Study on Effective Structural Parameters on Drying Rate of Kiwi Fruits in a Solar EHD Dryer

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***Abstract*— Applying an electric field to some water solutions or food materials has shown experimentally for increasing the drying rate. High voltage electric field drying technology as a novel method of non-thermal processing has been used particularly for heat sensitivity materials. This system includes: a high voltage power supply, grounded electrode, discharge electrode and some measurement instruments. In this method, an electric field was applied cross the interface of samples via electrodes located above and under the samples surface. Effects of three different grounded plates, namely galvanized iron, aluminum and copper on drying rate of kiwi fruit were studied , Moreover the effects of two types of grounded plates consist of flat plate and grid plate were also investigated . Results showed that effect of opening ratio of grounded electrode on drying rate was significant at less than 1 % probability level (P<0.01).**

***Keywords*–** Electric Field, Electrode, Drying Rate, High Voltage and Kiwi Fruit

I. INTRODUCTION

The kiwi fruits were introduced for the first time from southeastern China. The fruit is densely covered with light brown furs. Kiwi fruits can tolerate low temperatures for conservation, allowing storage up to 8 months [1]. The kiwi fruit has a high nutritional value and is rich mainly in vitamin C and fibers [1-2]. However, some nutrients such as vitamin C are destroyed by heating. Losses of this and other heat labile nutrients depend on the extent of heating and the other prevailing conditions, such as PH [3]. Generally, Drying of agricultural products is one of the oldest methods of food preservation [4-5]. Drying is defined as a way to reduction of moisture from the products and is used a most important process for preserving of agricultural products due to its great effect on the quality of the dried products [6]. It is also used to generate new products such as puree, essence, chips and etc [7].

At present, the conventional drying processes of agricultural products are solar drying and hot air drying. The latter often causes heat damage and adversely affects texture, color, flavor, and the nutritional value of dried products. Since the material to be dried only absorb a fraction of the energy conveyed by air or generated by heat exchangers, these techniques are normally low in the efficiency of energy utilization [8]. Fortunately, Solar drying does not need any special equipment and technology, and neither does it incur high expenses, however, it has some problems related to the contamination with dust, soil, sand particles and insects [9], and its drying conditions are difficult to be controlled. As a result, the product quality is often poor [10].

In response to the disadvantages of conventional drying processes, there is now a growing interest in non-thermal processing of food and similar materials [11-12]. Electrohydrodynamic (EHD) drying is a new non-thermal method of drying with the potential to be applied to the industrial drying of high-value agricultural products. EHD drying utilizes the energy transfer from electrons emitted from a charged electrode to the gas molecules in ambient air. EHD drying produces superior quality food products with high nutritional value and natural color and textural characteristics [13].

Effects of operating parameters on water evaporation in electric field have been studied by some researchers [14-16]. A very important issue in these investigations is that all experiments have been conducted on water evaporation as a general issue; however its application in drying process has not been reported by any researcher. The main objective pursued in this study is to investigate the effects of structural parameters on drying rate of kiwi fruit in a solar EHD dryer.

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II. MATERIAL AND METHODS

A. Materials

Kiwi fruits (cv. *Hayward*) were used during all experiments in this study and obtained from the Seed and Plant Breeding and Improvement, Karaj, Iran (Longitude: 51°21'N, Latitude: 36°12'E). Initial moisture content of the samples were determined using oven method based on ASAE standard S368.2 and obtained as 84% w.b [17].

B. Experimental Setup

The experimental setup, shown in Fig. 1, consisted of a direct current at high voltage which was applied to the electrode from a power supply. This power supply (Design and manufacture in the power laboratory) has a maximum output voltage of 30kV for both polarities. However, in the present study, only positive polarity was utilized. The accuracy of the power supply is ±100 V for voltage and ±0.002 mA for current. In this point-to-plane configuration, needles (0.1 mm in point diameter) were made of stainless steel and were connected to the high voltage source, vertically above the center of plane (25cm×28cm) which was used as an electrically earthed reception plane. The distance between the cathode and the anode electrodes was adjustable from 0 to 8 cm. Electric field was applied to the samples by adjusting the voltage and the electrodes spacing.

C. Temperature Measurement

The ranges for temperature and humidity measurement instrument are -40 to 125 ºC and 0 to 100% RH (non-condensing), respectively. The accuracy of the temperature measurement is 0.3 at 25 ºC. The accuracy for the humidity measurement is 2% over 10 to 90% RH at 25 ºC. The resolution for the temperature measurement is 0.01 ºC and for the humidity measurement is 0.03% RH. Infrared thermometer applied for measurement of sample surface temperature. The measurement resolution is 0.01 ºC and range for measurement is -70 to 380 ºC.

D. Determination of Moisture

The slices of the samples with diameters of 3.5-5 cm were placed on the plane electrode (Fig. 1). To measure the weight loss of water with time (i.e. the drying rate), a digital balance manufactured by AND Corporation was used. The capacity of these digital balances is 0 to 1000 g and 0 to 3000 g (dual ranges) and the readability of these ranges are 0.01 g and 0.1 g, respectively.

E. Methods

The initial weight of the samples was measured and then samples were prepared for drying. Ambient conditions in the laboratory during EHD drying were 24 ºC and 21.4 % relative humidity. EHD drying experiments were performed at voltages of 6, 10.5, and 15 kV and with field strength of 4.5 kV/cm. The samples were exposed continuously to drying during all experiments; weight was measured at 10 min intervals. Each set of measurements was completed in less than 30 seconds. During the entire experiment period, the change of ambient temperature was minimal since the lab was under well temperature control.

The drying rate (DR) of kiwi fruit during drying experiments was calculated using following Equation [18]:

$$DR = (M_{t+dt} - M_t) / dt$$

Where M_{t+dt} is moisture content at time $t+dt$ (kg water/ kg dry mater), M_t is moisture content at time t (kg water/ kg dry mater) and dt is drying time (min).

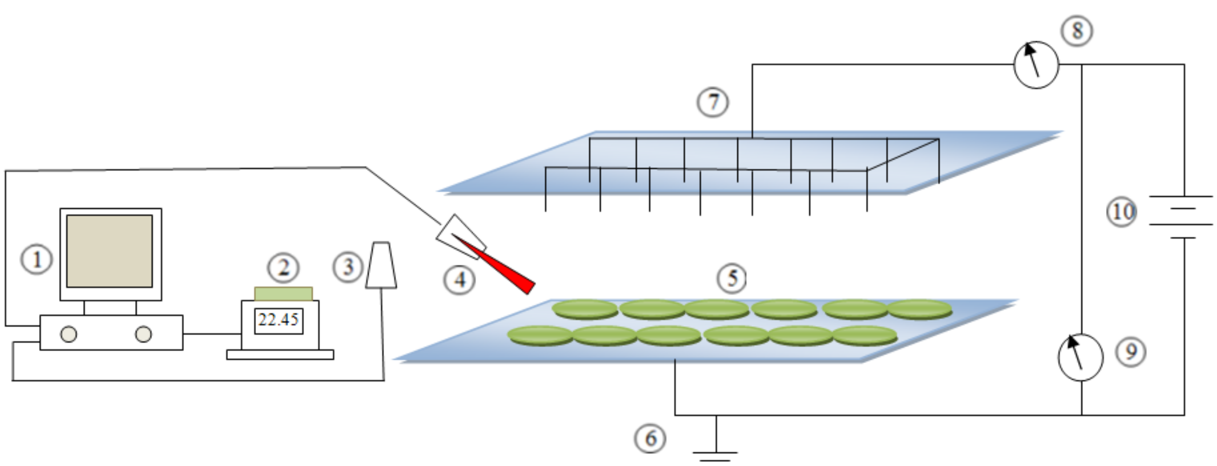

Fig. 1. Schematic of the experimental setup

1. Computer, 2. Digital balance, 3. Humidity/ Temperature sensor, 4. Infrared thermometer, 5. Samples, 6. Grounded electrode, 7. Discharge electrode, 8. Ammeter, 9. Voltmeter, 10. High voltage power supply

In order to study the effect of material type of ground electrode on drying rate of kiwi fruit, experiments carried out on three material types of grounded electrode, such as galvanized iron, aluminum and copper. Electrical properties of these materials report in Table 1 [19-20]. Each experiment lasted for 90 min and carried out in three replications. Moreover, with same produce, the effect of opening ratio of grounded electrode on the drying rate of samples is investigated in two levels (flat and grid plates). A grid that allows the passage of air may benefit to the drying rate. Finally, in this research, the effect of material type of drying box on drying rate was also investigated. Those types are glass, wood and air and its electrical properties report in Table 1 [20].

Table 1. Electrical property of used materials

	Dielectric constant		Electrical conductivity (S/m)
Glass	3.7	G. Iron	1.00×10^{7}
Wood	2.6	Aluminum	3.5×10^{7}
Air	1.0	Copper	5.96×10^{7}

This study was planned as a completely randomized block design. The drying rate was determined with three replications in each treatment. Experimental data were analyzed using analysis of variance (ANOVA) and to evaluate the effect of material type and opening ratio of grounded electrode on the drying rate, statistical analyses were performed by using the SAS/ STAT GLM Procedure.

III. RESULTS AND DISCUSION

In this section the effect of applied voltage and material type on drying rate of kiwi fruit were investigated. The analysis variance of the data carried out in two categories, in the first category the effect of variation of applied voltage and fixed material type on drying rate was investigated and then the effect of different material types and fixed applied voltage on drying rate was investigated. In the second category, interaction of applied voltage and material type on drying rate of kiwi fruit was studied. The analysis variance of the data is shown in Table 2 and 3. Results indicated that the applied voltage and material type (grounded electrode and box) created a significant effect on the drying rate ($P < 0.01$) in the case that just one of them varied.

The material types used in this study have been a significant effect on drying rate of kiwi fruit and this means that different material has different effects on drying rate (Table 2). As well as, based on Table 3, glass and wood box have been a significant effect on drying rate of kiwi fruit, due to their dielectric properties.

Table 2. The analysis variance of material types of grounded electrode

Source	DF	Type II SS	Mean Square	F Value	Pr > F
Voltage	2	33.957	16.9789	2278.49	<.0001
Material type	2	0.6017	0.3008	40.37	<.0001
Material type× Voltage	4	0.0577	0.0144	1.94	0. 1478
Error	18	0.1341	0.0074		
Total	26	34.7515			

Table 3. The analysis variance of material types of box

Source	DF	Type II SS	Mean Square	F Value	Pr > F
Voltage	2	30.364	15.182	4393.5	<.0001
Material type	2	0.6241	0.3120	90.31	<.0001
Material type× Voltage	4	0.0279	0.0069	2.02	0.1346
Error	18	0.0622	0.0034		
Total	26	31.0783			

According to Table 2 and 3 interaction of applied voltage and material type (grounded electrode and box) on drying rate was not significant in level of less 5% ($P > 0.05$) and according to this, it can be stated that material types and applied voltage separate from each other effect on drying rate of kiwi fruit. Results of analysis variance of the data by using the SAS/ STAT GLM Procedure are reported in Table 4.

Table 4. Variation of drying rate with considering the interaction between voltage and material types

Applied voltage (kV)	Drying rate ($\times10^{-3}$)					
	Material type of electrode*			Material type of box*		
	Copper	Aluminum	G.Iron	Air	Glass	Wood
6	25.6^{a}	25.8^{a}	25.0^{b}	24.1^{a}	25.1^{b}	25.0^{b}
10.5	28.8^{c}	29.4^{c}	27.8^{d}	26.4^{c}	27.9^{d}	27.8^{d}
15	36.5^{e}	37.2^{f}	35.2^{g}	33.8^{e}	35.6^{f}	35.2^{f}

*: Significant at less than 1 % probability level

As shown Table 4, the average value of drying rate for kiwi fruit was obtained as 29×10^{-3} (kg water/ kg dry mater.time) varying from 24.1×10^{-3} to 37.2×10^{-3} (kg water/ kg dry mater.time). Minimum value of drying rate was obtained in the applied voltage of 6 kV/cm and air box.

The analysis variance of the data showed that the effect of applied voltage on drying rate is significant at less than 1 % probability level (Table 2 and 3). In the other word, there was significant difference between drying rate of applied voltages 6, 10.5 and 15 kV. Bai and Sun reported similar results about applied voltage [21]. As said, different material has different effects on drying rate that is shown in Fig. 2 and Fig. 3.

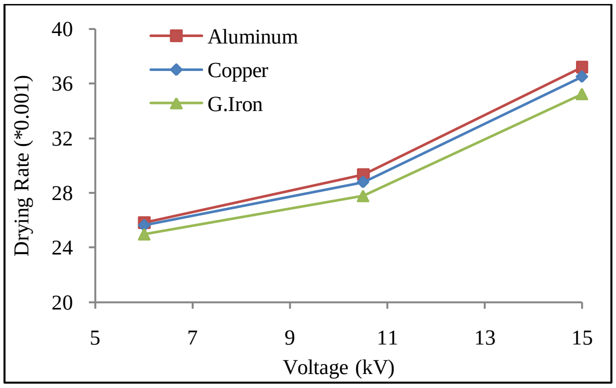

Fig. 2. Variation of drying rate with material type of grounded electrode

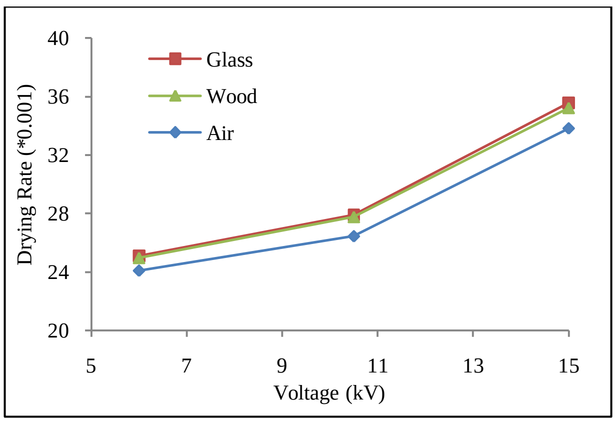

Fig. 3. Variation of drying rate with material type of box

As shown in Figure 2 drying rate of kiwi fruit with aluminum grounded electrode has the largest value with respect to copper and galvanized iron. However the difference between copper and aluminum was smaller respect to different between aluminum and galvanized iron. Moreover, Galvanized iron has the lowest value in drying rate respect to aluminum and copper grounded electrodes. Figure 2 indicated that different between drying rate value of different material increased when applied voltage increased. Data from Figure 3 reported that glass box has the largest amount of drying rate respect to wood and air box but there wasn't large difference between wood and glass box. The analysis variance of the data (Table 5) indicated that effect of opening ratio of grounded electrode on drying rate had significant at less than 1 % probability level and interaction of applied voltage and shape of grounded electrode on drying rate was significant (P <0.01).

Table 5. The analysis variance of opening ratio of grounded plate

Source	DF	Type II SS	Mean Square	F Value	Pr > F
Type of plate	1	0.1058	0.1058	30.67	0.0001
Voltage	2	22.511	11.255	3262.5	<.0001
Type of plate× Voltage	2	0.0481	0.0240	6.98	0.0098
Error	12	0.0414	0.0034		
Total	17	22.7068			

The results of data analysis for interaction between applied voltage and opening ratio of grounded plate is reported in Table 6. As shown drying rate reduced when applied voltage is reduced moreover as seen in Table 6 flat plate grounded electrode had lower value of drying rate respect to grid plate grounded electrode and the difference increased with increasing in applied voltage. Zheng et al. reported that results based on data analyze indicate that a grid have no influence on water evaporation enhancement by electric field [15]. Difference between results may be because, the water container was used in their experiments is that no possibility to exchange with ambient air from below.

Table 6. Variation of drying rate with considering interaction between voltage and opening ratio of grounded plate

Applied Voltage (kV)	Drying rate ($\times 10^{-3}$)*	
	Grid Plate	Flat Plate
6	25.1[a]	25.0[a]
10.5	28.4[b]	27.8[c]
15	36.4[d]	35.2[e]

*: Significant at less than 1 % probability level

Based on Table 6, The average value of drying rate for flat plate obtained as 29.3×10^{-3} (kg water/ kg dry mater.time) varying from 25×10^{-3} to 35.2×10^{-3} (kg water/ kg dry mater.time), while this value for grid plate was calculated as 29.9×10^{-3} (kg water/ kg dry mater .time) ranging from 25.1×10^{-3} to 36.4×10^{-3} (kg water/ kg dry mater.time).

IV. CONCLUSIONS

In this research, the effects of some structural parameters on drying rate of kiwi fruit are presented. From this study it can be concluded that:

1) Minimum value of drying rate was obtained in the applied voltage of 6 kV/cm and air box.
2) Galvanized iron has the lowest value in drying rate respect to aluminum and copper grounded electrodes.
3) Drying rate of kiwi fruit reduced with reducing in applied voltage.
4) Effect of opening ratio of grounded electrode on drying rate had significant influence on drying rate at less than 1 % probability level.
5) The applied voltage and material type (grounded electrode and box) created a significant effect on the drying rate (P < 0.01) in the case that just one of them varied.

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