Drying Kinetic Of Chilean Coigüe: Study Of The Global Drying Coefficient

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ABSTRACT

A one-dimension phenomenological wood drying model has been used to describe Chilean coigüe ***Nothofagus dombeyi*** conventional drying kinetic. This model is based on a global mass transfer coefficient K_x, and consists on four first class coupled differential equations, which are solved as an initial value problem. With the purpose of having K_x determined, four drying cycles were performed, thus varying wood thickness and drying air velocity. The model suitably predicted the moisture transient behavior during the coigüe wood drying. K_x varied with wood thickness, but did not regarding air velocity. This coefficient value ranged from $1.87 \bullet 10^{-5}$ and $3.37 \bullet 10^{-5}$ ($kg.m^{-2}.\ s^{-1}$). A preliminary running of a 100 m^3 filling up rate industrial dryer showed that the model accurately represented the average moisture content during drying. In such a case, the optimized K_x coefficient turned out to be $5.55 \bullet 10^{-6}$ $kg.m^{-2}.\ s^{-1}$.

Keywords: Drying rate, global mass transfer coefficient, *Nothofagus dombeyi*, Chile.

INTRODUCTION

The Chilean coigüe features a high commercial and industrial interest; however, this type of lumber drying has been limited by defects and collapse trends (Kauman and Mittak, 1964; 1966). The wood drying modeling led to the optimization of the industrial process. A simple drying modeling that applies to the wood industry would make the drying cycle time reduction possible and the achievement of better quality in dry wood possible.

Related literature shows many drying models which are based on transport phenomena, as well as on diffusion and phenomenological laws. Transport models include a greater amount of physical information about the drying phenomenon through mass and heat transfer equations than other models (Perré and Degiovanni, 1990; Turner, 1996; Perré and Turner, 1999). These drying models provide a clear description of what actually happens to wood piece, while helping to the understanding of wood drying behavior. Drying modeling of the whole stack by using phenomenological models best describes the industrial drying process (Ananías *et. al.*, 2001 a).

A simple phenomenological wood drying model may be featured by a global mass transfer coefficient (Karabagli *et. al.*, 1997). Such global mass transfer coefficient K_x includes internal moisture movement through the wood, as well as the mass transfer from wood surface to drying air flow. Consequently, it depends both on wood characteristics and drying parameters (Chrusciel *et. al.*, 1999).

This current research work shows drying kinetics represented by the differential equations system that have been introduced by Karabagli *et. al.* (1997). It requires the experimental setting up of K_x global mass transfer coefficient, for which sample data are collected. The purpose of this work is to state the Chilean coigüe drying kinetics by means of a phenomenological model.

MATHEMATICAL MODEL

The model states that drying rate turns out to be a linear function of the drying potential (MC-EMC) and a factor of proportionality characterized by the global mass transfer coefficient, which has been considered as a constant during drying. This hypothesis was also verified by Ananías *et. al.* (2001 b).

The model assumes that mass transfer and enthalpy take place in one direction, while the initial moisture content is homogenous and air distribution inside the wood stack is even. Besides, temperature features an average value and heat losses toward the outside are negligible. Moreover, moisture and temperature initial values for each sub-system (air-wood), as well as both global mass (K_x) and heat transfer (h) coefficients have to be well known.

Model equations were introduced by Karabagli *et. al.* (1997), and have been numerically solved in an additional study (Ananías *et. al.* 2001 a). Therefore, just those ratios that are relevant to this current work will be recalled. The equation below describes water mass balance in wood:

$$-M_B \cdot \frac{dMC}{dt} = K_x \cdot S \cdot (MC - EMC) \qquad (1)$$

If equation (1) is solved by means of the finite difference method, then we shall be able to calculate the theoretical wood moisture content at any time (MC^{j+1}). When rearranging this equation, the following relation is obtained:

$$\frac{dMC}{MC - EMC} = -K$$

where:

$$-K = \frac{K_x \cdot S}{M_B} \cdot \Delta\tau \qquad (2)$$

When having the transient terms discrete, the following is achieved:

$$\frac{MC^{j+1} - MC^j}{\frac{MC^{j+1} - EMC^{j+1} + MC^j - EMC^j}{2}} = -K$$

When rearranging the above equation to find moisture content at any time (MC^{j+1}), the following is obtained:

$$CH_t^{\ j+1} = \frac{(2-K)\cdot MC^j}{2+K} + \frac{K \cdot \left(EMC^j + EMC^{j+1}\right)}{2+K} \qquad (3)$$

Note that MC^j and EMC^j are experimental values and are related to the following error function:

$$E = ABS\,\frac{\left(MC_{ex} - MC_{teo}\right)}{MC_{ex}} \cdot 100 \qquad (4)$$

As it has been mentioned above, the model states that K_x keeps constant during drying. Therefore, if using the above equations to state such value, the sampling or experimental wood moisture content has to be computed at constant time intervals. It has been possible to have an equation for the experimental or sampling data by using the Table Curve 2D software.

MATERIALS AND METHODS

Experiment Device

A laboratory wood dryer was used in order to get the 0.3m^3 wood boards dried (Figure 1). Air and wood temperature at different levels in the stack was measured by using thermocouples. In turn, those measurements have been periodically saved in a computer data system. Experimental moisture content was stated through the gravimeter method, by using a scale, the precision of which being 0.01 g.

EXPERIMENTAL STUDY

Wood species used in this study was coigüe ***Nothfagus dombeyi***. Timber sizes were 110 mm in widths and 920 mm in lengths. On the other hand, wood thickness (19 – 30 mm) and air velocity (1.5 – 3 m.s^{-1}) made up the variable parameters. Finally, four drying cycles were performed (Table 1).

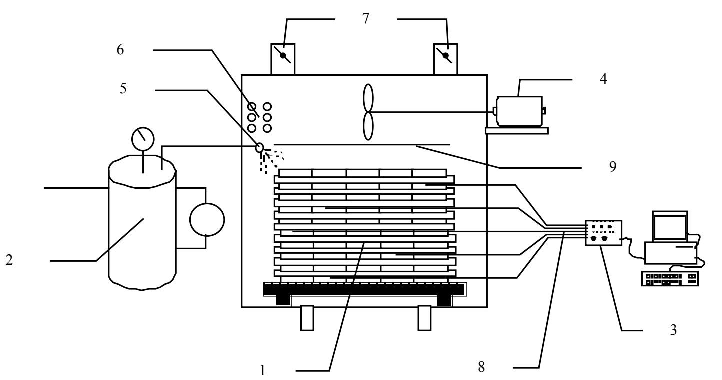


Figure 1: Experimental dryer: 1.- Wood to be dried. 2.- Boiler. 3.- PC data system. 4.- Motor with fan. 5.- Steam spray line. 6.- Heating coils. 7.- Vents. 8.- Thermocouples. 9.- Fan deck.

Table 1: Experimental design

Air velocity (m.s^{-1}))	**Thickness** (mm)	
1,5	18,4	21,7
3,0	29,6	30,8

Wood was placed in a 10-level-stack, and separated by 25-mm-stickers.

The four drying cycles were carried out by fixing temperature and air velocity during drying. The dry bulb temperature was established at 60ºC, while the wet bulb was fixed at 40ºC. Regarding these temperatures, relative air humidity reached up to about 30%, thus wood balance moisture content would amount up to approximately 4.5%, according to psychometric charts (Siau, 1984). Such severe drying conditions were just used to verify the model's prediction ability and they do not show dried wood final quality. The weight method was used in order to establish the experimental moisture content, measurements were carried out at different time intervals. Sample size was, in turn, stated by the statistical procedure described by Broche (2002).

RESULTS AND DISCUSSION

Magnitude of K_x values showed in Table 2 (1.87 – 3.37•10^{-5} kg.m^2·s^{-1}) are similar to those ones reported by Karabagli *et. al.* (1997); Ananías et al. (2001 b). Besides, it is likely to observe that K_x decreases as thickness increases. This means that coigüe wood drying is governed by water internal movement (k_s). This hypothesis has been supported by coigüe's refractory nature. According to Chrusciel *et. al.* (1999), K_x is a function of k_s and k_g partial mass transfer coefficients, in both the gas phase (air) and the solid phase (wood), respectively. This has become the reason why K_x shows a decrease in this current study, since internal conductivity in the solid phase (k_s) features a thickness-based decrease.

On the other hand, Table 2 also shows that, at least in this present study, there is no relation between K_x and air velocity. Coigüe's low permeability supports this behavior. Such air velocity and K_x related thickness ratio makes us assume that if coigüe's conventional drying is mainly regulated by moisture internal movement in the solid phase, external movement during the gas phase gets then added, thus stating transient behavior of the moisture content in terms of the global mass transfer coefficient (K_x) by the drying potential, which is expressed as the moisture content difference between the solid and gas phase. This supports the use of the model in the way it has been described by equation 1.

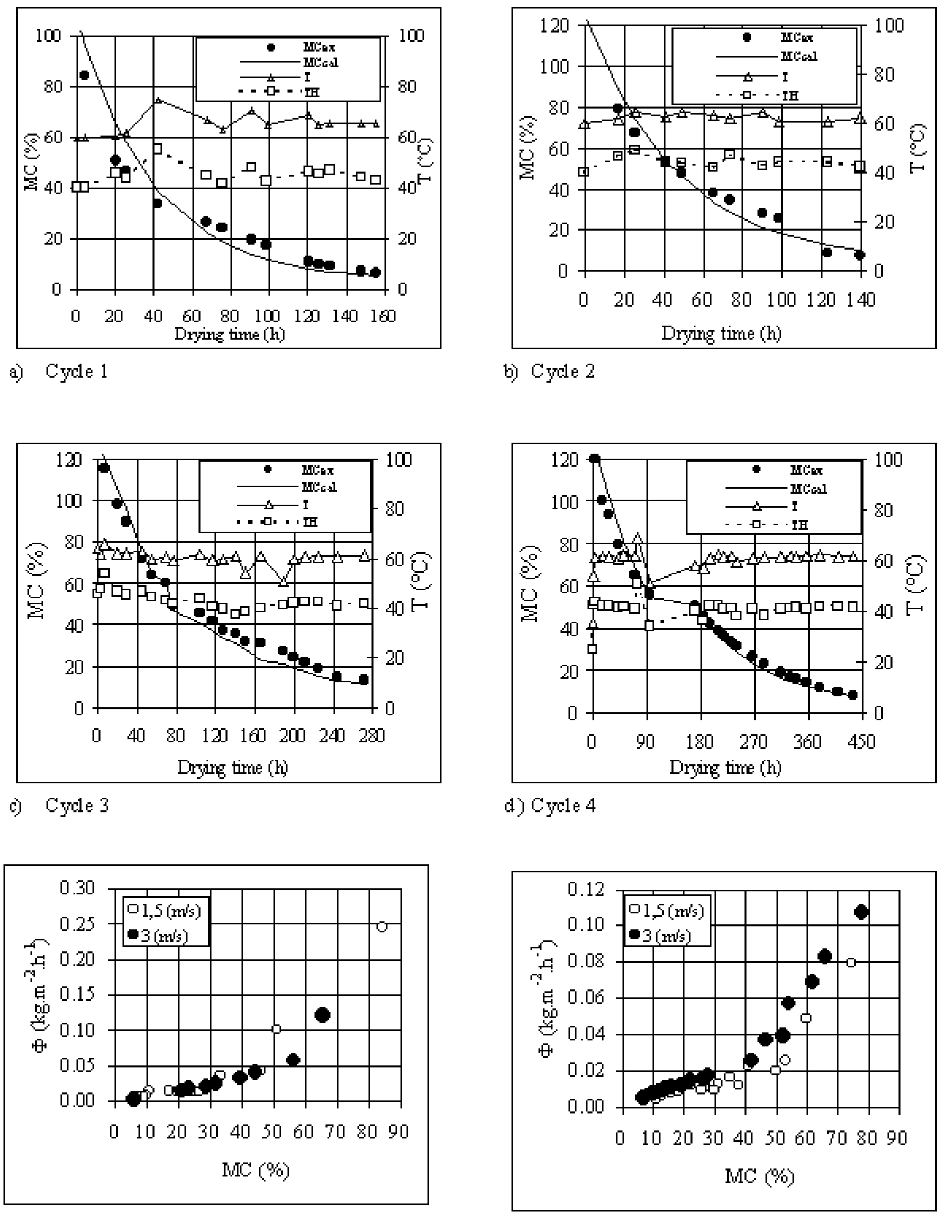
The "h" values magnitude, as shown in Table 2 (26.7 – 44.1 w.m^{-2}·K^{-1}) are similar to those ones reported by Salin (1996), Pang (1996), for similar operating conditions. This coefficient is only useful when calculating wood temperature (Karabagli *et. al.*, 1997; Ananías *et. al.*, 2001 a). Moreover, its importance turns out to be limited by the gaseous phase low influence in these refractory wood-based experiments.

On the other hand, the slight differences that have been observed between experimental and computerized wood moisture content (Figure 2) are partly due to temperature changes kinetics, which have not been taken into account in the suggested model. In addition to this, the modeled drying curve features a constant slope, thus assuming that K_x global mass transfer coefficient is constant during drying, which is not absolutely true.

A preliminary running of a 100m^3 filling up rate industrial dryer showed that the model accurately represented the average moisture content during drying. In such a case, wood thickness (38 mm) and air speed (2.5 m.s^{-1}) were the operating parameters, while K_x optimized coefficient was 5.55•10^{-6} kg·m^{-2} s^{-1}. Such K_x value is smaller than the experimental ones, because of thickness increase and the greater difficulty to keep the drying atmosphere homogeneous throughout the dryer.

Table 2: Operating conditions and global coefficients in all four experiments.

Cycle	Constants						Variables (Initial Values)				Global Coefficients
	G kg.s^{-1}	e m	S m^2	M_B kg	T_{in} ºC	W_{in} kg.kg^{-1}	MC %	W_{out} kg.kg^{-1}	T_{out} ºC	T_w ºC	K_x·10^5 kg.m^{-2}·s^{-1}
1	0,3057	0,0184	10,6	50,6	65	0,0359	107,5	0,0359	60	52	3,37
2	0,6116	0,0217	11,5	61,1	64	0,0359	104,1	0,0359	60	17	3,18
3	0,3058	0,0296	12,0	83,3	67	0,0530	107,7	0,0531	58	47	2,06
4	0,6116	0,0308	12,4	87,5	66	0,0474	107,5	0,0474	62	35	1,87



a) Cycle 1
b) Cycle 2
c) Cycle 3
d) Cycle 4
e) Drying rate cycles 1 and 2
f) Drying rate cycles 3 and 4

Figure 1: Drying kinetics of Chilean coigüe ***Nothofagus dombeyi***.

CONCLUSIONS

Variation in average moisture content during conventional drying of Chilean coigüe can be suitably described when having the model characterized by the K_x global mass transfer. K_x average value, as it has been stated by the researched variables, is about $1.87 \bullet 10^{-5}$ and $3.37 \bullet 10^{-5}$ $(kg.m^{-2}.\ s^{-1})$.

At least in this coigüe based experiments, K_x decreases in relation to thickness. However, air velocity does not have a remarkable effect on this coefficient, which has been justified by this kind of low permeability wood.

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List of symbols

MC Wood moisture content ($kg_{water}.kg^{-1}_{dried\ wood}$)
EMC Equilibrium moisture content ($kg_{water}kg^{-1}_{dried\ wood}$).
e Wood thickness (m)
E Error function (%)
G Drying air mass flow rate ($kg_{air.}\ s^{-1}$).
h Heat transfer coefficient ($w.\ m^{-2}K^{-1}$).
K_x Global mass transfer coefficient ($kg_{water}\ .\ m^{-2}{}_{dried\ wood}\ x\ s^{-1}$).
M_B Wood mass ($kg_{dried\ wood}$).
S Exchange surface between wood and air (m^2).
t Time (h)
T_H Wet bulb temperature (ºC)
T Dry bulb temperature (ºC).
T_{in} Air temperature at stack input (ºC).
T_{out} Air temperature at stack output (ºC).
T_W Average wood temperature (ºC).
W_{in} Absolute air moisture content at stack infeed ($kg_{water\ vapor}\ .\ kg^{-1}{}_{dried\ air}$)
W_{out} Absolute air moisture content at stack outfeed ($kg_{water\ vapor}\ .\ kg^{-1}{}_{dried\ air}$)

Subscripts

cal Calculated
ex Experimental
j;j+1 Iterative variable
teo Theoretical

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