Accelerated food processing through solar drying system

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Abstract. There are many techniques that necessitate food preservation among which drying is the foremost. It is the process of removing excess moisture content from the food products to inhibit the microbial growth. The moisture removal process entails more energy due to the high latent heat of water. Drying process consumes about 50% of energy in the food processing sector. The energy is mostly derived from fossil fuel reserves which is a source of green house gas emission to the environment. It is imperative to develop alternative technology for food processing industries. Solar drying technology that derives energy from solar energy is a better replacement. It also plays a vital role in producing high quality dried products. To analyze the drying rate and quality of dried products, a direct type solar tunnel drier with the capacity of 12 kg fresh products was designed and installed in the Centre for Green Energy Technology, Pondicherry University. The samples were tapioca, apple, tomato, pineapple and onion. The solar dried products are compared with electrically dried and open sun dried products. The initial moisture content 72.4%, 86.2%, 93.1%, 89.6%, 82.7% of tapioca, apple, tomato, pineapple and onion got reduced to 6.8%, 3.3%, 3.35%, 23.5%, 3.5% in 4, 4, 5, 6, 6 hours respectively in solar dryer. The drying rate was more in solar drying as compared to open sun drying due to high temperature and less humidity inside the drying chamber. In this paper, three types of drying namely solar, electrical and open sun are compared.

1. Introduction

The drying of agricultural products requires high temperature and low humidity of surrounding air. Ancient method of drying food products is by spreading the products in the open sun. The drying air should be maintained at low humidity for preventing the microbial growth. In the conventional method of drying natural convection takes place which is proved to be inefficient and time consuming. In natural convection process, the heat transfer is comparatively slow. The mode of air flow and
circulation in the solar dryers can increase the overall performance. Forced convection solar dryers are used to maintain the low relative humidity of air by circulating and replacing the moisture with fresh air from the surrounding. Based on the mode of operation, solar dryer can be classified into direct and indirect and mixed mode. In the direct mode of drying food products are exposed to solar radiation and there is no separate collector for air heating. A transparent wall is present for the radiant heat transfer[1-2]. In indirect mode of drying, separate thermal collectors are used for heating air which can be circulated to drying chamber for moisture removal application. [3-5]. In mixed mode solar dryers both the mode of drying is possible in which transparent cover is present for maximum radiation transfer with a separate drying chamber. There are different solar dryers developed by the researchers with various design parameters depending on the temperature requirement for different products [6-9]. The quality of products dried in solar dryer was found to be superior in comparing to open sun drying [10-11]. The solar dryers are economically feasible and the fuel cost is zero whereas electric dryers or other conventional dryers use fossil fuel resources [12]. In this paper three types of drying methods namely solar drying, electrical drying and open sun drying are compared and reported.

2. Materials and methods

The solar tunnel dryer is developed in the Centre for Green Energy Technology, Pondicherry University. The developed system is shown in Fig. 1. The dryer is classified as direct, forced convection type. The collector area is 2m². The chamber is of 2m length and width 0.9m. The drying system consists of two axial fans powered by photovoltaic panels. In order to increase the transmissivity of solar radiation, solar toughened glass (2 m×1 m) of 4 mm thickness was used as glazing material in the tunnel dryer. Absorber plate used was selective coated Aluminum sheet for maximum absorption of solar radiation in the short wave region and 50 mm thick polyurethane foam as insulation on sides and bottom to suppress heat loss to the ambient. The area of the absorber plate is 2 m². Product is loaded in eight perforated stainless steel trays of dimension (30 cm × 45 cm) each with 2 kg capacity of fresh products. Separate provision is present to place the trays inside the chamber. The atmospheric air is allowed to pass through the inlet via axial fans. The hot absorber plate in the chamber transfers thermal energy to the incoming air. The hot air is utilized for moisture removal of agricultural products kept in the tray.
The dryer was first tested under no load condition. The temperatures of glazing, absorber, inlet air, outlet air, and chamber were measured and recorded for every ten minutes starting from 9:00 AM to 5:00 PM. And then the dryer was tested with loaded condition. The products used were tapioca, apple, tomato, pineapple and onion with the thickness of 1mm, 2mm, 3mm, 5mm and 3mm respectively. The initial moisture content of the products was found by oven drying method. In this method the product was dried at 110˚C for 24 hours in hot air oven. The initial and final weights were measured using a weighing balance and initial moisture content was found using the equation (1). The final weight of the products was measured. The products were loaded in the solar dryer, electric dryer and in open sun for comparison. The weight of the product was measured for every hour. The products were dried till they attained equilibrium moisture content. The percentage moisture content is given by

\[ X = \frac{m_i - m_f}{m_i} \times 100 \]  

(1)

Where,

- \( m_i \) is the initial mass of fresh product and \( m_f \) is the final mass of dried product.

The drying temperature and outlet temperature were measured and recorded for every ten minutes. The dried samples were collected and stored in air tight container for further testing.

2.1. Instrumentation
Intensity of solar radiation was recorded using LP 471 Pyranometer with an accuracy level of 1°. RTD temperature sensors with 0.1°C accuracy was placed at required points to measure the temperature and connected to a 951D-16U universal datalogger for recording the temperatures. A digital weighing machine (± 0.001 g) of Model No.TTB 31 (Make-Wenser weighing scales limited) was used to measure the weight of the samples. A hot air oven (Make: Techniq, Model: 341P, 0-250°C) was used for estimating the moisture content of the product.

3. Results and discussion

The maximum solar radiation on the day of experiment was 850 W/m². The ambient temperature ranged between 30°C to 33°C. The hot air temperature inside the chamber ranged between 37°C to 65°C. The maximum temperature difference achieved was 32°C. The temperature inside the solar dryer was more than that of ambient temperature. The temperature in the electric dryer was set at 50°C for comparison. The temperature profiles at no load and loaded condition are shown in Fig.2 and Fig.3. The initial moisture contents of tapioca, apple, tomato, pineapple and onion are 72.4%, 86.2%, 93.1%, 89.6% and 82.7% respectively. The percentage moisture content reduced during the drying experiment is shown in Fig.4, 5, 6, 7, & 8 for different products. The drying duration is compared among solar drying, electric drying and open sun drying. In solar dryer the time taken to bring down the moisture to equilibrium for tapioca, apple, tomato, pineapple and onion are 4, 4, 5, 6 and 6 hours respectively. It is evident from the moisture reduction curves that the drying time is lesser in electric dryer comparing to other types due to the constant drying temperature and air flow in the electric dryer. The open sun drying was slower than solar drying due to higher humidity and lower temperature of ambient air and due to natural convection that result in lower drying rate. From the literature many solar drying systems were identified with various designs and performances. A solar dryer with sun tracking capabilities reached 70°C of hot air temperature that was tested by drying coffee beans from 54.8% moisture content on wet basis to below 13% in 2 days which took 5 to 7 days in open sun drying [13]. A multipurpose solar tunnel dryer took 50 hours to dry 500 to 600 kg of coffee beans which when dried in open sun took 75 hours [14]. Maintaining less humidity in the drying chamber helps continuous drying process. Silica gel beds were used in a desiccant bed solar dryer to maintain less humidity of drying air inside the chamber. Dehumidification helped to lower the drying duration of 8 kg of chili whose initial moisture content was 82% and the final moisture content was 13% compared to without dehumidification [15]. Fig. 9 shows the images of dried products in the developed system in our facility. Solar dried and electrical dried products are similar in color. The color loss seems to be less in solar dried and electrical dried products. Open sun dried products look faded in color which may not be suitable for fetching higher market value.
Fig. 2 Temperature inside solar drying chamber at no load condition

Fig. 3 Temperature profile of solar dryer at loaded condition
Fig. 4 Moisture reduction curve of apple

Fig. 5 Moisture reduction curve of onion
Fig. 6 Moisture reduction curve of pineapple

Fig. 7 Moisture reduction curve of tapioca
Fig. 8 Moisture reduction curve of tomato

Fig. 9 Fresh and dried products (a) Solar drier (b) Electrical drier (c) Open sun
4. Conclusion

The developed solar dryer was able to produce average temperature of 50°C. The drying kinetics of tapioca, apple, tomato, pineapple and onion showed drying rate per hour. Solar drying was compared with the electric drying and open sun drying. The drying duration of the samples dried in solar drier was 4, 4, 5, 6, 6 hours for tapioca, apple, tomato, pineapple and onion respectively. The drying time was extended in open sun drying. In electrical drying, the duration was lesser than solar drying due to constant temperature in the chamber. In solar drying and open sun drying the fuel cost was zero while in electric drying the energy required to remove the moisture was met by electricity. Usage of solar dryers results in saving of huge amount of conventional energy without compromising the drying duration and product quality.

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