HOUT 456

Increasing the efficiency

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Increasing the efficiency of high temperature drying

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SUMMARY

The drying efficiency of a commercial high temperature kiln was evaluated for the drying of structural pine timber. Various factors affecting drying efficiency were evaluated and their effects on dried board quality demonstrated. Significant gains in attainable V4 graded board volume were attained with modifications to heating system (9,9%), vertical control of booster coils (7,2%), end baffling of stacks (7%) and segregation of boards (4,4%).

OPSOMMING

Die drogingsdoeltreffendheid van 'n kommersiële hoë temperatuur droogkamer is geëvalueer vir die droging van dennekonstruksiehout. Verskillende faktore wat drogingsdoeltreffendheid beïnvloed is geëvalueer en hul invloed op gedroogde houtkwaliteit gedemonstreer. Beduidende winste in behaalbare V4-gegradeerde plankvolume is behaal d.m.v. veranderings aangebring aan verhittingstelsel (9,9%), vertikale kontrole van verhittingsklosse (7,2%), endskot van stapels (7%) en segregasie van planke in stapels (4,4%).

KEYWORDS

High temperature drying; drying degrade

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1. INTRODUCTION

High temperature (HT) drying is characterised by the use of high dry bulb (DB) temperatures (> 100 °C), large wet bulb (WB) depressions (> 30 °C) and high rates of air circulation (4 to 7m s-1) These severe drying conditions enable the attainment of very rapid drying rates. Compared to drying at conventional temperatures below 100 °C, 2 to 5 times shorter drying cycles are generally attained with the former. These benefits resulted in the increasing use of HT drying processes by industry for the drying of structural timber, since its first introduction in South Africa in the mid seventies. Some scepticism on the use of HT drying is, however, being voiced by industry. This is mainly due to one or a combination of the following factors:

- Variations in moisture content (MC%) of as large as 5 to 30 % that can occur after drying between and within stacks in a kiln charge and even between boards within a single board layer. This is seen as a direct result of the very rapid drying rates achieved as compared to drying at conventional temperatures, where the effect of the former on variability of final MC% distribution is proportionally accentuated due to material differences (MC% and density) and variability of kiln conditions. The image of HT drying has furthermore been harmed by the generally adopted practice of overdrying the timber in an attempt to narrow the final MC% range of the dried material, resulting in an increase of all forms of shrinkage associated drying degrade, and notably that of twist.

- Drying of timber to very low final moisture content, i.e. overdrying. This is due to the very low equilibrium moisture contents (EMC) created during HT drying (generally between MC% of 1,6 to 2,6 %) and which could easily result in overdrying if the drying process is not terminated in time.

High temperature, as a result, is labelled as producing overdried timber or timber of very variable moisture contents. This is, however, not a fair reflection on the capabilities of a HT drying process. It would be more correct to state that, due to the very rapid drying rates achieved, factors influencing its drying rate become more critical as compared to drying at conventional temperatures. In particular most of the present inefficiencies encountered with HT drying operations can directly be related to inefficient drying practices, e.g. inefficient stacking, uneven air and heat distribution in kiln, lack of moisture content control.

This study is directed towards evaluating and improving the efficiency of an industrial HT kiln.

2. EXPERIMENTAL PROCEDURE

The study was undertaken in an industrial HT kiln with which problems were experienced with regard to a high rejection rate of both MC% and twist. The kiln and stack details were as follows:

Building:	Al panels with glass fibre insulation, steel construction
Tracks:	2
Stack holding capacity:	8
Fans:	Overhead axial fans. Fans were reversed every hour.
Steam radiators:	Overhead radiators on both sides of fans, booster radiators between tracks.
Control:	Cam operated kiln recording/controlling instrument. Separate control for booster and top radiators, with front half of kiln further separately controlled from back half of kiln. One WB control for vents and steam sprays.
Stack dimensions:	Height 3,3 m Width 2,4 m Length 6,6 m
Sticker thickness:	29 mm

Six drying runs were undertaken with 50 x 152 mm material, consisting mainly of *P. patula* (± 90%) clearfelling. For the Control Run and for Runs 1 to 3, log diameters ranged from 27 to 29 cm and for Run 4 to 5, 33 cm. The purpose of the drying runs was as follows:

Control: 600 mm wide baffles on one side of stacks
Heating system was extensively modified after this run, to ensure efficient steam trapping and steam distribution to radiators in kiln. (However, still insufficient booster coil capacity serving stack layers 35 - 40.)

Run 1: 600 mm baffles as for control
Effect of modified heating system on moisture variation in kiln.

Run 2: 1200 mm baffles on one side of stacks

Run 3: 1200 mm baffled on both sides of stacks
Sticker thickness reduced to 22 mm

Run 4: 1200 mm baffles as for Run 2
Half of the stacks were segregated according to both stack and drying characteristics as described by Stöhr (1983)

Run 5: 1200 mm baffled as for Run 2
Stacks partially segregated
Kiln control of booster coils split into two separate vertical sections

Air velocity measurements (at ambient temperature) were done according to a grid pattern across the height and length of the stacks. Air velocity values at corresponding measurement locations/stack were averaged to obtain an air distribution pattern as represented by a stack.

A constant drying schedule of 115 °C DB and 75 °C WB was used for all the runs. Drying was terminated upon sample boards, extracted via inspection windows, attained a MC% of 12 %.

After drying, stacks (three to six stacks) originating from different positions in the kiln were selected. From these stacks, the following complete board layers were sampled (starting from topmost layer): Layers 1 (i.e. second layer from top), 5, 10, 15, 20, 25, 30, 35, 38 (or layer 40 for Run 3). These boards were then measured for MC% and twist, and further graded for structural timber according to SABS-1978 (as amended 1980) and according to the following downgrading factors:

-	Drying degrade:	MC%, twist, bow, spring, checking
-	Non-drying degrade:	Knots, wane, dimension, mechanical damage

The 1986 SALMA structural timber price list was used in determining the economical effect of degrade treatment. In all cases where boards failed structural board quality, these boards were, for calculation purposes, regarded as meeting black cross standards. Furthermore, boards that failed the structural grade due to both drying and non-drying degrade, were regarded as having failed only due to drying degrade.

The boards for the control run were only measured for moisture content, with the downgraded volume being obtained from mill records. Further, due to unforeseen circumstances, only layers from one complete stack (segregated) and from two partial complete stacks (not segregated) could be graded for Run 5. The information gathered from the latter, though incomplete, is still included to serve as a pointer of the effect of this treatment.

The number of boards graded for each treatment is shown in Table 1.

3. RESULTS

3.1 Air circulation

Endbaffling stretched across the full stack height and was erected across both stack ends and the kiln ends and across intermediate adjacent stack ends. The sides of the baffles extended for each baffle width just past the relevant sticker rows. This enabled the latter to act as a baffle within the stack.

The end baffles were intended to serve the dual purpose of:

- preventing air short circuiting past the ends of the stacks and hence more efficient utilization of the available air volume through the stacks.

- reducing the rate of drying at board ends. This would prevent overdrying of the latter, a common cause for end checking. It also offers a possibility of degrade reduction due to twist (Stöhr 1983).

The use of end baffling brought about a significant increase in air circulation rate (Table 2). Air circulation rate was increased by 0,8 ms-1 with the use of 600 mm wide baffles and by a further 1 ms-1 with a baffle width of 1,2 m. The former was, however, not affected by placing baffles at one or both sides of the stacks. The highest air circulation rate was obtained with 22 mm stickers (as compared to 29 mm stickers of the other treatment) and with the use of 1,2 m baffles.

The higher air circulation rates produced by end baffling are maintained across the full unbaffled stack length portion (Figure 1). End baffling also produced a more even airflow, except in the vicinity of the baffles where very high airflow rates occurred (Table 2, Figure 2). For stacks baffled on one side, air entry to the stack does, however, still take place across the full stack length (Figure 3).

The vertical air distribution of the central 3 m stack portion (to avoid stack end effects) is shown in Figure 4. The former is characterised by a fairly even air distribution in the central stack portion, with a steep increase in air circulation rate towards the top of the stacks in especially the unbaffled treatment. Air circulation further either decreases (unbaffled treatment, no bottom baffles) or increases (bottom baffles on air exit side installed) towards the stack bottom. Baffling and/or the use of thinner stickers did not appear to contribute significantly towards attaining a more even vertical air distribution.

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On the air entry side of the stacks the air circulation rate for the end baffled treatments decrease towards both the top and the bottom of the stacks (Figure 5). The latter could be attributed to both top and bottom baffles only being installed on the exit air side of the stacks. This could also explain the higher air circulation rates at the top and bottom of the stacks at the stack air exit side.

From the results it appears therefore that:

- air circulation rate through the stacks is significantly increased with the use of end baffles, ranging from an increase of 27,2 % (600 mm wide baffles) to 59,6 % (1200 mm wide baffles at bottom stack sides) as compared to that of unbaffled stacks (Table 3).

- benefits attained from end baffling are considerably less when only baffled on one stack side (Table 2). The latter also allows for some air circulation to occur behind the baffled of stack portion. The more efficient approach of baffling opposite stack sides appears, however, impractical to implement in practice (due to limited space between booster coils and stack sides).

- variability of air circulation rates reduced with the use of baffles.

- longitudinal top and bottom baffles are required at opposite stack sides to enable the attainment of a more even vertical air distribution.

3.2 Moisture content

All the boards in the sampled board layers were measured for moisture content. The bottommost layer sampled (generally layer 38) coincided with the height of the walkway in the kiln due to the insufficient height of the trolley base supports. The latter is, however, also fairly common practice by industry to attain benefits of increased stacked board volume. Hence, its inclusion in this study.

Total drying time was relatively unaffected by treatment (Table 4), with the largest difference in drying time (13,9 %) between the control and Run 5. For Run 2 and Run 3 drying was extended by one and two hours respectively to ensure board ends being satisfactorily dried behind the baffles. Hence, end baffling of especially at both stack sides (Run 3) appeared successful in retarding end drying. However, the additional drying time required also resulted in the attainment of lower overall stack moisture contents. No further drying of board ends was, however, required for Runs 4 and 5.

Except for Run 5, a large variation in moisture content is evident in the dried material. This is attributed to differences in drying rates as a result of one or a combination of the following factors:

- Effect of stack position in kiln
- Stack height effect
- Stack width effect

As the above are influenced by different factors. they will be treated separately.

3.2.1 Stack position effect

The HT kiln under study, having a capacity of eight stacks is considered unusually large for a HT kiln. This places additional stress on evenness of steam distribution to the radiators across the kiln length to enable the attainment of equal drying rate of the stacks placed at different positions in the kiln.

In the control run a large variation in MC% occurred between the stacks positioned at the kiln inlet side (Figure 6) as compared to those positioned at the kiln exit side (Figure 7). Except for the lower stack portions, the largest part of the latter was overdried ($\leq$ 7 %), whereas the largest part of the stacks at the kiln entry side was underdried (> 17 %). If the drying period had been extended to cater for the wet material at the kiln entry side, the stacks at the kiln exit side would have been overdried further. The latter would, in turn, have lead to increases of degrade due to twist.

The modifications made to the heating system to counter the above drying differences were evaluated during Run 1. The former brought about a clear improvement in attaining uniformity of drying rate between the kiln exit and entry sides (Figures 8 and 9). Differences in MC% did, however, still occur with the kiln inlet side now tending to dry to lower moisture contents as compared to the kiln outlet side. The largest variations in MC% are, however, attributable to vertical moisture differences in stacks (Figures 10 to 15).

3.2.2 Stack height effect

Differences in drying rate due to stack height are the result of uneven vertical

- air distribution
- temperature distribution

Runs 1 to 4 are characterised by both over and underdrying in the same stack portion. Overdrying is particularly severe in the top five layers, whereas the former further extends to the top half of the stack (Run 4). In Run 3 the largest proportion of the boards of the top 3/4 of the stack was overdried. The extent of underdrying generally increased with a decrease in stack height, with the largest percentage underdried material occurring at the bottom of the stacks.

Treatment effects of end baffling, thinner stickers and segregation did not appear to exert any marked difference on the extent of vertical moisture distribution. It further also appears that extension of drying time leads to a relatively small decrease in the proportion of underdried material, but at the cost of a large increase in overdried material (Run 3).

A significant improvement in the vertical moisture distribution was brought about with separate control of booster coils (Run 5). The latter also nearly completely eliminated overdrying. Underdrying is, however, still evident and occurs at and near the bottom of the stack. This is mainly attributed to booster coil inefficiencies mentioned earlier. This, however, also points to the fact that:

- top level of base supports should be such as to lift the bottommost board layer to above walkway level.

- vertical difference in coil capacities cannot simply be rectified via separate vertical booster coil control.

3.2.3 Stack width effect

The moisture gradient across the stack width decreases with a decrease in moisture content (Figures 16 to 21). Relatively small moisture gradients generally occur in the top 30 layers. This is especially the case for Run 5, where only small differences in moisture content occurred in that stack portion.

As the moisture gradient across the stack width is predominantly affected by the extent to which the layers have been dried, specific treatment effects are obscured.

From the foregoing it can be concluded that:

- modifications made to heating system and separate vertical control of booster coils were the dominant factors in attaining a more even MC% distribution within and between stacks in the kiln.

- factors of end baffling, segregation and sticker thickness played a minor role in moisture distribution. It does, however, also appear that 22 mm stickers could replace the 29 mm stickers without loss in drying efficiency. The former would also contribute towards negating the loss in stacked board volume by the required increase in base support thickness.

4. GRADED BOARD QUALITY

The extent of volume and value loss due to drying and other downgrading factors is shown in Table 5. From the results it is evident that:

- differences in treatment had a marked effect on drying degrade.
- the major drying downgrading factors are those due to twist and moisture content.
- drying degrade is of much greater economic importance as that due to other board downgrading factors.

In determining the effect of treatment on the extent of drying degrade, the following has to be taken into consideration:

- Log quality difference for Runs 4 and 5 as compared to the other runs. The effect of treatment is hence only meaningful if made between the control to Run 3 and between Runs 4 and 5.

- Downgrading due to bow and spring cannot be related to treatment effects. Comparison of the latter should hence be based on downgrading due to twist and moisture content and not on the total drying downgraded value. Further, as twist and moisture content are interdependent, these factors cannot be separated, but their combined downgraded value considered indicative of treatment effect (Table 6).

Accordingly, it appears that:

- modification of the heating system (control vs. Run 1) increased V4 grade by 9,9 %.

- using 1,2 m end baffles on one side of the stacks (Run 1 vs. Run 2) further increased V4 grade by 7 %, giving an additional return of R3,91/m³ dried material.

- using 1,2 m end baffles on both sides of the stacks (Run 2 vs.

Run 3) further increased V4 grade by 0,7 %, giving an additional return of R0,40/m^3 dried material.

- segregating boards in a stack increases V4 grade by 4,4 %, giving an additional return of R2,51/m^3 dried material.

- vertical control of booster coils (Run 4 segregated vs. Run 5) increases V4 grade by 7,2 %, giving an additional return of R3,97/m^3 dried material.

The efficiency of HT drying can hence be improved greatly in ensuring an efficient heating system, vertical control of booster coils, end baffling (1,2 m width on one side of stacks) and segregation. The returns on the investments to bring about the above in industrial systems are high enough to guarantee a relatively short payback period (four to six months).

It is, however, also apparent that the efficiency of HT operation can still be further increased via more efficient final moisture content control.

5. CONCLUSIONS

This study has shown that a relatively inefficient HT kiln can be converted to an efficient drying system by following certain basic drying principles. In order of the importance of their effects on dried board quality, these are:

- Ensuring a heating system with equal radiation efficiency in all parts of the kiln.

- Vertically controlling booster coils in two separate units.

- End baffling the one side of stacks with 1,2 m wide baffles to reduce end drying rate.

- Segregation of boards in a stack according to both stack end board drying characteristics.

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