A Comparative Analysis of Solar Tunnel Dryer and Indirect Solar Dryer for Drying Applications

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Abstract: In the quest for sustainable and energy-efficient drying solutions, solar drying technologies have gained prominence. The article presents a comprehensive comparative analysis between two prominent solar drying technologies: the Solar Tunnel Dryer (STD) and the Indirect Solar Dryer (ISD). Solar drying is an environmentally sustainable and economically viable method for reducing moisture content in various agricultural and food products. The Solar Tunnel Dryer, characterized by its tunnel-shaped design, facilitates direct solar radiation absorption by the products, resulting in efficient and accelerated drying. On the other hand, the Indirect Solar Dryer employs a collector to harness solar energy, subsequently transferring this energy indirectly to the drying chamber, affording precise control over drying conditions. This study evaluates the design, heat transfer mechanisms, efficiency, temperature and airflow control, application scalability, as well as cost and maintenance aspects of both dryers. Insights from this comparative analysis aim to aid in informed decision-making for selecting an appropriate solar drying technology based on specific drying requirements and circumstances.
Keywords: Solar dryer, solar drying, Solar tunnel dryer, Indirect solar dryer

1. Introduction

Drying is an outstanding way to overcome spoiling problems of food such as fruits, vegetables and grains (Bennamoun 2011). Drying is the process of removal of moisture from the product to a specified value due to application of heat energy. In short, drying is a combination of heat and mass transfer (Sebaii and Shalaby 2012).

Nowadays, the demand for dried agricultural produce, marine products and, medicinal plants have increased considerably world- wide. Solar drying is an effective method of utilizing energy of sun (Janjai et al. 2007).

Actually, earth receives a plenty annual amount of solar radiation energy which is greater than the world energy request by more than 10000 times (Tiwari 2016; Nguyen and Price 2007). Hence, renewable sources of energy, especially solar energy are the optimum method that can be used to reduce the cost of energy and decrease CO_2 (carbon dioxide) emissions.

Solar dryer is an appliance which transmits heat from heat source to a product, and transfers mass (moisture) from the surface of the product to the surrounding air (Chauhan et al. 2015). The basic function of a solar dryer is to rise the vapor pressure of moisture found inside the product and increase moisture carrying capacity of the drying air by decreasing its relative humidity (Sangamithra et al. 2014). During solar drying, warm air captures moisture from the dried product (Shringi et al. 2014). The amount of moisture removed depends on the temperature of the dried air where warm air has the ability to catch moisture more than cold air. Fig. 1 shows a schematic general the principle of solar dryer.

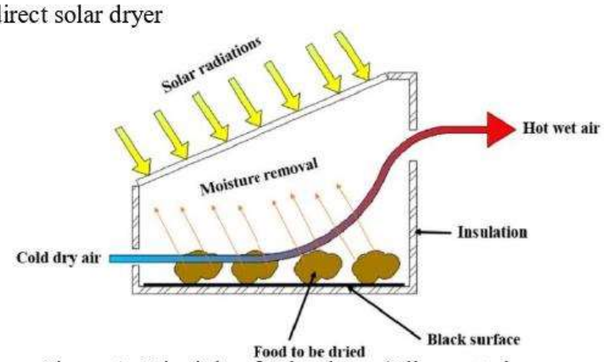

Figure 1: Principle of solar dryer (Elhage et al. 2018)

A new design of solar dryer, namely solar tunnel dryer has been suggested and successfully tested by the Institute for Agricultural Engineering, Hohenheim University, Germany (Lutz and Muhlbauer 1986). Solar tunnel dryer is a type of solar dryer in which the agricultural products are spread in thin layer and dried in the mass quantity. As the name suggest, these dryers are in tunnel shape to receive maximum solar radiations.

2 Type of Dryers

Solar tunnel dryers are working on the principal of thermal heat. Heat is required to increase the temperature of air and product, so the water contained in the product evaporates. A tunnel dryer receives the heat in different modes. Depending upon the heat gain, the dryer is classified as follows.

2.1 Direct mode

Solar radiations are directly incidents on the cover of solar tunnel dryer. As the transmittance of covering materials is high, it enters to the dryer and heat the air and product directly. The dryer receives the heat directly by solar radiations is called direct mode solar tunnel dryers. The drawback of direct mode is that in the absence of sunlight, the air inside the dryer would not be heated. Chauhan and Kumar

(2018) investigated dryer in direct mode in which a solar collector was also designed and fabricated inside the floor of the dryer reported the results that peak temperature of dryer has been achieved by 64.8°C situated in Bhopal, India.

2.2 Indirect mode

These dryers were consisted by solar collector and drying chamber. Solar collector collects the solar radiation by black absorbing material and transfer the heat to ambient air. This heated ambient air than goes to drying chamber by using fan or blower to drying the agricultural products. The dried agricultural products obtained from dryer gets good quality in terms of coloring as the drying chamber did not received direct solar radiations. Rabha et al. (2017) experimented indirect type forced convection solar dryer with two double pass solar heater and a blower. The results reported moisture content of chili samples was reduced from 89.6% to 12% in 123 hours and 193 hours in the dryer and under the open sun respectively. Table 1 represents the past researches those experimented indirect type solar greenhouse dryer.

Table 1: Past researches those experimented indirect type solar dryer

Literature	Specification of Drying system	Test Condition	Outcomes
Condorí et al., 2017	Size: 1.85*4.5*2.15 m^3 Drying Material: Vegetables	Huacalera, northern Argentina (latitude 23° 26′ S; longitude 65° 21′ W)	The solar dryer consisted with bank of solar collector produced a maximum rank of outlet temperatures of 80–90 °C and temperature gain is around 50–60 °C at noon with minimum air flow of 0.06 kg/s and without load. The maximum ambient temperature was 28°C at solar noon.
Rabha et al., 2017	Size: 2*0.85*0.37 m^3 Drying Material: Ghost chilli pepper and sliced ginger	Guwahati, India (latitude 26°11' N and longitude 91°44' E).	The drying air temperature was in the range of 44 °C to 66 °C with an average of 57 °C whereas the ambient temperature vary from 29°C to 37°C. The exegetic efficiencies for both the products were found to be high in the latter stages of the drying periods. It varied between 21% and 98% with an average of 63% for the Ghost chilli and between 4% and 96% with an average of 47% for the sliced ginger.
Shrivastava and Kumar, 2015	Size: 0.91*0.76*0.76 m^3 Drying Material: Fenugreek leaves	Bhopal, India located at 23.15 °N latitude, 77.25 °E longitude, 27–28 April 2013	Embodied energy analysis has been done for indirect solar dryer unit. The total embodied energy of the system is 1081.83 kWh. The energy payback time and CO2 emission are found to be 4.36 years and 391.52 kg per year respectively.

2.3 Mixed mode

This is a modified version of indirect type of dryers in which drying chamber is also receive direct solar radiation along with solar collector. This will enhance the drying rate. Eltawil et al. (2018) tested the dryer in mixed mode to drying of potato slices using the power of flat plate solar collector to enhance the performance of dryer.

2.4 Hybrid mode

The solar dryer connected with another source of power to heat the air in the absence of solar radiations is called hybrid type solar dryer. In the absence of solar radiation, another source of power e.g. biomass, electric heater etc. heat the air, then it goes to drying chamber for drying the products. Ayyappan (2018) investigated the dryer in hybrid mode using biomass heater that maintained the temperature inside the dryer between 35°C and 45°C during night. Chavan et al, 2016 reported that in solar biomass hybrid tunnel dryer, temperature were maintained from 34.2-57.2°C whereas in open sun drying, it were 31-40°C. During night, biomass stove was used that maintain the temperature of 40.6 – 55.7°C in the dryer.

3 Solar Tunnel Dryers

In the literature, there were many shapes of solar tunnel dryer to collect the maximum solar radiations. These shapes are chapel shape, parabolic shape, even span roof type shape, semi cylindrical shape etc. Various commodities were dried in the semi cylindrical shape of the dryer by many researchers (Seerangurayar et al. 2019; Morad et al. 2017; Natarajan et al. 2017; Bukke et al. 2016; Talbot et al. 2016; Perea-Moreno et al. 2016; Karthikeyan and Murugavelh 2018). Table 2 shows the various studies that uses different shapes of the dryer.

Table 2: Past studies that uses solar tunnel dryers

Literature	Shape of drying chamber	Specification of Drying system	Test Condition	Outcomes
Chauhan and Kumar, 2016	Chapel shape	Size: 1.5*1*0.5 m^3 Drying Material: No laod condition	Energy Centre, MANIT (Bhopal, India)	The inside room temperature of NWIGHD for Case-I is 4.11%, 5.08% and 11.61% higher than the Case-II during the experiment of day 1, day 2 & day 3 respectively.
Nimrotham et al., 2017	Parabolic	Size: 0.5*1.5*0.5 m^3 Drying Material: Red Chili	Chachoengsao Province	The drying chamber temperature range was around 29.86°C to 63.16°C and an average temperature chamber about 50°C. Ambient temperature range was around 28°C to 35°C, and an average temperature ambient about 30.74 °C.
Seerangurayar et al. (2019)	Semi Cylindrical	Size: 1500*200*130 cm^3 Drying Material: Dates	latitude 23.59°N and longitude 58.17°E Muscat Oman, 27 July 2017.	In GTD, force convective solar dryer and open sun drying, the temperature achieved was 51, 49 and 41°C (daytime average) respectively. The greenhouse tunnel dryer had 37, 38 and 38% lower drying time for khalal, rutab and tamr stage dates, respectively compared to open sun drying, whereas the drying time was lower by 15, 29 and 30%, respectively in forced convective solar dryer.
Morad et al., 2017	Semi Cylindrical	Size: 2*1*0.8 m^3 Drying Material: Peppermint plants	Egypt, which located at latitude of 31.06 N and longitude of 30.51 E	The results also showed that increasing the peppermint load in a greenhouse, the temperature was decreased. This is due to increasing the evaporation from the plant with increasing load leading to decreasing the dryer temperature and bulk temperature of whole plants and leaves. Operate the solar tunnel greenhouse by continuously fan operating system, which increased the drying rate by 22.78% and 24.8% for whole plants and leaves compared with periodical system.
Natarajan et al., 2017	Semi Cylindrical	Size: 2134*912*609 mm^3 Drying Material: Vitis vinifera, Momordica charantia	Negamam, India, (10°7426' N latitude and 77°1032' E longitude)	The ambient temperature ranged between 27 °C and 29 °C in open sun drying. The maximum temperature was recorded to be 67 °C and 57 °C in using sand for samples of Vitis vinefera & Momordica charantia respectively.
Perea-Moreno et al., 2016	Semi Cylindrical	Size: 14.85*8.30*3.7 m^3 Drying Material: Wood chips of Pinus pinaster	36°50'10" N of latitude and 4°13'33" W longitude, south of Spain	The solar greenhouse dryer can achieve 25.20 °C higher temperature and 20% less relative humidity than open sun drying for the experimentally tested in the south of Spain. The wood chips can be dried, 10% of relative humidity achieved in 13 days in normal conditions, with an average solar radiation of 13.74 MJ/m^2 (autumn season).

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Literature	Shape of drying chamber	Specification of Drying system	Test Condition	Outcomes
Eltawil et al., 2018	Even Span shape	Size: 1*2 m^2 Drying Material: Potato slices	College of Agricultural and Food Sciences, King Faisal University, Al Ahsa (25˚18' N Latitude, 49˚29' E Longitude), Saudi Arabia	The tunnel dryer performance was enhanced by using solar PV power and flat plate solar collector. The ambient temperature, collector outlet temperature, dryer temperature and PV panel temperature recorded were 24°C, 53.60°C, 46.45°C and 37°C in without load condition and 37°C, 57.20°C, 50.5°C and 55°C with load condition. The dehydration process carried out with and without (mixed mode) using black thermal curtain above potato slices. The highest drying efficiency of 28.49 and 34.29% was recorded at air flow rate of 0.0786 kg/s in case of without and with using thermal curtain, respectively.
Chauhan and Kumar, 2018	Even Span shape	Size: 1.35*0.85 m^2 Drying Material: No load condition	MANIT, Bhopal	Case-I is considered for solar collector kept inside the dryer and Case-II is dryer without solar collector The inside room air temperature of INWGHD for Case-I is 10.5 C at 15th h during the day 1, 10.8 C at 14th h during the day 2 and 12.3 C at 11th h during the day 3 greater than Case-II. The highest gain in room air temperature is found 19.5% during the day 1, 22.9% during the day 2 and 23.3% during the day 3 due to the application of solar collector inside the dryer.
Deeto et al., 2018	Gabble structure	Size: 0.5*0.6*0.7 m^3 Drying Material: Coffee bean	King Mongkut's University of Technology Thonburi, Bangkok, Thailand.	The solar greenhouse dryer assisted with solar collector along with producing solar hot water, gave the maximum dryer chamber temperature of 37.9°C (average) in forced circulation whereas the average ambient temperature was 31.1°C.

Conclusion

Based on the review of above literature, following conclusion have been drawn:

- In comparison to open sun drying and solar tunnel drying, solar tunnel drying have a better option because it reduces the drying time upto 50% to 70% and obtain a quality product free from insects dust etc.
- Force convection mode of air movement increases the drying rate rapidly because it maintain homogeneous temperature inside the dryer.
- The performance of solar tunnel dryer increases by adding external heat source. It may be in the form of solar energy or other biomass devices. Mixed mode and hybrid type solar dryer have a better option to increase the productivity.
- The shape of the dryer is in such a way that it utilizes maximum solar radiation and orientation is in south-north direction tom increase the performance of solar dryer.
- Thermal storage materials such as pebble bed, sand bed increased the performance. It liberate heats in the night time also to dry the crops.
- In the northern hemisphere, no any solar radiations fall on north wall of the dryer. To minimizes heat losses, insulate north wall increased the performance of the dryer.
- The selection of covering material is selected that have high transmittance in short wave solar radiation and low infrared transmittance for creating a good greenhouse effect in the dryer.
- Many researchers reported that the payback period of solar tunnel dryer was about 2 to 3 years which is significantly low in terms of their life span of about 10 to 15 years.
- The dryer running on solar energy save the carbon credits and environmental friendly as there is no emission of CO_2.

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