Asian Journal of Scientific Research

ISSN 1992-1454

Asian Journal of Scientific Research 7 (1): 56-65, 2014
ISSN 1992-1454 / DOI: 10.3923/ajsr.2014.56.65

Experimental Investigation of Solar Air Heater with Charcoal Porous Medium

[1]M. Pradhapraj and [2]V. Velmurugan
[1]Department of Mechanical Engineering, Hindusthan College of Engineering and Technology, 641032, Coimbatore, India
[2]SreeSakthi Engineering College, India

Corresponding Authour: M. Pradhapraj, Department of Mechanical Engineering, Hindusthan College of Engineering and Technology, 641032, Coimbatore, India

ABSTRACT

In this study, the testing and improvement of a new type of solar dryer, particularly meant for drying vegetables and grain, is described. The dryer split into two parts: first one solar collector and second drying chamber. The first compartment is converting solar radiation into thermal energy and second compartment is used for spreading and drying agro products. This arrangement is made to absorb maximum solar radiation by the absorber plate. The arrangement of drying chamber is connected separately and products loaded into the dryer, which prevents the problem of discoloration due to irradiation by direct sunlight. The absorber plate reaches a temperature of 110°C and the maximum air temperature obtained from solar collector is 82.5°C. The dryer is loaded with 5 kg of paddy for the analysis. The moisture content is reduced to 5 from 60% in 4 h of time. Different grains and food matters are considered for the drying and the results were recorded. Then a modification was carried out in the collector by introducing a porous medium. Charcoal was used as the porous medium. Again the drying processes were continued for the above mentioned grains with the modified collector. The results were recorded and an increase in the thermal efficiency was identified.

Key words: Solar air heater, moisture, paddy drying, charcoal porous medium

INTRODUCTION

Open sun drying is a traditional method practiced widely in tropical climates for drying agricultural products. Considerable savings can be made with this type of drying since the source of energy is free and sustainable. In natural conecvtion solar dryer, the drying air temperatures at the inlet of the drying chamber are found in the range of 45.5-55.5°C, which are suitable for drying most of the agricultural products (El-Sebaii *et al*., 2002). At higher mass-low rates (0.25 g sec^{-1}) low heights for the upper channel (20 to 30 mm) are recommended for best thermal performance of the collector. However, large duct heights (100 to 130 mm) also yield satisfactory results (Kolb *et al*., 1999). A 4 kg of bitter gourd is dried from 95% moister content to 5% in 6 h time with a maximum solar collector temperature of 78.1°C (Sreekumar *et al*., 2008). Drying constant (k) was greatly afected by drying air temperature and ratio exposed surface area to product mass (El-Beltagy *et al*., 2007). The product thickness should be lesser than 5 cm for obtaining moisture contents of nearly 20% (Sodha *et al*., 1985).

For large scale drying applications, a number of direct and indirect, natural circulation solar dryers have been developed. Greenhouse solar dryer using fan for air flow (Chua and Chou, 2003), solar tunnel dryer with chimney for natural air flow (Jayaraman *et al.*, 2000), solar tunnel dryer with integrated collector for air heating and fan for air flow (Tiris *et al.*, 1996), solar tent dryer and solar dome dryer (Midilli, 2001) have been reported in the literature. Most of these dryers have the drawback of absorbing solar radiation on horizontal surface and at higher latitudes, solar radiation input on horizontal surface is very low during winter. Besides, glazing area of these dryers is much more than the aperture area resulting in excessive heat losses. Hence, the temperature of the drying air remains low, resulting in higher equilibrium moisture content of the dried product. Insufficient airflow can result in slow moisture removal as well as high dryer temperatures. However, the internal resistance to moisture movement in agricultural products is much greater when compared to the surface mass transfer resistance because air flow rate beyond certain levels has no significant effect on the drying rate (Lahsasni *et al.*, 2004).

The solar collector is of two pass type with porous and non-porous medium. The porous medium is coal which is placed between the absorber plate and the base plate. Since the air is made to flow above and below the absorber plate, the heat transfer area is doubled resulting in better heat transfer. The drying chamber has a rectangular drying surface area and it houses two drying racks. The chimney runs above the drying chamber which helps to expel out the used up air. Porous bed (coal) is used below the absorber plate. It increases the time of air flow, as the air flows through the porous of the coal, thereby a considerable increase of air temperature can be obtained.

The food and grains are dried in order to avoid decay and spoilage due to moisture content present in it. A well dried food matter will contain 5 to 25% of moisture. The drying process depends on:

- Generation of high heat
- Dry air to absorb the released moisture
- Proper circulation and flow rate of air throughout the food container

The flavor, color and texture of the food should be taken care off during the drying process. Microorganisms may grow and spoil the food during low temperatures and also the food may become harder under the conditions too high temperature and low humidity. These conditions affect the drying of foods. Thus, the project helps to remove the moisture content of some agricultural products, like tea leaves in an effective manner. The project uses solar (renewable) energy; there are no GHG emissions and a cheap method. Because of the above mentioned reasons Solar dryers have a wide range of application and scope in future.

For large scale drying applications, a number of direct and indirect, natural circulation solar dryers have been developed. A fan is used for air flow in a greenhouse solar dryer (Zongnan *et al.*, 1987), natural air flow is obtained in a solar tunnel dryer with chimney (Norton *et al.*, 1986). In addition to the above system, an integrated collector air heating system is used (Lutz *et al.*, 1987). A solar tent dryer and a solar dome dryer (Ekechukwu and Norton, 1997) have been reported in the literature. Most of these dryers have the drawback of absorbing solar radiation on horizontal surface and at higher latitudes, solar radiation input on horizontal surface is very low during winter. Besides, glazing area of these dryers is much more than the aperture area resulting in excessive heat losses. Hence, the temperature of the drying air remains low, resulting in higher equilibrium moisture content of the dried product.

In state depots, only 30% of food is dried with help of machines whereas the remaining food dried in a open sun. At farm level the drying entirely depends on sun. Sun drying requires huge space and greater manpower. Commercial scale solar drying is very high even though the labor is relatively cheap. In addition, sun drying depends very much on the weather and takes more time. The open air sun drying experiences problems such as dust, airborne and fungi, insects etc and also drying is affected in humid climatic conditions. Foods and grains may get spoiled and wasted during bad weather conditions when lasts for long time. To overcome the above mentioned problems solar dryers are used. Here in this experimental setup different methods and configurations were tried out to bring out the best solar drying technology for foods and grains.

MATERIALS AND METHODS

The main experimental set up consists of 3 major parts; they are thermal collector, drying chamber and chimney. The entire setup is placed under the sun for a considerable time period. The blower is connected to the collector for forced convection mode and the flow rate is adjusted for the required mass flow rate. The ambient dry bulb and wet bulb temperatures are taken to determine the relative humidity, humidity ratio and enthalpy. The initial weight is measured the agricultural product (paddy) is to be dried. The air gets heated up in the collector. The heated air is then passed through the drying chamber and escapes out through the chimney. At regular time intervals the copper plate temperature, inlet and outlet air temperature drying chamber temperature, reduction in moisture are noted and tabulated. The reduction in weight of agricultural product is the amount of moisture removed. The design of the solar drier and its efficiency is analyzed theoretically and experimentally.

System description

Experimental setup: Flat-plate collectors are most suitable for low temperature applications such as domestic and agriculture. This collects both direct and diffuse radiation. It is not required that they track the sun, thus initial cost and maintenance are minimized. A properly designed flat-plate collector has a life expectancy of 10 to 25 years, or sometimes longer. All copper and glass systems currently exhibit the longest lives. The specifications of the solar air dryer used in this experiment are given in the Table 1. An absorber area of 1.30 m^2 is used to collect the solar energy and copper is used for this collector. A 0.086 m^3 of volume used for drying chamber to storage and drying of grains.

A porous medium is a material containing pores (voids). The skeletal portion of the material is often called the "matrix" or "frame". The pores are typically filled with a fluid (liquid or gas). The skeletal material is usually a solid, but structures like foams are often also usefully analyzed using concept of porous media. A porous medium is most often characterized by its porosity. The porous material used in this project is coal as shown in Fig. 1.

The thermal performance of solar-assisted dryer is studied for supplying heat to dry paddy and coconut cornel etc. The primary collector is a single pass air-heater with double duct and is tested with and without porous medium. The porous medium is coal which is placed between the collector plate and the base plate. The air flows in the same direction on both sides of the absorber plate thus providing twice as much surface area for heat transfer to the air compared to either the single-pass air-heater. The drying chamber is designed so as to dry 4 to 8 kg of paddy or coconut cornel.

Electroplated black nickel, black chrome, copper oxide or anodized aluminum is common types of selective coatings. Cost of selective surface coatings may be greater than an extra sheet of glass, but much research is being done to produce low cost, easily applied coatings. The stability of black nickel, chrome and aluminum in the presence of moisture has not yet been proven.

Fig. 1: Flat plate collector with charcoal porous medium

Table 1: Solar dryer components and specification

Description	Specifications
Collector	
Outer box (MS sheet)	Thickness = 90 mm
	Length = 1275 mm
	Width = 1125 mm
Inner box (MS sheet)	Thickness = 65 mm
	Length = 1225 mm
	Width = 1075 mm
Copper sheet	Thickness = 0.6 mm
	Length= 1225 mm
	Width= 1075 mm
Glass	Thickness = 5 mm
	Length= 1220 mm
	Width = 1070 mm
Drying chamber	Mild steel $600\times600\times240$ mm^3
Drying tray	2 trays 58×58 mm^2
Blower assembly	6-speed blower, 230-240 V, 2.2 A, 50-60 Hz, 500 W, 8500-16000 rev min^{-1}
Chimney	Height = 655 mm
	150×150 mm^2

RESULTS AND DISCUSSION

In this study, the efficiency of solar air heater both with porous and non-porous medium was investigated. Besides, a comparison was performed in terms of heat loss by using a dimensionless correlation as a ratio of heat loss to heat gain. Experiments of flat-plate collector, without porous and with porous collectors were carried out on the same day to make a true comparison. The radiation values change in the range of 400 and 887 W m^{-2} and it reaches the maximum in the midday. These values change approximately between 14 and 30°C for environment temperature.

The dryer is loaded with 5 kg of paddy having an initial moisture content of 95% and the final desired moisture content of 5% is achieved within 4 h, without losing the product color, while it was 11 h for open sun drying. As shown in Fig. 2. In this collector part charcoal is used for porous medium and two pass air flow to be used. The maximum temperature raise in drying chamber from

Fig. 2: Drying chamber loaded with paddy

without porous bed and with porous bed is around 58 and 63°C. The use of porous medium increases the system thermal efficiency by 20 to 30% the result of this study two pass and porous medium during drying equipment and higher flow rates increases the overall drying performance and especially efficiency.

Dryer thermal efficiency: Mumba (1995) studied photovoltaic powered forced convection solar dryer for drying maize with an initial moisture content of 33.3% dry basis to 14.3% dry basis and obtained the dryer thermal efficiency of 58.1% (Arinze *et al*., 1999) The thermal efficiency of their system for drying high quality hay of 79% has reported (Pawar *et al*., 1995) this efficiency for custard powder drying as 42.7% (Sodha *et al*., 1985). The conducted drying test on a solar cabinet dryer for drying mango and the overall thermal efficiency was about 25% has reported. Hallak *et al*. (1996) studied on a staircase design direct mode natural convection solar dryer for drying Apricots, figs, grapes, prunes, okra and tomatoes and the thermal efficiencies varied from 26 to 65% (Prasad and Vijay, 2005) compared the thermal efficiencies of solar, biomass and solar biomass dryer for drying ginger, turmeric and gauche. The efficiency reported was 29.1, 7.1 and 15.59% for ginger, 22.44, 5.5 and 14.74% for turmeric and 13.5, 3.4 and 7.5% for gauche, respectively for solar, biomass and solar with biomass drying. Singh *et al*. (2004) reported the thermal efficiencies of 28.55, 16.2 and 8.6% on first, second and the third day respectively for a portable natural circulation solar dryer. Bena and Fuller (2002) studied on a natural convection solar dryer with biomass backup heater and the overall thermal efficiency obtained was 8.6%. The efficiency of their dryer, when using the solar energy and biomass as the source is 22 and 6%, respectively.

Thermal analysis

Volume flow rate: The volumetric flow (also known as volume flow rate or rate of fluid flow) is the volume of fluid which passes through a given surface per unit time, as shown in Table 2:

$$Q = AV \tag{1}$$

where, Q = Volume flow rate ($m^3\ h^{-1}$), A = Cross section area at blower mouth (m^2), V = Velocity of air at blower mouth ($m\ h^{-1}$).

Table 2: Volume flow rate and mass flow rate for various blower speeds

Velocity (V) m h^{-1}	Volume flow rate (Q) m^3 h^{-1}	Mass flow rate (m) kg h^{-1}
39600	111.9	111900
50400	142.5	142500
68400	193.4	193400
79200	223.9	223900
93600	264.6	264600
100800	285	285000

Mass flow rate: Mass flow rate is the mass of substance which passes through a given surface per unit time. Its unit is mass divided by time, so kilogram per second in SI units:

$$m = Qg\rho \tag{2}$$

where, m = Volume flow rate (kg h^{-1}), g = Specific gravity of air = 1, ρ = Density of water (kg m^{-3}).

Mass flow rate

- A = 0.002827 m^2
- V = 39600 m h^{-1} for blower speed of 11 m sec^{-1}
- Mass flow rate (m) = 111900 kg h^{-1}

Dryer factor

$$F_d = \frac{M_1 - M_2}{100 - M_2}.100 \tag{3}$$

Dryer factor of drying for paddy (without porous medium) as shown in Fig. 3.

Heat utilization factor (HUF): This is the ratio of temperature decrease to cooling of the air during drying and the temperature increase due to heating of air.

HUF for drying of paddy(without porous medium) is shown in Fig. 4.

$$t_0 = 53.5\ °C,\ t_1 = 57\ °C,\ t_2 = 54\ °C$$

$$HUF = \frac{t_1 - t_2}{t_1 - t_0} = 0.857 \tag{4}$$

Coefficient of performance (COP)

$$COP = \frac{t_1 - t_2}{t_1 - t_0} = 0.857 \tag{5}$$

where, t_2 = DBT of exhaust air, t_1 = DBT of drying air, t_0 = DBT of ambient air:

- COP+HUF = 1
- 0.143+0.857 = 1

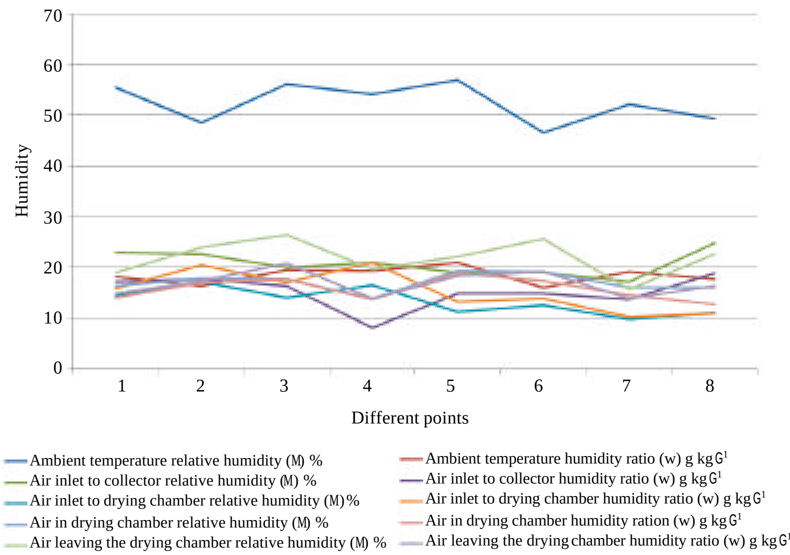

Fig. 3: Relative humidity and humidity ratio for drying of paddy versus different trial methods

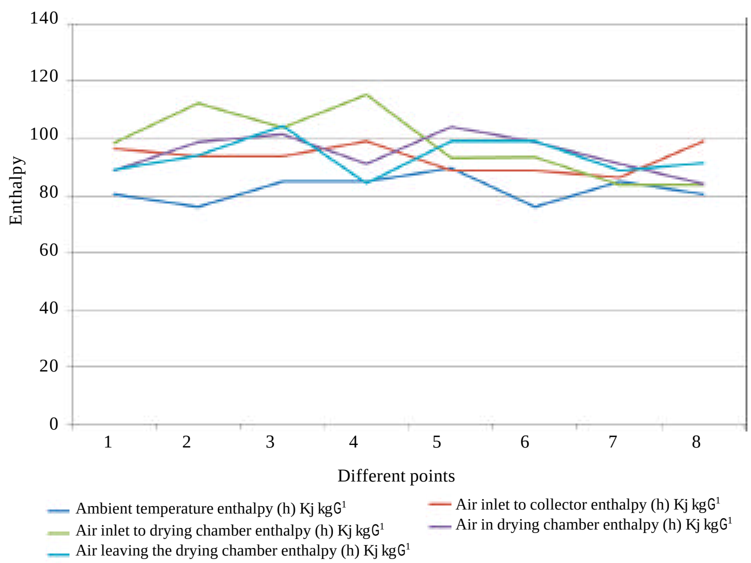

Fig. 4: Enthalpy for drying of paddy versus different trial methods

Relative humidity (Φ)

$$\phi = \frac{P_v}{P_s} \times 100 \quad (6)$$

$$P_v = P_w - \left[\frac{(P_b - P_s).(t_d - t_w)}{(1544 - 1.44 t_w)} \right] \quad (7)$$

Relative humidity of ambient temperature in drying of paddy (without porous medium) as shown in Fig. 3.

Therefore:

- $P_v = 0.02677$ bar, $\Phi = 51.74\%$

Humidity ratio or specific humidity (w)

$$w = 0.622\frac{P_v}{P_b - P_v} = 16.88\text{g kg}^{-1} \tag{8}$$

Enthalpy (h): Enthalpy is the quantity of heat necessary to raise the temperature of a substance from one point to a higher temperature. The quantity of heat includes both latent and sensible.

A quantity with units of energy symbolized H and defined by:

$$H = E+PV$$

where, E is internal energy, P is pressure and V is volume:

$$h = 1.022t_d + w\left\{h_{fg}+2.3t_{db}\right\} = 76.16 \text{ Kj kg}^{-1} \tag{9}$$

CONCLUSION

The performance of a solar air heater without porous medium is less compared to the performance of a solar air heater with porous medium. The performance of the air heater is dependent on the collector area, blower speed, air mass flow rate and porous medium used. The performance of the air heater is dependent on the temperature difference between the inlet air to the ambient air. Therefore, the efficiency will be maximum when the inlet air temperature is more than the ambient air temperature. The fluid conduction has no effect on the overall performance of the collector. Increased air flow ratio improves the dryer efficiency. The drying chamber air temperature is maximum during the peak sun shine hours (11 am to 1 pm). The double flow is more efficient compared to single flow mode due to increased heat removal. The use of porous medium increases the system thermal efficiency by 20 to 30% than that without porous medium. The drying chamber operates in the temperature range of 53 to 58°C which is an optimum temperature for drying paddy and in the temperature range of 55 to 63°C using porous medium. This performance improvement study will be useful in the later stage to examine the thermal behavior of the whole dryer and to develop an industrial solar dryer for drying agricultural products:

- To increase the collection of extra radiation and also improve the collector efficiency by using side mirrors and also find the optimum length and optimum angle of the side mirror
- Another method by using convective lenses in the glass cover to increase the temperature of the absorber plate and also investigate experimentally and theoretically by using single and double glass covers
- The dryer can be test with different porous materials like honey comb porous bed, rock bed, clay brick ceramic and activated charcoal

- To use turbo ventilator over the drying chamber instead of chimney to eliminate the use of blower and also to test the dryer in natural convection method.

ACKNOWLEDGMENTS

This study was financially supported by Government of India, All India Council for Technical Education (AICTE), New Delhi, under Research Promotion Scheme, vide FNO. 8023/RID/RPS-26/Pvt(IIPolicy)/2011-12 Dated 08/02/2012.

REFERENCES

Arinze, E.A., G.J. Schoenau and S. Sokhansanj, 1999. Design and experimental evaluation of a solar dryer for commercial high-quality hay production. Renewable Energy, 16: 639-642.

Bena, B. and J.R. Fuller, 2002. Natural convection solar dryer with biomass back-up heater. Solar Energy, 72: 75-83.

Chua, K.J. and S.K. Chou, 2003. Low-cost drying methods for developing countries. Trends Food Sci. Technol., 14: 519-528.

Ekechukwu, O.V. and B. Norton, 1997. Experimental studies of integral-type natural-circulation solar-energy tropical crop dryers. Energy Convers. Manage., 38: 1483-1500.

El-Beltagy, A., G.R. Gamea and A.H. Amer Essa, 2007. Solar drying characteristics of strawberry. J. Food Eng., 78: 456-464.

El-Sebaii, A.A., S. Aboul-Enein, M.R.I. Ramadan and H.G. El-Gohary, 2002. Experimental investigation of an indirect type natural convection solar dryer. Energy Conv. Manage., 43: 2251-2266.

Hallak, H., J. Hilal, F. Hilal and R. Rahhal, 1996. The staircase solar dryer: Design and characteristics. Renewable Energy, 7: 177-183.

Jayaraman, K.S., D.K. Dasgupta and N. Babu Rao, 2000. Solar Drying of Vegetables. In: Developments in Drying: Food Dehydration, Mujumdar, A.S. and S. Suvachittanont (Eds.). Vol. 1, Kasetsart University Press, Bangkok, pp: 179-206.

Kolb, A., E.R.F. Winter and R. Viskanta, 1999. Experimental studies on a solar air collector with metal matrix absorber. Solar Energy, 65: 91-98.

Lahsasni, S., M. Kouhila, M. Mahrouz, A. Idlimam and A. Jamali, 2004. Thin layer convective solar drying and mathematical modeling of prickly pear peel (*Opuntia ficus indica*). Energy, 29: 211-224.

Lutz, K., W. Muhlbauer, J. Muller and G. Reisinger, 1987. Development of a multi-purpose solar crop dryer for arid zones. Solar Wind Technol., 4: 417-424.

Midilli, A., 2001. Determination of pistachio drying behaviour and conditions in a solar drying system. Int. J. Energy Res., 25: 715-725.

Mumba, J., 1995. Development of a photovoltaic powered forced circulation grain dryer for use in the tropics. Renewable Energy, 6: 855-862.

Norton, B., P.D. Fleming and O.V. Ekechukwu, 1986. Passive autarkic solar drying techniques. Proceedings of the International Workshop on Physics of Solar Energy, November 24-December 6, 1986, New Delhi, India, pp: 447-466.

Pawar, R.S., M.G. Takwale and V.G. Bhide, 1995. Solar drying of custard powder. Energy Convers. Manage., 36: 1085-1096.

Prasad, J. and V. Vijay, 2005. Experimental studies on drying of *Zingiber officinale*, *Curcuma longa* l. and *Tinospora cordifolia* in solar-biomass hybrid drier. Renewable Energy, 30: 2097-2109.

Singh, S., P.P. Singh and S.S. Dhaliwal, 2004. Multi-shelf portable solar dryer. Renewable Energy, 29: 753-765.

Sodha, M.S., A. Dang, P.K. Bansal and S.B. Sharma, 1985. An analytical and experimental study of open sun drying and a cabinet type drier. Energy Conver. Manage., 25: 263-271.

Sreekumar, A., P.E. Manikantan and K.P. Vijayakumar, 2008. Performance of indirect solar cabinet dryer. Energy Convers. Manage., 49: 1388-1395.

Tiris, C., M. Tiris and I. Dincer, 1996. Energy efficiency of a solar drying system. Int. J. Energy Res., 20: 767-770.

Zongnan, L., T. Zhaofeng and L. Mingru, 1987. Design and performance of the integrated solar dryer. Proceedings of the Biennial Congress of the International Solar Energy Society, Volume 3, September 13-18, 1987, Hamburg, Germany, pp: 2505-2509.