Performance Study of a Solar Tunnel Dryer for Horticultural Crops

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ABSTRACT

Performance of a solar tunnel dryer developed at Central Institute of Agricultural Engineering, Bhopal was studied under no-load and for drying unripe peeled mango. It is a batch type dryer (80 to 90 kg wet product/batch), of modular construction to facilitate transport, installation and capacity enhancement. Solar air heaters are directly connected to the drying tunnel to reduce the cost. The dryer is 2.0 m wide, with a 4.5 m solar air heater and a drying tunnel of 8.0m. The heater and dryer are covered with U-V stabilized polyethylene film. The total collector area of the dryer is 25 sq. m. Solar photo-voltaic (SPV) operated axial flow fans have been provided at one end to push fresh air in to the dryer. An exhaust fan is provided at the other end to evacuate hot air and to control the air temperature, with the help of an electronic temperature controller automatically. Air temperature inside the dryer could be maintained in the range of 50 to 75°C on typical sunny days. Cut mango pieces were uniformly spread over the drying trays at the rate of 4.5 kg/m^2. Initial moisture content of mango was around 79%. The mango pieces could be dried in the solar dryer in four and half days to a moisture level of 4.2% as compared to ten days in the open drying to a moisture content of 4.7%. The average drying temperature in the tunnel was 60°C. Quality of the product dried in the tunnel dryer was found to be superior to the sun-dried product in terms of microbial load, appearance and acceptability.

1. INTRODUCTION

Inadequate preservation and storage facilities and lack of proper marketing avenues lead to the spoilage of large quantity of agricultural produce in the developing country. Drying of agricultural products, still the most widespread preservation technique, is becoming more and more an alternative to marketing fresh fruits, since demand for high quality dried product is continuously increasing all over the world. Moisture content of most of the fruits and vegetables varies between 65 to 85% and optimum drying temperature varies between 55 to 70°C [1, 2]. Traditionally, sun drying is the most common practice. Turning the crops at short intervals promotes uniform drying. Collecting the crop during night and rainy days and storing it under shelter prevents re-moistening, but require high labour input. Since sun drying process is relatively slow, considerable losses occur. In addition, a reduction in product quality takes place due to insect infestation, enzymatic reactions, growth of micro-organism and development of mycotoxin. Fruits that are properly dehydrated, particularly to a moisture content of the level below 5%, have the advantages of [3]: (a) good shelf life under proper storage conditions, because a high degree of inhibition of bacteria, enzymatic, and mould action is achieved; (b) substantially lower transportation, handling, and storage cost and do not require costly refrigeration during transport and storage; (c) dehydration hardly affects the main calorie-providing constituents of fruits. It leaves mineral constituents virtually unchanged; (d) they provide a consistent product, an important modern marketing requirement.

For drying small quantities of farm products, cabinet box or tent type dryers have been developed. Ventilation required for removing the evaporated moisture is generally provided by ascending air forces due to natural convection. Connecting a solar collector to the drying chamber can increase the drying capacity of these dryers. The drying air is heated up in the solar air heater and passes across the crop, which is spread in a thin layer on vertically stacked trays. Due to high resistance encountered when forcing the air through the crop, only a small number of trays can be stacked without significantly affecting the air movement. Furthermore, investigations have shown that during night and cloudy weather, air circulation breaks down completely in such dryers. This causes spoilage of the crop due to enzymatic reactions and the growth of micro-organisms. Comparatively high investment, limited capacity, and risk of spoilage during adverse weather condition have, up to now, prevented the wide acceptance of these dryers [4]. The high weather-dependent risk of using natural convection type solar dryers stimulated the development of solar tunnel dryer which incorporated fans, to provide sufficient airflow to remove the evaporated moisture. Solar tunnel dryers can be used for drying agricultural produce to reduce drying time and achieve improved quality of the dried products The solar tunnel dryer can be used for drying numerous agricultural commodities ranging from fruits, vegetables, root crops, medicinal plants and fish etc. Solar tunnel drying reduces the drying time to about one half compared to open sun drying and quality of the dried product was also found to be superior to the sun dried product [5]. In a study conducted on plastic film solar air heater [6] it was concluded that (a) the air temperature was raised 40-50°K above ambient which was sufficient to dry agricultural produce; (b) Polly vinyl carbonate (PVC) film cover shows certain advantages compared to polyethylene (PE) film, if the air temperature desired above 40°C. However, PVC-covered collector needed to be cleaned frequently since it accumulated more dust; (c) to guarantee long-life expectancy, UV-stabilized plastic film cover must be used. Mango fruits during early stages of growth are commonly used for sweet or sour pickle preparation in India. As the fruits attain stone hardening stage, they can be dried for making products such as *Amchoor* (fine powder of dried green unripe mango). *Amchoor* has a tart, acidic, fruity flavour that adds character to many dishes including meats, vegetables and curried preparations etc.

The paper covers performance of a solar tunnel dryer under no load conditions and drying of unripe mango.

2. DETAILS OF THE SOLAR TUNNEL DRYER

A batch type solar tunnel dryer for fruits and vegetables (capacity of around 100 kg wet product per batch) was developed (Figure 1a and 1b). The solar air heaters are coupled with drying tunnel, to provide additional heat for drying wet products. The solar tunnel dryer has the following features:

1. The solar air heaters are connected with the drying tunnel without additional air ducts.
2. Solar photo-voltaic (SPV) operated axial flow fans at one end to push hot air over the absorber and the dryer. Fan speed and hence the air flow rate is dependent upon available solar insolation.
3. An exhaust fan at other end with electronic temperature controller to reduce the drying air temperature, as per requirement.
4. Component parts of the dryer are designed using modular concept to facilitate easy transport and installation of the solar tunnel dryer and also for capacity enhancement.

The tunnel dryer consists of the plastic film-covered flat plate solar air heater and the drying tunnels. Bottom of the tunnel dryer has been provided with insulator consisting of glass wool (50 mm thick) sand-witched between two GI sheets (20 SWG) with teak wood battens as spacers. The insulators are held in place with the help of channels and MS angles to make the tunnel bed. Top surface of the insulators of the air heater portion (4.5 m length) was painted matt black to act as the absorber. The other portion of the tunnel (8 m length) was meant for keeping products for drying. To keep the moisture laden products for drying, the drying beds are provided with wire mesh. Perforated PVC mat has been placed over the wire mesh to keep the product on the drying bed. There is also a provision to roll the plastic film over the tunnel frame to cover and un-cover the tunnel to facilitate loading, mixing and unloading the products. The width of the tunnel dryer was kept 2.0 m for ease of loading and unloading of the drying materials. The dryer has been installed on the brick pillars (14 nos.), at a height of 0.9 m above ground level for loading and unloading the products conveniently.

The specifications of the pilot scale tunnel dryer is given below :

Collector area of the dryer	:	25 sq.m.
Insulated bed	:	11 nos, 1.1 m x 2.0 m
Solar air heater area	:	9 sq.m. (2m x 4.5m)
Drying area	:	16 sq. m (2m x 8m)
Width of the tunnel	:	2 m
Total length of the tunnel	:	12.5 m
Metal pipe frame to support plastic film	:	12 nos, 2 m width and 0.52 m height
Thickness of the UV stabilized transparent plastic film	:	200 micron
SPV operated axial fans	:	4 nos, brush-less, 24 V DC, 100 mm dia., 5W capacity
Exhaust fan	:	One no, 230 V AC, 375 mm dia. , 100 W capacity
Drying bed	:	7 nos.
Size of drying beds	:	1.1 m x 1.9 m

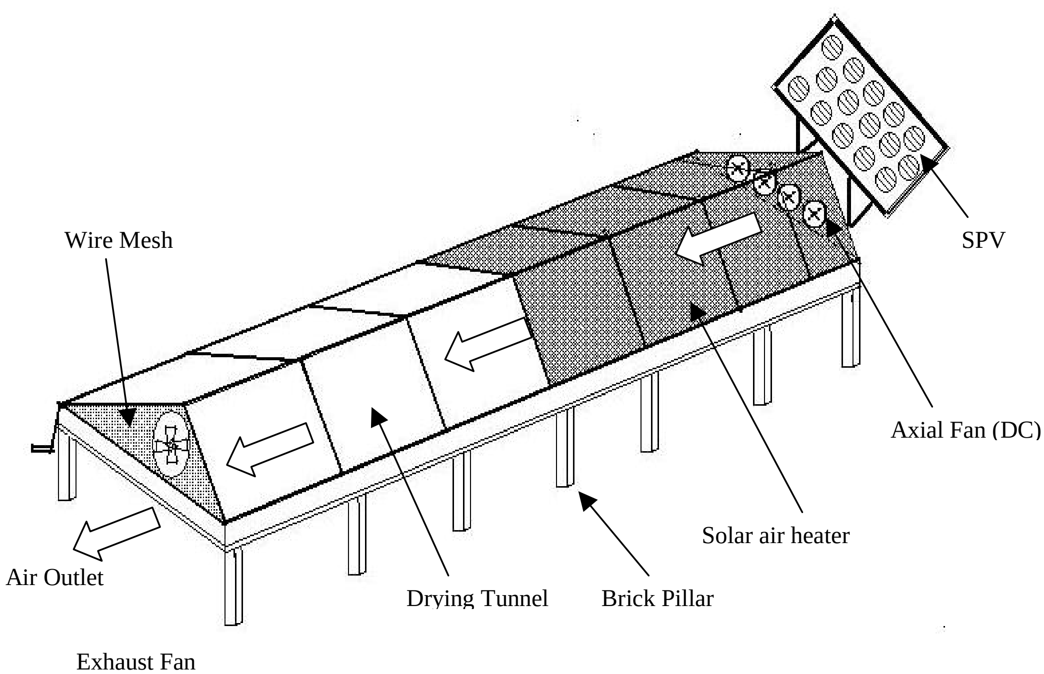


Fig.1a. Schematic diagram of the solar tunnel dryer

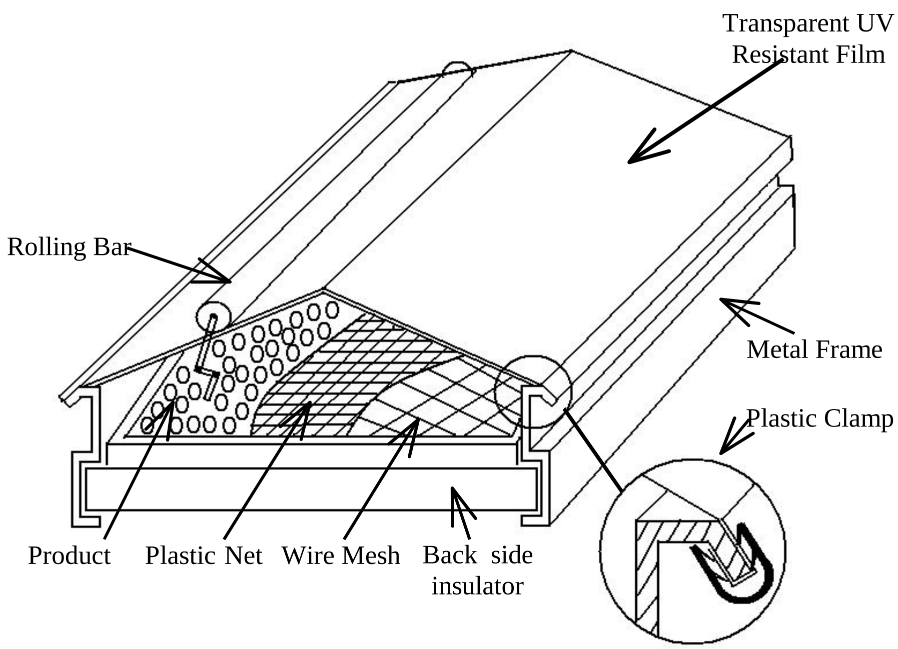


Fig. 1b. Details of the drying tunnel with rolling bar

3. MATERIALS AND METHODS

The solar tunnel dryer was tested under no load condition and loaded with unripe mangoes. Under no load conditions, the air temperatures at the inlet and outlet and air temperature inside the tunnel dryer across its length were recorded at definite intervals of time during a typical sunny day. The solar insolation, ambient temperature etc. were also recorded during the experiment. The air flow through the tunnel dryer was also measured. Temperature was measured using of pre-calibrated thermocouples and temperature indicators and the solar insolation was measured with the help of Pyranometer. Air speed was measured with a digital anemometer. Humidity of the ambient air was obtained from psychometric chart by measuring wet bulb and dry bulb temperature of air. All the data were analysed.

Sixty kg of peeled unripe mango (local variety) were spilt into two pieces and placed in the tunnel dryer for drying in the month of May. The temperature gradient inside the tunnel, air flow rate, solar insolation, ambient temperature, relative humidity were recorded during drying. Drying time, moisture content, microbial count and total acidity. of the dried product from the tunnel dryer and open sun were measured and analysed. The moisture content of the dried mango was measured by drying the samples (up to constant weight) in an electrical oven at 75°C. Total acidity of the dried samples were determined by titration method [7]. The microbial count of the dried mango samples were determined in triplicate as colony forming units/g by spread plate method of sample inoculums [8].

4. RESULTS AND DISCUSSION

4.1. Under No-Load Condition

Pilot scale solar tunnel dryer has been evaluated under no load conditions. Air temperature in the drying portion of the tunnel has been found to range between 50 to 75°C during typical sunny days in the month of March (Figure 2). The temperature in the tunnel was found to be dependent on available solar insolation and ambient temperature. Peak temperature of 75°C was attained during mid day when solar insolation was highest. Solar intensity varied from 300 W/m^2 to 920 W/m^2 during the day. Ambient temperature was between 32°C to 39°C and wind speed was 0.8 to 1.2 m/s and relative humidity between 25 to 50%. The air flow rate through the tunnel varied from 500 m^3/h to 800 m^3/h. The air flow rate was lower during morning and evening and peaked during mid-day.

The temperature gradient in the solar tunnel across the length at given time of the day has been shown in Figure 3. It was found to increase along the length of the tunnel (from solar air heater portion) up to about 3 m from the air outlet end. It decreased near the outlet.

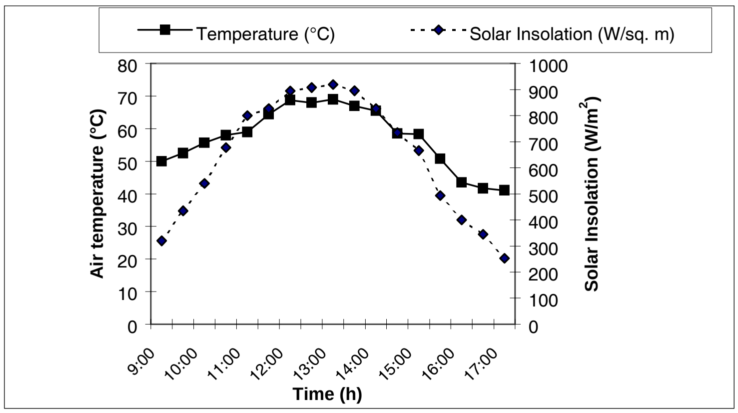


Fig. 2 Variation in air temperature inside the drying tunnel (average) on a typical sunny day in the month of March (Ambient temp.:32-39°C, air flow through the tunnel by DC fans: 500- 800 m^3/h).

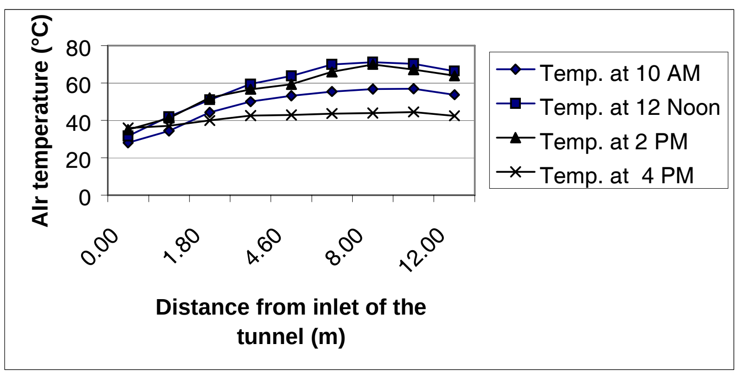


Fig. 3. Air temperature gradient in the solar tunnel dryer during a typical sunny day in the month of March (Solar insolation and ambient temp. : at 10:00 AM- 540 W/m^2, 28°C, at 12:00 Noon to 900 W/m^2, 32°C, at 02:00 PM- 827 W/m^2, 35°C, at 04:00 PM - 400 W/m^2, 36°C)

4.2. Under Loaded Condition (Mango Drying)

Sixty kg of peeled unripe mango were loaded in the tunnel dryer for drying. Mangoes were split in to two pieces for ease of drying. The weight of single mangoes varied between 110 to 175 g. Length of the sliced mango pieces were 50 to 60 mm and width 40 to 50 mm. The mango pieces were uniformly spread at the rate of 4.5 kg/ m^2 on the drying trays. Initial moisture content of the mango was 79%. Reduction in the moisture content of the mango was faster in the solar tunnel dryer as compared to open sun drying (Figure 4). This may be attributed to higher temperature maintained in the tunnel as compared to open sun drying. In the case of open sun drying, drying rate was found to fall drastically below 15% moisture content. Drying time in the tunnel dryer was four and half days as compared to ten days in the open sun drying. The moisture content of the solar tunnel dried mango was 4.2% and the open sun dried mango was 4.7%. Drying temperature in the tunnel varied from 45°C to 71°C (Figure 5). Average drying temperature in the tunnel was 60°C. Ambient temperature during the drying period was 30°C to 41°C and relative humidity ranged from 20% to 60%. Solar insolation was between 400 to 1000 W/m^2. The microbial count of the tunnel dried and the open sun dried mango were $30x10^4$ and $44x 10^4$ respectively. Lower microbial count in the solar tunnel dried mango may be due to conditions not favourable for the micro-organism and reduced drying time. Total acidity of the dried mango in the sun and solar dyer were almost same (0.9 % and 1.0% as citric acid in the sun dried and tunnel dried samples respectively). The dried mango in the tunnel dryer was also found to be superior to the sun dried product in term of appearance and acceptability.

Figure 6 shows the temperature gradient in the tunnel dryer along its length when the moisture content of the product was 75% and 20%. At these moisture contents, the solar insolation and ambient temperature were almost same (950 W/m^2 and about 38°C). At 75% moisture content, the temperature was found to decrease in the drying tunnel zone, whereas at 20% moisture content, the temperature gradually increased in the drying tunnel and started decreasing near the outlet (Figure 6). Decrease in the temperature at higher moisture content may be due to the utilization of a part of the heat energy for evaporation of water and absorbing latent heat.

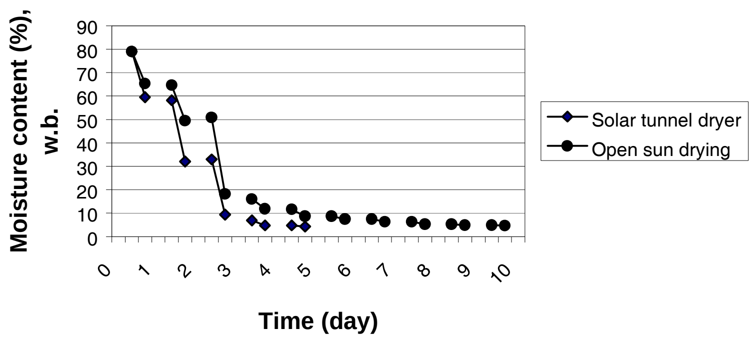


Fig. 4. Moisture content of mango during drying in the solar tunnel dryer and in open sun-drying

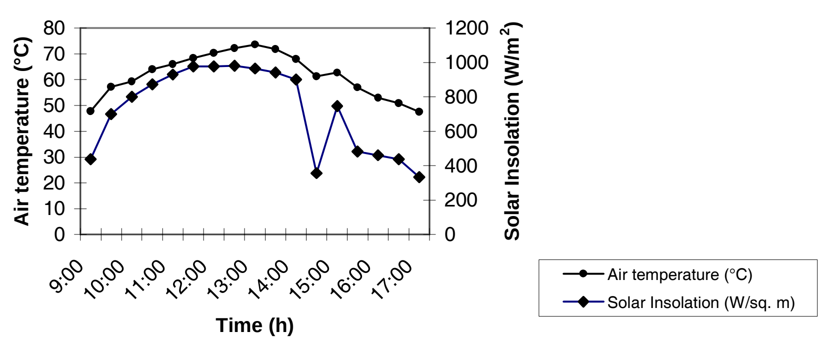
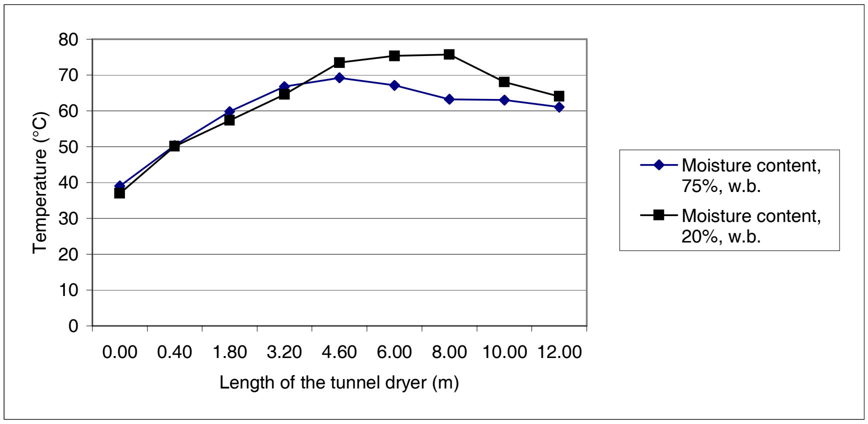


Fig. 5. Variation in air temperature inside the drying tunnel (average) during drying of mango (on second day) in the month of May (average ambient temp.: 37°C (30 to 41°C), Average air flow through the tunnel by DC fans: 650 m^3/h (500 to $800m^3/h$)



5. CONCLUSION

Performance of a batch type solar tunnel dryer (80 to 90 kg wet product/batch) was studied under no load conditions and by drying unripe mango. The collector area of the dryer was 25 m^2. Total length of the tunnel was 12.5 m and width 2.0 m. The dryer consists of solar air heater (4.5 m length) and drying trays (8.0 m length). The dryer maintained air temperature in the range of 50 to 75°C in the drying tunnel under no load condition on typical sunny days in summer months. The air flow through the tunnel was around 500 to 800 m^3/h. Unripe mangoes were dried in the tunnel in four and half days as compared to ten days in open sun drying in the month of May. Temperature in the tunnel during drying varied from 45 to 71°C. The average ambient temperature and humidity was about 38°C and 40% respectively. Moisture content of the dried mango was around 4.5%. The quality of the solar tunnel dried mango was found superior in terms of bacterial count, appearance and acceptability. Tunnel drying reduces labour and handling requirements for keeping the products during the night in shade. It also protects the product from rain, dust and bird droppings etc. thus preventing deterioration in the quality of the dried product. The solar tunnel dryer can be effectively used for controlled drying of horticultural crops.

6. REFERENCE

[1] Hall C. W. 1980. Drying and Storage of Agricultural Crops, Westport : AVI Publication. pp 18-96.

[2] Sodha MS, Bansal NK, Kumar Ashvini, Bansal PK and Mallik MAS. 1987. Solar Crop Drying, Vol II. USA: CRC Press Inc.

[3] Somogyi LP and Luh BS. 1986. Dehydration of Fruits. Commercial Fruit Processing, 2nd edition, Westport : AVI Publication Co., pp. 353-403.

[4] Muhlbauer, W. 1986. Present status of solar crop drying. *Energy in agriculture*, Vol 5, pp.121 137 .

[5] Esper Albert and Werner Muhlbauner, 1996. Solar tunnel dryer for fruits, *Plant Research and development*, Vol. 44, pp. 61-80.

[6] Esper A, Lutz K, and Muhlbauer W. 1989. Development and testing of plastic film solar air heaters, *Solar & Wind Technology*, Vol.6, No. 3, pp. 189-195.

[7] Ranganna, S. 1977. Hand book of analysis and quality control of fruits and vegetable products. New Delhi: Tata Mc-graw Hill pub. Co. Ltd.

[8] American Public Health Association (APHA).1984, Compendium of Microbiological Methods for Analysis of Food Samples. Washington : APHA Pub. pp107-131.