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Estimation of the Moisture Diffusivity and Activation Energy in Thin Layer Drying of Ginger Slices

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***Abstract*—**In the present work, the effective moisture diffusivity and activation energy were calculated using an infinite series solution of Fick's diffusion equation. The results showed that increasing drying temperature accelerated the drying process. All drying experiments had only falling rate period. The average effective moisture diffusivity values varied from 2.807×10^{-10} to $6.977 \times 10^{-10} m^2 s^{-1}$ over the temperature and velocity range. The temperature dependence of the effective moisture diffusivity for the thin layer drying of the ginger slices was satisfactorily described by an Arrhenius-type relationship with activation energy values of 19.313-22.722 $kJ.mol^{-1}$ within 40–70 °C and 0.8-3 ms^{-1} temperature range.

***Keywords*—**Ginger, Drying, Activation energy, Moisture diffusivity.

I. Introduction

During the drying process of agricultural food products, moisture diffusivity is the most crucial transport property for the calculation of moisture transfer inside the product. The knowledge of that factor is necessary not only to describe the drying kinetics and interpret experimental observations but also for simulation of the process [1]. Some researchers have studied the moisture diffusion and activation energy in the thin layer drying of various agricultural products [2-5]. Although much information has been given on the effective moisture diffusivity and activation energy for various agricultural products, very little published literature is available on the effective moisture diffusivity and activation energy data forginger during drying [6, 7]. The knowledge of effective moisture diffusivity and activation energy is necessary for designing and modelling the mass transfer processes such as dehydration or moisture adsorption during storage.

The subject of this study is to determine the moisture diffusion coefficient and the activation energy during convective drying of ginger slices. The method is based on the analytical solution of the differential equation given by [8]. The effect of air temperature and air velocity on the moisture diffusion coefficient and the activation energy is investigated.

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II. Material

Fig. 1 illustrates the schematic diagram of the cyclone type dryer, developed for experimental work by [9]. The system was introduced in the literature [3]. Briefly, it consists of fan, resistance and heating control systems, air-duct, drying chamber in cyclone type, and measurement instruments.

Fresh ginger slices were used in the experiments. Before the drying process, the gingers were cut into slices of 4 mm thickness and 30 mm in diameter with a mechanical cutter. After the dryer had reached steady state temperature conditions for operation, 150 g ginger slices are put on the tray of dryer and dried there. The initial and final moisture contents of the ginger slices were determined at 80 °C using an infrared moisture analyser (Mettler LJ16, Greifensee, Switzerland).

Drying experiments were carried out at 40, 50, 60, and 70°C drying air temperatures and 0.8, 1.5 and 3 ms^{-1} air velocities. Drying was continued until the final moisture content of the samples reached approximately 0.06 g water/g dry matter. During the experiments, ambient temperature and relative humidity, and the inlet and outlet temperatures of the drying air in the dryer chamber were recorded.

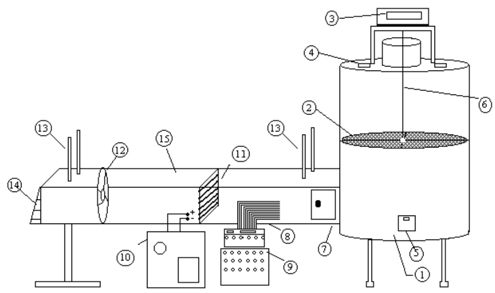

Fig. 1 Experimental set-up (1- drying chamber, 2- tray, 3- digital balance, 4- observation windows, 5- digital thermometer, 6-the balance suspension bar, 7- control panel, 8- thermocouples, 9- digital thermometer and channel selector, 10-rheostat, 11- heater, 12- fan, 13- wet and dry thermometers, 14- adjustable flap, 15- duct)

III. Method

The moisture ratio (*MR*) of the ginger slices during the thin layer drying experiments was calculated using the following equation:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (1)$$

where M_t, M_o and M_e are the anytime, the initial and equilibrium moisture contents (% dry basis) respectively [2-3].

Fick's second law of diffusion equation, symbolized as a mass-diffusion equation for drying of agricultural products drying in a falling rate period, is shown in the following equation:

$$\frac{\partial M}{\partial t} = D_{eff} \nabla^2 M \quad (2)$$

The analytical solutions of Fick's second law (Eq. (2)) for infinite slab can be given as Eq. (3) with the assumption that neglecting shrinkage, constant temperature and diffusion coefficients and uniform initial moisture distribution [8].

$$MR = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left(-\frac{(2n+1)^2 \pi^2 D_{eff}\, t}{4L^2} \right) \quad (3)$$

where, D_{eff} is the effective moisture diffusivity in $m^2.s^{-1}$, t is the time (*h*), *n* is a positive integer, *L* and *r* are the half-thickness and radius of samples (m), respectively. For long drying periods, the Eq. (3) can be further simplified to only the first term of the series. Eq. (4) is written in a logarithmic form as follows [10]:

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad (4)$$

The effective moisture diffusivity was calculated from a slope of a straight line by plotting data in terms of *ln*(*MR*) versus drying time, which gives a straight line with a slope of (*K*), in which:

$$K = \frac{\pi^2 D_{eff}}{4L^2} \quad (5)$$

The dependence of the effective diffusivity on temperature is generally described by the Arrhenius equation [11, 12]:

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{R(T + 273.15)} \right) \quad (6)$$

Here D_0 is the pre-exponential factor of Arrhenius equation in $m^2.s^{-1}$, E_a is the activation energy in $kJ.mol^{-1}$, *R* is the universal gas constant in $kJ.mol^{-1}\ K^{-1}$, and *T* is temperature in °C.

IV. Results and Discussions

Ginger slices 4.8 g water/g dry matter (average initial moisture content) were dried to 0.06 g water/g dry matter in the cyclone dryer. The final moisture contents represent moisture equilibrium between the sample and drying air under dryer conditions, beyond which any changes in the mass of sample could not occur. In order to normalize the drying curves, the data involving dry basis moisture content versus time were transformed to a dimensionless parameter called as moisture ratio versus time (Fig. 2).

The effective moisture diffusivity was calculated by Eq. (6), using slopes derived from the linear regression of ln $[(\pi^2/8) \cdot MR]$ versus time data shown Fig. 3. It is noticed that the drying curves have a concave form when the curves of $\ln[(\pi^2/8) \cdot MR]$- time are analyzed [3]. The determined values of the effective moisture diffusivity values of ginger slices were found to range between $2.807\text{x}10^{-10}$-$6.977\text{x}10^{-10} m^2\ s^{-1}$. The moisture diffusivity was affected by air temperature and air velocity. The effective moisture diffusivity values are increased with increasing of air temperature and velocity, which is in accordance with the previous studies [6-7]. The effective moisture diffusivities are reported to vary in the range of 5.009×10^{-11} to $1.735\times10^{-10}\ m^2s^{-1}$ and 6.101×10^{-11} to $1.944\times10^{-10}\ m^2s^{-1}$ for the drying of ginger slices in the temperature range of 40–60 °C at the tray drying and heat pump dehumidified drying [6], respectively.

The average values of effective diffusivities of ginger slices in the thin-layer vacuum drying drying process at 40–65 °C were found in the range of 1.86 to $4.78\times10{-}8\ m^2.s^{-1}$ by [7].

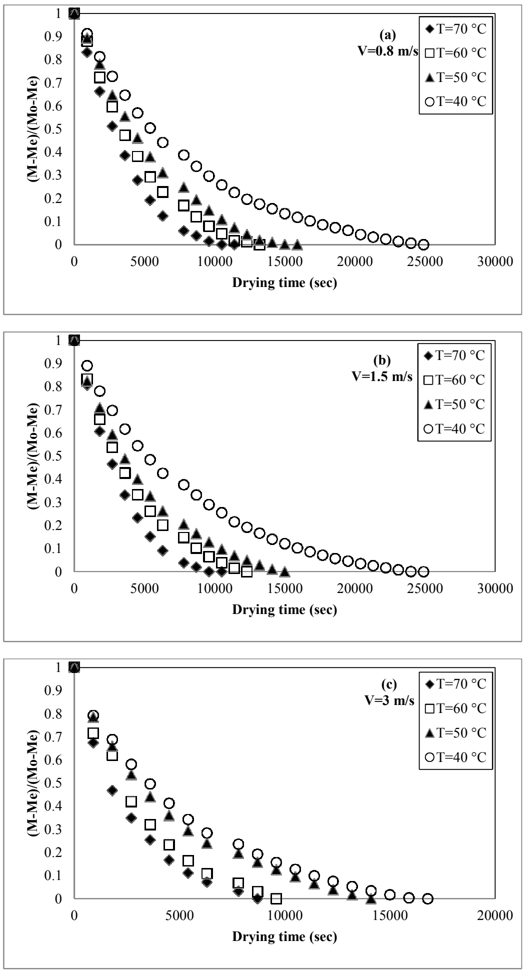

Fig. 2 Variation of moisture ratio *(MR)* with drying time at different air temperatures *(T)* and velocities *(V)*

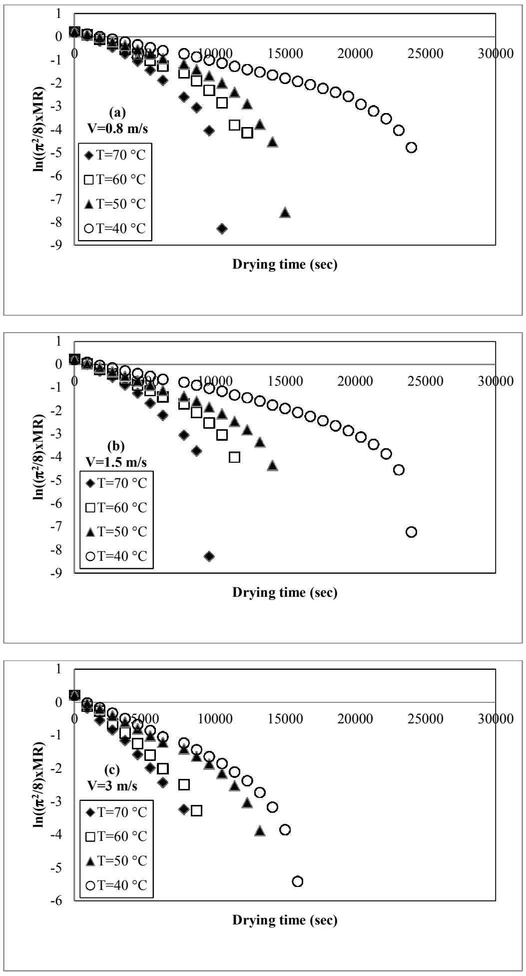

Fig. 3 Variation of *ln(MR)* with drying time at different air temperatures (T) and velocities (V*)*

The activation energy was calculated by plotting ln *Deff* versus the reciprocal of the temperature (1/(*T* + 273.15)), and presented in Fig. 4. Equation (6) shows the effect of temperature on D_{eff} .The activation energy values were found to be 19.313, 20.153 and 22.722 kJ.mol^{-1} for air velocity of 3 m.s^{-1}, 1.5 m.s^{-1} and 0.8 m.s^{-1}, respectively. Activation energy was claimed to be 35.675 kJ.mol^{-1} for drying of ginger slices by [7].

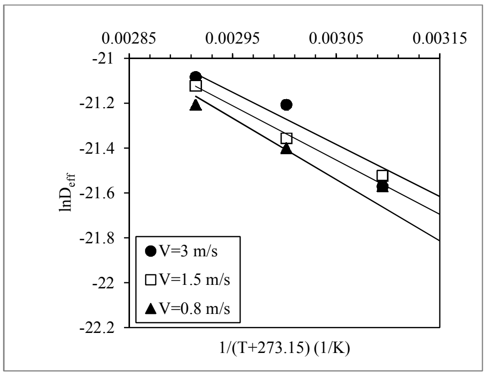

Fig. 4 Arrhenius-type relationship between effective moisture diffusivity and reciprocal absolute temperature

V. Conclusions

The effective moisture diffusivities were determined to be between 2.807x10^{-10} and 6.977x10^{-10}m^2 s^{-1} for ginger slices in the temperature range of 40–70 ◦C. The activation energies for samples were varied to be 19.313-22.722 kJ.mol^{-1}. Moisture diffusivity increased as air temperature and velocity increased. It was found out that; the temperature is the major effect on the drying process, and, air velocity has less important effect on the drying of ginger slices.

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