EXPERIMENTAL DETERMINATION O THE MASS DIFFUSIVITY IN PLASTER PLATES FOR USE IN THE CIVIL CONSTRUCTION

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Abstract. The knowledge of the mass diffusion is indispensable for evaluation and optimization of drying processes. These results can be obtained experimentally through direct measures or through analysis with inverse methods. In the present work, with experimental data obtained form a tunnel dryer, the thermal diffusivity was determined for plates of plaster with similar characteristic with those found commercially in the civil construction. Initially, it was made a study on the model more adapted to calculate the drying rate, trying to identify the periods of constant and variable rate, and with that, it was obtained a model capable to predict the time of drying of plates of plaster. Considering the plate of plaster as a body difusivo, was obtained values of the mass diffusivity as a function of the temperature and of the humidity.

***Keywords**: Diffusivity, Plaster Plates, drying*

1. Introduction

Due to the extensive application of the drying techniques and its importance in different production processes, many theoretical and experimental studies around drying techniques, effect of the involved parameters and on mathematical and numeric models for simulation of the drying process have been accomplished and published in the literature.

Leon et al. (2002) presented a study where revise the different parameters used to test and to evaluate several kind of solar dryers, for drying of food products. Based on that study, the authors propose an analysis methodology, the experiment conditions and a table of simple evaluation that contain the most significant parameters. El-Sebaii et al. (2002-a), they produced an experimental study on a kind of solar dryer formed by a camera of drying coupled to a collector solar type plate it planes where the air is heated up. The collector is projected to receive, below of the plate absorption, some material can store heat and increased the capacity of heating of the air. The experimental procedure were driven with and without material of storage of heat and for different environmental conditions, enrolling the incident solar radiation, the temperature and relative humidity of the air ambient, the temperature in the entrance and exit of the heater and the temperature distribution in different parts of the system. The same authors, El-Sebaii et al. (2002-b), they proposed some correlations for the kinetics of the drying based on that same experimental study.

It is very known that the drying process is a complex thermal process in the one which the transfer of heat and mass happens simultaneously. In this process, the heat is transferred by convection of the hot air for the product, increasing the temperature of the product and of the water in him contained in the humidity form. The mass transfer happens when the present humidity emigrates in the liquid or vapor form into the product for the surface in contact with the hot air, being transferred for the air in the form of vapor of water. Thus, the factors that govern the rates of these processes, they determine the drying rate (Perry, 1973). This process is influenced by the temperature and speed of the fluid that it circulates around the product (Strumillo and Kudra, 1989).

In the point view of the mechanisms of heat transfer involved in the industrial dryers, these can use heat transfer for convection, conduction, radiation, or a combination of these. Even so, independent in the way of heat transfer, the heat has to flow of the external surface into the solid. The only exception is the dielectric and microwaves drying, in which the high electric frequency generates heat intern and produces a high temperature inside of the material and in the surface. Thus, for a good project of a dryer or the choice of the drying strategy, two parameters are fundamental for the influence that exercise about the speed of heat and mass transfer of the migration through the solid material to be evaporated. These parameters are the thermal and mass diffusivity. Both should be determined well by some experimental rehearsals controlled and frequently, when the experimental measures are obtained form a dynamics form, analyze inverse it is the tool more used for its determination. For the inherent importance of these parameters many of them are known broadly and controlled, however, many other they needed completely of this type of information. Example of that is some materials of construction whose production process goes by a drying stage as it is the case of the production of bricks, mortar, tiles, concrete, and gypsum (Mendes et al., 1996).

In the literature they are found several works to the respect of the determination of the thermal and mass diffusivity. Sahin and Dincer (2002) they presented a simple graphic method to determine the mass diffusivity and the coefficient of mass transfer for solid products starting from experimental data. The work exhibition the validation of the method and as that methodology it can be used for practical applications.

Ratti and Mujumdar (1997) they developed a numeric code based on the method of finite differences to simulate and to predict the acting of a solar dryer solar type fixed bed under conditions of temperature of the air in the entrance varying with the time. All the parameters involved in the model were obtained of experimental data on solar drying. Results of numeric rehearsals accomplished with the model present a good agreement with experimental results on drying of pieces of carrots with cylindrical formats.

Some correlations based on the Dincer and Biot numbers, and on the Reynolds and Biot numbers, they were developed recently by Dincer and Hussain (2002) and Dincer et al. (2002) respectively for applications drying of solids in the cylindrical, spherical and plans formats. These correlations can be used later on for the determination of the mass diffusivity and the coefficient of mass transfer. Values obtained under this methodology agree well with experimental results.

In the present work it was used experimental data of the rate of drying of a plate of plaster, submitted to a drying process in a wind tunnel, to determine the mass diffusivity.

2. Mass Difusivity

To evaluate the mass difusivity of a material, it is important to have a notion of how happens as the fuid flow in one gypsum plate inner during a drying process. In the vision of Keey (1973), the internal flow of liquid can happen through several mechanisms depending on the structure of the solid. Some possible mechanisms are: (1) diffusion in continuous homogeneous solids, (2) capillary flow in granular and porous solids, (3) flow caused by shrink and pressure gradients, (4) flow caused by gravity, and (5) flow caused by a successive vaporization-condensation. In general, a mechanism prevails, in a certain moment in a solid during the drying, but it is not uncommon to find different mechanisms that prevail in different moments during the drying cycle. Second Festa (1992), the plaster can be characterized as a material that has a diffusive behavior, in during the drying.

2.1 Fluxo Difusivo em Sólidos

Two types of diffusive processes exist in solids, the first is that which the humidity content can move for diffusion of the vapor in the solid, as long as a temperature gradient is established by heating, creating like this a gradient of vapor pressure. The vaporization and vapor diffusion can happen in any solid where the heating comes for a surface and the humidity content comes out for other, where it is stored among cells of the solid.

The second is for liquid diffusion, where the movement of the liquids for diffusion in solids is restricted to the situation where the content of balance humidity is below the point of atmospheric saturation, and for systems which humidity and solid are mutually soluble.

The first class are applies to the last phases of the drying of the mud, starch, flour, woven, papers and wood; and the second class includes the drying of soaps, glues, gelatins, and graze.

Having in mind that several mechanisms can happen in a drying process, since the humidity content decreases, it varies the resistance to the flow of the fluid inside the solid. This way, it is reasonable to suppose that the diffusivityvaries with the variation of the humidity. Keey(1978), presented a graph, presented below as illustration 1, that shows the diffusivity behavior during the drying, of an hygroscopic material. Seeing the illustration 1, it is verified that the diffusivity is constant in the area of superficial humidity, that corresponds to the beginning of the process, and it decreases while the humidity prevails internally, and it presents an inflection point growing to reach a maximum again, during the influence of the multimolecular adsorption mechanism in the fluid flow, and decreasing again, during the influence of the monomolecular adsorption. The space CD and OF, has the format of the characteristic curve of the drying rate. Therefore, it is of hoping the behavior of the drying rate gives an idea of the behavior of the diffusivity curve as a function of the humidity.

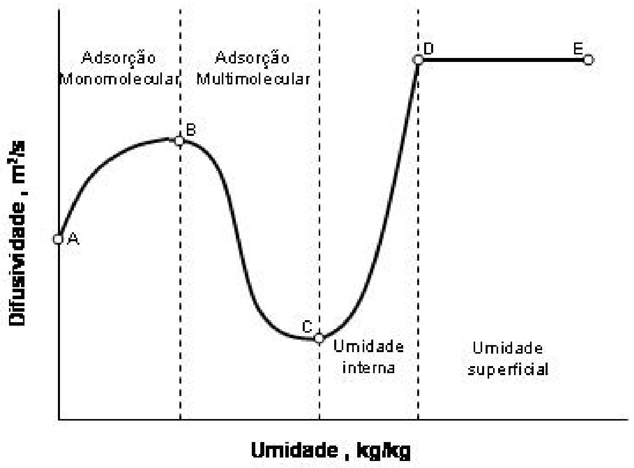

Figure 1 –Diffusivity and. Humidity.

According to Michalewicz (2003), in the case of the plaster plate, the curve of the secagem rate doesn't present a behavior that characterizes a period of constant rate. Someone observes looking at the drying rate curve, that there are two different periods. But there are both of variable rates. In the first, there is a soft fall of the rate, and in the second an accentuated variation, as one can see in the figure 1.

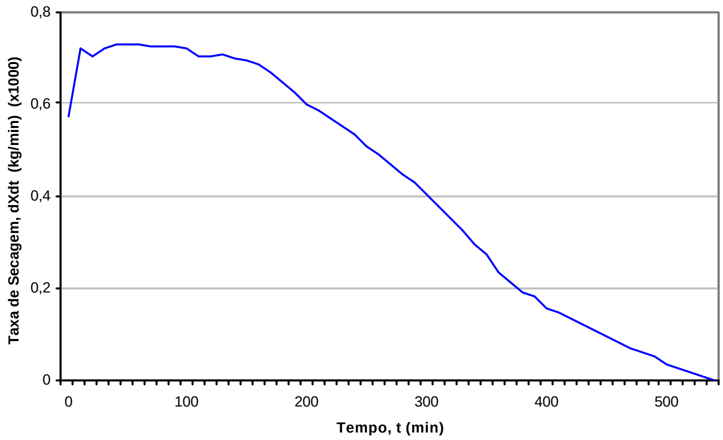

Figura 2 – Curva da taxa de secagem em relação ao tempo na temperatura de 80ºC

2.1 Mathematical Model

Considering the plaster as a material with a diffusive behavior, the phenomenon mass transfer process can be modeled, as one dimension phenomenon, being the humidity variation in the time and in the space. This way, the differential humidity balance equation can be used to describe that phenomenon, the eq. (1).

$$\frac{\partial X}{\partial t} = D_1 \frac{\partial^2 X}{\partial x^2} \tag{1}$$

Where, X is the humidity content, x is the space coordinate, D_1 is the diffusivity inside the plaster, and t it is the time.

The solution of the equation diferencial above is obtained as Fourier series (Perry, 1973), and presented for medium values of humidity in the space, for the eq. (2). In agreement with Perry (1973), this solution was proposed by Sherwood, assuming that the material is superficially dry, or that the balance humidity and the initial distribution of humidity is uniform. For those conditions it was obtained the following solution:

$$\frac{\bar{X} - X_{eq}}{X_{Cr} - X_{eq}} = \frac{8}{\pi^2}\left[e^{-D_1 t (\pi/2d)^2} + \frac{1}{9} e^{-9 D_1 t (\pi/2d)^2} + \frac{1}{25} e^{-25 D_1 t (\pi/2d)^2} + \ldots \right] \tag{2}$$

The solution of this equation is obtained for medium values of the humidity varying with the time, among the initial humidity, named Xi and the balance humidity with the atmosphere in the end of the process, named Xeq. In the same equation, d represents the value of the half of the thickness of the plate when the drying goes for the two faces, or the total thickness of the plate when the drying happens just for one of the faces.

For long drying periods as it is the case of the plaster plates, according Party (1992), the eq. (2) can be simplified through the cutting of the series in the first term, as showing in the eq. (3):

$$\frac{\bar{X}-X_{eq}}{X_{Cr}-X_{eq}}=\frac{8}{\pi^2}e^{-D_l t(\pi/2d)^2} \tag{3}$$

Using humidity medium values, related to the time, obtained experimentally, and the values of Xi and Xeq, through the eq. (3), the plaster diffusivity was calculated, as a function of the time.

2.2 Results and Analyses

The figures 2, 3 and 4, show some curves obtained from equation 3, exemplify the behavior of the plaster diffusivity as a function of the humidity content. The experiments was made with plaster plates placed in a dryer of rectangular section, Michalewicz (2003), using 7,0 cm of distance between plates and speed of the air with 1,43 m/s. The figures correspond to experiments done in the temperatures of 50, 65 and 80 º C, respectively.

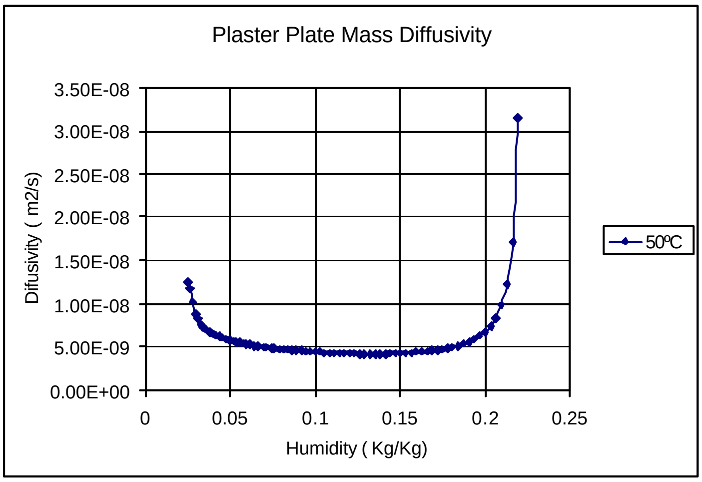

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Figura 3 –Diffusivity against Humidity in a drying process at 50º C.

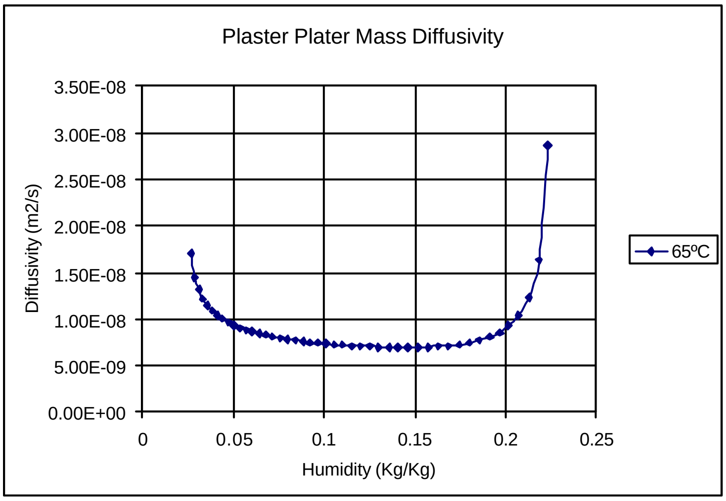

Figura 4 – Diffusivity against Humidity in a drying process at 65º C

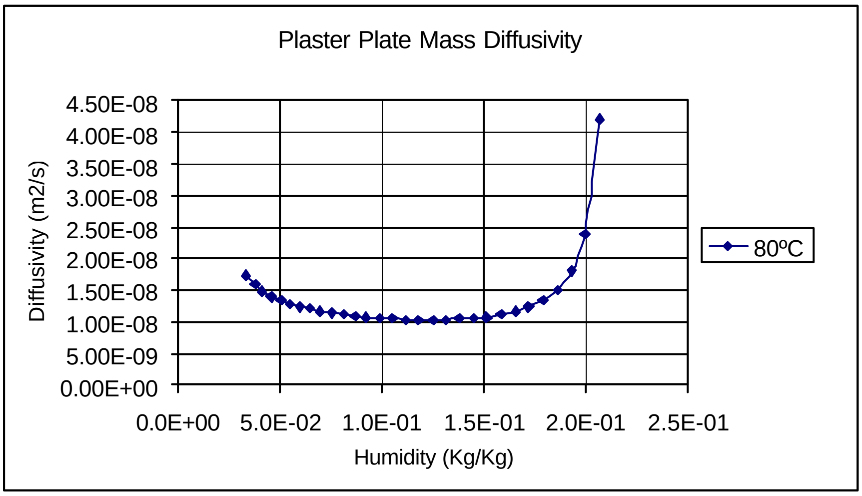

Figura 5 – Diffusivity against Humidity in a drying process at 80º C

An analysis of the figures 3, 4, and 5 shows that the behavior the diffusivity seems with the difusividade model presented in the illustration 1. Here and there the diffusivity has a maximum in the beginning of the drying process, and after that, it drops to a minimum value and later, it grows in the end of the process again.

Being evaluated the diffusivity average as a function of the temperature, it can be verified that the diffusivity also varies with the temperature. The diffusivity medium values of the diffusivities presented in the figures 3, 4 and 5, are presented in the table 1, and placed in one graph in figure 6. Applying a nonlinear regression, exponential, it is obtained a value to r^2 =0.9968, that allows to obtain a quite precise equation to determine the variation of the diffusivity as a function of the temperature.

Tabela 1 – Médium diffusivity

Temperature (ºC)	Medium Diffusivity (m^2/s)
80	1.31E-08
65	9.31E-09
50	6.14E-09

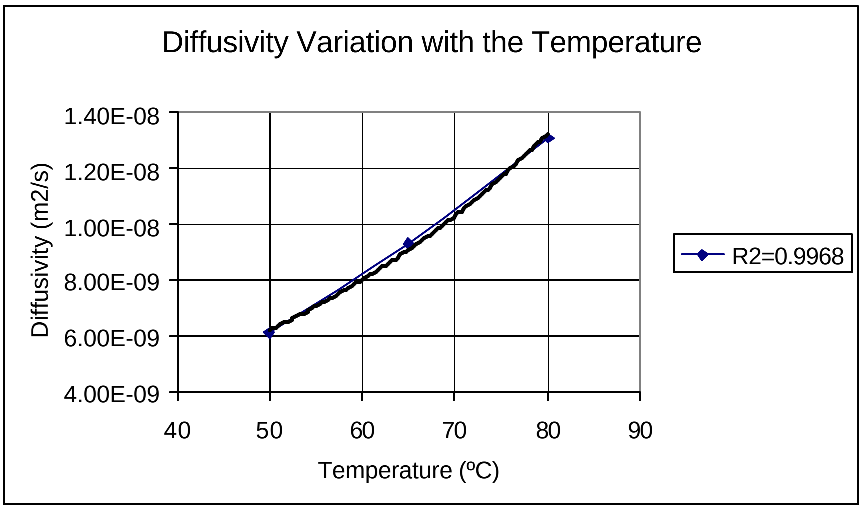

Figura 6 – Médium diffusivity as a temperature function

5. Conclusions

Considering that there are not plaster properties data published in the open literature, this work presents the diffusivity behavior as a humid content function, and the diffusivity medium values as a temperature function. In spite of the beginning of this investigation, one can tell the results obtained are interesting to the civil construction, and for the gypsum industries. The authors are investigating the effect of cutting the series in the first term, and a comparison with results obtained numerically.

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7. References

Dincer, I., M.M. Hussain, 2002, "Development of a new Bi–Di correlation for solids drying, International Journal of Heat and Mass Transfer" , 45, pp. 3065–3069.

Dincer, I., M.M. Hussain, A.Z. Sahin, B.S. Yilbas, 2002, "Development of a new moisture transfer (Bi–Re) correlation for food drying applications, International Journal of Heat and Mass Transfer" , 45, pp. 1749–1755.

El-Sebaii, A.A., S. Aboul-Enein, M.R.I. Ramadan, H.G. El-Gohary, 2002a, "Experimental investigation of an indirect type natural convection solar dryer, Energy Conversion and Management ",43, pp. 2251–2266.

El-Sebaii, A.A., S. Aboul-Enein, M.R.I. Ramadan, H.G. El-Gohary, 2002b, "Empirical correlations for drying kinetics of some fruits and vegetables, Energy" , 27, pp. 845–859.

Festa, Jean, 1992, "Le Plâtre-Et ses applications traditionnelles et modernes", Eyrolles.

Keey, R.B., 1992, "Drying of Loose and Particulate Materials", Hemisphere Publishing Corporations.

Keey, R.B., 1972, "Drying: Principles and Practice", Pergamon Press, Oxford.

Keey, R.B., 1978, "Introduction to Indutrial Drying Operations", Pergamon Press.

Leon, M. Augustus, S. Kumar ., S.C. Bhattacharya, 2002, "A comprehensive procedure for performance evaluation of solar food dryers, Renewable and Sustainable Energy Reviews" , 6, pp. 367–393.

Mendes, L.M.; Silva J.R.M.; Lima, J.T.; Trugilho P.F.; Rezende, E.C, 1996, " Secagem da madeira ao ar livre e alguns pontos básicos para compra de madeira serrada", Cien. E Prat., UFL, boletim técnico nº 21, 30p.

Michalewicz, J.S., 2003, "Estudo paramétrico da secagem de placas de gesso: desenvolvimento de um protótipo em escala laboratorial", Dissertação de Mestrado, Programa de Pós-Graduação em Engenharia Mecânica da UFPE Universidade Federal de Pernambuco.

Perry, R. H., 1973, "Chemical Engineers' Handbook", Fifth Edition, Mcgraw-Hill, Section 20, pp. 44-45.

Ratti, C. And Mujundar, A.S., 1997, "Solar drying of foods: modeling and numerical simulation, Solar Energy" , v. 60, n. 3-4, pp. 151-157.

Sahin, A.Z., I. Dincer, 2002, "Graphical determination of drying process and moisture transfer parameters for solids drying, International Journal of Heat and Mass Transfer" , 45, pp. 3267–3273.

Strumillo,C., Kudra, T., 1989, " Drying: Principles, Applications and Design", Gordon and Breach Sciences Publishers.

5. Responsibility notice