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Experimental Analysis of Potato Slices Drying Characteristics using Solar Dryer

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Abstract: The objective of the study was to investigate the drying characteristic curves and the drying duration when potato slices dried using natural convection solar dryer. For that sake an experimental setup was developed. Measurements of total solar radiation on the plane of the collector, ambient air temperature and humidity, drying air temperature and relative humidity inside the dryer as well as solid's moisture loss-in-weight were collected. A data logger was used for data acquisition of all the drying parameters. These data were employed to study the potato slices drying characteristics and its nature. A number of experiments were conducted using potato slices. It was observed that the drying time for 6.3 kg m^{-2} potato was reduced by about 30% compared to direct sun drying. Furthermore, the potato slices drying rate decreases to zero and hence potato is a hygroscopic material. The dryer inlet temperature was 14-29°C higher than the ambient temperature. The study showed, other than the reduction in the drying time, application of the natural convection solar dryer generates improved quality dried materials than direct sunshine drying. The results could be used as an input for process and product optimization.

Key words: Experimental analysis, potato slices, natural convection, solar dryer, drying characteristics

INTRODUCTION

It has been proved to prevent bacteria, yeast, mold and enzymes spoiling a food, its moisture content should be reduced to 10-20%. At the same time the nutritional values and the flavour are concentrated and maintained (Scanlin, 1997). The typical traditional method to reduce the moisture content is to use open sun drying. It involves spreading the agricultural products in a thin layer such as crops, fruits, vegetables and tobacco on the ground and turned regularly. Turning the products continuously until the food moisture content reduced to the required moisture level (dried) for storage purpose. This method is still widely used in the developing countries. However, there exist many problems associated with open sun drying. It has been seen that open sun drying has the following disadvantages. It requires long drying time and large surface area. Since the products are open to the air they could easily get damaged by the hostile weather conditions, degradation by overheating, infestation by animal and contamination by foreign materials. Crops are also susceptible to re-absorption of moisture if they are left on the ground during periods of no sun and the drying process cannot be controlled. These could lead to slow drying rate, contamination and poor quality of dried products and loss in production.

The aforementioned problems can be avoided if agricultural products are dried in a sheltered area or chamber using a stream of heated air by solar energy to reduce its relative humidity. Moreover, speed of operations from harvest to storage forced the implementation and use of heated air for drying (Hall, 1980; Ergunes *et al*., 2005). Consequently, various drying devices were implemented for drying crops such as woodfuel driers, oil-burned driers, electric dryers and solar dryer. However, the high cost of oil and electricity and their scarcity in the rural areas of most third world countries have made some of these driers very unattractive. Therefore, interest has been focused mainly on the development of solar driers (Veziroglu, 1989).

Based on the mode of air flow solar dryers are classified into two groups natural convection and forced convection dryers. Forced convection dryer requires external fan or blower to create the air current in the dryer which require power source. Whereas in natural convection with the proper design of the dryer the air current is generated due to density gradient of the air along the dryer, i.e., does not require power source. However, low air flow rate and the long drying time result in low drying capacity (Bala *et al*., 2005). As a result natural convection solar dryer is limited for drying small amount of agricultural products for family consumption.

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If large amount of products are required to be processed, then forced convection dryers should be used. Performance of forced convection maize and bean solar dryer was evaluated by Gatea (2010, 2011). Stiling *et al.* (2012) used concentrating solar panels to improve solar drying for Roma tomatoes and showed a considerable increase in drying rate on sunny days. This study focused on natural convection solar dryer so that it can be used anywhere else as it does not need power input except the solar radiation.

The objective of this study was to analyze experimentally the drying characteristics of potato slices using free convection solar drying system. It is mainly concentrated on the practical field test performance of a locally manufactured, solar dryer. The experiment was conducted in the Faculty of Technology, Addis Ababa University in Ethiopia.

EXPERIMENTAL SETUP

The solar collector is parallel piped shape with dimension of L = 2 m×W = 1 m×0.14 m having 80 mm channel depth, 40 mm gap between the absorber plate and glass cover, 20 mm thick fiber glass insulation was used at the bottom of the collector to reduce the back and edge losses. The solar collector which is inclined at an angle of 12° from the horizontal is oriented along the N-S direction. Blackened stainless steel flat sheet of thickness 1 mm is used as the absorber plate. The solar collector is covered with 4 mm thick commercial glass. The lower end face of the collector (1×0.08 m) is the air inlet whereas, its higher face end is connected to the rectangular duct of the chamber. For the study of the drying characteristics of potato slices in the solar dryer, measuring instruments and thermocouples are used and are all connected to data logger. Figure 1 shows the location and types of the sensors applied.

The drying chamber has 1.2×1.04×0.55 m outer dimensions. Out of the three shelves/trays only two trays TR1 and TR2 were placed inside the drying chamber. The depth of each tray is 19 mm with wire mesh at the bottom. The two drying trays TR1 and TR2 have areas of A_1 = 0.39 m^2 and A_2 = 0.42 m^2, respectively, with a total area of 0.81 m^2. The relative positions of the three trays, TR1, TR2 and TR3 are 0.18, 0.32 and 0.46 m, respectively, above the drying chamber base (hot air entry point). Holes were drilled on the drying chamber for inserting the rod-shaped measuring probes.

The potato slices were characterized by analyzing their moisture content and drying rate curves both on wet and dry basis. The initial moisture content on wet and dry basis of the potato slice was determined by AMB (AMB 310) moisture balance. The AMB balance test was set at Mode 1, with strobe time interval of 2 sec and drying temperature 160°C. Then, slices of potato samples were placed on the AMB moisture balance tray. Samples of the potato of weight ω_O were dried in the moisture balance at 160°C until the dried sample weight, ω_d became stable. The moisture content on wet basis of the potato used was 81.56% (42.3% moisture content on dry basis). The moisture content, dry basis, Md_o of the potato is expressed as:

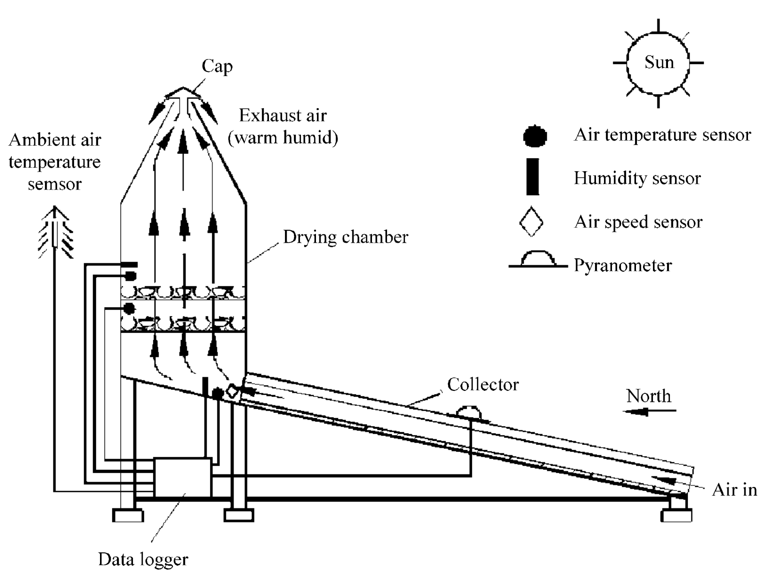

Fig. 1: Schematic representation of the drying setup

$$Md_O = \frac{\omega_O - \omega_d}{\omega_d} 100\% \quad (1)$$

For the determination of the moisture content, dry basis, Md_i of the potato at any time t_i during the drying process, the following equation is used:

$$Md_i = \frac{\omega_i - \omega_d}{\omega_d} 100\% \quad (2)$$

or moisture content, wet basis, of the potato at any time t_i during the drying process where ω_i is the weight of the potato at time t_i is expressed as:

$$M\omega_i = \frac{\omega_i - \omega_d}{\omega_O} 100\% \quad (3)$$

The moisture content on dry basis and wet basis is related by Eq. 4 and 2:

$$Md = \frac{M\omega}{100 - M\omega} 100\% \quad (4)$$

The determination of the potato weight was done by weighing the drying tray with its load of potato at any time in the drying process. For the determination of the instantaneous drying rate RDd_i, dry basis, Eq. 5 is applied:

$$RDd_i = \frac{\Delta\omega_i}{\omega d * \Delta t} = \frac{\omega_{i-1} - \omega_i}{\omega_d (t_{i-1} - t_i)} [kg_w / kg_d.min] \quad (5)$$

where, t_{i-1} and t_i are successive times corresponding to when two successive measurements of a drying material are made.

RESULTS AND DISCUSSION

Figure 2 shows the moisture content of potato as a function of the drying time. Initially the moisture content of the potato slices is high. The moisture content reduced with time and similar potato moisture content profile during drying was shown by Srikiatden and Roberts (2008) and Putranto *et al.* (2011). As may be expected, TR1 the one placed nearer to the hot air, exhibits the most rapid drying. At 6 PM of the first day, the potato moisture content of TR1 and TR2 which are located in the dryer and TR3 which is located in the open sun dropped to about 4.38, 7.88 and 11.49%, wet basis, respectively. During the second day, the moisture content decreased gradually. By 10 AM of this day the moisture content dropped to about 2.62, 3.05 and 5.6%. The final moisture contents at 1 PM were 2.62, 2.93 and 3.58% on wet basis and which are considered as the equilibrium moisture contents of potato. These moisture contents indicate that the first tray reached the equilibrium moisture content after 2 h of the second day, whereas the potato in the open sun tray reached equilibrium moisture content after seven hours of the second drying day. This means a reduction of the drying period of 4-5 h was obtained using the solar dryer compared to the traditional open sun drying which also depends on the prevailing weather conditions. Other advantages are the protection against direct sunshine, dust and insects. During the night times the inlet and the exit of the dryer were closed and the control sample was placed in a room to prevent the potato from moisture regain.

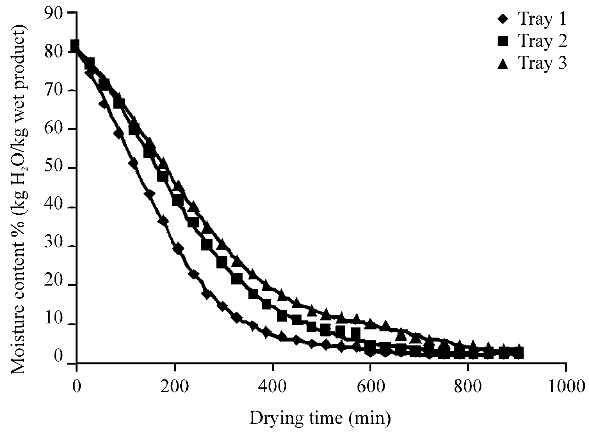

Fig. 2: Moisture content curves for potato slices in solar dryer and open air sun dryer

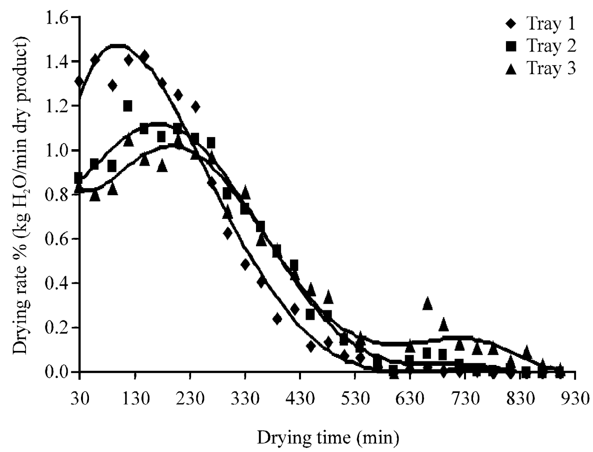

Fig. 3: Drying rate curves plotted for potato slices on a dry basis

Figure 3 shows the drying rate of potato as a function of the drying time. As can be seen from the curves in the figure, the drying rate for the first tray, placed at the bottom of the drying chamber, expectedly has the highest

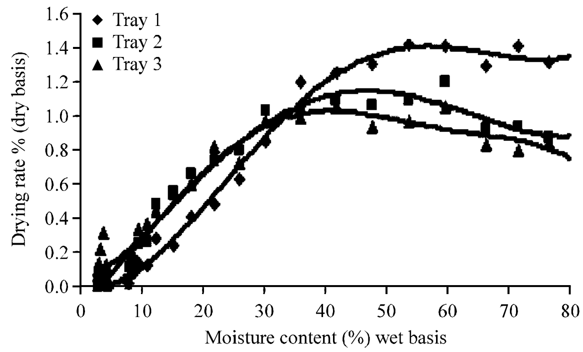

Fig. 4: Drying rate curves

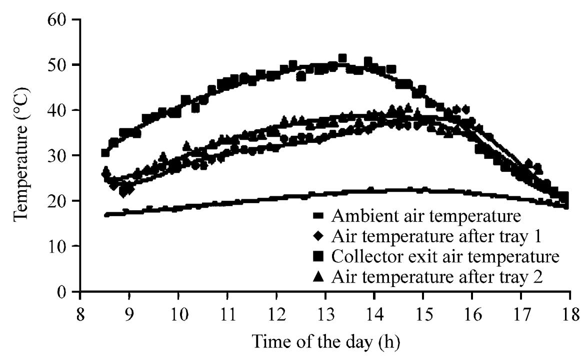

Fig. 5: Temperature variations with respect to the vertical distance from the drying chamber bottom

drying rate during the first 3 h. However, once a large quantity of moisture has been removed, its drying rate decreases. The drying time of the potato on the second tray is higher than the first tray because the drying air moisture-absorbing capacity is reduced after it has absorbed moisture from the first tray.

During the initial stage of drying, the rate of moisture migration is sufficient to maintain the surface in a completely wet condition, as shown in Fig. 4. During this period, the rate of drying of the material is controlled by the rate of evaporation from the surface. This is controlled by the condition of air adjacent to the surface. Thus, during this period, the rate of drying is relatively constant as shown in Fig. 4, which is known as the constant rate period. The point where the drying rate starts to decrease is known as the critical moisture content. Thereafter, the period of drying is known as the falling rate period. This is the period when the surface of the material is not wetted completely, by migration of moisture. The drying rate tends to go to zero when the rate of evaporation from the surface equals the rate of absorption of moisture by the material and is known as the equilibrium moisture content. Since the drying rate decreases to zero with a certain

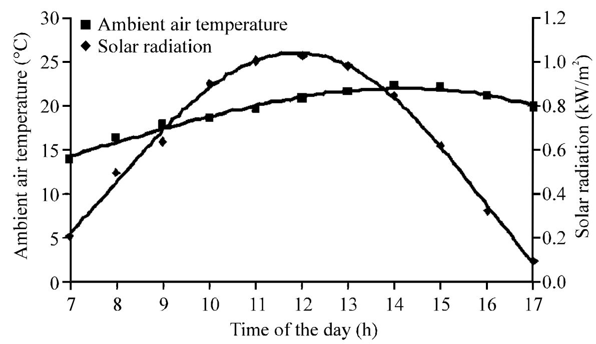

Fig. 6: Weather data for the test period: measured total solar radiation and ambient temperature obtained from the pyranometer and temperature sensor

bound moisture, potato is a hygroscopic material. Srikiatden and Roberts (2007) said potato is one of the hygroscopic foods. Furthermore, the drying rate trends showed a typical hygroscopic material curve as reported by Mujumdar and Devahastin (2000).

Figure 5 displays the variation of air temperature with vertical distance from the bottom of the drying chamber. Ambient air temperature is included in the graph for comparison. A major drawback of the shelf-type dryer is the uneven drying. As a result of the migration of the drying front, the materials at the entrance are dried while at the exhaust are under dried. This problem can be alleviated by rotating the drying shelves. In such a rotating operation, the hot air from the collector is used to heat the product already in the latter stages of drying, falling rate period while the unsaturated air is used to remove moisture from product in the upper shelves.

METRO LOGICAL DATA DURING THE TEST

The weather throughout the experiments was clear at day time. The maximum ambient temperature reached 22.65°C at 2:41 PM and radiation reached 1.0357 kW m^{-2} around noon. These are shown in Fig. 6. The average relative humidity of the ambient air was 30.41% compared to the relative humidity of the air at the collector exit which has an average of 11.89% in the morning, 8.7-8.9% between 11:00-15:00 h, with a minimum of 6.6% at 13:30 h and an average of 18.97% in late afternoon.

CONCLUSION

Solar energy was utilized to dry potato slices in the shelf or batch type solar dryer with 2m^2 flat plate collector. The collector produced air temperatures of 14-29°C, from

8:30 AM- 4:00 PM, higher than the ambient air temperature in a clear day. The hot air was used to dry 6.3 kg m^{-2} potato slices on trays inside a dryer. The final moisture content of the potato is 2.62-2.93% which was observed after 10 sunny hours. The drying time required by traditional open sun drying is reduced by 4-5 h, about 30%, in natural convection dryer under the existing environmental conditions. The drying rate curves of potato slices were produced. Furthermore, the drying material is protected from direct solar radiation, infestation by insects and contamination by dust, producing a product with improved quality.

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