DRYING PINE LUMBER AT VERY HIGH TEMPERATURES AND AIR VELOCITIES

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ABSTRACT

Dry-bulb temperatures and air velocities above those typically found in industrial pine kilns were used to reduce drying time in an experimental kiln. Experimental accelerated schedules employed temperatures of 265 and 300 F and air velocities of 1,200 and 2,000 feet per minute (fpm). Additional charges were dried at a temperature commonly used in industrial kilns (230 F) and at air velocities of either 1,200 or 2,000 fpm. Regression analysis showed that air velocity, dry-bulb temperature, and final moisture content had a significant effect on drying time. For example, drying time at 300 F, 2,000 fpm, was nearly half that at 230 F, 1,200 fpm. In the experimental kiln, rapid drying did not require more heat than slower drying.

Keywords: High-temperature drying, southern pine, drying energy, moisture content variation.

INTRODUCTION

Southern pine dimension lumber dried at high temperature does not have significantly different strength, stiffness, or toughness from similar lumber dried conventionally (Koch 1971; Yao and Taylor 1979). Also, high-temperature drying does not significantly increase drying degrade (due to warp) over that which occurs in conventional low temperature drying (Price and Koch 1980). The effect of high-temperature drying on mechanical properties was reviewed for several species by Salamon (1969). Approximately one-half of the studies reported that high temperatures caused no significant changes in the wood properties being measured, and the other half reported some small, but significant, reductions. However, most of the studies that did result in a significant reduction in strength properties exposed the wood to high temperatures longer than necessary for normal high-temperature drying (Hartley 1975).

OBJECTIVE

The objective of this study was to demonstrate the effects of high temperatures and air velocities on drying time for pine dimension lumber. Experimental studies have indicated that drying time can be reduced by using either higher temperature or increased air velocity (Herzberg et al. 1985; Price and Koch 1981). If the drying schedule can be accelerated to reduce drying time without decreasing lumber quality, commercial implementation of the process would increase the cost efficiency of producing lumber.

APPROACH

Although research has experimentally proven that drying time can be reduced by using high temperatures, such research has taken place in small experimental dryers with narrow load widths and short lengths of lumber. The rate of energy

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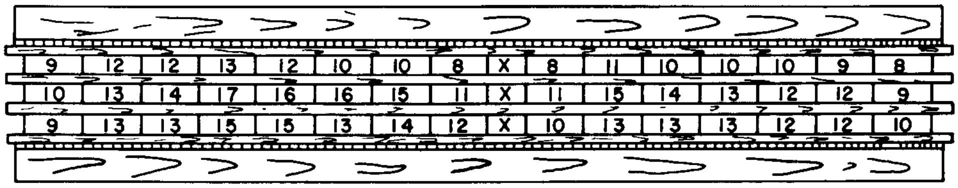

FIG. 1. End view of kiln charge showing plywood platforms (top and bottom), three layers of lumber (15 pieces wide), and ¾-inch stickers. Numbers are average final moisture content values for the 12 boards dried in that position by the accelerated schedules (265 F and 300 F). Note the x's near the center which indicate the location of the spaces between boards.

consumption and the amount of time required to dry in experimental dryers cannot be accurately extrapolated to larger, commercial kilns. Laboratory experiments should be repeated in commercial kilns. However, commercial kilns cannot readily be used to evaluate accelerated drying because they lack the capability for increased temperature and air velocity. Therefore, experimental schedules were evaluated in a research kiln large enough to dry standard-size lumber in a commercial width package. This was assumed to produce reasonable estimates of drying time and energy consumption.

PROCEDURE

An experimental kiln at the Mississippi Forest Products Utilization Laboratory was modified to permit control of temperature and air velocity in the ranges chosen for the accelerated drying experiment. Modification included increasing insulation, adding electrical resistance heaters, adding fan blades, and increasing fan horsepower.

Experimental charges consisted of 45 pieces of 12-foot-long 2- × 6-inch dimension lumber selected from the green chain of a local sawmill. The lumber was stacked in 3 layers, 8 feet wide, separated by ¾-inch-thick stickers spaced at 2-foot intervals. Boards were placed side-by-side without space except for one small space near the center of each layer to permit vertical alignment of edge boards. Top and bottom layers were separated from a plywood cover and support platform by ¾-inch stickers (Fig. 1). Three charges were dried per combination of 265 and 300 F temperature, and 1,200 and 2,000 fpm air velocity through the lumber (12 total charges).

Two additional charges were dried at a temperature commonly used in industrial kilns (230 F), but with the same air velocities used for the accelerated schedules (1,200 and 2,000 fpm).

When the green lumber was being stacked, each piece was weighed. After drying, the lumber was removed from the kiln, cooled for 24 hours, and reweighed. The moisture content of each piece of dry lumber was estimated by a series of electrical resistance meter readings. Moisture meter readings were made at the center and 18 inches from the ends of each piece.

The green weight, dry weight, and moisture content values for each piece were used to calculate other properties. Oven-dry weight was calculated. From this value, the green moisture content and specific gravity of each piece were calculated. Calculated specific gravity values are believed to be reasonably accurate because the green dimensions of pieces were quite uniform in size.

TABLE 1. *Average values of variables measured or controlled for individual charges.*

Drying temp. (°F)	Air velocity (fpm)	Drying time (h)	Final MC (%)	Green weight (lb)	Final weight (lb)	Calculated dry weight (lb)	SG	Green MC (%)	Water lost (lb)	Thermal energy (Btu's × 10^6)	Energy per lb H_2O evaporated (Btu's)	Final TDAS (°F)
300	2,000	6.50	13	2,471	1,303	1,151	0.47	114	1,168	2.220	1,901	35
300	2,000	6.67	13	2,485	1,287	1,131	0.46	121	1,198	2.304	1,923	31
300	2,000	7.00	11	2,476	1,250	1,131	0.46	121	1,226	2.390	1,949	29
300	1,200	9.50	8	2,493	1,314	1,215	0.49	107	1,179	2.316	1,964	27
300	1,200	9.00	10	2,476	1,303	1,182	0.48	110	1,173	2.200	1,876	32
300	1,200	8.50	11	2,396	1,270	1,144	0.46	112	1,126	2.167	1,925	34
265	2,000	7.17	15	2,443	1,365	1,188	0.48	107	1,078	1.829	1,697	23
265	2,000	8.50	11	2,469	1,287	1,164	0.47	113	1,182	2.102	1,778	18
265	2,000	8.17	12	2,410	1,261	1,127	0.46	113	1,149	2.030	1,767	20
265	1,200	10.33	12	2,485	1,325	1,188	0.48	111	1,160	2.212	1,907	23
265	1,200	10.17	17	2,410	1,365	1,160	0.47	108	1,045	2.237	2,141	29
265	1,200	11.00	11	2,474	1,369	1,235	0.50	102	1,105	2.443	2,211	25
230	2,000	10.00	13	2,394	1,336	1,188	0.48	103	1,058	2.072	1,958	22
230	1,200	13.00	13	2,471	1,322	1,208	0.49	106	1,109	2.567	2,315	13

Dry-bulb and wet-bulb temperatures and total weight of the experimental charge were monitored and recorded with a data logger at 10-minute intervals during drying. Temperature of the air was measured by thermocouples in the plenum chamber on each side of the load. Thermocouples were also placed at the edge of the stack to monitor the entering and leaving air temperature, to determine the temperature drop across the stack (TDAS), in the conduits formed by lumber and stickers. Four thermocouples on each side of the stack were used to monitor temperature across four conduits of each charge.

Air velocity was determined by Pitot tubes located in the stream of air passing through the lumber. Air velocity was measured during drying.

Drying energy was measured by the use of meters on the electric heater circuits, and steam energy use was measured by the method described by Taylor (1982).

The target moisture content to which the charges were dried was 12%. However, in high-temperature drying it is very difficult to stop drying at a given final target moisture content. Neither drying time, TDAS, nor relative humidity of the kiln are precise indicators of average charge moisture. It was especially difficult to determine the end-point for drying these experimental charges since lumber had not previously been dried at the high experimental temperatures and air velocities. The weight of experimental charges was monitored during drying, but weight is not a precise estimator of moisture content because of variations in specific gravity.

RESULTS

Drying time

Dimension lumber was dried quite rapidly at high temperatures and air velocities (Table 1). The quality of dried lumber was not measured in this study. However, subjective evaluation revealed no unusual degrade. In fact, lumber appeared to have less warp than commercially dried lumber. Rapid drying was possible because dry-bulb temperature was reached very quickly after start-up. Such quick heating was possible because a relatively small charge of lumber was used, electric strip heaters provided supplemental heat during the early stages of drying, and the kiln was completely preheated. The kiln temperature was above the boiling point of water almost immediately after start-up. In every charge, setpoint was approached within an hour.

The time required to dry charges at 300 F varied from 6.5 to 9.5 hours, depending upon the moisture content to which the charge was dried and upon the air velocity. Multiple regression analysis showed that air velocity, final moisture content, and temperature were significant factors affecting drying time and were related by the equation:

$$\mathrm{D} = 30.5 - 0.0030\mathrm{V} - 0.1552\mathrm{F} - 0.0543\mathrm{T}; \qquad R^2 = 0.96 \qquad (1)$$

where:

D = drying time (hours)
V = air velocity (feet per minute)
F = average final moisture content (percent)
T = temperature (F).

Average initial (green) moisture content of the charge, average specific gravity, and amount of water removed during drying had no significant effect on drying time. Predicted times deviated from actual drying times by 3.7%, on the average. The minimum deviation was 0.1% and the maximum was 8.5%.

Drying curves

Because of the wide variation in the final moisture content, actual drying times are not completely comparable. To adjust for differences in the green and final moisture contents among the charges, moisture content was expressed as the relative moisture content (E), defined as:

$$\mathrm{E} = \frac{\mathrm{M} - \mathrm{Me}}{\mathrm{Mo} - \mathrm{Me}}$$

where M is the moisture content of the charge as determined by load cell measurements, Mo is the initial moisture content of the charge, and Me is the equilibrium moisture content of the kiln. The equilibrium moisture content of the kiln was estimated using the wet-bulb and dry-bulb temperatures (Kauman 1956), and varied from 1.0 to 2.5% EMC. Relative MC is not equivalent to the average MC based on dry weight, but it is close because the average initial MC of the southern pine lumber used in this study is 111% and the EMC conditions in the kiln were near zero. Mean drying curves for each of the six drying schedules used are presented in Fig. 2. Each curve represents the average drying rate exhibited by three charges dried at that schedule, except for the 230 F schedules, which represent only one charge. Drying curves are steeper for higher temperature and higher air velocity schedules. The time to dry to a relative moisture content (E) of 0.15 at 300 F and 2,000 fpm is almost half (6.1 hours) that required when drying at 230 F and 1,200 fpm (11.5 hours).

End point estimation

Neither TDAS nor total charge weight was sufficient for the determination of final moisture content (final target moisture content 12%). The influence of dry-

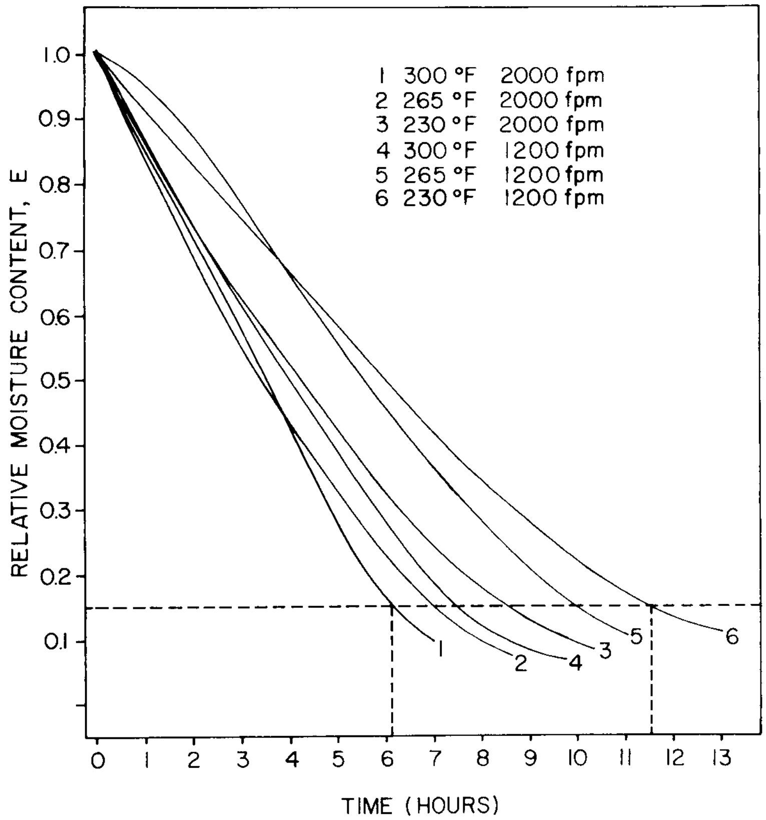

FIG. 2. Drying curves for each of the six drying schedules. Each drying curve represents the average drying rate of three replications, with the exception that only one charge was dried at each of the 230 F schedules.

bulb temperature and air velocity on the TDAS made the accurate estimation of desired final moisture content difficult.

The total charge weight was not useful for estimating actual moisture content because of variations in initial moisture content and specific gravity. Final charge weight, determined by weighing each piece of lumber (Table 1), was not strongly correlated to final moisture content. There was a trend for heavier charges to have a higher moisture content, but the correlation was not strong ($R = 0.467$).

In a production kiln, where larger loads are repeatedly dried in the same configuration, either charge weight or TDAS may be used to develop an accurate method for determining final average moisture content. However, results of this study indicate that they are not precise research tools for determining accurate moisture content of small charges.

Drying energy

Total thermal energy consumption varied considerably among charges dried by similar schedules, but there was no recognizable pattern associated with drying temperature or air velocity (Table 1). Statistical evaluation of the average data showed that neither the total thermal energy used to dry charges nor the Btu's

TABLE 2. *Average final moisture content of 15 pieces of lumber dried in each layer, for 12 charges.*

Drying temp. (°F)	Air velocity (fpm)	Top layer	Middle layer	Bottom layer
300	2,000	9.3	14.3	15.2
300	2,000	10.5	15.0	13.6
300	2,000	10.0	10.4	11.3
300	1,200	6.7	9.1	8.6
300	1,200	8.6	10.5	11.3
300	1,200	10.3	11.3	11.5
265	2,000	12.5	16.7	15.9
265	2,000	9.8	11.8	9.9
265	2,000	11.1	13.1	11.1
265	1,200	11.1	13.3	11.1
265	1,200	14.2	20.5	17.6
265	1,200	8.9	12.2	11.3
	Average	10.2	13.2	12.4

per pound of water removed were significantly different among air velocities or temperatures. The relationship of kiln volume and wall surface to the lumber volume in the experimental kiln was much larger than for commercial kilns. Studies on a different scale are needed to determine more precisely the effect of accelerated drying on energy consumption. These results indicate that, although accelerated drying requires more heat capacity to reach and maintain higher temperatures, no more total energy is required.

Influence of board location on drying

Values for each board parameter were segmented into specific stack locations, as illustrated for average final moisture content values in Fig. 1. By knowing the position of each piece of lumber in the stack, there was an opportunity to evaluate the influence of position on drying. Lumber on the top layer dried to the lowest average moisture content and lumber in the center layer dried to the highest average moisture content (Table 2).

Such drying differences for layers were expected. One side of the lumber on both top and bottom layers was adjacent to air conduits (sticker spaces) bounded by completely dried plywood rather than another piece of lumber. Air passing through these conduits remained hotter because moisture was evaporated from only one side. Also, air velocity in these conduits may have been different from conduits in the interior of the stack. Therefore, temperature and air flow measurements were made on only interior conduits and, for moisture content variation analysis, only lumber in the center course was considered. The assumption is that lumber in this course was subjected to conditions similar to interior courses in larger charges.

Pieces located on the edge of the stack were lower in final moisture content than interior pieces (Fig. 1). Statistical analysis showed that the average values of 9 and 10% final average moisture content for the edge pieces of the center layer were significantly lower than the average values for pieces dried in the interior positions of the center layer.

There was also a noticeable moisture content reduction for pieces adjacent to the "flue" near the center of the stack (Fig. 1). The flue resulted from maintaining a constant stack width for every kiln charge. Constant width was maintained by laying edge pieces exactly 8 feet apart. Interior pieces were adjacent to the edge pieces with all the accumulated space left between the center pieces of each layer. The width of this space, about 4 inches, varied with rough green width and crook.

Possible explanations for greater drying of center course pieces near the "flue" are: (1) hotter air from top and bottom conduits mixed in the flue, (2) one edge and two sides were exposed to the air stream, and (3) greater air turbulence existed near the flue. Mixing of hotter air from top and bottom conduits seems an unlikely explanation, because the pieces adjacent to the flue in these layers were also lower in moisture content than other pieces in the interior of these layers. Future studies should evaluate the effect of intermittent spacing of lumber pieces on drying rate and moisture uniformity.

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