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(A Comparison of the Results of Treatment, by Pressure and Nonpressure Processes, on End-Matched Douglas-Fir and Shortleaf Pine Lumber)

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STUDY OF THE PRESERVATIVE TREATMENT OF LUMBER[1]

(A Comparison of the Results of Treatment, by Pressure and Nonpressure Processes, on End-Matched Douglas-Fir and Shortleaf Pine Lumber)

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Object of Study

The object of this study was to compare the results obtained in the treatment of end-matched Douglas-fir and southern yellow pine lumber by pressure and nonpressure processes. Results were desired for lumber nominally 2 and 4 inches thick, both unseasoned and seasoned and, in the case of 4-inch Douglas-fir, both unincised and incised. Results were also desired for each of the three standard types of preservatives, creosote, oilborne, and waterborne.

Selection of Lumber

The lumber used for the tests consisted of 2- by 8- and 4- by 6-inch material furnished in 16-foot lengths to provide four 4-foot end-matched specimens, 1 for each of 4 treating processes. Enough material was furnished to provide 10 specimens for each test variable. The lumber was cut, selected, and shipped during December to avoid fungus infection. It arrived at the Forest Products Laboratory within 2 to 3 weeks after its selection at the sawmills.

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[1] In cooperation with the American Wood-Preservers' Institute.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

The Douglas-fir lumber was of the Pacific Coast type, manufactured on the West Coast from logs originating in Thurston and Lewis Counties, Wash. The material was green and all heartwood. The 2 by 8's were grade B and Better, flat grain, and unsurfaced. The 4 by 6's were grade C and Better, clear, and surfaced four sides. Incising, where required, was done on the West Coast after surfacing and prior to shipment. The lumber for treatment in the unseasoned condition was wrapped in moisture-resistant paper to prevent drying in transit.

The southern yellow pine lumber was shortleaf pine manufactured in Arkansas. All material was green and was dipped in stain control chemicals immediately after it was sawed. The 2 by 8's were grade B and Better and unsurfaced, and were selected on the basis that they contained between 50 and 75 percent of sapwood. The 4 by 6's were Select Structural grade and unsurfaced, and were selected on the basis that they contained at least 50 percent of sapwood. The lumber for treatment in the unseasoned condition was wrapped in Sisalkraft to prevent drying in transit.

At the Forest Products Laboratory, the material for treatment in the unseasoned condition was stored in its wrappings at a temperature of 36° F. and a relative humidity of 82 percent until it was treated. The lumber to be treated in the seasoned condition was immediately dried in a kiln to a moisture content of 20 to 23 percent. It was then stored outdoors under a tarpaulin until ready for treatment.

Except for the Douglas-fir 4 by 6's, which had already been surfaced, the lumber was surfaced to uniform dimensions a few days prior to treatment and then cut into 4-foot test specimens. The 4- by 6-inch lumber at the time of treatment varied in thickness from 3.5 to 3.8 inches and in width from 5.5 to 6.0 inches. The 2- by 8-inch lumber varied in thickness from 1.6 to 1.9 inches and in width from 7.4 to 8.1 inches. No signs of blue stain, mold, or other fungus infections were found. Samples of representative pieces were cut for moisture content determinations by the ovendrying method. The moisture ranges were as follows:

	Moisture content at time of treatment (Percent)
Douglas-fir	
Unseasoned	33 to 37
Seasoned	15 to 19
Shortleaf pine	
Unseasoned	59 to 79
Seasoned	17 to 20

For identification, each 4-foot, end-matched specimen was numbered to indicate the 16-foot piece from which it was cut and its position in the piece. After being surfaced, cut, and numbered, the test specimens were returned to the cold storage room in order to retard moisture changes until ready for treatment. During the storage interval, a benzidine indicator was applied to both ends of the shortleaf pine specimens to permit ready differentiation between heartwood and sapwood. The percentage of sapwood was estimated and recorded for each test specimen.

In summarizing, the following types of lumber were covered in the study:

Douglas-fir (All heartwood)	Shortleaf pine (Containing both heartwood and sapwood)
4 by 6, unseasoned, unincised	4 by 6, unseasoned
4 by 6, unseasoned, incised	2 by 8, unseasoned
2 by 8, unseasoned, unincised	
4 by 6, seasoned, unincised	4 by 6, seasoned
4 by 6, seasoned, incised	2 by 8, seasoned
2 by 8, seasoned, unincised	

Preservatives

The tests included treatments with a standard coal-tar creosote, pentachlorophenol solution as a standard oilborne preservative, and chromated zinc chloride as a standard waterborne preservative.

Coal-Tar Creosote

The coal-tar creosote[3] conformed to the requirements of the American Wood-Preservers' Association Standard P1-54 for creosote. The analysis of the creosote, as furnished by the supplier, showed the following:

Specific gravity at 38° C./15.5° C.	1.070
Benzol insoluble, percent by weight	0.3
Water, percent by volume	0.3
Distillation, percent by weight:	
Up to 210° C.	2.5
Up to 235° C.	17.4
Up to 270° C.	40.7
Up to 315° C.	56.7
Up to 355° C.	80.1
Residue	19.8

[3]Contributed by Koppers Company, Inc., and distilled at Carrollville, Wis.

Coke residue, percent by weight	1.0
Specific gravity of fraction between 235° and 315° C. at 38° C./15.5° C.	1.039
Specific gravity of fraction between 315° and 355° C. at 38° C./15.5° C.	1.116

No solids were noticed in the creosote at room temperatures varying from 73° to 82° F.

Pentachlorophenol

The pentachlorophenol solution consisted of 5 percent of pentachlorophenol, by weight, in an aromatic petroleum oil[4] to which approximately 10 percent of low-viscosity aromatic tar[4] was added to darken the color of the solution and thereby aid in penetration observations. The pentachlorophenol conformed to American Wood-Preservers' Association Standard P8-51 for oilborne preservatives. The aromatic petroleum oil was selected to conform to American Wood-Preservers' Association Standard P9-52 for petroleum used in pentachlorophenol and copper naphthenate solutions, heavy petroleum solvent, and further for its suitability for boiling under vacuum and nonpressure application without heating.

The analyses of the aromatic petroleum oil and the aromatic tar, as furnished by the supplier, showed the following:

Aromatic petroleum oil

Gravity, °API at 60° F.	18.2
Viscosity, SSU at 100° F.	43
SSU at 210° F.	30
Flash point (Pensky-Martens), °F.	230+
Distillation, °F.	
IBP	476
5 percent	509
10 percent	516
20 percent	523
30 percent	528
40 percent	532
50 percent	537
60 percent	543
70 percent	550
80 percent	562
90 percent	589
93 percent	600

[4] Contributed by Enjay Company, Inc., from North Baton Rouge, La., refinery.

Total aromatics (by Katwinkle), percent	64.5
Pentachlorophenol solvency, percent by volume at:	
77° F.	16
100° F.	18

Aromatic tar

Gravity, °API at 60° F.	1.6
Viscosity, SSU at 210° F.	70
Unsulfonated residue, percent	5
Sulfur, percent by weight	1.25
Water and sediment (BS&W) percent by weight	0.2
Flash point (Pensky-Martens), °F.	235
Carbon, percent by weight	90.5
Hydrogen, percent by weight	8.5
H/C ratio	1.13

Chromated Zinc Chloride

The chromated zinc chloride conformed to American Wood-Preservers' Association Standard P5-54 for waterborne preservatives. A 5 percent solution was used for treating Douglas-fir and a 3 percent solution for shortleaf pine.

Treating Processes

The treating processes selected for testing included, in addition to the standard pressure process, several of the better known nonpressure processes.

The processes used for treatment with the three preservatives were as follows:

Creosote and pentachlorophenol	Chromated zinc chloride
Pressure, empty-cell (Rueping)[5]	Pressure, full cell[5]
Vacuum[6]	Vacuum[6]
Cold soaking 24 hours	Steaming and vacuum process[7]
Dipping 3 minutes	Steaming and soaking process[8]

The treating schedules used were based on recommendations by those using the respective processes and were considered, for the most part, to be typical of those that would be used in commercial practice for the types of lumber involved. Mention should be made, however, of the fact that, in the case of nonpressure processes, some producers prefer to limit application of their process to selected species, with limits on heartwood content and moisture content. Following are the details of each schedule.

Pressure Process

1. Conditioning of unseasoned lumber.

	Shortleaf pine treated with all preservatives	
Steam Conditioning	2 by 8's	4 by 6's
Steaming up to 259° F. (hours)	1	1
Steaming at 259° F. (hours)	3	5
Vacuum, 27-1/2 inches (hours)	2	2

[5] Schedule selected on basis of suggestions received from Committee of the Board of the American Wood-Preservers' Institute.

[6] Schedule selected on basis of suggestions received from Vacuum Wood Preservers' Institute and from Protection Products Manufacturing Company.

[7] Schedule selected on basis of suggestions received from the Osmose Wood Preserving Company of America, Inc. Although a pressure of 7 pounds per square inch was applied in the steaming and vacuum process, this treatment is generally recognized as a nonpressure method and is discussed on that basis in this report.

[8] Schedule selected on basis of suggestions received from American Celcure Wood Preserving Corporation.

Steam Conditioning	Douglas-fir treated with chromated zinc chloride 2 by 8's and 4 by 6's
Steaming up to 230° F. (hours)	1
Steaming at 230° F. (hours)	3
Vacuum, 27-1/2 inches (hours)	2

Boultonizing	Douglas-fir treated with creosote and pentachlorophenol 2 by 8's and 4 by 6's
Temperature of preservative (°F.)	190
Vacuum during heating (inches)	26.5 to 27.5
Duration of heating (hours)	8

2. Impregnation

	Unseasoned and seasoned Douglas-fir 2 by 8's and 4 by 6's treated with creosote and pentachlorophenol	Shortleaf pine 2 by 8's and 4 by 6's treated with creosote and pentachlorophenol	
		Unseasoned	Seasoned
Initial air (P.s.i.)	30	60	70
Initial air time (Min.)	30	30	30
Treating pressure (P.s.i.)	125	175	175
Treating pressure time (Hr.)	12	3	3
Preservative temperature			
creosote (°F.)	200	200	200
pentachlorophenol (°F.)	150	150	150
Duration of final vacuum, 27-1/2 inches (Hr.)	1	1	1

	Unseasoned and seasoned Douglas-fir 2 by 8's and 4 by 6's treated with chromated zinc chloride	Unseasoned and seasoned shortleaf pine 2 by 8's and 4 by 6's treated with chromated zinc chloride
Initial vacuum, 27-1/2 in. (Min.)[9]	30	30
Treating pressure (P.s.i.)	125	175
Treating pressure time (Hr.)	12	3
Preservative temperature (°F.)	100	100

Vacuum Process

	Unseasoned and seasoned Douglas-fir and shortleaf pine 2 by 8's and 4 by 6's treated with creosote, pentachlorophenol, and chromated zinc chloride
Initial vacuum, 27.5 in. Time (Min.)	30
Soaking in unheated preservative at atmospheric pressure (Hr.)[10]	8
Recovery vacuum, 27.5 in. Time (Hr.)	2

Steaming and Vacuum Process

	Douglas-fir treated with chromated zinc chloride				Shortleaf pine treated with chromated zinc chloride			
	Unseasoned		Seasoned		Unseasoned		Seasoned	
	2x8's	4x6's	2x8's	4x6's	2x8's	4x6's	2x8's	4x6's
Vacuum (22 in. Min.) Time (Hr.)	1	1	0.75	0.75	0.75	1	0.5	0.75
Steaming (240° F. Max. for Douglas-fir and 259° F. Max. for shortleaf pine) Time (Hr.)	3	6	4	6	1.5	4	1.5	3

[9] In the case of unseasoned Douglas-fir and shortleaf pine, the vacuum used in the conditioning procedure was substituted for the initial vacuum.

[10] For seasoned 2 by 8 shortleaf pine the desired gross absorption of 9 pounds per cubic foot was reached in 4 hours with creosote and in 2 hours with pentachlorophenol.

Steaming and Vacuum Process (continued)

	Douglas-fir treated with chromated zinc chloride				Shortleaf pine treated with chromated zinc chloride			
	Unseasoned		Seasoned		Unseasoned		Seasoned	
	2x8's	4x6's	2x8's	4x6's	2x8's	4x6's	2x8's	4x6's
Vacuum (14 in. Min.) Time (Hr.)	1.5	2	1.5	1.5	0.5	0.5	0.5	0.5
Steaming (240° F. Max.) Time (Hr.)	1.5	2	1.5	2	...	...	...	...
Vacuum (14 in. Min.) Time (Hr.)	0.5	0.5	0.5	0.5	...	...	...	...
Soaking in unheated preservative (at 7 p.s.i.) Time (Hr.)	4	4	4	4	2	2	2	2

Steaming and Soaking Process

	Unseasoned and seasoned Douglas-fir and shortleaf pine treated with chromated zinc chloride	
	2 x 8's	4 x 6's
Steaming, 200° to 212° F. Time (Hr.)	2.5	4
Soaking in unheated preservative Time (Hr.)	8	8

Measurements of Preservative Retention and Penetration

Retention

Preservative retention measurements, in pounds per cubic foot of wood, were obtained by weighing specimens of known volume before and after they were treated. Where specimens were subjected to either steaming or steaming and vacuum conditioning prior to treatment, representative pieces were weighed after the conditioning to correct for the loss (or gain) due to moisture changes. The differences in weight brought about by steaming or steaming and vacuum were as follows:

	Moisture loss (-) or gain (+)			
	Douglas-fir		Shortleaf pine	
	Unseasoned	Seasoned	Unseasoned	Seasoned
	(Pound per cubic foot)			
Steam conditioning prior to pressure treatment	-0.3to-0.8	....	-4.7to-5.7	....
Steaming and vacuum process	+0.3to+1.1	+1.3to+1.7	-0.6to+1.0	+0.9to+1.3
Steaming and soaking process	+1.2to+1.8	+1.2to+1.8	-0.8to-0.9	+1.5

In the case of the pressure treatments of unseasoned Douglas-fir, involving conditioning by Boultonizing, no correction was applied to specimen weights, since the limited quantity of water removed from the vacuum condenser indicated that the specimens had no significant moisture loss.

Penetration

From the middle of each 4-foot treated specimen, a cross section was sawed to determine the average transverse penetration in inches in both the radial direction, or perpendicular to the annual rings, and the tangential direction, or parallel to the annual rings. For southern pine, measurements were made in both the sapwood and the heartwood. One of the 2-foot-long ends from each specimen was split lengthwise in the middle to determine longitudinal penetration and, again in southern pine, measurements were made in sapwood and heartwood.

In both shortleaf pine and Douglas-fir, longitudinal penetration is greater in the dense summerwood bands than in the springwood. As a result, longitudinal penetration is solid for a distance and then becomes fingered. Three longitudinal penetration measurements were taken, (1) solid penetration, or the distance to which all of the springwood and summerwood bands were penetrated, (2) minimum fingered penetration, or the distance of the least summerwood penetration, and (3) average fingered penetration, or the estimate of the average distance of penetration in the summerwood bands. The points at which these three penetration determinations were taken are illustrated in figure 1, a split section of pentachlorophenol-treated Douglas-fir.

Following penetration measurements, the remaining half-length of each specimen was put aside until the four treatments on similar material with the same preservative were completed. New cross sections and longitudinal sections were then exposed for photographing. To reduce spreading of creosote and pentachlorophenol solution to untreated areas prior to photographing, the freshly exposed surfaces were sprayed with Krylon graphic arts protective coating. Although it was not practicable to prepare and photograph all of the test specimens treated with creosote and pentachlorophenol, representative sets of end-matched specimens were photographed to show comparative results for the four treatments (figs. 2 to 6).

In the case of the chromated zinc chloride treatments, the specimens were kiln dried after treatment and no spreading was noted over the cut surfaces. To detect the presence of chromated zinc chloride, a stain indicator was applied to the cut surfaces in accordance with American Wood-Preservers' Association Standard A3-54, Method for Determining Penetration of Preservatives. Photographs were taken of the cross sections of all the specimens treated with chromated zinc chloride, but only one set of representative specimens was photographed to show longitudinal penetration (figs. 7 to 12). Transverse penetration of 2- by 8-inch shortleaf pine by chromated zinc chloride is shown in figure 13.

Results

Retention and penetration results are given in tables 1, 2, and 3 for creosote, pentachlorophenol, and chromated zinc chloride treatments, respectively. Standard deviations are shown in these tables for preservative retentions and for average fingered longitudinal penetration. Figures 14 and 15 are bar graphs for Douglas-fir and shortleaf pine, respectively, showing minimum, average, and maximum preservative retentions for each 10-specimen set. Minimum, average, and maximum penetration measurements for each set of 10 specimens are shown in the bar graphs in figures 16 through 20. The average values given in the tables and bar graphs usually represent 10 test specimens. The exceptional cases in which averages represent less than 10 specimens are noted.

The photographs of transverse and longitudinal penetrations are shown in the following figures:

Creosote and pentachlorophenol treatments	- Figures 2 through 6
Chromated zinc chloride treatments	- Figures 7 through 13

Discussion of Results

In these tests, conclusions should be based principally on comparisons between treating processes, inasmuch as specimens were end matched only as to treating processes. Comparisons between other variables involving unmatched specimens, however, also show significant differences, particularly in comparisons of shortleaf pine with Douglas-fir, unseasoned with seasoned wood, and unincised with incised wood.

The aim in treating lumber with preservatives is to penetrate the wood as deeply as possible without leaving too much or too little of the preservative in the treated area. The quantity of preservative must be great enough to give the desired protection and to meet the minimum retention requirements of recognized standards of treatment.

In pressure treatments with creosote and oilborne preservatives, the usual empty-cell procedure is to inject into the wood more preservative than is specified in order to obtain deep penetration, and then to recover part of the preservative. This procedure was used in this study for the creosote and pentachlorophenol pressure treatments, and to a limited extent, in the vacuum treatments with these preservatives. With the fixed schedules outlined above, there was no opportunity to vary the retentions of preservative. Therefore, the retention values for creosote and pentachlorophenol in themselves will not accurately reflect the relative effectiveness of the four treating processes with those preservatives.

With waterborne preservatives, the retention of dry preservative is regulated by varying the strength of the solution. Therefore, it is practicable and usually desirable to leave as much of the preservative solution in the wood as it will hold. In the four treatments with chromated zinc chloride in these tests, no attempt was made to recover part of the treating solution. The retentions of chromated zinc chloride solution, therefore, reflect the effectiveness of the various treating processes when applied to similar types of material.

Attention is called to certain possible inconsistencies in the penetrations as shown in the tables and photographs. As described earlier, longitudinal penetration measurements and the photographs were not taken from the same split sections. It should be recognized also that radial and tangential penetration values obtained from cross sections will vary within wide limits according to differences in the position and direction of the annual rings. For southern pine, in which measurements were made in both the sapwood and the heartwood, the transverse penetration values also will vary as the thickness of the sapwood. Some differences in sapwood thickness can be expected, even in end-matched pieces that are selected to keep such differences to a minimum. Values for transverse penetration, therefore, should be considered only in general comparisons.

Preservative oils.--The data for the various pressure treatments show average retentions of creosote and pentachlorophenol to vary from 7.3 pounds to 18.9 pounds per cubic foot (tables 1 and 2, figs. 14 and 15). With variations in the initial air pressure, these values could be raised or lowered to meet the minimum retention requirements of American Wood-Preservers' Association Standard C2-54 of 8 pounds per cubic foot for southern pine and 10 pounds for Douglas-fir lumber and timbers.

Average creosote and pentachlorophenol solution retentions for the vacuum process varied from 2.5 pounds to 4.3 pounds per cubic foot in unseasoned Douglas-fir, and from 2.1 to 4.2 pounds per cubic foot in unseasoned shortleaf pine. These retentions, and those obtained by all the cold soaking and dipping treatments, are considerably below the minimum retentions usually specified for those preservatives when a high degree of protection is desired. In seasoned Douglas-fir and shortleaf pine, however, retentions of preservative oils obtained in the vacuum process varied from 7.7 pounds to 22.2 pounds per cubic foot.

The data in tables 1 and 2, the bar graphs in figures 16, 17, 19, and 20, and the photographs in figures 2 to 6 show transverse and longitudinal penetrations of creosote and pentachlorophenol solution to be greater for the pressure than for the other processes, particularly cold soaking and dipping. In seasoned shortleaf pine, however, sapwood penetrations obtained with the vacuum process sometimes compared favorably with those obtained with pressure treatment. Pressure treatment with creosote and pentachlorophenol practically always furnished deeper heartwood penetration, especially in shortleaf pine, than that obtained with other treatments with those oils.

Differences in transverse heartwood penetration between pressure and nonpressure treatments were often greater than would be indicated by differences in preservative retention. In table 1, for example, the average creosote retentions in 4- by 6-inch unincised, seasoned, Douglas-fir were 17.7 pounds and 10.3 pounds per cubic foot, respectively, for the pressure and vacuum treatments. The averages for radial heartwood penetration were 0.75 inch and 0.08 inch, respectively, and for tangential penetration 0.87 inch and 0.18 inch.

In pressure treatments, oil retentions were somewhat lower in unseasoned material than in seasoned lumber of both species. Differences were even more pronounced in the vacuum treatments on seasoned and unseasoned material. Vacuum treatment with oils usually showed better penetrations in seasoned than in unseasoned lumber; in pressure treatments, differences in penetrations due to seasoning were less noticeable (figs. 2 to 6).

Retentions in unincised Douglas-fir treated by all processes, were usually lower than in incised specimens, but not significantly so. Transverse penetration in the vacuum treatment was improved through incising but did not as a rule extend to the full depth of the incisions (figs. 2, 3, and 16, and tables 1 and 2). In the pressure treatment of Douglas-fir with oils, transverse penetration in both incised and unincised lumber practically always averaged more than the depth of the incisions.

Chromated zinc chloride.--The data on retentions of chromated zinc chloride obtained in the four treating processes supply information on the questions (1) whether sufficient quantities of a preservative salt can be applied to meet recognized minimum standards and (2) whether the quantity of solution is sufficient to furnish good penetration and distribution in the wood.

One of the waterborne preservatives in AWPA Standard C2 must show a minimum dry salt retention of 0.35 pound per cubic foot. Since the solubility of this preservative limits treating solutions to about a 5 percent concentration, a minimum solution retention of 7 pounds per cubic foot would be required. With preservatives of greater solubility, minimum solution retentions would be correspondingly less than 7 pounds per cubic foot. Reference to table 3 and to the bar graphs in figures 14 and 15 indicates that an average solution retention of 7 pounds per cubic foot or higher was obtained in the following test schedules used in this study:

Pressure treatment - in all cases.

Vacuum treatment - (1) incised, seasoned, 4- by 6-inch Douglas-fir; (2) seasoned 2- by 8-inch Douglas-fir; (3) unseasoned 2- by 8-inch shortleaf pine; and (4) seasoned, shortleaf pine (both sizes).

Steaming and vacuum - (1) incised, seasoned and unseasoned, 4- by 6-inch Douglas-fir; (2) seasoned and unseasoned 2- by 8-inch Douglas-fir; and (3) seasoned and unseasoned shortleaf pine (both sizes).

Steaming and soaking - (1) seasoned, 2- by 8-inch Douglas-fir; (2) unseasoned, 2- by 8-inch shortleaf pine; and (3) seasoned, shortleaf pine (both sizes).

The relationship between solution retentions and preservative distribution in this study can be noted in figures 7 to 13 and table 3. The average solution retentions for unincised 4- by 6-inch, heartwood Douglas-fir are shown in table 3 to be 22.5 pounds and 21.5 pounds per cubic foot, respectively, for the unseasoned and seasoned material. In figures 7 and 9 the pressure-treated specimens that showed a high percentage of the cross section unpenetrated had solution retentions on individual specimens varying from 9.9 to 17.1 pounds per cubic foot. The individual specimens with complete or nearly complete penetration always showed retentions varying from 20.1 pounds to 37.9 pounds per cubic foot for the unseasoned Douglas-fir and 21.5 pounds to 41.0 pounds for the seasoned treated specimens. A similar relationship exists in the pressure-treated incised 4- by 6-inch and the 2- by 8-inch Douglas-fir.

In the unseasoned 4- by 6-inch shortleaf pine that was pressure treated (fig. 11), the average solution retention was 20.9 pounds per cubic foot. However, the individual specimens showing complete or nearly complete sapwood penetration had solution retentions that were higher than this average, while those with incomplete sapwood penetration averaged 18.2 pounds per cubic foot. In the seasoned pine of both dimensions (figs. 12

and 13, bottom) that was treated by pressure and nonpressure methods, the specimens showed a high percentage of sapwood penetration when solution retentions averaged around 20 pounds per cubic foot or higher. In the pressure treatment of seasoned pine of both dimensions, solution retentions averaging 31.5 pounds and 32.5 pounds per cubic foot resulted in considerable penetration of the heartwood.

In general, chromated zinc chloride penetrations were considerably better in pressure than in nonpressure treatments. This was particularly the case with the Douglas-fir (figs. 7, 8, 9, and 10), and the unseasoned shortleaf pine (figs. 11 and 13, top). Good sapwood penetration was obtained in each of the four processes on seasoned shortleaf pine (figs. 12 and 13, bottom). Pressure treatment furnished significantly better heartwood penetration in the air-seasoned shortleaf pine than was obtained with the nonpressure processes.

Incising of the Douglas-fir helped to improve transverse penetration with the nonpressure treatments and also in the more resistant specimens treated by pressure (figs. 7, 8, 9, and 10). The degree of seasoning was of less importance in influencing penetrations of chromated zinc chloride in Douglas-fir than in shortleaf pine.

Conclusions

The following conclusions are reached from the results of this study:

1. In treatments with creosote and pentachlorophenol solution, recognized minimum retentions were always obtained or closely approached by pressure impregnation.

2. Recognized minimum creosote and pentachlorophenol retentions were obtained by the vacuum process in seasoned shortleaf pine of both sizes, and in 2- by 8-inch seasoned Pacific Coast Douglas-fir. In seasoned 4- by 6-inch Pacific Coast Douglas-fir, such minimum retentions were obtained with creosote but not with pentachlorophenol. Penetrations with the vacuum process were best in the sapwood of seasoned pine.

3. Cold soaking and 3-minute dip treatments with preservative oils always furnished substandard retentions and limited penetrations. In seasoned pine sapwood, transverse and longitudinal penetrations of oils in cold soaking for 24 hours were considerably better than those obtained in dipping for 3 minutes.

4. Chromated zinc chloride solution retentions of at least 20 pounds per cubic foot were necessary to obtain good preservative penetration or distribution under the conditions used in this study. Such reten-

tions were obtained only in pressure impregnation, except in seasoned shortleaf pine where retentions approached or exceeded 20 pounds in treatments by the vacuum and steaming and vacuum processes on 2- by 8-inch and 4- by 6-inch material, and by the steaming and soaking process on the 2-inch seasoned pine.

5. The penetrations obtained in pressure treatments with chromated zinc chloride were less uniform than those with creosote and pentachlorophenol, particularly in the heartwood Douglas-fir and the unseasoned shortleaf pine sapwood and heartwood.

6. Pressure treatment furnished uniformly better transverse and longitudinal penetration of preservative oils and chromated zinc chloride than the nonpressure process used, particularly in the sapwood of unseasoned shortleaf pine and in the heartwood of unseasoned and seasoned Douglas-fir and shortleaf pine.

7. Incising of Douglas-fir improved transverse penetration in the specimens most resistant to treatment and thereby helped to assure good penetration by pressure impregnation. Incising also improved the penetration of chromated zinc chloride in seasoned and unseasoned Douglas-fir treated by steaming and vacuum. It was less helpful in the other nonpressure treatments with chromated zinc chloride and oils, since penetrations in such treatments did not average or approach the full depth of the incisions.

Table 1.--Average creosote retentions and penetrations in Douglas-fir and shortleaf pine lumber treated by different processes

Treating process	Lumber size	Incised	Sapwood	Preservative retention		Transverse penetration				Longitudinal penetration							
						Sapwood		Heartwood		Sapwood				Heartwood			
				Amount	Standard deviation[1]	Radial	Tangential	Radial	Tangential	Solid	Minimum fingered	Average fingered	Standard deviation[1]	Solid	Minimum fingered	Average fingered	Standard deviation[1]
	In.		Percent	Lb. per cu. ft.	Lb. per cu. ft.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
A. UNSEASONED DOUGLAS-FIR																	
Pressure	4 x 6	No	0	15.6	4.40	...	...	1.11	1.83	...	...	...	...	2.16	18.50	21.30	2.83
Vacuum			0	2.5	2.03	...	...	.04	.05	...	...	...	...	.38	1.10	1.54	1.43
Cold soaking			0	.6	.20	...	...	.02	.04	...	...	...	...	.08	.27	.17	.08
Dipped 3 minutes			0	.3	.07	...	...	.01	.02	...	...	...	...	.10	.34	.21	.05
Pressure	4 x 6	Yes	0	15.9	3.08	...	...	1.20	1.32	...	...	...	...	1.86	18.60	21.62	2.75
Vacuum			0	4.2	2.32	...	...	.03	.06	...	...	...	...	.22	1.28	1.74	1.95
Cold soaking			0	1.3	.36	...	...	.02	.02	...	...	...	...	.13	.39	.56	.31
Dipped 3 minutes			0	.6	.08	...	...	.02	.02	...	...	...	...	.05	.81	.23	.10
Pressure	2 x 8	No	0	17.8	5.46	...	...	.81	2.58	...	...	...	...	13.81	18.65	21.08	5.67
Vacuum			0	4.3	1.56	...	...	.03	.09	...	...	...	...	.22	1.55	2.38	1.46
Cold soaking			0	.9	.21	...	...	.02	.02	...	...	...	...	.04	.17	.33	.21
Dipped 3 minutes			0	.3	.06	...	...	.01	.01	...	...	...	...	.02	.13	.19	.12
B. SEASONED DOUGLAS-FIR																	
Pressure	4 x 6	No	0	17.7	4.56	...	...	.75	.87	...	...	...	...	7.70	10.22	15.52	5.46
Vacuum			0	10.3	8.03	...	...	.08	.18	...	...	...	...	2.60	4.10	7.15	5.34
Cold soaking			0	1.4	.45	...	...	.02	.02	...	...	...	...	.10	.22	.52	.27
Dipped 3 minutes			0	.4	.11	...	...	.02	.02	...	...	...	...	.05	.14	.26	.15
Pressure	4 x 6	Yes	0	18.9	2.44	...	...	.78	.98	...	...	...	...	3.46	6.00	15.80	3.68
Vacuum			0	12.2	5.00	...	...	.05	.04	...	...	...	...	.81	1.34	4.72	3.21
Cold soaking			0	1.9	.36	...	...	.02	.02	...	...	...	...	.08	.27	.52	.11
Dipped 3 minutes			0	.8	.07	...	...	.02	.02	...	...	...	...	.04	.15	.28	.18
Pressure	2 x 8	No	0	18.8	3.47	...	...	.56	1.66	...	...	...	...	8.81	10.90	17.61	6.38 (9)
Vacuum			0	17.5	10.06	...	...	.22	.27	...	...	...	...	4.64	6.36	11.20	7.27
Cold soaking			0	2.4	.61	...	...	.03	.03	...	...	...	...	.09	.48	1.04	.66
Dipped 3 minutes			0	.5	.11	...	...	.02	.02	...	...	...	...	.05	.22	.29	.10
C. UNSEASONED SHORTLEAF PINE																	
Pressure	4 x 6	No	73	7.3	1.47	1.68	1.92	.55	.66	13.72	15.10	19.30	5.72	6.75	8.45	12.35	5.21
Vacuum			75	3.4	.70	.08	.08	.04	.04	.64	2.18	4.32	3.08	.16	.26	.83	.74 (9)
Cold soaking			73	1.1	.36	.07	.08	.02	.02	.28	.82	1.30	.72	.06	.13	.25	.14 (6)
Dipped 3 minutes			75	.4	.31	.02	.02	.02	.02	.03	.10	.17	.17	.02	.04	.06	.04 (9)
Pressure	2 x 8	No	53	9.4	1.78	.73	2.02	.81	1.60	19.88	21.50	23.20	1.93	15.88	17.76	20.00	7.07
Vacuum			62	4.2	1.48	.08	.08	.04	.05	.95	4.11	5.56	3.28	.23	.66	.89	1.24 (9)
Cold soaking			61	1.2	.30	.09	.09	.02	.02	.15	.61	.72	.46	.03	.08	.10	.04 (8)
Dipped 3 minutes			80	.4	.08	.04	.03	.02	.02	.04	.12	.24	.17	.02	.04	.06	.04 (8)
D. SEASONED SHORTLEAF PINE																	
Pressure	4 x 6	No	72	10.1	2.22	2.41	2.02	.52	.45	23.60	23.60	23.98	.08	3.49	6.88	9.97	8.03 (8)
Vacuum			63	9.5	2.76	1.30	1.87	.05	.02	16.60	19.10	21.00	4.27	.10	.14	.24	.13 (8)
Cold soaking			68	1.4	.32	.18	.20	.02	.03	.42	1.61	2.43	.88	.03	.07	.12	.07 (7)
Dipped 3 minutes			62	.4	.09	.06	.04	.02	.02	.10	.34	.66	.45	.02	.07	.12	.03 (8)
Pressure	2 x 8	No	62	12.2	1.41	.89	2.26	.23	.41	24.00	24.00	24.00	0	4.69	12.11	18.86	5.49 (7)
Vacuum			65	9.0	2.55	.57	1.44	.05	.03	21.20	21.80	22.00	4.24	.54	1.35	3.34	5.16 (8)
Cold soaking			62	2.0	.81	.25	.30	.03	.03	.22	1.32	2.50	3.08	.04	.24	.35	.39 (9)
Dipped 3 minutes			63	.5	.10	.05	.06	.01	.01	.14	.41	.62	.27	.02	.06	.15	.10

[1] Values based on averages of 10 specimens unless the number of specimens is otherwise indicated in parentheses.

Z M 106 383

Forest Products Laboratory
Madison 5, Wisconsin

Table 2.--Average pentachlorophenol solution retentions and penetrations in Douglas-fir and shortleaf pine lumber treated by different processes

Treating process	Lumber size	Incised	Sapwood	Preservative retention: Amount	Preservative retention: Standard deviation[1]	Transverse penetration: Sapwood: Radial	Transverse penetration: Sapwood: Tangential	Transverse penetration: Heartwood: Radial	Transverse penetration: Heartwood: Tangential	Longitudinal penetration: Sapwood: Solid	Longitudinal penetration: Sapwood: Minimum fingered	Longitudinal penetration: Sapwood: Average fingered	Longitudinal penetration: Sapwood: Standard deviation[1]	Longitudinal penetration: Heartwood: Solid	Longitudinal penetration: Heartwood: Minimum fingered	Longitudinal penetration: Heartwood: Average fingered	Longitudinal penetration: Heartwood: Standard deviation[1]
	In.		Percent	Lb. per cu. ft.	Lb. per cu. ft.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
A. UNSEASONED DOUGLAS-FIR																	
Pressure	4 x 6	No	0	14.3	4.00	...	...	0.82	0.97	...	...	...	...	6.00	13.85	18.60	4.40
Vacuum			0	2.8	2.75	...	...	.03	.03	...	...	...	...	.55	.96	2.48	2.93
Cold soaking			0	.5	.10	...	...	.01	.01	...	...	...	...	.04	.10	.19	.08
Dipped 3 minutes			0	.2	.05	...	...	.01	.01	...	...	...	...	.05	.18	.38	.29
Pressure	4 x 6	Yes	0	14.9	3.09	...	...	.49	1.11	...	...	...	...	7.36	15.10	19.80	5.27
Vacuum			0	3.4	1.59	...	...	.03	.03	...	...	...	...	.36	.76	2.15	1.39
Cold soaking			0	.7	.18	...	...	.01	.01	...	...	...	...	.06	.10	.18	.09
Dipped 3 minutes			0	.5	.08	...	...	.01	.01	...	...	...	...	.04	.23	.46	.34
Pressure	2 x 8	No	0	15.4	4.43	...	...	.60	1.72	...	...	...	...	5.38	18.00	18.92	5.86
Vacuum			0	3.4	1.52	...	...	.05	.06	...	...	...	...	.39	1.91	2.78	1.67
Cold soaking			0	.9	.16	...	...	.01	.01	...	...	...	...	.03	.28	.60	.32
Dipped 3 minutes			0	.3	.08	...	...	.01	.01	...	...	...	...	.07	.38	.60	.38
B. SEASONED DOUGLAS-FIR																	
Pressure	4 x 6	No	0	14.5	4.50	...	...	1.23	1.08	...	...	...	...	8.44	12.52	17.76	6.69
Vacuum			0	7.8	6.97	...	...	.12	.16	...	...	...	...	1.83	2.91	5.74	5.09
Cold soaking			0	.6	.23	...	...	.01	.01	...	...	...	...	.06	.28	.46	.49
Dipped 3 minutes			0	.3	.11	...	...	.01	.01	...	...	...	...	.12	.30	.56	.27
Pressure	4 x 6	Yes	0	15.0	2.19	...	...	.96	.95	...	...	...	...	4.81	6.44	15.59	5.21
Vacuum			0	7.7	3.53	...	...	.08	.04	...	...	...	...	.54	1.32	3.70	2.55
Cold soaking			0	.8	.08	...	...	.01	.01	...	...	...	...	.06	.16	.28	.15
Dipped 3 minutes			0	.6	.07	...	...	.01	.01	...	...	...	...	.12	.16	.34	.11
Pressure	2 x 8	No	0	15.5	1.98	...	...	.73	2.88	...	...	...	...	20.02	20.98	22.46	4.39
Vacuum			0	22.2	6.96	...	...	.46	1.07	...	...	...	...	8.98	10.58	16.20	6.14
Cold soaking			0	1.2	.31	...	...	.02	.02	...	...	...	...	.11	.70	1.00	.98
Dipped 3 minutes			0	.7	.18	...	...	.03	.04	...	...	...	...	.12	.35	.53	.23
C. UNSEASONED SHORTLEAF PINE																	
Pressure	4 x 6	No	60	7.5	2.22	1.87	2.11	2.04	.93	24.00	24.00	24.00	0	8.91	13.69	17.38	5.58 (8)
Vacuum			63	2.7	2.91	.21	.13	.34	.03	.46	2.20	3.82	2.50	.21	.39	1.85	3.61 (7)
Cold soaking			66	.6	.16	.04	.03	.02	.01	.21	.85	1.38	.76	.04	.11	.23	.08 (8)
Dipped 3 minutes			65	.3	.06	.02	.02	.02	.01	.24	.79	1.24	.54	.03	.17	.30	.21 (9)
Pressure	2 x 8	No	59	8.8	1.62	1.56	1.50	.63	.76	22.40	22.60	23.60	1.29	9.82	12.22	18.70	5.42
Vacuum			58	2.1	.91	.24	.24	.03	.02	.76	3.44	5.94	3.68	.09	.11	.22	.09 (9)
Cold soaking			51	.8	.39	.07	.07	.03	.02	.38	.88	1.34	.88	.06	.12	.20	.06
Dipped 3 minutes			62	.3	.07	.02	.02	.01	.01	.26	.62	.90	.32	.04	.11	.23	.18 (7)
D. SEASONED SHORTLEAF PINE																	
Pressure	4 x 6	No	68	8.2	2.40 (7)	2.16	2.11	.66	.82	23.40	23.90	23.86	.38 (7)	3.85	12.05	16.60	7.47 (5)
Vacuum			70	12.4	3.33	2.27	2.05	.03	.05	22.40	22.70	22.80	3.79	.10	1.02	1.54	3.30 (7)
Cold soaking			71	1.4	.27	.38	.30	.02	.02	.40	2.86	4.52	2.92	.05	.42	.66	.64 (7)
Dipped 3 minutes			73	.4	.06	.04	.03	.01	.01	.04	.71	1.08	.49	.02	.12	.21	.10 (8)
Pressure	2 x 8	No	57	7.9	1.85	.60	1.70	.22	.08	24.00	24.00	24.00	0	8.10	8.36	8.48	12.05 (6)
Vacuum			66	8.4	4.28	.80	1.17	.04	.03	18.27	19.55	21.50	4.30	.06	.11	.28	.32 (7)
Cold soaking			64	2.0	.50	.48	.52	.03	.03	.69	15.60	17.85	7.37	.07	.15	.26	.12 (8)
Dipped 3 minutes			68	.4	.17	.04	.04	.01	.01	.03	.99	2.60	3.45	.02	.12	.20	.13 (8)

[1] Values based on averages of 10 specimens unless the number of specimens is otherwise indicated in parentheses.

Z M 106 384

Forest Products Laboratory
Madison 5, Wisconsin

Table 3.--Average chromated zinc chloride solution retentions and penetrations in Douglas-fir and shortleaf pine lumber treated by different processes

Treating process	Lumber size	Incised	Sapwood	Preservative retention: Amount	Preservative retention: Standard deviation[1]	Transverse penetration, Sapwood: Radial	Transverse penetration, Sapwood: Tangential	Transverse penetration, Heartwood: Radial	Transverse penetration, Heartwood: Tangential	Longitudinal penetration, Sapwood: Solid	Longitudinal penetration, Sapwood: Minimum fingered	Longitudinal penetration, Sapwood: Average fingered	Longitudinal penetration, Sapwood: Standard deviation[1]	Longitudinal penetration, Heartwood: Solid	Longitudinal penetration, Heartwood: Minimum fingered	Longitudinal penetration, Heartwood: Average fingered	Longitudinal penetration, Heartwood: Standard deviation[1]
	In.		Percent	Lb. per cu. ft.	Lb. per cu. ft.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
A. UNSEASONED DOUGLAS-FIR																	
Pressure	4 x 6	No	0	22.5*	7.74			1.42	2.00					17.50	18.30	21.55	3.50
Vacuum			0	1.9	.90			.06	.05					.60	.78	1.02	.48
Steaming and vacuum			0	5.1*	1.85			.38	.39					3.88	4.98	9.90	3.38
Steaming and soaking			0	2.2*	1.30			.03	.03					.78	1.08	1.35	.36
Pressure	4 x 6	Yes	0	24.5*	7.37			1.65	1.38					16.18	16.82	20.04	4.50
Vacuum			0	3.4	1.53			.04	.04					.35	.59	.96	.10
Steaming and vacuum			0	7.6*	2.29			.67	.96					4.88	5.80	12.15	2.65
Steaming and soaking			0	4.1*	1.86			.10	.10					.86	1.18	2.04	2.84
Pressure	2 x 8	No	0	27.6*	10.03			.69	1.82					16.60	17.75	19.40	5.93
Vacuum			0	3.0	1.24			.13	.14					.44	.82	1.26	.74
Steaming and vacuum			0	6.9*	2.60			.31	.36					5.48	6.52	10.70	3.75
Steaming and soaking			0	3.8*	2.92			.20	.21					2.48	4.24	6.31	6.57
B. SEASONED DOUGLAS-FIR																	
Pressure	4 x 6	No	0	21.5	12.37			.73	1.01					11.82	13.30	17.60	6.26
Vacuum			0	4.4	4.62			.13	.07					1.46	1.65	2.96	4.63
Steaming and vacuum			0	5.0*	2.60			.25	.29					2.78	3.47	6.95	3.42
Steaming and soaking			0	3.2*	2.90			.07	.06					1.43	2.04	2.74	4.40
Pressure	4 x 6	Yes	0	30.2	6.65			1.25	1.87					14.75	15.90	20.60	3.84
Vacuum			0	7.4	3.65			.11	.12					2.62	3.08	4.86	4.55
Steaming and vacuum			0	8.0*	2.01			.44	.48					2.78	3.68	9.40	3.20
Steaming and soaking			0	6.1*	2.34			.03	.12					.55	1.05	1.62	1.60
Pressure	2 x 8	No	0	32.8	11.77			.67	1.88					10.15	13.58	16.95	7.37
Vacuum			0	17.2	9.06			.29	.52					5.62	6.84	11.09	6.28
Steaming and vacuum			0	15.1*	7.44			.45	1.34					10.70	12.48	15.60	7.27
Steaming and soaking			0	12.6*	6.69			.24	.69					8.70	9.69	13.38	8.69
C. UNSEASONED SHORTLEAF PINE																	
Pressure	4 x 6	No	74	20.9*	4.39	1.34	1.16	.59	.45	20.25	20.55	21.83	4.56	12.94	13.54	15.32	8.10 (7)
Vacuum			74	5.4	1.60	.22	.26	.04	.03	7.82	8.82	10.85	6.45	.51	.56	.75	.31 (9)
Steaming and vacuum			75	9.3*	2.52	.45	.28	.30	.15	9.28	10.45	14.20	3.46	1.03	1.15	1.54	1.07 (9)
Steaming and soaking			72	4.4*	1.10	.23	.21	.09	.06	5.08	5.60	8.40	4.29	.72	.76	1.11	.72 (8)
Pressure	2 x 8	No	79	25.0*	3.82	.83	.68	.55	.33	23.70	23.70	23.80	.63	18.12	18.48	20.85	5.04
Vacuum			69	7.4	2.65	.29	.22	.04	.04	9.30	11.05	14.55	6.58	.29	.31	.47	.18 (9)
Steaming and vacuum			82	12.6*	5.33	.27	.51	.08	.08	12.42	13.18	15.81	8.13	.67	.81	1.69	.84 (8)
Steaming and soaking			65	6.9*	1.15	.36	.29	.07	.06	11.60	12.62	16.05	7.19	.40	.48	1.10	1.46
D. SEASONED SHORTLEAF PINE																	
Pressure	4 x 6	No	64	32.5	5.04	2.44	2.15	1.75	1.12	24.00	24.00	24.00	0	15.80	16.46	16.88	10.83
Vacuum			66	20.7	8.23	2.48	1.79	.02	.05	18.95	19.80	22.10	3.54	2.68	3.19	3.83	7.34
Steaming and vacuum			62	19.2*	5.26	2.37	1.84	.08	.07	20.68	20.92	21.60	4.53	.48	.60	.82	.31
Steaming and soaking			58	9.4*	4.52	1.19	1.16	.06	.05	4.66	6.20	11.94	5.43 (8)	.37	.47	.68	.73 (9)
Pressure	2 x 8	No	60	31.5	2.53	.70	1.12	.79	.45	24.00	24.00	24.00	0	16.92	17.22	21.00	5.93
Vacuum			69	23.1	8.77	.74	.92	.03	.02	24.00	24.00	24.00	0	3.37	4.39	5.76	7.58 (7)
Steaming and vacuum			69	25.4*	8.52	1.08	.80	.08	.06	24.00	24.00	24.00	0	.28	.38	.54	.28
Steaming and soaking			64	19.2*	7.47	1.32	.80	.40	.03	24.00	24.00	24.00	0	2.76	2.80	5.18	8.21

[1]Values based on averages of 10 specimens unless the number of specimens is otherwise indicated in parentheses.
*Based on weights after steaming.

Z M 106 385

Forest Products Laboratory
Madison 5, Wisconsin

3 1 5

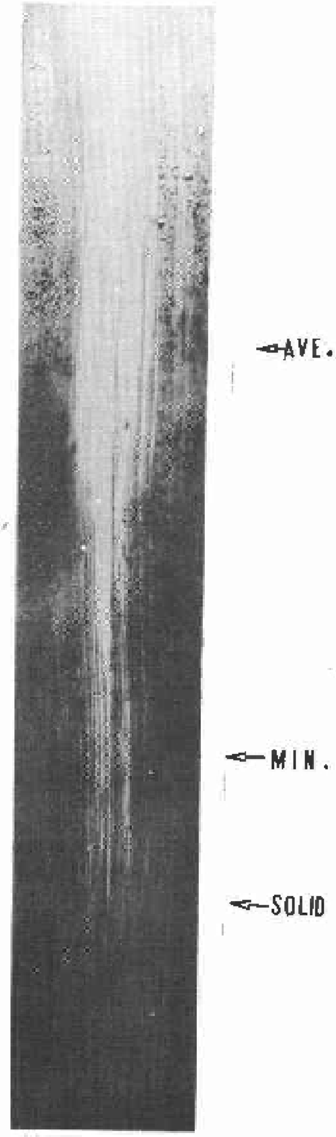


Figure 1.--Split section of unincised, air seasoned, 4- by 6-inch Douglas-fir after pressure treatment with pentachlorophenol solution to illustrate manner in which measurements on longitudinal penetration were taken.

Z M 105 284

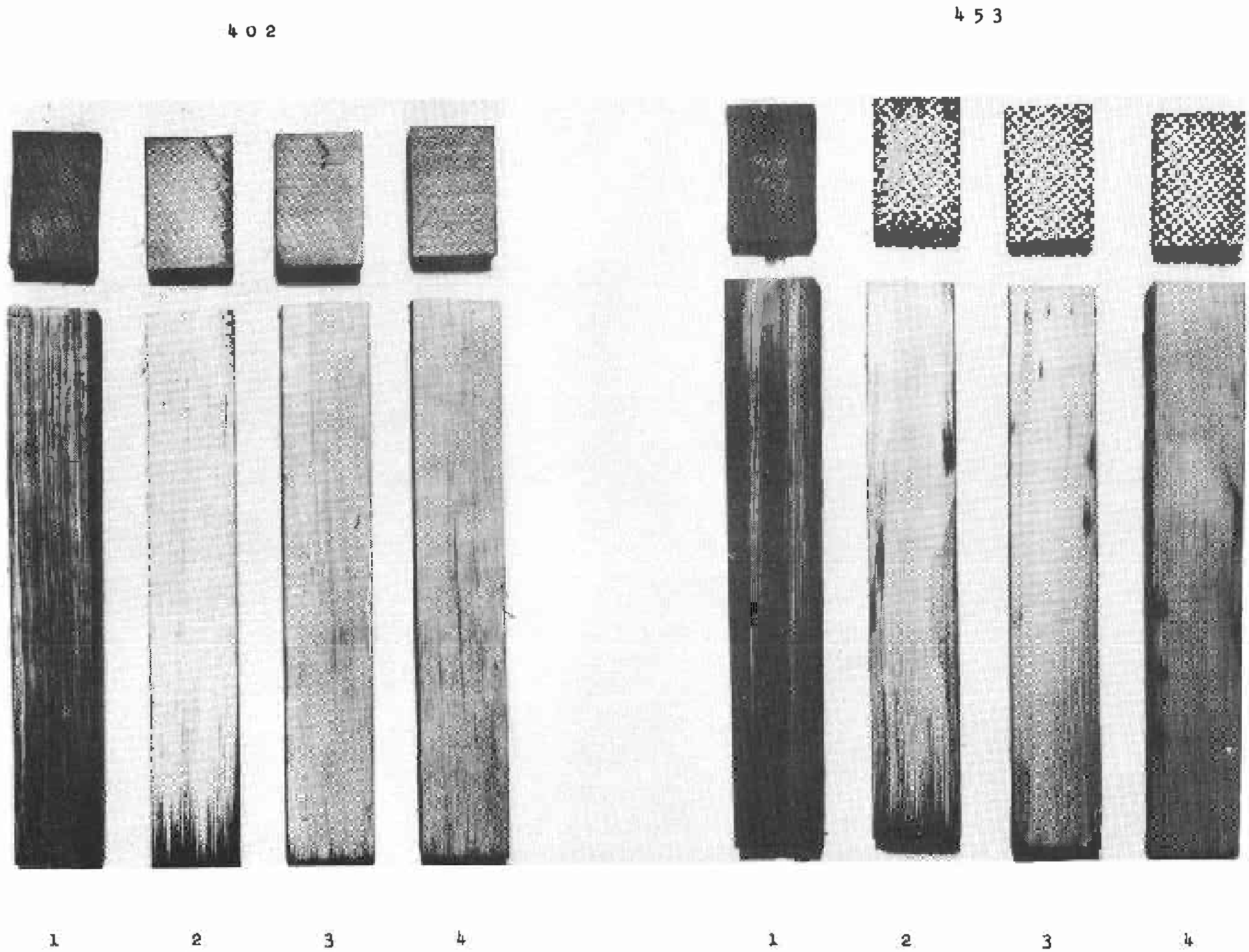


Figure 2.--Cross and split sections of representative end-matched, unseasoned, 4- by 6-inch, all-heartwood Douglas-fir to show transverse and longitudinal penetration of coal-tar creosote. Left, group No. 402, unincised. Right, group No. 453, incised. 1, pressure treated; 2, vacuum treated; 3, cold soaked 24 hours; 4, dipped 3 minutes.

Z M 106 893

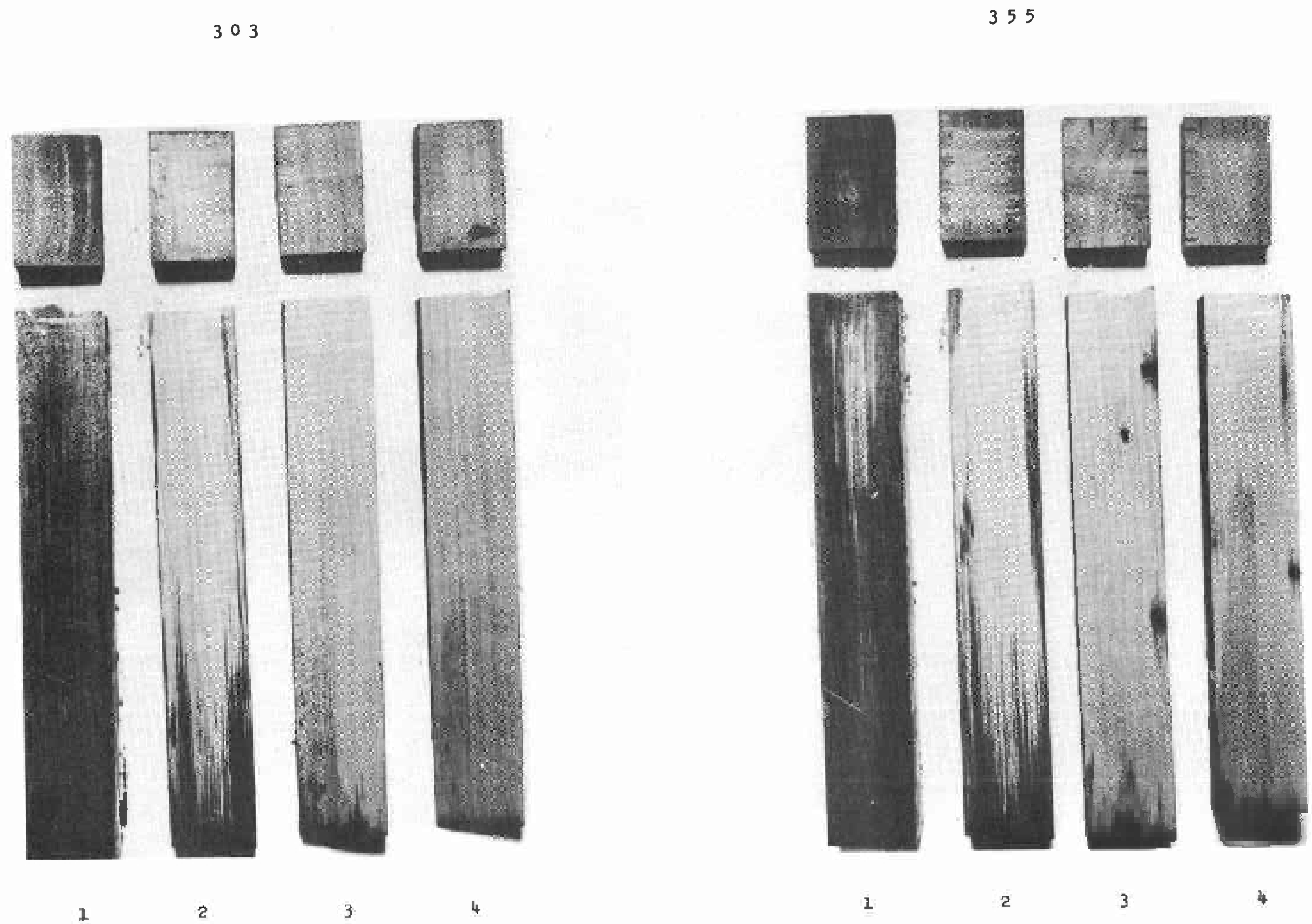


Figure 3. --Cross and split sections of representative end-matched, seasoned, 4- by 6-inch, all-heartwood Douglas-fir to show transverse and longitudinal penetration of coal-tar creosote. Left, group No. 303, unincised. Right, group No. 355, incised. 1, pressure treated; 2, vacuum treated; 3, cold soaked 24 hours; 4, dipped 3 minutes.

Z M 106 886

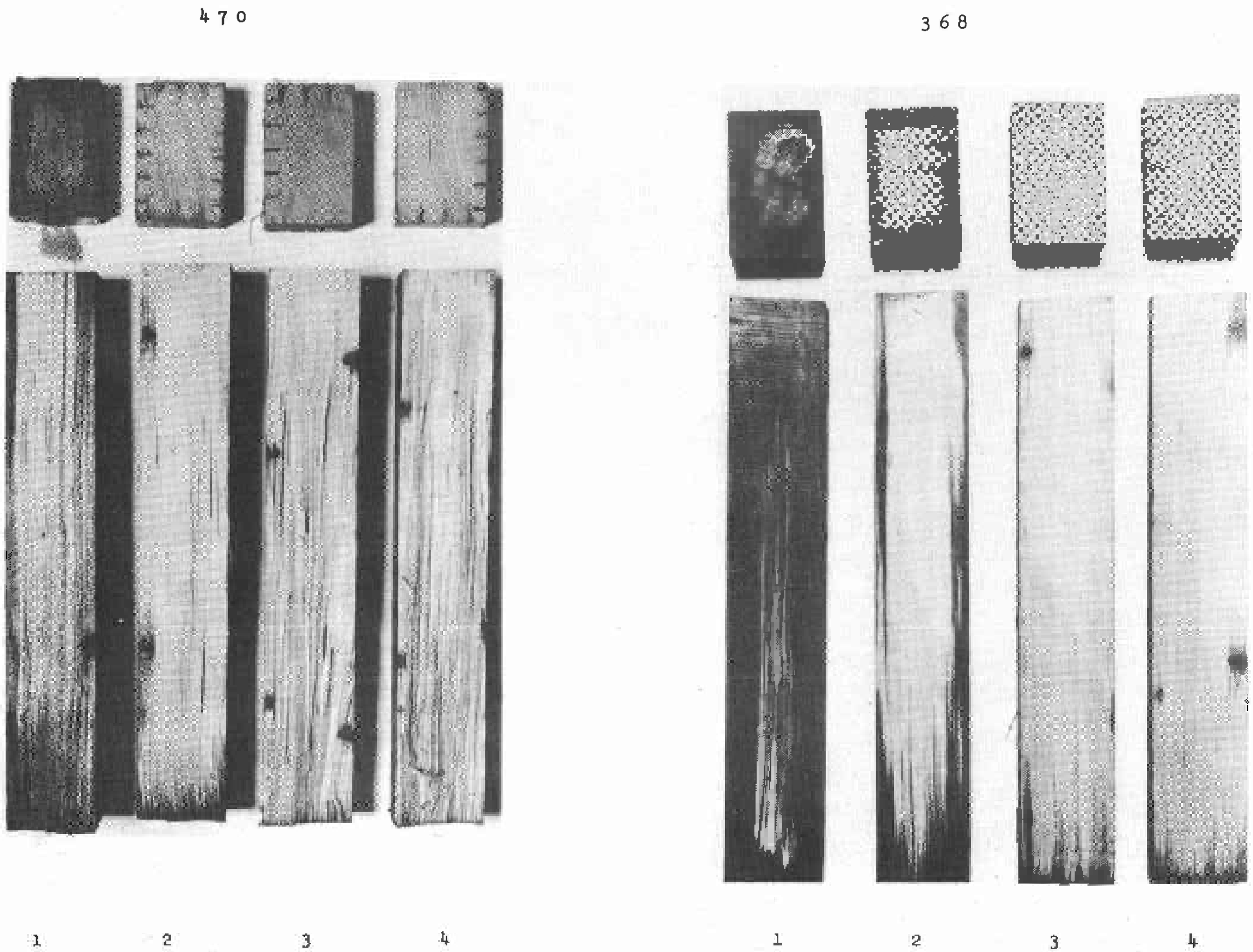


Figure 4. --Cross and split sections of representative end-matched, seasoned and unseasoned, 4- by 6-inch, all-heartwood, incised Douglas-fir to show transverse and longitudinal penetration of pentachlorophenol solution. Left, group No. 470, unseasoned; right, group No. 368, air seasoned. 1, pressure treated; 2, vacuum treated; 3, cold soaked 24 hours; 4, dipped 3 minutes.

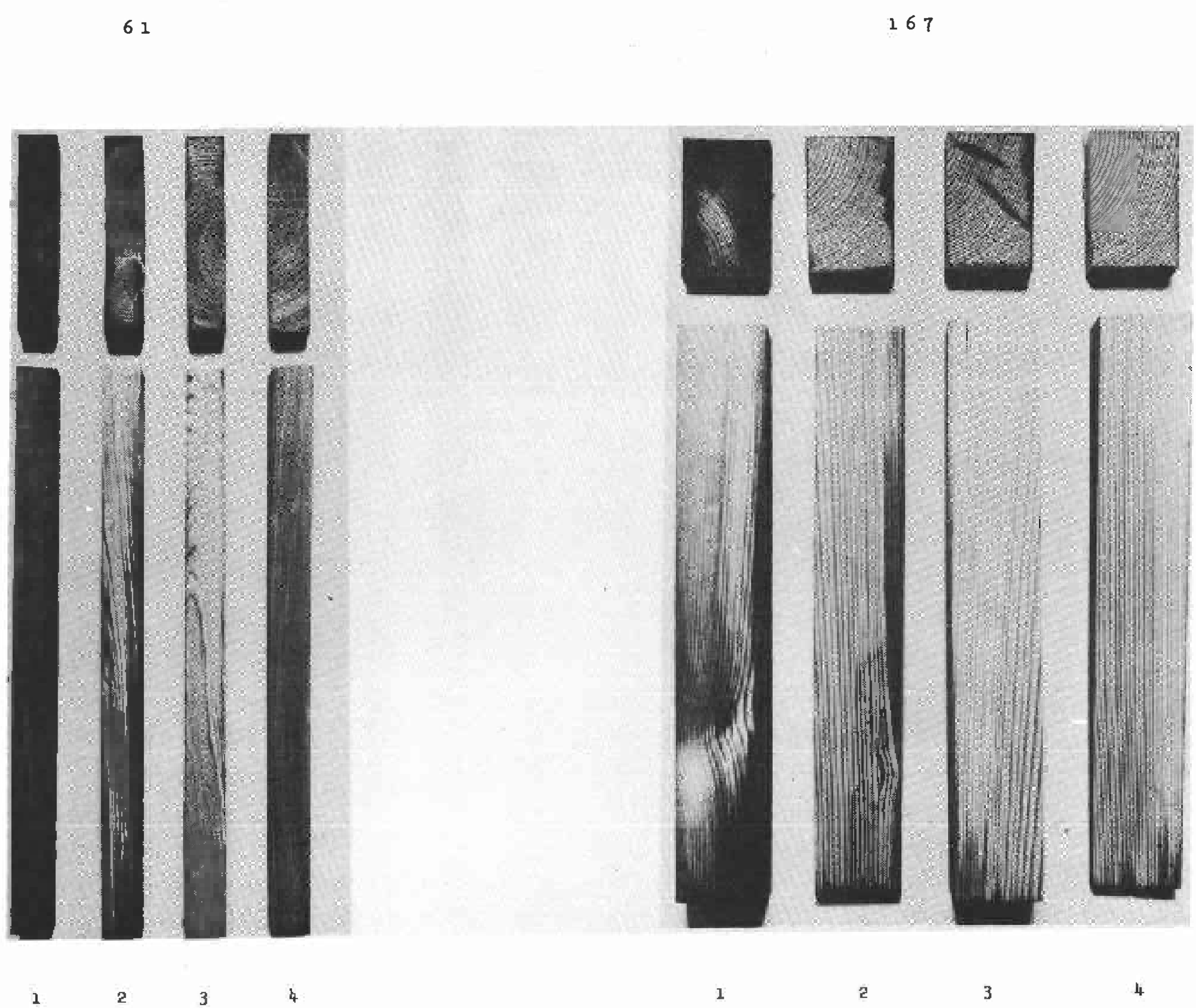


Figure 5. --Cross and split sections of representative end-matched, unseasoned, mixed sapwood and heartwood shortleaf pine to show transverse and longitudinal penetration of pentachlorophenol solution. Left, group No. 61, 2- by 8-inch lumber; right, group No. 167, 4- by 6-inch lumber. 1, pressure treated; 2, vacuum treated; 3, cold soaked 24 hours; 4, dipped 3 minutes.

Z M 106 884

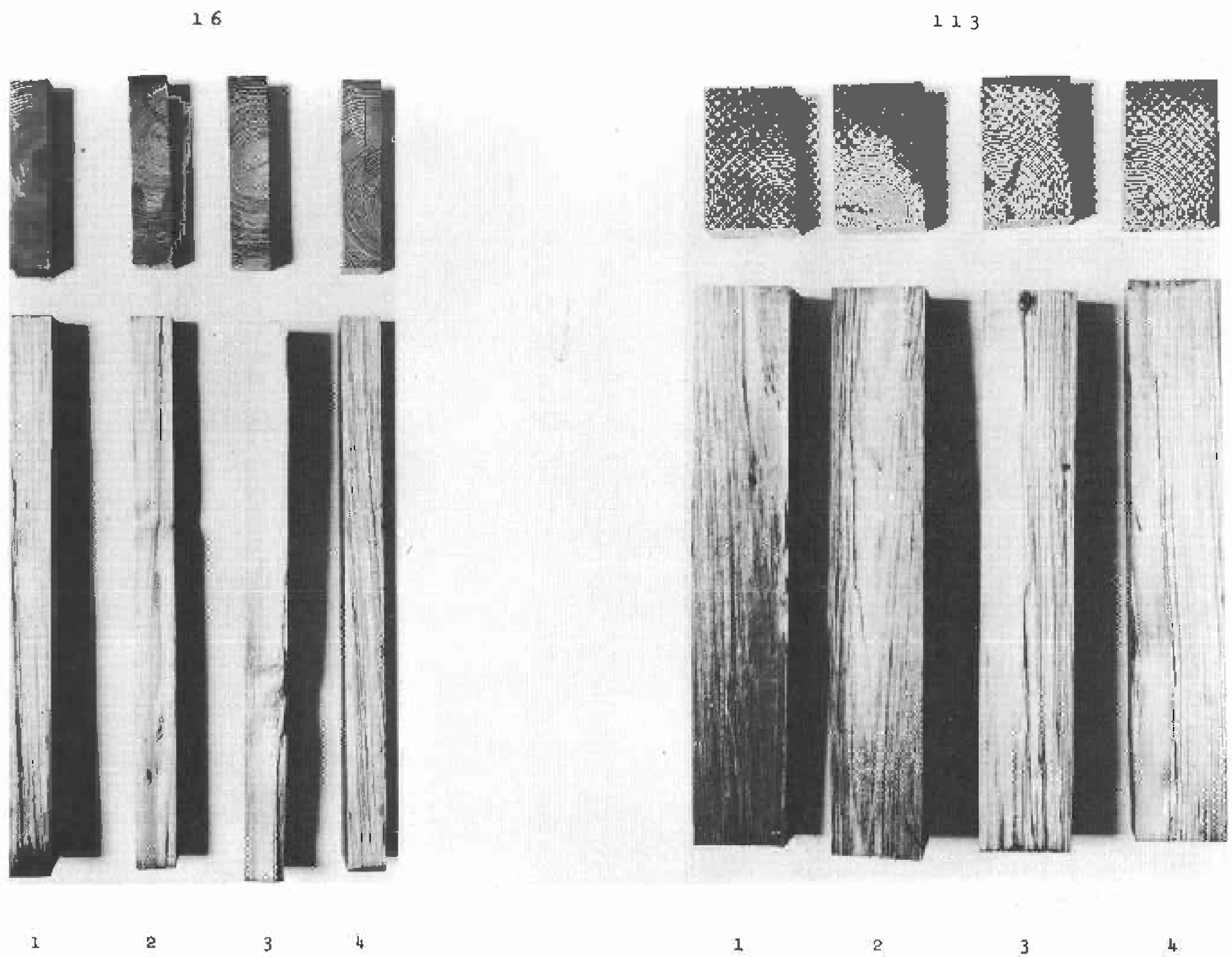


Figure 6. --Cross and split sections of representative end-matched, seasoned, mixed sapwood and heartwood shortleaf pine to show transverse and longitudinal penetration of pentachlorophenol solution. Left, group No. 16, 2- by 8-inch lumber; right, group No. 113, 4- by 6-inch lumber. 1, pressure treated; 2, vacuum treated; 3, cold soaked 24 hours; 4, dipped 3 minutes.

Z M 106 894

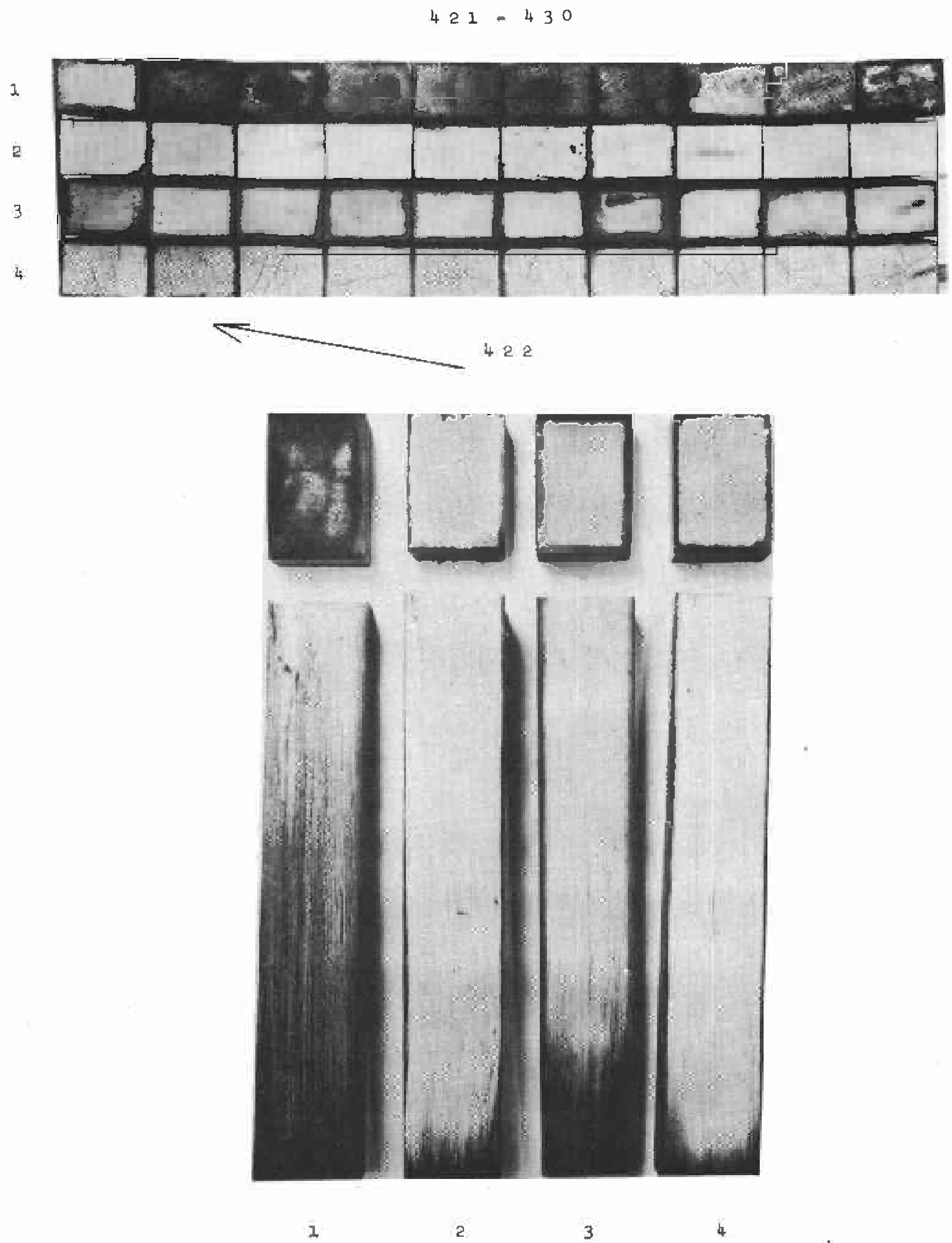


Figure 7. --Stained sections of 4- by 6-inch unseasoned, unincised, all-heartwood Douglas-fir show penetration of chromated zinc chloride when treated by (1) pressure, (2) vacuum, (3) steaming and vacuum, and (4) steaming and soaking. Top, cross sections of specimen groups 421-430 show transverse penetration for each treatment. Each specimen group (vertical rows) end matched. Bottom, enlarged cross sections of specimen group 422 show transverse penetration, split sections longitudinal penetration.

Z M 106 888

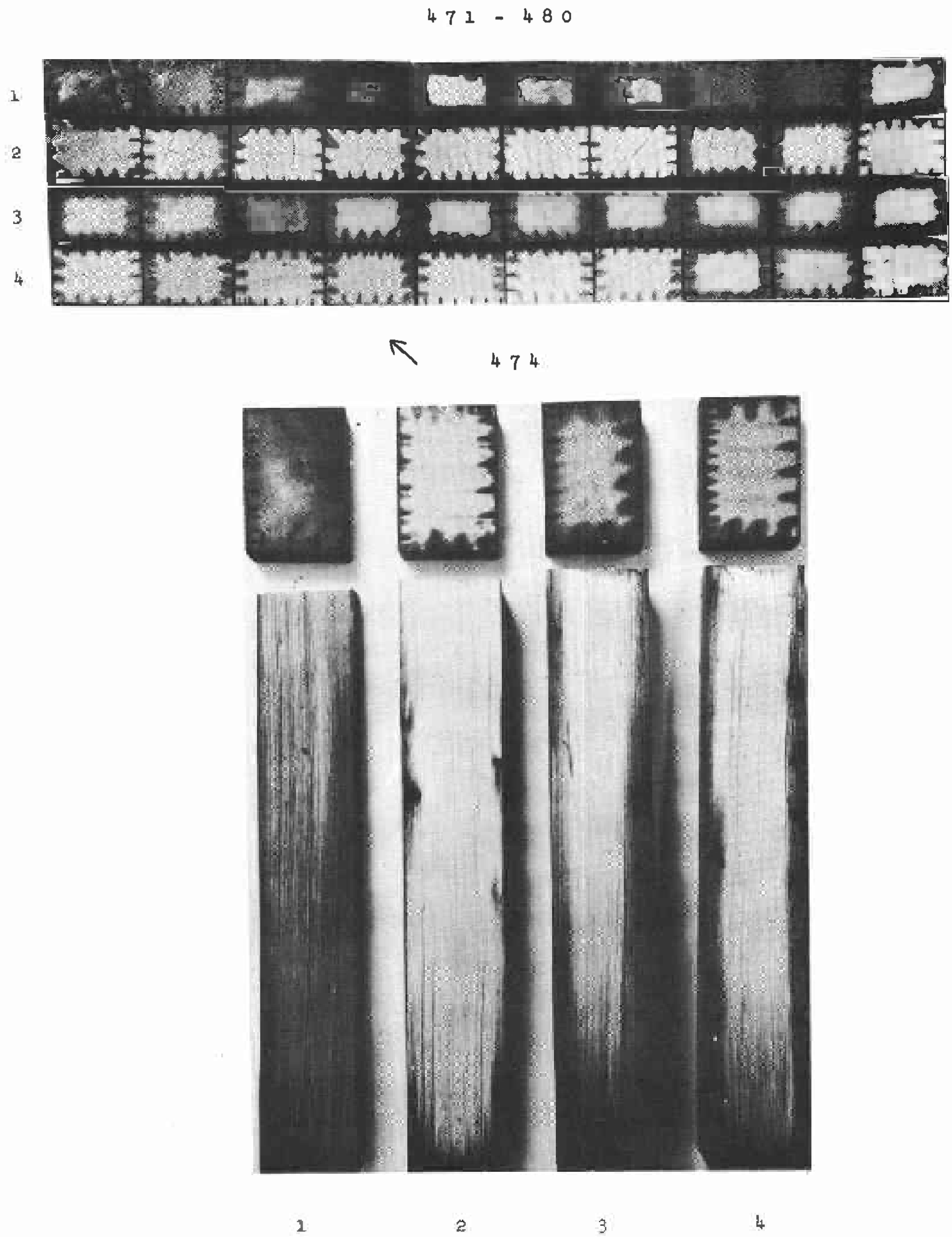


Figure 8.--Stained sections of 4- by 6-inch, unseasoned, incised, all-heartwood Douglas-fir show penetration of chromated zinc chloride when treated by (1) pressure, (2) vacuum, (3) steaming and vacuum, and (4) steaming and soaking. Top, cross sections of specimen groups 471-480 show transverse penetration for each treatment. Each specimen group (vertical rows) end matched. Bottom, enlarged cross sections of specimen group 474 show transverse penetration, split sections longitudinal penetration.

Z M 106 890

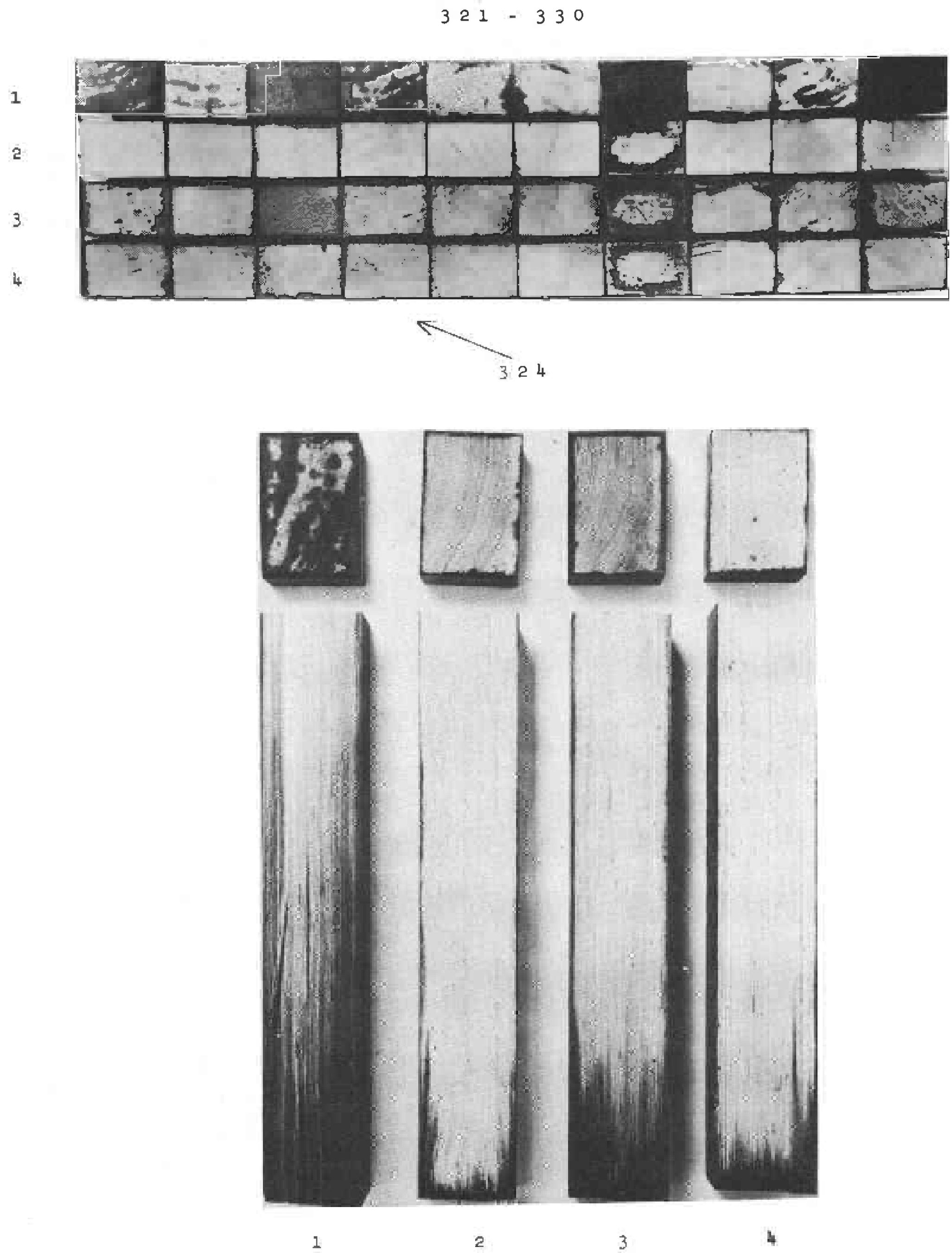
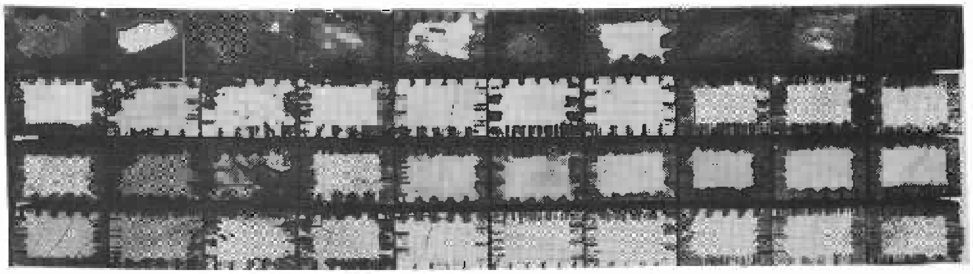


Figure 9. --Stained sections of 4- by 6-inch seasoned, unincised, all-heartwood Douglas-fir show penetration of chromated zinc chloride when treated by (1) pressure, (2) vacuum, (3) steaming and vacuum, and (4) steaming and soaking. Top, cross sections of specimen groups 321-330 show transverse penetration for each treatment. Each specimen group (vertical rows) end matched. Bottom, enlarged cross sections of specimen group 324 show transverse penetration, split sections longitudinal penetration.

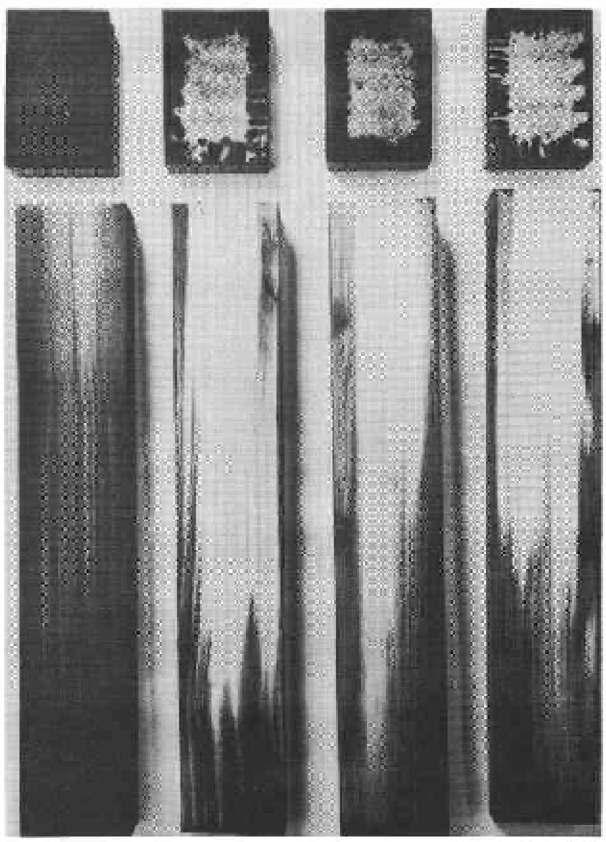
Z M 106 887

371 - 380

1
2
3
4



378



1 2 3 4

Figure 10.--Stained sections of 4- by 6-inch, seasoned, incised, all-heartwood Douglas-fir show penetration of chromated zinc chloride when treated by (1) pressure, (2) vacuum, (3) steaming and vacuum, and (4) steaming and soaking. Top, cross sections of specimen groups 371-380 show transverse penetration for each treatment. Each specimen group (vertical rows) end matched. Bottom, enlarged cross sections of specimen group 378 show transverse penetration, split sections longitudinal penetration.

Z M 106 891

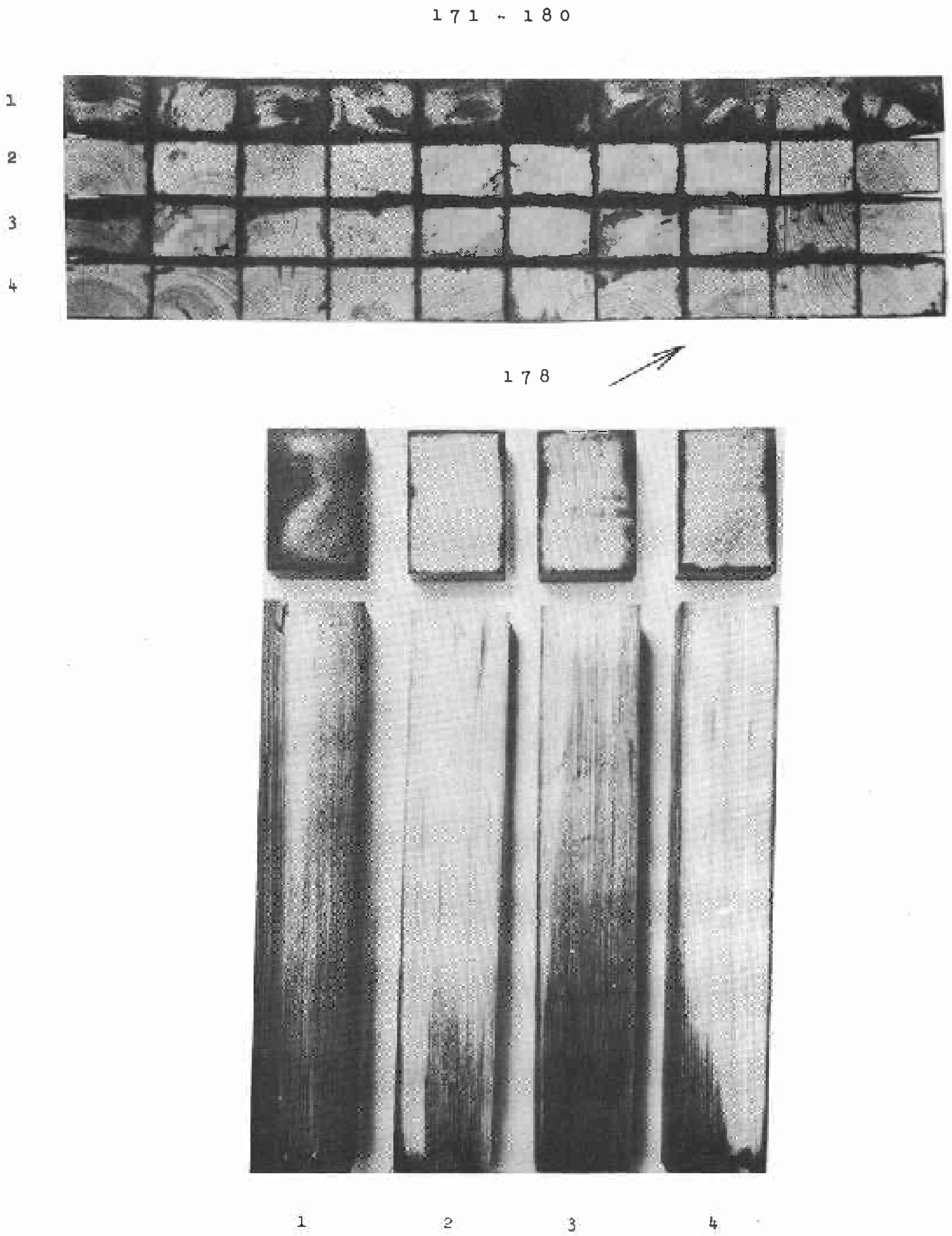
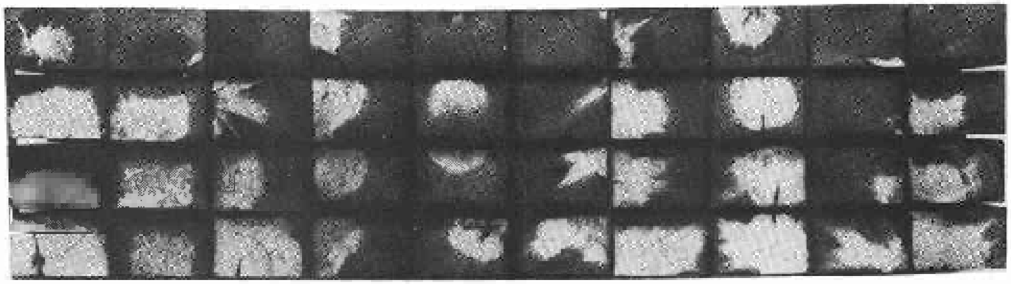


Figure 11. --Stained sections of 4- by 6-inch, unseasoned, mixed sapwood and heartwood shortleaf pine show penetration of chromated zinc chloride when treated by (1) pressure, (2) vacuum, (3) steaming and vacuum, and (4) steaming and soaking. Top, cross sections of specimen groups 171-180 show transverse penetration for each treatment. Each specimen group (vertical rows) end matched. Bottom, enlarged cross sections of specimen group 178 show transverse penetration, split sections longitudinal penetration.

Z M 106 889



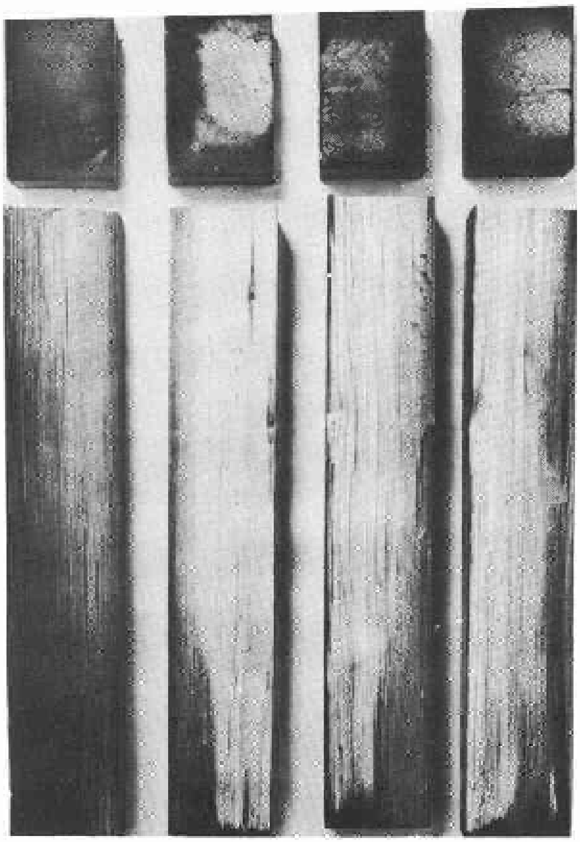


Figure 12. --Stained sections of 4- by 6-inch, seasoned, mixed sapwood and heartwood shortleaf pine show penetration of chromated zinc chloride when treated by (1) pressure, (2) vacuum, (3) steaming and vacuum, and (4) steaming and soaking. Top, cross sections of specimen groups 121-130 show transverse penetration for each treatment. Each specimen group (vertical rows) end matched. Bottom, enlarged cross sections of specimen group 122 show transverse penetration, split sections longitudinal penetration.

Z M 106 892

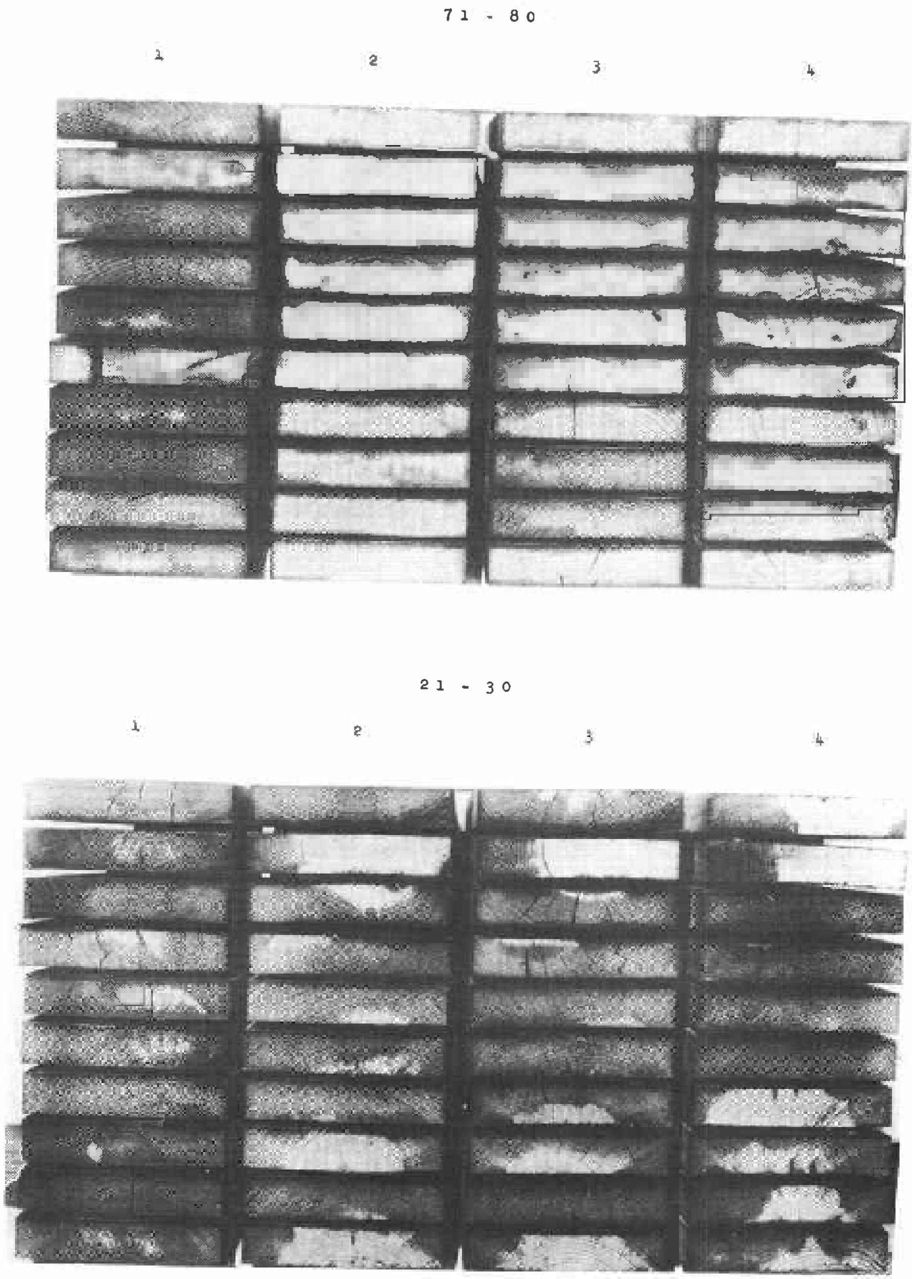


Figure 13. --Stained cross sections of end-matched (horizontal rows), 2- by 8-inch, mixed heartwood and sapwood shortleaf pine show transverse penetration of chromated zinc chloride when treated by (row 1) pressure, (row 2) vacuum, (row 3) steaming and vacuum, and (row 4) steaming and soaking. Top, Nos. 71-80, unseasoned; bottom, Nos. 21-30, air seasoned.

Z M 106 883

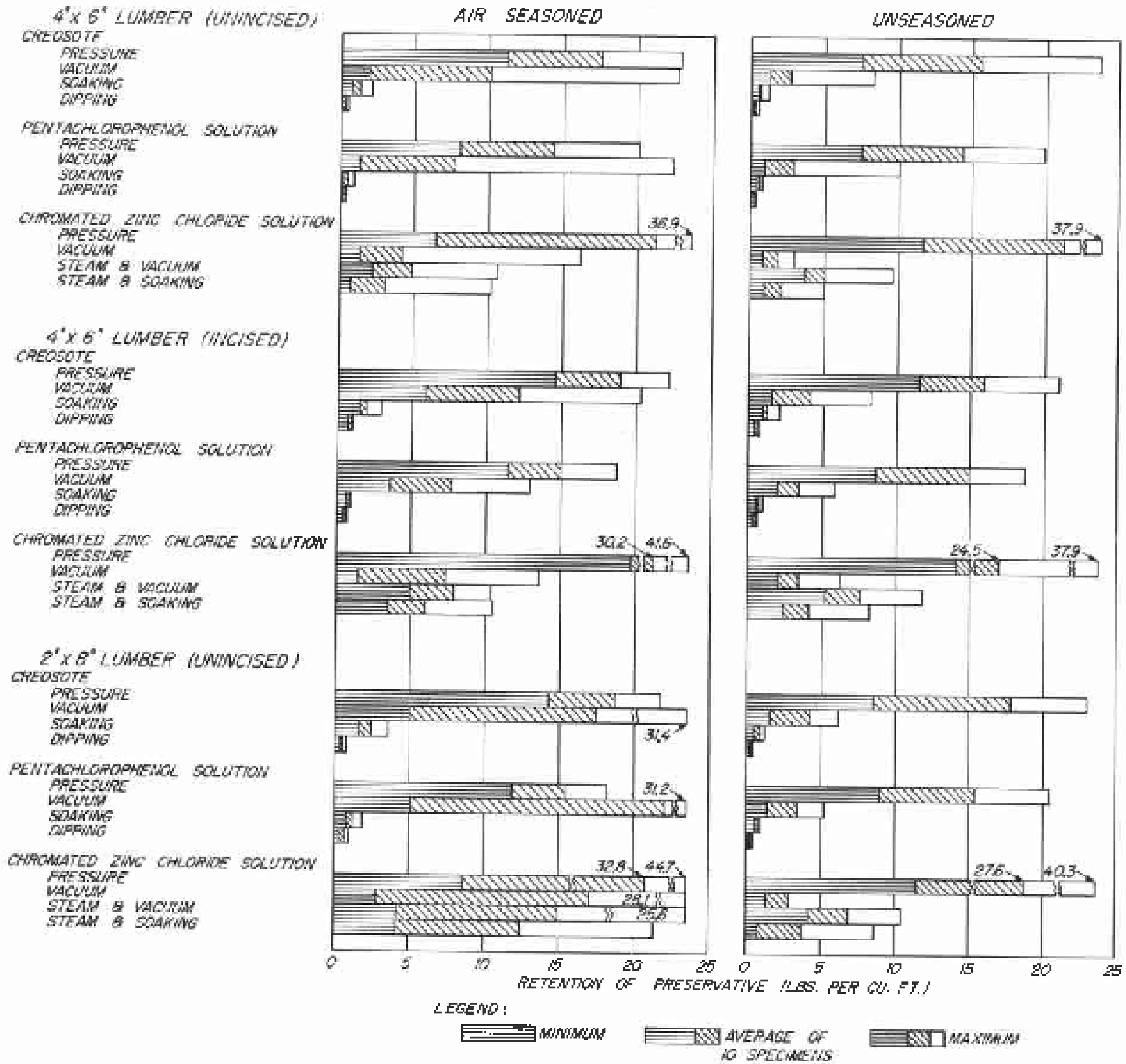


Figure 14. --Retention of preservatives in Douglas-fir heartwood lumber treated by various processes.

Z M 106 132

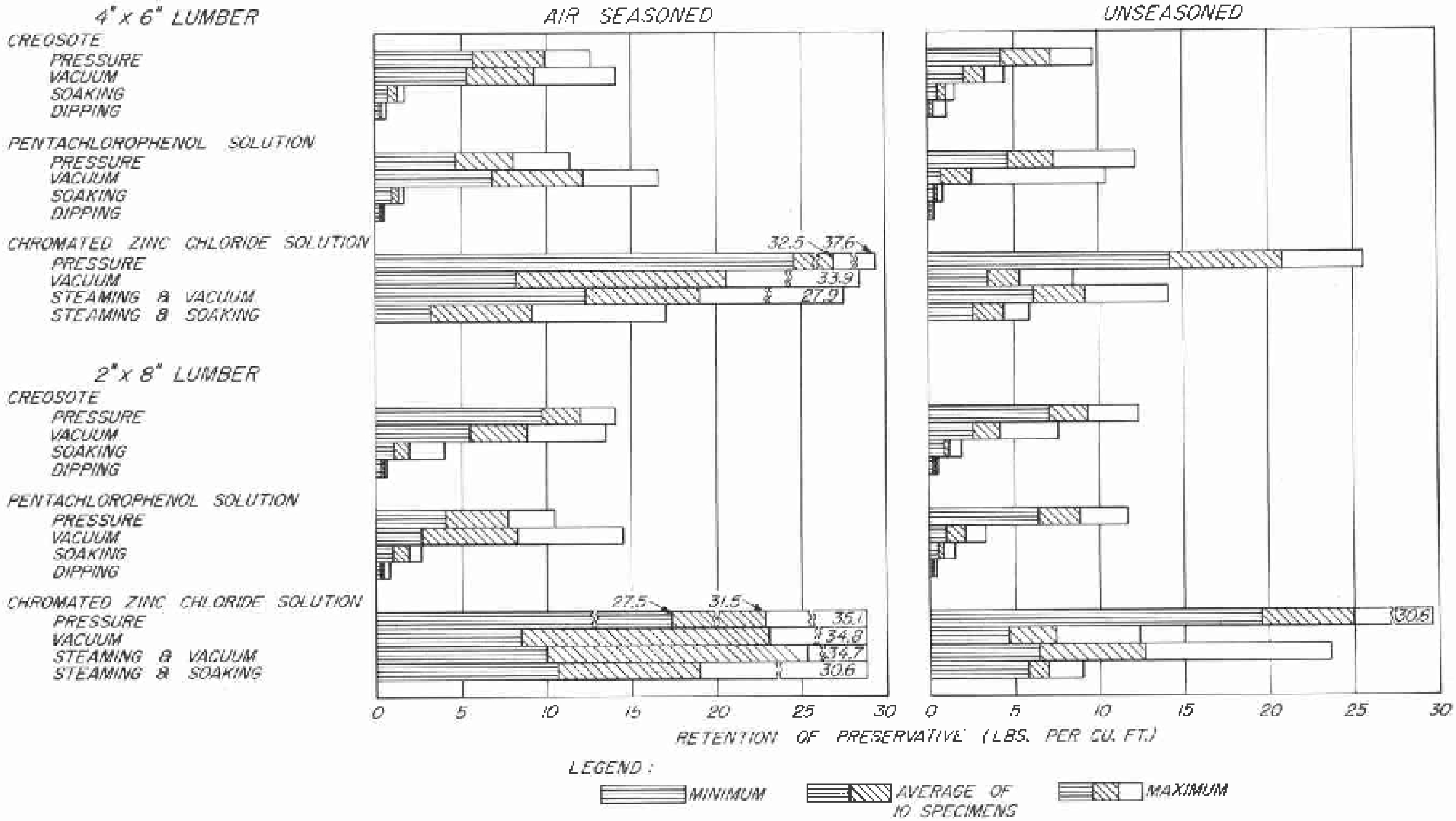


Figure 15. --Retention of preservatives in shortleaf pine lumber treated by various processes.

Z M 106 131

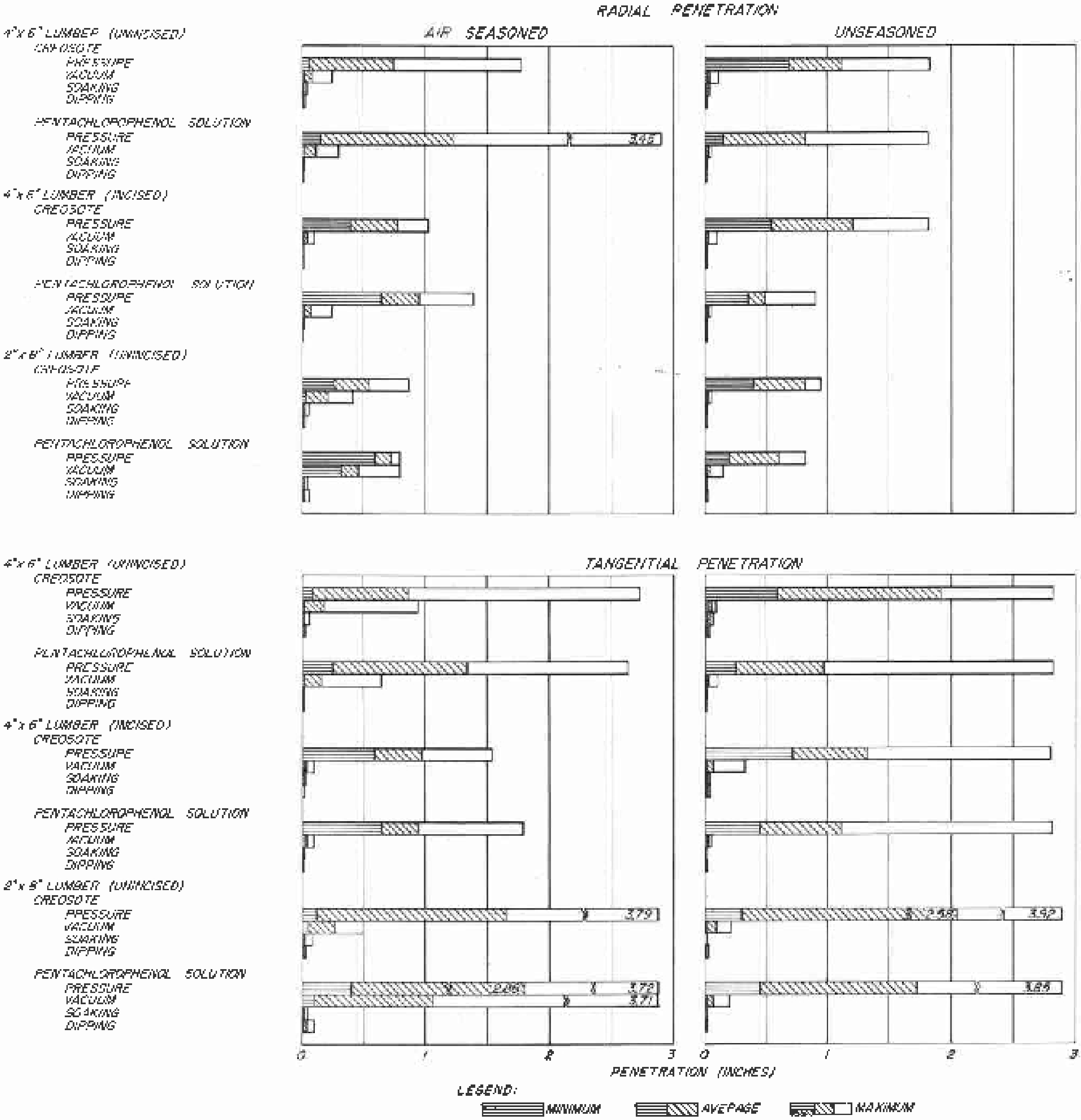


Figure 16. --Transverse penetration of preservative oils in heartwood Douglas-fir lumber treated by four processes.

Z M 106 130

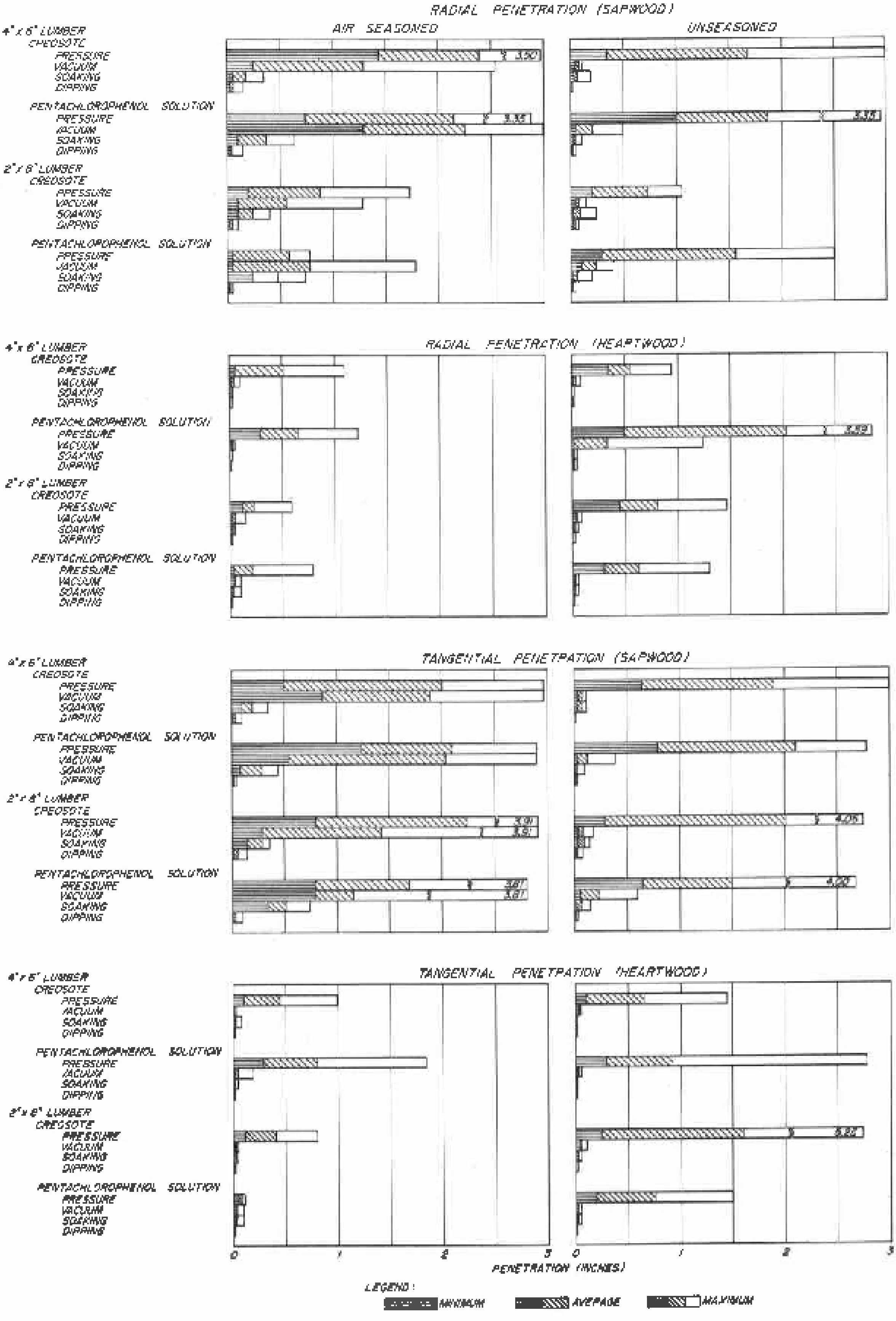


Figure 17. --Transverse penetration of preservative oils in shortleaf pine lumber treated by four processes.

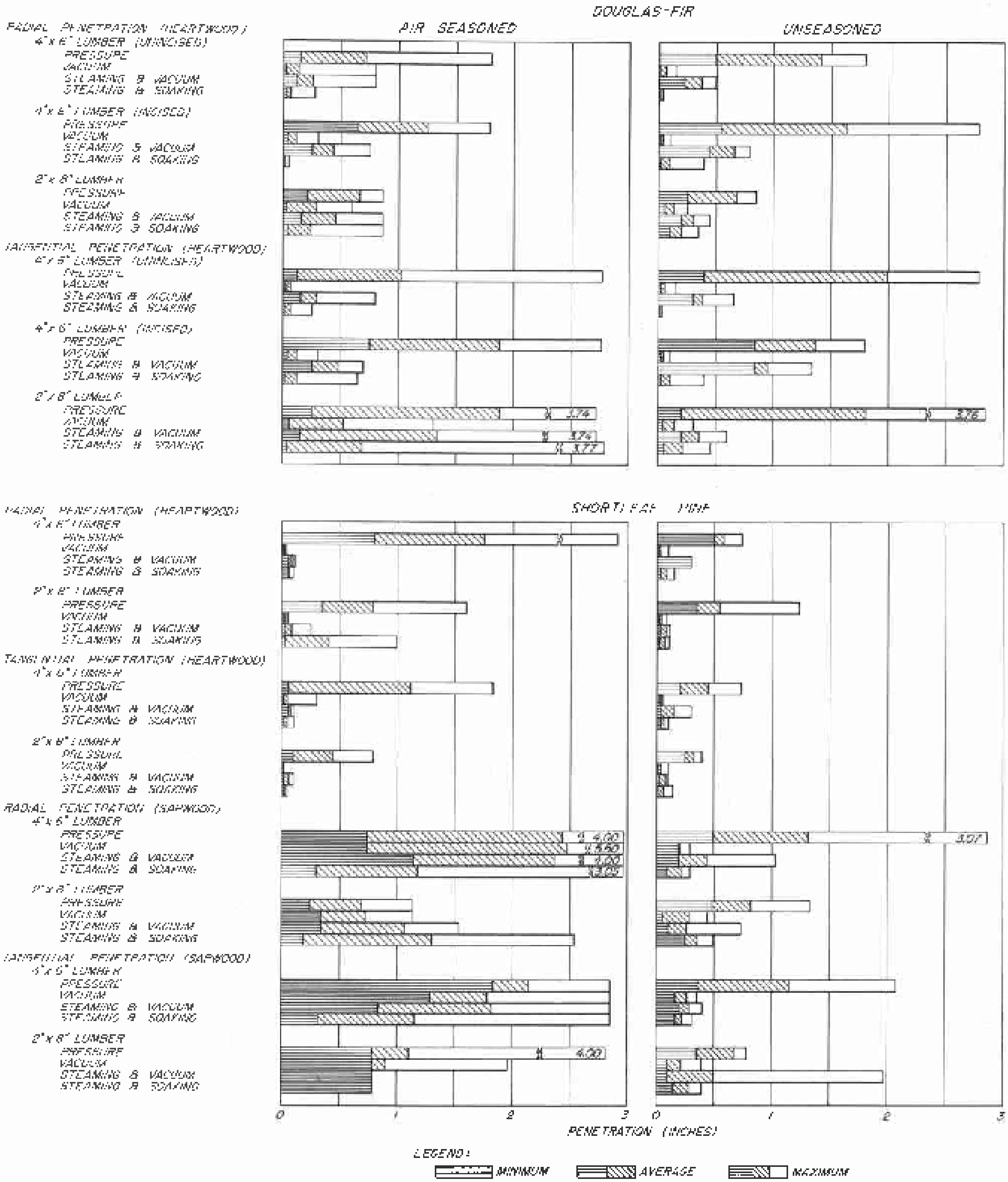


Figure 18. --Transverse penetration of chromated zinc chloride in Douglas-fir and shortleaf pine treated by four processes.

Z M 106 134

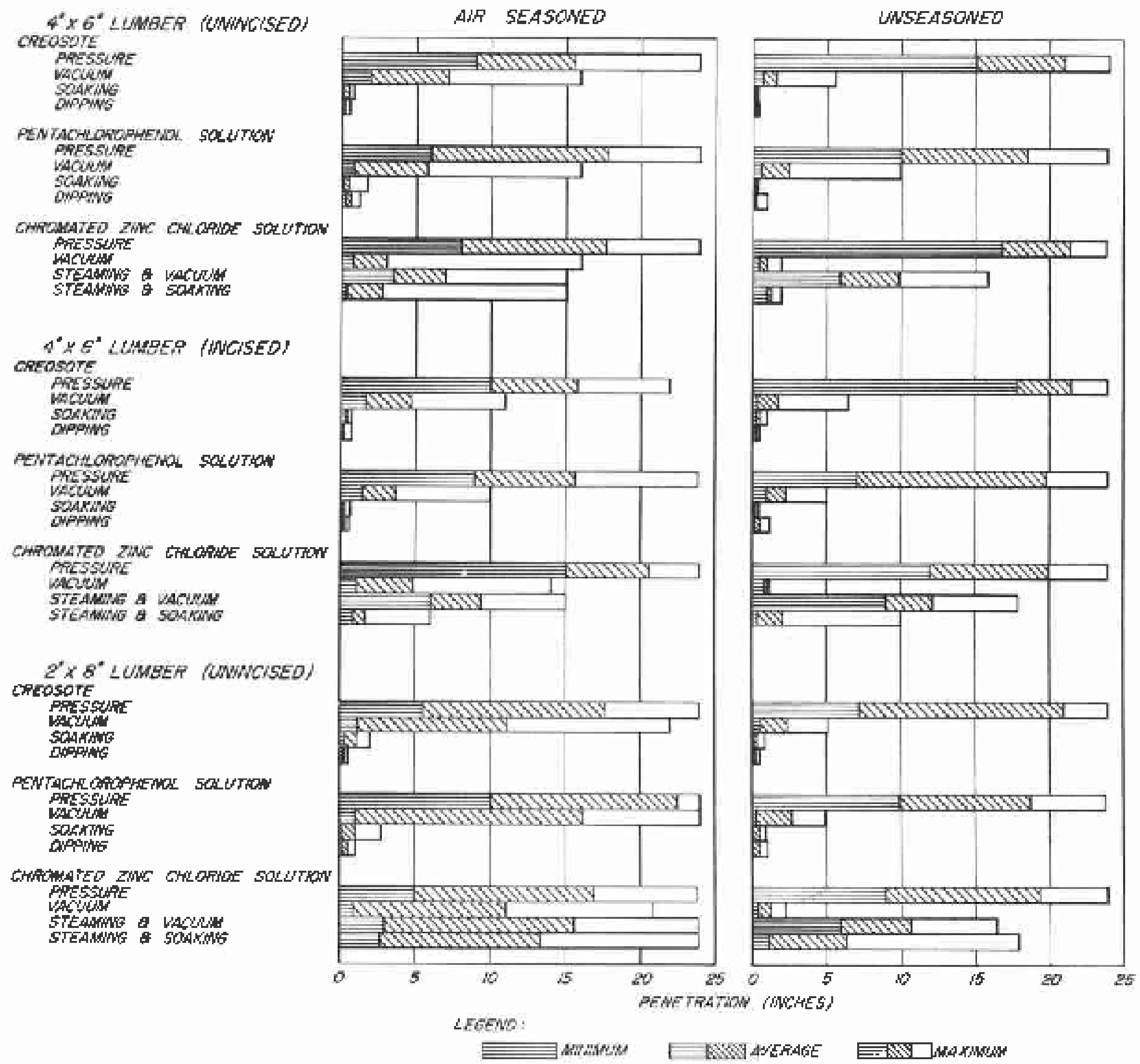


Figure 19. --Longitudinal penetration of preservatives in Douglas-fir heartwood treated by different processes.

Z M 106 135

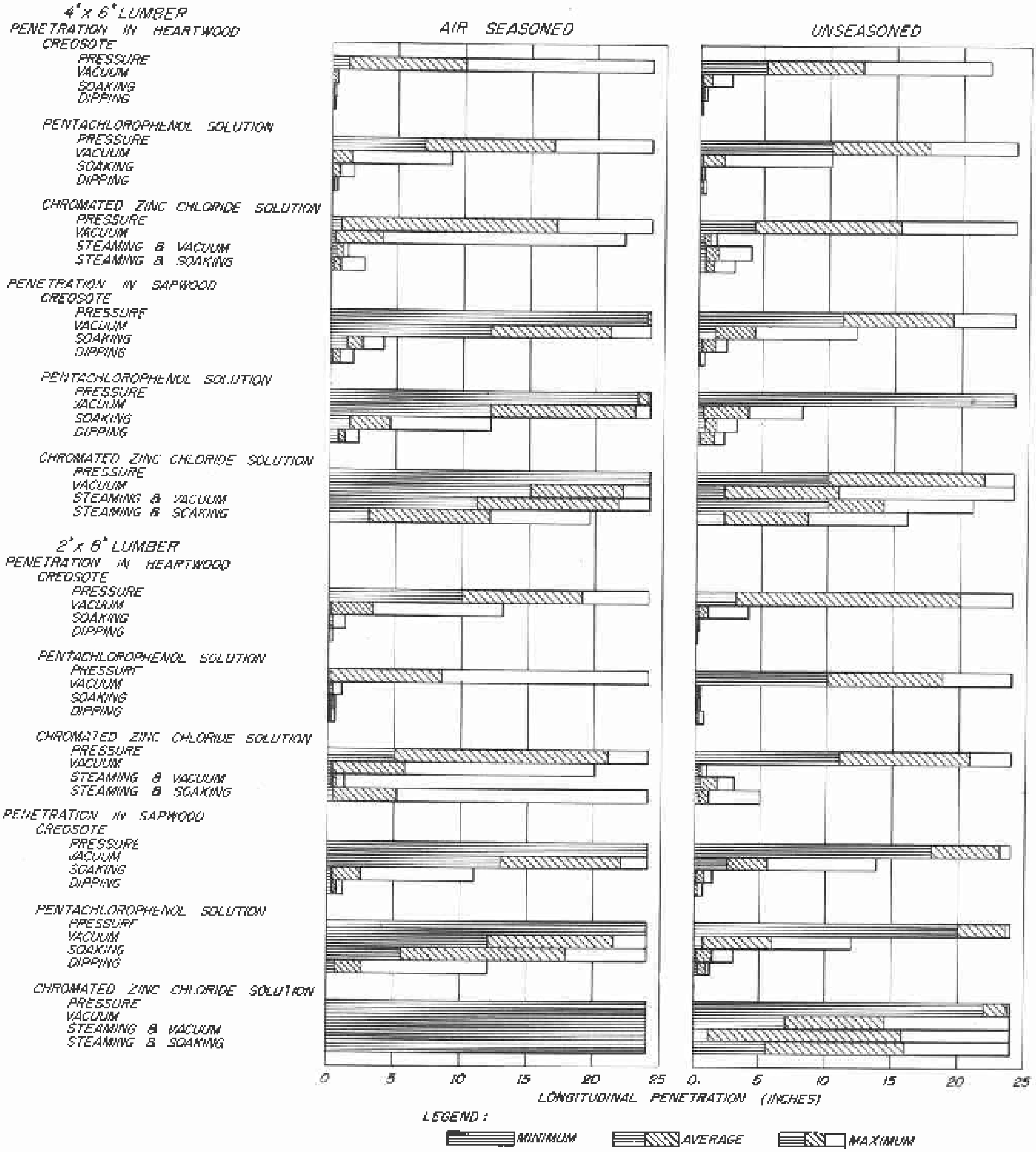


Figure 20. --Longitudinal penetration of preservatives in heartwood and sapwood of shortleaf pine treated by different processes.

Z M 106 136