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Analysis of the kiln drying process of a sawmill in Espírito Santo state, Brazil: a case study

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ABSTRACT There is great interest in assessing the wood drying process due to its importance in the further processing of lumber. The objective of this work was to analyze the process of kiln drying of wood in a selected mill located in the Espírito Santo state, Southeastern Brazil. The analysis was carried out *in situ*, represented by the monitoring of the entire drying cycle of three kilns and encompassed four stages: dry kilns and manpower, lumber preparation for drying, drying schedules and quality of the dried lumber. The initial hypothesis was confirmed, that the mill's managers need more technical knowledge on kiln drying practices. The main problem was observed in the conduction of the drying process, in which there was no moisture content control during any stage of the cycle.
Keywords: wood drying; lumber; *Pinus* spp.

Introduction

Wood drying is recognized in both academy and industry as one of the most important stages of primary wood processing because dried wood has significant advantages over freshly sawn wood, such as higher mechanical and decay resistance. For higher value-added products, such as flooring and mouldings, wood drying is a mandatory step because it permits wood to be machined to precise dimensions, as well as finishings and fastenings are more effective in dried wood.

Because of its importance, several studies have been conducted in different mills to evaluate the technical aspects of the wood drying process in different regions of Brazil, such as Northern (Manaus, Amazonas state) (SALES-CAMPOS et al., 2000), Midwest (Sinop, Mato Grosso state) (ANJOS et al., 2011), Southeast (Tietê, São Paulo state) (DUCATTI et al., 2003) and Southern (Rio Grande do Sul state) (GATTO et al., 2004).

In all those studies, the authors detected significant problems regarding the lack of technical skills required to manage drying processes, whether in air-drying or kiln drying. As a result, substantial degrade losses are incurred and therefore, in many cases the drying process does not fulfill its main objective of adding value to the lumber.

For example, Sales-Campos et al. (2000) reported that in some mills the lumber was stacked before air-drying directly on the ground, and without stickers between the layers. Under those conditions, air-drying will not be effective, resulting in lumber with non-uniform final moisture content. In the case of Sinop, seven of the twelve sawmills assessed had no control of the wood moisture content throughout the drying process (ANJOS et al., 2011).

When assessing three companies in Southeastern Brazil that perform kiln drying, it was observed that none of them kept any records or quality control of the dried lumber (DUCATTI et al., 2001). Lastly, it was concluded that air-drying of *Pinus* sp. considerably worsened the quality of the dried lumber, reducing the volume classified as "first quality" and

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increasing the portion classified as "third quality" (GATTO et al., 2004).

Although wood drying is a well stablished area in Brazil, with several centers offering training for different types of labor, the adoption of proper wood drying techniques is still lacking in the industry. This is detrimental to the wood industry, because it reduces competitiveness and rational use of raw materials.

On the other hand, some partnerships between research institutes and wood drying industries in Brazil have been reported, in which many activities to share industrial experience and technical information have quite successful (JANKOWSKY; LUIZ, 2006).

We postulated the following research problem: what is the current state of the kiln drying of wood in a mill located in the Espírito Santo state? According to the literature review, the initial hypothesis was that the mill lacks technical knowledge to carry out good practices for kiln drying of wood.

The objective of this work was to analyze the process of kiln drying of wood in a selected mill located in the Espírito Santo state, Southeastern Brazil.

Materials and methods

Mill characterization

A mill located in the Southwest Highlands Microregion of Espírito Santo state was selected. As the work was a case study, we asked permission to the mill's managers to carry it out before its start and they agreed but requested anonymity.

The mill processes *Eucalyptus* spp. and *Pinus* spp., but it only performs kiln drying of the latter, which is marketed for different purposes – from timber for construction to furniture components. The wood drying process is carried out in three kilns. As the purpose of the study was not to compare the kilns, the evaluation of this stage was done as a whole and the presentation of results corresponds to an overall analysis of the kiln drying process.

Data collection was carried out *in situ* by systematic observation and the information collected was properly registered. The evaluation period corresponded to a complete drying cycle in each kiln, from the preparation of the lumber stacks to the assessment of the quality of the dried lumber. The evaluation was carried out in four stages: i) kilns and manpower; ii) lumber preparation for drying; iii) drying schedules; and iv) quality of the dried lumber.

Kilns and manpower

The following aspects were analyzed at this stage: i) types of kilns; ii) drying classification (operational techniques and temperature); iii) process control (manual, automatic or semi-automatic); iv) physical conditions of the kilns; v) qualification of the manpower.

For item iv, a general qualitative assessment was made by attributing a satisfactory or unsatisfactory score. The satisfactory score was assigned to the items that were working as expected. When this did not occur, the unsatisfactory score was assigned. The following items were analyzed: i) physical condition of the kilns (floors, doors, walls and ceiling); ii) drying control devices (thermometers, sensor pins and hygrometers); iii) components of different kiln systems (heating, air circulation and exhaustion/humidification); and iv) track rails and kiln trucks.

Stacking

The following aspects were analyzed at this stage: i) the raw material used: species and lumber dimensions; ii) initial moisture content and desired final moisture content in the process; iii) the final product that was envisioned from raw material; and iv) stickers and bolsters.

The volume of the lumber stacks and the kiln charge were calculated using the Equations 1 and 2, respectively.

$$Vs = N \times T \times W \times L \quad (1)$$

$$Vt = Ns \times Vs \quad (2)$$

In which: Vs: lumber stack volume (m^3); N: number of layers of lumber per stack; T: thickness of the board (m); W: stack width (m); L: stack length (m); Vt: total volume of kiln charge (m^3); Ns: number of lumber stacks.

Drying schedule

The suitability of the drying schedule was evaluated regarding the following items: i) wood species; ii) lumber dimensions; iii) initial and final moisture content; and iv) final quality desired of the products.

Evaluation of the dried lumber quality

This evaluation was carried out qualitatively, based only on the presence or absence of warping and any other significant drying defect that could potentially result in degrade. After drying, the evaluation was carried out visually by operational personnel. Boards were classified into two grades: acceptable or unacceptable, according to the quality standard required by the customer. The entire batch was examined, i.e., each board was analyzed individually. Lastly, the volume of the boards classified as unacceptable was determined.

Results and discussion

Kilns and manpower

The mill has three identical kilns (Benecke, Brazil), which were built of brick, with nominal capacity of 30 m^3. They were installed in the 1980s. By operational techniques, they are classified as track-loaded compartment kilns (single-track kilns), while by operating temperature (between 40 and 90 °C), they are considered conventional-temperature kilns. Both classifications are according to Simpson (1991).

The drying control was achieved manually, i.e, the kilns did not have automated equipment to control the parameters. In the past, the kilns relied on automation provided by the company called Digisystem. However, the equipment was not in use at the time of the study. Instead, the operators carried out control of the process manually, and the process information was manually recorded. This situation is different from that reported by Ducatti et al. (2001), who found that the three mills evaluated in Tietê (São Paulo, Brazil) used automated control for kiln drying.

The drying sector consisted on the following personnel: three boiler operators, who rotate in three 8-hour shifts per day; four assistants, who prepare the lumber for loading and unloading; one tractor driver, who moves the lumber stacks; and one supervisor. Among these workers, only the boiler operators remain in the drying sector all the time. The others perform activities in other sectors of the mill, especially in the log breakdown sector. None of the operators had any formal technical qualification related to the wood drying process. They were trained in-house, which was the same situation reported by Ducatti et al. (2001). Anjos et al. (2011) also found that ten out of the twelve companies evaluated in Sinop (Brazil) did not have qualified professionals to monitor both air-drying and kiln drying processes.

The kilns have two doors, one at each end. However, both loading and unloading were carried out only through one door because of the absence of track rails outside the other end of the kilns. This was a negative feature because it neutralizes a major advantage of the kiln loaded by trucks, which are able to place a prepared load of green lumber at the front of the kiln before removal of the dried load. However, for this purpose, in addition to installing the track rails, it would be necessary to purchase another set of kiln trucks.

Table 1 shows the summary of the results of the kilns assessment. In general, the physical conditions of the structure of the kilns (floor, doors, walls and ceiling) were satisfactory, despite of the wear and tear caused by roughly 30 years of operation.

Table 1. Kiln assessment: items working as expected

Item	Classification
Physical condition of the kilns: floors, doors, walls and ceiling	Satisfactory
Drying control devices: thermometers, sensor pins and hygrometers	Unsatisfactory
Moisture content control of lumber	Unsatisfactory
Air circulation and exhaustion systems	Satisfactory
Humidification system	Unsatisfactory
Heating system	Satisfactory
Track rails	Satisfactory
Kiln trucks	Unsatisfactory

Each kiln has a set of wet-bulb (Twb) and dry-bulb (Tdb) thermometers, the former being mercury thermometers and the latter are bimetallic thermometers. These thermometers did not have any seals indicating regular calibration, and were classified as unsatisfactory because there was no assurance that the measured temperatures were correct. These were the only devices installed in the kilns, which did not have contact pins or any probe to control the lumber's moisture content. Kiln samples for monitoring moisture content loss during the process were not used and therefore the control of drying rates during the process was also classified as unsatisfactory.

The air circulation system of each kiln consisted of three lateral non-reversible fans, with about 180 cm in diameter, all of them arranged on the same sidewall and distributed evenly along the length. Each fan had two dampers triggered manually (on/off), one above and one below the fan installed on the same wall. Air circulation systems and exhaustion were classified as satisfactory.

The kilns did not have humidification system to control the relative humidity. The operators did not know whether the kilns were equipped with humidification control. Furthermore, the manufacturer of the kilns could not say whether they were installed with this system, since the installation logs could not be found. The humidification system might have been installed in the kilns and then suffered corrosion over the time, prompting its removal. In any event, the humidification system was rated as unsatisfactory.

For each fan, a set of heat exchangers made of carbon steel was arranged vertically on the wall opposite to the fans. The steam was generated in a fire-tube boiler (Benecke, Brazil), and according to information given by its operator, it has regular maintenance and was designed to meet the needs of three kilns simultaneously. The heating system was considered satisfactory. Steam transmission lines were not evaluated, as well as the condensate return lines and their components (pipes, fittings, valves, filters and meters).

The track rails were found to be in good condition, but the same was not true of the kiln trucks, which were in unsatisfactory condition. The structure of the kiln trucks where the lumber stacks were held was significantly deformed, thus impairing stacking and jeopardizing the stability of the stacks.

Stacking

At the time of the study, the mill was drying *Pinus elliottii* and *Pinus taeda* lumber in the same load, which were sawn in-house and coming from their own plantations. The mill did not perform any pre-sorting of the lumber prior to kiln drying.

Although there are recommendations in the literature not to dry different species in the same kiln (HILDEBRAND, 1970; LANGRISH; WALKER, 2006; SIMPSON, 1991), the mill has adopted this practice for many years without reporting problems. It is noteworthy that these wood species are widely recognized as easy to dry, besides the fact that their anatomical and physical properties are similar. Thus, it is reasonable to expect that the drying of both species under the same schedule should not bring significant technical implications, which reinforces the choice adopted by the mill's managers.

The lumber was sawn in three nominal sizes (30 x 120 x 2,200 mm, 30 x 160 x 2,200 mm, 30 x 200 x 2,200 mm), which are designed to meet a request from a door manufacturer. The dimensions of the lumber were suitable for drying, regarding nominal length and thickness, which were uniform for all boards.

The uniformity in length facilitates the box piling, and it optimizes the volume of lumber in the kiln. Loading boards with the same thickness is also crucial for the uniformity of the drying cycle, because thicker pieces take longer to dry. In addition, it provides greater stability to the lumber stack and minimizes warping. Although the widths of the boards were different, this is not relevant to the physical aspects of drying, requiring only attention from mill personnel in the preparation of the lumber stacks, seeking to maintain standardization of the width of the different layers of boards so as not to compromise the stack's stability (CULPEPPER, 2000).

The mill did not conduct any moisture pre-sorting of the lumber. However, the lumber was freshly-sawn, given that it was prepared immediately after breaking down at the mill. As requested by the customer, the desired final moisture content of the wood had to be between 12% and 14%. Further discussion on the moisture control is presented in the next section.

The stacking of lumber was done manually at the sawmill, immediately after the break down. Therefore, mill personnel used a wooden jig in the shape of an "L", which had the same dimensions as the lumber stack and was also painted with marks for alignment of the stickers and bolsters.

The lumber stacks were prepared with the following composition: one layer of bolsters, supported on the base of the kiln trucks; 31 layers of stickers and 32 layers of boards (laid side by side, with no spaces between the boards), resulting in dimensions 1,700 x 1,810 x 2,200 mm (width x height x length). All the characteristics of the lumber stacks that have been discussed can be seen in Figure 1, showing a representative lumber stack.

Figure 1. Representative lumber stack of the mill.

The lumber was stacked without any type of restriction to minimize dimensional movement of boards on the upper layers. Although the kiln trucks have structures for supporting the lumber stacks ("I" shaped welded to the base), they were significantly damaged, as mentioned, which required an adaptation using bolsters to give support to the stacks. Operators assembled a layer of bolsters, followed by another of boards (not from the drying process), and then mounted the lumber stack itself, starting with another layer of bolsters.

The load in each kiln was composed of six lumber stacks, one per kiln truck, each with an average volume of 3.5904 m^3, resulting in 21.5424 m^3 per kiln and 64.6272 m^3 of installed capacity (three kilns). A complete kiln charge is shown in Figure 2, just moments before being placed in one of the kilns.

Figure 2. General view of the drying sector during the preparation prior to loading.

The wood used for manufacturing the stickers and bolsters was the same from the drying process (*Pinus* sp.), and was in unsatisfactory shape, with many defects such as warping and cracks, as well as defects caused by handling (broken pieces). The storage of the stickers was also done improperly, in direct contact with the ground and without any kind of classification, which is a negative practice because the quality of the stickers influences the preparation of the lumber stacks and represent a significant cost to the mill.

The stickers and bolsters were 25 x 50 x 1,700 mm and 75 x 100 x 1,700 mm (thickness x width x length), respectively. Each layer of stickers had five pieces, while the bolster layers had only three pieces. The average distance between the bolsters ranged from 880 to 980 mm, whereas between the stickers it varied from 360 to 660 mm.

In general, the dimensions of different stickers were uniform, which is positive from the standpoint of airflow and stability of the lumber stacks, minimizing the strain on the lumber. However, the cross-section dimensions were larger than recommended, as discussed below. The dimensions of the various bolsters were also uniform.

For example, stickers with 16 x 25 mm of cross section are recommended for drying lumber 30 mm thick (HILDEBRAND, 1970), whereas an overall size of 19 to 22 mm thick and 38 mm wide is also acceptable (CULPEPPER, 2000). A negative aspect of over-thickness of the stickers is the reduced volume of lumber loaded in the kiln, which reduces the mill's productivity. A negative aspect of using overly wide stickers is the generation of "wet pockets" in the region of contact with the boards, resulting in moisture content heterogeneity.

If the mill adopted stickers with 16 mm thickness with the same bolsters (75 mm thick) and lumber (30 mm thick), also using lumber stacks with the same height (1,810 mm), it would be possible to add six layers of lumber per stack. This would represent an increase of 0.6732 m^3 per lumber stack and 4.0392 m^3 per kiln charge, which would increase the kiln capacity from 21.5424 m^3 to 25.5816 m^3. With this configuration, the installed capacity of the mill would increase from 64.6272 m^3 to 76.74440 m^3, representing an increase of 18.75% in productivity.

The repair of the base of the kiln trucks would also allow adding a few layers of stacked lumber, by eliminating the layers of bolsters and boards used to support the lumber stacks, as previously mentioned.

With a new configuration the initial heating step of the drying schedule would take longer, if it was conducted (discussed below), simply because of the greater lumber volume loaded. However, it is possible that the production cost ($/$m^3$) would be reduced because of the greater capacity. A positive aspect of stickers with over-thickness, however, is the increased airflow between layers of lumber, which favors the reduction of the drying cycle, and similarly, the production cost ($/$m^3$). This assessment can be the objective of further research. Another positive aspect is that wider stickers have longer life span than narrower ones, because of the greater mechanical strength.

The distance between the stickers and therefore their number per layer (between 400 and 800 mm) was according to what was proposed by Hildebrand (1970) for 30 mm thick boards. However, the alignment between the stickers of different layers was variable, which can cause destabilization of the lumber stack, and warping during the drying cycle.

The location of the stacking was approximately 100 meters away from the kilns, and the transportation of the lumber stacks was carried out by a tractor forklift. The ground was slightly uneven, so the transportation caused some movement of the boards in the stack, because of vibration, which affected stack quality. The same situation was reported for three kilns loaded by forklift (DUCATTI et al., 2001).

Another negative aspect of the stacking was the uneven number of bolsters (three) at the base of the lumber stack and stickers (five) between layers, which may also cause deformation in the boards during stacking and warping during drying. This was also one of the major stacking problems noted by Anjos et al. (2011).

The lumber stacks were placed in the kiln trucks with the same tractor, and when necessary, stacks would be manually reorganized, particularly the upper layers (Figure 2). After that, the kiln trucks were slowly pushed into the chamber by the tractor. It is noteworthy that a horizontal gap of about 500 mm was left between the ends of the lumber stacks (tops of boards), which causes problems in the air circulation, reducing the kiln capacity and thus the productivity of dried lumber.

The preparation of the lumber stacks is one of the most important stages of the drying process, but in general it is one that has been most neglected by mills, as observed in this study and reported in the literature for other Brazilian mills (ANJOS et al., 2011; DUCATTI et al., 2001; SALES-CAMPOS et al., 2000).

Drying schedule

As mentioned, the mill does not perform any kind of moisture content control of the lumber, either before, during or after drying. Thus, it was not possible to calculate any drying gradient (wood moisture content/equilibrium moisture content) during the evaluation. The decision of when the wood reaches the desired final moisture content, which in this case was supposed to be 12-14%, was made by the kiln operator who relied on his own experience to determine when the drying process should be interrupted.

A similar situation was reported in Sinop (Mato Grosso, Brazil), because in seven out of the 12 companies evaluated, no moisture control was performed; and in three mills sensory control was employed, in such cases in visual form (Anjos et al., 2011).

The drying schedule adopted was based on time-temperature, conducted in accordance with the experience acquired over the years by the mill's managers. Controlling the drying was manual and conducted by the kiln operator on duty; at each hour, he recorded temperatures of Tdb and Twb in a spreadsheet, and handled the flow of steam and the opening of dampers to achieve the desired environmental conditions in the kiln.

The drying schedule was divided into many steps (15), which is not common for the time-temperature schedule type (Simpson, 1991). The mill did not perform an initial heating step of the lumber, starting the schedule at 40 °C Tdb and 36 °C Twb, resulting in relative humidity (RH) and equilibrium moisture content (EMC) of 77% and 14.1%, respectively. Although pine wood is considered easy to dry, tolerating the psychrometric difference adopted in the first program phase, the initial heating step is important for uniform heating of the whole system (kiln + charge) and decreasing the variation of the initial drying rate between the boards, minimizing the moisture gradient and therefore the drying stresses.

Tdb was gradually increased up to the maximum of 86 °C and Twb to 82 °C in the last phase of the drying schedule, resulting in RH and EMC of 84% and 12.5%, respectively. In 10 out of the 15 steps, the psychrometric difference (PD) adopted was equal to four; equal to six in two steps; equal to eight in two steps, and equal to 10 (maximum) in one step only, when the elapsed cycle was about 12 hours.

Therefore, the drying schedule was not designed for the progressive increase in PD between steps, which would make the hygrometric conditions in the kiln favorable to drying during the cycle. In fact, the drying did not seem to be conducted according to a specific schedule, but according to the kiln operator's experience.

The average drying cycle performed by the mill was 60 hours for 30 mm thick boards. In accordance with this, the drying schedule adopted was inappropriate from a technical standpoint and it can be significantly improved. A different situation was observed by Ducatti et al. (2001), who considered appropriate the drying schedules used by three mills drying tropical lumber, but they highlighted the need to improve the stages of equalizing and conditioning.

As reported in the literature on drying species such as *Pinus* spp. grown in Brazil, the initial Tdb of the drying schedule may be greater than the 40 °C adopted by the mill, potentially being, at least, 55 °C (CULPEPPER, 2000). For the species *Pinus elliottii* and *Pinus taeda*, it is recommended to start with a Tdb of 60 °C and 76.5 °C, for drying schedules aiming at "high-quality" or "regular", respectively (BOONE et al., 1988). The final Tdb adopted (86 °C) may be maintained in accordance with the required quality standard. Likewise, Boone et al. (1988) recommended final Tdb of 82 °C and 87.5° C for these species, according to the quality standard required.

The PD should also be adjusted by gradually increasing it during drying, as well as conducting the initial heating step. In accordance with the required quality, the steps of equalizing and conditioning can be programmed. However, for this it is essential to convince the mill's managers to perform moisture control of the lumber throughout the process.

Unfortunately, no consideration can be made regarding the drying gradient (DG), because the mill did not perform moisture control of the lumber. Nevertheless, according to the literature, the DG for species of *Pinus* spp. varies between 3.1 and 5.2 (HILDEBRAND, 1970), respectively for more conservative and more severe drying schedules in accordance with the properties of the wood and the required quality standard. The use of a suitable drying schedule surely shortens the drying cycle and increases the quality of the dried lumber, making the process more profitable.

The drying schedule did not include the steps of equalizing and conditioning, and the mill also did not perform any evaluation of drying stresses or moisture gradient. Ducatti et al. (2001) also reported that the three mills evaluated in their study did not perform any kind of assessment or registration of the quality of the dried lumber, or even the final moisture content, moisture gradient, residual stresses and defects.

Evaluation of the quality of dried lumber

The only evaluation of the quality of drying performed by the mill was regarding the presence of defects, especially warping. The average volume of lumber with drying defects considered unacceptable was equal to 1.1418 m^3, represented by approximately 108 boards per load or 5.30% of the loads, which was a low rate when considering kiln drying in industrial scale. For example, warping ratios of 33.4%, 45%, 46% and 50% were observed of the total boards sampled of tropical lumber in four different kilns (DUCATTI et al., 2001).

Some factors contributed to the low rate of defective boards evaluated. The first is that a larger number of boards had defects but were classified as acceptable according to a flexible quality standard. On the other hand, the methods adopted by other authors (DUCATTI et al., 2001) have quantified the warped boards regardless of the degree of defect.

Another point to consider is that the drying schedule used may be considered too mild for the species *Pinus elliottii* and *Pinus taeda*, resulting in a low incidence of defects. For example, the initial Tdb of 40 °C has been recommended for the drying of juvenile wood of eucalypt species (BATISTA et al., 2013), which are known to be more difficult to dry than pine species.

Presumably the warping occurred mainly by low quality of the stacking performed, with misaligned stickers between the layers, in addition to the lower number of bolsters (three) relative to stickers (five).

The operators also graded boards with wane, which represented an average of 4.01% of the loads or about 82 boards per load. Although the volume of declassified boards was considerable (9.31%), all this wood was sold at a lower price to other customers, which produced sofas, upholstered chairs and internal components for furniture.

Conclusions

The initial hypothesis that the mill lacks technical knowledge to carry out kiln drying of wood was confirmed.

The lack of moisture content control in any of the steps was the most serious problem analyzed regarding to the drying process. Therefore, the mill needs to invest in moisture content control by automation (sensors pins) or adopt the practice of control with kiln samples. The drying schedule adopted for *Pinus taeda* and *Pinus elliottii* species, corresponding to the final moisture content required (12% to 14%), should be revised.

The low quality of stacking was the second most serious problem observed, where the mill should invest in training manpower for that sector. The transport of the lumber stacks by tractor, which is performed with a considerable distance between the stack preparation area and the kilns, is a problem more difficult to solve because it involves reorganizing the physical space of the mill's facilities.

To make better use of the capacity of the kilns, it is necessary to repair the kiln trucks, reduce the cross section of the stickers and dry longer boards, according to the length of the kiln trucks.

Regular maintenance is recommended for all equipment and components of the kiln systems (heating and air circulation), as well as installing a system for humidification by sprinkler, given the physical characteristics of the kilns.

Essentially, the improvements needed by the kiln drying units of the mill depend on investment in skilled people in process management positions. The industry must undergo constant reassessment and adjustment, by installing a continuous program of quality control.

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