of anchovy fish is reduced exponentially with respect to the time.
period as the moisture level in the fish is removed by drying with solar intensity. During the experiments it is found that the moisture content available in the tray 2 (bottom tray) is higher than the moisture content available in tray (1). This is due to the direct solar radiation and the reflected solar radiation is focused on the top (tray 1) rather than the bottom tray (tray 2). The radiation from the sun and reflected rays with the mirror heat the entire mass of fish for rapid moisture removal. The amount of time taken to dry the 1.6 kg of anchovy fish using the open solar drying technique is found as 96 h while the solar dryer required a time of 56 h. The variations in moisture removal from the anchovy fish using conventional open solar drying and modified solar drying is plotted in Fig. 10. It is observed that the initial moisture content available in the anchovy fish during conventional open solar drying and modified solar dryer with reflector is the same at the start of experiment. On increasing the drying time, the moisture content available in the fish starts to decrease. The amount of moisture present in the anchovy fish available in tray 1 and tray 2 are found as 23.3 ad 27.2%, respectively. The moisture content in tray 2 is higher to about 3.9% than the moisture present in tray 1. This is due to the thermal barrier by the insulator placed in tray 1 and also, tray 2 is kept just beneath tray 1. Moreover, tray 1 is exposed directly to the radiation from the sun and the reflected radiation from the mirror reduced the moisture content present in anchovy fish. On comparing the moisture content available in conventional open solar drying techniques, the moisture content available in the fish is found as 32.68%.

**Drying rate**

The drying rate is defined as the difference in the amount of moisture content available before drying and after drying to the total time taken for drying the sample. Mathematically it is expressed as (Akoy et al. (2006); Khalifa et al. (2012); Panchal et al. (2013)),

\[
\text{Drying rate} = \frac{M_1 - M_2}{t_d}
\]

where, \(t_d\) is the time for drying sample (days)

The hourly variation in drying rate using conventional open solar drying and modified solar drying is plotted in Fig. 11. It is seen that on increased time duration, the rate of drying is decreased as the amount of moisture content available in the fish is reduced. With higher rate of focusing radiation with external reflector, the drying rate in tray 1 and tray 2 of modified dryer has increased while compared to that of conventional open solar drying technique. Also, with decreasing drying rate, the material is no longer exposed to the saturated vapor. Similarly, the diffusion of the moisture occurs between the solid and surface (Diamante and Munro (1993)). The drying rate of both the open drying and dryer drying is compared for fishes. The drying rate of fishes at open drying and dryer drying with external reflector is found as 0.012 kg/h and 0.031 kg/h, respectively (Table. 2). On comparing both the values, it is clear that the drying rate of dryer drying is much higher than the open drying. The time taken for drying the product is also less for dryer drying when compared to open drying.

**Dryer efficiency**

The dryer efficiency of the solar dryer using proposed modification (with reflector) is mathematically expressed as (Akoy et al. (2006); Khalifa et al. (2012); Panchal et al. (2013)),

\[
\text{Thermal efficiency of dryer, } \eta_d = \frac{(M_1 - M_2) \times h_l}{A_d \times I(t) \times t_d}
\]

where, \(\eta_d\)—Dryer Efficiency (%)
From the experiments it is found that due to direct exposure of the fish with direct solar radiation and reflected radiation from the mirrors, the upper tray (dryer 2) exhibits higher thermal efficiency than the lower tray (dryer 1). The average daily efficiency of the modified solar dryer with external reflectors is found as 19.34 and 16.73% from dryer 2 and dryer 1, respectively.

**Heat energy for drying**

The heat energy used for drying the fish is defined as the product of dryer efficiency, latent heat of vaporization, and mass of water removed. Mathematically it is expressed as (Akoy et al. (2006); Khalifa et al. (2012)),

\[
\text{Heat used for drying} = m_w \times h_v \times \eta_d \tag{4}
\]

where, \(\eta_d\) — Efficiency of the dryer (s), \(M_w\) — the amount of water removed (kg)

Similarly, the latent heat of vaporization is estimated using Eq. (5) (Youcef-Ali et al. (2001); Akoy et al. (2006); Khalifa et al. (2012)),

\[
\text{Latent heat of vaporization} = 4.186 \times 10^3 \left(597 - (0.56 \times T_p)\right) \tag{5}
\]

where, \(T_p\) — is the temperature of product (K)

Based on the amount of water removed from the dryer, dryer efficiency, and latent heat, the amount of heat for drying the estimated for solar dryer drying is found as 362.3 kJ.
Percentage of time saving for solar drying with external reflector

The heat energy used for drying the fish is defined as the product of dryer efficiency, latent heat of vaporization, and mass of water removed. Mathematically it is expressed as (Akoy et al. (2006); Khalifa et al. (2012)),

\[
\text{Energy time saving from dryer} = \frac{T_{\text{open}} - T_{\text{dryer}}}{T_{\text{open}}} \times 100\% \tag{5}
\]

where,

- \(T_{\text{open}}\) time for drying in open solar drying (hrs)
- \(T_{\text{dryer}}\) time for drying in solar dryer drying (hrs)

Heat conduction through the insulator

The rate of heat conduction through the insulator plays a vital role in heat transfer between the trays for efficient drying of the fishes. It depends on the temperature inside the dryer, the thermal conductivity of the insulator, ambient temperature, and the area of the tray. Mathematically it is given as (Holman (2008)),

\[
\text{Heat conduction rate through Insulator} = \frac{kA_d(T_d - T_a)}{t} \tag{6}
\]

where,

- \(k\) Thermal Conductivity (W/m K),
- \(T_d\) Drying chamber temperature (K),
- \(T_a\) Surrounding ambient temperature (K),
- \(t\) Thermal insulator thickness (m)

The amount of heat conduction rate through the dryer insulation provided is provided in Table 2. It is seen that the rate of conduction through the dryer insulation is found as 365 kJ.

Conclusions

The following conclusions are derived from the experimental investigation:

- The drying is carried out using conventional natural convection open solar drying and modified solar dryer techniques for drying anchovy fish.
- The average relative humidity on using conventional open solar drying is found between 50 and 65%, whereas, using the modified solar dryer it is found between 20 and 35%.
- With lowered relative humidity inside the drying chamber, the quality of the fish is not affected.
- The product dried in the dryer is free from dust and insects and also the loss of color in the product is less compared to open drying.
- The drying thermal efficiency of dryer 1 is 16.73% and the drying thermal efficiency of dryer 2 is 19.34%. The drying thermal efficiency is found to be higher in dryer 2.
- Compared to open solar drying, nearly about 20.05% of energy could be saved using the modified solar dryer with external reflectors.

Authors contributions Conceptualization, Methodology, Resources, Formal analysis, Writing—original draft preparation, review and editing, Supervision and investigation were carried out by Abd Elnaby Kabeel, Ravishankar Sathyamurthy, Ali Chamkha. Writing—original draft preparation, review and editing were carried out by Paul Durai Leon Dharmadurai, Sathiyaseelan Vasanthaseelan, Bharathwaaj Ramani, Athikesavan Muthu Manokar.

Availability of data and materials Not applicable.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

Competing interests The authors declare no competing interests.

References

Akoy E, Ismail MA, Ahmed EFA, Luecke W (2006) Design and construction of a solar dryer for mango slices. In: Proceedings of International Research on Food Security, Natural Resource Management and Rural Development-Tropentag. University of Bonn, Bonn
Azam MM, Eltawil MA, Amer BM (2020) Thermal analysis of PV system and solar collector integrated with greenhouse dryer for drying tomatoes. Energy 212:118764
Bal LM, Satya S, Naik SN (2010) Solar dryer with thermal energy storage systems for drying agricultural food products: a review. Renew Sust Energ Rev 14(8):2298–2314
Chandrasekar M, Senthilkumar T, Kumaragurubaran B, Fernandes JP (2018) Experimental investigation on a solar dryer integrated with condenser unit of split air conditioner (A/C) for enhancing drying rate. Renew Energ 122:375–381
Daghagh R, Shaifiean A (2016) An experimental study of a heat pipe evacuated tube solar dryer with heat recovery system. Renew Energy 96:872–880
Dharmadurai PL, Vasanthaseelan S, Bharathwaaj R, Dharmaraj V, Gnanasekaran K, Balaji D, Sathyamurthy R (2020) A comparative study on solar dryer using external reflector for drying grapes. In: Materials Today: Proceedings
Diamante LM, Munro PA (1993) Mathematical modelling of the thin layer solar drying of sweet potato slices. Sol Energy 51(4):271–276
Ekechukwu OV, Norton B (1999) Review of solar-energy drying systems ii: an overview of solar drying technology. Energy Convers Manag 40:615–655

Eltawil MA, Azam MM, Alghannam AO (2018) Energy analysis of hybrid solar tunnel dryer with pv system and solar collector for drying mint (menthaviridis). J Clean Prod 181:352–364

Essali H, Tadili R, Bargach MN (2017) Conception of a solar air collector for an indirect solar dryer. pear drying test. Energy Procedia 141:29–33

Fudholi A, Sopian K, Ruslan MH, Alghoul M, Sulaiman MY (2010) Review of solar dryers for agricultural and marine products. Renew Sust Energ Rev 14:1–30

Holman JP (2008) Heat Transfer (St Units) Sie. Tata McGraw-Hill Education

Jairaj K, Singh S, Srikanth K (2009) A review of solar dryers developed for grape drying. Sol Energy 83:1698–1712

Khalifa AJN, Al-Dabagh AM, Al-Mehemdi WM (2012) An experimental study of vegetable solar drying systems with and without auxiliary heat. Int Schol Res Notic 2012:789324

Koya Y, Shiot A, Mitani Y, Qudaih YS, Fuji K (2015) An index to evaluate the amount of the solar radiation for a surface with eight directions. Int J Smart Grid Clean Energy 4:241–246

Kumar M, Sansanwal SK, Khatik P (2016) Progress in solar dryers for drying various commodities. Renew Sust Energ Rev 55:346–360

Lingayat A, Chandramohan VP, Raju VRK (2017) Design, development and performance of indirect type solar dryer for banana drying. Energy Procedia 109:409–416

Mohana Y, Mohanapriya R, Amukiruthika T, Yoha KS, Moses JA, Anandharamakrishnan C (2020) Solar dryers for food applications: concepts, designs, and recent advances. Sol Energy 208:321–344

Murali S, Amulya PR, Aliyia PV, Delfiya DA, Samuel MP (2020) Design and performance evaluation of solar-LPG hybrid dryer for drying of shrimps. Renew Energy 147:2417–2428

Mustayen AGMB, Mekhilef S, Saidur R (2014a) Performance study of different solar dryers: a review. Renew Sust Energ Rev 34:463–470

Mustayen A, Mekhilef S, Saidur R (2014b) Performance study of different solar dryers: a review. Renew Sust Energ Rev 34:463–470

Nabnean S, Janjai S, Thepa S, Sudapraset K, Songprakoop R, Bala B (2016) Experimental performance of a new design of solar dryer for drying osmotically dehydrated cherry tomatoes. Renew Energy 94:147–156

Panchal S, Solanki SK, Tilk AK, Nagaich R (2013) Design, construction and testing of solar dryer with roughened surface solar air heater. Int J Innov Res Eng Sci 7(2):7–12

Sengar S, Khandetod Y, Mohod A (2009) Low cost solar dryer for fish. Afr J Environ Sci Technol 3:265–271

Spall S, Sethi VP (2020) Design, modeling and analysis of efficient multirack tray solar cabinet dryer coupled with north wall reflector. Sol Energy 211:908–919

Subarkah R, Hendrarsakti J (2013) Drying characteristic of anchovy fish. J Food Sci Eng 3:87

Swami VM, Autee AT, Anil TR (2018) Experimental analysis of solar fish dryer using phase change material. J Energy Stor 20:310–315

Udomkun P, Romuli S, Schock S, Mahayothee B, Sartas M, Wossen T, Njukwe E, Vanlaeze B, Miller J (2020) Review of solar dryers for agricultural products in Asia and Africa: an innovation landscape approach. J Environ Manag 268:110730

Yousef-Ali S, Messaoudi H, Desmons JY, Abene A, Le Ray M (2001) Determination of the average coefficient of internal moisture transfer during the drying of a thin bed of potato slices. J Food Eng 48(2):95–101

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.