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Moisture Transfer in Wood Packaging below the Fiber Saturation Point

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Abstract: ***Moisture is an essential element which can develop in different support including wood for food packaging, under the influence of climatic elements and their variations; humidity causes various phenomena that can affect the quality of food packaging. This article describes the one-dimensional transfer of moisture in wooden food packagings in conditions of temperature and moisture fixed, where wood is in contact with a salt solution, some transfers are implemented According to a complex process. The method used in this work, consists in combining the modeling and the experiment to understand the transfer of the interface packaging / salt solution. The kinetics of the absorption of moisture in a temperature of (20±2) °C and a relative humidity of 33 % as well as the diffusivity of moisture following the longitudinal direction were determined. A mathematical model was developed to give better information on the concentration of the solution of Magnesium Chloride inside the wooden packaging material.***

Keywords: Diffusion, Modeling, Moisture, packaging material

1. Introduction

Nowadays, most of the foods are conditioned in packaging materials. Wood is one of the best-known porous materials as packaging material, in fact the wood packaging material, take a significant growth in different areas, especially at the level of food seen that they insure as well roles of protection, transport and communication. So, in spite of the functional qualities of the wooden packagings, their contents in moisture stay one of the main factors which can entail negative effects for the packed product, On the other hand the wet wood can in itself be attacked by fungi which can entail the decay and the decrease of the resistance under certain climatic conditions favorable to their development.

Generally, the process of transfer of moisture in the wood of packaging is controlled by transient diffusion.

This transfer influences on products packed as well as on packaging materials. It is necessary to indicate that the study of the mechanism of diffusion has scientific and industrial interests considerable.

The movement of moisture through wood is a very complex process. Moisture in wood exists in three basic forms: bound water within the cell wall, free water in liquid form, as well as water vapor, in the voids of the wood. In general, water can move through wood in three forms; as water vapor through the cell cavities and permanent pit membrane pores, as bound water in the wood substance and as free liquid water in the same structure. The behavior of these two types of water is different.

Below the fiber saturation (FSP) obtained when the relative humidity (RH) of the surrounding air tends to 100%, only bound water and vapor exists. An equilibrium is attained between the bound water content and RH of air, and the equilibrium moisture content increases with RH until the cell wall becomes saturated when RH tends to 100% [1].

The first purpose of this investigation to study the process of absorption of moisture under transient conditions below fiber saturation point is to:

- Describe the process of absorption of moisture in the wood below the fiber saturation point, in particular when the wood is in contact with water vapor for fixed conditions of temperature and humidity ((20±2°C), 33 %).
- Determine the diffusion kinetics, diffusion coefficient and the concentration profile of moisture in the wood following the concerned direction.
- Elaborate a mathematical model that describes the process of absorption of the moisture inside of the packaging material.

2. Theoretical Part

The most useful geometry in the result of this study is that of a plane sheet and for which we will give more theoretical details. The transfer of moisture in the wood is governed by transient diffusion in one dimension [2]-[3]-[4]-[5]-[6].

$$\frac{\partial\,(MC)}{\partial t} = \frac{\partial}{\partial x}[D.\frac{\partial\,(MC)}{\partial x}]$$

Which becomes:

$$\frac{\partial\,(MC)}{\partial t} = D.\frac{\partial^2 (MC)}{\partial x^2}$$

When the diffusivity D is constant: Moisture absorption is controlled by the diffusion phenomenon, in this case, the

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material studied in a uniform concentration C_i, and the surfaces are maintained at the constant moisture content MC_1 during the process.

The initial conditions: $t = 0 \quad 0 < x < L \quad MC = MC_i$

The boundary conditions: $t \geq 0 \quad x = 0 \quad MC = MC_1$

$$x = L \qquad MC = MC_1$$

In this case, an analytical solution exists for the concentration $C_{x,t}$, at time t and the position x:

$$\frac{MC_1 - MC_{x,t}}{MC_1 - MC_i} = \frac{4}{\pi} \cdot \sum_{n=0}^{\infty} \frac{1}{2n+1} . \sin\left(\frac{(2n+1)\pi x}{L}\right) . \exp\left(\frac{-(2n+1)^2 \pi^2}{L^2} Dt\right) \qquad (1)$$

The total amount of the substance entered or taken out of the sheet at the moment t, M_t, is given depending on the amount of substance diffusing after an infinitive time: [6]

$$\frac{M_\infty - M_t}{M_\infty} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} . \exp\left(\frac{-(2n+1)^2 \pi^2}{L^2} Dt\right) \qquad (2)$$

Another expression of the concentration $C_{x,t}$ is the following one:

$$\frac{MC_{x,t} - MC_i}{MC_1 - MC_i} = \sum_{n=0}^{n} (-1)^n erfc \frac{(2n+1)L - 2x}{4(Dt)^{0,5}} + \sum_{n=0}^{n} (-1)^n erfc \frac{(2n+1)L + 2x}{4(Dt)^{0,5}} \qquad (3)$$

For the amount of substance transported at the moment t, M_t is given by:

$$\frac{M_t}{M_\infty} = \frac{4}{L} (Dt)^{0,5} . \left\{ \pi^{-0,5} + 2 \sum_{n=1}^{\infty} (-1)^n .ierfc \frac{nL}{2(Dt)^{0,5}} \right\} \qquad (4)$$

In the case of short time and when the M_t/M_∞ report is rather small, the equation reduces to the following relation:

$$\frac{M_t}{M_\infty} = \frac{4}{L} \left(\frac{Dt}{\pi} \right)^{0,5} \qquad (5)$$

For longer periods, when M_t/M_∞ is sufficiently large, the equation (2) is reduced, the first term disappeared with n=0

$$\frac{M_\infty - M_t}{M_\infty} = \frac{8}{\pi^2} \exp\left(- \frac{\pi^2 D_t}{L^2} \right) \qquad (6)$$

3. Materials and methods

3.1 Materials

The used material is the wood of packaging (poplar) which is mainly used for the light packaging. Our salt solution used is the Chloride of Magnesium with the chemical formula ($MgCl_2$). During the contact, we measured the specific mass of the sheet each time to study the evolution of the mass according to the time with a balance (10^{-3}g sensitivity).

3.2 Experimental Procedure

The preparation of samples does not require big means. Indeed the sample that will be used in our study is taken along a longitudinal direction. Our choice was focused on thin sheets of wood packaging.

Contact

The studied system is formed by a wooden sheet of packaging in contact with a salt solution of the Chloride of Magnesium ($MgCl_2$).

We was prepared a solution widely saturated with the salt of chloride of magnesium in the relative humidity 33% which was afterward distributed in the crystallizer placed at the bottom in the desiccator on a height of some centimeters so as to have a surface of maximal evaporation.

The wood sample is contacted with a saturated salt solution of magnesium chloride (RH = 33%) at 20° C. During the contact, the hygroscopicity of our sample was determined by the followed of the evolution of absorption of moisture by the sample conditioning at a relative humidity of 33%.

4. Results and Discussion

In the work undertaken three types of results are of major interest:

- The kinetics of absorption of moisture by the wood
- The model validated by the method adopted during the research that combines experimentation and modeling.
- The concentration profile of the salt solution of magnesium chloride inside the wood.

The Measured Parameters

The equation below is used to calculate the percentage of mass variation of our wooden sample after a contact with the salt solution of Chloride of Magnesium according to time.

$$\Delta m = \frac{m_t - m_0}{m_0} \times 100$$

The diffusion coefficient according to the longitudinal direction is given by the following equation:

$$\frac{M_t}{M_\infty} = \frac{4}{L} \left(\frac{Dt}{\pi} \right)^{0,5}$$

In cm²/s: D= 4.8254.10^{-4} cm²/s

On the figure 1, we have plotted the evolution of the mass variation $\Delta m(\%)$ of moisture, which has diffused in the wood according to the time.

The figure 1 gives a general overview on the nature of diffusion, so it leads us to conclude that:

- The transfer process of moisture in the material is governed by the diffusion phenomenon.
- The moisture content in the wood increases during the contact time until equilibrium reached.
- The quantity of the salt solution of Chloride of Magnesium (RH=33%) absorbed at equilibrium was obtained from the kinetics with a good precision.

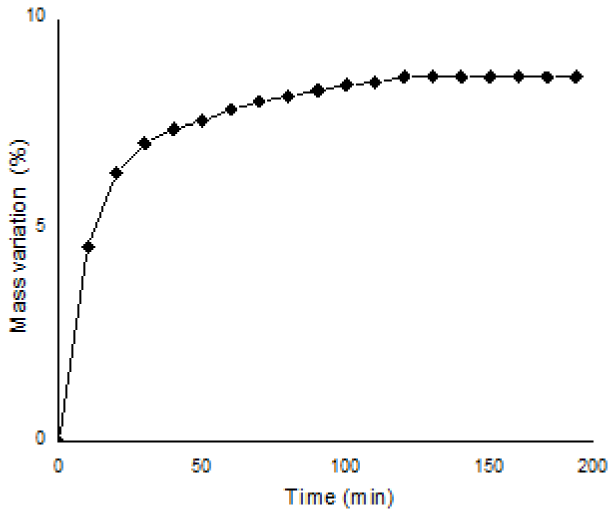

Figure 1: variation of moisture content in the wood

The figure 2 shows that the experimental values coincide with the theoretical values; that which indicates the validity of both proposed models namely the analytical model and numerical model.

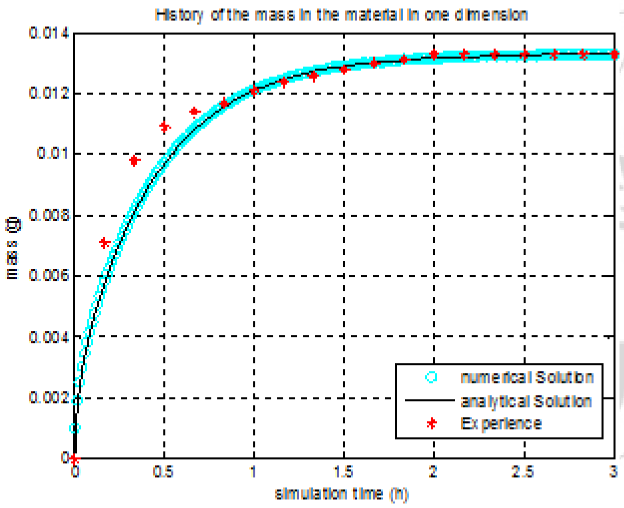

Figure 2: The amount of moisture transferred into the sample according to the simulation time

The figure 3 represents the profile of the concentration of the salt solution after each 10 minutes. We find that:

- The concentration increases within the sample over time, until equilibrium is reached as illustrates the figure 3 which shows clearly this state of equilibrium.
- The profile of concentration informs us about the concentration inside the wood, so we can determine for each point of our sample the concentration easily.

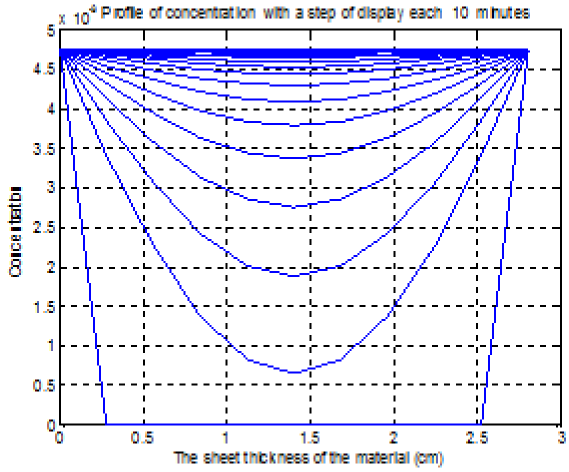

Figure 3: The concentration profile after each 10 min

5. Conclusion

In the present work, we have contributed to the study of new experiences of coupling of the experimental methods with modeling to understand the behavior of the wooden packaging in contact with food products.

- In this perspective the process of absorption of the moisture content below the fiber saturation point was studied. The study was led by weighed by following the evolution of the mass transferred over time. The following results are obtained:
- The contact of $MgCl_2$ at a temperature of (20±2°C) showed that the quantity of the latter in the wood increases over time.
- The elaborate mathematical model was validated by comparing the theoretical results to those of the experience.
- The obtained profile gave us good information onto the concentration of moisture inside the wood of packaging.
- It appears that the mathematical models allowed us to simulate the transfer phenomena and allow to better understand these phenomena.

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