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Experimental Studies on Drying Characteristics of Tomato in a Solar Tunnel Greenhouse Dryer

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Abstract: A natural convection solar tunnel greenhouse dryer was designed and developed for studying the drying characteristics of tomatoes. Three experimental runs with 30 kgs of tomatoes were carried out in the dryer during the month of June 2014. The performance of the dryer was studied (drying time and product quality) in comparison with open sun drying method. It was found that the solar tunnel greenhouse dryer took only 29 hours for reducing the moisture content of tomatoes from 90% (w.b.) to 9% (w.b.) whereas the open sun drying took 74 hours for the same. Also, the quality of dried tomatoes produced from solar tunnel dryer are much superior compared to that of open sun drying.

***Index Terms*: Moisture content, open sun drying, quality, solar tunnel dryer, tomato.**

I. INTRODUCTION

In the present days, the demand for the tomatoes is increasing steadily with an increase in population and its likeliness towards tomato. India is the 4th major tomato producing country in the world next to China, USA and Turkey. Presently, India is the major exporter of tomatoes to Pakistan, Bangladesh, U.A.E, Nepal, Maldives and Oman (Anonymous, 2010). The world average yield of tomato is 23 tonnes per hectare. Indian average yield of tomato is 9.6 tonnes per hectare. At current time, spoilage of fresh tomatoes is significant and ultimately, the small-scale producers in India cannot match their products to high value market in urban areas. There are two methods to avoid spoilage and wastage of food stuffs especially tomatoes. The first being the cold storage method where the food stuffs will be stored in a highly refrigerated room thereby enhancing the small-scale farmers to meet the sudden and high demands in the market without any significant wastage. This method is an expensive one and small-scale farmers cannot afford it. The second method is drying of the product which is the most appropriate solution for reducing spoilage, gaining prolonged shelf-life and enhancing the market value of the products, thereby allowing poor small-scale farmers to achieve profit. Drying process is the most significant form of food preservation and also for its extended shelf-life. It is a simultaneous heat and mass transfer process in which moisture is removed from the food material by the hot air. In this purpose, there have been many studies on the drying behaviour of vegetables and fruits such as sweet pepper and garlic [1], tomato seed [2], grape [3] & [4], pineapple [5], tomato [6], figs and onion [7], red pepper [8]. Reference [9] & [10] determined the effects of drying air temperature, air flow rate and air relative humidity on the drying kinetics of quince, apple and pumpkin using a convective dryer [11]. It has been noticed that increasing the temperature or velocity of the drying air decreased the total drying time, while decreasing the relative humidity decreased it [9] & [12]. On the other hand, increasing the drying air temperature decreased the equilibrium moisture content and the total drying time [13] & [14]. Therefore drying of tomatoes with a suitable technology will enhance its shelf-life, prevent the wastage of tomatoes. Open sun drying is a well-known food preservation technique that is still, the most common method used to preserve agricultural product in the tropical and subtropical countries. However, tomatoes dried under natural conditions may be exposed to dust, rain and high temperatures. In these conditions some problems such as crack of the structure, bleaching, hard texture, loss of flavour and nutritional properties, low rehydration capacity, non-enzymatic browning which makes tomatoes to worsen in its quality [15]. In spite of that, a rising attention to the production of dried tomatoes is clear owing to the several ways of their use and cooking [16]. Therefore, there is a rising demand by the consumer of finished products having their nutritional and sensorial characteristics preserved as much as possible. To overcome the practical difficulties of open sun drying, a solar tunnel greenhouse dryer was constructed which basically operates on the principle of green house effect. A greenhouse is essentially an enclosed structure which traps the short wavelength solar radiation and stores the long wavelength thermal radiation to create a favourable micro-climate for higher productivity. A greenhouse heating system is used to increase the thermal energy storage inside the greenhouse during the day or to transfer excess heat from inside the greenhouse to the heat storage area. This heat is recovered at night to satisfy the heating needs of the solar tunnel greenhouse dryer. Thus, the temperature inside the dryer will be increasing steadily, thereby ensuring quicker drying of the products than the open sun drying method. Various investigators have studied the greenhouse for crop drying [1], [17] & [18]. Reference [19] shows a solar dryer with a greenhouse as a collector for drying grapes.

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Reference [20] shows the solar energy collection characteristics of a fibre reinforced plastic drying house for paddy drying.

This study was undertaken to investigate the drying characteristics of tomatoes in solar tunnel greenhouse dryer and open sun drying and also to compare the quality of tomatoes being dried in solar tunnel dryer and under open sun. Various parameters such as relative humidity, temperature, velocity of air, moisture content, solar intensity & air flow rate of the samples (tomatoes) were calculated and compared accordingly as solar tunnel dried tomatoes and open sun dried tomatoes.

II. EXPERIMENTAL SECTION

Experiments were carried out under meteorological conditions of Pollachi (latitude, 10.39°N; longitude, 77.03°E) in India during the summer months of 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 Negamam 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.

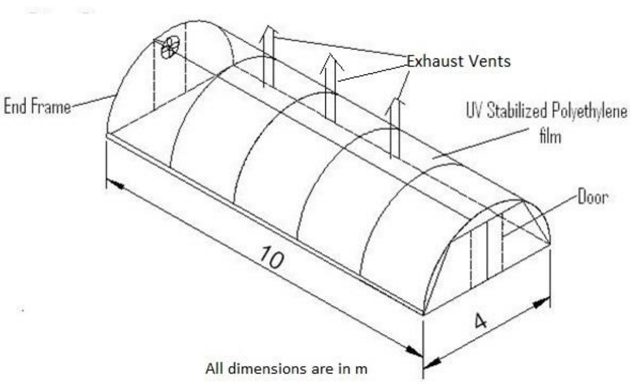

Fig.1 Solar tunnel greenhouse dryer

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.

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

Experiments were conducted during 3-5th of June 2014 under meteorological conditions of Pollachi, India. Matured and good quality tomatoes were sliced into several pieces. Initial moisture content was calculated by taking 10 different samples from different locations. Sliced tomatoes were loaded over the trays (porosity 90%) of drier unit. Then, exhaust vents were opened to exhaust initial high humid air. Solar intensity, ambient wet and dry bulb temperatures were measured every 1 h interval till end of drying.

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VII. DATA ANALYSIS

A. *Determination of Moisture Content*

Samples (10g) were chopped from randomly selected 5 tomatoes and kept in a convective electrical oven, maintained at 105± 1°C for 5 h. 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 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.

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VIII. RESULTS AND DISCUSSIONS

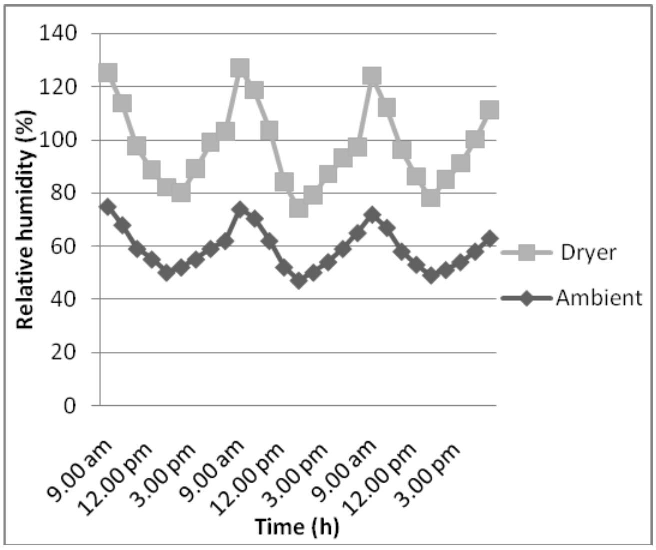
B. Variation of solar intensity and temperature with time

The fig.2 shows the variation of solar intensity, ambient temperature and dryer temperature during the experimental period (3-5th June, 2014). During the first day, the solar intensity varied between 313 W/m^2 and 717 W/m^2, the ambient temperature varied between 31°C and 39°C with a peak value of 39°C at around 1.00 p.m. and the dryer temperature varied between 39°C and 61°C with a peak value of 61°C at around 1.00p.m. During the second day, the solar intensity varied between 305 W/m^2 and 737 W/m^2, the ambient temperature varied between 30°C and 39°C with a peak value of 39°C at around 1.00 p.m. and the dryer temperature varied between 34°C and 63°C with a peak value of 63°C at around 1.00p.m. During the third day, the solar intensity varied between 320 W/m^2 and 720 W/m^2, the ambient temperature varied between 32°C and 39°C with a peak value of 39°C at around 1.00 p.m. and the dryer temperature varied between 41°C and 67°C with a peak value of 67°C at around 1.00p.m.It is clear from the figure that the dryer temperature was 22°C to 26°C more than the ambient temperature in all the three days of experiment which suggests that the products kept inside the drier are dried very effectively. Also, the drier temperature varied according to the solar intensity during this experimental period. The maximum solar radiation observed was about 737 W/m^2

Fig.2. Variation of solar intensity and temperature with time

C. 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 28% and 50% whereas the ambient relative humidity varies between 50 % and 75%. During the second day, the relative humidity of the dryer varied between 27% and 53% whereas the ambient relative humidity varied between 47% and 74%. During the third day, the relative humidity of the dryer varied between 29% and 52% whereas the ambient relative humidity varied between 49% and 72%. Because of the decreased relative humidity inside the dryer, all the time (due to the green house effect), the temperature inside the dryer was high which is sufficient enough to dry the tomatoes at an early time.



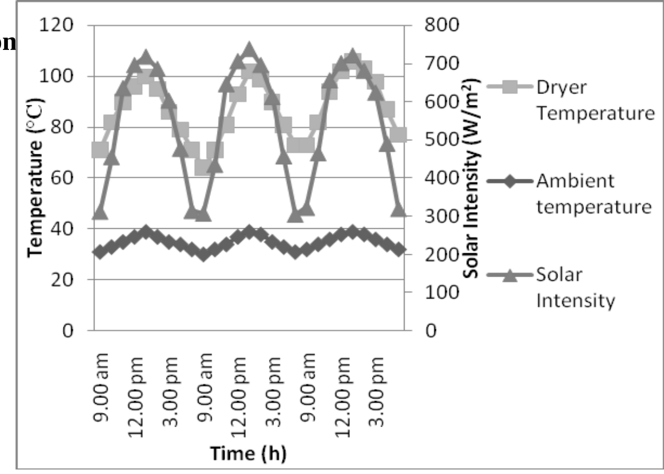


Fig.3 Variation of relative humidity with time

D. Variation of air velocity with time

The fig.4 shows the variation of ambient air velocity and Dryer air velocity during the two days of experimental period. During the first day, the ambient air velocity varied between 1.7 m/s and 3.5 m/s whereas the dryer air velocity varied between 1.3 m/s and 2.7 m/s.

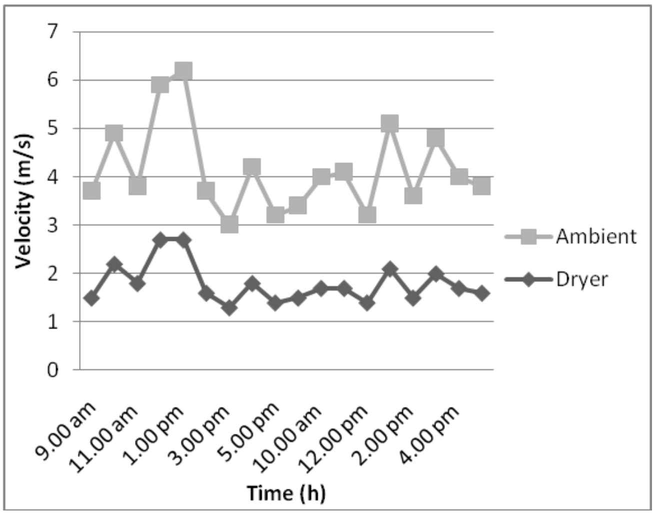


Fig.4 Variation of air velocity with time

During the second day, the ambient air velocity varied between 1.8 m/s and 3 m/s whereas the dryer air velocity varied between 1.4 m/s and 2.1 m/s which are quite lesser than the variation in first day. It was evident that the dryer air velocity is lesser than the ambient air velocity due to the buoyancy effect where there is no natural convection. This is the reason for the lower air velocity and increased drying rate inside the dryer.

E. Variation of air flow rate with time

The fig.5 shows the variation of air flow rate with time during the experimental period. During the first day, the air flow rate varied between 0.52 m^3/s and 1.08 m^3/s. During the second day, the air flow rate varied between 0.56 m^3/s and 0.88 m^3/s with a peak of m^3/s at p.m. The air flow rate variation in second day is lesser than that of first day and it varies accordingly with time.

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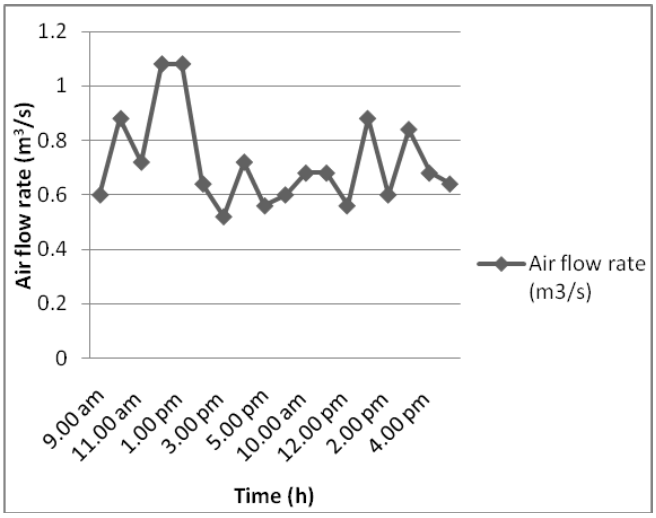

Fig.5 Variation of air flow rate with time

F. Variation of moisture content with time

The fig.6 shows the variation of moisture content of tomatoes being dried inside the dryer and in the open sun during the experimental period. During the first day, the moisture content of the tomatoes inside the dryer reduced from 90% to 40% whereas for the open sun dried tomatoes, it is reduced from 90% to 56%. During the second day, the moisture content of these tomatoes inside the dryer reduced from 40% to 9% whereas for the open sun dried tomatoes, it is reduced from 56% to 30.5%. By the mid of second day, the moisture content of the tomatoes inside the dryer was reduced to 9% which was the maximum level of moisture removal from tomatoes.

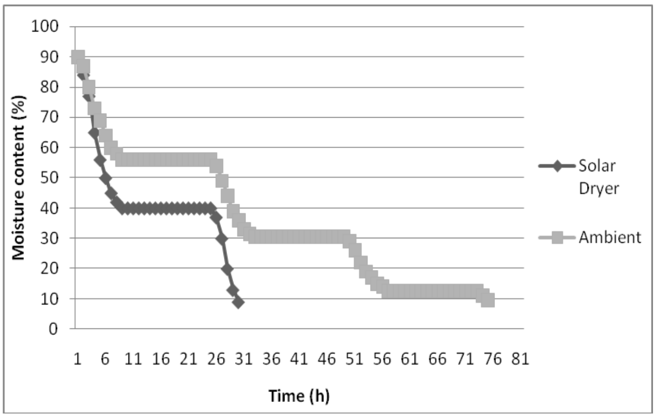

Fig.6 Variation of moisture content with time

During the third day and fourth day, the moisture content of open sun dried tomatoes reduced from 30.5% to 12.5% and from 12.5% to 9.5%. In the open sun drying, the products has an initial moisture content of 90%, is reduced to 9.5% for time period of 74 hours, while in the solar tunnel dryer, the products which has an initial moisture content of 90%, is reduced to 9% for time period of 29 hours. The solar dryer appears to be the effective and quicker method of drying of tomatoes (products) since the drying time is very less compared with open sun drying. This is due to the green house effect inside the solar tunnel dryer where the temperature inside the dyer keeps on increasing with decrease in relative humidity inside the dryer.

IX. CONCLUSION

Experiments were conducted in a natural circulation solar tunnel greenhouse dryer in order to study the drying characteristics of tomato in comparison with open sun drying during the month of June 2014. Three full scale trails were conducted with 30 kg of tomato. It was found that the solar greenhouse tunnel dryer reduced the moisture content of tomato from 90% (wet basis) to 9% (wet basis) in 29 hours, whereas open sun drying method took 74 hours for reducing the moisture content of tomato to the same level. Also, the quality of dried tomato produced from solar tunnel greenhouse dryer was superior when compared to open sun dried tomato. Therefore, solar greenhouse tunnel dryers are more suitable for producing high quality dried agricultural products like tomatoes, chillies, grapes, coconuts etc.

Fig.7 Tomatoes dried inside the solar tunnel dryer

The fig.7 shows the drying of tomatoes inside the solar tunnel dryer during the month of June, 2014.

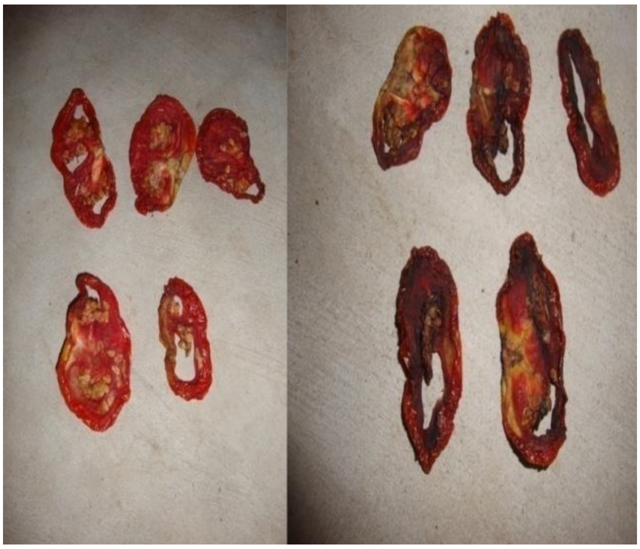

Fig.8 Quality comparison between open sun dried and solar tunnel dried tomatoes

The fig.8 shows the comparison between solar tunnel dried and open sun dried tomatoes. The solar tunnel dried tomatoes were found to be superior to that of open sun dried tomatoes.

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Publications ***(number only)***

Books	Research Papers/ Reports	General Articles	Patents	Others (Please specify)
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- Improved Coconut post harvest technologies for empowering the women of Pollachi Region funded by Department of Science & Technology (Govt. of India, New Delhi.), 2007-2009.
- Consolidation of food security in south India.(Addressing out-reach activities in improved postharvest technologies) funded by CIDA in Collaboration with McGill University, Canada, 2002-2004.

Publications *(number only)*

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