ACTIVATION ENERGY KINETICS IN THIN-LAYER DRYING OF ONION

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ABSTRACT

The goal of this work was to look at the drying kinetics of onions (Allium cepa L.) and calculate the effective moisture diffusivity and diffusion activation energy. The test was carried out in a constant temperature and humidity test chamber at various temperatures with a relative humidity of 15%. At air temperatures of 45 °C, 50 °C, and 55 °C, the drying time required to reduce the moisture content of onion from 81 percent (wb) to 8 percent (wb) was 23, 19, and 17 hours, respectively. The Henderson-Pabis drying model was used to fit the experimental results in order to determine the diffusion activation energy (Ea) of onion. Ea was computed as 23.03 kJ/mol. When the drying air temperature was increased from 45 °C to 55 °C, the effective diffusivity of the onion increased from 1.85 109 m/s to 2.42 109 m2/s.

Keywords: solar energy, drying kinetics, thin layer drying, drying curve.

1. INTRODUCTION

Since ancient times, Malaysia has been known for its rich produce. Spice trading is among Malaysia's economic sources. Many merchants from around the world visit Malaysia to obtain this quality and important agricultural produce. Spices are widely used in cooking to add tartness and ease to the food. Most of these herbs possess distinct, fresh, and scattering aromas and flavours, thereby making them necessary ingredients in a variety of dishes. In addition to their use in cooking, herbs also exhibit many useful properties for body and beauty care. In the Malay community, onion, turmeric, and lemongrass are common necessities in the kitchen. Onion, a main ingredient in each cuisine, shows high efficacy. Onions not only add to the food content, but they are also highly nutritious. Onion is sensitive to ambient conditions or local climate. If not properly guarded, then the onion will rapidly rot, be easily infected with the disease, and quickly wither. Given these problems, the producer becomes less qualified to reach the sale level.

In the food industry, drying is a food preservation precaution that can provide advantages in terms of space, storage period, transportation, product weight, and quality maintenance. Traditionally, crowded users, especially farmers, use direct drying methods or drying under the sun to prevent damage and rotting of harvest. Plants for drying are placed in an open area and left under the sun for direct exposure. Agricultural products that are often dried include rice and tea leaves. However, open drying presents several disadvantages, such as insect and rodent attacks and hygienic factors. The success of drying also depends on several factors, such as weather, hotness, humidity, and wind. These factors can affect the quality and quantity of the dried product. The drying process involves the dehydration of dried material. In this process, water is removed from a substance where physical and mass transfer changes occur. Mass transfer is the change in water particles in a material. Drying is accomplished when the dried material loses part or all of its water content. The main process during drying is evaporation, which occurs when water becomes a volatile material, i.e. when heat conditions are applied to the substance. Drying can also occur through other means by breaking the bonds of water molecules in the material. When the water molecule bonds consisting of elemental oxygen and hydrogen are solved, the molecule is released from the material. Consequently, the material loses its water [1-7].

Ten drying models are commonly used in analysing material drying kinetics. The Page, Newton, modified Page, logarithmic, Henderson, and Pabis, two terms, diffusion approach, modified Henderson and Pabis, Midilli et al., and offset modified Page models are among these models. The Newton, Page and Henderson, and Pabis models were used in this investigation [8-12]. The experimental data were also used to evaluate the activation energy and moisture diffusivity of onion thin-layer drying kinetics using the Henderson and Pabis drying model (Allium cepa L.).

2. METHODOLOGY

Onion is dried using the constant temperature and humidity test chamber (CTHTC), as shown in Figure-1. The temperature and relative humidity of the air is determined during the drying process based on the appropriateness of the item to be dried. This CTHTC is located in the Physics Department, Faculty of Science and Technology, Universiti Kebangsaan Malaysia (UKM). The temperature and humidity allowed in these dryers range from - 40 °C to 180 °C and from 10% to 98%, respectively. The airspeed is kept constant at 1 m/s. This CTHTC can hold approximately 1000 g, depending on the type of material.

Onion is peeled, cleaned, and sliced with a thickness of ± 1.0 cm. Cultivation aims to obtain a uniform test material and expand the surface to facilitate and hasten to dry. Afterward, the onion slices are weighed using an electronic balance. The onion hoist required for each test is within ± 100 g. Subsequently, the onion slice is placed into an aluminium foil slip inside the CTHTC where the relative temperature and humidity of the air are established. Following the removal study, the ideal water level in onions is in the range of 8%-12%. Therefore, the onion must be dried to obtain a water content of 8%–12% or below 14% [13]. The maximum allowable temperature for onions is 55 °C, and the drying time is in the range of 24–48 h. The onions are dried from the initial moisture content of 80%-85% until the moisture content of 6%-10% [14].

The drying temperature and the relative humidity of the air in the material are the two key elements in the drying process. The temperatures in this test were 50°C and 55°C, with relative air humidities of 10%, 15%, and 30%, respectively. The drying process runs at 10:00 am until the sample reaches complete drying.

The dryer phase started with a 45°C drying temperature and a humidity level of 15%. Afterward, the test is continued at 50 °C and 55 °C. Prior to the drying process, the dryer is heated in advance for at least 15 min before the operation to obtain single heating. Data reads are noted on the computer screen adjacent to the CTHTC. Data are recorded every 5 min and stored orderly in the Microsoft Office Access Database program.

Figure-1. Test chamber with constant temperature and humidity (Model DY110, Angelantoni Asean Pte Ltd., Singapore).

The moisture content of the onions (X) can be obtained through dry or wet basis. The moisture content dry basis is given by the following equation [15, 16]:

$$X = \frac{w(t) - d}{d} \tag{1}$$

The moisture content wet basis is as follows:

$$X = \frac{w(t) - d}{w} \times 100\% , \tag{2}$$

where d is the mass of dry onions, and w(t) is the mass of wet onions at instant t. Fick's diffusion equation for the infinite slab is used to calculate the effective moisture diffusivity as follows:

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

Where Deff represents the effective moisture diffusivity (m2/s) and L represents the half thickness (m). The equilibrium moisture content, starting moisture content, and moisture content at time t are represented by Xe, Xt, and Xi respectively, which are all expressed on a dry basis (db). In this case, onions with slab geometry are considered. For particles with slab geometry and long drying times [17], the following equation is used:

$$\frac{X_t - X_e}{X_i - X_e} = MR = \frac{8}{\pi^2} \exp\left(- D_{eff} \frac{\pi^2 t}{4L^2} \right), \tag{4}$$

MR stands for moisture ratio. Eq. (4) can be rewritten in the following:

$$MR = A \exp(-kt) \tag{5}$$

Where

$$k = \frac{\pi^2 D_{eff}}{4L^2} \ . \tag{6}$$

Effective diffusivity (D_{eff}) can be related to the temperature by the Arrhenius equation as follows:

$$D_{eff} = D_0 \exp\left(- \frac{E_a}{RT} \right) \cdot \tag{7}$$

When both sides of Eq. (7) are logarithmized, the following equation is obtained:

$$\ln(D_{eff}) = \ln(D_0) - \left(\frac{E_a}{R} \right) \left(\frac{1}{T} \right) \cdot \tag{8}$$

Eq. (8) is a linear equation in which Ea and D0 are found by plotting ln (Deff) versus 1/T. T is the absolute temperature (K), R is the universal gas constant (8.314 103 kJ/mol K), Ea is the activation energy (kJ/mol), and D0 is the constant comparison to diffusivity at an infinitely high temperature (m2/s) in Eq. 8. [18].

3. RESULT AND DISCUSSIONS

At a relative humidity of 15% and different temperatures, Figures 2 and 3 illustrate a decrease in moisture content in dry and wet bases with drying time. When drying times are long, the moisture content is quickly depleted. In addition, at low drying temperatures, drying time is prolonged. In Figure-4, onion drying takes 22 hours and 45 minutes at a humidity level of 15% and a temp of 45 °C to reduce the moisture content from 80.0 % to 8.3 %. The process is repeated using the heat gain of 50 °C and 55 °C. At 50 °C, the process requires 19 h to reduce the moisture content from 80.8% to 9.1%. At 55 °C, the process takes 17 h to reduce the moisture content from 81.5% to 5.6%.

When both sides of Eq. (5) are logarithmized, the formula can be linearized as follows:

$$\ln MR = \ln A - kt . \tag{9}$$

The activation energy is calculated using the ln (Deff) and 1/T graphs (Figure-5). In the temperature range studied, the plot shows a solid line, indicating Arrhenius's dependence. The diffusivity constant (D0) and activation energy (Ea) are 0.0113 m2/s and 23.03 kJ/mol, respectively, according to the slope of the straight line provided by the Arrhenius equation.

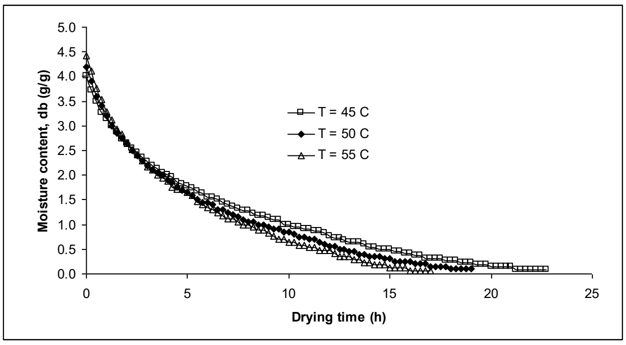

Figure-2. Change in moisture levels on a dry basis as a function of drying rate at a relative humidity of 15%.

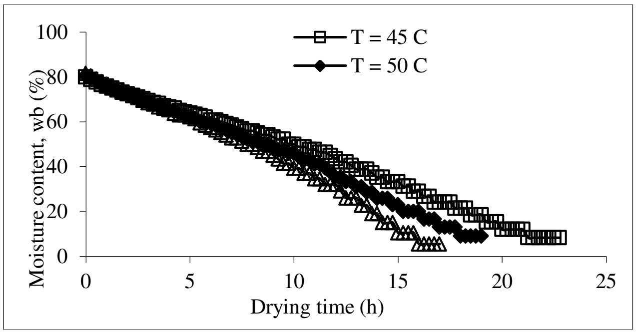

Figure-3. Change in moisture levels on a wet basis as a function of drying time at a relative humidity of 15%.

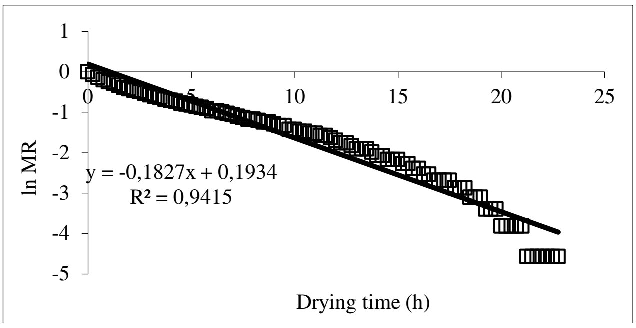

Figure-4. ln MR versus. drying time at 45 °C, Henderson and Pabis drying model.

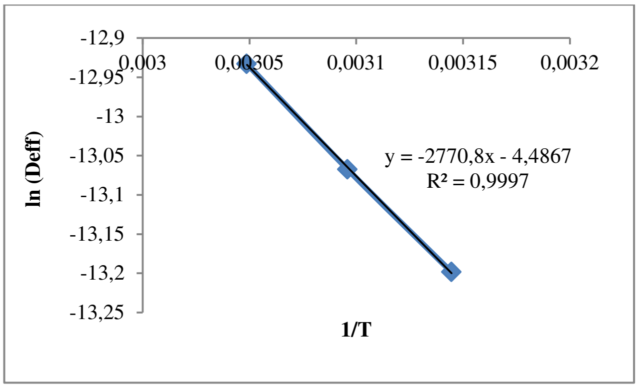

Figure-5. Plot of effective moisture diffusivity vs. 1/T.

4. CONCLUSIONS

Onion drying was performed using CTHTC. The drying experiments were carried out at varied temperatures of 45 °C, 50 °C, and 55 °C with a relative humidity of 15%. Onion drying kinetics were also discussed. Experimental results showed that approximately 23 h is required to minimize the organic content information from 80.0% to 8.3% at 45 °C with a relative air humidity of 15%. Furthermore, 19 and 17 h are required to achieve the final moisture contents of 9.1% and 5.6% at the same relative humidities but with air temperatures of 50 °C and 55 °C, respectively. A nonlinear regression method was used to calculate the activation energy of the thin-layer drying of onion. Constants were determined by the graphical method. When the drying air temperature of a thin-layer drier is increased, the effective moisture diffusivity of the onion increases. Diffusion's activation energy (Ea) is 23.03 kJ/mol.

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