ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 1, Issue 8, December 2016

Performance of a Forced Convection Solar Tunnel Dryer with and without Thermal Storage for Drying of Tomatoes

[1]Rajendra Patil, [2] Rupesh Gawande
[1][2] Department of Mechanical Engineering
[1] Bapurao Deshmukh College of Engineering, Wardha 442102
[2] Rashtrasant Tukadoji Maharaj Nagpur University, 440001, Nagpur, India

***Abstract*:-- A forced convection Hohenheim type of solar tunnel dryer incorporated with sensible heat storage material has been developed to test its performance for drying of tomatoes under the environmental conditions of Wardha, Nagpur India. The purpose of present work is to study a forced convection (PV powered) Hohenheim STD with and without the integration of heat storage material. Thermal bricks (Cp =840J/Kg) were used as a heat storage media. Both tests have been carried out for the same mass of commodity and almost for same environmental conditions. Hourly values of global solar insolation and some meteorological data (temperature, relative humidity, wind speed etc.) have been recorded. Experiments were performed at varying mass flow rates ; varying from 0.023 to 0.038 kg/s and 0.025 to 0.036 kg/s with and without HSM. A uniform air temperature in the collector was observed with integration of heat storage material thus provides continuous drying. The Hohenheim STD with heat storage material is capable of producing an average temperature of 62.5 0C, which is suitable for dehydrating most of agro products; while an average temperature of 54.4 0C was recorded in dryer without use of heat storage media. The equilibrium moisture content for tomatoes was reached after 330 and 370 minutes when the system was used with and without heat storage material respectively. Therefore, the heat storage material reduced the drying time by 40 minutes and also increases thermal efficiency of dryer by 2.8 %. The quality of dried tomatoes in term of color, flavor, texture and time required for drying was favorable as compared to open sun drying and forced convection drying without heat storage material. However the performance of dryer can be increased by increasing loading rate and minimizing heat loss to surrounding.**

***Index Terms*— brick, solar tunnel dryer, thermal storage, tomatoes.**

I. INTRODUCTION

India is the fourth chief tomato producing nation in the globe after USA, China and Turkey. At present, India is the main exporter of tomatoes to Bangladesh, Nepal, Maldives, U.A.E, Oman and Pakistan. Indian typical yield of tomato (9.6 ton per hectare) is 42% of world's average yield (23 ton per hectare). Tomatoes are luscious and have numerous nutritional benefits. Tomatoes are loaded with phytochemicals which increases the cancer–fighting abilities and prevents cardio-vascular and heart disease [1]. Now days, spoilage of fresh tomatoes is momentous and in due course, the small-scale producers of India cannot go with their goods to high worth market in municipal areas. The spoilage and wastage of tomatoes can be avoided by use of cold storage (expensive process) and by drying of produce. The drying of foodstuff is the most precise solution for reducing the wastage, gaining extended shelf-life and enhancing the market price of the produce, thus allowing poor farmers to get revenue. Drying of produce in India is usually done by sun drying. Even though sun drying is economical process, it regularly results in low-grade quality due to its reliance on environment and exposure to the attack of germs, bacteria, insect, pests and dust. In addition, it suffers with the lack of process control and uniformity in drying. Thus solar drying is a competent method of utilizing solar energy. Solar drying is a technical process and works on principle of greenhouse effect. A numerous types of solar dryer have been developed and mainly classified into direct, indirect and mixed modes. The restrictions of certain dryers next to the fact of reducing drying time, encourages the researchers to fabricate latest designs like tunnel and green- house type dryers. Tunnel is an enclosed duct apart from entrance and outlet and used for heating of air in several applications together with drying. Basically a Hohenheim solar tunnel dryer is a tunnel of framed structure covered with transparent glass or UV polythene sheet, where agricultural and industrial goods could be dried in control environment [2]. The most important benefit of STD is quicker drying rate with less spoilage and microbiological infestation since produce receives heat energy from collector plus from incident solar radiations. Numerals of studies have been presented on greenhouse tunnel dyers by different researchers. A numerous study on hohenheim solar tunnel dryer at Mymensingh, Bangladesh were conducted by Bala et al. since 2003-2011 for drying of pineapple, jackfruit and leather. Thermal performance was found to be satisfactory. They also reported energy and exergy analysis along with a theoretical basis for drying process by means of ANN [3]-[5]. Derbala et al. conducted experiments for drying of squash in a solar tunnel dryer for investigating the effect of slice thickness on drying rate and relationship between air temperature, solar insolation and relative humidity [6]. The comparative analysis for solar tunnel dryer is presented in a roof type greenhouse dryer was developed by Tiwari and Jain in 2001 for drying of cabbage and peas under the metrological conditions of New Delhi, India [7]. Sultana et al. presented the drying performance of solar tunnel and rotating dryer. The studies were conducted on three marine fishes: Silver Jew fish, Bombay duck and Ribbon fish under the environmental conditions of Bangladesh [8]. A solar tunnel dryer was designed and constructed by Palled et al. in 2010 for drying of grapes under the metrological conditions of Raichur, India [9]. Dulawat and Rathore tested a semi cylindrical solar tunnel dryer in forced convection mode at Udaipur, India for drying processed tobacco [10]. Kagande et al. investigated a solar tunnel dryer for drying of tomatoes under forced convection mode at Zimbabwe's scientific research and development Centre (SIRDC) [1].

An incessant process is necessary during drying of a few agricultural products until it reaches a preferred moisture content which is not possible with solar drying after sunshine hours or even in bad weather conditions. Thus, for nonstop drying, a thermal storage could be provided with the solar collector. Energy storage has a key role in economy of fuels and moreover leads to an extra cost effectual method lessening wastage of energy and capital price. Sensible and latent heat storage methods are frequently used for thermal energy storage in uninterrupted solar drying systems [11]. The general sensible heat storage materials used to accumulate the sensible heat are sand, gravel bed, rocks, concrete, water etc. Table 1 shows the details of some commonly used sensible heat storage materials [12].

Ayensu and Asiedu-Boudzie (1986-1997) constructed a solar dryer with a rock as thermal storage media, while Aboul-Enein et al. (2000) studied a solar air heater with and without thermal storage for drying of agro-commodities. El-Sebaii et al. (2002) also studied the solar dryer with thermal storage material for drying of various agricultural commodities [13]-[16]. Tiwari et al. proposed and analyze an innovative design of thin layer crop drying cum water heater; which operates throughout the year. The system can be used to give hot water when the drying system is not in operation and the water heater underneath the air heater systems would behave as a storage material for drying the crop during off sunshine periods [17]. Mohanraj and Chandrasekhar (2009) developed a forced convection cabinet solar dryer incorporated with gravel as a heat storage material for chili drying [18]. Ayyappan and Mayilsamy (2010) studied a natural convection dryer with sand as a heat storage material for drying of copra [19].

The purpose of current work is to develop a forced convection Hohenheim type of solar tunnel dryer incorporated with thermal brick as a heat storage material for drying of tomatoes. The performance of dryer under forced convection mode with and without heat storage material was discussed in this paper. The various parameters such as moisture content, dryer efficiency, air flow rate and temperature of drying air were calculated and compared accordingly.

Table 1 A List of selected solid-liquid materials for sensible heat storage [12]

Medium	Temperature Range (°C)	Density (kg/m³)	Specific Heat (J/kgK)
Rock	20	2560	879
Bricks	20	1600	840
Concrete	20	1900	880
Water	0-100	1000	4190

II. MATERIALS AND METHODS

Materials

The good quality tomatoes were sorted and purchased from the local market of Wardha and then washed with clean water, weighed and cut in slices of uniform thickness (3mm) by using knife of stainless steel to avoid blackening on the surface. The pretreatment was given to the slices of tomatoes by using KMS (Potassium Meta bisulphate) solution. The initial moisture content of tomatoes was 94% (w.b) [20].

Experimental Setup

Fig. 1 shows the pictorial view for Hohenheim type of solar tunnel dryer of size 1m (w) x 4m (L) x 0.5m

(H). The dryer consists of an air heating unit (collector), a tunnel and small fan to provide the required air flow rate over the tomatoes to be dried. A solar collector and a drying tunnel are connected in series and covered with transparent glass having transmmitivity of 0.80. Inside the dryer two GI sheets of 1mm thickness coated with black paint was used as a absorber. The tomato slices were place in a thin layer on a net in drying tunnel. Thermocol is used as an insulation material to reduce the heat loss. The whole system is placed on a MS stand and oriented to face south to maximize the solar radiation incident on the dryer.

Instrumentation

PT 100 (Uncertainty ±0.5 0C) type of thermocouples was used to measure the temperature of air in solar collector and drying chamber at every hour of interval. The relative humidity at inlet and exit of the dryer was recorded with the aid of digital hygrometer (Uncertainty ±1%). Relative humidity of ambient air was high during morning hours due to cloudy conditions and gets reduced by 3% to 4% as it passes through the solar collector. The intensity of solar radiation was measured by solar meter (Uncertainty ±10%). During experimentation solar intensity varies in the range of 700 W/m2 to 1000W/m2. The average value of 900 W/m2 was used in analysis. An anemometer was used to measure wind speed. Experiments were performed at varying mass flow rates ; varying from 0.023 to 0.038 kg/s and 0.025 to 0.036 kg/s with and without HSM. The mass losses were recorded by using electronic balance having an accuracy of ±0.01 g.

Experimental Procedure

The experiments were carried out under the environmental conditions of Wardha, Nagpur (latitude of 20.7453° N; longitude of 78.6022° E) India. Experiments were conducted in month of summer 2015. Initial moisture content of tomato is determined by oven method and found to be 90%. Initially the dryer was run at no load condition for about 30minutes and then loaded with 5600g of pretreated tomato slices. The DC fan operated by PV module is used to move the required quantity of air over the produce. The drying was carried out to final moisture content of 10% from initial moisture content of 90% (w.b). For this purpose various readings like solar intensity, wind speed, relative humidity at inlet and outlet and temperature of drying air at various locations (eight locations) at every hour interval till end of drying were recorded.

Fig. 1: Pictorial view of Hohenheim type of STD

III. DATA ANALYSIS

1. **Mass flow rate of air**

The air flow rate through the solar collector was estimated by using following equation

$$m_a = \rho_a \times A_i \times v_a$$

Where

ρ_a = density of air $= \dfrac{P_a}{R_a T_a}$

T_a = Ambient temperature

A_i = Area for airflow

v_a = Velocity of air

2. **Solar energy input**

Solar radiations are incident on the aperture area of collector and get transmitted into the collector chamber. The amount of energy received from the solar insolation is given by the following equation

$$\text{Heat input} = I \times A_C = I \times A_C \times \tau$$

Where

I = Solar insolation

A_C = Collector area

τ = Transmitivity of glass

3. **Heat utilized**

The heat utilized by air flowing through the collector is given by following equation

$$Q_u = m_a \times C_{Pa} \times (T_C - T_a)$$

Where

T_C = air temperature in collector

C_{Pa} = Sp. heat of air

4. **Collector efficiency**

It is the ratio of amount of heat utilized to the heat received by collector.

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 1, Issue 8, December 2016

$$\eta_C = \frac{Q_u}{I \times A_C \times \tau} \times 100$$

5. **Dryer efficiency**
The thermal efficiency of Hohenheim solar tunnel dryer was estimated by following equation

$$\eta_d = \frac{m_w \times \{[C_{Pw} \times (T_d - T_a) + H_l]\}}{(Q_u + I \times A_{dryer} + W) \times t} \times 100$$

Where
T_d = Drying air temperature
C_{Pw} = Sp. heat of water
W = Wattage of fan
H_l = Latent heat of vaporisation
t = Drying time

6. **Percentage of moisture removed**
The amount of moisture removed can be represented in wet basis and expressed as percentage.

$$M = \frac{M_i - M_f}{M_i} \times 100$$

Where
m_w = mass of water removed = $M_i - M_f$
M_i = Initial mass
M_f = Final mass

IV. RESULTS AND DISCUSSION

1. Variation of collector temperature of air with time

Fig. 2 shows the comparison between variation of average temperatures of air in collector with and without heat storage material. The temperature in solar collector varies from 41 - 66^{0}C for dryer without HSM and 58 - 67^{0}C with HSM. Also Hohenheim type of STD with HSM is capable of producing average temperature of 62^{0}C, which is suitable for dehydrating most of the agro products; while an average temperature of 550C was recorded in collector without HSM. Figure shows that a consistent temperature is maintained inside the dryer when HSM is used.

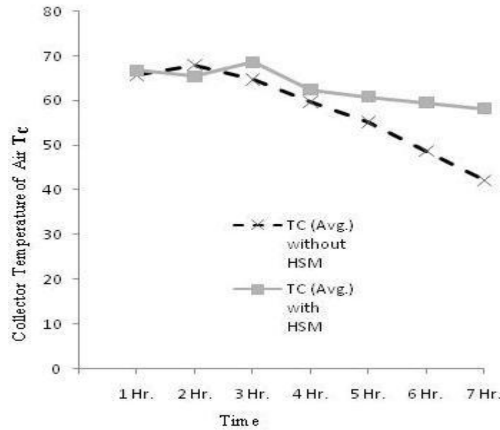

Fig. 2 Variation of collector temperature of air with time

2. Variation of drying air temperature with time

Fig. 3 shows the comparison between variation of average drying air temperature with and without heat storage material. The temperature in drying chamber varies from 37-60.5^{0}C without HSM and 53 - 63^{0}C with HSM. Figure shows a consistent temperature in drying chamber when HSM is used while a lot of variation in drying temperature lowers the drying rate.

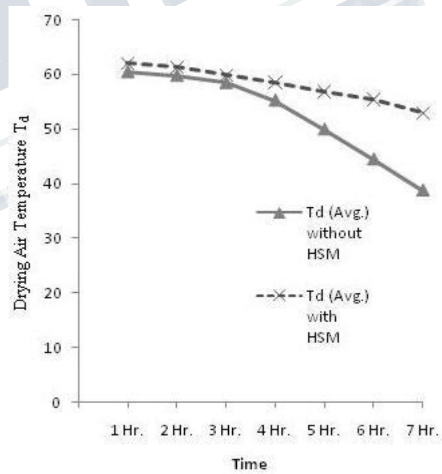

Fig. 3 Variation of drying air temperature with time

3. Variation of dryer efficiency with time

Fig. 4 shows the variation of dryer efficiency with and without integration of HSM. The maximum efficiency of dryer was found to be 72% and minimum was 11% with an average efficiency of 40% without HSM. The drying efficiency of Hohenheim STD using thermal brick as a HSM was found to be 4-5% more than the efficiency without HSM. This is due to fact that HSM (Thermal Brick) maintains the consistent desired temperature

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 1, Issue 8, December 2016

throughout the drying and prolongs the drying even in bad weather conditions.

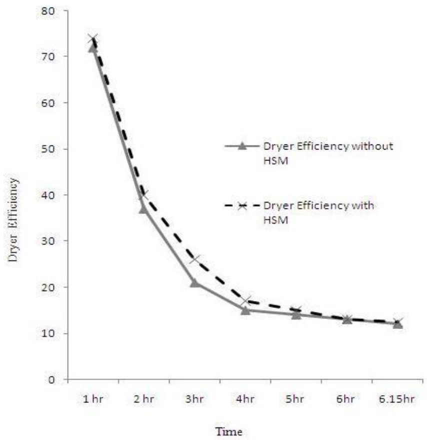

Fig. 4 Variation of dryer efficiency with time

4. Variation of moisture content with time

The variation of moisture content with drying time for solar tunnel dryer with and without heat storage material (HSM) was illustrated in Fig. 5. The moisture content of tomato slices were reduced from an initial value of 90% (w.b) to a final value of 10% (w.b) within 330 minutes in presence of heat storage material and 370 minutes without heat storage media. Initially the moisture removal rate was very high in early hours of drying due to rapid evaporation of free moisture from the outer surface. Afterwards the moisture removal rate gets reduced due to internal moisture movement from inner layers to the surface, which results in a progression of constant drying. Heat stored in a thermal birck reduces the drying rate and saves 40 minutes of drying.

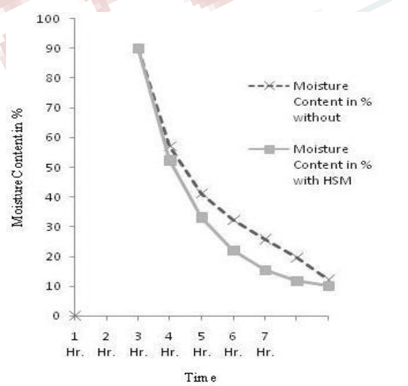

Fig. 5 Variation of moisture content with time

V. CONCLUSION

The investigations with alumina bricks as a thermal energy system shows a significant reduction in drying time and an improvement of the product quality. The quality of the final product is acceptable in taste and appearance, in fact better than natural drying as pre-treatment was done. The reduction in drying time was between 30 - 50 % compared to natural sun drying and between 10 - 12 % compared to drying in STD without thermal storage. Although the initial cost is relatively high, the running cost is low and the payback period is less than two years. Heat storage therefore permits drying to continue even when the environmental conditions such as rainfall and high relative humidity make it difficult for open-air sun drying to take place. From the experimental analysis it is suggested that for best economy and efficiency, mass of commodities can be increased to utilize the thermal energy developed.

REFERENCES

1. L. Kagande1, S. Musoni and J. Madzore, “ Design and performance evaluation of solar tunnel dryer for tomato fruit drying in Zimbabwe,” IOSR Journal of Engineering, Vol. 2, Issue 12, pp. 01-07, December 2012

2. R. Patil and R. Gawande, “A review on solar tunnel greenhouse drying system,” Renewable and sustainable energy reviews, vol. 56, pp. 196-214, 2016.

3. B. K. Bala ,M. R. A. Mondol, B. K. Biswas and B. L. Das, “ Solar drying of pineapple using solar tunnel drier,” Renewable Energy, vol. 28, pp. 183–90, 2003.

4. B. K. Bala, M. A. Ashraf Uddin, S. Janjai, “Experimental and neural network prediction of the performance of a solar tunnel drier for drying jackfruit bulbs and leather,” J Food Process Eng., vol. 28, pp.552-566, 2005.

5. B. K. Bala, M. M. I. Chowdhury and M. A. Haque, “.Energy and exergy analysis of the solar drying of jackfruit leather,” Biosystem Engineering, vol. 110, pp. 222-229, 2011.

6. A. Derbala, N. A. Udroiu, A. Mitroi and C. Iacomi, “.Drying of squash using solar tunnel dryer with photovoltaic, ”MisrJAgricEng, vol. 26(2),pp.922-934, 2009.

7. D. Jain and G. N. Tiwari, “Effect of greenhouse on crop drying under natural and forced

convection I: evaluation of convective mass transfer coefficient," Energy Conversion and Management, vol. 45, pp. 765-783, 2004.

8. S. Sultana, M. N. Shikha and M. Islam, "Drying performance of rotating and solar tunnel dryer for production of quality dried fish," ProgAgric, vol. 20(1– 2), pp.173–81, 2009.

9. M. S. Dulawat and N. S. Rathore, "Forced convection type solar tunnel dryer for industrial applications,"AgricEngInt: CIGRJ, vol. 14(4), pp. 5-9, 2012. [Open access at ⟨http://www.cigrjournal.org⟩].

10. V. Palled, S. R. Desai, M. Anantachar, R. S. Yaranal and W. Shankar, "Grapes drying in solar tunnel dryer – an approach," In: Proceedings of the 23rd national convention of agricultural engineers held at MPKV, Rahuri,6–7 February 2010.

11. L. M. Bal, S. Satya and S. N. Naik, "Solar dryer with thermal energy storage systems for drying of agricultural food products: A review," Renewable and sustainable energy reviews, vol. 14, pp. 2298-2314, 2010.

12. A. Sharma, V.V Tyagi, C. R. Chen and D. Buddhi, "Review on thermal energy storage with phase change materials and applications," Renewable and sustainable energy reviews, vol. 13(2), pp. 318-345, 2009.

13. Ayensu, "Dehydration of food crops using a solar dryer with convective heat flow, Solar energy, vol. 59, pp. 121-126, 1997.

14. Ayensu, V. Asiedu-Boudzie, "Solar drying with convective self-flow and energy storage, Solar and wind technology, vol. 3, pp. 273-279, 1986.

15. Enein, "Parametric study of solar air heater with and without thermal storage for solar drying," Renewable energy, vol. 21, pp. 505-522, 2000.

16. E. Sebaii, "Experimental investigation of an indirect type natural convection solar dryer," Energy conversion and management, vol. 43, pp. 2251-2266, 2002.

17. G. N. Tiwari, P. S. Bhatia, A. K. Singh and R. K. Goyal, " Analytical studies on crop drying cum water heating system," Energy conversion and management, vol. 38(8), pp.751-759, 1997.

18. M. Mohanraj and P. Chandrasekhar, "Performance of a forced convection solar drier integrated with gravel as heat storage material for chili drying," Journal of engineering science and technology, vol. 4(3), pp. 305- 314, 2009.

19. S. Ayyappan and K. Mayilsamy, "Solar tunnel dryer with thermal storage for drying of copra," In: Proceedings of the 37th national and 4th international conference on fluid mechanics and fluid power , IIT Madras, Chennai, India, 16-18 December 2010.

20. R. Patil and R. Gawande, "Comparative analysis of cabinet solar dryer in natural and forced convection mode for tomatoes," International journal of research and scientific innovation (IJRSI), vol. 3 (7), pp. 49-52, 2016.