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EXPERIMENTAL AND NUMERICAL STUDY OF CONDUCTIVE DRYING KINETICS OF MINT LEAVES

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ABSTRACT

This paper deals with drying kinetics of mint leaves in an incubator. Experimental data for drying of mint was obtained at four temperatures and two flow rate. A one-dimensional numerical model was developed to estimate the moisture content of the mint leaves mint. In order to validate the model, the experiments were carried out at 35 ºC, 45°C and 55ºC so as to determine the coefficient of diffusion of the mint leaves for three temperatures.

***Keywords*:** Conductive Drying, mint leaves; Modelling; coefficient of diffusion

INTRODUCTION

Mint was originally used as a medicinal herb to treat stomach ache and chest pains. During the middle ages, powdered mint leaves were used to whiten teeth. Mint tea is a strong diuretic. Mint also aids digestion. In order to preserve this seasonal plant, and make it available to consumers during the whole year, it undergoes specific technological treatments, such as drying [1, 2, 3]. Drying provides a very useful preservation. Generally, a part of the mint may be tied in small bundles and hung up, or the leaves and flowering tops spread on a screen and dried in the shade. Drying is one of the oldest methods of food preservation, and it represents a very important aspect of food processing. The main aim of drying products is to allow longer periods of storage, minimise packaging requirements and reduce shipping weights [4]. Solar drying is the most common method used to preserve agricultural products in the world and also Morocco. However, it has some problems related to the contamination with dust, soil, sand particles and insects, and being weather dependent. Also, the required drying time can be quite long. Therefore, the drying process should be undertaken in closed equipments to improve the quality of the final product [5]

The aim of this work was to develop a one-dimensional numerical model to estimate the moisture content of the leaf of mint undergoing drying as function of time, the average moisture content and the effective moisture coefficient of diffusion of the leaf.

MATERIAL AND METHOD

Model development

The mathematical model is based on the diffusional model. A three-dimensional model is proposed to describe the drying of rectangular leaf of mint. The model is based on the following assumptions:

- The moisture content is uniformly distributed throughout the particle.
- The environmental conditions are constant.

The diffusion model is given by equation 1.

$$\frac{\partial X(x,t)}{\partial t} = D\frac{\partial^2 X(x,t)}{\partial x^2} \qquad (1)$$

With the following boundary and initial conditions, for a Cartesian coordinate system with its origin placed at the particle center are:

$$\begin{cases} \dfrac{\partial X(x,t)}{\partial t} = D\dfrac{\partial^2 X(x,t)}{\partial x^2} \\ k\dfrac{\partial X}{\partial x} + h(X - X_{eq}) = 0 \quad for\ x = 0,\ t > 0 \\ -k\dfrac{\partial X}{\partial x} + h(X - X_{eq}) = 0 \quad for\ x = e,\ t > 0 \\ X = X_0 \quad \text{à} \quad t = 0 \ \text{ for } 0 < x < e \end{cases} \qquad (2)$$

This problem is no homogeneous because of the boundary conditions. It must be to divide into two problems: a stationary problem of solution $X_s(x)$ and a homogeneous problem of solution $X_h(x,t)$.

The stationary solution is:

$$X_s(x) = X_{eq}$$

The general solution of the problem is the sum of the stationary solution and the homogeneous solution:

That is to say :

$$X(x,t) = X_h(x,t) + X_s$$

The homogeneous solution is:

$$\overset{*}{X}(x,t) = \frac{X(x,t) - X_{eq}}{X_0 - X_{eq}} = \sum_{m=1}^{\infty} e^{-D\beta_m{}^2 t}\psi(x,\beta_m).\frac{2e}{2B_i + (\beta_m e)^2 + B_i{}^2}\frac{B_i + \beta_m e\sin(\beta_m e) - B_i\cos(\beta_m e)}{\beta_m e}$$

With, $B_i = \dfrac{he}{k} = He$ number of Biot

But the mass is a total measurement on the sample it does not depend on the position. The answer is thus that the mass $\overset{*}{M}(t)$ is the average on the sample of $\overset{*}{X}(x,t)$ is

$$\overline{\overset{*}{X}}(t) = \int_0^e \overset{*}{X}(x,t)dx = \overset{*}{M}(t)$$

That is to say :

$$\overline{\overset{*}{X}}(t) = \sum_{m=1}^{\infty} e^{-D\beta_m{}^2 t} \frac{2e}{2B_i + (\beta_m e)^2 + B_i^2} \frac{B_i + \beta_m e \sin(\beta_m e) - B_i \cos(\beta_m e)}{\beta_m e} \frac{B_i - B_i \cos(\beta_m e) + \beta_m e \sin(\beta_m e)}{\beta_m e^2}$$

Experimental procedure

An incubator was used to dry the leaf of mint as shown in the schematic setup (Fig. 1). The leaf was placed in the incubator, hanging by a wire, which was attached to the bottom of an electronic balance. The leaf was partially shielded by a metal wall to avoid the effect of air circulation. Mass loss was monitored continuously. The drying temperature was monitored by two thermocouples, one near the sample and the other in the incubator chamber. Before starting the drying, the leaf was weighed. The experimental results on mass loss were collected until constant weight was obtained. Drying conditions were maintained constant throughout the runs. Mass loss during drying was recorded.

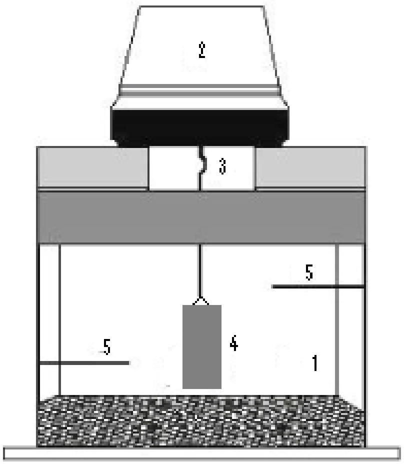

Figure 1: Schematic setup
Legend: (1) - Incubator; (2) - Balance; (3) - wire; (4) - sample; (5)-thermocouples

RESULTS AND DISCUSSION

The experiments were carried out at 35 ºC, 45°C and 55ºC. The drying of the leaf of mint was described by plotting the moisture content versus time, as shown in Figure 2. The rate of moisture removal increased when the air temperature increased from 35 ºC to 55ºC. The drying rate curve was calculated by numerical differentiation of the moisture content with respect to time. Data were plotted against moisture content, as shown in Figure 3. This curve indicates that the drying occurs in the falling rate period, with no constant rate period. The theoretical results were obtained by averaging local values. Figures 4, 5 and 6 show numerical and experimental curves at 35 ºC, 45°C and 55ºC, respectively. The agreement between experimental and predicted results is satisfactory. Figure 7 shows the values of coefficient of diffusion, the plot was found to be essentially a straight line in the range of temperature investigated. Table 1 shows values for the diffusion coefficient for leaf of mint. The coefficients of diffusion of dried simples of sludge at 35 °C, 45 °C and 55 °C vary in the range of 9.155 10^{-12} to 3.288 10^{-11} $m^2.s^{-1}$.

Table 1: Values of coefficient of diffusion obtained for mint leaf at different temperatures

Temperature (°C)	Coefficient of diffusion (m^2/s)	Nomber of transfert Biot
35	9.155 10^{-12}	7
45	9.326 10^{-12}	5
55	3.288 10^{-11}	3

The values of D increased notably with increasing temperature. These values are comparable with some others reported in the literature [6, 7, 8, 9]. The effective diffusivity of water vapor within the shale and the mass coefficient of water vapor from slab surface to the incubator had to be assumed in the model. The diffusion coefficient value for the leaf of mint was calculed, the mass transfer coefficient values assumed to calculate the Biot number at 35ºC, 45°C and 55ºC (Table 1).

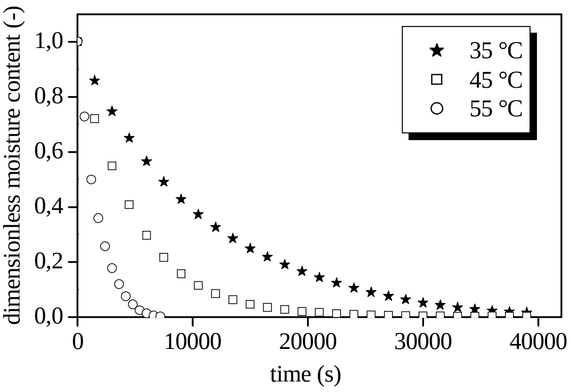

Figure 2 : Dimensionless moisture content curves

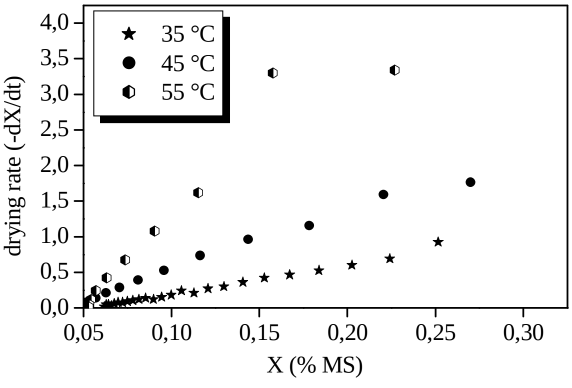

Figure 3 : Drying rate curves

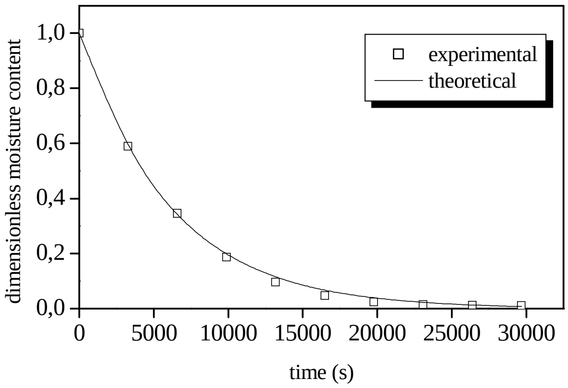

Figure 4: Theoretical and experimental dimensionless moisture content at 35°C

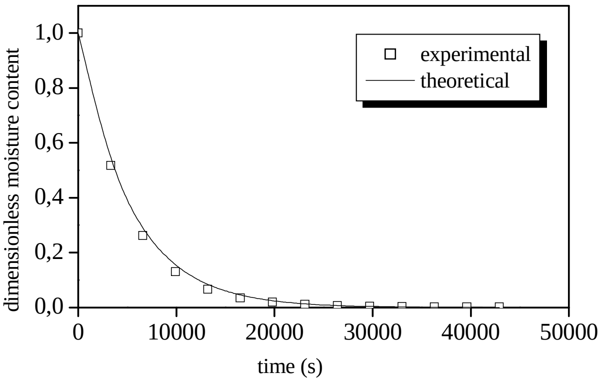

Figure 5: Theoretical and experimental dimensionless moisture content at 45°C

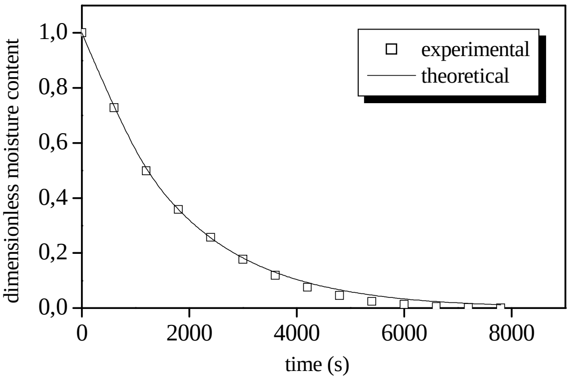

Figure 6: Theoretical and experimental dimensionless moisture content at 55°C

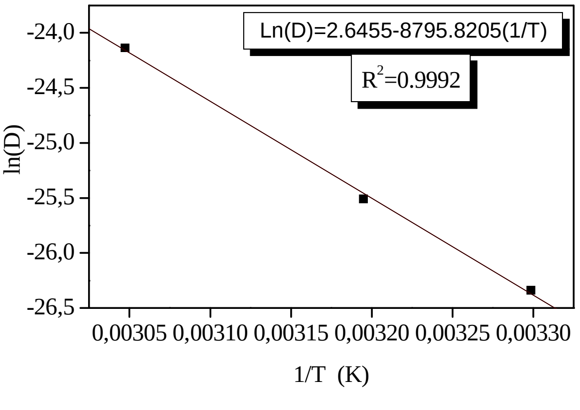

Figure 7: Influence of temperature on the coefficient of diffusion of mint leaf

CONCLUSION

The mathematical model developed enables prediction of the distribution of moisture within rectangular leaf of mint undergoing drying. Results indicate that the predicted and measured moisture content profiles agree satisfactorily. The coefficient of diffusion of the mint leaf determined for the three temperatures and the results are of the same order as those found in the literature.

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