KILN-DRYING OF BRITISH COLUMBIA SOFTWOODS AT HIGH TEMPERATURES *

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INTRODUCTION

In the past two decades considerable research has been done to develop drying schedules at temperatures exceeding the boiling point of water. Successful commercial application of these schedules is rare, and lack of sufficient information on the effect of discoloration, degrade, and changes in mechanical properties restrict current usage to small kilns in furniture factories. The Ottawa and Vancouver Laboratories of the Forest Products Research Branch have been working for a number of years on this project, and in 1957 preliminary results of experiments conducted on one-inch lumber from several coniferous species of western Canada were described (1). Since then the objective in the Vancouver Laboratory has been to develop schedules applicable to dimension lumber.

The purpose of this paper is to present the results obtained using mixed schedules which employ conventional temperatures until the fibre saturation point, ranging from 18 to 26 per cent moisture content, has been reached, and then using temperatures above 212°F.. In this second phase, above 212°F., two types of drying medium were employed:

(1) High-temperature air-mixture using temperatures slightly above the boiling point of water and high saturations.
(2) Superheated steam.

As a further step in the study, a series of co-operative tests were made on matched lumber dried at high-temperature schedules in the Laboratory's small experimental kiln, and at conventional schedules in the commercial kiln of a co-operating company[1]. The results of this work were favourable and are discussed briefly.

Small clear specimens of Douglas fir using four different kiln schedules were tested to determine the effect of high-temperature schedules on the strength values of structural lumber.

Procedures

Figure 1 shows the Laboratory experimental kiln used in the tests. A scale was installed in the kiln so that the weight of the lumber could be determined at any time.

Three shipments, comprising 2 by 8 inch construction-grade Douglas fir lumber in 16-foot lengths, were obtained and prepared in 3-foot lengths for the kiln. Each charge consisted of 36 pieces. Four matched charges were cut from each shipment. The moisture content and oven-dry weight of each board were calculated on the basis of sections taken from both ends of each piece.

Various schedules were allotted randomly to the twelve charges. From previous experience it was decided to use an air circulation of 600 f.p.m., and this circulation resulted in a narrow range of final moisture content (2).

Three runs (91, 92, and 94) of the first shipment were dried with a high-temperature air-mixture, and the fourth (93), with superheated steam. The four charges from the second shipment were dried as follows: one high-temperature (96), one conventional (97), and two levels of superheated steam runs (95 and 98). Three runs of the third shipment (100, 101, and 102), were dried at two levels of superheated steam condition. A conventional schedule was used to dry the last run of the final series (103). The dried lumber from each charge was left to stabilize for two days in an open shed prior to grading and final moisture content determination. Sections taken from the middle of each board were used for both the moisture content and moisture distribution measurements. Both halves of each piece were then dressed two sides and graded.

Following the above experimental work a co-operative experiment series was carried out on matched pieces of three shipments, using high-temperature and conventional schedules. A 3-foot piece of each piece was dried at high temperatures in the experimental kiln at the Vancouver Laboratory, and a 6-foot matched piece was dried at conventional schedules in one of the industrial kilns of the co-operating company.

The lumber from runs 95, 96, 97, and 98, was selected for strength evaluation and kept under dry-shed conditions for at least two months. Clear specimens for bending, compression parallel to the grain, and toughness tests were then cut from these pieces. The testing procedure in respect to these small clear specimens was in accordance with prescribed ASTM test procedures, secondary method.

Subsequent to bending and compression tests, one 1 - by - 1-by 4-inch block was cut from each specimen close to the zone of failure. Basic specific gravity of the 4-inch piece was determined by the usual volume-displacement method. Growth rate and per cent summerwood were also measured.

Experiments and Discussion

Runs 91, 92, 94, and 96 were dried at high temperatures with air-mixture schedules (Table 1). Warm-up temperatures for all but run 91 were 195°f. D.B. with a 5°F. W.B. depression. The changes to high-temperature were made at 20.4, 21.1, 29.5 and 26.6 per cent moisture content respectively. The settings of the highest ranges were 218°F. D.B. and 200°F.W.B.. In run 94, temperatures of 240°F.D.B. with 195°F.W.B. were used to evaluate the effect of this high temperature. The drying times varied from 57 1/2 hrs. to 116 1/2 hours. The final moisture content averaged 12.3 per cent.

Superheated steam was used for runs 93, 95, 98, 100, 101, and 102. The warm-up temperatures of these runs were the same as those dried in air-mixture. Gradually the settings were changed, between 20.7 and 27.5 per cent moisture content the kiln being brought to saturation (212°F. W.B.) and the dry-bulb temperature was raised to 220-225°F.. The final moisture content averaged 12.3 per cent. The drying times varied from 86 1/2 to 118 hours.

Runs 97 and 103 followed conservative conventional schedules, using temperatures not exceeding 170°F. D.B. with a 20°F. W.B. depression. The final moisture content averaged 12.4 per cent. Total drying times were 153 and 116 1/2 hours respectively.

The longest drying times of both types of high-temperature runs were equal to those of the slower conventional drying. However, as there was a considerable difference in the greem moisture content of the charges — the initial moisture content of the former being 60 to 63 per cent, and that of the conventional schedule, 41 per cent — no direct comparisons can be made.

Table 1 shows the parameters of the drying medium and the range of moisture content of the lumber during drying. The warm-up temperatures of 190 to 195°F. used in the high-temperature runs were higher than usually used in conventional drying. From the equilibrium moisture content it is obvious that run 94 was dried with the most severe schedule. The high temperatures and low saturation applied in the second phase of drying resulted in heavy degrade. The green moisture contents of the twelve charges ranged from 36 to 68 per cent. The range in final moisture content was below 7 per cent except in runs 91, 92, 94, and 98, where it was up to 12 per cent.

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* A contribution of the Vancouver Laboratory, Forest Products Research Branch, Department of Forestry, Canada.
[1] Rayonier Canada Limited.

The change in schedule to temperatures above 212°F. should be made at the fibre saturation point. Attempts to measure this moisture content at the temperatures used in the kiln were unsuccessful, so the changes were made by trial and error at from 20.0 to 29.5 per cent.

Figure 2 shows distribution of the final moisture gradients for various conditions. Run 94 is shown separately, and the others are grouped by different temperature levels. The best results were achieved with the lower level of superheated steam drying when a shell-core moisture differential of less than 3 per cent was achieved in 90 per cent of the pieces, and less than 5 per cent in 98 per cent of the pieces. Except for run 94, the higher level of superheated steam, the conventional and the high-temperature air-mixture schedules showed a moisture gradient of less than 5 per cent in 84 per cent of the pieces. In run 94, with its high temperature and low saturation, only 56 per cent of all the pieces showed a moisture gradient of less than 5 per cent. Experience has shown that degrade occurs when the moisture gradient is above 5 per cent.

Most of the differences in moisture content between shell and core were below 4 per cent, as shown in Figure 2. In run 94, although the average deviation was 3.9 per cent, many boards exceeded 5 per cent, and these developed a honeycomb type degrade.

Surface defects were negligible and any that developed were removed by surfacing. No end-checks occurred and knots were not seriously damaged. Honeycomb type checks were the most serious defects and these developed only after cross-cutting. The lumber was graded on the basis of these honeycomb checks, as shown in Figures 3 and 4. No checks and slight checks, as in A and A 1, were graded together as A; a few checks as B; and severe checking as C. The result of this grading are shown in Figure 5 for each of twelve runs.

The next step was to compare the results of conventional commercial drying with those of the high-temperature kiln. Matched pieces of 2-by-8-inch Douglas fir clears and glulam stock; 7/4-by 8-inch western hemlock clears; 2- by 10-inch western hemlock construction grade; and 2- by 8-inch western red cedar clears were dried and compared.

No defects developed in the Douglas Fir lumber at high temperature. The knots were damaged less by high temperature, as shown on the right side of Figure 6, than those of lumber from the conventional drying shown on the left. No checks developed, and no cup or twist occurred in the former, but a few checks appeared on some of the pieces of the conventional drying run as indicated on the left of Figure 7. The colour of the lumber from the high-temperature charges was slightly darker, as seen on the right side of Figure 8. The average time-saving of 24 per cent between the conventional schedule of run 97 and the high-temperature run 95 is shown in Figure 9, and is typical of the time saved by high-temperature drying.

The schedule used for the high-temperature drying of western hemlock is shown in Figure 10, and was based on the results of a few preliminary runs. The time saving for the matched boards was 15 per cent, compared with the conventional schedule, in spite of the differences in final moisture content which averaged 10 per cent for the high-temperature runs and 13 per cent for the conventional. The clears were dried most satisfactorily without and defects in the high-temperature runs. The construction lumber showed cupping varying from 1/16 to 3/16-inch when the final moisture content was as low as 10 per cent, which is much drier than normal for this grade of material. The knots were not damaged except for normal star checks which never extended beyond the knot boundary in both types of drying. The discoloration, which could not be avoided at the high temperature, was slight.

A few preliminary runs of western red cedar with normal moisture contents averaging 74 per cent were made to establish a suitable high-temperature schedule. However, the lumber for the co-operative tests was very wet, averaging 96 per cent moisture content, with wide variations up to 123 per cent green moisture content. As a result, about half of the shipment showed wet spots in cross-sections of lumber dried at the high temperatures, and about 40 per cent in the conventional. The degrade in the two runs was similar. Figure 11 shows the high-temperature schedule.

Strength Properties

One shipment of Douglas fir from which runs 95, 96, 97, and 98 were made, was selected for tests in bending, compression paralled to the grain, and toughness. Thus a comparison was obtained of matched boards from the conventional, high-temperature air-mixture, and two levels of superheated steam runs.

Table 2 shows a summary of the mean values of individual tests as computed for fibre stress at the proportional limit, modulus of rupture, modulus of elasticity, and maximum crushing strength. The data are adjusted to 12 per cent moisture content according to logarithmic equations published by the Forest Products Laboratory at Madison(3).

In order to make the data directly comparable, the strength properties were further adjusted to a common specific gravity of 0.460. The mean values of figures adjusted individually for fibre strength at the proportional limit, modulus of rupture, modulus of elasticity, and maximum crushing strength, are shown in Table 3. The standard deviations indicate a normal distribution of values for wood. Run 97 was dried according to conventional schedule and shows normal values for Douglas fir. Runs 95, 96, and 98 were dried at high temperatures and show lower strength values.

These values were summarized and expressed as a percentage decrease in strength based on the values obtained for run 97 (see Table 4). The high-temperature air-mixture in run 96 and the superheated steam in run 95 did not appear to have any different effect on strength. However, total time at high temperature, as shown in the superheated steam runs 95 and 98, appears to have a marked effect on strength properties.

Toughness tests could not be adjusted for specific gravity and the data are shown in Table 5. In this table the results of the two superheated steam charges were presented together. Both the tangential and the radial impact showed a decrease for wood dried at high temperature.

Conclusions

Two-inch Douglas fir, western hemlock, and western red cedar were dried successfully in the laboratory kiln at temperatures above 212°F..

The change to temperatures above 212°F., and not exceeding 225°F. D.B., with 200 to 212°F. W.B., for Douglas fir was made safely when the moisture content of the lumber reached 18 to 20 per cent.

Western hemlock schedules similar to those for Douglas fir were also satisfactory.

High temperatures of 218°F. D.B., with 170°F. W.B., were used for western red cedar. No time saving was achieved on western red cedar of very high moisture content. However, the low degrade suggests that further investigation would be justified.

Some of the observed advantages of high-temperature drying are summarized as follows:

1. Drying time is shorter by 20 to 30 per cent.
2. Final moisture distribution is more uniform.
3. Core and shell differential moisture contents are lower than obtained with conventional schedules.
4. No twisting or checking occurred.
5. Knot damage is slightly less than with conventional schedules.
6. The durability of western red cedar is not impaired (4).

Some disadvantages are:

1. Some discoloration occurs.
2. The reduction in strength properties found in Douglas fir dried at high temperatures is sufficient to make the use of this method of drying for structural material questionable at the present time.

However, no definite conclusions should be made at this stage in the investigation. Tests made on selected lumber dried in industrial kilns should be compared with lumber dried in industrial high-temperature kilns to obtain true differences.

References

(1) Guernsey, F.W. 1957. High temperature drying of British Columbia softwoods. Forest Products Journal, October.

(2) Calvert, W.W. 1958. High temperature kiln drying of lumber — A summary of Eastern Canadian progress. Forest Products Journal, July.

(3) Wood Handbook. 1955. U. S. Department of Agriculture.

(4) Roff, J.W. 1960. Unpublished data. Forest Products Research Branch, Department of Forestry, Canada.

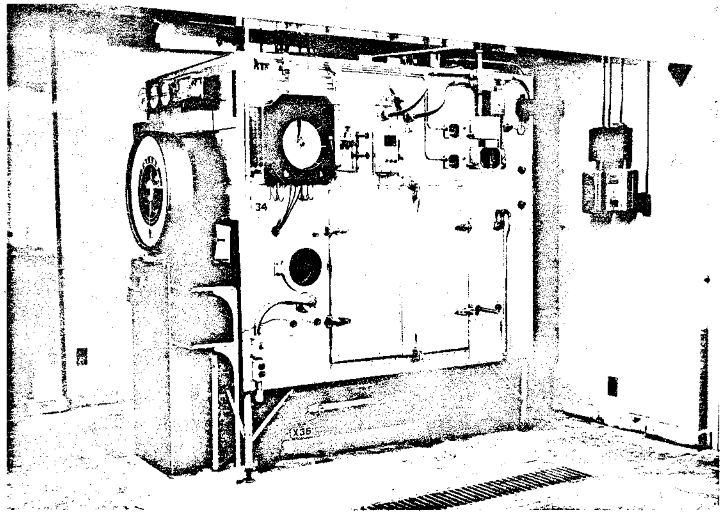
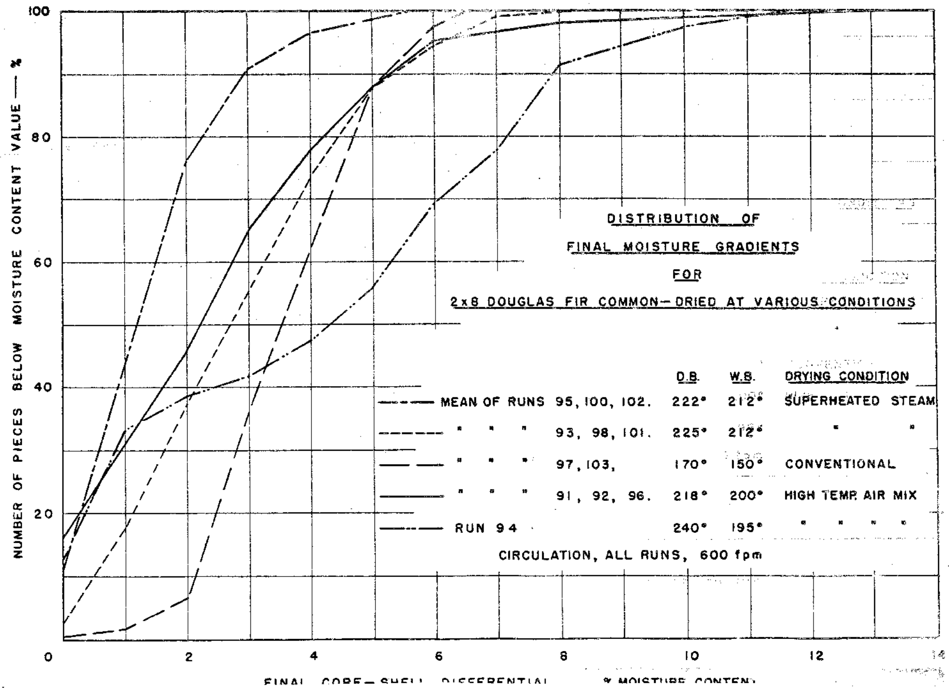
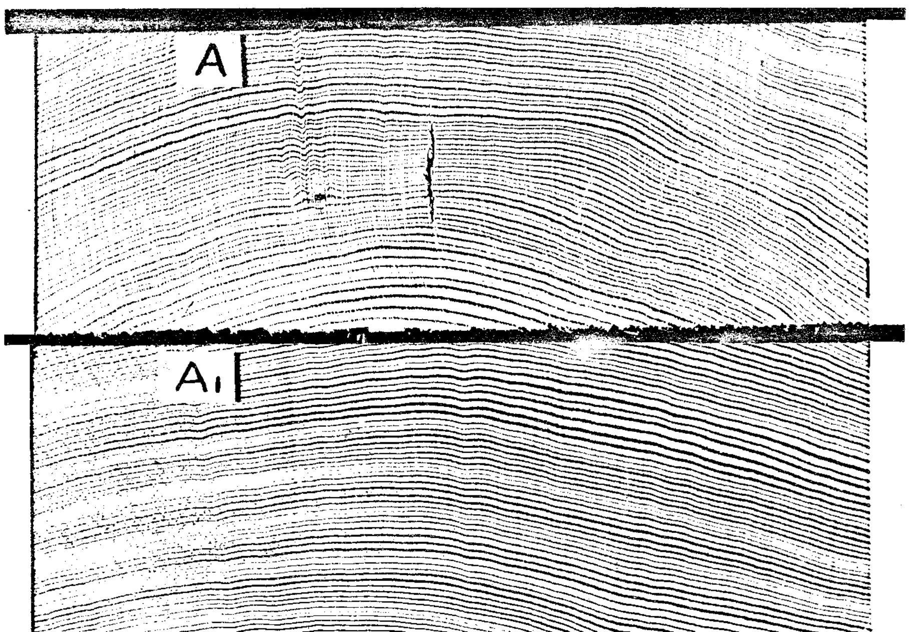
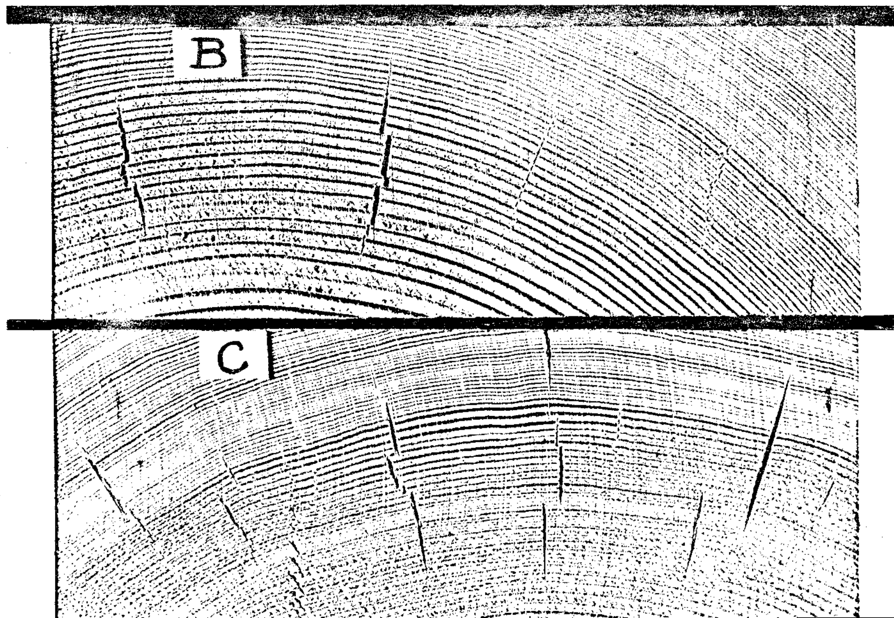


Fig. 1


DISTRIBUTION OF
FINAL MOISTURE GRADIENTS
FOR
2x8 DOUGLAS FIR COMMON— DRIED AT VARIOUS CONDITIONS
D.B. W.B. DRYING CONDITION
MEAN OF RUNS 95, 100, 102. 222° 212° SUPERHEATED STEAM
" " " 93, 98, 101. 225° 212° "
" " " 97, 103, 170° 150° CONVENTIONAL
" " " 91, 92, 96. 218° 200° HIGH TEMP. AIR MIX
RUN 94 240° 195° " " " "
CIRCULATION, ALL RUNS, 600 fpm
NUMBER OF PIECES BELOW MOISTURE CONTENT VALUE — %
100
80
60
40
20
0
2
4
6
8
10
12
14


A
A1


B
C

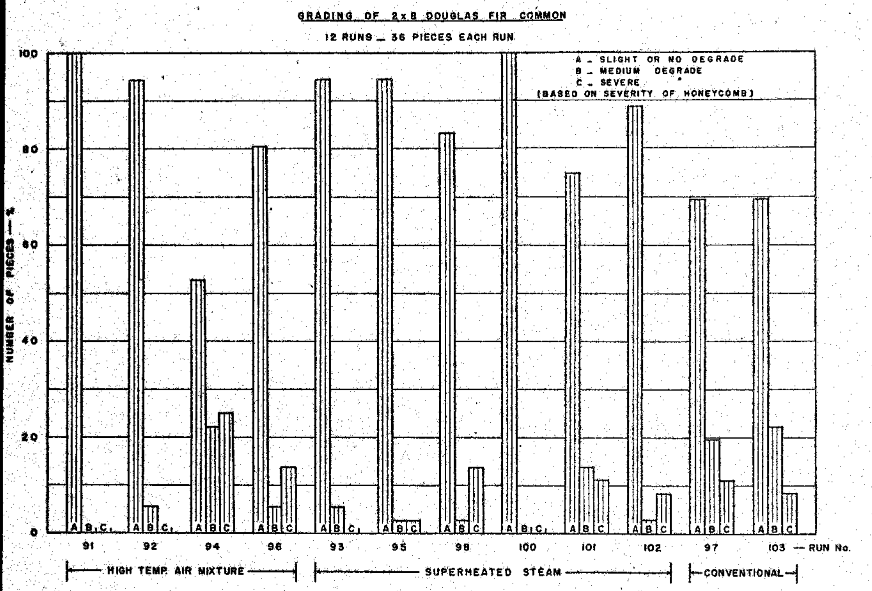


FIGURE 5

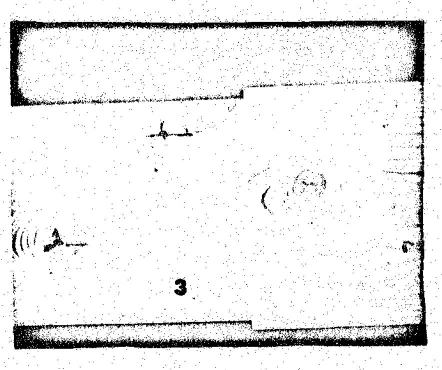


FIG. 6

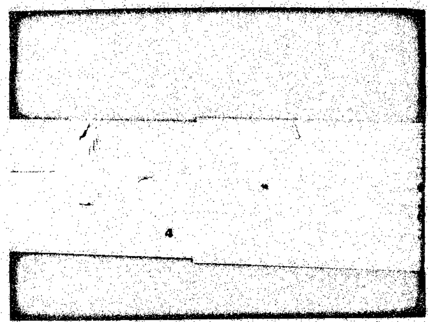


FIG. 7

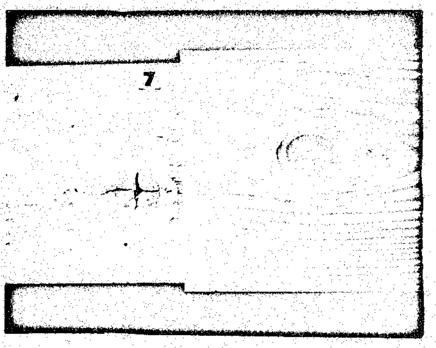


FIG. 8

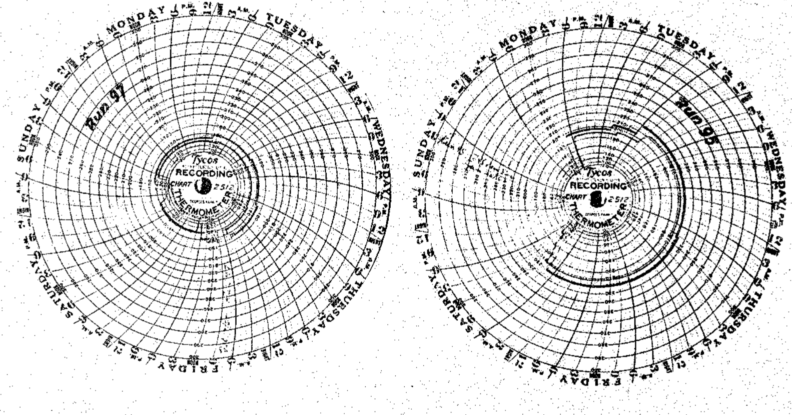


FIG. 9

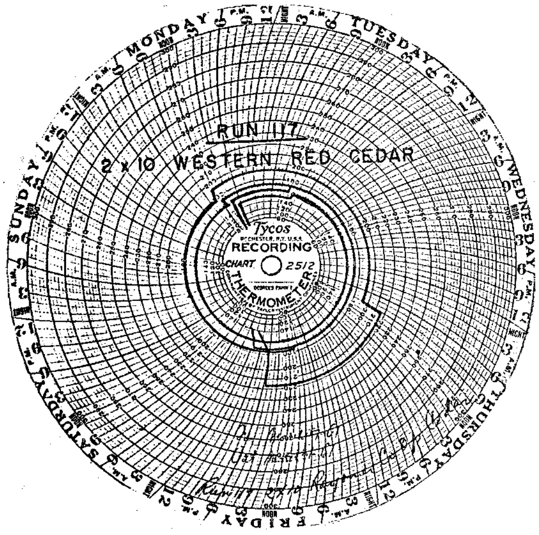


FIG. 11

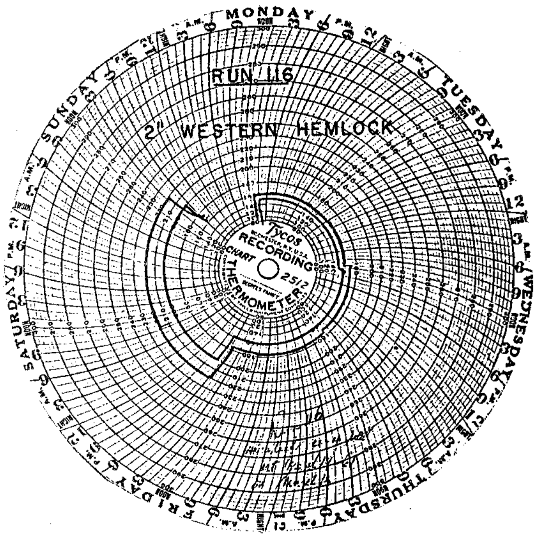


FIG. 10

TABLE 1

PARAMETERS OF DRYING MEDIUM & MOISTURE CONTENTS OF LUMBER DURING DRYING

NO. OF RUN	WARM-UP TEMP — °F		DRYING SCHEDULE												MOISTURE CONTENTS DURING DRYING IN %							DRYING MEDIUM *
			DRYING ABOVE F.S.P						DRYING BELOW F.S.P						INITIAL			CHANGE IN THE SCHEDULE (F.S.P)	FINAL			
			AT START			AT END			AT START			AT END										
	D.B. °F	W.B. °F	D.B. °F	W.B. °F	E.M.C. %	D.B. °F	W.B. °F	E.M.C. %	D.B. °F	W.B. °F	E.M.C. %	D.B. °F	W.B. °F	E.M.C. %	MIN.	AV.	MAX.		MIN.	AV.	MAX.	
91	190	165	190	185	15.0	210	200	10.9	218	200	7.1	218	200	7.1	30.8	43.0	61.4	20.4	10.1	13.0	21.0	HTA
92	195	190	195	190	14.8	210	200	10.9	218	200	7.1	218	200	7.1	34.8	44.0	53.2	21.1	10.0	13.4	19.4	HTA
93	195	190	195	190	14.8	210	200	10.9	212	212	19.5	225	212	8.7	31.7	44.3	57.0	20.7	10.2	12.7	16.6	SH2
94	195	190	205	190	8.8	205	195	11.3	240	195	3.5	240	195	3.5	34.5	45.3	62.9	29.5	8.6	12.5	17.2	HTA
95	195	190	195	190	14.8	218	212	13.8	222	212	9.7	222	212	9.7	32.5	59.6	152.7	25.3	11.5	13.4	17.3	SH1
96	195	190	195	190	14.8	210	200	10.9	218	200	7.1	218	200	7.1	36.5	63.0	159.6	26.6	8.6	10.4	14.3	HTA
97	140	135	140	135	16.7	140	135	16.7	160	145	9.6	170	150	7.8	35.4	62.1	147.3	21.7	9.9	12.4	16.0	CON
98	195	190	195	190	14.8	210	200	10.9	225	212	8.7	225	212	8.7	33.5	68.5	141.6	25.2	8.6	12.8	20.5	SH2
100	195	190	195	190	14.8	205	195	11.3	218	212	13.8	222	212	9.7	25.9	38.0	88.4	27.5	9.4	11.1	14.3	SH1
101	195	190	195	190	14.8	218	212	13.8	225	212	8.7	225	212	8.7	26.2	36.3	69.5	23.9	9.7	12.0	16.6	SH2
102	195	190	195	190	14.8	218	200	7.1	222	212	9.7	222	212	9.7	30.9	41.8	88.4	24.9	9.6	11.6	14.1	SH1
103	142	135	142	135	14.5	160	145	9.6	165	148	8.9	170	150	7.8	32.4	41.4	58.3	20.0	10.2	12.4	15.3	CON

* HTA – HIGH TEMPERATURE AIR MIXTURE
SH1 – SUPERHEATED STEAM, 222° LEVEL
SH2 – " " , 225° "
CON – CONVENTIONAL AIR MIXTURE

CIRCULATION, ALL RUNS — 600 fpm

THE RELATION OF KILN TREATMENT TO STRENGTH PROPERTIES OF 2" DOUGLAS FIR

TABLE 2

SHOWING MEAN VALUES ADJUSTED TO 12% M.C.

RUN NO.	STATIC BENDING							COMPRESSION PARALLEL TO GRAIN				
	NO. PCS. TESTED	BASIC SP. GRAVITY	RINGS PER INCH	SUMMER-WOOD-%	F.S. AT P.L. (PSI)	M.O.R. (PSI)	M.O.E. (1000 PSI)	NO. PCS. TESTED	BASIC SP. GRAVITY	RINGS PER INCH	SUMMER-WOOD-%	MAX. CR'SH'G STR'GTH-PSI
95	34	0·466	17	34	6880	10,447	1675	34	0·467	18	37	6175
96	30	0·468	15	35	7472	10,334	1598	30	0·467	16	—	6458
97	34	0·461	19	37	8880	13,740	1816	34	0·462	18	35	7297
98	32	0·456	18	33	7780	10,926	1675	33	0·455	17	—	6424

KILN TREATMENT

RUN NO.	DRY BULB	WET BULB	DRYING CONDITION
95	222°	212°	SUPERHEATED STEAM
96	218°	200°	HIGH TEMP. AIR MIXTURE
97	170°	150°	CONVENTIONAL
98	225°	212°	SUPERHEATED STEAM

CIRCULATION, ALL RUNS —— 600 fpm

THE RELATION OF KILN TREATMENT TO STRENGTH PROPERTIES OF 2" DOUGLAS FIR

TABLE 5

SHOWING TOUGHNESS TEST RESULTS

RUN NO.	IMPACTED SURFACE	NO. PCS. TESTED	AV. VALUES INCH-LBS.	STD. DEV.
97	TANGENTIAL	11	342·5	173·1
95 & 98	"	15	240·9	130·1
96	"	9	213·3	136·1
97	RADIAL	11	170·6	29·5
95 & 98	"	24	155·6	61·0
96	"	10	166·9	57·1

KILN TREATMENT

RUN NO.	DRY BULB	WET BULB	DRYING CONDITION
95	222°	212°	SUPERHEATED STEAM
96	218°	200°	HIGH TEMP. AIR MIXTURE
97	170°	150°	CONVENTIONAL
98	225°	212°	SUPERHEATED STEAM

CIRCULATION, ALL RUNS —— 600 fpm

THE RELATION OF KILN TREATMENT TO STRENGTH PROPERTIES OF 2" DOUGLAS FIR

TABLE 3

SHOWING MEAN VALUES ADJUSTED TO 12% M.C. AND 0·460 BASIC SPECIFIC GRAVITY

RUN NO.	STATIC BENDING							COMPRESSION PARALLEL TO GRAIN		
	NO. PCS. TESTED	F.S. AT P.L. (PSI)		M.O.R. (PSI)		M.O.E. – (1000 PSI)		NO. PCS. TESTED	MAX. CRUSHING STRENGTH	
		AVERAGE	STD. DEV.	AVERAGE	STD. DEV.	AVERAGE	STD. DEV.		AVERAGE	STD. DEV.
95	29	7107	1276	10,239	1558	1626	311	30	6034	939
96	29	7299	1290	10,107	1689	1557	339	30	6368	869
97	29	8843	1115	12,763	1114	1773	317	30	7251	640
98	29	7926	1065	11,152	1289	1686	239	30	6404	535

KILN TREATMENT

RUN NO.	DRY BULB	WET BULB	DRYING CONDITION
95	222°	212°	SUPERHEATED STEAM
96	218°	200°	HIGH TEMP. AIR MIXTURE
97	170°	150°	CONVENTIONAL
98	225°	212°	SUPERHEATED STEAM

CIRCULATION, ALL RUNS —— 600 fpm

TABLE 4

SHOWING EFFECT OF TEMPERATURE ON STRENGTH PROPERTIES OF 2x8 DOUGLAS FIR

RUN NUMBER		97	95	96	98
DRYING TIME – HRS.		153·5	118·0	116·5	95·0
TREATMENT – °F AND 600 fpm CIRCULATION		CONVENTIONAL 170° D.B — 150° W.B.	SUPERHEATED STEAM 222° D.B. — 212° W.B.	HIGH TEMP. AIR MIX 218° D.B. — 200° W.B.	SUPERHEATED STEAM 225° D.B. — 212° W.B.
		——	% DECREASE IN STRENGTH BASED ON RUN 97 VALUES		
STRENGTH PROPERTIES (MEAN VALUES)	F.S. AT P.L. (psi)	8843	19·6	17·5	10·4
	M.O.R. (psi)	12,763	19·8	20·8	12·6
	M.O.E. (1000 psi)	1773	8·3	12·2	4·9
	MAXIMUM CRUSHING STRENGTH – (psi)	7251	16·0	12·1	11·6