THE DRYING OF RED OAK AT VACUUM PRESSURE♣

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In memoriam of Dr. H. Peter STEINHAGEN

ABSTRACT

In this work we present a mathematical model to predict the red oak wood vacuum drying kinetics. The mathematical model considers molecular diffusion and two-dimensional flow of humidity. The experimental work was carried out in controlled conditions of temperature and relative humidity to estimate the effective diffusion coefficient and moisture content in the wood. An "Arrhenius" type expression was employed for temperature dependence of diffusion coefficient.

Key words: diffusion, red oak, vacuum pressure, wood drying

INTRODUCTION

Traditionally, the drying sequences for soft wood are used for the drying of hard wood, that which generate defects in the wood, like cracks, fissures, warped and diamond form, reducing the commercial value in the wood (Pérez et al., 2001). Hardwood drying at vacuum pressure is an alternative not much studied, to eliminate defects in controlled conditions, obtaining quality wood (Pérez et al., 2003). It is attractive to dry thick wood at vacuum pressure, where the drying time using conventional methods, it is increased in an exponential form (Keey, 2000; Pérez et al., 2000). This work presents an extension of the traditional drying models, to predict the lumber drying kinetic of red oak with square traverse section at vacuum pressure. This model assumes diffusive control as well as bidirectional moisture flow, equilibrium conditions in the entire sample surface at the drying chamber conditions and variable diffusion coefficient in the whole range of the content of humidity in the wood and residual humidity.

THEORY

We were considered a square structure for the samples and the physical structure, those which had the next dimensions: 0.3m*0.04m*0.05m, for this reason we considered the humidity migration only in the "x" and "y" axis, ignore in this form the migration in the "z" axis; in this way, the mathematical solution was obtain in a single element, under the assumption that migration of the moisture is similar in the "x" and "y" axis; and the moisture flow from the center toward the surface in the sample, according to the Figure 1

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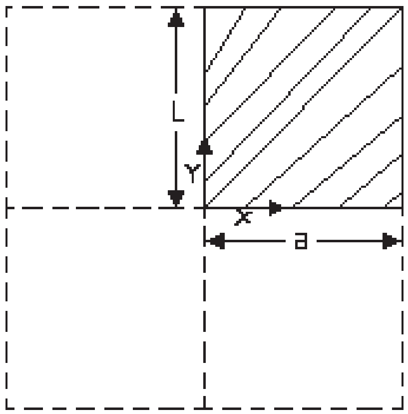

Fig. 1.- Physical structure for the mathematical model solution.

The second Fick's law solution for bi-dimensional flow is given by:

$$MR = \frac{Hs(t) - Heq}{Hs_0 - Heq} = \frac{16}{\pi^2} * \sum_{n=1}^{\infty} \left(\sum_{m=1}^{\infty} \left(\begin{array}{l} \frac{(-1)^{2+m+n}}{(2n-1)(2m-1)} \cos\left(\frac{(2n-1)\pi}{2} \xi \right) * \\ * \cos\left(\frac{(2m-1)a\pi}{2l} \varepsilon \right) * \\ * e^{-\frac{D_{ef}}{a^2}\left(\left(\frac{2n-1}{2} \right)^2 \pi^2 + \left(\frac{(2m-1)a\pi}{2l} \right)^2 \right) t} \end{array} \right) \right) \tag{1}$$

Where:

$$\xi = \frac{x}{a} \tag{2}$$

$$\varepsilon = \frac{y}{a} \tag{3}$$

Meanwhile the average moisture content in the sample was evaluated through equation 5

$$\langle Hs(t) \rangle = \frac{\int_v Hs(t) dv}{\int_v dv} = \frac{\int_y \int_x Hs(t) w dx dy}{\int_y \int_x w dx dy} \tag{4}$$

At the end we was able to calculate the solid moisture content normalized (MR) in the sample surface only as a time function without depth dimension influence.

$$Hs(t) = Heq + (Hs_0 - Heq) \frac{64}{\pi^4} \sum_{n=1}^{\infty} \sum_{m=1}^{\infty} \frac{(-1)^{4+2m+2n}}{(2n-1)^2 (2m-1)^2} * \\ * e^{-\frac{D_{ef}}{a^2}\left(\left(\frac{2n-1}{2} \right)^2 \pi^2 + \left(\frac{(2m-1)a\pi}{2l} \right)^2 \right) t} \tag{5}$$

EXPERIMENTAL METODOLOGY

The red oak (*Quercus spp*) samples, was employed in the drying at vacuum pressure test. Each sample was cut in two pieces of 0.0254 m, one in each side of the sample (Figure 2)

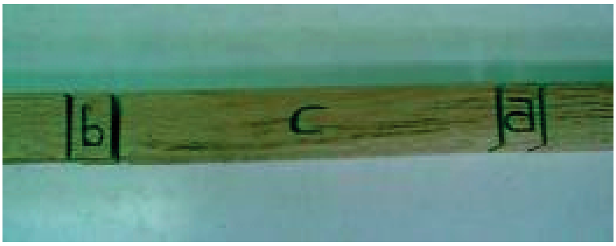

Fig. 2.- Cuts in the experimental sample.

The initial samples moisture content ("c" section), was estimated as an average between "b" and "a" extremes sections. To develop the experimental drying An 2^2 factorial design was employed, with temperature and vacuum pressure variations. In each experience four wood samples were dried a discontinued vacuum, vacuum was broken only to weigh the samples every 24 hours in order to determine the drying kinetics. Each experience was carried out in a vacuum chamber with 1 m^3 capacity; additionally a dry agent was inserted into dryer chamber to keep relative moisture.

RESULTS

The figures 3 and 4 show the model predictions at two different operation conditions in the vacuum pressure.

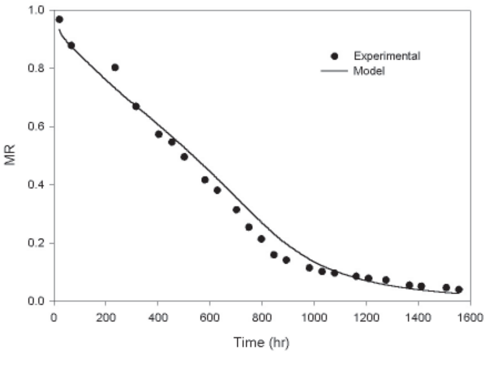

Fig.3.- Drying vacuum kinetics prediction. High vacuum pressure.

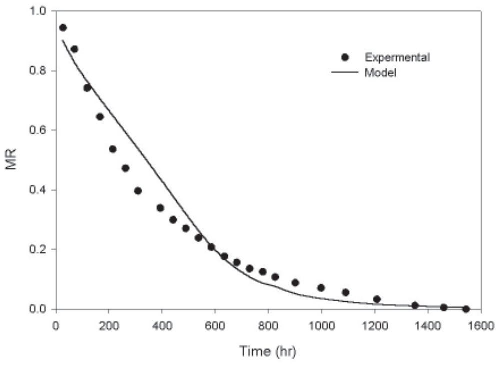

Fig. 4.- Drying vacuum kinetics prediction. Low vacuum pressure.

Our model is able to reproduce the drying kinetics at high vacuum pressure, showing two stages, constant rate drying and diffusive control. The model predictions showed deviations at the beginning because it was difficult to maintain constant relative moisture in the drying chamber. As well as, the model predictions are good at moisture levels lower than fiber saturation point, where the diffusive control is dominant.

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NOTATION

a	wood dimension in the "x" axis	m
D_{ef}	effective diffusion coefficient	m/s
Hs(t)	wood moisture content in the time	water kg/dry solid kg
Heq	equilibrium wood moisture content at the drying conditions	water kg/dry solid kg
l	wood dimension in the "y" axis	m
MR	solid moisture content normalized	Adimensional
t	Time	s
Greek symbols		
ε	depth parameter in the "y" axis	adimensional
ξ	depth parameter in the "x" axis	adimensional