Experimental and Comparison Studies on Drying Characteristics of Green Chilies in a Solar Tunnel Greenhouse Dryer and in the Open Sun Drying Method

S. Arun, K. Vinoth Kumar, P. Kumaran

Abstract*— A natural convection solar tunnel dryer was designed and developed for carrying out the experimental and comparison studies on drying characteristics of green chillies in Negamam region of Pollachi, Tamil Nadu (India) during the month of April, 2014. About 50 kgs of green chillies were carried out in the dryer and is repeated for three trails. The drying parameters such as product quality and drying time were taken into account for finding the best suitable method of drying of products. The solar tunnel greenhouse dryer dried the green chillies which has an initial moisture content of 88.5% to a final moisture content of 7.4% over a time period of 55 hours whereas the open sun drying method took 125 hours for the same. Also the quality of green chillies obtained from the solar tunnel greenhouse dryer was found to be of superior quality to that of open sun dried green chillies.

***Index Terms*—Drying time, green chillies, moisture content, open sun drying, product quality, solar tunnel greenhouse dryer.**

I. INTRODUCTION

Chilli is a commercial crop in India. The major chilli producing states in India are Tamil Nadu, Andhra Pradesh, Maharashtra and Karnataka. India is the world's largest producer, consumer and exporter of chillies. Total production of chillies is nearly 1 million tons per year. The spices like chillies constitute an important group of agricultural commodities which have been considered indispensable in the culinary art for flavouring foods. As chilli is a highly perishable crop, after harvesting, it often leads to spoilage of chillies. Ultimately, the farmers cannot meet the requirements and demands of traders and consumers. In order to extend the shelf life of the chillies and to avoid spoilage, the practice of removing moisture content from the chillies was developed. In order to avoid spoilage of the chillies, the initial moisture content of green chillies was found to be 88.5% (w.b.) which is then has to be reduced to a final moisture content of 7.4%(w.b.). The use of solar energy for this dehydration process is gaining interest in tropical countries like India. Sun shines in India over an average 3000- 3200 h/yr delivering about 2000 kWh/m 2-yr of solar radiation on horizontal surface (Anonymous). This abundantly available solar energy can be used for drying of chillies.

Manuscript Received on October 2014.

S. Arun, Department of Mechanical Engineering, Dr. Mahalingam College of Engineering and Technology, Pollachi, India.

K. Vinoth Kumar, Department of Mechanical Engineering, Dr. Mahalingam College of Engineering and Technology, Pollachi, India.

P. Kumaran, Department of Mechanical Engineering, Dr. Mahalingam College of Engineering and Technology, Pollachi, India.

The most traditional method of drying is the open sun drying method where the products will be spread over the floor of the drying yard. But this method has many disadvantages mainly being the extended drying time. Excessive delay in the drying results in bacterial and fungal infections thereby degrading the quality of the products. Also, due to the high humidity in the atmosphere during the time when there is a fall in sunshine (after 5PM), the quality of the products will further be degraded by contamination from insects, rodents, damage by birds and animals, windborne problems like dust & dirt. In order to overcome these practical difficulties of drying, a natural convection solar tunnel greenhouse dryer was designed and developed in Kondegoundenpalayam village of Pollachi, Tamil Nadu (India). This dryer basically operates on the principle of greenhouse effect where all the solar radiation falling into the dryer will be absorbed and will not be re-radiated back, thus acting as a solar trap. This solar trap is particularly responsible for the high temperature environment inside the dryer thereby drying the products at an earlier time. Reference [1] has developed and evaluated a farm solar dryer for chilly drying in a selected village of Raichur district. They reported that on an average 41.5 per cent of higher temperature was obtained in farm solar dryer over the ambient temperature. A total drying time of 30 hours was required for chilly drying in farm solar dryer to reduce the moisture content from 76.5 per cent (w.b) to about 9.0 per cent (w.b) as compared to that of 48 hours for open sun drying for the same level of moisture contents. Various studies have been reported for solar drying of food stuffs [2]-[6]. This study was undertaken to experimentally investigate and compare the drying characteristics of green chillies in solar tunnel greenhouse dryer and in open sun drying method. Also, the quality of green chillies produced from both the drying methods was compared so as to choose the best drying method for green chillies.

II. EXPERIMENTAL SECTION

Experiments were carried out under meteorological conditions of Pollachi (latitude, 10.39°N; longitude, 77.03°E) in India during the month of April, 2014. On the basis of measurement, sunshine duration at this location was measured to be about 11 h per day. However, potential sunshine duration is only 8 h per day (9.00 am- 5.00 pm) based on higher solar intensity.

III. SOLAR TUNNEL GREENHOUSE DRYER (STD)

An STD (Fig.1) as a community model solar tunnel greenhouse drier [4 m (W) x 10 m (L) x 3 m (H) at centre] was designed and constructed at Kondegoundenpalayam village using locally available materials. Semicircular portion of drier was covered with UV (200µ) stabilized polyethylene film. No post was used inside the greenhouse, allowing a better use of inside space. Three exhaust vents with adjustable butterfly valves were provided at roof top. Inside drier, cement flooring was coated with black paint to improve its performance. STD is provided with metallic racks for keeping the products in layers for drying. To investigate the influence of parameters affecting the performance of solar tunnel drier, various measuring devices were installed. A pyranometer was used to measure the incident solar radiation falling on the roof of the solar tunnel green house dryer. Thermocouples were used to measure air temperature at four different points inside the dryer and ambient air. To measure the relative humidity of the air, a hygrometer was employed. The electric signals from the thermocouples and the pyranometer were recorded with an 8-channel data logger. A sling psychrometer was also used to measure the dry bulb temperature and wet bulb temperature of the air.

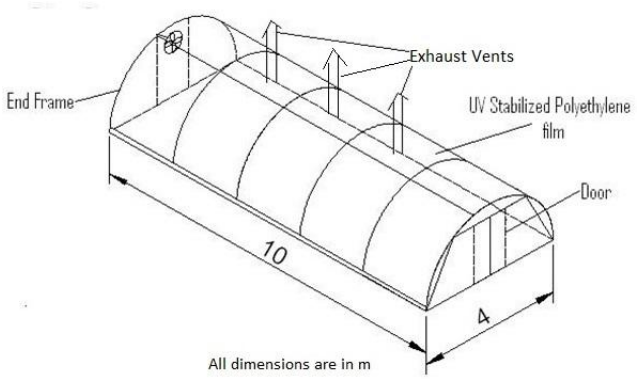

Fig. 1 Solar Tunnel Greenhouse Dryer

IV. INSTRUMENTATION

Figures Calibrated thermocouples (8 numbers, PT 100, uncertainty ±1%) were fixed at different locations inside drier to measure air temperature. Humidity sensors (4 numbers, uncertainty ±1%) were placed at different locations inside drier for measuring air humidity. Ambient humidity was calculated based on measured values of wet and dry bulb temperatures, using two calibrated thermometers, one covered with wet cloth. A solar intensity meter (Delta Ohm, Italy; uncertainty, ±10%) was used to measure instantaneous solar radiation. All temperature sensors, humidity sensors and solar intensity meter were connected to a computer through a data logger (Simex, Italy). Air velocity at drier exit was measured by using a vane type thermo-anemometer (Equinox, Germany; uncertainty ± 0.1%) was used for weighing samples.

V. PRINCIPLE OF SOLAR TUNNEL GREENHOUSE DRYER

The solar radiation is transmitted into the drying chamber by the UV stabilized polyethylene film which provides the greenhouse effect. This film allows all the outside solar radiations to pass into the drying chamber and prevent the re radiation from the drying chamber to the outside and there by helps to accumulating the heat inside the drying chamber. Therefore, the temperature inside the drier is always more than the ambient temperature. This will helps to remove the moisture content of the product placed inside the dryer and therefore it gets dried.

VI. EXPERIMENTAL PROCEDURE

Experiment was conducted during 3-5th of April, 2014 for the drier placed at Kondegoundenpalayam village of Pollachi, Tamil Nadu (India). Fresh and good quality green chillies were loaded into the dryer. Initial moisture content was calculated by taking 10 different samples from different locations inside the drier. Fresh green chillies were loaded over trays (having 90% porosity) of drier unit. Then, the exhaust vents were opened to exhaust initial high humid air. Solar intensity, ambient temperature, dryer temperature and air velocity were measured every 1 h interval till end of drying.

VII. DATA ANALYSIS

A. Determination of Moisture Content

About 10 g samples were chopped from randomly selected five cups and kept in a convective electrical oven, maintained at 105 ± 1^{O}C for 5 hrs. Initial *(m_i)* and final mass *(m_f)* at time (t) of samples were recorded using electronic balance and repeated every 1 h interval till the end of drying. Moisture content on wet basis (M_{wb}) is defined as

$M_{wb} = (m_i - m_f) / m_i$

where, m_i and m_f are initial and final weight of samples respectively.

VIII. RESULTS AND DISCUSSIONS

B. Variation of Solar Intensity and Temperature with Time

The fig.2 shows the variation of solar intensity, ambient temperature and dryer temperature during the experimental period (3-5th April, 2014). During the first day, the solar intensity varied between 313 W/m^2 and 719 W/m^2, the ambient temperature varied between 30°C and 40°C with a peak value of 40°C at around 1.00 p.m. and the dryer temperature varied between 40°C and 62°C with a peak value of 62°C at around 1.00p.m.

During the second day, the solar intensity varied between 308 W/m^2 and 772 W/m^2, the ambient temperature varied between 28°C and 39°C with a peak value of 39°C at around 1.00 p.m. and the dryer temperature varied between 37°C and 63°C with a peak value of 63°C at around 1.00p.m.

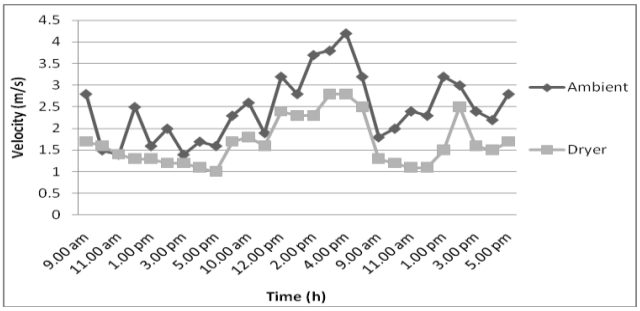

Fig. 2 Variation of Solar Intensity and Temperature with Time

During the third day, the solar intensity varied between 312 W/m^2 and 802 W/m^2, the ambient temperature varied between 28°C and 38°C with a peak value of 38°C at around 1.00 p.m. and the dryer temperature varied between 42°C and 63°C with a peak value of 63°C at around 1.00p.m. It is clear from the figure that, in all the three days of experiment, the dryer temperature was 11°C to 22°C more than the ambient temperature. This shows that the dryer temperature increased effectively due to the green house effect thereby drying the products (green chillies) inside the drier at an earlier time than the open sun drying method. Also, the drier temperature varied according to the solar intensity during this experimental period. The maximum solar radiation observed was about 802 W/m^2. The high temperature inside the solar tunnel greenhouse dryer due to the greenhouse effect ensures quicker and healthy drying of green chillies.

C. Variation of Relative Humidity with Time

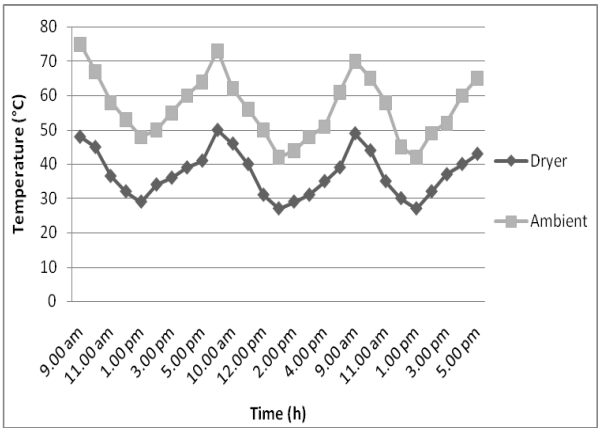

Fig. 3 Variation of Relative Humidity with Time

The fig.3 shows the variation of dryer relative humidity and ambient relative humidity during the experimental period. During the first day, the relative humidity of the dryer varied between 29% and 41% whereas the ambient relative humidity varies between 48 % and 75%. During the second day, the relative humidity of the dryer varied between 27% and 50% whereas the ambient relative humidity varied between 42% and 73%. During the third day, the relative humidity of the dryer varied between 27% and 49% whereas the ambient relative humidity varied between 42% and 70%. It is evident that in all the three days of the experimental period, the relative humidity of the dryer was less than that of ambient relative humidity due to the green house effect which is responsible for the high temperature inside the dryer so that there would not be any bacterial and fungal infections over the green chillies. This ensures that in solar tunnel dryer, the green chillies can be dried at a quicker time than the open sun drying method and also the products will be of superior quality than the open sun dried products.

D. Variation of Air Velocity with Time

The fig.4 shows the variation of ambient air velocity and dryer air velocity during the experimental period. During the first day, the ambient air velocity varied between 1.4 m/s and 2.8 m/s whereas the dryer air velocity varied between 1 m/s and 1.7 m/s. During the second day, the ambient air velocity varied between 1.9 m/s and 4.2 m/s whereas the dryer air velocity varied between 1.6 m/s and 2.8 m/s. During the third day, the ambient air velocity varied between 1.8 m/s and 3.2 m/s whereas the dryer air velocity varied between 1.1 m/s and 2.5 m/s. It was evident that the dryer air velocity is lesser than the ambient air velocity due to the buoyancy effect inside the dryer. This is the reason for the lower air velocity and increased drying rate inside the dryer.

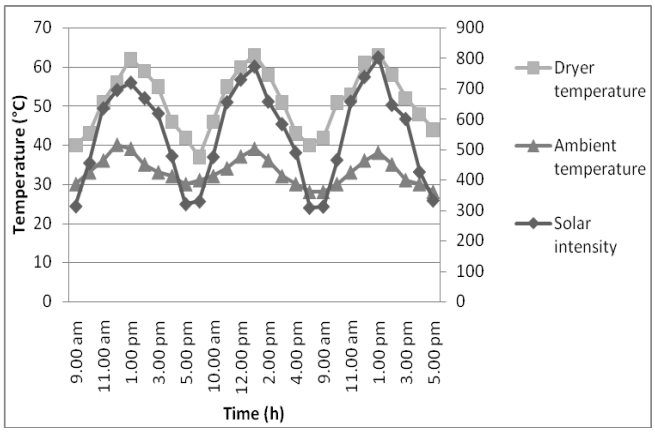

Fig. 4 Variation of Air Velocity with Time

E. Variation of Moisture Content with Time

The fig.5 shows the variation of moisture content of green chillies dried inside the dryer and in the open sun during the experimental period. During the first day, the moisture content of the green chillies inside the dryer reduced from 88.5% to 44.30% whereas for the green chillies dried in the open sun drying method, it is reduced from 88.5% to 64.50%. During the second day, the moisture content of the green chillies inside the dryer reduced from 44.30% to 20% whereas for the green chillies dried in the open sun drying method, it is reduced from 64.50% to 45.59%. During the third day, the moisture content of the green chillies inside the dryer was reduced from 20% to 7.38% whereas for the green chillies dried in the open sun drying method, it is reduced from 45.59% to 32.50%. By the end of third day, the moisture content of the green chillies inside the dryer was reduced to 7.4% which is the maximum level of moisture content that should be removed from green chillies for its safer storage without any spoilage and quality deterioration. During the fourth day, fifth day and sixth day of the experiment, the moisture content of green chillies dried in the open sun drying method, reduced from 32.50% to 19.02%, from 19.02% to 9.98% and from 9.98% to 7.4% respectively.

By mid of the sixth day, the moisture content of the green chillies dried in the open sun drying method was reduced to 7.4% which is the maximum rate of moisture removal from green chillies. From the fig.5 , it can be seen that the products which has an initial moisture content of 88.5%, is reduced to 7.43% for time period of 125 hours in the open sun drying method, whereas in the solar tunnel dryer, the products which has an initial moisture content of 88.5%, is reduced to 7.4% for time period of 55 hours. This further reveals the fact that the solar tunnel green house dryer dried the products (green chillies) at an earlier time than the open sun drying which is primarily due to the high temperature and low relative humidity prevailed inside the dryer as a result of greenhouse effect. Also, the dryer proves to be efficient in drying since the drying time is very less than that of the open sun drying method.

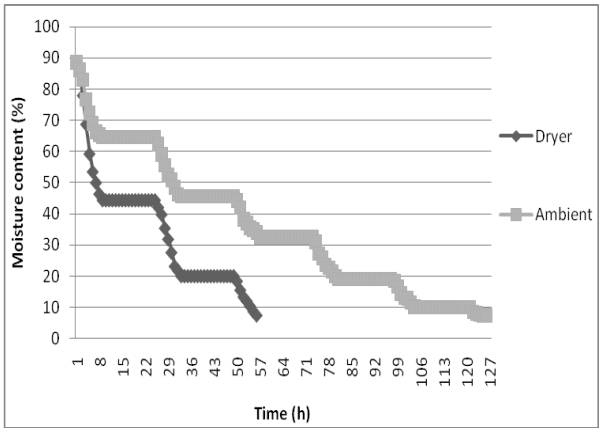

Fig. 5 Variation of Moisture Content with Time

IX. CONCLUSION

Experiment was carried out in a natural convection solar tunnel dryer situated at Negamam village of Pollachi, Tamil Nadu (India) for carrying out the experimental and comparison studies on drying characteristics of green chillies during the month of April, 2014. Three trails of 50 kgs of green chillies were carried out in the dryer. The green chillies which has an initial moisture content of 88.5% was reduced to a final moisture content of 7.4% over a time period of 55 hours in the solar tunnel greenhouse dryer whereas the open sun drying method took 125 hours for reducing the moisture content of green chillies to the same level.

Fig. 6 Comparison of Open Sun Dried and Solar Tunnel Dried Green Chillies

The high temperature and low relative humidity inside the dryer is primarily responsible for the quick drying of products which were prevailed as a result of greenhouse effect. The green chillies dried in the open sun drying method were found to be degraded in its quality since the chillies were infected by fungus and bacteria, damaged by birds and animals and carried away by wind. The solar tunnel greenhouse dryer prevents those quality deteriorating factors since the dryer will be having high temperature and low relative humidity inside it. Thus this dryer proves to be producing green chillies of superior quality (Fig.6). Therefore, the green chillies can be effectively dried in the solar tunnel greenhouse dryer than in the open sun drying method due to the reduced drying time and superior quality than the open sun drying method.

ACKNOWLEDGMENT

The financial support by Science for Equity, Empowerment & Development division of Department of Science and Technology, Govt. of India, New Delhi for this study in the framework of the project, “Popularization of solar tunnel dryers for copra production in Pollachi region (Tamil Nadu)” is gratefully acknowledged.

REFERENCES

1. S. R. Desai, Vijaykumar and T. Guruswamy, “Multi rack solar dryer for fig drying. In :*Proc. of All India Seminar on Advances in Agricultural Mechanization* organized by Institutions of Engineers (I) in association with KAEA, Bangalore from 27 – 28 December, 2002, pp: 161-168.
2. A. O. Dissa, J. Bathiebo, S. Kam, P. W. Savadogo, H. Desmorieux, and J. Koulidiati, “Modelling and experimental validation of thin layer indirect solar drying of mango slices”, *Renewable Energy*, 2009, vol. 34(4), pp. 1000 – 1008.
3. M. Aktas¸, I. Ceylan, and S. Yilmaz, “Determination of drying characteristics of apples in a heat pump and solar dryer”, *Desalination*, 2009, vol. 238, pp. 266 – 275.
4. R. P. F. Guin´e, D. M. S. Ferreira, M. J. Barroca, and F. M. Gonc¸alves, “Study of the drying kinetics of solar-dried pears”, *Biosystems Engineering*, 2007, vol. 98(4), pp. 422 – 429.

5. A. O. Dissa, D. J. Bathiebo, H. Desmorieux, O. Coulibaly, and J. Koulidiati, "Experimental characterization and modelling of thin layer direct solar drying of Amelie and Brooks mangoes", *Energy*, 2011, vol. 36(5), pp. 2517 – 2527.
6. B. M. A. Amer, M. A. Hossain, and K. Gottschalk, "Design and performance evaluation of a new hybrid solar dryer for banana", *Energy Conversion and Management*, 2010, vol. 51(4), pp. 813-820.
7. S. Desai, V. Palled, and M. Anantachar, "Performance evaluation of farm solar dryer for chilly drying", *Karnataka Journal of Agricultural Sciences*, 2009, vol. 22(2), pp. 382 – 384.
8. S. Mangaraj, A. Singh, D. V. K. Samuel, O. P. Singhal, "Comparative performance evaluation of different drying methods for Chillies". *Journal of Food Science and Technology*, 2001, vol. 38 (3), 296–299.
9. M. A. Hossain, J. L. Woods , B. K. Bala, "Thin layer drying of Thai red chilli" , ADC 333-335.
10. B. K. Bala, M. R. A. Mondol, B. K. Biswas, B. L. Das Chowdury, & S. Janjai, " Solar drying of pineapple using solar tunnel drier", *Renewable Energy*, 2003, vol. 28, pp.183-190.
11. T. Y. Tunde-Akintunde, "Mathematical modeling of sun and solar drying of chilli pepper", *Renewable Energy*, 2011, vol. 36 (8), pp. 2139 – 2145.
12. J. Kaewkiew, S. Nabneaan, and S. Janjai, "Experimental investigation of the performance of a large-scale greenhouse type solar dryer for drying chilli in Thailand", *Procedia Engineering*, 2012, vol. 32, pp. 433 – 439.
13. M. A. Hossain and B. K. Bala, "Drying of hot chilli using solar
14. tunnel drier", 2007, *Solar Energy*, vol. 81 (1), pp. 85-92.

AUTHORS PROFILE

S. Arun, Junior Research Fellow, Mechanical Engineering, Dr. Mahalingam College of Engineering & Technology, Affiliated to Anna University, Chennai, Udumalai Road, Pollachi, **Education: University/ College:** Dr. Mahalingam College of Engineering & Technology, Pollachi. **Degree:** B.E. Mechanical Engineering, **Year:** 2013

K. Vinoth Kumar, Junior Research Fellow, Mechanical Engineering, Institute/University: Dr. Mahalingam College of Engineering & Technology, Affiliated to Anna University, Chennai, Udumalai Road, Pollachi, **Education: University/ College:** Dr. Mahalingam College of Engineering & Technology, Pollachi. **Degree:** B.E. Mechanical Engineering, **Year:** 2014

P. Kumaran, Student-Mechanical Engineering, B.E., Mechanical Engineering, Dr. Mahalingam College of Engineering & Technology, Affiliated to Anna University, Chennai, Address: Udumalai Road, Pollachi, **Education: University/ College:** Dr. Mahalingam College of Engineering & Technology, Pollachi. **Degree:** Third year-B.E. Mechanical Engineering (pursuing), **Year:** 2014