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DRYING BEHAVIOR AND PERMEABILITY OF *Eucalyptus grandis* LUMBER♣

Ivaldo P. Jankowsky[1] , Gilson Roberto V. dos Santos[2]

In memoriam of Dr. H. Peter STEINHAGEN

ABSTRACT

Although the increasing economic importance of Eucalyptus lumber to furniture and other value added products manufacturing, its industrial use is still small. One of the main reasons is the difficulty to dry the lumber and related loses of row material. There is a general recommendation in literature to use a low drying rate in initial stages of the process, and changing to a more aggressive drying after removal of liquid water from the lumber. According classical theory about drying of porous material, this point should coincide with the predominance of diffusion phenomena in the moisture movement; which could be determined through the characteristic drying curve of the material. With the objective to get better knowledge about the drying of *Eucalyptus grandis* lumber, its characteristic drying curve was determined, and the results proved that *Eucalyptus grandis* lumber is not permeable to liquid flow. Based on its characteristic drying curve, it is possible to suggest the change of drying conditions when lumber moisture content, dry basis, is between 35% and 40%, then starting a more aggressive drying.

Keywords: lumber drying, Eucalipt lumber, characteristic drying curve

INTRODUCTION

Wood is a hygroscopic, porous, anisotropic and nonhomogeneus material. After log sawing, the lumber contains liquid water in fiber cavities (capillary water) and bound water inside the fiber wall (hygroscopic water). As wood shrinks due moisture loss, the previous drying before lumber processing is crucial.

Lumber drying can de understood as the balance between heat transfer from air flow to wood surface and water transport from the wood surface to the air flow.

According Kollman and Cotê (1968); Rosen (1983) and Jankowsky (1995), during the drying process by convection there are three distinct phases (Figure 1); which are determined by the drying rate variation and give the drying characteristic curve for the material.

In the first phase (constant rate period) the liquid water moves by capillary forces to the surface in same proportion of moisture evaporation. Moisture movement across the lumber will depend on the wood permeability and the drying rate itself is controlled by external conditions in this period.

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[1] USP, ESALQ, Department of Forest Sciences, P.O. Box 09, 13418-900 – Piracicaba, SP, Brazil. ✉: ipjankow@esalq.usp.br
[2] FUNTAC - Fundação de Tecnologia do Estado do Acre, Av. das Acácias, L-01, Zona “A”, Distrito Industrial, 69917-100, Rio Branco, AC, Brazil.

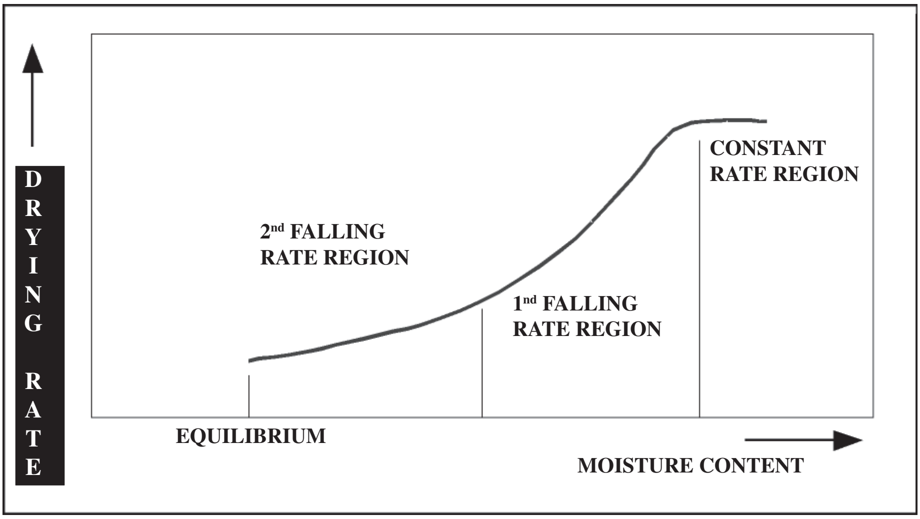

Fig. 1.- Characteristic drying curve for a porous material (Rosen, 1983).

Part of energy received by the surface increase temperature in this region, and the heat transfer to the inner part of lumber starts. When the capillary flow decreases, moisture content at surface reaches the Fiber Saturation Point (FPS) and the first falling rate period begin.

As the lumber dries, the liquid water or wet line recedes into wood and the internal moisture movement involves the liquid flow and diffusion of water vapor and hygroscopic water. Hygroscopic water is “bounded” to cell wall components by hydrogen bridges, and its diffusion is affected by the wood specific gravity, by the moisture gradient between the inner part and the surface and by the heat flow from surface to the center. The effect of internal resistance on the drying rate increases.

In the last phase (second falling rate period) there is no more liquid water in the lumber, and the drying rate is controlled only by internal resistance (material characteristics) until an equilibrium moisture content is reached.

The conventional kiln drying follows a drying schedule, set according lumber characteristics as dimensions, specific gravity, tendency to show defects or degrade and desired quality standard. The decreasing of drying rate is compensated by continuous changes in the drying medium (air flow) turning drying conditions more aggressive. However, some species of genus *Eucalyptus*, including *Eucalyptus grandis*, show a high tendency to degrade during the first steps of kiln drying.

The tendency of eucalipt lumber to collapse and develop surface and internal checks is attributed to the low permeability. During capillary flow, liquid water moves from one fiber to the next fiber through small openings called pit, which can be obstructed by air bubbles or wood extractives deposition. In many cases, the observed wood permeability shows considerable deviations from Darcy’s Law (Kauman et al., 1992).

Consensual recommendation to kiln drying of eucalipt lumber is to use low temperature (below 45°C) and high relative humidity (above 75%) until the most part of capillary water is removed, as cited by Northway (1996); Ciniglio (1998); Martins *et al*. (1999) and Andrade (2000).

This recommendation implies in very low drying rates and the industrial process becomes anti-economical.

An alternative to reduce kiln drying time and cost is to combine the air drying of wet lumber with the conventional process for pre-dried lumber (Ciniglio, 1998; Franzoni, 2001). Although there is a general concordance about positive effects of the eucalipt lumber pre-drying, there is no agreement regarding the more adequate moisture content to move the wood from yard to the kiln (Stöhr, 1977; Campbell and Hartley, 1988; Northway, 1996 and Franzoni, 2001).

The main objective of the present study was to determine the characteristic drying curve for *Eucalyptus grandis* lumber and to evaluate its drying rate.

METHODOLOGY

The lumber used in this experiment was supplied by Companhia Agro-Florestal Santa Bárbara Ltda, State of Minas Gerais, from a 16 years old *Eucalyptus grandis* planted forest. Twenty samples 490 mm long, 80 mm wide and 20 mm thick were cut from randomly select commercial boards. All samples were from heartwood and tangential position in the log.

The samples were stacked in two rows (10 samples per row), using stickers with 13 mm of thickness between samples, inside a Hildebrand kiln model HD4004, with fully automatic control. Drying condition was constant, with temperature of 35°C and relative humidity of 76% (resulting a 14% expected equilibrium moisture content in the lumber). Air velocity through the rows was set 1.2 m/s.

Periodically the samples were weighed to register the loss of mass, until the moisture content reaches a value around the expected equilibrium value. At end of experiment, the samples were oven dried in an oven at 103°C (±2), to get the sample mass without water and to calculate current moisture content along experimental drying. Drying rate was estimated according equation 1:

$$\mathbf{DR = \Delta m_{H2O} / \Delta t} \qquad \mathbf{(1)}$$

where: **DR** = drying rate (g/h);
$\mathbf{\Delta m_{H2O}}$ = mass of water evaporated between two consecutive weighing (g);
$\mathbf{\Delta t}$ = period of time (h) between the two weighing in which $\mathbf{\Delta m_{H2O}}$ was registered.

RESULTS

Values of drying rate were plotted against lumber moisture content using linear regression analysis, and the resulting curves are presented in Figure 2.

As expected, relationship between drying rate and lumber moisture content fits well a non linear equation (second degree), a characteristic of wood material. A wood species as *Eucalyptus grandis* have a ratio of 0.8:1.0 of capillary water and hygroscopic water, respectively, when moisture content is 50%. As the lumber dries, this ratio decreases and resistance to remove water from the lumber increases; and it results a continuous decreasing in drying rate. The coefficient R^2 was 0,9918 proving that the drying rate depends exclusively on the material moisture content.

The whole drying curve can be divided in two linear equations, representing the drying behavior when the lumber contains capillary and hygroscopic water (Curve A, right side of Figure 2), with an average drying rate of 1.44 g/h; and when it contains only hygroscopic water (Curve B, left side of Figure 2), with average drying rate of 0.31 g/h.

Curve A can be understood as the first falling rate region in the characteristic drying curve for the material. There is a liquid water movement through the capillary structure of the lumber, but the quantity of liquid water reaching the wet line is smaller than the moisture evaporation at lumber surface. Considering that still is a reasonable quantity of liquid water at this phase, it is clear that there is a restriction to the capillary flow. This behavior proves the low permeability of *Eucalyptus grandis* lumber, corroborating previous descriptions presented by Campbell and Hartley (1988) and Vermaas (2000). Another evidence of the lumber impermeability is the absence of constant rate region in the drying curve.

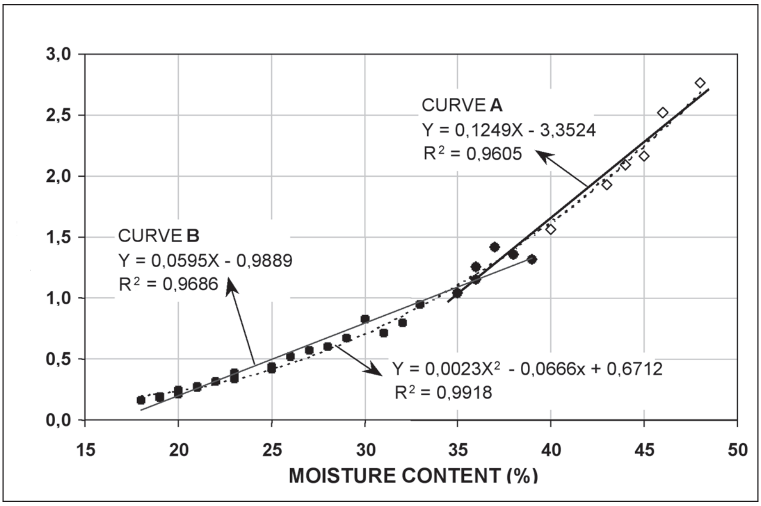

Fig. 2.- Characteristic dryng curve for *Eucalyptus grandis* lumber.

According Rosen (1983), the water movement in lumber during the first falling rate period is part by capillary flow and part by diffusion (hygroscopic water and some capillary water which turns to hygroscopic due the lumber impermeability). As the diffusive movement also depends on the moisture gradient between surface and inner part of the lumber piece, to decrease relative humidity of air flow should result in faster surface drying and to increase internal moisture gradient. However, the shrinkage at surface when moisture content drops below FSP will causes internal stress, because the lumber below wet line is still wet and did not shrinks yet. The greatness of drying stress is proportional to the moisture gradient, and is the main reason for the incidence of surface checks, perceptible indication of mechanical rupture of the material.

Curve B represents the second falling rate region. Considering the lumber material, it means the diffusive movement of hygroscopic water, which depends near exclusively on wood specific gravity. In this period all the lumber tends to shrink and, although the shrinkage is not homogeneous across the lumber thickness, the drying stresses can be controlled enough to avoid surface or internal checks. So, when moisture content drops below 35% it is possible to apply a conventional drying schedule with continuous changes in the drying medium to achieve a constant moisture gradient from surface to the center of the lumber piece.

The inflection point between first and second falling rate regions (Figure 2) corresponds to moisture content about 35%. Considering the operational practice, this is the most adequate moment to stop the air drying and move the lumber to the conventional kiln, regardless any theoretical consideration about water movement in the lumber. This result is in disagreement to recommendations from Stöhr (1977) and from Campbell and Hartley (1988), and is similar to Franzoni (2001) citation as an operational procedure.

CONCLUSIONS

Based on the characteristic drying curve for *Eucalyptus grandis* lumber, obtained in this experiment, it is possible to conclude:

- *Eucalyptus grandis* lumber is a species difficult to dry, with restrictions to capillary and diffusive water flow;
- there is no constant rate region in the characteristic drying curve, that proves the lumber is impermeable;
- as an operational procedure, it is recommended to stop air drying when moisture content is about 35%, to get a more efficient conventional kiln drying.

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