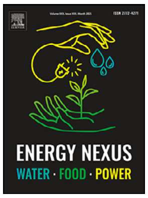
Energy Nexus 9 (2023) 100182

Contents lists available at ScienceDirect

Energy Nexus

journal homepage: www.elsevier.com/locate/nexus



Enhancement in thermal performance of solar dryer through conduction mode for drying of agricultural produces

Rupal Jain[a,*], Arjun Sanjay Paul[b], Deepak Sharma[a], Narayan Lal Panwar[a]

[a] Department of Renewable Energy Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur (Rajasthan) 313001 India
[b] Department of Renewable Energy Engineering, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj (Ayodhya) 224229 India

ARTICLE INFO

Keywords:
Solar conduction dryer
Dryer efficiency
Drying rate
Thermal performance of the dryer

ABSTRACT

This paper presents the development and performance analysis of a solar conduction dryer (SCD) used for drying agricultural produce. Compared with other conventional solar dryers, which are mostly based on convection mode, it was found to be more efficient in terms of thermal efficiency, drying time, and drying rate. In addition to increasing the dryer's aperture area, reflectors were placed on both sides, which enhanced its thermal performance. Furthermore, reflectors can also be used as a closing cover to enhance the life of the covering material against rainstorms, hailstones, etc., when the dryer will not be used. The maximum temperature inside the dryer was 77.4 °C and 61.2 °C with and without the use of reflectors during no load conditions, while maximum temperatures inside the dryer with and without the use of reflectors measured 59.1 °C and 51.8 °C respectively during full load conditions. With and without reflectors, the drying efficiency of the developed solar dryer was found to be 59.4% and 50.09% respectively, which are much higher than that of other general solar dryers (~35%). However, the drying rate varied between 1.525 to 0.005 g of water evaporated per gram of dry matter per hour when reflectors were used and 1.397 to 0.005 g without reflectors. A cost analysis showed that the capital invested for the development of SCD could be recovered in 1.02 years.

1. Introduction

Food is essential for the survival of every human being. As the world grows, it is becoming difficult to maintain a balance between food supply and consumption. There are many farmers in Asian nations like India who produce a lot of food or crops, but because of the high volume, they are not able to receive a reasonable price for their produce [1,2]. Other seasons have higher prices for the same product as a result of lower supply and higher demand. The farmer faces significant difficulty in India in reducing food losses. The use of effective post-harvesting practices will have a positive effect on developing nations' economies by reducing the amount of food that is lost after harvest [3].

Among the various postharvest practices, drying is one of the easiest and most convenient methods of preservation of food material for a longer period, and it has been practiced since the dawn of civilization [4–7]. The process of drying involves the simultaneous transfer of mass and heat. This process involves removing surplus water from a product in order to acquire a specific moisture content. Different agricultural products tend to have a moisture content between 70 and 90% [8,9]. The process of drying allows food to be preserved and stored for an extended period of time without deterioration. A wide variety of drying methods such as mechanical, electrical, infrared, osmosis, fluidized bed, solar drying, etc. have been utilized for the drying of agricultural and non-agricultural products. Out of these methods, solar drying is gaining more attention due to several advantages such as it operates on solar (renewable) energy, it can reduce drying costs by 27–80% [10], it has zero impact on the environment and is easy to use [11].

Researchers are, however, working to design and develop efficient solar dryers primarily for drying agricultural products. Solar dryers primarily involve the heating and movement of air within the chamber. Insulation on all sides of the drying chamber is essential in order to achieve uniform heating. Solar dryers are now mostly used in convection mode. Furthermore, solar convection dryers can be classified into direct, indirect, and mixed mode types. This type of dryer is the simplest, since it receives solar radiation directly from the sun and transmits it to the product. In this type of dryer, products get directly exposed to solar radiation, which means that the drying and storage of products occur at the same place [12]. Direct solar dryers are also popular as cabinet dryers. Direct solar dryer exposes the product to direct solar radiation, while indirect solar dryers are not directly exposed to solar radiation. Generally, this type of dryer consisted of two separate chambers, namely a solar collector and a drying chamber. Upon receiving solar radiation, the collector heat up the air inside, and the heated air is then passed to the drying chamber [13]. As a result of a mixed-mode dryer, the prod-

---

[*] Corresponding author.
E-mail address: rupal281996@gmail.com (R. Jain).

https://doi.org/10.1016/j.nexus.2023.100182
Received 24 December 2022; Received in revised form 9 February 2023; Accepted 17 February 2023

uct placed in the drying chamber receives heat energy from both direct solar radiation and hot air generated by the heater [14].

It has been observed that through these convection mode solar dryers, significant heat loss occurs due to the movement of hot air, and therefore it takes longer to dry and has less drying efficiency [15,16]. In the case of solar dryers, thermal efficiency plays a major role, because it directly affects both the drying area and drying time. Thermal efficiency of natural convection solar dryers is primarily determined by the convection of heat transfer between the absorber plate and the moving air. The thermal efficiency of direct, indirect, and mixed-mode dryers at no load conditions was reported by Mahapatra and Tripathy [17] to be 31.40%, 27.60%, and 41.43%, respectively.

In addition, solar conduction dryers have become increasingly popular in recent years due to their unique working principle, which consists of a radiation absorbing heat conducting surface. Conduction dryers transfer heat majorly via conduction, followed by convection and radiation, resulting in improved thermal efficiency. Furthermore, Chavan et al., [18] investigated the effect of conduction, convection, and radiation on drying kinetics and basic heat transfer analysis in solar conduction dryers (SCDs). In SCD heat transfer occurs in order of mode conduction, radiation, and convection. Similarly, Bheda et al., [19] studied the substantial heat transfer between the open sun and solar conduction drying. Based on effective diffusivity and mass transfer coefficient, the solar conduction dryer performed better than the open sun drying method. Borah et al., [20] have experimented with drying turmeric drying in a solar conduction dryer. As a result of the study, it was determined that the developed solar conduction dryer achieved an overall thermal efficiency of 55% and reduced the moisture content of turmeric from 78.65% (wb) to 6.36% (wb). Similarly, Subedi and Bhattarai [21]) reported that the thermal efficiency of the developed solar conduction dryer was found to be 50.97% for drying ginger samples of 9–11 mm.

The purpose of this paper aims to study the development and performance of solar conduction dryer. In the developed SCD dryer, products get heated by means of black-coated metal surface by conduction, and they become dry as a result. Dryers primarily consist of radiation absorbing heat conducting surfaces that conduct heat. Products are directly in contact with the metal surface in order to receive maximum heat from it. About 20–30% of its surface area is left unfilled so that the metal surface receives the maximum amount of solar radiation. The black-coated trays place inside the dryer absorb most of the heat, which is then transferred to the air inside the dryer by convection. In this way, the heat is trapped in the air inside the dryer through convection in addition to radiation, which is used to absorb all the heat. Based on the literature on solar drying for agricultural products it is observed that solar dryers with conduction mode can be used to reduce heat losses due to air convection of air (particularly in solar convection dryers) [20,22] In addition to achieving more drying efficiency and reducing the time required for drying reflectors were used in the developed system. Therefore, a solar conduction dryer (SCD) was designed and developed to reduce drying time of drying and maximize thermal efficiency. The thermal performance of the developed dryer was assessed by drying the beetroot with and without reflectors.

2. Experimental setup

2.1. Description of developed SCD

The solar conduction dryer was designed and developed for the purpose of investigating the thermal performance of the dryer in an experimental setting. The developed SCD consists of a closed chamber, the radiation-absorbing heat-conducting surface (absorber tray), a polythene sheet transparent cover, reflectors, and a chimney. Fig. 1 illustrates the schematic diagram of the developed SCD. The silver acrylic mirror sheet is used as reflective material and the aluminum metal sheet is used as an absorber material (thickness 3 mm). The developed SCD has a length and a width of 2.25 and 1.12 m respectively. The dryer had a total area of 2.5 m^2, in which 3 drying trays each measuring 1.1 × 0.7 × 0.02 m are arranged. The chimney was designed with a diameter of 0.2 and a height of 0.3 m, respectively. Dryer are fabricated using MS angles for the foundation structure and GI sheets for the drying chamber. An inclination angle of 25° was chosen for the transparent sheet in order to maximize the amount solar radiation received. The experimental investigation was carried out in the month of January 2022.

2.2. Preparation of raw material

Red beetroot (*Beta vulgaris* L.) was selected as a drying material for the present study due to the widespread demand for its dried form in different sectors. The product was obtained from the local market, in Udaipur, Rajasthan, India. Fresh beetroot was washed out using water, peeled, cut into slices of 4–5 mm thickness, and put in the dryer on the same day. A preliminary moisture content of 89.8% wb was determined for the sample. Digital moisture analyser were used to determine moisture content.

2.3. Performance evaluation

In order to measure the performance of SCD, it was tested on sunny days with and without the use of reflectors, under no load and full load conditions. These measurements were performed in order to determine the maximum temperature achieve inside the dryer, the drying rate, and the drying efficiency. The dryer was oriented towards the south in order to obtain the maximum amount of solar radiation during the day. The reflector opposite to the east direction was used in the morning time (9:00 to 11:00 h) and the reflector opposite to the west direction was used in the evening time (15:00 to 16:00 h). During the experiment, the partially dried product was wrapped in aluminum foil and kept in the airless chamber, used for the next day to continue drying till the constant weight is obtained. In order to calculate parameters such as the rate of moisture removal and drying efficiency, the following formula was used.

2.3.1. Amount of moisture removed

The amount of moisture removed from the beetroot was determined using the following equation. The rate of moisture removal from the product was carried out every hour.

$$\text{Moisture content} = \frac{W_1 - W_2}{W_1} \times 100 \tag{1}$$

Where,

W_1= initial weight of the product, Kg

W_2= Final weight of the sample, after drying, Kg

2.3.2. Drying efficiency

It is defined as the ratio of the heat utilized by the dryer to the heat supplied to the dryer. It is expressed in percentage and given by the following formula

$$\eta = \frac{Q}{A \times I \times t} \times 100 \tag{2}$$

Where,

Q = Total quantity of heat utilized for drying, J

$= M\,C_p\,(T_d - T_a) + M_w\,\lambda$

M = mass of the product, kg

C_p = Specific heat of wet product, kJ/kg K

T_d = temperature of the drying air, K

T_a = temperature of the inlet/ambient air, K

M_w = Mass of water to be removed during drying, kg

λ = Latent heat of vaporization of water, kJ/kg

η = efficiency of the drying system

A = collector area, m^2

I = solar insolation (W/ m^2) t = time for which dryer exposed to solar radiations, sec

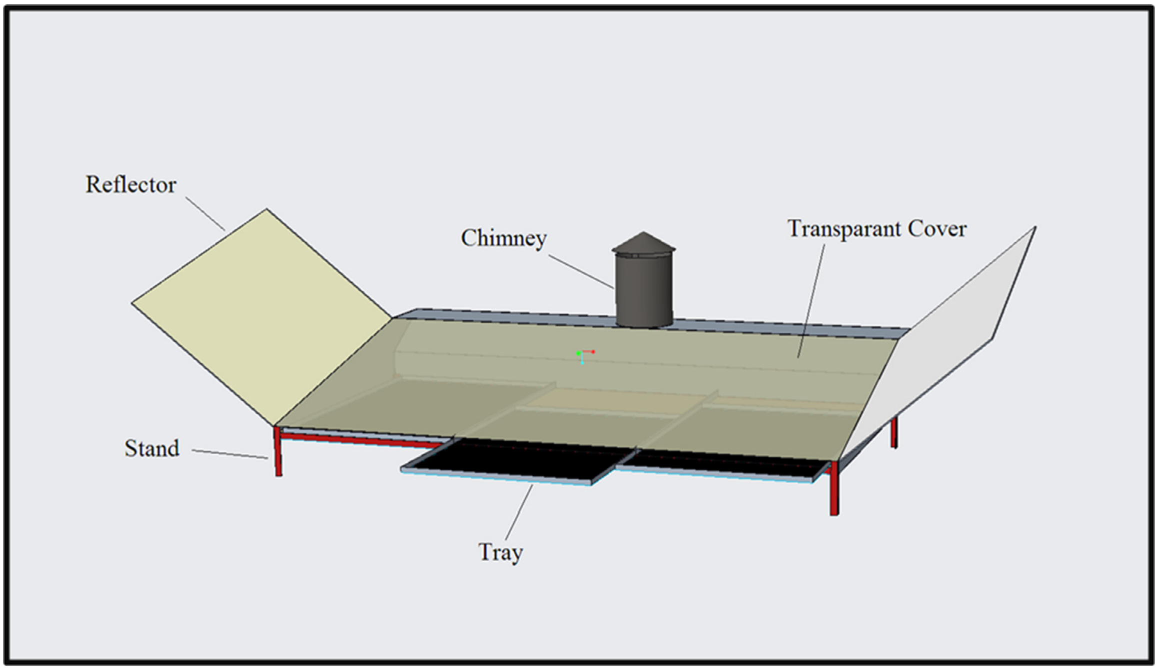


Fig. 1. Schematic figure of developed Solar Conduction Dryer.

2.3.3. Drying rate

The drying rate is defined as the ratio of weight loss of material at a particular time interval and the difference in the time period. The drying rate of the sample was determined by the following formula

$$D_r = \frac{\Delta \mathrm{M}}{\mathrm{W}_2 \times \ \Delta \mathrm{t}} \tag{3}$$

Where,

$\mathrm{D_r}$ = Drying rate, (g of water evaporated/g of dry matter/ h)
ΔM = Weight loss at any time, g
$\mathrm{W_2}$ = Weight of sample after drying, g
Δt = Time difference, hour

2.4. Economic analysis

The economic analysis of the developed dryer was carried out to find out its economic feasibility. For the promotion and successful commercialization of new technology in the market analysis of its economic viability is very essential. The economics of developed SCD was determined using the following parameter [23].

2.4.1. Payback period

The payback period of the system indicates the time required to recover the invested amount. It is calculated as,

$$\text{Payback period} = \frac{\text{Total investment}}{\text{total profit}} \tag{4}$$

2.5. Instruments used during the experiment

A Digital Solarimeter manufactured by M/s. Surya Solar System, Ahemdabad was used to measure solar radiation falling on the horizontal surface. The temperature inside the dryer was recorded by an electronic data logger EMCON – 1359 equipped with twelve temperature sensors (probes) manufactured by M/s Century Instruments Limited, Chandigarh, was used to record the temperature at different locations inside the dryer. The data logger was able to display as well as record any temperature from 0 °C to 600 °C with 0.1 °C resolution. A Sartorius MA100 Moisture Analyzer was used to determine the moisture content of the Beetroot slices quickly and accurately. It has range of 0.005% to 100% of moisture content. The mass of the sample measurement was done by using Sartorius Electronic Weighing Balance BSA224S – CW. Capacity of 220 gs with a readability of 0.0002 g. A Digital Hygrometer was used to measure the relative humidity and ambient temperature of the air. It has range of 10 to 99 percent of relative humidity and the corresponding provision of measuring temperature in the range of 0–70 °C with display accuracy of 3%.

Fig. 2. Developed solar conduction dryer.

3. Results and discussions

The solar dryer as shown in Fig. 2 was developed to dry beetroot slices using the conduction mode and two reflectors each side. During the experiment following data such as solar radiation, ambient temperature, dryer temperature, chimney temperature, humidity and weight of samples were measured. The data were analyzed in order to determine the moisture content, drying rate, and drying efficiency under the

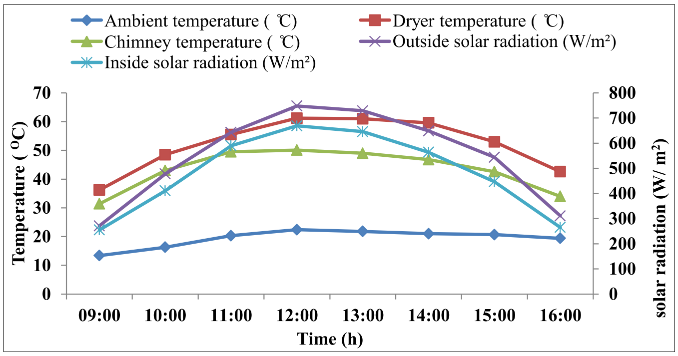


Fig. 3. Temperature profile under no load conditions without use of reflectors.

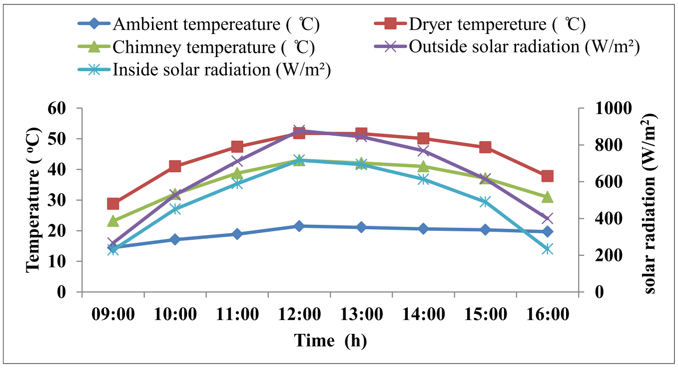


Fig. 4. Temperature profile under full load conditions without use of reflectors.

following conditions, with and without the use of reflectors. Furthermore, reflectors can also be used to cover the dryer when it is not in use, thereby extending the shelf life of the covering material (polythene sheet) by preventing direct sunlight exposure.

3.1. Performance of the system without use of a reflector

3.1.1. No load testing

The no-load testing was conducted to assess temperature variation profile at different parts of the dryer, shown in Fig. 3. It was seen that the maximum and minimum temperatures of 61.2 °C and 36.2 °C were recorded at 12:00 h and 9:00 h, respectively in the dryer. Nevertheless, the maximum surrounding air temperature was 22.4 °C at 12:00 h, and the minimum surrounding temperature was 13.4 °C at 9:00 h. It was observed that a rise of temperature of 38.8 °C takes place in the dryer in contrast to the surrounding air temperature. The solar radiation was received on the experimental site in the range of 271 W/m^2 at 9:00 h to 878 W/m^2 at 12:00 h.

3.1.2. Full load testing

To conduct the full load test, the dryer was loaded with 25 kg of beetroot slices averaging 4–5 mm thick and the temperature variation profile at different points of dryer is shown in Fig. 4. In the dryer, maximum and minimum temperatures of 51.8 °C and 28.8 °C were recorded at 12:00 h and 9:00 h, respectively. However, the maximum surrounding temperature recorded at 12:00 h and the minimum temperature at 9:00 h was 21.5 °C and of 14.5 °C, respectively. It was observed that there is rise of 30.3 °C temperature inside the solar conduction dryer when compared with the surrounding air temperature. Moreover, Fohr and Arnaud [24] reported that in natural convection solar dryer the difference in inside and outside dryer temperature of was only 20 °C.

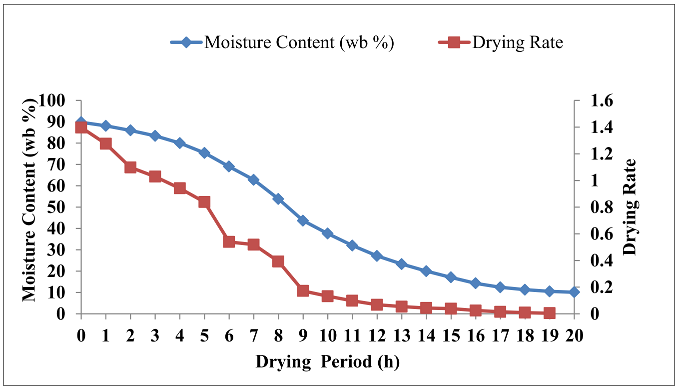


Fig. 5. Variation in drying rate of beetroot with respect to time and moisture content without use of reflectors.

3.1.3. Drying rate

The beetroot slices of thickness 4–5 mm were dried from the initial moisture content of 89.8 to 10.13% (wb) within 20 hrs only. It is evident from Fig. 5 that the drying rate of beetroot slices varies with respect to moisture content and time. The study found that initially the drying rate was found to be 1.397 g H_2O/g dry matter/h and it decreases sharply during the first 9 h of drying and then gradually decreased to 0.005 g H_2O/g dry matter/h with decreasing moisture and increasing drying period. The rate of drying is inversely proportional to the drying time. The study conducted by Schiavone et al., [25] found that in natural convection solar dryer the 9.5 kg mango slices were reduced to 10.3% (wb) from 84.5% (wb) within 36 hrs. Very few researchers had tried to determine the drying rate of solar conduction dryers. Moreover, Subedi and Bhattari [21] reported that the drying rate of solar conduction dryer was higher than open sun drying.

3.1.4. Drying efficiency

It is defined as the ratio of the heat used by the dryer to the heat supplied to it. It is expressed in percentages. During full load testing, the average solar radiation was found to be 626 W/m^2 and the drying time for 25 kg beetroot was 20 h without use of reflectors, and drying efficiency of 50.09% was determined by calculation; however, Schiavone et al., [25] found the efficiency of natural solar convection dryers were 25.9% for drying of tropical fruits during the summer season.

3.2. Performance of the system with the use of reflector

3.2.1. No load testing

During no-load testing as shown in Fig. 6, the maximum temperature 77.4 °C was achieved within the dryer at 12:00 h, and the minimum was 44.3 °C was achieved at 9:00 h. The maximum and minimum surrounding air temperatures were recorded as 23 °C at 12:00 h and 13.1 °C at 9:00 h, respectively. However, it was observed that a temperature addition of temperatures 15.6 °C was observed in the no-load test with the application of the reflector, and a temperature addition of 54.4 °C was observed in the SCD with the application of the reflector, in comparison to the surrounding air temperature.

3.2.2. Full load testing

During full load test with a reflector as depicted in Fig. 7, the maximum and minimum temperatures inside the dryer was 59.1 °C at 12:00 h and 39.2 °C at 9:00 h, respectively. However, the maximum and minimum surrounding air temperatures were recorded as 23.8 °C at 12:00 h and 14.1 °C at 9:00 h, respectively. As compared to the surrounding air temperature, a temperature increase of 35.3 °C was observed inside SCD. During the experimental investigation, it was observed that a temperature increase of 5 °C temperature (with respect to surrounding air

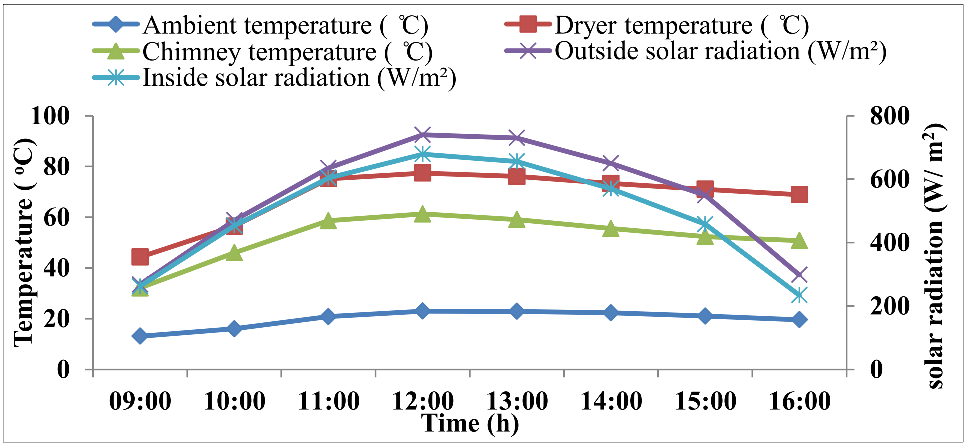


Fig. 6. Temperature profile under no load conditions with the use of reflectors.

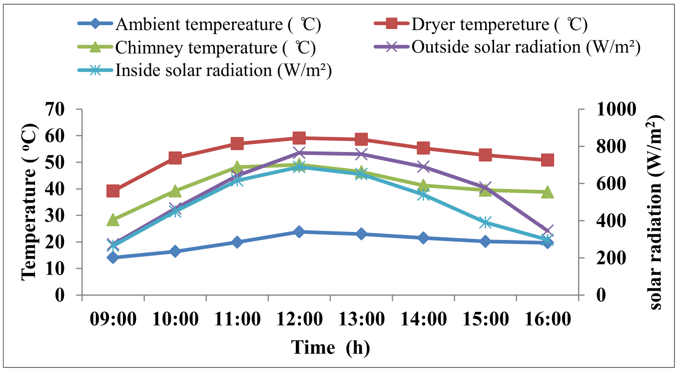


Fig. 7. Temperature profile under full load conditions with the use of reflectors.

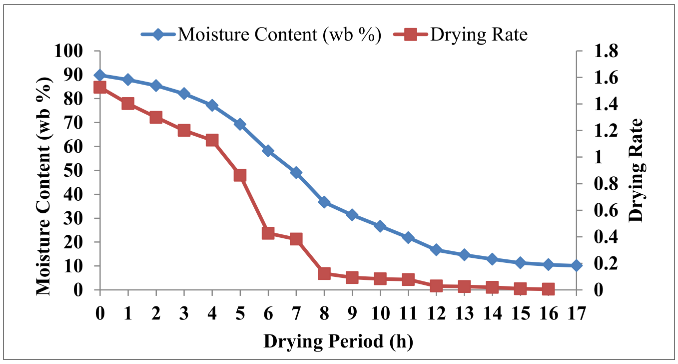


Fig. 8. Variation in drying rate of beetroot with respect to time and moisture content with use of reflectors.

temperature) was observed inside SCD when compared to the same application without the use of reflectors.

3.2.3. *Drying rate*

Approximately 4–5 mm thick beetroot slices were dried from 89.8% moisture content (wb) to 10.13% moisture content within 17 h only. It was also observed that the drying rate of beetroot slices varies with respect to moisture content and time, as depicted in Fig. 8. Initially, the drying rate of dry matter is 1.525 g H_2O/g dry matter/h, which decreases sharply during the first 8 h of drying and then gradually decreases to 0.005 g H_2O/g dry matter/h with decreasing moisture and increasing drying time. The reflector improved the initial drying rate of the beetroot slice from 1.397 to 1.525.

Table 1
Economic analysis of developed SCD.

Sr. No.	Parameters	Values (USD)
1	Capital cost of dryer (A)	342.89
2	Repair and maintenance cost per year	17.14
3	Cost required for raw material (beetroot) per year	1751.16
4	Labor cost required per year	400.26
5	Total cost of production per year (B)= (2 + 3 + 4)	2168.57
6	Money recovered from selling dried beetroot (C)	2521.68
7	Total net profit per year (C-B)	353.10
8	Payback period	1.02 year

3.2.4. *Drying efficiency*

During full load testing average solar radiation was found to be 565 W/m^2 and the time taken by the dryer to dry 25 kg beetroot was 17 h with the use of reflectors and after calculation drying efficiency was found to be 59.4%. with use of reflectors, the drying efficiency of SCD was increased by 9.31%. despite this, Spall and Sethi [26] reported that only 5% drying efficiency was increased of multi-rack tray solar cabinet dryers with use of reflectors as compared to those without. In terms of temperature attained inside the dryer and efficiency, the present study's results were found better than those of Spall and Sethi [26] and Borah et al., [20], in terms of temperature attained inside the dryer and efficiency with using reflectors.

3.3. *Economic analysis*

An economic analysis of the developed SCD was conducted using the following parameters and calculated values are presented in Table 1. However, some assumptions were made such as the life of the developed SCD is 10 years and the operation time of the dryer in a year is 300 days. The capital cost of SCD was 342.89 USD (1 USD= 74.95 INR as on 30 January 2022). Maintenance and repair costs were considered to be 5% of the capital. The cost of labor for performing and monitoring the drying operation was 400.26 USD per annum. The 25 kg beetroot was processed in two days and the cost of beetroot was 0.46 USD/kg. The annual requirement of beetroot was 3750 kg and the dried beetroot quantity was 600 kg. The market value of dried beetroot was 4.20 USD/kg. Therefore, based on the calculations, presented in Table 1. it was determined that a capital investment of 342.89 USD can be recovered (payback period) within 1.02 years.

4. Conclusions

The drying performance of the SCD was evaluated with and without reflectors by thin layer drying of beetroot slices. During no-load testing with and without a reflector, the maximum drying temperature inside the dryer was 77.4 °C and 61.2 °C respectively, whereas during the full load testing the maximum temperature attained within the dryer with and without the use of reflectors was found to be 59.1 °C and 51.8 °C, respectively. There was an increase in temperature increment inside of SCD of 15.6 °C when there was no load and 5 °C when there was a full load with the use of reflectors. Fresh beetroot's moisture content decreased from 89.8% (wb) to 10.13% (wb) within 20 h without the use of a reflector and within 17 h with the use of reflectors. The drying efficiency of the dryer was found to be 50.09% without and 59.4% with reflectors, respectively. A comparison was made between drying efficiency without reflectors and drying efficiency with reflectors, which shows a 9.31% increase in drying efficiency. As a result of reflectors, it was found that solar conduction dryers provide a greater degree of temperature gain, a shorter drying time, and a higher level of thermal efficiency. The payback period of the developed SCD was found to be 1.02 years.

Author contribution

Rupal Jain and Arjun Paul: conceptualization, and writing the original draft; Deepak Sharma, N. L. Panwar: literature analysis, review, and editing.

Declaration of Competing Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Data availability

The data that has been used is confidential.

Acknowledgment

The authors are grateful to Indian Council of Agricultural Research (ICAR), Govt. of India for providing financial aid under AICRP on EAAI to complete the research project.

References

[1] M.R. Patel, N.L. Panwar, Drying kinetics, quality assessment and socio environmental evaluation of solar dried underutilized arid vegetable Cucumis callosus, Energy Nexus 7 (2022) 100128, doi:10.1016/J.NEXUS.2022.100128.

[2] N. Divyangkumar, S. Jain, N.L. Panwar, Influences of latent heat storage heat sink integrated with solar dryer to enhance drying period, Energy Nexus 8 (2022) 100160, doi:10.1016/J.NEXUS.2022.100160.

[3] M.R. Nukulwar, V.B. Tungikar, A review on performance evaluation of solar dryer and its material for drying agricultural products, Mater. Today Proc. (2021), doi:10.1016/j.matpr.2020.08.354.

[4] S. Vijayan, T.V. Arjunan, A. Kumar, Exergo-environmental analysis of an indirect forced convection solar dryer for drying bitter gourd slices, Renew. Energy. (2020) 146, doi:10.1016/j.renene.2019.08.066.

[5] Z. Tagnamas, Y. Bahammou, M. Kouhila, S. Hilali, A. Idlimam, A. Lamharrar, Conservation of Moroccan truffle (Terfezia boudieri) using solar drying method, Renew. Energy. (2020) 146, doi:10.1016/j.renene.2019.06.107.

[6] Z. Tagnamas, H. Lamsyehe, H. Moussaoui, Y. Bahammou, M. Kouhila, A. Idlimam, A. Lamharrar, Energy and exergy analyses of carob pulp drying system based on a solar collector, Renew. Energy. (2021) 163, doi:10.1016/j.renene.2020.09.011.

[7] Y. Bahammou, H. Lamsyehe, Z. Tagnamas, M. Kouhila, A. Lamharrar, A. Idlimam, A. Naji, Exergetic and techno-economic analysis of Moroccan horehound leaves (Marrubium vulgare L.) in forced convection solar and microwave drying, Heat Transf. 51 (2022) 6048–6070, doi:10.1002/htj.22579.

[8] U.E. Ekpunobi, S. Chijioke Ukatu, B.O. Ngene, C. Thankgod Onyema, P.U. Ofora, E. Uche, S. Ekpunobi, B.O. Chijioke Ukatu, C. Ngene, P. Thankgod Onyema, O. Uche, Investigation of the thermal properties of selected fruits and vegetables, Am. J. Sci. Technol. Am. J. Sci. Technol. (2014) 1.

[9] M.U. Hasan, A.U. Malik, S. Ali, A. Imtiaz, A. Munir, W. Amjad, R. Anwar, Modern drying techniques in fruits and vegetables to overcome postharvest losses: a review, J. Food Process. Preserv. (2019) 43, doi:10.1111/jfpp.14280.

[10] S. Şevik, M. Aktaş, E.C. Dolgun, E. Arslan, A.D. Tuncer, Performance analysis of solar and solar-infrared dryer of mint and apple slices using energy-exergy methodology, Sol. Energy. (2019) 180, doi:10.1016/j.solener.2019.01.049.

[11] N.L. Panwar, Energetic and exergetic analysis of walk-in type solar tunnel dryer for Kasuri Methi (Fenugreek) leaves drying, Int. J. Exergy. (2014) 14, doi:10.1504/IJEX.2014.062926.

[12] A. Saleh, I. Badran, Modeling and experimental studies on a domestic solar dryer, Renew. Energy. (2009) 34, doi:10.1016/j.renene.2009.03.001.

[13] A. Lingayat, V.P. Chandramohan, V.R.K. Raju, Design, development and performance of indirect type solar dryer for banana drying, Energy Procedia (2017), doi:10.1016/j.egypro.2017.03.041.

[14] D.V.N. Lakshmi, P. Muthukumar, Design and development of mixed mode forced convection solar dryer for drying of curcuma zeodaria, Twelve Int. Conf. Therm. Eng. Theory Appl. 1 (2019).

[15] E. Baniasadi, S. Ranjbar, O. Boostanipour, Experimental investigation of the performance of a mixed-mode solar dryer with thermal energy storage, Renew. Energy. 112 (2017) 143–150, doi:10.1016/J.RENENE.2017.05.043.

[16] W. Wang, M. Li, R.H.E. Hassanien, Y. Wang, L. Yang, Thermal performance of indirect forced convection solar dryer and kinetics analysis of mango, Appl. Therm. Eng. (2018) 134, doi:10.1016/j.applthermaleng.2018.01.115.

[17] A. Mahapatra, P.P. Tripathy, Thermal performance analysis of natural convection solar dryers under no load condition: experimental investigation and numerical simulation, Int. J. Green Energy. 16 (2019), doi:10.1080/15435075.2019.1671417.

[18] A. Chavan, V. Vitankar, A. Mujumdar, B. Thorat, Natural convection and direct type (NCDT) solar dryers: a review, Dry. Technol. (2021) 39, doi:10.1080/07373937.2020.1753065.

[19] B. Bheda, M. Shinde, R. Ghadge, B. Thorat, Drying of algae by various drying methods, in: 2019. https://doi.org/10.4995/ids2018.2018.7761.

[20] A. Borah, K. Hazarika, S.M. Khayer, Drying kinetics of whole and sliced turmeric rhizomes (Curcuma longa L.) in a solar conduction dryer, Inf. Process. Agric. 2 (2015) 85–92, doi:10.1016/J.INPA.2015.06.002.

[21] T.Raj Subedi, R.Nath Bhattarai, Experimental performance analysis of solar conduction dryer (SCD) for ginger drying, Proc. IOE Grad. Conf. 5 (2017) 2350–8906 http://conference.ioe.edu.np/publications/ioegc2017/IOEGC-2017-78.pdf.

[22] A. Chavan, V. Vitankar, B. Thorat, CFD modeling and experimental study of solar conduction dryer, Dry. Technol. 39 (2021) 1087–1100, doi:10.1080/07373937.2020.1846051.

[23] N.L. Panwar, S. Kothari, S.C. Kaushik, Techno-economic evaluation of masonry type animal feed solar cooker in rural areas of an Indian state Rajasthan, Energy Policy 52 (2013), doi:10.1016/j.enpol.2012.10.020.

[24] J.P. Fohr, G. Arnaud, Grape drying: from sample behaviour to the drier project, Dry. Technol. (1992) 10, doi:10.1080/07373939208916445.

[25] D.F. Schiavone, A.A. Teixeira, R.A. Bucklin, S.A. Sargent, Design and performance evaluation of a solar convection dryer for drying tropical fruit, Appl. Eng. Agric. (2013) 29, doi:10.13031/aea.29.9896.

[26] S. Spall, V.P. Sethi, Design, modeling and analysis of efficient multi-rack tray solar cabinet dryer coupled with north wall reflector, Sol. Energy. (2020) 211, doi:10.1016/j.solener.2020.10.012.