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Thin-layer Drying Kinetics of Robusta Coffee

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Abstract

This paper was aimed to study the drying kinetics of coffee and to investigate the thin-layer drying kinetics of coffee by using a convective air dryer. The coffee was dried for the temperatures of 40, 50 and 60 ^{0}C *with relative humidity in the range of 14-25% the airflow rate fixed at 1 m/s. According to the experiment result, the drying rate curve showed that drying process took place only in the falling rate period. Seven thin layer drying models (Newton, Page, Henderson and Pabis, Logarithmic, Wang and Singh, Two terms, Modified Henderson and Pabis) were fitted to the experimental moisture content data. The Two-trem model was found to be a better model for describing the characteristics of coffee for the temperatures of 40, 50 and 60* ^{0}C*. The effective moisture diffusivity of coffee increased when the drying temperature increased. The value was in the range of* 4.5028×10^{-11} *to* 6.4803×10^{-11} m^2/s*.*

Keywords*: Coffee, Diffusivity, Drying, Model*

NOMENCLATURE

D_{eff}	effective diffusivity [m^2/s]
MR	dimensionless moisture content ratio
M_0	initial moisture content [%, db]
M	moisture content at given time [%, db]
M_e	equilibrium moisture content [%, db]
$MR_{exp,i}$	ratio of the moisture derived from the experiment
$MR_{pre,i}$	moisture derived from the prediction
N	number of observations
R^2	coefficient of determination
RMSE	root mean square error [%]
r_0	the radius of cherry coffee [m]

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1. INTRODUCTION

Drying is an important process which has been used for a long time in food preservation. The purpose of drying is to make osmotic water and free water evaporates from the product because these kinds of water are water which are useful for fungi and bacteria moreover, drying make the product lighter. The product needs less area for storage. It has a longer shelf-life. And it is convenient for transportation.

Coffee is one of the most popular drinking beverages in the world. The caffeine in the coffee will stimulate the sympathetic nervous system to make humans awake and recover from fatigue. Like grapes, the coffee has anti-free radical substances. However, there are more antioxidant in coffees than in blueberries. Furthermore, magnesium in the coffee makes the body cells sensitive to insulin, preventing us against diabetes. Coffee is a natural product which is traded in the second rank of the world, second to petroleum. The output of coffee and coffee seeds must undergo many processes before they become green coffee seeds. One important process for this is drying. The objectives in this study were to study the results of drying temperature affecting the characteristics of coffee, to find out the suitable model to describe the drying process and to determine the effective moisture diffusivity which took place during the drying process of the coffee.

Many studies have been reported on thin-layer drying of agricultural products and food materials [1-3].

2. MATERIALS AND METHODS

2.1Drying Experimental

The coffee used in this experiment was Robusta coffee grown in Chumphon province. The average diameter of the coffee was 8.63 mm. The initial moisture content was determined through oven drying method. In thin layer drying models, the test followed the over flow designed by drying at the following temperatures: 40, 50 and 60 ^{0}C respectively. The wind speed remained stable at 1 m/s. A schematic diagram of this laboratory dryer is shown in Fig. 1. The laboratory dryer consists of a ceramic packed bed for producing saturated air at a given temperature, an electrical heater, a blower, a drying section, measurement sensors and a data recording and controlling system with a personal computer. In this laboratory dryer, the blower forces ambient air through a humid ceramic packed bed. The air absorbs moisture while it passes through the packed bed. At the top of the packed bed, this air leaves in a humidified condition. Then, this saturated air is heated by the air heater and passed across the product placed in the tray. Users can choose the through-flow drying mode of over-flow drying mode by closing or opening the air valves to control the flow direction. The relative humidity and temperature of the drying air are controlled by adjusting the power supply to the air heater and the water heater using a psychometric chart as a guideline. After setting the condition for the drying equipment entered steady state under the conditions of the experiment, 100 g of cherry coffee was arranged in uniformly spread on a rectangular plate in single layer. The test was done based on the specified scope. The volume of the water which moved outside the product during the drying process was recorded at each interval of 2 hours by electronic balance of 0.01g accuracy. The drying process continued until there was no large variation in the moisture loss.

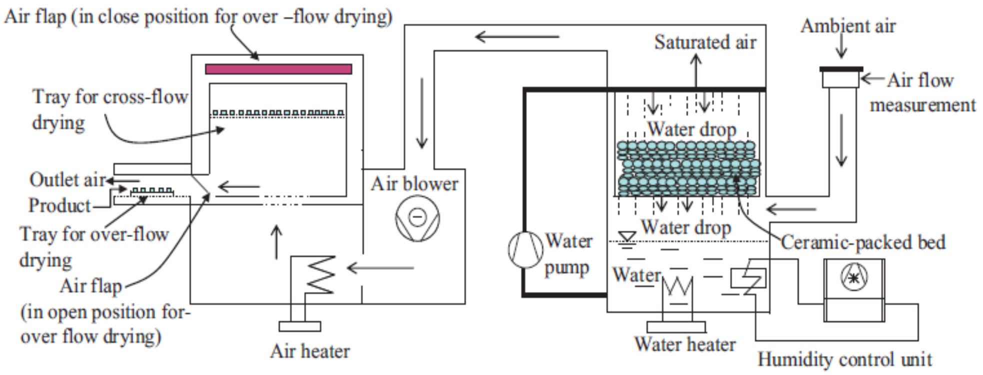

Figure 1. Schematic diagram of the laboratory dryer.

2.2Mathematical modelling

The moisture ratio (MR) of coffee during the drying process could be determined through the following equation

$$MR = (M-M_e) / (M_o-M_e) \tag{1}$$

Where M_o, M, and M_e are the initial moisture content, the moisture content at given time and equilibrium moisture content, respectively.

In choosing thin layer drying models, the suitable models needed to be chosen for describing the drying process of the coffee. There were eight models fit the experiment data as shown in Table 1. In choosing the model, there are the values to be considered coefficient of determination (R^2) and root mean square error (RMSE). A good model must have higher R^2 and the lowest RMSE [4]. The equation is given below.

$$R^2 = 1 - \frac{\text{Residual sum of squares}}{\text{Corrected total sum of squares}} \tag{2}$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i})^2 \right]^{1/2} \tag{3}$$

where $MR_{exp,i}$ and $MR_{pre,i}$ are the ratio of the moisture derived from the experiment and the moisture derived from the prediction. N was the number of observations.

Table 1. Mathematical models applied to drying curves of coffee

Model	Mathematical expression
Newton	$MR = \exp(-kt)$
Page	$MR = \exp(-kt^d)$
Handerson and Pabis	$MR = a\exp(-kt)$
Logarithmic	$MR = a\exp(-kt) + c$
Wang and Singh	$MR = 1 + at + bt^2$
Two-term	$MR = a\exp(-kt) + b\exp(-gt)$
Modified Henderson and Pabis	$MR = a\exp(-kt) + b\exp(-gt) + c\exp(-pt)$

2.3Moisture diffusivity of cherry coffee

Fick's law of diffusion incorporated with drying experiments has been widely used to determined moisture diffusivities of various fruits and other biological materials [5]. Fick's second law of unsteady state diffusion, neglecting the effects of temperature and total pressure gradient, can be used to describe the drying behavior of fruits [6].

$$\frac{\partial M}{\partial t} = Div(D\ grad\ M) \tag{4}$$

where M is moisture content on a dry basis (%,db), D is moisture diffusivity and t is time.

To solve Eq. (4) for sphere of drying material, it is assumed that the diffusivity of the material is independent of the position in that material. For the case of the component of cherry coffee fruit, this assumption is valid because the material of each component is relatively homogeneous. The analytical solutions of Eq. (4) for sphere can be written as;

$$\frac{M - M_e}{M_0 - M_e} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-n^2\pi^2\frac{D_{eff}\,t}{r_0^2}\right) \tag{5}$$

Where D_{eff} was effective diffusivity (m^2/s), r_0 was radius of cherry coffee (m) and n is positive integer. Thin layer drying models of sphere for cherry coffee were fitted to experimental data of thin layer drying of the components of the cherry coffee fruit. The suitability of the models was determined by using standard error of estimate and coefficient of determination. Eq. (5) was fitted to the experimental data of cherry coffee which were sphere in shape. Only the first term (n=1) of these equations was significant and used. Moisture diffusivity of each of the components of the cherry coffee fruit was determined by minimizing the sum of square of deviations between the experimental and predicted values for thin layer drying of the components under controlled conditions of air temperature and relative humidity.

3. RESULTS AND DISCUSSION

3.1Drying characteristics of cherry coffee

The time required for coffee drying from initial average moisture content 170.878%(db) to levels with the least change of moisture content were 56, 44, and 36 hours at the drying temperature of 40, 50, and 60 ^{0}C respectively. The temperature of the drying air was important for the drying at high temperature, resulting quick removal of moisture and reduced time for drying . The decrease in the time used for drying when the temperature was high due to the fact that high drying temperature increases the kinetic energy of the water molecule until it could break free the cohesive force. The water in the product evaporates in the air more than when the drying temperature is low. The ratio of the drying which took place was falling rate period as shown in Figure 2. The moisture content of cherry coffee reduced exponentially when there was more time for drying.

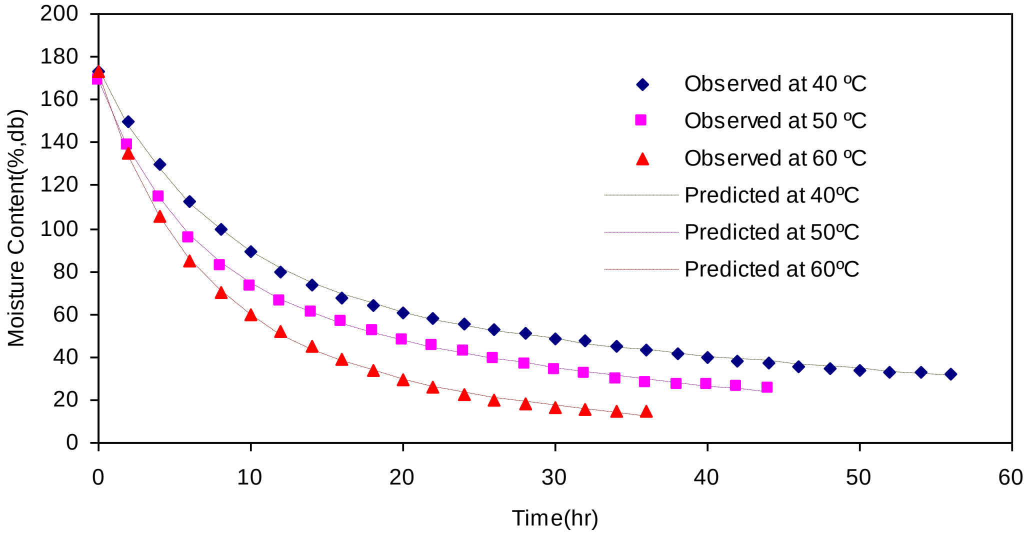

Figure 2. The results from the experiment and the prediction of moisture Content by Two term model.

3.2Mathematical modeling of drying curves

Seven thin layer drying models (Newton, Page, Henderson and Pabis, Logarithmic, Wang and Singh, Two terms, Modified Henderson and Pabis) were used to describe the drying process during the drying cherry coffee. It was found that the suitable model which had high coefficient of determination (R^2) and low root mean square error (RMSE) at the drying temperatures of 40, 50 ^{0}C and 60 ^{0}C was two terms are 0.98 and 1.08%, 0.99 and 1.31% and 0.99 and1.30%, respectively.

3.3Calculation of effective diffusivity

According to the experiment results, it was found that the drying was in the type of falling rate drying period. This could be analyzed through Fick's second law of the unsteady state diffusion for sphere in shape. The assumption was as follows: negligible shrinkage during drying, constant moisture diffusivity and temperature. From Eq. (5). The value of effective diffusivity of cherry coffee could be determined by minimizing the sum of square of derivations between the experimental and predicted value for thin-layer drying. It could be found that the value changed according to the drying temperature. It increased when the drying temperature increased. The value was in the range between 4.5028×10^{-11} to 6.4803×10^{-11} m^2/s as shown in Table 2

Table 2. Moisture diffusivity of the cherry coffee

Temperature ($^{\circ}C$)	Diffusivity (m^2/s)
40	4.5028×10^{-11}
50	5.4737×10^{-11}
60	6.4803×10^{-11}

4. CONCLUSION

According to the study of drying kinetics of coffee in laboratory dryer at the drying temperatures of 40, 50, and 60 ^{0}C and the wind speed fixed at 1 m/s, it was found that all the drying processes which took place were in the type of falling rate period only. There was no constant rate period. The period reduced when the drying temperature increased. Seven thin layer drying models were used to determine the suitability to describe the drying process during drying of coffee. It was found that the model with high coefficient of determination (R^2) and low root mean square error (RMSE) at the drying temperatures of 40, 50 and 60 ^{0}C was two term model. The effective diffusivity which was determined through the calculation was high in accordance with the increase of the temperature which ranged from 4.5028×10^{-11} to6.4803×10^{-11} m^2/s.

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