Energetic Analysis of Solar Tunnel Greenhouse Drying For Tomato

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Abstract: A direct forced convective solar tunnel greenhouse dryer (aperture area of 4 m^2) was designed, manufactured and commissioned at Wardha, India for food processing. The dryer is outstanding for mass production, superb transportability, easy tracking, effortless assembling at site makes it a DIY (Do It Yourself) kit. In this paper, drying kinetics of amla candy was investigated by evaluating convection heat and mass transfer coefficient. Experimental data was used to find the values of constants C and n by using linear regression and accordingly, values of convection heat (2.17-13.51 $W/m^2\,{}^0C$) and mass transfer (94-650 $W/m^2\,{}^0C$) coefficients was estimated. Result showed that the technology can be easily adopted for commercial use by the farming venture for small and medium scale farmers in India. Thermal modeling plays a noteworthy role in perfect design as well as improvement of dryer.

***Index Terms* – Energetic, Convection heat transfer, Greenhouse, Moisture**

I. INTRODUCTION

Farmers in India have usually small land holdings and nearly all of them are not well educated. These farmers have to face the unpredictability of the market. Due to reduced market rates for the product, a lot of farmers have committed suicide in recent years because of high loan. Since nearly all of the farm produce is perishable, there is nothing a farmer can do if rates in the marketplace drop. Processing of perishable agro-product to a processed foodstuff can be an excellent option for such farmers, whereby shelf life of the food is improved [1]. Tomato (Lycopersicon esculentum Mill.) is one of the essential vegetable/fruit in our diet, as they are rich with vitamin C, vitamin E, lycopene as well as dietetic fiber. It is a multi-use product which can be eaten fresh or else processed to utilize in a broad set of products to improve flavor. Presently, the demand for tomato is increasing steadily with an increase in population and its likeliness towards tomato. India is the 4th major tomato producing nation in the globe next to China, USA and Turkey. At the moment, India is the exporter of tomatoes to Pakistan, Bangladesh, U.A.E, Nepal, Maldives and Oman. Indian normal yield of tomato is around 10 tons per hectare; however the world average yield is 24 tons per hectare. Every year a huge amount of tomato is being spoiled because of lack of appropriate processing along with preservation amenities. Accordingly, worth of tomato falls severely and farmers cannot even get a return on their production cost. The quantity of tomato, which is being spoiled, can be reduced and value added by appropriate drying of newly harvested produce. There are two methods to shun spoilage along with wastage of food stuffs. The primary being the cold storage method where the produce is stored in a refrigerated space thus enhancing the small-scale farmers to meet the sudden as well as high demands in the market devoid of any significant wastage. This method is an expensive one and small-scale farmers cannot afford it. The second technique is drying of the product which is the most suitable way for diminishing spoilage, gaining extended shelf-life and increasing the market value of the products. Drying process is the most significant form of food preservation and also for its extended shelf-life. It is a concurrent heat and mass transfer process in which moisture is removed from the product by hot air. Dried tomatoes are extensively used as ingredients in pizzas, salads and spicy dishes. They are also packed in canola oil with the addition of herbs, garlic and spices. Further dried tomatoes can be used in tomato soups, herbs, salsa, sauces, pesto and so forth [2-5]. However the open-air drying below the sun is one of the historical methods for food preservation and has numerous disadvantages like spoilage of product due to rain, duct, wind, storms, animals and leads to losses in quantity as well as quality. Also open sun drying needs huge land and drying time. For this reason to protect agro-products from damage and to control the drying process, efforts had been made to improve the sun drying to solar drying [3-10]. In this regard author has designed a simplified version of direct type of solar tunnel greenhouse dryer, which is affordable at rural area in India and in the region of latitude around 15 – 30^0 N. Though the quality of dried product in indirect dryers is superior to direct type of solar dyers, especially solar cabinet and Hohenheim tunnel dryers are expensive and of complex mechanism thus not affordable to small and medium scale farmers. Hence in this work, author tried to overcome all the limitations of above dryer and proposed a simple direct type of solar tunnel greenhouse dryer. The investigation of proposed dryer during drying of fresh tomato is the major intention of this research work. The precise objective is to check the energetic performance of proposed dryer for tomato drying.

II. EXPERIMENTAL SETUP

Figure 1 shows the pictographic view of proposed dryer (aperture area of 4 m^2). The dryer comprises of two tunnels of same size with aperture area of 2 m^2 each and connected in series with a small rectangular opening for movement of hot drying air through it. Based on the product to be dried, 10-15 kg of produce can be loaded in a lot in each tunnel. The dryer has the shape of a home cabinet with tilted transparent glass top of 40^0 which is suitable for the location having latitude of 15-30 ^{0}N.Fater drying rate

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is achieved by maintaining exact air flow rate throughout the tunnels of dryer. This is done by using PV operated DC fans at the inlet and outlet of tunnel since it is directly depends on the solar intensity.

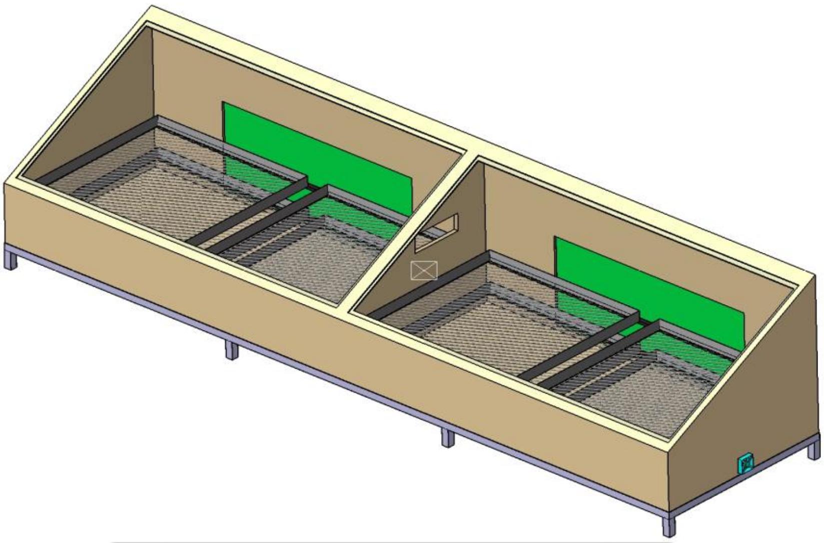

Figure 2.1: Pictorial View of Solar Tunnel Greenhouse Dryer

III. INSTRUMENTATION

Thermocouple (PT 100 RTD) with accuracy of ±0.5 ^{0}C was used for measuring temperature of drying air at various locations of tunnel greenhouse. The digital hygrometer with accuracy ±10% was used for measuring RH (relative humidity) of ambient and greenhouse air. A digital solar meter with accuracy of ±10% was used for measuring solar insolation. An anemometer and velocity sensor was used to measure wind speed throughout the greenhouse. A digital responsive balance **(**±0.01g accuracy) having an utmost 4 kg capacity was used for moisture content measurement of amla flakes. A 16 channel (SUNPRO, India) data logger is used for recording temperatures of drying air at every interval of ten minutes.

IV. MATERIALS AND METHODS

From local bazaar of Wardha, fresh tomatoes were sorted visually by color and size. Fresh samples of tomatoes purchased was clean with water then weighed and cut in slices of identical thickness (3-5 mm) by using stainless steel knife to avoid blackening on the surface. The pretreatment by KMS was done to the tomato slices. The initial moisture content of tomato samples was 90% (w.b). Tomato is a vegetable/fruit of vast popularity and considered to be hygroscopic material [2]. Air oven method was used to find initial moisture content of tomato. Prior to experimentation all equipments was checked cautiously and setup was run (no load condition) for the requisite drying condition until the dryer had become steady. Later on samples of pretreated tomato slice (thickness 3-5±2mm) were spread equally on the trays of both tunnels. Drying was sustained for 12 hours until the tomato slices attain constant weight. The mass flow rate of air was controlled by 12V DC fans throughout the drying process. The PV module (10 watt) was used to run the fans.

4.1Energetic Analysis

The energy analysis for drying of any agro-commodity should be carried out to discover the energetic aspects with behavior of drying air all over the drying system. The solar dehydration process was considered as a steady flow process because it entails heating, humidification as well as cooling processes. The first law analysis, i.e. energy analysis of solar dryer, was performed to determine the best utilization of solar energy in solar dryer. The performance of any dryer could be distinguished by its various performance indicators like moisture removal rate, drying efficiency, pickup efficiency, specific energy consumption and specific moisture extraction rate, Energy utilization ratio and Heat utilization factor [1].

$$M_{wb} = \frac{W_0 - W_d}{W_0} \quad (1)$$

$$\eta = \frac{m_w \times h_{fg}}{I \times A_{ap} + P_{fan}} \times 100 \quad (2)$$

$$\eta_{pickup} = \frac{w_o - w_i}{w_{as} - w_i} \times 100 \quad (3)$$

$$SMER = \frac{\text{Mass of water removed}}{\text{Total energy consumption}} \text{ in kg/kWh} \quad (4)$$

$$SCE = \frac{1}{SMER} \quad (5)$$

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$$EUR = \frac{m_a \times C_{Pa} \times (\Delta T)_a}{I \times A_{ap} \times \tau} \quad (6)$$

$$HUF = \frac{(\Delta T)_{lost}}{(\Delta T)_{gain}} \quad (7)$$

where W_0 is the initial weight of undried produce; W_d the is weight of dry matter in produce; m_w is mass of water evaporated; h_{fg} is latent heat of evaporation; I is solar insolation; A_{ap} is aperture area P_{fan} is power required to drive the fan; w_i & w_o are the humidity ratio of inlet and outlet drying air and w_{as} is absolute humidity of the air entering the dryer at the point of adiabatic saturation.

V. RESULTS AND DISCUSSION

5.1 Drying Conditions of the Solar Dryer

Table 1 shows the variation of all energy performance indicators during tomato drying. Specific moisture extraction ratio explains the effectiveness of drying and gives the amount of water evaporated per unit energy consumption. EUR indicates how much energy is utilized from the total energy supplied and is based on the structure along with moisture content of the product while HUF is purely a function of dry bulb temperature of incoming and outgoing drying air and illustrates that, the drying air heated by particular solar dryer is reasonable or not with the purpose of increase its capacity in favor of taking up moisture.

Table 5.1 Energy Performance Indicators

Drying Day	Average Dryer Efficiency	Average Pickup Efficiency	SMER kg/kWh	SEC kWh/kg	EUR	HUF
DAY 1	34%	32%	0.87	1.34	27%	0.61
DAY 2	16%	19%	0.26	5.21	19%	0.51

It is observed that the relationship between drying efficiency and drying time is exponential and further drying efficiency decreases with decrease in moisture content. In general drying efficiency was higher during the first hours of drying and afterward reduced as drying progressed. Moreover the drying efficiency depends directly on amount of moisture removed since less drying means high drying efficiency and the average drying efficiency of 35% and 16% was observed for consecutive drying days as shown in Fig. 2. Pickup efficiency is a direct measure of how efficiently the capacity of the (heated) air to absorb moisture is utilized and generally decreases with decreasing moisture content in the product. All the findings are in accord with the findings of different researchers.

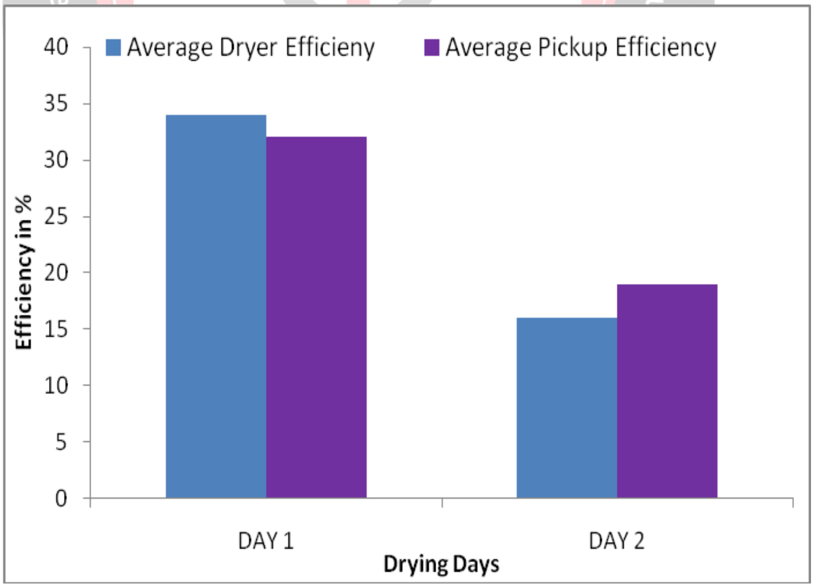

Figure 5.1: Variation of average drying and pickup efficiency against drying time

Figure 3 shows the variation of moisture content of tomato slices against time for solar tunnel greenhouse dryer. The moisture content of tomato was reduced from 90% to 10% w.b. in 18 hours for the open sun drying, whereas the solar tunnel dryer took only 12 hours. The proposed dryer appears to be the effective and quicker method of tomato due to saving of almost 6 hours of drying time. This is due to the better construction and easy tracking of dryer. The moisture removal rate was more during first few hours of drying due to rapid evaporation of free moisture from the outer surface. In last hours of drying moisture removal rate gets reduced due to internal moisture movement from inner layers to the surface, which results in a progression of consistent drying out [10].

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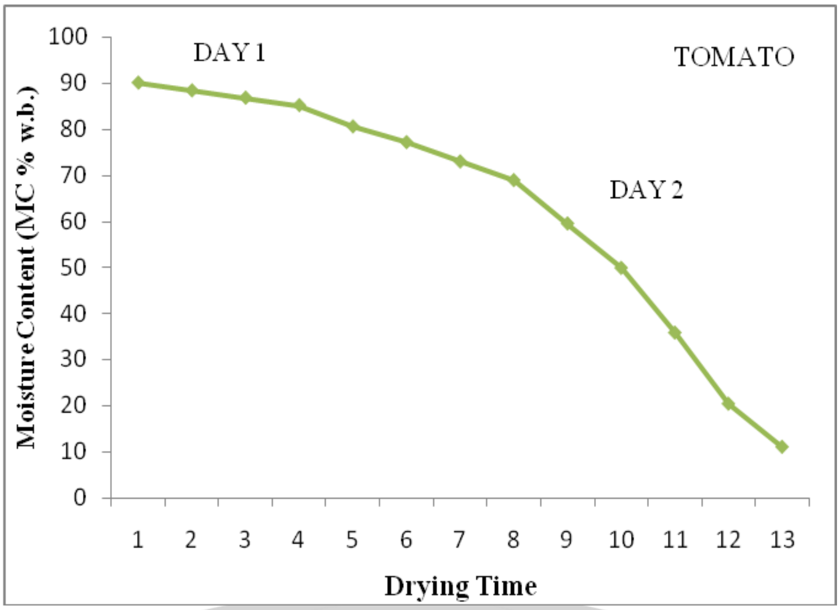

Figure 5.2: Variation of moisture content against drying time

5.2 Uncertainty Analysis

Errors and uncertainties in the experimentation can take place from instrument selection, condition, calibration, observation, ambiance, reading and trial scheduling. In this work different observations like temperatures, RH, speed of drying air, moisture content of produce, solar radiation and weight loss were measured by appropriate utensil. Throughout the measurement of above parameters, the experimental error i.e. uncertainties takes place are shown in Table 2.

Let X_R is the uncertainty in result and X_1, X_2 ---- Xn be the errors in the individual variables.

$$X_R = [(x_1)^2 + (x_2)^2 + (x_3)^2 ----+(x_n)^2]^{\frac{1}{2}} \qquad (8)$$

Table5. 2 Uncertainty Analysis

Uncertainty	Solar dryer	Sun drying
Ambient air temperature	±0.381	±0.381
Drying air temperature in tunnel 1	±0.381	-
Drying air temperature in tunnel 2	±0.381	-
Drying air outgoing temperature from greenhouse	±0.381	-
Weight loss	±0.500	±0.500
Relative humidity (RH)	±0.141	±0.141
Air speed at inlet	±0.173	±0.173
Solar radiation (I)	±0.141	±0.141

VI. CONCLUSIONS

The conclusions drawn from the present study may be summarized as follows:

1. The moisture content of tomato was reduced from 90% to 10% w.b. in 18 hours for the open sun drying, whereas the solar tunnel dryer took only 12 hours. This is due to the better construction and easy tracking of dryer.
2. The drying air is heated by the tunnel greenhouse adequately with the purpose of increase its capacity in favor of taking up moisture from the product.
3. The monetary examination specifies that initial investment can be recovered within 2 years and thereafter; net profitability increases, which can progress the financial conditions of farmers.

From above discussion, a new proposed design of STD is most excellent option for end user. This design is outstanding for mass production, ease of tracking, has superb transportability and assembling at site is effortless and can be truly a DIY (Do It yourself) kit

REFERENCES

[1] Sablani, S. 2006. Drying of Fruits and Vegetables: - Retention of Nutritional/ Functional Quality. Drying Technology.24, pp.428–432.

[2] Patil, R. and Gawande, R. 2016. Comparative analysis of cabinet solar dryer in natural and forced convection mode for tomatoes. International Journal of Research and Scientific Innovation. III (VII), pp.49-52.

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[3] Patil, R. and Gawande, R. 2016. A review on solar tunnel greenhouse drying system. Renewable and Sustainable Energy Review. 56, pp. 196–214.
[4] Sharma, V. and Sharma, N. 2012. Construction and performance analysis of an indirect solar dryer integrated with solar air heater. Procedia Engineering. 38, pp.3260 – 3269.
[5] Ayyappan, S. and Mayilsamy, K. 2010. Experimental investigation on a solar tunnel drier for copra drying. Journal of Scientific & Industrial Research. 69, pp. 635-638.
[6] Patil, R. and Gawande, R. 2017.Mathematical modeling of solar drying system," in Solar Drying Technology-Concept, Design, Testing, Modeling, Economics, and Environment, Om Prakash and Anil Kumar, Eds. Singapore**:** Springer Nature 2017,pp. 265-316.
[7] Patil Rajendra and Gawande R (2016). Performance of a Forced Convection Solar Tunnel Dryer with and without thermal storage for drying of Tomatoes. International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE); Vol. 1(Issue 8), PP: 111-116.
[8] Patil Rajendra and Gawande R (2017). Thermal and Mathematical Modeling of Solar Drying of Tomato in Thin Layers. International Conference on Advances in Thermal systems, Materials and Design Engineering (ATSMDE-2017) at VJTI Mumbai (India), 21-22 December2017.
[9] Patil Rajendra and Gawande R (2017). Comparative Analysis of Solar Tunnel and Cabinet Drying System. International Conference on Quality Up-gradation in Engineering, Science & Technology(ICQUEST-2017) at B.D. COE, Sevagram Wardha, Nagpur (India), 27th September 2017.
[10] Patil Rajendra and Gawande R (2016). Performance of a Forced Convection Solar Tunnel Dryer with and without Thermal Storage for Drying of Tomatoes in 2nd World Conference on Applied Science Engineering and Technology, 29th-30th December, 2016, Goa, India.

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