A SUMMARY OF AVAILABLE DATA

ON

CHEMICAL SEASONING OF DOUGLAS FIR

by

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A Summary of Available Data

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LISTS OF FIGURES AND TABLES

A Summary of Available Data

on

Chemical Seasoning of Douglas Fir

A. INTRODUCTION

(a) Complete statement of problem or purpose

Chemical seasoning is a difficult and nearly impossible subject on which to obtain data. Therefore, the purpose of this thesis is to present in condensed form all available subject matter in such a way that it is useable and understandable to the average student who does not have the time or the desire to assimilate this information from the various sources for himself.

(b) Importance of problem

The importance of chemical seasoning is realized by every lumber manufacturing concern who has had to contend with degrade losses from checks and splits since the first tree was cut. Modern mills, because of increasing demands for high-grade lumber, are especially interested in chemical seasoning as a means to prevent or minimize seasoning degrade, trim losses, improve appearance, and retain the full natural strength and utility of lumber--in kiln drying, air drying, or while lumber is seasoning in use.

As yet chemical seasoning is but in the experimental stage. In the past few years various individuals and organizations have been investigating the possibilities of chemical

seasoning, and as a result of their findings the lumberman may now apply these new principles to produce high-grade lumber more economically.

The lumber industry being one of the leading industries of the Pacific Northwest, it is only natural that any improvement in manufacturing methods, especially in these times of National Defense, is of great importance not only to those engaged in the industry itself but to all who may be economically effected.

B. REPORT OF THE STUDY UNDER PROPER CHAPTER HEADINGS

I. Explanation of Ordinary Wood Drying

Wood drying, like most everything else, is brought about by the drawing out of the water it contains by evaporation. From the core of the piece to the surface, moisture is drawn from one layer of fibers to the next until it is drawn into the air as a vapor. Therefore, a piece of lumber dries by the movement of water toward the drier outside fibers. It is this simple process, effected by various underlying factors that is the whole basis behind chemically treating lumber.

(a) Factors that contribute to wood drying

(1) Vapor pressure

The movement of the water from the center core to the surface in the fibers of the wood is produced by a difference in vapor pressure. A piece of lumber when drying on the outside contains less moisture in that zone than in the inside of the piece which has more moisture. Therefore, the vapor pressure is less on the outside than the inside. Unless the vapor pressure of moisture in the surrounding air is less than that of

moisture in the wood, drying cannot take place. Heat and wind cause rapid evaporation of moisture in lumber, because heat raises the vapor pressure of wood moisture.

(2) Relative humidity

Relative humidity is the ratio of the quantity of water vapor present in the atmosphere to the quantity which would saturate the atmosphere at the same temperature, and it plays a prominent part in wood drying. Low humidities increase the evaporation of surface moisture but often cause checking in lumber, because the surface moisture is evaporating faster than water can move on the inside. Therefore, humidity control must be exercised.

(3) Fiber saturation point

There are two ways in which moisture is held in green wood. One is the free water, which is the water that partly fills the cavities of hollow wood fibers. The second way is the hygroscopic water, which is water bound within the fiber tissue. The fiber saturation point is that moisture content where all the free water has left the fiber cavities, but the fiber walls still hold all the water that they can. For Douglas fir this point is about 25 per cent moisture content. Loss of hygroscopic moisture in wood tends to cause shrinkage, where loss of free water causes no change in the dimensions of a piece of wood.

(4) Equilibrium moisture content

The amount of hygroscopic moisture that wood will hold depends on the water vapor pressure and the temperature. When lumber remains in an atmosphere of constant

temperature and relative humidity, it reaches a moisture content that is in equilibrium with the air--it neither loses nor gains moisture. This is known as the equilibrium moisture content.

(5) Moisture gradient

The gradual difference in moisture content of the various layers of wood fibers from the core to the surface is the moisture gradient. The steeper the moisture gradient, the more rapid the rate of drying, and the greater the danger of checking.

(b) Causes of lumber checking

When lumber shrinks unevenly as its moisture content decreases, it causes checking. This shrinkage creates stresses which tend to rupture fibers, causing checks and is a natural tendency of lumber when exposed to rapid drying conditions while still green and plastic.

(1) Steep moisture gradient

As lumber dries below the fiber saturation point, it begins to shrink and will shrink as long as it continues to lose moisture. The outer surface, having dried more rapidly than the inner fibers, causes a too steep moisture gradient and the outside squeezes against a swollen inside, thus causing such a tension as to bring about checks and splits.

(2) Unequal direction shrinkage

Douglas fir shrinks in a tangential (flat-grain) direction an average of 7.8 per cent while drying from green to zero moisture content; but in a radial

(vertical-grain) direction, the shrinkage is only 5.0 per cent with the same drying. This variable shrinkage in different directions causes drying stresses that open checks. See Figure 1.

(3) Rapid end-drying

Because the ends of a piece of lumber are most exposed to drying, checking is greatest at that point.

II. Chemicals as an Aid in Lumber Seasoning

The use of seasoning aids results in establishing a condition on the exterior of each piece of lumber which causes the moisture inside the piece to move toward the outside at a more rapid rate than at the very outside of the piece. The usual drying process is really reversed. Chemical seasoning does not depend upon any chemical reaction between the wood and the chemical used, but it does cause a more uniform drying of the entire piece.

(a) Prevent or minimize checking

If the surface of lumber can be kept moist and surface shrinkage can be reduced during seasoning, checking would be prevented. Certain chemicals can bring about this result in two ways.

(1) Moisture retention effect

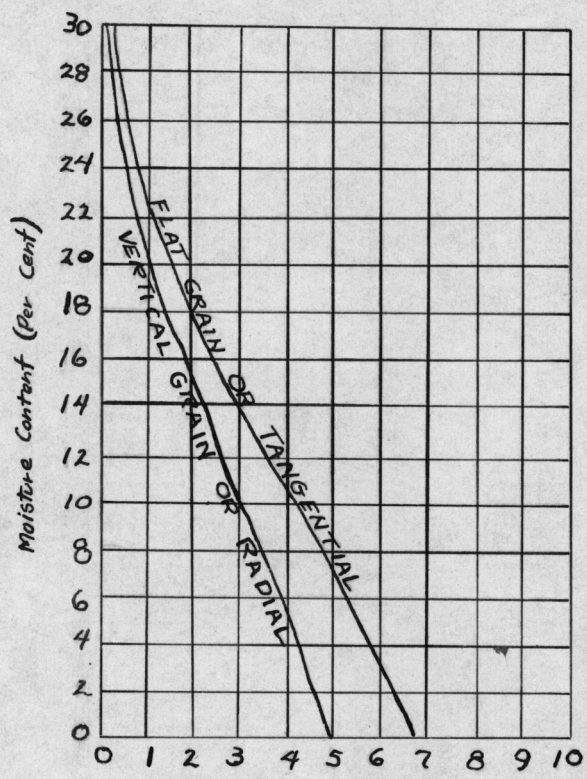
a. Lowers vapor pressure

Ordinary lumber depends upon a reduction in surface moisture to effect a lowering of vapor pressure, whereas treated lumber depends upon a chemical to lower the surface vapor pressure. While the chemical lowers the vapor pressure on the

Figure 1[1]

AVERAGE SHRINKAGE CURVE FOR DOUGLAS FIR

This curve may be used to estimate the changes in dimension that takes place with changes in moisture content of lumber. In commercial lumber, the full radial and tangential shrinkage does not always occur, due to the variable curve and position of annual rings.



Shrinkage--(Per Cent of Green Dimension)

From Forest Products Laboratory

[1] Progress Report No. 1, published by West Coast Lumbermen's Association, page, 7.

surface of a piece of wood, the untreated wood within still maintains its normal water vapor pressure. It is this vapor pressure gradient that causes the movement of moisture in chemically treated lumber and allows it to dry. For this reason treated lumber is able to dry while still retaining more surface moisture than untreated lumber.

b. Retains surface moisture

Chemically-treated wood retains its surface moisture and thereby prevents the surface from rapid drying, shrinking and checking. As an example, a large Douglas fir timber when dried in relative humidities as high as 90 per cent will check. The surface fibers of the same timber, if it has been treated with sodium chloride in the outer shell, will remain damp and unshrunken in a relative humidity of 75 per cent.

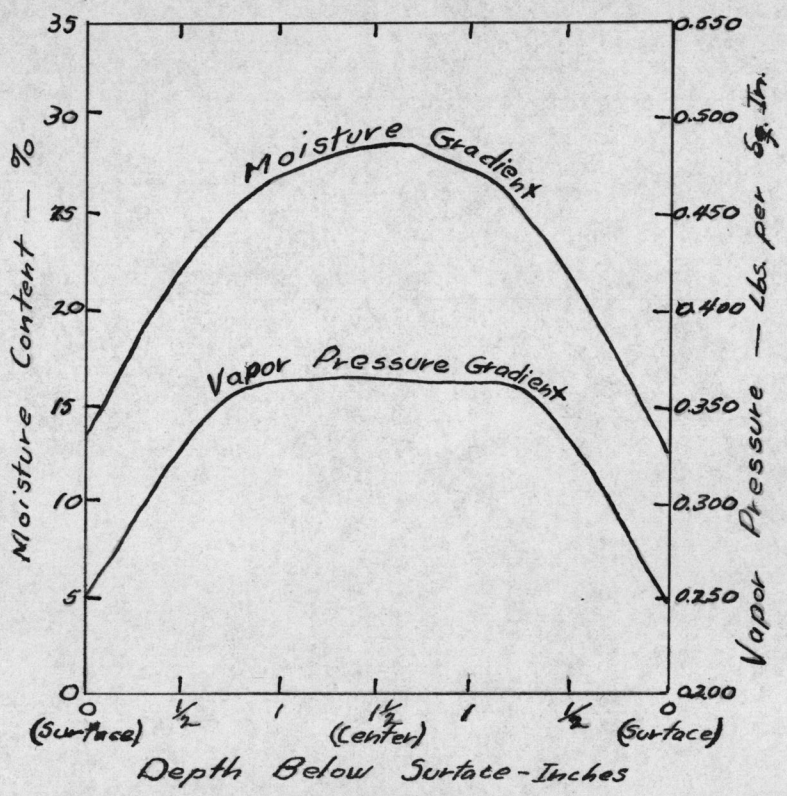
c. Equilibrium moisture content is higher

Moisture will condense on the surface of treated lumber when the relative humidity of the air exceeds the relative humidity in equilibrium with the vapor pressure of the chemical solution in the wood. Yet drying may continue. This is because in a given relative humidity, the untreated interior has a lower equilibrium moisture content than the exterior which has been treated and is

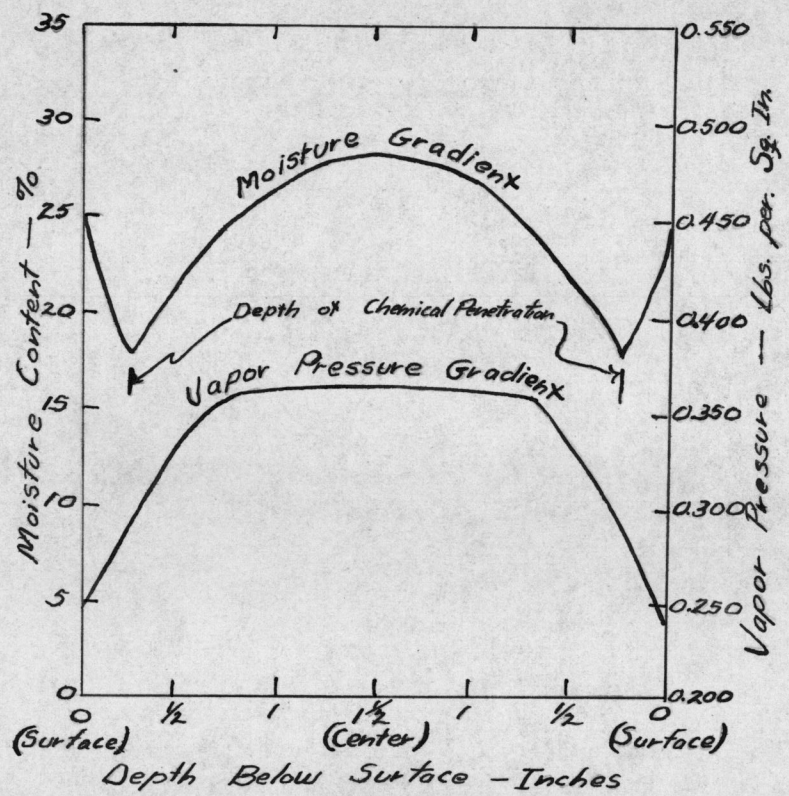
Figure 2[1]

MOISTURE AND VAPOR PRESSURE GRADIENTS OF UNTREATED

AND CHEMICALLY-TREATED WOOD WHILE DRYING



A. UNTREATED WOOD



B. TREATED WOOD

Note that the vapor pressure gradient of untreated and treated wood is about the same. Since vapor pressure largely controls the speed of moisture movement in wood, the moisture in the treated piece would move out just as rapidly as in the untreated piece, despite the higher surface moisture content of the treated wood.

[1]Progress Report No. 1, published by the West Coast Lumbermen's Association, page 13.

retaining the moisture. Therein is stated one of the basic principles of chemical seasoning.

d. Moisture gradient

The lowering of vapor pressure controls the moisture gradient, because a chemical gradient extends from the surface to the depth of penetration. From that point to the center of the piece thickness the distribution of moisture is normal. See Figure 2.

(2) Anti-shrink effect

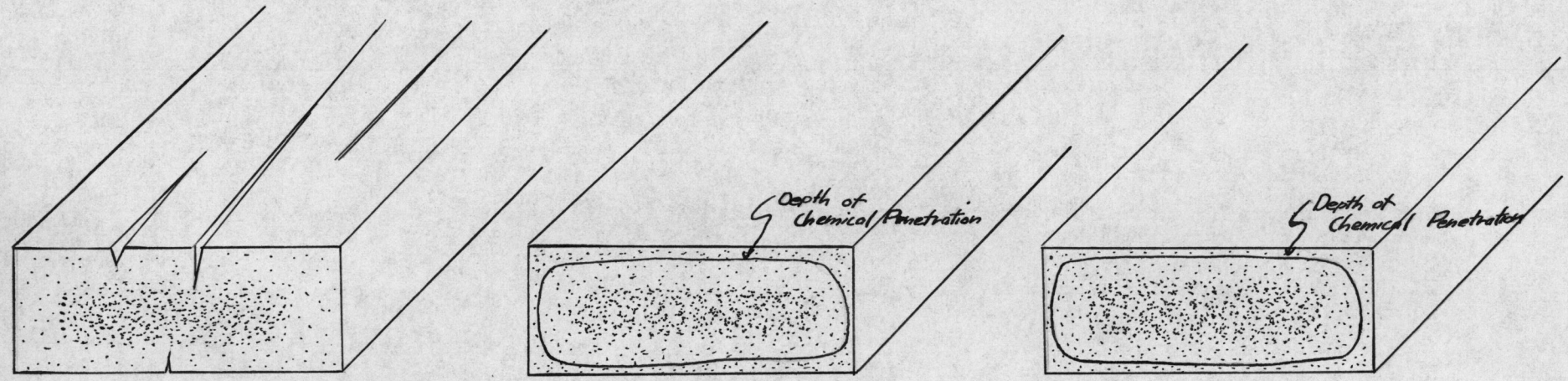
When treated lumber dries, the chemical present tends to precipitate in both the fiber cavities and walls. The chemical, therefore, acts as a plug inbetween the units of the fiber wall, thus reducing the shrinkage of the wood somewhat. Even though the chemical may reduce shrinkage in just a small portion of the treated piece, it nevertheless minimizes stress and helps prevent checking. See Figure 3.

(b) Does not change the drying rate

If drying conditions are the same, treated and untreated lumber of the same size dry at about the same rate. This is because the inner part of treated lumber has a moisture gradient identical with that which develops in untreated wood. Therefore, the moisture movement is similar in both instances. The surface of a treated piece of wood evaporates moisture at a normal rate because the chemical has lowered the vapor pressure of the wood water to the same degree as in untreated wood under the same drying conditions. Because of the higher

Figure 3[1]

HOW CHEMICALS PREVENT CHECKING



(Dots Represent Concentration of Moisture)

Untreated Piece of Wood Drying Under Severe Conditions.

Wood Treated with Water-Retaining Chemical and Drying under Severe Conditions.

Wood Treated with Anti-Shrink Chemical and Drying Under Severe Conditions.

[1] Progress Report No. 1, published by West Coast Lumbermen's Association, page 15.

moisture content of the surface of treated lumber, it can be rapidly and safely dried in relative humidities that cause untreated lumber to check.

III. Choosing the Chemical

Ideally, a chemical would be one that could be sprayed on lumber, in solution; or sprinkled over it as a dry powder. It would also be one that would allow the treated lumber to go through a dry kiln or through air drying in a mill yard or directly into service--with no checking of sufficient extent to injure its utility. Besides this, it should not impart to the lumber any undesirable color, or odor, susceptibility to fungus attack or to fire. It should be easy to handle, not too viscous, and inexpensive to use.

(a) Depends upon the properties

(1) Hygroscopity

Hygroscopity is the property of attracting and holding moisture. It's water retention effect required for seasoning is most useful when the saturated chemical solution is in equilibrium with a relative humidity of 75 to 80 per cent. Salt when exposed to dampness will become wet and lumpy by merely absorbing that moisture from the air. This is the most common example of the principle of hygroscopity.

(2) Solubility

Solubility allows quick mixtures into concentrated solutions, assists diffusion, permits effective lowering of vapor pressure; and in general, facilitates treatment.

(3) Anti-shrink

Chemicals which remain in solution and do not crystallize in the fiber cavities as drying progresses

are most effective in preventing shrinking with resultant checking.

(4) Diffusivity

Shorter treating time is brought about by chemicals that diffuse into wood easily.

(5) Permanence

Stability of a chemical should be taken into consideration, as some chemicals gradually decompose, especially in high kiln temperatures.

(6) Combining chemicals

Sometimes better seasoning properties are obtained by combining chemicals, and also combinations add beneficial qualities to wood such as resistance to decay and fire.

(b) Must be beneficial to the wood

(1) Corrosion

Because of their rusting action on metals, corrosive chemicals are limited in use for seasoning lumber.

(2) Electrical conductivity

For most purposes high electrical resistance is not required of wood, but when it is required chemicals which do not affect electrical conductivity should be used.

(3) Condensation of moisture

Some chemicals cause treated lumber to become damp on the surface when exposed to high humidities.

(4) Color change

Some chemicals will darken or otherwise alter the natural color of the wood, while others will cause little or no color change. This change could be due to several causes. Treating conditions may effect the chemical; the chemical may react with a wood constituent; high kiln temperatures often effect the chemical.

(5) Resistance to decay and insects

When treated with toxic chemicals, lumber has increased resistance to decay and insects. Some chemicals, however, render wood less resistant to the two above mentioned factors, and to overcome this disadvantage, it is possible to mix water-soluble wood preservatives with the less resistant chemicals. Well known water-soluble preservatives are zinc chloride, chromated zinc chloride and sodium fluoride.

(6) Fire retardance

Only a very slight increase in fire resistance can be expected from the usual chemical seasoning treatment. If a material reduction in inflammability is desired, heavier absorptions of chemical must be used.

(7) Strength

By successful chemical treatment the full shear strength can be retained in timbers.

(8) Weight

Treated Douglas fir heartwood weighs about 40 pounds per thousand board feet more than untreated lumber at the same moisture content, due to the weight of the dry

chemical absorbed. But if it is seasoned after treatment and then surfaced, the weight does not differ much from that of untreated lumber in the same condition.

(c) Depends upon the treating methods

For best results in treating lumber it should be taken when very green, because if the wood dries enough to surface check before treatment, these checks cannot be controlled by treating. Therefore, adequate penetration and concentration of chemical are required to prevent checking.

(1) Application methods

a. Steeping

This method consists of immersing the lumber in a tank in which the chemical has been dissolved in water for a sufficient period to allow adequate chemical diffusion depending upon the thickness of the lumber. The solution may be at air temperature or heated to higher temperatures.

b. Dipping

There are limits on the amount of chemical that can be applied by dipping because sufficient chemical will not adhere to the surface to treat very thick sizes. The chemical is applied by dipping, or by short periods of immersion, and then solid piling the lumber so that the chemical on the wet surface will diffuse to the necessary depth of penetration. Mechanical vats are a low-cost means of applying the dipping method.

c. Spraying

When using this method the lumber is first sprayed and then, as in dipping, a period of solid piling is required after spraying to gain diffusion into the wood. The problem here is to hold enough chemical on the surface.

d. Dry spreading

The chemical in dry form is applied directly to the green lumber by hand, spreading it over the flat-grain faces. Along the middle of each piece and near the ends where the checking mostly occurs, the chemical is spread heavier. This method is not applicable to boxed-heart timbers and is not as effective as the ones which soak the lumber in chemical solutions. As spreading progresses, the lumber is solid piled and it is while in this form that the chemical diffuses into the wood.

(2) Diffusion time and penetration of the above methods

It takes time for chemicals to diffuse into lumber. A rough rule of thumb is to allow a minimum of one day of diffusion time for each inch of lumber thickness. For check prevention a chemical penetration to a depth of from 3/16 to $\frac{1}{2}$ inch is required, depending upon the thickness of the lumber. Forty pounds per thousand board feet is a satisfactory amount of chemical to use; that is, calculated by weight. Greater amounts are more effective.

While penetration of water-soluble chemicals into moist sapwood is rapid, penetration into Douglas fir

heartwood is much slower because of its low moisture content.

(3) Other methods of application

In pressure and hot-and-cold methods the chemical is forced into the wood bodily as a solution. The advantage of pressure methods is quicker and possibly better treatment. But they are expensive and require more skilled operation.

(d) Depends upon the seasoning method

(1) Drying in the solution at high temperatures

Because of the lowering of vapor pressure by the dissolved chemical, it is possible to dry lumber in a heated chemical solution. The lumber will dry at about the same rate as untreated lumber subject to the same drying conditions.

(2) Kiln drying

If the relative humidities of the kiln are adjusted to the moisture retention properties of the chemical employed, it is possible to kiln dry lumber without surface checking.

(3) Air drying in stickered piles

This method of seasoning can be satisfactorily used for treated lumber. However, the more effective chemicals should be used, since the relative humidities cannot be controlled as in a kiln. Here the rate of drying treated lumber is about the same as of untreated lumber, but the lumber should be protected against direct rain to avoid leaching and washing off of the chemical.

(4) Drying in use

This method appears to be the most practicable for large construction timber. The lumber can be shipped while still green, but the most effective treating methods and chemicals must be used in this case.

(6) Depends upon the cost

Determining the chemical cost per thousand board feet is based on the quantity used and the cost of chemical. There is a wide range in the cost of chemicals from $\frac{1}{2}$ cents per pound for sodium chloride to about 9 cents per pound for monoammonium phosphate. Urea, at a cost of 5 cents per pound, is about average.

The expense of application and handling, charges of equipment and cost of end coating if applied must all be added to the chemical cost. All of these charges vary with the size of lumber, the method of treating and the handling facilities available.

IV. Chemicals to be Used

A list of chemicals to be used, together with the various properties they possess, is given in Table I. This table was made up by the Forest Products Laboratory and was published in Progress Report No. 1 on Chemical Seasoning by the West Coast Lumbermen's Association.

V. Mill Experience with Chemical Seasoning

Several mills, one of them being the Weyerhaeuser mill at Longview, Washington, have tried using sodium chloride by dry spreading on thick dimension and heavy clears, and in most cases cheking was greatly reduced. This seasoning chemical is the cheapest

TABLE I[1]

Rank according to price	CHEMICAL	Price per pound a	Water retention: Relative humidity in equilibrium with saturated solution, 68° F.[b]	Antishrink[c]: Observed	Antishrink[c]: Calculated	DEGREE OF USE PERMITTED BY INDIVIDUAL PROPERTIES: Corrosiveness[d]	Color	Fire Hazard	Condensation	Electrical Conductivity	Toxicity		Fire retardant rating**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
		Dollar	Percent										
1	Sodium chloride.....	0.0075	75	a12.7	14.1	*3	1	1	2	2	1	NaCl.....	59
2	Ferrous sulphate.....	.01	.....	.....	7.6	2	3 or 4	.....	.....	2	1	$FeSO_4 7H_2O$.....	.....
3	Sodium sulphate.....	.01	93	.....	c1.74	*2	1	.....	1	2	1	$Na_2SO_4 10H_2O$...	61
4	Aluminum sulphate.....	.012	.....	.....	10.3	4	1	.....	.....	2	1	$Al_2(SO_4)_3$.....	20
5	Ammonium sulphate.....	.014	81	b27.8	28.5	*2(Air dry) 4(Kiln dry)	1	1	2	2	1	$(NH_4)_2SO_4$.....	20
6	Calcium nitrate.....	.014	56,65°F.	.....	30.2	*1	1	3	3	2	1	$Ca(NO_3)_2$.....	.....
7	Calcium acetate.....	.0165	.....	.....	0	.....	.....	.....	.....	2	1	.....	70
8	Sodium phosphate.....	.021	95	.....	3.98	*1	1	1	1	2	1	$Na_2HPO_4 12H_2O$..	47
9	Sodium carbonate.....	.023	87	.....	c2.7	*2	1	1	1	2	1	$Na_2CO_3 10H_2O$...	38
10	Sodium nitrate.....	.029	76	b24.6	24.5	*1	Bleaches	3	2	2	1	$NaNO_3$.....	.....
11	Zinc sulphate.....	.029	90	.....	36.9	2	1	1	1	2	1	$ZnSO_4 7H_2O$.....	.....
12	Barium chloride.....	.04	88,75°F.	a.8	.75	3	1	1	1	2	1	$BaCl_2 2H_2O$.....	65
13	Copper sulphate.....	.045	95	.....	c4.45	3	3	1	1	2	1	$CuSO_4 5H_2O$.....	.....
14	Urea.....	.045	80	b55.8	43.9	1	1	1	1	1	1	$(NH_2)_2CO$.....	.....
15	Potassium chloride.....	.05	78	a14.6	14.5	4	1	1	2	2	1	KCl.....	62
16	Invert sugar 75 percent solids 0.04: Dry.....	.053	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	40% solution	.....	95	61.4	29.7	1	1	1	1	1	2	.....	.....
17	Ammonium chloride.....	.06	77.2	a18.1	18.2	4	1	1	2	2	1	NH_4Cl.....	19
18	Tribasic calcium phosphate	.065	.....	.....	0	.....	.....	.....	.....	2	1	.....	.....
19	Calcium arsenate.....	.0675	.....	.....	0	.....	.....	.....	.....	2	1	.....	.....
20	Sodium dichromate.....	.07	52	.....	29.9	*1	3 or 4	1	3	2	1	$Na_2Cr_2O_7$..... $2H_2O$....	36
21	Manganese sulphate.....	.075	85,86°F.	.....	33.3	*1	2	1	1	2	1	$MnSO_4 4H_2O$.....	39
22	Manganese chloride.....	.075	54	a19.6	19.9	3	3	3	3	2	1	$MnCl_2 4H_2O$.....	18
23	Potassium nitrate.....	.079	93	.....	5.9	2	1	3	1	2	1	KNO_3.....	67
24	Strontium.....	.08	.....	.....	23.1	2	1	3	.....	2	1	$Sr(NO_3)_2 4H_2O$..	.....
25	Ammonium carbonate.....	.08	.....	.....	....	.....	.....	.....	.....	.....	.....	.....	.....
26	Magnesium sulphate.....	.08	86	.....	31.4	*2	1	1	1	2	1	$MgSO_4 7H_2O$.....	39
27	Ammonium phosphate.....	.08	88	.....	42.1	*1	1	1	1	2	1	$(NH_4)_2HPO_4$....	18
28	Aluminum chloride.....	.08	.....	.....	c22.3	4	1	1	.....	2	1	$AlCl_3 6H_2O$.....	16
29	Lead acetate.....	.10	.....	.....	....	2	1	1	.....	2	1	$Pb_2(C_2H_3O_2)_2OH$	
30	Lead nitrate.....	.10	98	.....	7.9	2	1	1	1	2	1	$Pb(NO_3)_2$..... Normal wood	 83

[1]For Footnotes please see following page.

Chemical Table and Chemical Ratings by Forest Products Laboratory.

Table published in Progress Report No. 1 by West Coast Lumbermen's Association, page 17.

Footnotes for TABLE I

[a]Prices are quotations given in Oil Paint and Drug Reporter, October, 1938. (Most prices are in carload lots f.o.b. production plant.)

[b]Values indicate minimum relative humidity at which treated fibers will not shrink. Relative humidities higher than those indicated will cause condensation.

[c]Antishrink properties are expressed as the percentage reduction in total shrinkage (green to oven dried) based on shrinkage of untreated controls.

[a]Effect of inorganic salt upon the swelling and shrinking of wood, by Dr. Stamm;
[b]unpublished data by Johnson and Loughborough;
[c]except when checking experimental values calculations are made on solubility at 32°F. calculated values marked C based on solubility of dehydrated chemical. When antishrink of urea-treated wood is based on dimension of wood after treatment the antishrink is 45.6 checking the calculated value 43.9 very nicely.

[d]Arbitrary ranking as to corrosiveness.

*Indicate ranking based on accelerated test.
**Fire-tube data. Values indicate weight loss in per cent under conditions of standard test.

Ranking given in columns 7 to 12 is arbitrary but indicates:

1. Very extended use (presence of chemical practically no handicap to use).

2. Extended use (wide application but effects deleterious or inadequate for some items of wood and special uses).

3. Limited application but may not exclude use of chemical for some purposes.

4. Very limited (very deleterious may exclude chemical for seasoning work).

known and therefore desirable to many mill owners to use. But because of its corrosive properties which caused the corrosion of metal equipment from the drip of salt brine at high humidities, the use of sodium chloride has been discontinued by most mills that have tried it. One manufacturer, who had been using this chemical, was forced to discontinue because of customer objection to corrosion and condensation difficulties of the salt-treated lumber in service. As W. B. Greeley, secretary-manager, West Coast Lumbermen's Association says in his statement on "Chemical Aids in Seasoning Lumber," printed by the E. I. du Pont de Nemours & Company, Inc., "Until we can find a mixture of chemicals, or some other means of ridding lumber of this corrosive quality, we must regretfully keep common salt on the kitchen shelf."

There are many other chemicals from which to choose, but experimentation with most of them has been practically nil. That is, excepting urea, which so far from both experimentation by the West Coast Lumbermen's Association and various mills has proved to be quite successful. In order to explain why it has been so successful, the remainder of this thesis will delve into the subject more thoroughly.

VI. Urea as an Aid in Seasoning Lumber

(a) Properties of urea

Urea is a white-odorless, crystalline solid, in appearance resembling table sugar. It is composed of nitrogen, hydrogen, oxygen and carbon. It is produced synthetically by reacting ammonia with carbon dioxide at high pressure. Urea is harmless to the skin, and even has some healing properties.

(1) Hygroscopity

Urea is hygroscopic and will lower the vapor pressure within practical limits when in solution. According to Table I its vapor pressure is in equilibrium with a relative humidity of 80 per cent.

(2) Solubility

The solubility of urea in water varies with temperature and may be shown as follows:

Solubility of Urea[1]

Temperature Deg.C	Deg.F	Lbs. Urea per 100 lbs. water	Lbs. Urea per gall. water	% increase in volume at saturation	Relative humidity of air in equilibrium with saturated solution %
0	32	67	5.6	49.0	86
20	68	105	8.7	78.9	78
40	104	163	13.6	125.7	68
60	140	245	20.4	193.0	59

(3) Anti-shrink property

In lumber treated in an experiment by the West Coast Lumbermen's Association over a period of 10 months, measurements show slight anti-shrink effects of the treatments. The shrinkage in treated 2x12 is 90%; 2x16, 87%, and 4x12, 80% of the same widths in untreated controls.

(4) Diffusivity

Urea diffuses into the wood easily. A study made of urea distribution as related to time in bulk pile

[1] Progress Report #2, published by West Coast Lumbermen's Association, page 4.

proved the importance of "gradient" in the diffusion of urea. In 20 hours a steep gradient of diffusion was shown to a maximum depth of 7/32". In 140 hours a more gradual gradient was shown, to a maximum depth of 10/32". This shows that the best results in check prevention follow a steep gradient; that is, heavy concentration of the chemical in a shallow layer of lumber.

(5) Permanence

Urea is stable and can be stored indefinitely without deterioration. It is subject to gradual chemical break-down at the higher kiln temperatures used in drying clear Douglas fir.

(b) Beneficial to the wood

(1) Corrosion

Urea is not corrosive and timber so treated can be used with metal fasteners without fear of injury.

(2) Electrical conductivity

Urea does not affect electrical conductivity.

(3) Condensation of moisture

In moderate concentration urea does not condense moisture until the relative humidity of the air is higher than 80 per cent.

(4) Color change

Little or no color change has been observed in lumber when dry treated with urea, except that a slightly pinkish or red-orange shade has been noticed occasionally in the sap of treated pieces.

(5) Resistance to decay and insects

Some laboratory tests with urea, by cooperating research laboratories, indicate that it may increase the decay resistance of Douglas fir.

"With the fungus Lenzites trabea, 2.5 per cent of Urea (dry weight basis) caused a very marked inhibition of growth. At 3.35 per cent of Urea and all greater concentrations, there was no fungus growth at all. With the fungus Trametes serialis, the lowest concentration stopping growth is 4.32 per cent Urea. Higher concentrations are completely inhibitory. In this series of experiments there were no test pieces between Urea concentrations of 4.32 per cent and 0.73 per cent. At 0.73 per cent and below, the growth of Trametes serialis developed; but in no case was it greater than on Urea-free Douglas fir.

"These tests show that Urea has a moderately toxic effect and adds to the natural durability of the wood treated."[1]

(6) Fire retardance

Tests made have proved that urea makes the wood more flame retardant and higher temperatures are required to cause charring.

(7) Other advantages

a. Urea does not dull saws and planer knives.

b. It does not affect the gluing characteristics of the wood.

c. It has shown no effect on paint, varnish, or lacquer finishes applied to panels of various woods which are on extended outdoor exposure tests.

(c) Treating methods

In treating lumber with urea, it should be remembered that when urea is dissolved in water, it produces a cooling

[1] Progress Report #2, published by West Coast Lumbermen's Association, page 4.

effect, and this fact should be taken into consideration. When solutions are to be prepared at a given temperature, the water should be considerably hotter than the desired temperature of the final solution. The application of heat and also the use of stirring or agitation will markedly hasten the solution of urea.

(1) Steeping or soaking

The lumber to be treated should be soaked in about a 50% solution of urea in water. To make about 21 gallons of solution use 100 pounds of urea in twelve gallons (110 pounds) of water at room temperature (70°F.). Hot water should be used in preparing the solution. The time in the tank can roughly be stated as one day for each one inch of thickness; thus three days for 3-inch lumber and 12 days for 12-inch lumber. If the piece contains a high percentage of green sap wood, the soaking time can be materially reduced.

(2) Dipping

When dipping the lumber, it should be immersed for 5 to 15 seconds in a saturated solution of urea. For rough lumber 2" thick, or less, a solution saturated at room temperature (approx. 50%) has been found to apply in the neighborhood of 40 pounds of urea per 1,000 board feet in a 10 seconds dip. At 70°F., 100 gallons of saturated solution is made up by dissolving 500 pounds of urea in 55 gallons (about 450 pounds) of water.

It may be necessary to use more concentrated solutions on lumber thicker than 2" to get 40 pounds or

more of urea per 1000 feet on the lumber. Since urea becomes progressively more soluble as the temperature is raised, these more concentrated solutions can be prepared by heating. In this way, it is possible to get almost any given amount of urea on the wood surface by merely varying the temperature at which the solution is saturated. The amount of urea absorbed also depends upon the length of time the lumber is in the solution, and upon the character of the surface of the wood. The E. I. du Pont de Nemours & Co., Inc., in experiments on rough lumber has found that a solution saturated at about 105° - 110°F. is adequate for 3" to 4" stock. At 110°F. 100 gallons of saturated solution is made by dissolving 620 pounds of urea in 43 gallons of water.

(3) Spraying

Equipment for this method consists of a relatively low capacity iron gear or centrifugal pump and a small make-up tank for urea solution. The pump is connected to the make-up tank and a spray head by rubber tubing or iron piping. The spray head may comprise a suitable length of 1" pipe drilled with a series of small holes along one side. A shallow trough under the wood being treated returns excess urea solution from the spray to the make-up tank. Experiments by the E. I. du Pont de Nemours & Co., Inc., have found that wood absorbs the same amount of urea from a spray as from an equal time in a dip or soak treatment.

Since it is desirable to get a high concentration of chemical on the surface of the lumber, a near-saturated solution of urea should be used for the corresponding temperature at which the spray is applied. A spray solution using 42 lbs. of urea to 58 pounds of water has given good results. After spraying the lumber should be bulk-piled to allow time for chemical diffusion.

(4) Dry spreading

In this method the urea is spread as the solid crystal on the faces of the green lumber, making the application heaviest at the ends of the boards and along the middle of the width of the pieces where checking is most likely to occur. If the moisture content is low, it may be necessary to wet down the surfaces of the boards before applying the urea. Forty pounds per thousand board feet, which is 48/100 pounds per cubic foot (for ease in computing, use $\frac{1}{2}$ lb.), gives good results.

A simple rule for determining the amount of chemical per piece--at 40 pounds per thousand feet--is:

Thickness in inches times width in inches times length in feet; divide by three and point off two decimals. e.g. for 3x12--16':

$$\frac{3x12x16}{3} = 1.92 \text{ lbs. per piece}$$

After treatment, the lumber should be bulk-piled to obtain diffusion of the chemical.

a. Rules for urea seasoning by dry spreading[1]

1. "Place urea in pails or kegs for ease in handling.

2. "Lumber should be green from saw and free of initial checks; if shipped green surfaced, dress before treatment.

3. "Put light spreading of urea on floor at bottom of bulk pile.

4. "Sprinkle with water the heart sides of pieces forming first course; and lay them heart-side down.

5. "Sprinkle water on sap sides of same pieces so as to wet lumber well just before applying dry urea.

6. "Distribute the urea by hand over the flat grain faces of the lumber on sap side; spreading heaviest amounts at the ends of the faces and along the middle of the width of each piece. Use urea at the rate of 40 pounds per M board feet, which is 48/100 pounds per cubic foot." Use formula given under dry-spreading for computing amount of chemical needed.

7. "Pile next course on first course in solid pile; repeat for each course until pile height is reached; then place cover boards on top and weight down.

[1] Progress Report #2, published by West Coast Lumbermen's Association, page 11.

8. "The period required for urea to dissolve and diffuse into the lumber should be determined at the rate of one day per each inch of thickness.

9. "When chemical is dissolved, lumber should be repiled on strips for air or kiln seasoning.

10. "In lumber 4 inches or thicker, it is advisable to seal ends with gloss oil or some other end coating."[1]

b. Equipment for dry spreading crystal urea[2]

1. "Tight box, about 24"x30"x24" deep, may have handles to move box around; removable top.

2. "Screen of $\frac{1}{4}$" mesh to sift urea into box, may be framed to fit box and removable.

3. "About 3 ordinary buckets.

4. "One calcimine brush--to apply urea solution to ends."

(5) Other methods of application

Urea solutions may also be applied to the surface of lumber by means of a brush.

(6) End coating

Chemical treatment will minimize but not eliminate end checking in the larger sizes of lumber 3 inches or thicker. To prevent end checks, a suitable coating such as hardened gloss oil should be applied. For best results,

[1] Progress Report #2, published by West Coast Lumbermen's Association, page 11.

[2] Progress Report #1, published by West Coast Lumbermen's Association, page 22.

the end seal should be applied before chemical treatment by the dry or spray method; and after chemical treatment by soaking.

(d) Seasoning methods

(1) Drying in the solution at high temperatures

This method could be applied after treating the lumber by soaking. Lumber will dry and lose weight faster by this means, but very high temperatures at the start may dry the lumber too rapidly so that the diffusion of the chemical is impeded.

(2) Kiln drying

When kiln drying items on which the chemical has gone into solution, the initial relative humidity of the kiln should be adjusted to the relative humidity of air in equilbrium with the chemical solution; that is, at 78 per cent to 80 per cent for urea. Humidities should be somewhat higher for thicker items.

The West Coast Lumbermen's Association made several tests in kiln drying of lumber into which urea had been diffused by the usual bulk piling. As a whole the results were uniformly good in preventing checking. Some of these tests are shown in Table II. Pieces treated with urea came through the kilns uniformly in better condition than untreated controls subjected to the same tests. Dry spreading proved the most dependable application method before kiln drying.

TABLE II[1]

RESULTS OF SEASONING TESTS WITH UREA--KILN DRYING

	Treatment	Size	Moisture Content		Days in Kiln	Temper-ature	Relative Humidity	Checking	
			Green	Dry				Faces	Ends
1.	Soaking.....	6x6 bx.ht.	35.1	24.4	6.9	110	70	None	Fine
2.	Soaking.....	6x6 sd. cut	34.0	21.1	7.0	160-180	71-56	None	Fine honey-comb
3.	Dry 40 lb.....	4x12	31.8	13.3	10.5	160	80-70-60	None	Fine to small
4.	Spraying 33 lb.	4x12	32.3	13.1	10.5	160	80-70-60	None	Fine to small
5.	Spraying.....	3x12	35.0	16.7	3.7	160-180	77-31	Few small checks	Fine to open, short
6.	Dry 40 lb.....	3x12	34.6	17.0	4.0	160-180	70-50	None to fine	None
7.	Dry 30 lb.....	3x12	34.6	17.0	4.0	160-180	70-50	Fine to small	Small
8.	Spraying 30 lb.	3x12	46.2	23.4	4.0	160-180	77-50	None to fine	None
9.	Dry.....	2x12	32.6	17.6	2.4	110-140	70-49	None	Fine
10.	Spraying.....	2x12	32.5	17.3	2.4	110-140	70-49	None to fine	Fine

[1]Progress Report No. 2, published by West Coast Lumbermen's Association, page 11.

Because of the controlled temperatures and relative humidities the results in kiln drying urea-treated lumber were more satisfactory and more uniform than those obtained in air drying.

Kiln-drying time is shortened by urea treatment, and more severe drying schedules can be used. For example, 4x12 was dried to a moisture content of 13.3% in 10½ days. For many items, the shortening of drying time will probably pay the cost of chemical treatment.

(3) Air drying

Experiments have been made in air drying urea treated lumber. As noted above, urea treatment cannot overcome the effects of sudden changes in temperature and relative humidity to which air-drying lumber is exposed. It minimizes the effects of such changes upon lumber in the process of seasoning by keeping its surface layers relatively moist. It cannot eliminate them. Table III gives results of seasoning tests made by dry-spreading and then air drying as conducted by the West Coast Lumbermen's Association. As a whole the treated pieces came through slightly but consistently better than the untreated ones.

(e) Cost of urea treatment

The price of urea in ton lots is 6 cents per pound delivered, Portland, Seattle and points taking the same water rate. In 20-ton lots (a minimum carload), the price is 4 3/4 cents per pound. Figuring 40 pounds per thousand feet and 6 cents per

TABLE III

RESULTS OF SEASONING TESTS WITH UREA--AIR DRYING

Lumber Treated by Dry Spreading; and Air-Dried 10 months

October, 1938 to August, 1939

Size		No. of Pcs.	Moisture Cont. Green	Moisture Cont. Dry	Shrinkage Thickness	Shrinkage Width	Checking Faces	Checking Ends
2x12:	Treated.....	10	33.3%	14.8%	0.0%	2.3%	Few fine scattered face checks in some pcs. None on heart face.	Few 1/64 in. to 1/32 in. open.
2x12:	Untreated Controls	4	34.1%	15.9%	1.0%	2.6%	Checked more than treated pcs.--for length of of face; 1/64 in. to 1/32 in. open.	Slightly more than treated.
2x16:	Treated.....	10	32.8%	13.7%	2.0%	2.6%	Free of open face checks.	Few 1/64" to 1/16" open.
2x16:	Untreated Controls	4	32.7%	10.0%	3.0%	3.0%	Fine face checking for length of face on most pieces.	All end checked 1/64 in. to 1/16 in. open.
4x12:	Treated.....	10	33.5%	15.8%	1.0%	1.3%	All but one pc. free of open face checks.	None to very few, fine.
4x12:	Untreated Controls	4	32.5%	16.4%	2.2%	1.7%	Checked more than treated pcs.--for length of face, 1/16 in. open on all but one pc.	One 1/16 in. open check on all but one pc.
6x6 :	Treated.....	5	33.7%	17.7%	1.3%	0.7%	All side-cut without checks; boxed-heart checked length pc.	None to very fine.
6x6 :	Untreated controls	2	37.1%	15.5%	1.6%	1.2%	None on side-cut, checked severely length of pc. on boxedheart.	None on side-cut, open end checks on boxed-heart.
6x6 :	Coated--Treated...	5	34.6%	23.4%	....	....	None on side-cut, open checks for length of pc. on boxed heart.	Only on boxed-heart.
6x6 :	Coated--Controls..	2	36.3%	25.5%	....	....	None on side-cut; open for length of pc. on boxed-heart.	Only on boxed-heart.
8x16:	Treated.....	5	32.1%	20.4%	....	....	Very slight on one pc. Other pcs. for length of pc. 1/16 in. open; boxed-heart most severe.	1/64 in. to 1/16 in. open.
8x16:	Untreated Controls	2	33.6%	20.5%	....	....	About same astreated; boxed-heart very severe.	1/16 in. open.
8x16:	Coated--Treated...	5	32.1%	24.6%	....	....	None.	Fine to 1/16 in. open.
8x16:	Coated--Controls..	2	32.4%	26.2%	....	....	Face checks open near ends on side-cut; severe on boxed-heart.	1/16 in. open.
12x12:	Treated.....	5	35.6%	21.4%	....	....	Checked moderately to severe, length pcs.	1/64 in. to 1/16 in. open.
12x12:	Untreated Controls	2	34.9%	19.3%	....	....	Checks slightly more open than in treated and for length of pcs.	1/16 in. open.
12x12:	Coated--Treated...	5	35.2%	25.7%	....	....	Face checks near ends on side-cut; on one side of boxed-heart.	1/64 in. to 1/16 in. open.
12x12:	Coated--Controls..	2	36.6%	30.6%	....	....	About same astreated; slightly more open.	1/64 in. to 1/16 in. open.

[1] Progress Report No. 2, published by West Coast Lumbermen's Association, Page 10.

pound, the chemical cost is $2.40; and at 3/4 cents--$1.90 per thousand board feet. To this cost must be added the expense of application and handling, which varies with the size of lumber and the handling facilities.

(f) Mill experience

An outstanding example of a mill that has been using urea for seasoning is the Eclipse Mill Company of Everett, Washington. This mill which has a daily 8-hour capacity of about 250,000 feet per day specializes in high-grade lumber. Ed Stuchell, manager of the company, has stated the following:

"Much of the lumber we are now treating with urea is high priced lumber. It runs from 2" thick to 12" in thickness. If we were to attempt to produce these items without treating them, there is no question the checking would be considerable and we would have on our hands a lot of high priced material which would be hard to dispose of."

The hand method of applying urea is employed, and although Mr. Stuchell believes this method is rather primitive, he wants to be certain of doing a good job as the lumber being treated now is to be used on government defense projects.

One mill, using the dry method with bulk piling and then strip piling for a period successfully treated three cars of 8x16-28' select structural stringers and is now treating two more cars.

Another mill has treated 6x8 and 8x10 clears; and piled for air seasoning with satisfactory results. This mill also treated 6x6 and 8x8 clears, which were subsequently kiln dried with no falldown. It brought a repeat order.

One mill had difficulty in seasoning 3x8 to 16 V. G. clears and tried urea dry treatment with such satisfactory results that it is now their standard practice. This has been their experience:

V. G. CLEARS

Size	Kiln Days	Moisture Content	Drying Degrade
3x12	15	11.0	None
3x6 to 12	17	12.5	None
3x6 to 12	17	9.8	None
3x6 to 12	19	9.0	None
3x8 to 16	11	13.3	None

Another mill dry treated 6x6, 8x10 and 12x14 select structural. The 6x6 was kiln dried to 12 per cent moisture content. The other sizes were placed in a structure on the outside of a building without seasoning; and after one year of exposure show no checking. Nine pieces of 12x30-45', seven of them boxed-heart, were dry treated and placed in a school building. No checks developed for eight months. Summer weather caused an open check at one end of a boxed-heart piece; slight or hair-line checks on other boxed-heart pieces; no checks on side-cut pieces.

Mills have used urea applied by dry spreading to treat pontoon lumber for national defense of clear and select structural grades, in sizes $2\frac{1}{2}$"x$12\frac{1}{2}$", 3"x12", $4\frac{1}{2}$"x$6\frac{1}{2}$", 6"x$8\frac{1}{4}$", and 8"x10", mostly sawn flat-grain. The specifications were for a moisture content not to exceed 19 per cent; and with checking limited to 4 moderate surface checks not more than $\frac{1}{2}$" deep,

and well distributed. Some mills that seasoned pontoon lumber without benefit of chemical seasoning experienced losses from degrade running as high as 40 to 60 per cent. These same mills later used urea and cut their checking loss to 1 to 5 per cent. The cost of urea treatment for pontoon lumber is estimated to be from $3.00 to $5.50 per thousand board feet.

One mill minimized its checking degrade in kiln drying railway car framing by using urea applied by dry spreading. The sizes treated are $3\frac{1}{2}$"x$7\frac{1}{2}$", 4"x$7\frac{1}{2}$", $5\frac{1}{2}$"x$7\frac{1}{2}$", and $6\frac{1}{2}$"x$7\frac{1}{2}$" clear Douglas fir. Degrade for checking was 1.8 per cent on one charge, and 4.8 per cent on another kiln charge of 60 thousand board feet. Treating and chemical cost on this order was approximately $4.25 per thousand feet.

Several other mills are using urea treatment to reduce checking on items difficult to dry, or on special orders which specify that such treatment be given.

(g) Other experiments

Tests and experiments have been made, and are continuing to be made by the West Coast Lumbermen's Association, the Forest Products Laboratory of Modison, Wisconsin, the E. I. du Pont de Nemours & Co., Inc., of Wilmington, Delaware and by west coast manufacturers in trying to find out more about chemical seasoning of wood, especially as pertains to the use of urea.

(h) New uses for urea

During a series of tests on the fire resistance of urea treated wood, it was accidently discovered that test samples

when heated to about 175°F. would bend very easily. In fact the wood becomes quite plastic and can be readily bent, twisted, and compressed without causing fracture and, if held in its altered shape until it cools somewhat, it retains this shape and resumes its normal rigidity and hardness. On reheating the wood again becomes plastic and can be reshaped. This opens up an entirely new field for urea in the way of boat ribs, wagon rims, furniture products etc. However, it must be remembered that when treating wood with urea to prevent splitting and checking an amount of 40 pounds per thousand board feet is generally used. In treating wood for bending, the wood is completely impregnated with urea and contains more than 500 pounds of urea per thousand board feet.

C. SUMMARY

(a) Findings

The information contained in this thesis all points to the fact that chemical seasoning is now more than a mere theory. The study of chemical seasoning was started about four years ago by the West Coast Lumbermen's Association, and since that time the progress made in that particular project has made such headway that West coast manufacturers and mills are now beginning to use chemical seasoning methods in their plants. It has been found from both laboratory experiments and mill experience that chemical seasoning can be beneficial to the lumber itself, to the mill owner, to the manufacturer, and to the consumer also. It has been proved that chemical seasoning does reduce losses from degrade as a result of checking and

splitting. Some chemicals have a positive effect in reducing the natural shrinkage of lumber. Others have a definite toxic, effect against fungi. Still others have real fire-retardant qualities. As a whole, urea has proved to be the best chemical for seasoning so far because of the flexibility and simplicity in its use. The knowledge now possessed about chemical seasoning has come a long way from the methods used generations ago, when the skilled craftsmen of Europe learned to soak their oak billets in brine as a step in seasoning wagon-wheel spokes and hubs. But it is still a new subject, and there is much yet to learn. However, it can be predicted that chemical seasoning is opening up an entirely new and important field in lumber treatment--a worthwhile field, too.

(b) Conclusions

Chemical treatment in seasoning is not universally used to date, but many west coast companies have been able to adopt a feasible working plan. The transition between theory and actuality having been accomplished chemical seasoning will hold one of the major places in good seasoning practice for a majority of the lumber manufacturers in the future. Now, with the demand for greater production placed upon all the lumber companies, chemical seasoning, and especially the use of urea, may take its place in the great all-out effort for national defense.

(c) Recommendations

As has been pointed out many times in the foregoing thesis, chemical seasoning, although more or less still in

the experimental stage, is an up and coming factor in the lumber game. More study and experiemce are needed before the art of using chemical for seasoning is mastered. The cheapness and simplicity of putting chemical into lumber by the simple process of water diffusion opens up real possibilities. Therefore, from the data compiled here and the facts learned, it can safely be said that chemical seasoning is recommended to all who are interested for being worth at least a try as a prevention against losses from degrade.

L. A. Nelson, Department of Grades and Inspection, in the West Coast Lumbermen's Association makes the following statement about urea in Progress Report No. 2:

"We recommend the use of urea by west coast lumber manufacturers for any items where this cost is justified. This may be to overcome present unsatisfactory results in either air or kiln drying; or unsatisfactory service to the buyer, in the condition of lumber when received or after put in use. We recommend urea particularly for thick or wide clear items; select structural items--such as railroad stringers; lamella blanks, trusses and like structures. We recommend it, in fact, for any item where the delivery of a check-free product is worth the cost of urea treatment to the manufacturer."

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