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ELECTROHYDRODYNAMIC AND FAR-INFRARED ASSISTED DRYING OF ALOE VERA

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Keywords: Aloe Vera; Electrohydrodynamic; Drying; Far-infrared Radiation

ABSTRACT

Electrohydrodynamic (EHD) assisted drying has been successfully applied to enhance the drying rate of various materials, while far-infrared radiation (FIR) has also received much attention as an additional heat source for drying a wide range of agricultural products. The aim of the present work was to investigate the feasibility of combining EHD and FIR to assist drying of aloe vera. The experiments were performed at the electric voltages of 0, 5, 10 and 15 kV and at the controlled temperatures at the center of aloe vera pieces of 50 and 70 oC. It was found that the drying time decreased with an increase in the voltage at a fixed controlled temperature as a result of the increased intensity of the generated corona wind. As expected, the drying time decreased and the drying rate increased when the controlled temperature increased. In terms of the specific energy consumption, it was noted that the specific energy consumption decreased with an increase in the electric voltage. On the other hand, the specific energy consumption increased with an increase in the controlled temperature at aloe vera center.

INTRODUCTION

Aloe vera (*Aloe barbadenis* Mill.) is commonly used as herbal medicine in several countries. It has also been used as a food supplement. Aloe gel could be used for treatment of wounds, minor burns, skin irritations, ulcers, coughs, diabete, headaches, arthritis and immune-system deficiencies [1-2]. In addition the gel is familiar ingredient in a range of health care and cosmetic products such as suntan lotion, dry skin lotions, bubble baths and shampoos. However, aloe vera is perishable and deteriorates rapidly after harvesting, hence the need to apply a suitable post-harvest technology to prolong the shelf life of aloe vera. Most common techniques used to preserve aloe vera are hot air drying and spray drying. These drying techniques, however, cause much quality degradation, either in terms of the physical or nutritional quality.

Electrohydrodynamic(EHD) assisted drying has been successfully applied to enhance the drying rate in wheat [3], chopped onion [4], potato slab [5] and apple slice [6]. It should be noted that the enhancement of water evaporation by electric field was investigated by [7-9]. In addition to its ability to enhance the drying rate, EHD-assisted drying also requires low electric power as compared to the conventional drying techniques. The mechanism of EHD drying was occurred by the corona wind produced by applying a high voltage to an electrode. When the electrode has a high voltage, air around the electrode surface is ionized and moved toward to the opposite electrode with high velocities. The ions will collide with neutral gas molecules and the momentum exchange occurs among them. The results lead to the occurring of ion-drag flow known as corona wind. The corona discharge can take place at room temperature and atmospheric pressure hence the EHD drying can apply to low temperature drying which is suitable for thermal-sensitive materials expected to deteriorate by high temperature drying.

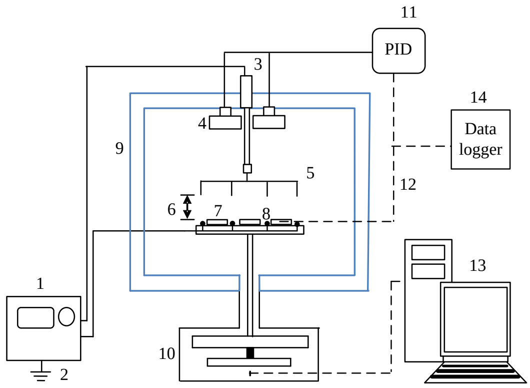
Far-infrared radiation (FIR) has also recently received much attention as an additional heat source to enhance the efficiency of a drying system. Radiation energy penetrates through the product and is converted into heat [10]. Therefore, the product is heated rapidly and uniformly without heating surrounding air. In addition, the energy consumption of FIR drying is lower compared with conventional drying. Infrared radiation has been applied to several drying processes because it can assist to increase drying efficiency and the dried product quality is also higher [11-12]. Many researchers have successfully applied FIR to assist drying process for agricultural products such as rice [13], potato [14] and banana [15-16].

The aim of the present work was to investigate the feasibility of combining EHD and FIR to assist drying of a food material; aloe vera was used as a test material as it is widely used either for medicinal or purpose or as an ingredients in cosmetics and food supplement. The drying rate and energy consumption of the process was examined.

MATERIALS AND METHODS

Experimental set up

A schematic diagram of the combined electrohydrodynamic and far-infrared (EHD-FIR) dryer is shown in Fig. 1. The dryer consist of a glass drying chamber with the dimension of 30 x 20 x 20 cm. Two FIR heaters are installed at the top of the drying chamber. It should be noted that a FIR heater (Infrapara, model A-2-200, Malaysia) generates power of 200 W. The distance between the FIR heater and a tray is fixed at 15 cm; the tray is made of Teflon and placed on a load cell. A high voltage power supply (LEYBOLD, 521721, Germany) was applied to 14 electrode pins made of copper. The pins are arranged in a staggering fashion; each pin has a diameter of 0.5 mm. The temperature at the center of an aloe vera piece (3×3×1 cm) was measured continuously via type K thermocouples, which were connected to a datalogger (Yokokawa, FX-100, Japan) with accuracy of ±0.2°C. The signals were multiplexed to a data acquisition card installed in a PC. A proportional-integral-differential (PID) controller (Shinko, JCS-33A-R/M, Japan) was used to control the FIR heater via the pre-determined temperature at the sample center. A load cell (Tedea-Huntleigh, 1022, Taiwan) with accuracy of ±0.2 g was used to measure weight loss of Aloe vera continuously during drying process.



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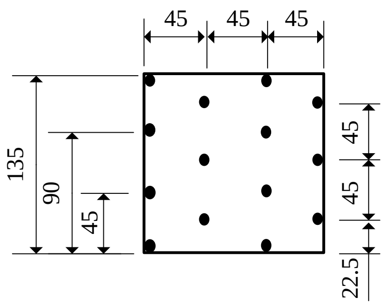

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Fig. 1 a) Schematic diagram of EHD-FIR drying system in side view; 1 high voltage power , 2 ground, 3 adjust probe, 4 far – infrared radiator, 5 anode electrode, 6 electrode gap, 7 samples, 8 cathode electrode 9 drying chamber, 10 load cell, 11 PID controller, 12 thermocouple, 13 computer, 14 data logger
b) Arrangement of the electrode pins in top view (unit in figure is millimeter)

Materials

Fresh Aloe vera (*Aloe barbadenis* Mill.) was obtained from a local market (Jatujak market). It was peeled and sliced by a slicing machine to the dimension of 3x3x1 cm. The initial moisture content [17] was in the range of 60-62 kg/kg (d.b.)

Methods

The sliced samples (approximately 9 pieces) were washed with fresh water (approximately 25°C) and placed on a Teflon tray. Experiments were performed at the controlled temperatures of 50 and 70 °C with various electric voltages (0-15 kV). The samples were dried until reaching the final moisture of 0.05 kg/kg (d.b.). In addition, temperature and weight loss of Aloe vera were detected continuously every 5 min interval. All experiments were carried out in duplicates and the mean values were reported.

Drying rate

The initial moisture content of fresh Aloe vera had variation hence moisture ratio was applied to express the drying characteristic of Aloe vera drying in this work. Drying rate was calculated from the suitable empirical equation fitted to the change of moisture content in experimental data and was differentiated with respect to time. The moisture ratio and drying rate are following

$$MR = \frac{X - X_e}{X_i - X_e} \tag{1}$$

$$R = -\frac{dX}{dt} \tag{2}$$

where MR is the moisture ratio, X is moisture content at any time (kg/kg (d.b.)), X_e is equilibrium moisture content of Aloe vera slice (kg/kg (d.b.)), X_i is initial moisture content of Aloe vera slice (kg/kg (d.b.)), R is drying rate (kg/ kg (d.b.) min) and t is time (min). In addition, the equilibrium moisture content was calculated from the desorption isotherm of fresh Aloe vera [18]

Evaluation of specific energy consumption

The energy consumption of EHD-FIR drying was measured by the Kilowatt-hour meter. It composed of the electric energy supplied to the FIR heater and a high voltage power supply. Specific energy consumption (SEC) was used to evaluate the energy efficiency utilized during drying process. The SEC is the energy required to remove 1 kg of water from the sample being dried. In this work, the SEC of EHD-FIR drying was calculated by

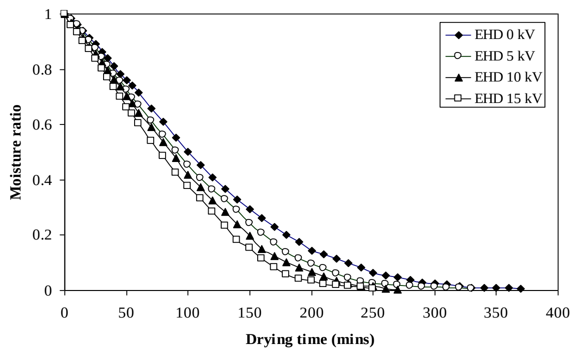
$$SEC_{EHD-FIR} = \frac{E_{EHD} + E_{FIR}}{m_{water}} \tag{3}$$

where $SEC_{EHD-FIR}$ is the specific energy consumption of EHD-FIR dryer (kWh/kg water), E_{EHD} is the measured electric energy consumption of a high voltage power supply (kWh), E_{FIR} is the measured electric consumption of the FIR heater (kWh) and m_{water} is the amount of water removed (kg) until the reaching the final moisture of 0.05 kg/kg (d.b.).

RESULTS AND DISCUSSION

Effect of electric field on drying kinetics

Drying curves of Aloe vera slice undergoing combined electrohydrodynamic and far-infrared drying are shown in Fig. 2. It was seen that the drying time decreased with an increase in electric field. At temperature of 50°C, the drying times for voltage of 0, 5, 10 and 15 kV were 370, 330, 270 and 250 min, respectively. In addition, the rate of moisture reduction increased with an increase in the electric field at the same drying temperature. This is due to the fact that corona wind was increased when the electric field increased. The corona wind occurred when the ionized airs around electrode pins were accelerated by an increase in electric field then the momentum was transferred from the ions to neutral air molecules in drying chamber. Consequently, the air moved toward to the opposite side of electrode pins with turbulence flow and struck on the Aloe vera slice. The magnitude of corona wind velocity is proportional to the electric field strength [3]. Since the velocity of corona wind increased, the mass transfer rate of Aloe vera slices also increased. The increasing of the mass transfer rate could be attributed to the corona wind induced by electrohydrodynamic as the main driving force [19].



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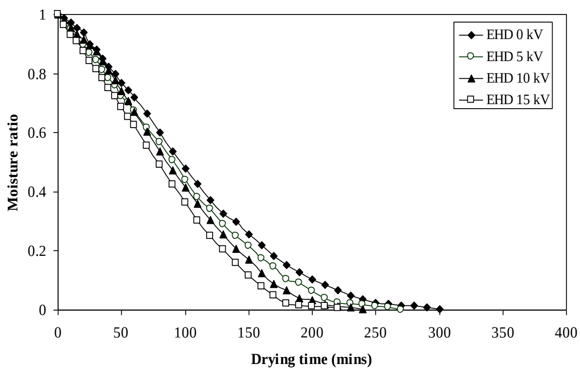
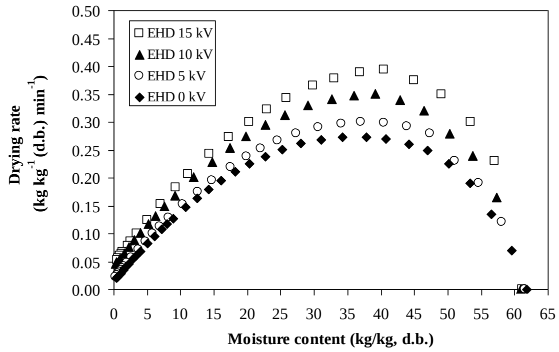


(b)

Fig. 2 Drying curves of aloe vera at temperature of a) 50^{o}C b) 70^{o}C

Fig. 3 shows the plots of drying rate versus the moisture content of Aloe vera slices at various electric fields. It was found that the drying rates increased with an increase in electric field at the same temperature. In Fig. 3, the drying rates increased rapidly during the initial stage of drying (warm-up period). This is because thermal energy of far-infrared radiation was more absorbed by aloe vera slices which had high moisture content. The radiation absorptivity of food products increased with an increase in moisture content [20]. After the initial stage of drying, the constant drying rate period occurred. It can be seen from this figure that the constant drying rate period was short. The falling rate period occurred after constant drying period. In this period the drying rate was steady decreased continuously.



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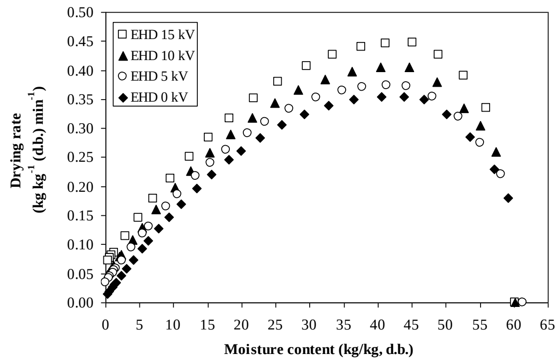

(b)

Fig. 3 Drying rate of aloe vera and moisture content at temperature of a) 50^{o}C b) 70^{o}C

Effect of temperature on EHD-FIR drying

As expected, the drying time increased with an increase in temperature of an aloe vera slices as shown in Fig. 2. However, it was found that the constant drying rate period at the temperature of 70^{o}C was shorter than that one at 50^{o}C. This is due to evaporated water from aloe vera slice at the temperature of 70^{o}C was higher than that at 50^{o}C leading to the shorter constant drying rate period. The temperature evolution at the center of an aloe vera slices is shown in Fig. 4. In case of controlled temperature at the center of an aloe vera slices of 50^{o}C (See Fig. 4a), it was seen that the temperature increased rapidly to the pre-determined temperature at electric field of 0 kV. This is due to the fact that thermal energy from the far-infrared radiation was more absorbed by high moisture content in product [21]. When the electric field increased, time reaching pre-determined temperature also increased. It is seen that the temperature at the same drying time before reaching the pre-determined temperature decreased with an increase in electric field. Since, the increasing of corona wind with an increase in electric field led to an increase in the evaporated water [3]. As water evaporated it removed heat from Aloe vera slices in form of heat of vaporization therefore the temperature was dropped. In case of controlled temperature at the center of an aloe vera slices of 70^{o}C , it was found that the temperature evolution was in the same trend as at temperature of 50^{o}C.

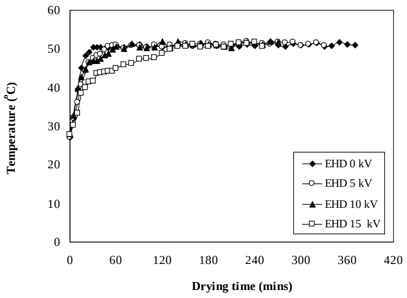

Fig. 4 Temperature evolution at the center of an aloe vera slices at various voltages for 50°C

Energy consumption

Table1 shows energy consumption and specific energy consumption of EHD-FIR drying. It was found that the energy consumption of FIR decreased with an increase in electric field because of the shorter drying time with increasing of electric field. In case of specific energy consumption it was seen that the specific energy consumption decreased with an increase in electric field. As expected, the energy consumption and specific energy consumption were higher when the drying temperature increased.

Table1 Specific energy consumption for Aloe vera drying using combined FIR and EHD

Drying Temp (°C)	Voltage (kV)	Drying time (min)	Energy consumption (MJ)		SEC (MJ/kg water)
			E_{FIR}	E_{EHD}	
50	0	370	4.440	0.000	442.709
	5	330	3.960	0.028	362.497
	10	270	3.935	0.027	292.831
	15	250	3.851	0.029	264.332
70	0	300	6.426	0.000	529.936
	5	270	5.796	0.023	427.417
	10	240	5.142	0.024	345.222
	15	220	4.712	0.026	290.893

CONCLUSION

A combined electrohydrodynamic and far-infrared drying aloe vera slice was investigated in the present work. Based on the experimental results, it was found that the drying rate increased with an increase in electric field. As expected, the drying rate also increased with an increase in the temperature at center of an aloe vera slice. The evolution temperature of an aloe vera slices at the same drying time before reaching the pre-determined temperature decreased with an increase in electric field. In case of specific energy consumption, it was seen that the specific energy consumption decreased with an increase in electric field.

ACKNOWLEDGEMENTS

The authors express their sincere to the National Science and Technology Development Agency of Thailand (NSTDA) for supporting this work financially.

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