Continuous Tunnel Kiln Direct-Fired With Bark to Dry 1.75-Inch Southern Pine in 12 Hours

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Abstract

Length-sorted lumber is surfaced on one side to 1.75-inch thickness, mechanically stacked 5 feet wide and 10 feet high on 1-1/4-inch-thick sticks, and continuously transported through a zone-controlled tunnel kiln at 8 ft./hr. to yield 500,000 fbm of lumber dried to 9 percent average MC per 168-hour week. In the tunnel, the lumber is dried for 8 (possibly 10) hours at 270°F, conditioned for 3 hours at 195°F, and cooled for 1 hour before discharge to cooling sheds and subsequent unstacking. During drying and conditioning, wet-bulb temperature is held constant at 185°F. Air velocities vary by zone; i.e., 1,600 fpm at inlet, 300 fpm while conditioning, and 1,000 fpm while cooling. To control warp, a top load (12 in. of concrete) is automatically placed on the moving lumber stacks as they enter the tunnel kiln and removed as they exit.

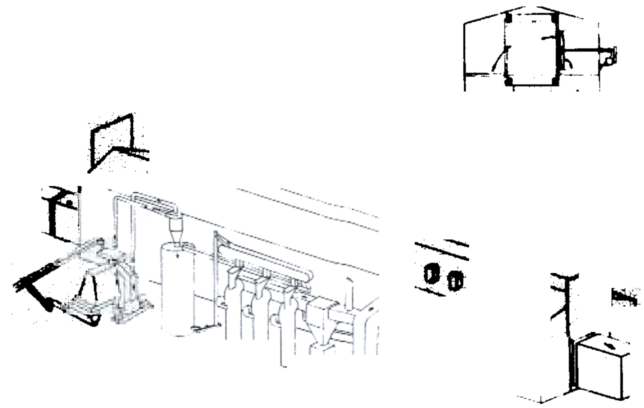

Figure 1. — Continuous tunnel kiln direct-fired with three suspension burners fueled with green bark. Inset shows transverse cross section of 10-foot-high kiln stack top-loaded with a caterpillar-like track having 12-inch-thick concrete flights. (Drawing from Moore-Oregon, Memphis, Tenn.)

For 12 years the Southern Forest Experiment Station's laboratory in Pineville, Louisiana, has been studying high-temperature drying of southern pine lumber. The objectives of these studies have been to diminish warp in lumber dried to the moisture contents (MCs) (8 to 10%) at which most of it will serve in heated and air-conditioned homes, to diminish time in the kiln, and to reduce energy requirements. The concept presented in this paper is a refinement of the design proposed by Koch (1974b, pp. 33 and 34).

The Concept

Green, random-width or width-sorted southern pine will be surfaced for thickness uniformity, preferably on a two-way thicknessing planer (see Koch 1972, Fig. 19-87c). The lumber will then be sorted by length and mechanically stacked on 1-1/4-inch-thick sticks in piles 5 feet wide and 10 feet high. The cars of stacked lumber will travel continuously through a tunnel kiln (Fig. 1) provided with zone control of heat, humidity, and air velocity (Table 1). Speed through the tunnel will be about 8 ft./hr. to yield 500,000 board feet of 8/4 lumber each 7 days of 24-hour operation. Lumber 1-3/4 inches thick will be dried to an average MC of about 9.0 percent; 95 percent of the pieces dried should have an MC in the range from 5.4 to 12.6 percent, and none should exceed 15 percent. Dwell time in the kiln proper will be about 12 to 14 hours including about 8 (possibly 10) hours for drying, 3 hours for conditioning, and 1 hour for cooling (Table 1). Because the tunnel kiln has short entrance and exit zones, total time for passage through the tunnel will be about 14 to 16 hours. After kilning, lumber will be left

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Table 1. — AIR TEMPERATURES AND VELOCITIES, FAN POWER, AND LUMBER DWELL TIME IN ZONES OF A CONTINUOUS TUNNEL KILN FOR 1-3/4-INCH-THICK SOUTHERN PINE LUMBER.

Kiln phase and zone[1]	Temperatures (°F) Dry-bulb	Temperatures (°F) Wet-bulb	Air velocity (fpm)	Connected fan power (hp)	Time in zone (hr.)
Drying					
1 and 2	270	185	1,600	60	2
3 and 4	270	185	1,400	40	2
5 and 6	270	185	1,200	25	2
7 and 8	270	185	1,000	15	2
Conditioning					
1, 2, and 3	195	185	300	7-1/2	3
Cooling	Ambient	Ambient less 5°F	1,000	10	1

[1]Each zone is 8 feet in length.

on sticks in a cooling shed for at least 24 hours, preferably more, before unstacking for remanufacture.

The kiln can be heated by any convenient direct-firing burner, but we propose using green bark burners based on the Jasper and Koch (1975) design (Fig. 2). These burners, which accept coarsely hogged green bark or sawdust, feature a hot, vertical infeed tube which substantially dries the fuel before it reaches the combustion zone. Three such burners should provide the flexibility and turn-down ratio needed to accommodate the usual thicknesses of southern pine lumber. To permit maintenance on the bark burners, a gas or oil back-up burner should be provided to take over the load during short term shutdowns.

Temperatures can be varied in each 8-foot section of the 96-foot-long kiln. Such variation may be needed if partially dried lumber is admitted to the kiln. Temperature control in each 8-foot section could be biased to reflect dry-bulb temperature drop across the width of the load—an indicator of lumber MC.

Warp will be controlled by top-loading the kiln cars with weight sufficient to make each 4-inch length of stick bear on the lumber below with a force of 90 to 330 pounds, depending on position in load and degree of lumber dryness. To apply this load, an overhead caterpillar track carrying concrete slabs 5 feet wide, 4-1/2 feet long, and 12 inches deep will move at the same rate as the lumber. The ends of each concrete slab will carry a pair of wheels designed to ride steel rails positioned on each side of, and just below, the top of the 10-foot-high kiln loads. With lumber in the kiln, the concrete slabs will ride the top of the loads; with no kiln stack present, the slabs will be carried by the steel rails. In the 64-foot drying zone, these rails will slope downward about 3.5 inches to follow shrinkage in the stacked lumber. To conserve heat in the top-load system, the powered headshaft, tailshaft, and track will all be contained within the heated portion of the kiln (Fig. 1, inset).

Reversing fans will circulate air in alternate directions hourly. In spite of the high velocities contemplated, total electrical power demand for the fan system will be only 134 horsepower because of efficient fan design and use of 1-1/4-inch-thick kiln sticks.

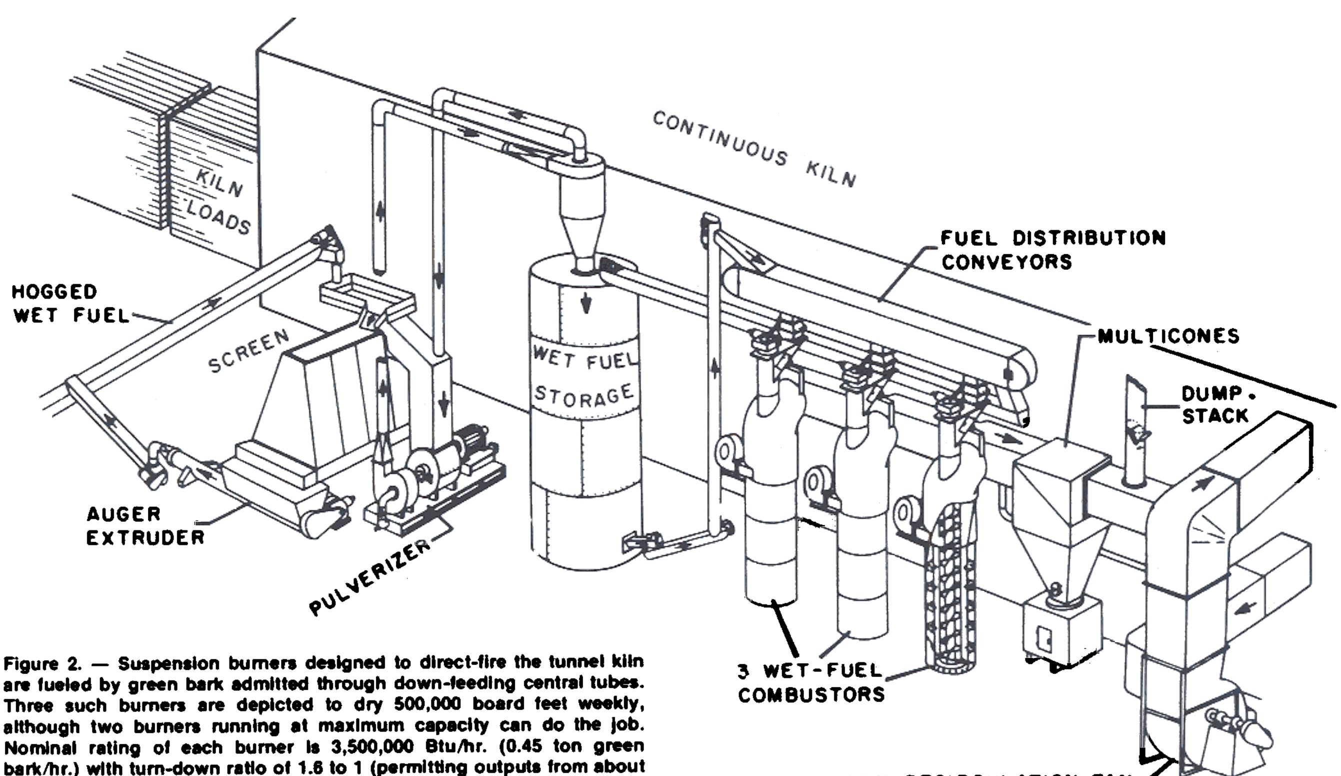

Figure 2. — Suspension burners designed to direct-fire the tunnel kiln are fueled by green bark admitted through down-feeding central tubes. Three such burners are depicted to dry 500,000 board feet weekly, although two burners running at maximum capacity can do the job. Nominal rating of each burner is 3,500,000 Btu/hr. (0.45 ton green bark/hr.) with turn-down ratio of 1.6 to 1 (permitting outputs from about 3 to 5 million Btu/hr.). (Drawing from Energex Ltd., North Portland, Oreg.)

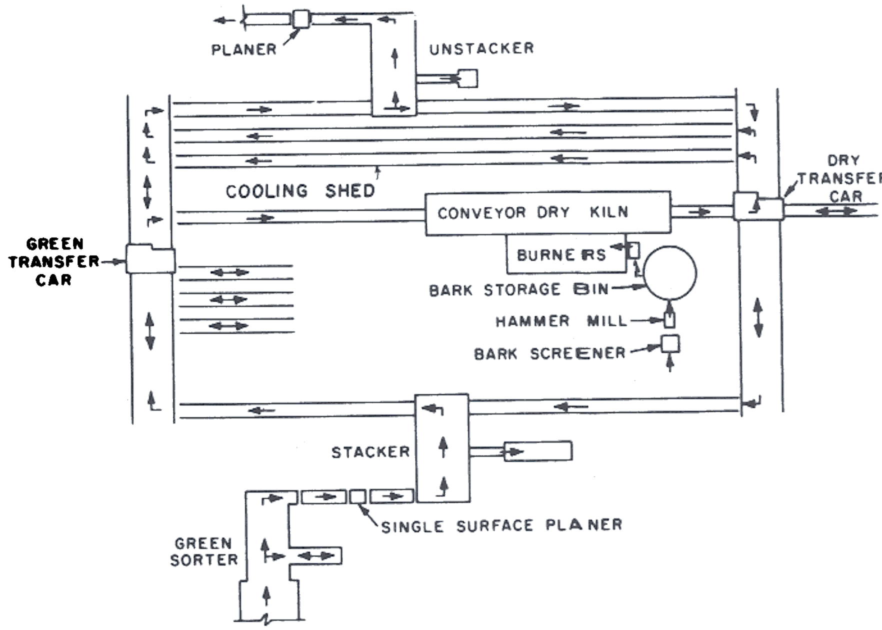

Figure 3. — Plan of system showing single-surfacer, stacker, infeed transfers, continuous tunnel kiln with bark burners for direct-firing, outfeed transfers, cooling shed, and unstacker.

The total drying system consists of a single-surfacer, stacker, infeed transfer to kiln, continuous tunnel kiln, outfeed transfer, cooling shed, and unstacker (Fig. 3). Operation requires a total of 288 man-hours a week: the planerman, stacker operator, and unstacker operator will each work a 40-hour week and four kiln technicians (who will also operate the burners and transfer cars) will each put in a 42-hour week to keep the kiln operating around the clock 7 days a week. Labor input will therefore be about 0.58 man-hr./Mfbm of lumber stacked, dried, and unstacked.

Connected power on the system will total 512 horsepower, and mechanical energy expended per 7 days will be 36,766 horsepower-hours (Table 2). Weekly electrical cost should be about $823, or $1.65/Mfbm dried, assuming that energy costs 3 cents/kWh.

Thermal efficiency of the kiln will be high for several reasons. First, the kiln will constantly remain hot—unlike batch kilns, which are intermittently cooled when doors are opened during normal charging cycles. Second, hot water vapor driven off during the 270°F drying phase will be used to raise humidity in the 195°F conditioning phase before venting. Third, the heat load will be constant during drying—thereby permitting burners to operate steadily at optimum rates. Finally, since a tunnel kiln has more wall area per thousand board foot holding capacity than does a more cubical batch kiln, 50 percent thicker insulation is contemplated for roof, walls, and floor.

For these reasons, each 1,000 board feet of lumber dried should require heat expenditure of only 3 million Btu. Weekly consumption of fuel in the burners should therefore total less than 200 tons of green bark—probably about 170 tons. Since production of 500,000 board feet of southern pine lumber yields a residue of 200 to 300 tons of green bark, additional heat energy should not be required.

Table 2. — SCHEDULE OF ELECTRIC MOTORS CONNECTED THROUGHOUT THE SYSTEM, AVERAGE POWER DEMAND DURING SHIFTS OF OPERATION, AND WEEKLY HOURS OPERATED.

System portion and function	Connected motors (hp)	Average power demand[1] as percent of motor nameplate rating (%)	Weekly hours of operation (hr.)	Energy expenditure each 7 days (hph)
Single-surfacer layout	80	60	40	
Stacker system	25	50	40	
Three-burner system				
Fuel preparation equipment	133	55	40	2,926
Burner-related motors	66-1/2	75	168	8,379
Stand-by oil burner	20	(operated during bark burner maintenance only)		
Tunnel dryer				
Fans	157-1/2	85	168	22,491
Kiln-car transport	2	85	168	286
Transfer cars				
Infeed	15	10	40	60
Outfeed	15	10	40	60
Unstacker system	18	20	40	144
Total	512+20 standby			36,766

[1]During the shifts the equipment is operating.

Uninstalled price of equipment illustrated in Figure 3 (including a full complement of kiln sticks but excluding green lumber sorter and four-side dry lumber planer) is estimated at about $1,000,000. The bark burners will be manufactured in North Portland, Oregon, by Energex Ltd.,[1] and the rest of the equipment (except for the single surfacer) will be made by Moore-Oregon in Memphis, who will coordinate

[1]After test-stand proving of a commercial prototype in 1977.

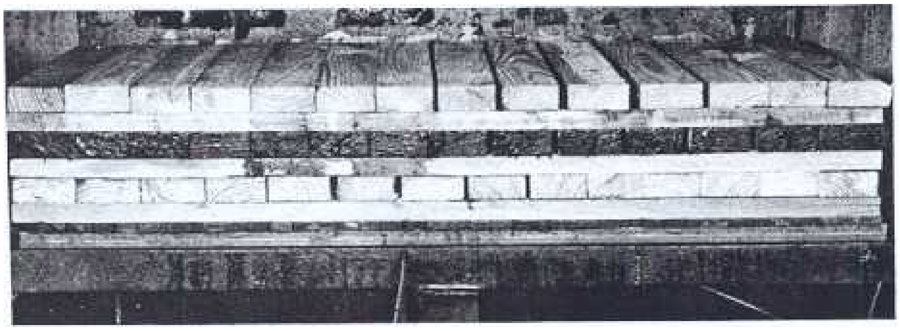

Figure 4. — In each kiln load, 42 boards measuring 4 inches wide, 1-3/4 inches thick, and 24 inches long were dried between 1-1/4-inch-square sticks. The test course of 14 boards (with end-coating of asphalt mastic) was sandwiched between buffer courses on top and bottom. Courses measured 5 feet in width.

installation of the entire system. Of the total price, the burners and fuel preparation system comprise nearly half ($480,000) and the tunnel kiln with complement of sticks about a quarter ($270,000); the balance of the price is for conveying, stacking, unstacking, and single-surfacing equipment.

Experiments Support the Concept

In early experiments with jet dryers, 7/16-inch southern pine was heated in 300°F air and dried to 10 percent MC in 45 to 75 minutes; time required was inversely correlated with air velocity in the range from 600 to 10,000 fpm. At 350°F and 10,000 fpm air velocity, time to 10 percent MC was less than 40 minutes (Koch 1964). Also, kiln time to 10 percent MC is linearly proportional to board thickness when southern pine is dried at temperatures above the boiling point of water (Koch 1974a). These data suggested that 1-3/4-inch green southern pine should dry to 8 or 9 percent MC in 5 to 6 hours at a kiln temperature of 300°F with air velocity of 1,600 fpm. To validate this prediction and gain data for the proposed continuous tunnel kiln, a series of experiments was performed.

Procedure

Two lots of green southern pine 2 by 4s were procured, one from central Louisiana and the other from western Tennessee. Both lots were surfaced on one side only to a thickness of 1-3/4 inches and submerged under water for 1 to 3 days while awaiting kiln-drying. For each kiln charge, the lumber was crosscut to 24-inch lengths and stacked on 1-1/4-inch-square sticks—14 boards to a course, three courses deep; load width was 5 feet. The central course was end-coated with an asphaltic mastic to inhibit moisture movement through the ends (Fig. 4).

Kiln charges of lumber from each source were dried 4, 6, or 8 hours, for a total of 6 charges. The kiln schedule was simple; dry-bulb temperature was held constant at 300°F while the wet-bulb temperature was held at 200°F. About 1 hour was required from the time the kiln doors were closed until desired temperatures were achieved. Air velocity was held constant at 1,600 fpm, and direction was reversed hourly.

Just before kilning, each of the 14 test pieces from the central course was weighed, and its thickness and width were measured 8 inches from either end. On removal from the kiln, the same measurements were taken again. Finally, 3/4-inch-thick cross-sectional slices were removed from the gage points, weighed, ovendried, and reweighed. The green 2 by 4s had an average MC of 109.0 percent and average specific gravity (SG) of 0.50 (Table 3).

Table 3. — PROPERTIES OF GREEN 2 BY 4S.[1]

Property	Mean	Standard deviation	Maximum	Minimum
		19.1	164.9	45.0
		.45	7.08	4.88
		.06	24.1	23.8
		.08	4.24	3.84
		.01	1.79	1.73
		.05	.71	.42

[1]These properties did not vary significantly among charges of lumber dried at 4, 6, and 8 hours.
[2]Based on ovendry weight and green volume.

Top and bottom courses of the lumber dried for 6 hours were used to evaluate postdrying treatments. To assess the benefits of conditioning, these courses of Tennessee lumber were exposed for 4 hours at dry- and wet-bulb temperatures of 193 and 182°F, respectively, and then solid-piled at 70°F for 36 hours. After this treatment, cross-sectional slices were removed, weighed, ovendried, and reweighed to permit computation of MC.

To assess the effect of cooling—without prior conditioning—top and bottom courses of the Louisiana lumber kiln-dried for 6 hours were solid-piled for 91 hours, and then cross-sectional slices were removed for determination of MC.

In addition, a single charge of 2 by 4s (mixed lumber from both geographic sources) was dried, conditioned, and cooled in the test kiln (Table 4), and then board MC was measured. During this last run, temperature drop across the load was measured at frequent intervals during the drying phase.

Three auxiliary experiments were also performed. One tested the amount of cooling obtainable in an hour. In another, four thicknesses of kiln sticks were evaluated in a cool kiln to determine the effect of stick thickness on cross-circulation air velocity and pressure drop across a 5-foot-wide load of lumber thicknessed on one side only to 1.75 inches. Finally, the effect of various kiln-stick designs on warp control was evaluated.

Table 4. — DRYING CONDITIONS FOR EXPERIMENT TO EVALUATE TEMPERATURE DROP ACROSS 5-FOOT-WIDE LOAD.

Phase	Temperatures Dry-bulb (°F)	Wet-bulb (°F)	Air velocity (fpm)	Time (hr.)
Drying	300	200	1,600	
	300	200	1,300	
	300	200	1,000	
Conditioning	195	185	300	
Cooling	75	70	1,600	
			Total	

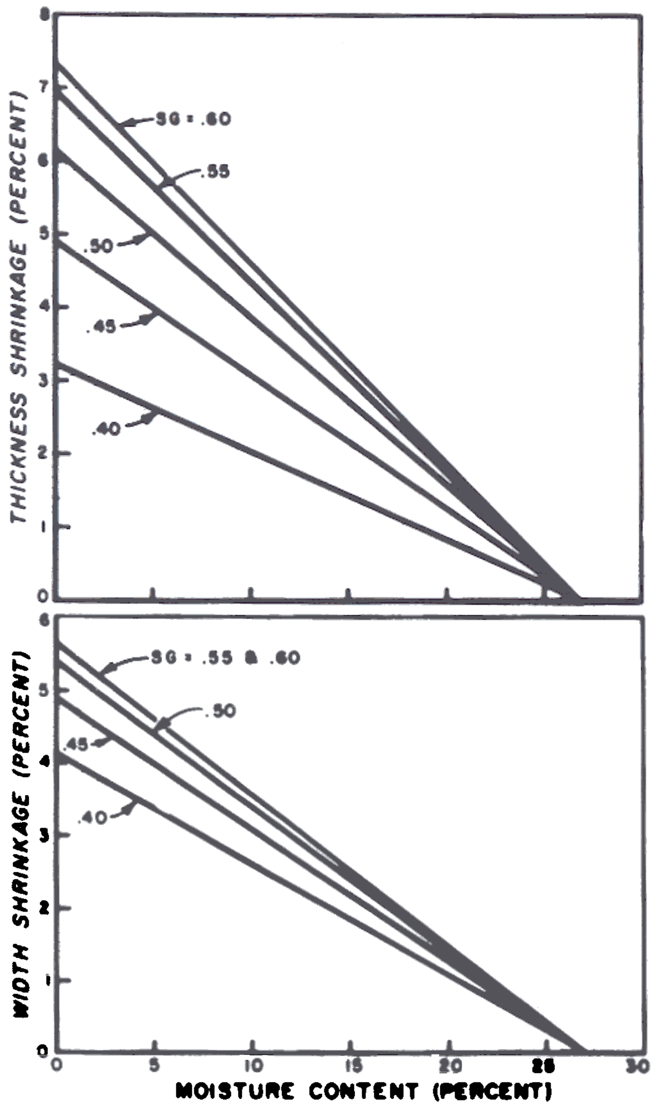

Figure 5. — Shrinkage of 2 by 4s in width and thickness related to MC and SG based on ovendry weight and green volume.

Results

Shrinkage—Shrinkage data on lumber dried at 300°F is required to determine green sizes necessary to yield planed lumber of standard width and thickness. Since shrinkage is negatively correlated with board MC and positively correlated with SG, regression analyses of the data were made to yield plots for the range of MCs and gravities observed (Fig. 5). These data show that boards of 0.50 SG dried from green condition to 9 percent MC should shrink about 4 percent in thickness and 3-3/4 percent in width. These shrinkage values are comparable to those reported in the literature for southern pine dried at lower temperatures (e.g., see Koch 1972, p. 290).

MC—MC of the 8/4 lumber after drying with air velocity constant at 1,600 fpm was as follows:

Statistic	Hours in kiln 4	6	8
		%	
Mean	20.5	6.6	1.8
Standard deviation	5.9	2.3	1.2
Maximum	31.9	11.6	6.2
Minimum	12.5	2.5	.6

The data indicate that 6 hours of drying at 300°F is probably necessary to bring most of the boards below

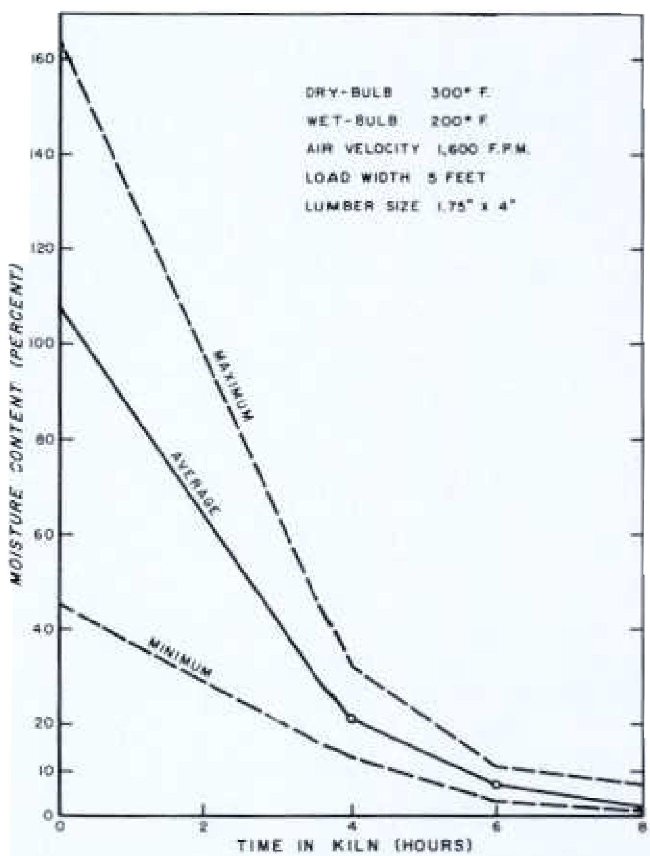

Figure 6. — Drying curves for 1.76- by 4.04-inch southern pine. Solid line shows average; dashed lines define envelope containing all boards. Each data point at 4, 6, and 8 hours is an average for two kiln loads, each containing 14 boards.

Table 5. — MC AND CHECK FREQUENCY IN LUMBER FROM TWO SOURCES DRIED 6 HOURS AND GIVEN VARIOUS POSTDRYING TREATMENTS.

Source	Treatment[1]	No. of boards	MC Mean (%)	MC Range (%)	MC Std. Dev. (%)	Percent of boards showing internal checks
Tenn	Not conditioned[2]	14	6.3	2.5 - 11.6	2.8	86
Tenn	Conditioned[3]	23	6.4	4.7 - 8.1	1.1	58
La.	Not conditioned[2]	14	6.9	3.9 - 9.7	1.7	93
La.	Cooled 91 hours after drying, but not conditioned	25	6.1	3.6 - 12.1	2.2	52

[1]Both lots of lumber (from Tenn. and from La.) were dried for 6 hours at 300° dry-bulb temperature and 200°F wet-bulb temperature. Air velocity was constant at 1,600 fpm; direction was reversed hourly.
[2]MC wafers cut immediately on completion of drying phase.
[3]After the drying cycle, this lot of lumber was conditioned (at 193°F dry-bulb and 182°F wet-bulb temperatures) for 4 hours, then solid-piled at ambient temperature for 36 hours before wafers were cut to determine MC.

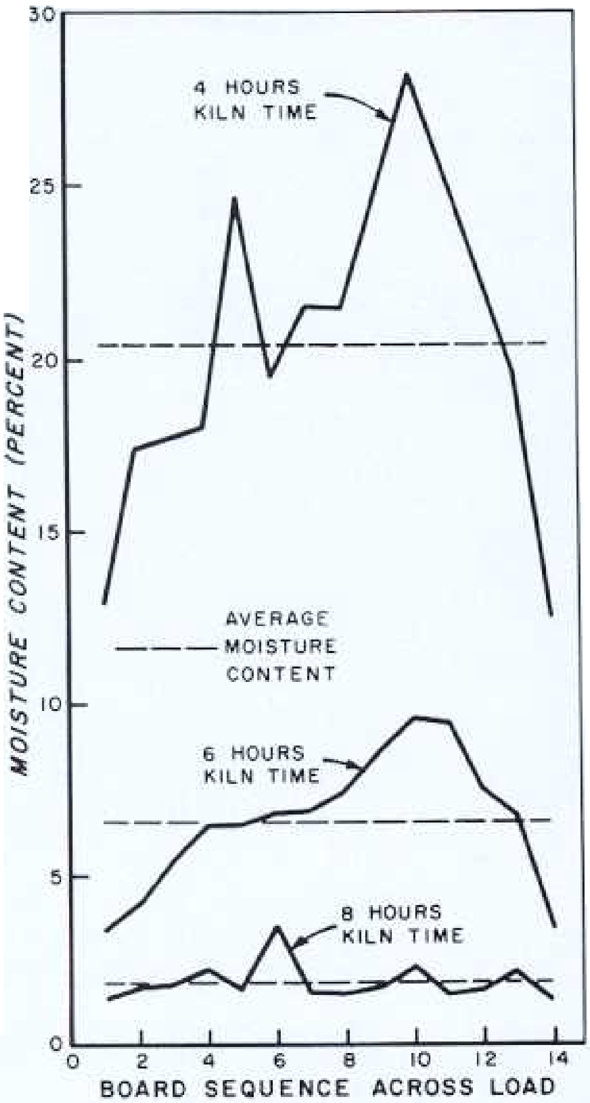

Figure 7. — Variation in MC with position across 5-foot-wide lumber course according to time in kiln.

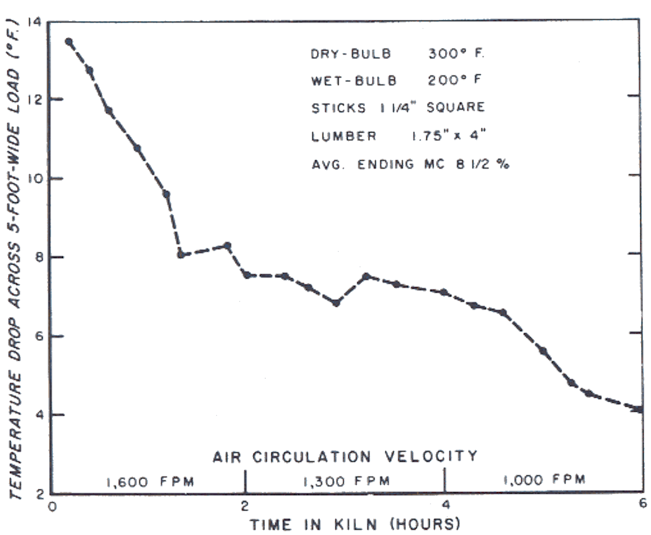

Figure 8. — Temperature drop across 5-foot-wide load related to time in the drying zone.

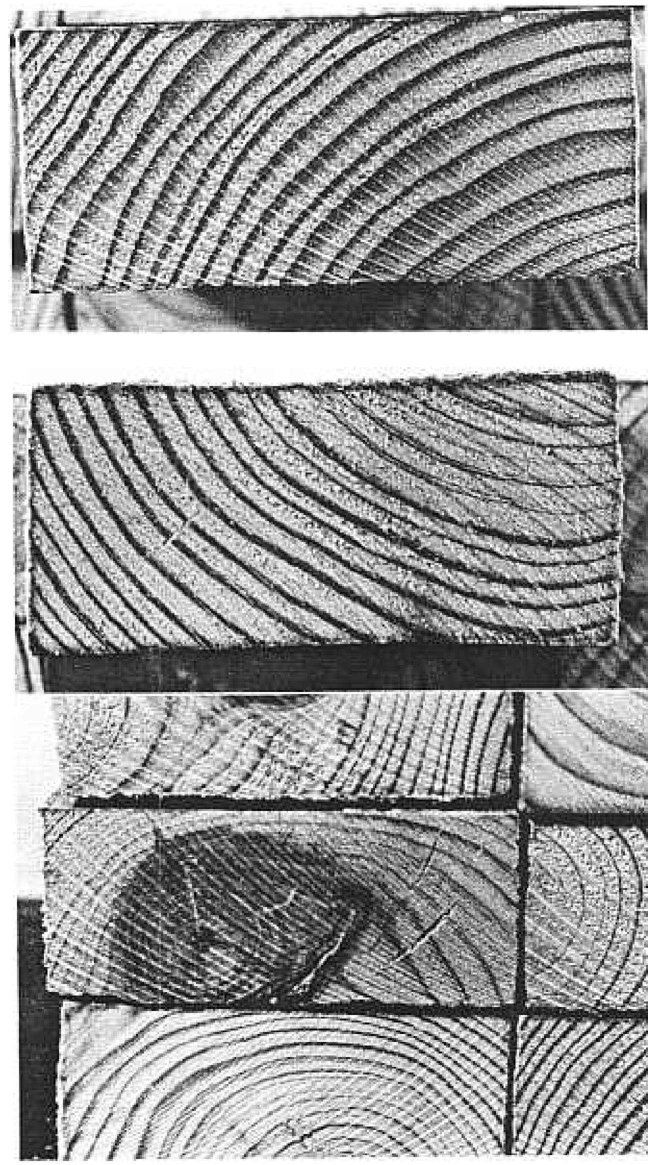

Figure 9. — Transverse sections of southern pine 2 by 4s dried 6 hours, conditioned 4 hours, and cooled 36 hours. (Top) About half the pieces dried were check-free. (Center) About half had single hairline checks. (Bottom) In vicinity of massed pitch, a few pieces had easily visible checks.

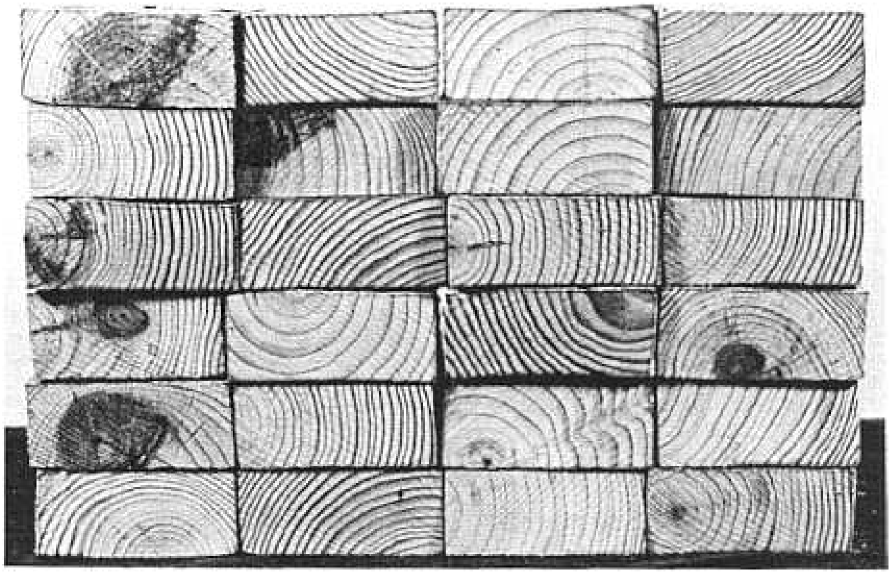

Figure 10. — Southern pine 2 by 4s kiln-dried in 6 hours, conditioned for 4 hours, cooled for 36 hours, and cut transversely to expose end grain. MC at time photographed averaged 6.4 percent. Darkened surfaces are evident.

10 percent MC (Fig.6). The kiln times of 4, 6, and 8 hours included 1 hour warm-up time; a continuous tunnel kiln would heat the green lumber in considerably less time than did the batch kiln used in our test.

Variation of MC within kiln loads was a function of position across the load width and of the time in the kiln. In spite of frequent fan reversals and high air velocities, boards in the center of each load showed substantially higher MCs at 4 and 6 hours than those on the edges (Fig. 7). This effect was caused by a substantial drop in temperature of air flowing across the width of the load—particularly during the first 2 hours of the drying cycle as indicated by data from the subsequent run with varied air velocities (Fig. 8).

MC varied less in lumber that was conditioned after drying than in lumber analyzed immediately after discharge from the drying phase (Table 5). Twenty-three 2 by 4s dried 6 hours, conditioned 4 hours in the kiln and then cooled in a solid pile for 36 hours, had an average MC of 6.4 percent with standard deviation of only 1.1 percent and range from 4.7 to 8.1 percent. To minimize moisture variation, therefore, the schedule should contain a conditioning phase.

Varying the air velocity from 1,600 to 1,000 fpm during the drying cycle resulted in a higher average MC (8.5%), a greater standard deviation (2.6%), and a greater range (4.5 to 12.5%) even though the lumber was conditioned and cooled after drying.

Cooling.—On the assumption that it is desirable to cool the lumber before removal of the top load and discharge from the kiln, the degree of cooling achievable in an hour was assessed. Seven 4-foot southern pine boards measuring 1-3/4 inch thick by 4 inches wide were brought to equilibrium temperature of 200°F and MC of about 9 percent; high-humidity air at 70°F was then streamed over them at a velocity of 1,000 fpm. After an hour's exposure, the boards were crosscut at midpoint, and temperatures there were

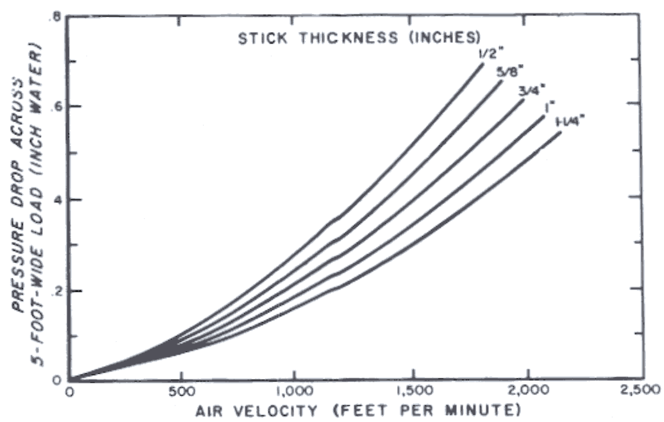

Figure 11. — Stick thickness related to pressure drop required across a 5-foot-wide load to achieve a range of air velocities through lumber courses. Measurements taken at 70° F.

measured. The maximum (occurring at midcore) averaged 86°F and ranged from 84° to 90°F. Surface temperatures averaged 84°F and ranged from 82° to 85°F.

Color changes and checks.—Lumber surfaces darkened somewhat during drying (Figs. 9 and 10), and considerable resin exuded from some boards. When planed, however, the lumber was bright and showed no massed pitch.

When cut transversely, many of the dry 2 by 4s displayed one or more checks (Table 5, last column). In the conditioned lumber, 58 percent showed checks of hairline size—usually one to a board; in a very few boards, checks were larger (Fig. 9, bottom). Experienced lumbermen and kiln operators viewing the results considered the checks (Fig. 10) not structurally damaging and not substantially more severe than those frequently observed in 8/4 southern pine dried more conventionally on slower schedules. (For illustration of checks in southern pine dried at 240°F, see page

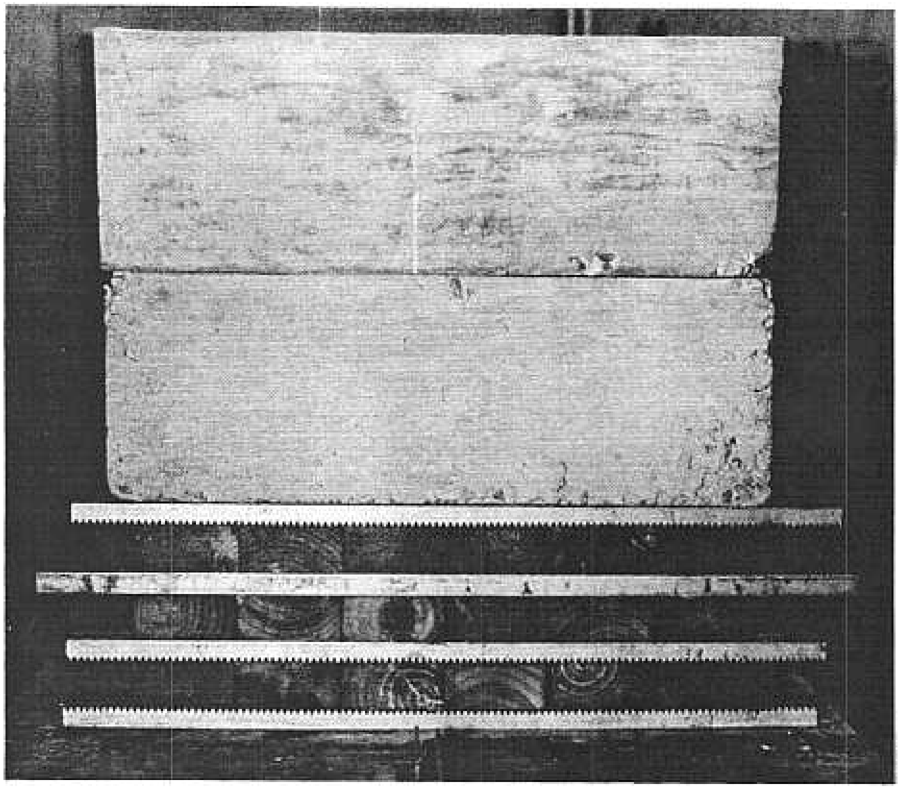

Figure 12. — End view of top-loaded charge of 2 by 4s ready for kilning. Sticks simulated were smooth on both sides, serrated on one side, or serrated on both sides. Serrations in toothed sticks were 3/16-inch deep with 1/4-inch pitch.

137 of Koch 1973). Some boards showed a slight tendency toward hour-glass shapes in cross section (Fig. 10).

Lumber strength.—Mechanical properties of the lumber dried in this experiment were not evaluated. In a succeeding experiment, however, 1.75-inch southern pine dried for 6 hours at 300°F was compared to matched lumber dried 5 days at 180°F. Average values for toughness, stress at proportional limit, modulus of rupture, modulus of elasticity, and hardness of small clear specimens cut from the 2 by 4s dried at 300°F exceeded values for lumber dried at 180°F (differences were significant only for end hardness and modulus of rupture). These results will be reported in detail in a subsequent paper.

Similarly, previous evaluations of 7/16-inch southern pine dried at 300°F and 350°F (Koch 1964) and 8/4 southern pine dried at 240°F (Koch 1971) detected no significant diminution of board strength caused by high-temperature drying.

Kiln stick thickness.—Sticks 3/4-inch thick have been used in most reported research on high-temperature drying of southern pine. We chose 1-1/4-inch-thick sticks to increase both mass and turbulence of airflow and thereby decrease MC variation across the width of kiln loads. Pressure observations taken across a 5-foot-wide load in a cool kiln showed that the pressure drop required to achieve a desired velocity is inversely correlated with stick thickness (Fig. 11). For example, at a pressure drop of 0.5 inch of water, air velocity with 1-1/4-inch-thick sticks was slightly greater than 2,000 fpm; i.e., about 54 percent greater than observed with 1/2-inch-thick sticks.

Table 6. — EFFECT OF KILN STICK DESIGN ON CROOK, BOW, AND TWIST IN ROUGH, DRY, 8-FOOT SOUTHERN PINE 2 BY 4S KILN-DRIED UNDER A TOP LOAD AT 240°F TO 8.75 PERCENT MC.[1]

Treatment	Crook (in.)	Bow (in.)	Twist (in.)
Studs gripped from both sides by serrated sticks	0.14 (0.30) *0.064*	0.18 (0.45) *0.086*	0.12 (0.40) *0.081*
Studs gripped on one side by a serrated stick and on the other by a smooth stick	.16 (.40) *.081*	.20 (.55) *.114*	.14 (.50) *.098*
Studs gripped between smooth sticks	.16 (.39) *.078*	.21 (.65) *.127*	.15 (.57) *.103*

[1]Maximum observed value is shown in parentheses alongside each average, and standard deviation in italics below. The average values are based on 54 studs, i.e., on 9 kiln loads of lumber, each with six 2 by 4s per treatment.

From these data it is concluded that, with 1-1/4-inch-thick sticks and high-efficiency fans, the velocities stipulated in Table 1 can be achieved by expenditure of the horsepower noted.

Warp control afforded by various stick designs.—In a separate experiment,[2] degree of warp control provided by three kiln-stick designs was assessed when studs were stacked under a concrete top load sufficient to press down on each 4 inches of stick

[2]Koch, P. 1974. Effectiveness of kiln sticks serrated on one side or two sides (compared to smooth sticks) in reducing warp in southern pine studs sawed from veneer cores and dried to 9 percent MC at 240°F, with a top load of 100 pounds per stick pair per stud. Final Report FS-SO-3201-2.72. So. Forest Expt. Sta., Pineville, La.

length with a force of 100 pounds. The 8-foot southern pine 2 by 4s were dried to 8.75 percent MC in a kiln held at 240°F dry-bulb and 160°F wet-bulb temperatures for 21 hours after startup, and then steamed for 3 hours at 195°F/185°F. The three designs evaluated were: serrated both sides, serrated one side, and smooth both sides; all sticks were of aluminum, 1.5 inches wide and 0.75 inches thick (Fig. 12). With this heavy top load warp did not vary significantly (0.05 level) with stick design (Table 6). Thus, smooth sticks should provide a substantial degree of warp control if lumber is top-loaded with 12 inches of concrete. Crook in 8-foot 2 by 4s stacked on such sticks and dried to 9 percent MC in the proposed tunnel kiln should average about 0.15 inch; 95 percent of the rough dry pieces should have less than 0.30-inch crook.

Schedule to eliminate internal checks.—Although 6 hours at 300°F caused no diminution in wood mechanical properties compared to 5 days at 180°F, internal checks (Table 5) in the 300° lumber were cause for concern. A follow-up experiment was therefore run in which three 5-foot-wide courses of boards (45 pieces total) 1.75 inches thick and 4 inches wide were end-coated and dried on a 12-hour schedule in which wet-bulb temperature was held constant at 160°F and the dry-bulb temperature was held at 270°F for the first 5 hours, at 240°F for the next 4 hours, and at 195°F for the final 3 hours. Initial MC of the boards averaged 133 percent.

This schedule yielded an average MC of 9.1 percent with standard deviation of 1.8 percent and range from 5.8 to 13.3 percent. Boards near the edges of the 5-foot-wide courses averaged 7 to 8 percent MC; those in the center averaged near 11 percent. Boards were free of internal checking, and surface discoloration could be removed by a 1/32-inch-deep planing cut.

Based on these data, the schedule shown in Table 1 was selected to minimize drying time without causing significant internal checking, hour-glass shrinkage, or discoloration in excess of 1/32-inch depth.

Conclusions and Discussion

The experiments described and the literature cited support the concept proposed. We believe that the continuous tunnel kiln has substantial advantages. Foremost among the advantages is a high degree of warp control achieved by the labor-free application of a heavy top load. Next in importance is the thermal efficiency of this bark-fired kiln and its independence from fossil fuel. Also, the continuous nature of the kiln lends itself to a high degree of mechanization. Finally, the proposed process provides the consumer with lumber dried to an average MC at which most of it will be used; i.e., 8 to 10 percent. We believe the concept has immediate commercial usefulness to both industry and consumers.

It is recognized that there is considerable hazard in projecting drying time for 8-foot and longer lumber from results obtained on end-coated 2-foot-long 2 by 4s. A follow-on experiment with 8-foot 2 by 4s, 2 by 8s, and 2 by 12s, has indicated that, for wide lumber, 10 hours might be required in the drying zone (rather than the 8 hr. heretofore discussed). Our experiments with batch kilns that require 1 to 3 hours of warmup time do not accurately duplicate the almost immediate warmup of lumber entering an always-hot tunnel kiln, however. Moreover, zone control of temperatures in a tunnel kiln—perhaps in excess of 270°F at the outset—presents additional possibilities for adjusting time required to dry to 9 percent MC. In short, a full-scale trial of the idea is required to accurately determine schedules practical for industrial operation. It seems prudent that initial industrial trials be on kilns dedicated to 2 by 4 studs; the standard length and uniform cross section of studs would simplify kiln operation and control of results.

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