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Temperature effect on the drying kinetics of the Tunisian raw-clay

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***Abstract*— The aim of this work is to evaluate the influence of drying temperature on convective drying process of raw-clay. The study is performed on Tunisian raw-clay product in here simple spherical geometry. Air-drying characteristics were investigated in a laboratory convective hot air dryer for a temperature range 30 to 60°C at a constant air velocity of 1,44 m/s. Drying curves are then fitted by applying Fick's model and the effective diffusivities were calculated. According to the obtained results, it was verified that the increase in the temperature of drying air, increases the drying rate of the raw-clay. The result showed also that with increasing temperature from 30 to 60°C, the effective diffusivities varied from 3.10^{-10} to $4{,}97.10^{-10}$ m^2/s. The calculated values of effective diffusivities were then used to calculate the activation energy by applying the Arrhenius equation.**

***Keywords*— Activation energy, Clay, Effective diffusion coefficient, Drying**

I. Introduction

It is commonly recognized that in an industrial process, the drying step is the most energy-consuming. In recent years, despite the increase in energy prices, stricter constraints on quality, pollution and safety have been imposed. To meet these requirements and optimize spending related to energy, research actions must be taken to better manage industrial processes. Scientifically, drying is a process characterized by mass transfer of heat, mass and momentum.

The modelling of the drying process is very useful to optimize the operating conditions. So to find the optimal drying regime, it is necessary to understand the transport mechanisms that take place in and on the surface of the clay product. The diffusivity of moisture regarded as a material transport is the most important mechanism of mass transport mainly for calculating and modelling different Tunisian clays processing operations.

A small number of studied papers that describe the drying process are available in literature, such as Chemkhi et al., 2005, Zagrouba et al., 2002 Mihoubi, 2004, Skansi et al., 2004, Milos et al., 2011 [1, 2, 3, 4, 5], etc.

In this paper it was analyzed the effect of temperature on drying behavior. The slop method is used for the determination of the effective diffusivity based on Fick's law diffusion.

II. Theory

The term effective diffusivity is defined to describe the rate of moisture movement, no matter which mechanism is involved [6].

A. Determination of the effective diffusivity

The theoretical model used in this study is based on Fick's diffusion law for a spherical coordinates. The mathematical Fick's diffusion model can be solved basing on the following hypotheses:

- The initial moisture content must be uniform throughout the spherical solid;
- The surface moisture of the solid is equal to the equilibrium moisture content at the given conditions of drying;
- The dimensions of the solid remains constant during drying;
- The solid is homogeneous and isotropic (the diffusional properties are constant in each direction);
- Shrinkage of solid is neglected.

By considering that the diffusion is radial and moisture content (X) to be a function of radius (r) and time (t) only, the one dimensional diffusion equation in spherical coordinates can be expressed as [7]:

$$\frac{\partial X(r,t)}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 D_{eff}\frac{\partial X}{\partial r}\right) \quad \text{Eq.1}$$

Considering the following initial and boundary conditions at the surface and at the center of the raw-clay simple:

$$X(t=0, 0 \le r \le R) = X_i \quad \text{Eq.2}$$

$$X(t \ge 0, R) = X_{eq} \quad \text{Eq.3}$$

$$\left(\frac{\partial X}{\partial r}\right)_{r=0} = 0 \quad \text{Eq.4}$$

The solution of the Eq.(1) for a homogeneous sphere with initially moisture content and equilibrium moisture content can be writing as [7, 8]:

$$XR = \frac{X(t) - X_{eq}}{X_0 - X_{eq}} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-\frac{n^2\pi^2 D_{eff}}{R^2}t\right) \quad \text{Eq.5}$$

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Where XR is the moisture ratio, X(t) is the moisture content of the sphere at time t, X_{eq} is the moisture content for $t \to \infty$; X_0 is the initial moisture at t=0, and D is the effective diffusivity.

For long periods of drying time t and for very small sample radius, the terms in the summation of the above series corresponding to n> 1 are relatively small; for this purpose Eq.(5) can be simplified only in the first term of the series. The value of X_{eq} is relatively small compared with X and X_0. Thus, the moisture ratio XR can be simplified to (X/X_0).

By introducing the logarithm to both sides of the Eq.(5), we obtain:

$$\ln(\mathrm{XR}) = \ln(\frac{X}{X_0}) = \ln\left(\frac{6}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}}{R^2} t\right) \qquad \text{Eq.6}$$

Based on this equation, the moisture diffusivity D_{eff} can be calculated applying the slopes method [9, 5]. Diffusivities were then determined by plotting experimental drying data in terms of $\ln(X/X_0)$ versus time in Eq.(6), providing a straight line with the slope given by:

$$Slope = \frac{\pi^2 D_{eff}}{R^2} \qquad \text{Eq.7}$$

The dependence of the effective diffusivity on drying air temperature may be described by the Arrhenius equation as follows [1]:

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{RT}\right) \qquad \text{Eq.8}$$

Where E_a is the activation energy (kJ/mol), R is the universal gas constant (8,314 J/mol.K), T is the drying air temperature (K), and D_0 is the pre-exponential Arrhenius factor (m^2/s). The activation energy could be calculated from the slope the straight line of $\ln(D_{eff})$ versus (1/T).

III. MATERIALS AND METHOD

The drying experiments were conducted using a laboratory convective hot air dryer installed in Applied Thermodynamic unit research of National Engineering School of Gabes, Tunisia. Tunisian raw-clay from El-Hicha sud-est Tunisia was used for the drying experiments. The drying experiments were carried out at different drying air temperatures 30, 40, 50 and 60°C, constant relative humidity 30%, and with constant air velocity of 1.44 m/s. In each experiment, the dryer was adjusted to the selected conditions for about half an hour in order to achieve the steady state conditions of drying before drying material was introduced. After the desired drying conditions had stabilized, the spherical sample of raw-clay with average diameter of 13,6 mm was prepared and placed on the sample holder. A digital balance (AS220.R2) with accuracy of 10^{-3} connected to a computer was used to control continuously the mass loss during drying process. Drying was stopped when equilibrium moisture content of the sample was approximately accomplished. Samples are then dried until 0% moisture content content in the oven at 105°C for 24h in order to obtain the exact moisture content at the end of the experiment.

IV. RESULTS AND DISCUSSION

A. Influence of drying air temperature

In order to study the influence of air-drying temperature, we vary the air temperature from 30°C to 60°C at constant relative humidity and air velocity (Hr=30%, V = 1,44 m/s).

The influence of drying air temperature on drying curves of convective drying of Tunisian raw-clay is presented in fig.1. It can be seen there is an absent of the drying rate period, what's mean that the drying process takes place in the drying falling rate. This mean also that diffusion is the dominant physical governing moisture movement in raw-clay samples. According to the results, it can be seen that the drying air temperature is an effective factor on the moisture ratio, and the moisture content decrease continuously with the drying time. Similar results were obtained by Zagrouba et al., 2002; Mihoubi, 2004; Chemkhi et al., 2005[3, 4, 1]. The time required to dry raw-clay in his spherical geometry was 156000, 11400, 7200 and 6300 s at 30°C, 40°C, 50°C and 60°C.

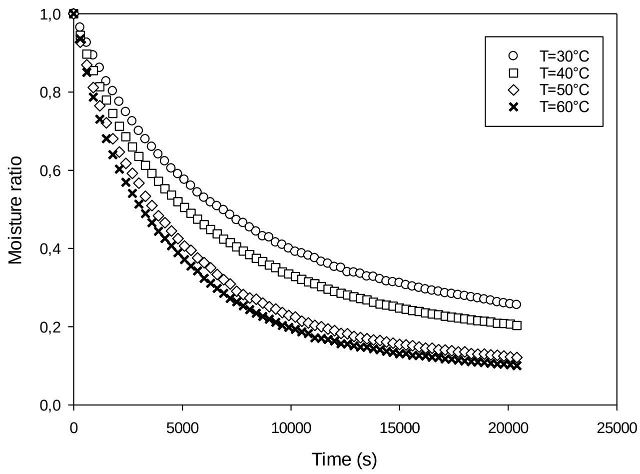

Fig. 1 Influence of drying air temperature on drying kinetics of Tunisian raw-clay.

B. Estimation of the effective diffusivity

By applying Eq.(6) to the experimental data, the logarithm of the moisture ratio can be plotted against time for various drying air temperature (Fig. 2) and then the effective diffusivity were determined using the method of slopes derived from the linear regression of the ln(XR) against time. The results of this method are given in Fig. 3. The effective diffusivities of Tunisian raw-clay were 3.10^{-10}, $3{,}46.10^{-10}$, $4{,}63.10^{-10}$ and $4{,}97.10^{-10}$ m^2/s at 30, 40, 50 and 60°C, respectively. It can be seen that the values of D_{eff} of clay samples varied considerably with temperature.

The calculated values of D_{eff} were plotted in the form of $\ln(D_{eff})$ versus (1/T), as shown in Fig. 4. The plot was found to be a straight line which revealed the existence of linear relationships between the parameters. The activation energy of clay was estimated from the slop of the straight line in Fig. 4, and was found to be 14,96 kJ/mol.

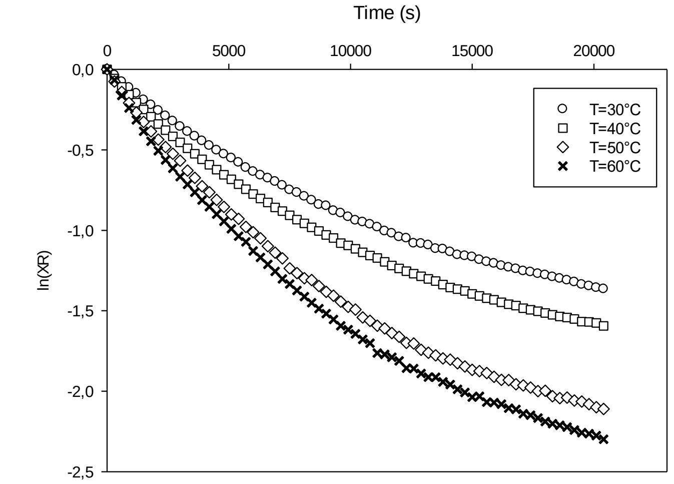

Fig. 2 Logarithmic drying curves at various temperature of Tunisian raw-clay.

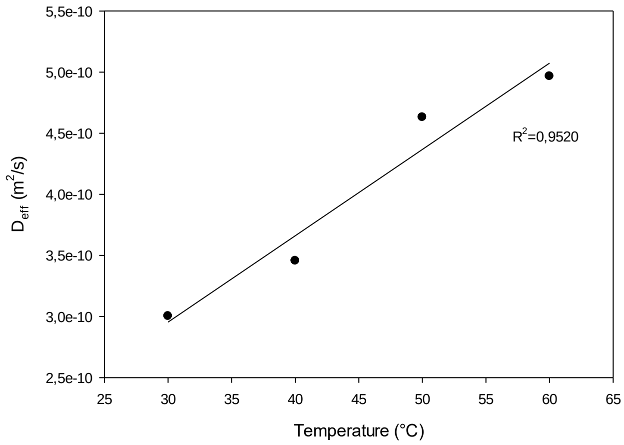

Fig. 3 Influence of drying air temperature on the effective diffusivity.

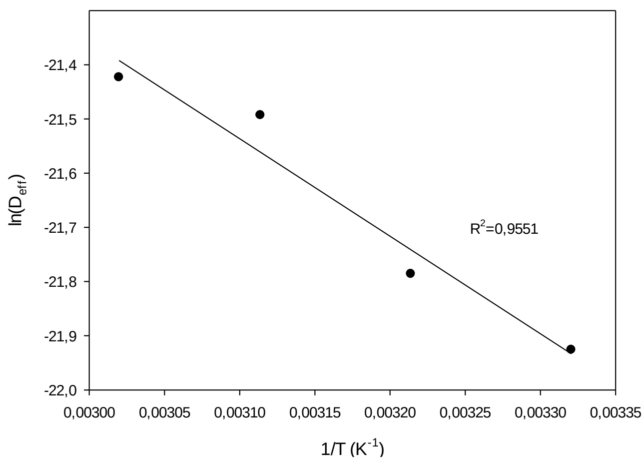

Fig. 4 Variation of logarithm of effective diffusivity with (1/T).

V. CONCLUSION

The aim of this study was the identification of the effective diffusion coefficient by applying the second law of Fick to the Tunisian raw-clay in a range of drying air temperatures from 30°C to 60°C. The obtained results of the effective diffusion coefficient were evaluated in the range of 3.10^{-10} to $4,97.10^{-10}$ m^2/s. The value of the activated energy was estimated to be 14,96 kJ/mol.

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