Drying Kinetics of Forced Convection Solar Dryer for Fruit Drying

E.Veeramanipriya, AR. Umayal Sundari

Abstract*: The primary objective of this work presents the drying kinetics of forced convection solar dryer aided with evacuated tube collector for chemically untreated red apple under the climatic conditions of Thanjavur, India. The outlet temperature of evacuated tube collector (59 – 108℃) is found to be much greater than the ambient temperature (33.5 – 35.5℃). This enhances the rate of drying in the evacuated tube collector based solar dryer. It takes 5 hours for apple to reach the equilibrium moisture content whereas it takes 8 hours for natural sun drying. The quality of the dried sample is observed to be better. The use of conventional fuel is minimized and the dryer is found to be eco – friendly.

Keywords: Forced Convection Drying, Evacuated Tube Collector, Red Apple, Outlet Temperature.

I. INTRODUCTION

One of the biggest problems faced by all the developing countries is preserving agricultural products. During harvesting time, most of the vegetables and fruits contain more than 80% water content. Consequently, products get spoiled. Preservation is the most significant process of food storage for years together. In the case of fruits and vegetables, 50 – 70 % of loss is due to improper conservation and storage [1]. Drying (dehydration) is the widely used classical methods for preservation of agricultural products (fruits and vegetables) [2]. It is generally defined as the process of removal of moisture from a solid by heat and mass transfer simultaneously [3]. Dehydration is the oldest technique to reduce microbial activity and often used to improve the quality and extend the shelf - life of the moist products to make them long time usable by removing their moisture content to a certain value [4 – 5].

Nowadays 85% of industrial dryers are the conventional dryers with hot air. Also the main disadvantage of the industrial dryers are their high energy consumption and over cost [6-7]. Solar drying is a great alternative to the other conventional dryers in many tropical and subtropical countries. This result has been led to the evolution of versatile methods of solar dryer in the past few years.

Apple [Malus Domestica] is the most popular and healthiest fruit grown all over the world. It is an important food product with good source of fibre and vitamin C. Apples are considered as fourth world fruit crop and horticultural product of human nourishment; Also it is rich in terms of antioxidant. Dried apples are an attractive snack in the form of crisps and used in the production of baby food [8].

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Salah Ben Mabrouk et al., demonstrated the experimental study and numerical modelling of drying characteristics of apple slices [9]. Mustafa Aktas et al., have performed the determination of drying characteristics of heat pump and solar dryer for apple drying. From the result, the effective moisture diffusivity of heat pump dryer and solar dryer were found to be 2.36 X 10^{-8} m^2/s and 1.03 X 10 $^{-8}$ m^2/s respectively [10].

Ibrahim Doymaz presented the effect of citric acid and blanching pre – treatments on drying and rehydration of Amasya red apples. Blanching and 0.5% citric acid pretreatments were used earlier to the drying process. The result exhibits that pretreatment affected the drying time. The effective moisture diffusivity value of citric acid pretreated apple samples was higher than the other chemical pretreated samples [11]. Agnieszka Kaleta et al., described the drying models of the fluidized bed dryer for drying apple. From the result, page model is the most appropriate to describe the drying characteristics of apple [12].

Mandala et al., enquired the influence of different osmotic pretreats on apple used in air dryer and analyzed their physical characteristics. Samples were plunged in sucrose or glucose of 30% and 45% at various times and the experiment was carried out in air dryer. The osmosed high sugar concentration apple samples in glucose have better physical characteristics than the lower concentration [13]. Schultz et sl., examined the effects of pretreatments on apple slices using convecting drying compared to the drying without pretreated apple slices [14].

Romano et al., analysed the energy and environmental parameters of solar cabinet dryer for drying of apple and carrot. The result shows that the energy necessary to remove the moisture content from apple and carrot ranging from 3300.19 and 7428.28 KJ/Kg respectively during the total period of drying [15]. Omid Reza et al., designed the solar dryer with inclined collector for thin layer drying of apple chips (Golab). The experiment was run in two levels of collector tilted angle (30 and 45℃) and three levels of air flow rates. The result exhibits that more drying intensity happened with 30℃ of slope angle and the air flow rate of 0.018 m^3/s respectively [16].

Hail ataley et al., developed the solar dryer with air heater to determine the drying rate of apple. The designed packed bed thermal energy storage system was provide the continuous drying process. The result indicates that, it consumes less energy at the rate of 76.8% than other drying methods [17]. Wang et al., studied the mathematical modelling on thin layer hot air drying for apple pomace drying. The results demonstrates that the drying air temperature from (50, 60 and 70℃) and the drying velocities (0.6, 1.2 and 1.8 m/s) respectively [18].

Ahmad determined the drying characteristics of apple

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using passive shelf solar dryer compared with the open sun drying. The results shows that the drying period decreased by 40% and 22% for 5mm and 10mm thickness of the apple slices compared to the open sun drying of 57% [19].

Solar vacuum tubes type dryer was designed, fabricated and tested for different fruits such as grapes, amla, mango and vegetables such as cluster beans, brinjal, potato by Umayal et al. [20 - 22]and Mahesh et al., [23].

Literature survey reveals that the performance of Evacuated Tube Collector (ETC) based solar dryer is better compared to other solar dryers [24]. Also from the review it is observed that drying of apple slices in ETC based solar dryer has not been carried out so far. Hence, the present work aims to study the performance of ETC based solar dryer for drying chemically untreated apple and compare it with open sun drying under the meteorological condition of Thanjavur.

II. METHODOLOGY

A. Experimental Procedure

The ETC based solar dryer used for the present study consists of four important parts - drying chamber, chimney, evacuated tube collector and blower [20]. The photograph of ETC based solar dryer employed for the present study is pictured in Fig. 2.1.

Fresh apple made into thin slices is used as sample for drying. 200g of fresh and good quality apple slices are spread in hot air oven at a temperature of 105℃ for 24 hours. Final mass of bone dried apple is measured with digital electronic balance. Using the initial and final mass of the apple slices, the initial moisture content of the apple slices is determined.

Fig. 2.1: Photograph of Evacuated Tube Collector Based Solar Dryer

Fresh apple cut into thin slices and spread on all the three trays are situated inside the drying chamber. In the solar dryer, the atmospheric air is passed through ETC with the help of the blower motor. The air is transported into the collector when blower is switched on and gets heated up quickly. The hot air is held to pass into the drying chamber where the samples (apple slices) are loaded in the perforated aluminium trays. This hot air helps to remove the moisture content from the apple slices. The entire experiment is also performed under open sun drying. The mass of the sample, temperature at various locations and solar insolation are taken on hourly basis from 9.30 am to 5.30 pm until the apple reaches the equilibrium moisture content.

Fig. 2.2: Apple before solar drying

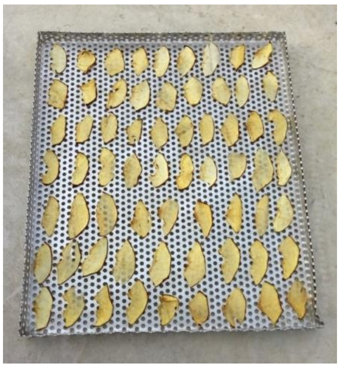

Fig. 2.3: Apple after drying in ETC based solar dryer

Fig. 2.4: Apple after drying in open sun drying

B. Measuring Instruments and Devices

The relative humidity, wind velocity and ambient temperature are measured using electronic digital (humidity) anemometer. Solar power meter is used to calculate the solar radiation throughout the day on hourly basis. Digital electronic balance is used for weighing the sample materials on hourly basis. Temperature is measured using Pt 100 sensor at various locations of the dryer. Sample before drying and after drying (ETC dryer & Open sun drying) are respectively shown from Fig. 2.2 to 2.4.

C. Data Analysis

(i) Determination of Moisture Loss (ML)

The initial (m_i) and final mass (m_f) of the apple slices is noted on hourly basis. Moisture loss is calculated using the formula [25],

$ML = m_i - m_f$ (1)

(ii) Determination of Moisture Content (MC)

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The percentage of moisture content on wet basis (M_{wb}) is found using the formula [25, 26, 27],

$$\% M_{wb} = \frac{m_i - m_f}{m_f} x\ 100 \quad (2)$$

Where:

m_i and m_f are the initial and final mass of the apple slices.

(iii) Determination of Moisture Ratio (MR)

The moisture ratio is determined by [25,26],

$$MR = \frac{[M - Me]}{[Mo - Me]} \quad (3)$$

Where:

M is the moisture content at any time, M_e is the equilibrium moisture content and M_o is the initial moisture content of apple slices.

(iv) Determination of Drier Efficiency

The drying efficiency of the ETC based solar drier is given by [21],

$$\eta d = \frac{ML}{IAt} \quad (4)$$

Where:

M is the mass of the water evaporated from the apple slices, L is the latent heat of vaporization of water, I is known as solar insolation, t and A are the time and effective area of the collector.

(v) Determination of Specific Moisture Extraction Ratio (SMER)

The SMER of the ETC based solar dryer is given by [25],

$$SMER = m_d / P_d \quad (5)$$

Where:

m_d is the Final mass of the apple slices at any time and P_d is the Blower power (kWh) respectively.

III. RESULT AND DISCUSSION

The experiment is carried out with ETC based solar dryer at Thanjavur during the month of May. In the course of entire experimental period, variation of relative humidity (RH), wind velocity, ambient temperature (T_0), solar insolation (SI) and temperature at various locations of ETC inlet (T_6), ETC outlet (T_5), Lower tray (T_4), Middle tray (T_3), Upper tray (T_2) and Chimney (T_1) noted on hourly basis are given in Table 3.1.

Throughout the experimental period, the solar insolation is observed to vary from 206 to 1051 W/m^2. The ambient temperature and the outlet temperature of ETC ranges from 33.5 to 35.5℃ and 59 to 108℃ respectively. The temperature inside the drying chamber is observed to vary from 36 to 59℃. It is much more than the ambient temperature. This reveals that drying rate in ETC based solar dryer is larger than open sun drying consequently reducing the drying time in ETC based dryer. The moisture parameters determined during solar and sun drying of apple is given in table 3.2.

Fig. 3.1 and 3.2 indicates the fluctuaion of moisture content with drying time for drying of apple in ETC based solar dryer and open sun drying. ETC based solar dryer takes 5 hours to reduce the moisture content of chemically untreated apple slices from 85.4% (wb) to 1.5% (wb) whereas open sun drying takes 8 hours.

Table 3.1: Hourly variations of different parameters recorded for solar drying of apple slices

Time	Solar Insolation	RH	Wind Velocity	Temperature						
				T_0	T_1	T_2	T_3	T_4	T_5	T_6
Hrs	W/m^2	%	m/s	℃	℃	℃	℃	℃	℃	℃
9.30	534.4	60	0.27	33.5	37	39	39	38	59	44
10.30	1020	57.7	1.42	34.5	49	50	49	51	100	64
11.30	1051	54.7	1.04	35.0	45	46	48	49	105	68
12.30	572	53.5	0.18	35.0	53	54	53	58	99	60
13.30	520.2	52.5	2.62	35.0	57	56	54	59	108	63
14.30	424.2	48	0.81	35.5	51	53	52	54	86	62
15.30	295.2	50	4.55	35.2	44	44	45	45	77	61
16.30	209.7	60.5	4.82	34.7	38	36	38	38	71	58
17.30	206	59	4.21	34.0	-	-	-	-	-	-

Table 3.2: Hourly variations of moisture content, moisture loss & moisture ratio of apple in ETC based solar dryer and open sun drying

Time (hr)	Solar Drying (ETC)			Open Sun Drying		
	% MC (wb)	ML (g)	MR = M/M$_o$	% MC (wb)	ML (g)	MR = M/M$_o$
0	85.4	-	1.0000	85.4	-	1.0000
1	40.8	42.1	0.4776	66.1	19.5	0.7736
2	12.5	26.7	0.1465	50.6	15.6	0.5925
3	2.4	9.5	0.0281	36.4	14.3	0.4264
4	1.6	0.8	0.0186	23.8	12.7	0.2790
5	1.5	0.1	0.0170	15.1	8.8	0.1768
6	1.5	0.0	0.0170	7.8	7.4	0.0909
7	1.5	0.0	0.0170	2.5	5.3	0.0294
8	1.5	0.0	0.0170	0.6	1.9	0.0073

To study the variation of moisture ratio of apple, a graph is diagrammed between moisture ratio and drying time and is indicated in fig. 3.3 and 3.4. It is viewed that moisture removal is initially greater and is found to be decreasing exponentially.

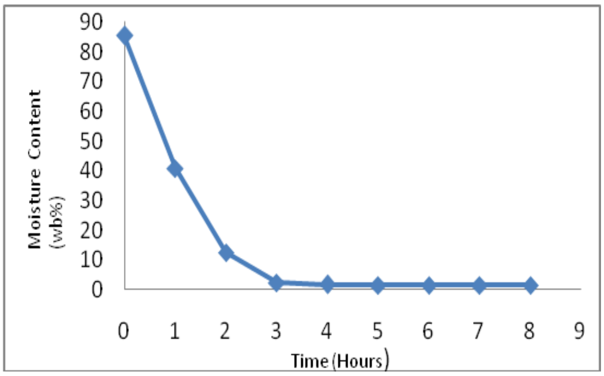

Fig. 3.1: Moisture content vs. Drying time for drying apple in ETC solar dryer

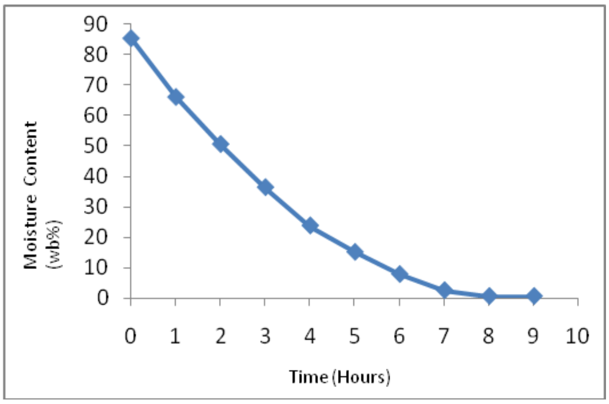

Fig. 3.2: Moisture content vs. Drying time for drying apple in open sun drying

The average efficiency of the ETC based solar dryer is found to be 16.05% and Specific Moisture Extraction Ratio (SMER) for solar drying of apple is found to be 0.2623 Kg/KWh. Also the quality of the solar dried apple slices is

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better in terms of flavour, colour, odor and appearance than the open sun dried apple slices.

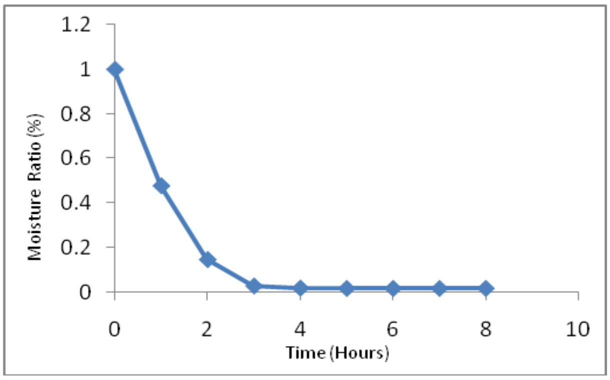

Fig. 3.3: Moisture Ratio vs. Drying time for drying apple in ETC solar dryer

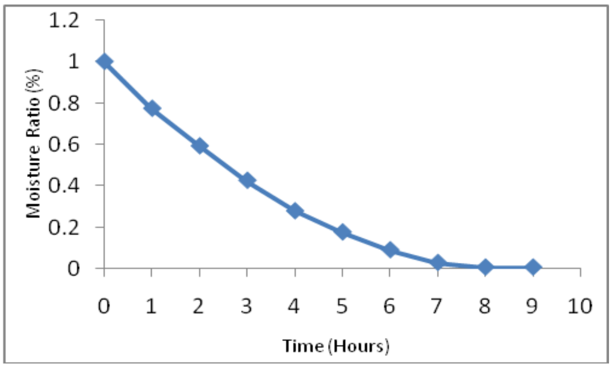

Fig. 3.4: Moisture Ratio vs. Drying time for drying apple in open sun drying

IV. CONCLUSION

In the present work the performance of ETC based solar dryer is analysed for drying of apple and compared with open sun drying. The evacuated tube collector based solar dryer minimizes the drying period of apple. The temperature of the drying chamber is much greater than the surrounding (ambient) temperature due to the presence of evacuated tube solar collector. The efficiency of the solar dryer for drying apple slices is found to be 16.05%.ETC based solar dryer is pollution free and can be employed to dry any kind of agricultural products. Also there is a wide scope to save the conventional fuel. This type of dryer makes the high standard dried product for exporting and can make a good profit.

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