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March 1948



No. R1701

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison 5, Wisconsin
In Cooperation with the University of Wisconsin

MAJOR EXPERIMENTS IN THE CHEMICAL SEASONING OF WOOD

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Introduction

The use of chemicals as an aid to seasoning wood is not new. The ancients soaked wood in sea water before drying it in order to reduce surface checking and for many years salt has been sandwiched between layers of lumber in air-seasoning piles. But the process was not understood until the Forest Products Laboratory began to study it in 1930.

The Laboratory's work on the use of chemicals to aid in the seasoning of wood is based on the knowledge of the way wood dries and the way chemicals act when dissolved in water. It is well-known to chemists that the vapor pressure of water is diminished when chemicals are dissolved in it, and that a dissolved chemical diffuses from a zone of high concentration to one of lower concentration. As a result of an attempt to correlate known facts regarding the drying of wood with known facts regarding the properties of chemicals in solution, the following simple hypotheses were formulated.

1. A water soluble chemical will diffuse into the water contained in green wood, and water in the wood will diffuse into the surrounding chemical solution.
2. The presence of the chemical in unseasoned wood lowers the vapor pressure of the water within the wood, thus tending to retain more water in the wood and permitting the wood affected to remain in a swollen or partially swollen condition while it is being dried in specific relative humidities.
3. The presence of the chemical in the fine swelling structure of the wood decreases its normal shrinkage.

This theoretical approach broadened the base for using chemicals in lumber seasoning and started a long chain of empirical experiments that were designed to test the accuracy of the proposed hypotheses.

Preliminary Studies

Preliminary experiments readily proved that water-retention properties are imparted to wood by any chemical which, on going into solution, reduces the vapor pressure of water. It was found that, when green wood was submerged in an aqueous solution, the chemicals readily diffused into the water within the wood. If the diffusion process were continued long enough, the chemicals in the free and hygroscopic water in the wood attained virtually the same

concentration as in the water solution in the bath. When the hygroscopic moisture became saturated with the chemical, the shrinkage of the wood was reduced by an amount equal to the fractional volume occupied by the dry chemical in solution.

The green wood of all species loses moisture when submerged in an aqueous chemical solution. Some species, like the heartwood of Douglas-fir and pine, can be completely seasoned when steeped in the chemical seasoning agent, provided the desired final moisture content is not less than the wood will attain in the reduced vapor pressure of the solution at the maintained temperature. As research continued, it became apparent that the practice of completely drying wood in a chemical solution at elevated temperatures was a poor one. Large Douglas-fir timbers honeycombed while thus seasoning, since the outside treated zone could not shrink as the wood dried. Less easily treated thick oak tended to surface check in the bath when maintained at a temperature above 115° F. As a result of these effects, the timber was removed from the treating solution after a limited amount of chemical had diffused into the wood. The drying was completed by either a kiln or air drying process.

It was found desirable to combine various chemicals in order to obtain specific results. Thus, boric acid may be added to borax to increase the solubility of the borax. Potassium dichromate may be added to decrease the corrosive effect of the residual chemicals in the wood. Highly soluble chemicals that remain liquid throughout the drying process when combined with chemicals that crystalize and precipitate were found to improve greatly the antishrink properties of the chemical seasoning agent.

Thus the hypotheses behind chemical seasoning were verified and expanded by the early laboratory experiments. The cardinal principles of the process of chemical seasoning having been confirmed, test runs on green Douglas-fir heartwood timbers 6 inches by 12 inches in cross section showed that this material could be dried from an average moisture content of 61 percent to a moisture content of 53 percent during a short steeping process in a saturated solution of sodium chloride and to 20 percent in six days when exposed to a temperature of 180° F. and a relative humidity of about 75 percent.

Encouraged by the results of the experiment, the process was given a commercial trial.¹ The first lot of material dried was boxed heart 12- by 12-inch Douglas-fir timbers. These timbers required that the relative humidity within the kiln be maintained no lower than the relative vapor pressure of salt-saturated water within the wood. They were dried in 28 days with almost no degrade. But the salt solution that dripped from them during the course of the drying played havoc with the kiln trucks, the tracks, and metal duct work. Thus, the best chemical seasoning agent developed up to that time to control seasoning degrade had to be discarded. A relatively cheap, noncorrosive chemical with the proper vapor pressure characteristics was needed. Previous work at the Forest Products Laboratory had demonstrated that urea

¹Study made in cooperation with West Coast Lumbermen's Association at Longview, Wash.

met these requirements but had not been used extensively because it cost considerably more than sodium chloride. Field tests indicated that a bath treatment with urea gave satisfactory control of checking when a suitable kiln schedule was employed. A bath treatment of invert sugar fortified by urea permitted boxed heart 8- by 16-inch Douglas-fir timbers to air dry without checking. For large-scale operation the bath treatment was impractical; hence, the lumber industry in cooperation with the Forest Products Laboratory developed the dry spread method, which will be described subsequently. The urea dry spread chemical seasoning method became a tool of the industry, but it was not commercially utilized until there was a demand for large, clear timbers that had to be dried without surface checking. For this purpose the process was eminently suitable since it accomplished results that otherwise could not have been attained and the cost of the process could easily be borne by the product.

How Chemical Seasoning Works

In order to understand how different chemical seasoning processes and different chemical seasoning agents function it is necessary to understand the basic principles that govern these specific actions. Although in the process of chemical seasoning, both air drying and kiln drying methods are employed, chemical seasoning is essentially different from either of these traditional methods. In the normal seasoning process moisture in wood moves from a zone of higher to a zone of lower moisture content. As wood fibers are dried below the moisture content of 30 percent, the vapor pressure (analogous to steam pressure) of the contained water becomes progressively less and less. Obviously, the vapor pressure drops to zero when all the water has been removed (zero percent moisture content). Thus, in normal drying, moisture moves in response to a vapor pressure gradient for the same reason that steam flows from points of high to points of low steam pressure.

In drying wood by the common methods of air drying and kiln drying, the surfaces of the lumber must be drier than adjacent interior zones. The unequal distribution of moisture produces unequal shrinkage which in turn produces the drying stresses that result in surface and end checks.

By chemical seasoning methods the process is reversed. The reason is simple. It is a well-known fact that at a given temperature the vapor pressure of water is lowered when a chemical is dissolved in it. The degree of vapor pressure reduction is controlled by the characteristics and the amount of chemical dissolved in the water. If, then, all the moisture in the outside portions of a plank is saturated with a given chemical, these portions will tend to remain moist as long as the vapor pressure of surrounding air (relative humidity) is equal to or higher than that of the chemical solution in wood. The high moisture content of the surface fibers of a chemically treated board does not reduce the drying rate of the board as a whole, since the chemically free water in the center will have a normal high vapor pressure and will move toward and be evaporated from the surface at a rate that is controlled by the relative humidity of the drying atmosphere. This movement takes place despite the fact that, in the treated portion of the wood, the

moisture must move from a zone of low to a zone of higher moisture concentration. From a moisture gradient standpoint, the movement of moisture in chemically treated wood seems to be an "uphill" process, since the moisture content in the surface fibers is higher than that of fibers a short distance in from the surface. Figure 1 shows a typical moisture and chemical distribution in a treated Douglas-fir heartwood timber at the end of salt treatment. If a proper balance can be maintained between the relative humidity of the air and the vapor pressure of the chemical solution in the wood, the moisture content of the surface fibers will remain high enough to prevent their shrinkage and hence surface checking becomes impossible.

Moisture Retention Properties

When dried in identical conditions of temperature and relative humidity, all chemical seasoning agents have the common property of maintaining a higher moisture content in the surface fibers of wood treated with them than that obtained in wood without prior chemical treatment. Consequently, no checking will develop in chemically treated lumber when the drying conditions are just sufficiently severe to cause the untreated lumber to check.

In general, lower relative humidities can be used to produce a given standard of allowable checking in treated than in untreated lumber of the same species, moisture content, and cross section. This fact is the only reason that chemical seasoning dries wood faster than ordinary methods. Actually, the chemicals in themselves do not increase the normal drying rate of wood; they merely permit the use of more severe drying conditions.

With respect to water retention properties, chemical seasoning agents vary among themselves in accordance with their vapor pressures. By way of illustration, table 1 shows the relative humidities of the air at a temperature of 68° F. that is in equilibrium with the vapor pressure of the saturated aqueous chemical solution of a number of chemicals.

It is evident from table 1 that a thin zone at the surface of green wood, when thoroughly saturated with a solution of sodium chloride, will neither gain nor lose moisture when exposed to an atmosphere having a temperature of 68° F. and a relative humidity of 78 percent. Likewise, if the same or similarly treated specimens were exposed to a higher relative humidity, moisture from the atmosphere would condense on them. For this reason, it is not desirable to use chemicals that are particularly hygroscopic; since, after the wood is dry, the contained chemical will attract moisture from the damp air. Wood that is to be used in a greenhouse subjected to high relative humidities, for example, should not be given a preseasoning chemical treatment that will remain hygroscopic after the wood is dry. On the other hand, since furniture and interior trim are rarely exposed to relative humidities in excess of 70 or 75 percent, it is safe, from the standpoint of condensation to use common house salt, but unsafe to use calcium chloride, as a chemical seasoning agent.

Partially saturated solutions have higher relative vapor pressures than do fully saturated solutions. Further, temperature has an effect on the amount of chemical required to saturate a solution and the relative vapor pressure of the solutions. For instance, 84 grams of urea fully saturate 100 grams of water at 50° F., making a 45.7 percent solution with a relative vapor pressure of 82 percent. At 113° F., 181 grams of urea are required to saturate 100 grams of water. This makes a 64.4 percent solution with a relative vapor pressure of 65 percent. At 113° F., a 45.7 percent solution would be only 46.4 percent saturated. Its relative vapor pressure would be 83.7 percent, slightly higher than its vapor pressure at 50° F.

Anti-shrink Properties

All hygroscopic chemicals tend to cause the treated fibers to swell beyond their green dimension. During the treating process, the moisture in the outer fibers of the wood tends to attain a chemical concentration that is equal to the concentration in the treating solution. The volume of the water in the cell walls is increased by the addition of chemical, and, as a result, the volume of treated fibers tends to swell proportionally. When, in drying, the treated fibers lose their moisture, the chemical is precipitated in both the cavities and walls of the cells. The chemical that is thus deposited in the cell cavities does not affect their ultimate shrinkage. The chemical that is deposited in the cell walls, however, fills some of the chinks between the elements of the cell wall structure, thus reducing the shrinkage of the treated wood. Because the treated zone is usually so thin in comparison to the total thickness, the absorbed chemical ordinarily does not materially affect the overall shrinkage of the boards, planks, or timbers. However, the anti-shrink effect of the chemical tends to reduce the shrinkage and resultant tension stress of the outer treated fibers. Consequently, in this way, the preseasoning chemical treatment contributes to surface checking control.

In general, the more soluble and more bulky chemicals have the greatest anti-shrink effect since the shrinkage reduction is proportional to the partial volume of the dry chemical in solution. For example, 35.7 grams of sodium chloride can be added to 100 grams (or cubic centimeters) of cold water. The specific gravity of sodium chloride is 2.163, hence the volume of 35.7 grams of salt is $\frac{35.7}{2.163}$, or 16.5 cubic centimeters. The combined volume of the salt and water is therefore 116.5 cubic centimeters and the fractional volume of the salt is $\frac{16.5}{116.5}$, or 0.142 cubic centimeters. When the wood is completely filled with a saturated salt solution, the volumetric shrinkage can be calculated with the aid of the following equation:

$$(1-0.142) S = Y$$

where S is the normal shrinkage and Y the reduced shrinkage.

The calculated shrinkage for the salt-treated blackgum strips illustrated in figure 2 is in perfect agreement with the observed values.

When all of the hygroscopic moisture is saturated with a single treating chemical, the maximum anti-shrink effect of that chemical is obtained. In such a system there is no mechanism that will induce any chemical that precipitates in the cell cavity to find its way into the swelling structure of the wood. However, it is often desirable to use two chemicals in a chemical seasoning agent in order to increase the anti-shrink effect. The first chemical may well be of crystalline nature, quite soluble in water, and have a relative vapor pressure of about 0.75 (be in equilibrium with 75 percent relative humidity). This chemical is added to a partially saturated chemical solution that will not crystallize out when the moisture in the cell cavities is evaporated. This chemical also should be highly soluble in water and its concentration should be so adjusted that its relative vapor pressure will not materially affect the relative vapor pressure of the first chemical solution.

Salt, urea, and monoammonium phosphate are examples of the crystalline part of such a chemical seasoning agent. Glycerine, diethelene glycol, molasses, invert sugar, and corn syrup are examples of the noncrystallizing chemical. The advantage of using a partially saturated solution of a noncrystallizing chemical is that it gradually becomes more and more concentrated as the wood dries and, being a liquid, continues to diffuse into the moisture in the cell walls. A chemical seasoning agent of this type produces much more antishrink than can be obtained with the crystalline solution alone which, first of all, must be chosen because of its vapor pressure characteristics rather than its anti-shrink properties.

An example of a chemical seasoning agent of this type is a mixture of salt and invert sugar. The invert sugar is thinned with water so that it will be composed of 40 percent sugar and 60 percent water. Thirty-five pounds of salt are then added for each 100 pounds of water in the syrup. If urea is used instead of salt, 1 pound of the dry chemical is added for each pound of water in the syrup. Both chemicals diffuse into the water in the wood during treatment. The invert sugar in the cell cavities remains a liquid and continues to diffuse into the cell walls until the solution in the cell is so concentrated that it is in equilibrium with about 25 percent relative humidity. The effectiveness of this type of chemical seasoning agent is illustrated by figure 2. The data presented were obtained from 3/16-inch strips of blackgum that were soaked until they were thoroughly saturated with the respective solutions before drying.

Composition of Chemical Seasoning Agent
Modified to Accomplish Miscellaneous
Objectives

When chemicals are impregnated into wood, by imparting certain of their properties they modify the natural properties of the wood. Chemical seasoning agents can be compounded so as to obtain other benefits beside checking control. For example, wood treated with a chemical seasoning agent that contains a suitable amount of borax is more resistant to blue stain than

natural wood. By the addition of certain rust-inhibiting chemicals, one commercial company has developed a sodium chloride chemical seasoning agent with reduced corrosive properties. By using a chemical seasoning agent that is composed of resin-forming chemicals, the hardness of the wood is increased and the natural rate of moisture regain is decreased. Chemical seasoning agents of this type overcome the common tendency for chemically treated wood to act as a condenser when exposed to moist atmospheres. Urea has the property of combining with the lignin in hardwood to form a thermoplastic material that behaves in an interesting manner. Figure 3 shows a urea-treated oak square that was easily twisted when hot. It retained the shape in which it is held while cooling. Moreover, while cooling it regains stiffness. The ammonium radical of certain chemicals, including urea, darkens wood, giving it a fumed appearance. Other examples could be given that show how the chemical seasoning agent modifies the natural wood, but enough has been given to show that a chemical seasoning agent can impart both good and bad properties to the wood depending on how it is to be used.

Methods Used in Chemically Treating Wood for Seasoning

The preseasoning chemical treatment makes use of diffusion to get the chemical into the wood. Since water is the medium through which the chemical diffuses, only green wood can be impregnated by this means. In the earliest chemical seasoning experiments, the green wood was submerged in a tank of chemical solution (fig. 4). In the course of these experiments it was demonstrated that, when green wood was soaked in a saturated salt solution, the water in the untreated zone moved toward the surface in response to the vapor pressure gradient created by the dissolved chemical in the bath. For example, green Douglas-fir boards dried to 12 percent moisture content when boiled at atmospheric pressure in a saturated salt solution. Generally, however, after soaking for various periods ranging from 1 day to 2 weeks depending on species and cross section, the material was removed from the tank and immediately put in the kiln. By this method, the wood can be treated and dried very satisfactorily. In fact, millions of feet of 12/4-inch southern oak have been treated this way prior to air seasoning. However, loading and unloading the tanks involves a lot of labor. If color is of no consequence, the solution can be used over and over. At the start, however, the cost of the chemicals is high and probably should be considered a capital investment.

When lumber is to be kiln dried subsequent to treatment, it makes for efficiency if the tanks and kilns be designed with reference to the daily cut of the item being chemically seasoned. If this policy is carried out, the tanks and kilns ordinarily will be small and, in comparison with the larger equipment, they will cost more per unit of capacity. If, however, the size of the tanks and kilns is not coordinated with the daily cut, it becomes necessary to delay the treating and drying until the proper amount of stock has been accumulated for each process. Moreover, if the size of the tanks and kilns are out of balance with the daily cut, extra care must be taken to prevent the stock from drying before treatment, and a large inactive supply of chemical solution must be kept on hand to fill the voids in the tank when the lumber is treated. Whether the tanks be large or small,

considerable money must be invested in equipment and chemicals before a large production item can be dried by the soaking and kiln drying method of chemical seasoning. The problem is simplified somewhat if air drying after treatment is expedient, but there seems to be no satisfactory way of avoiding the necessity of providing a number of tanks equal to the number of days that the item must be soaked.

There were so many objections to the soaking method of treating that, when it became necessary to season large quantities of Douglas-fir timbers, a dry spreading method was developed for treating them. This method of application is illustrated in figure 5. It involves spreading the dry chemical crystals on the green lumber. Because the green heartwood of many softwood species has a comparatively low moisture content, it should be sprinkled with water just before the chemical is applied. In order that both faces of a plank or board may receive their share of chemical, the dry spread method requires that the lumber be bulk piled with a sandwich of chemical between each course. In time the chemical will go into solution and diffuse into the lumber. The pile may then be taken down and the lumber piled on sticks for drying. The advantage of this method is that it is simple and requires practically no outlay for equipment. Its principal disadvantage is that it requires considerable hand labor. By either the "bath" or "dry spread" method the cost of application considerably exceeds the cost of the chemical seasoning agent.

In the hope of decreasing costs of application, the "dip" method of applying the chemical was devised (fig. 6). Under certain circumstances it may be expedient to arrange a vat containing the chemical seasoning agent on the green chain in such a way that the boards automatically pass through the solution. Experience shows that it is unnecessary to leave dipped hardwood lumber in a bulk pile during the diffusion period. In fact, after dipping, this class of material can be immediately piled with stickers ready for air drying or kiln drying. By this method the cost of the chemical treatment is limited to the cost of the chemicals and the cost of installing and maintaining the dipping vat.

Regardless of the method of application it is necessary that, on an average, each board be given no more nor no less chemical than necessary to control checking. By the bath method the amount of chemical absorbed is regulated by the soaking period; usually about 2 days per inch of thickness for softwoods and for the heartwood of hardwood about 4 days per inch of thickness. By the dry spread method the desired quantity of chemical supplied to each course of lumber is weighed or measured out and then sowed or sprinkled on the lumber. In carrying out the dip method it is necessary to regulate the viscosity of the solution so that enough chemical will cling to the board to satisfy the requirements. Usually, softwood lumber requires no more than 40 pounds of dry chemical per thousand board feet to give adequate protection. Depending on how refractory it is, hardwood items require from 50 to 150 pounds per thousand board feet. The viscosity of a chemical seasoning agent can be increased by thickening it with starch. The desired chemical retention can be regulated by varying the starch concentration and the drain period after dipping, before piling.

Properties of Chemically Seasoned Wood

Corrosion

Most salts are corrosive although a few, such as the chromates, may even inhibit corrosion. In order to obtain a concept of the relative corrosiveness of various chemicals that might be used as chemical seasoning agents, an experiment was made involving accelerated corrosion conditions, common fourpenny nails, and kiln dried Douglas-fir that had previously been treated with various chemicals. On the basis of the compared strength values of the nails when withdrawn from the boards at the end of the accelerated corrosion treatment the chemicals were classified in accordance with their corrosive properties. Using 808.3 pounds as the strength of the new nails, the first group of treatments included those having mean tensile strength values ranging from 808.3 to 741.4 pounds. The second group of treatment included those having strength values ranging from 741.4 to 674.5 pounds; the third group more than 607.6 but less than 674.5 pounds; the fourth group more than 540.7 but less than 607.6, and a fifth group having a tensile strength value of less than 540.7 pounds. It may be noted that the upper and lower limit of each group differs by 66.9 pounds, a value determined by a statistical analysis which indicated, for this series of tests, that any difference less than 66.9 pounds might be due to chance rather than to the chemical. Table 2 summarizes the results of the study.

Table 2 indicates that chemicals impregnated into wood have widely differing effects on nails and similar fastenings. Boards treated with some chemicals seem to corrode nails less than untreated boards whereas boards treated with sodium chloride and ammonium sulphate seriously corrode nails. Moreover, the table indicates that the common rust inhibitors have no appreciable effect on sodium chloride.

In a field study a large quantity of Douglas-fir timbers were treated with sodium chloride by the bath method prior to kiln drying. From the standpoint of check control and reduction of drying time the process was a success. However, the overall process was a complete failure due to the damage done to kiln trucks, tracks, and metal duct work. This experiment involved boxed heart 12- by 12-inch timbers. The surface fibers of timbers of this size may not be permitted to shrink at all during the drying process. To prevent them from shrinking, the treated material was dried in a relative humidity high enough to keep the timbers moist. The condensed moisture, with some dissolved salt, dripped on the iron below. The truck bearings were frozen and the rails were so badly pitted that they had to be removed. Salt-treated 3-inch Douglas-fir planks, however, caused no such trouble since they can be dried in relative humidities low enough to prevent condensation. As dry kilns represent a big capital investment, however, they should not be used to dry sodium chloride treated lumber of any size or species.

The Laboratory made a preliminary corrosion test of the proprietary sodium chloride chemical seasoning agent for which the manufacturer claims corrosion-inhibiting properties. The proprietary agent has been called a buffered sodium chloride for convenience. Matched samples of steel wool and galvanized iron screen were submerged in a saturated solution of this agent,

distilled water, and a saturated solution of sodium chloride. In order to accelerate the test, first pure oxygen, and finally air, was bubbled through the vessels containing the materials being tested. Table 3 shows the results of this preliminary test.

The buffered sodium chloride was not materially better than sodium chloride in its effect on galvanized screen but was strikingly effective in controlling the rate at which steel wool corrodes. This test was not exhaustive, but the results were sufficiently favorable to encourage the belief that a commercial kiln would not ordinarily be damaged in drying lumber treated with this chemical seasoning agent. As a result, buffered sodium chloride was used in a series of chemical seasoning experiments at Chapman, Alabama. In all, four kiln runs were made. One run lasted for 22 days. Some drip was noted in all four kiln runs but there was no evident damage to the iron work of the kiln.

In general, organic chemicals have an advantage over inorganic chemicals as seasoning aids because they are not corrosive. Because of its price, solubility, and its effect on vapor pressure lowering, urea, an organic chemical that resembles sodium chloride in appearance, was readily substituted for salt in the program of chemically seasoning Douglas-fir timber. Outside of its noncorrosive properties, however, urea is not the equal of common house salt as a chemical seasoning agent. Corn syrup, invert sugar, and molasses are also noncorrosive. When used alone or in combination with water soluble crystalline chemicals, they are effective as chemical seasoning agents.

Condensation Problems

The characteristics that make the water retention properties of chemically treated wood advantageous during seasoning create condensation problems when the dry wood is put in use. With a few exceptions the chemically treated wood will become moist when exposed to a relative humidity that exceeds the relative humidity with which a saturated solution is in equilibrium. In table 1 data are given that indicate the relative humidity in a closed container over saturated solutions of the various chemicals listed. The values given indicate the minimum relative humidities that may be used in drying wood whose external fibers are saturated with the given chemical without causing them to lose any hygroscopic moisture. In general, the relative humidities given indicate the maximum values to which the treated wood may be exposed without causing drops of moisture to form on its surface. Treating solutions that are in equilibrium with relative humidities that range from 75 to 85 percent are preferred since in use the treated wood will rarely be exposed to a more moist atmosphere for an extended period.

The condensation aspect of chemically seasoned wood can be easily over-emphasized. If properly treated, the chemical will be confined largely to the surface fibers and consequently largely removed when surfaced. Some zone beneath the surface of the heartwood of Douglas-fir timbers, for example, soon dries below the fiber-saturation point and further salt diffusion is prevented (figs. 1 and 7). However, cases are known where cypress was made unfit for use in wet climates because the salt had penetrated so deeply. It is desirable, therefore, not to apply salt too liberally to wood having a

high moisture content since the salt continues to diffuse in it during the drying process (fig. 8). Diffusion of the chemical from the surface during drying is one reason chemical seasoning is not so successful with oak as with Douglas-fir.

For some reason not yet understood, some chemicals do not cause the treated wood to sweat in relative humidities that exceed the relative vapor pressure of the treating solution. For example, while the relative vapor pressure of sodium chloride and urea are substantially the same, salt-treated wood will become damp in relative humidities slightly in excess of 75 percent, whereas the same degree of dampness will not develop in urea-treated wood unless exposed to an atmosphere of 90 percent or more. It has been shown many times that resin-forming chemicals, such as buffered-urea formaldehyde solutions, possess adequate water retention during the critical stages of drying but become nonhygroscopic in the final stages when the resin is formed. Chemical seasoning agents of this type are to be preferred when it is necessary for the product and its finish to be protected from the effects of a moist atmosphere.

Buffered sodium chloride does not cause the treated wood to sweat so much as does sodium chloride. Like sodium chloride, however, it causes the dry, thoroughly treated wood to pick up more moisture and at a faster rate than untreated wood when exposed to a relative humidity above 80 percent. Moreover, in attaining a moisture content that is in equilibrium with a given relative humidity less than 75 percent, oven dry specimens saturated with either buffered sodium chloride or sodium chloride will swell more than matched untreated oven dry wood. Figure 9 shows the result of one experiment on small pieces of oven-dry basswood measuring 1 inch along the grain and 1 by 4 inches in cross section. After being oven dried and weighed, one group of specimens was soaked in a saturated solution of sodium chloride, another group was soaked in a saturated solution of buffered sodium chloride and a third group was untreated. All the specimens were again oven dried and placed in a closed container over saturation solution of sodium chloride and allowed to attain equilibrium moisture content and dimension. The buffered sodium chloride and the sodium chloride groups attained a moisture content of 18.5 percent whereas the untreated wood attained a moisture content of only 11 percent. Whereas these specimens were impregnated with all the saturated chemical solution they could hold, boards or timbers chemically seasoned with either of these chemicals would exhibit no such swelling tendency. With respect to dimension stability, properly chemically seasoned wood behaves much like wood that has been ordinarily kiln dried. The difference between thoroughly saturated small specimens and chemically seasoned commercial items of lumber is accounted for by the distribution and amount of chemical absorbed. The data obtained from the small specimens, however, indicate that the hygroscopic properties of sodium chloride and buffered sodium chloride are equal. Moreover, the experiment indicates that in carrying out the process of chemical seasoning no more salt should be used than necessary to control surface checking. Since resin-forming chemicals lose their hygroscopic properties when the resin is formed, it is unnecessary, in the interest of dimension stability, to limit their penetration into the wood.

Electrical Conductivity

Solutions of salts are capable of conducting electricity more readily than water alone. Hence, such items as cross arms and poles for electric transmission lines should not be seasoned with a chemical seasoning agent that includes a salt. After they were treated with sodium chloride, western redcedar poles have been both kiln dried and air dried without checking. In analyzing a mass of electrical resistance measurement data, it was found that the mean electrical resistance of untreated western redcedar poles having a moisture content of about 17 percent was 17.4 megohms. Salt-treated poles at the same moisture content averaged only about 0.123 megohm. It is thus evident that the salt treatments reduced the electrical resistance almost 140 fold.

Organic chemical seasoning agents, such as sugar syrups, glycols, and urea, being nonelectrolytic, do not increase the electrical conduction of water in wood. It is therefore preferable to use organic chemical seasoning agents when electrical resistance is of major concern.

Color and Miscellaneous Properties

In a broad sense, chemically treated wood is no longer wood but a new composition product, the properties of which are controlled by the chemical seasoning agent and the technique of employing it. Among the properties that should receive consideration in this connection are color, plasticity, and hardness.

Some chemicals, like sodium chloride, buffered sodium chloride, or diethylene glycol, cause little or no change in color, in fact, they may prevent the normal darkening effect of air drying. Others alter the natural color of wood considerably. The effect of those that change the color of wood is intensified by exposure to high temperatures for long periods.

The ammonia compounds, such as urea, monoammonium phosphate, and ammonium sulfate, have a range of effects on color varying from an aged appearance to a dark brown. When exposed to temperatures in excess of 150° F., urea gives Douglas-fir a deep brown color. Redwood is turned dark brown when chemically seasoned with urea alone, but when urea and bicarbonate of soda are used together, the natural redwood color is changed to a reddish tan. Urea tends to give an aged appearance to light-colored woods like spruce, sap maple, and sap gum, and to give oak, walnut, and the heartwood of beech a dark appearance, as if they had been fumed with ammonia. After a time the color change becomes uniform throughout the wood regardless of the depth of the original urea penetration. Thus, if color effects are desired, urea is both a useful chemical seasoning agent and a coloring agent.

A comparison of figures 10 and 11 may serve to indicate the magnitude of the effect of urea on the color of oak. Both groups of material were dried in the same kiln charge by the best known schedule for this item of wood.

The buffered urea aldehyde chemical treatment tends to bleach hardwood somewhat; although some might say that it brings out the natural yellow tints at the expense of the browns. When used alone or in mixture with other chemicals, diethylene glycol tends to preserve the natural wood color. Invert sugar has much the same effect as the glycols provided the drying temperatures are kept at 150° F. or less. Low-grade corn and cane syrups, being dark themselves, tend to discolor hardwoods somewhat but the color change may not be detrimental. In fact, when combined with urea, blackstrap molasses has produced some attractive effects in oak flooring. Unless a dark wood product is desired, chromates should not be used alone or as a corrosion inhibitor in conjunction with sodium chloride.

In general, with proper handling the coloring effects of the usual chemical seasoning agents are not great.

In an attempt to modify certain physical properties of birch and per-simmon squares in order to make them more suitable for shuttle blocks, one group of each species was soaked in buffered urea-formaldehyde solution for 7 days; another group of each species was soaked in the same chemical seasoning agent for 14 days. Some of the squares were routed slightly before treatment. After being dried to a low moisture content, each block was tested for hardness by measuring the pressure required to embed a 0.444-inch ball one-half its diameter into the wood. Table 4 shows the result of the test.

For some reason not yet understood, urea tends to react with the lignin in hardwood to form a thermoplastic. Thus, when dried after treating with urea, 2-inch oak squares are made just as plastic by heating to a temperature of 212° F. in dry heat as they become when heated in steam or boiled water.

Urea tends to encourage the growth of mold on treated wood, but it increases the decay resistance to a certain extent. The sugars, when used alone, render the wood less resistant to decay and molds. Buffered sodium chloride, while not recommended for stain control, tends to reduce the stain hazard considerably. Buffered urea aldehyde is more effective than urea in retarding decay, but not nearly so effective as the commonly used wood preservatives.

Effectiveness of Various Chemical Seasoning Agents with Respect to Seasoning Problems

Influenced by Drying Schedules

In order to evaluate various chemicals used as chemical seasoning agents it is necessary to understand that the chemical treatment is only a part of the chemical seasoning process. The subsequent drying process, (kiln schedule or air drying condition) has more effect on drying rate and seasoning degrade than does the chemical treatment. This important fact has not been made clear in previous discussions of the subject. General

information on the subject has given rise to the impression that chemical seasoning is dedicated to the cause of rapid seasoning. It is not generally known that, in research on chemical seasoning, more time is spent in studying drying schedules than in seeking more efficient chemical seasoning agents. In this respect, chemical seasoning research parallels or coincides with research in kiln drying. It has been found that a preseasoning chemical treatment supplements, but does not replace, the recognized tools of the seasoning trade, namely temperature and relative humidity. Although a charge of chemically treated lumber can be safely dried by temperature and relative humidity conditions that would be ruinous to similar untreated material, each item of chemically treated wood seems to have its own set of critical temperatures and relative humidities (drying schedule) which may not be exceeded without drastic results. The generic process of kiln drying is not judged by the results of certain charges that have been damaged by improper kiln schedules. Neither should the added tool of preseasoning chemical treatment be evaluated solely on the basis of experiments in which the drying rate of the treated lumber has been increased too much. The total potentialities of the treating and drying process should also be given consideration. With reasonable and identical drying conditions, properly chemically treated lumber always dries with less checking than untreated lumber. By modifying the drying schedules in order to produce a like amount of checking, chemically treated wood can be dried somewhat faster than matched untreated stock. So far, however, the strong point of chemical seasoning has been its ability to dry, without serious seasoning degrade, items of wood that defy ordinary kiln and air drying practices.

Before the advent of chemical seasoning, numerous futile attempts had been made to kiln dry large Douglas-fir timbers. The drying time for 6- by 12-inch side cut timbers was of the order of 80 days and the resultant degrade high. When soaked in a saturated salt solution for 3 days, green timbers of this class were subsequently dried to 14 percent moisture content in 18 days. A long series of preliminary experiments proved that the success of the process was not alone due to the chemical treatment but that it was equally due to the drying schedule, namely 160° F. and 73 percent relative humidity for the entire drying period. When a 70-percent relative humidity was used, many of the timbers checked. Similar items treated with urea had to be dried in a temperature of 140° F. and a relative humidity of 80 percent.

Whether treated or not, thick oak is particularly sensitive to changes in kiln condition. A further example of how much the results of chemical seasoning depend on drying schedules is illustrated by comparing figures 11 and 12 with figures 13 (urea) and 14 (buffered urea-aldehyde). The oak shown in figures 11 and 12 was dried in an experiment at Madison and the oak shown in figures 13 and 14 was dried in a pilot test in a commercial kiln at Marietta, Ohio. Figures 11 and 13 show the condition of two respective groups of 4- by 6-inch Appalachian oak that were kiln dried after being soaked in concentrated urea solutions. Figures 12 and 14 show the condition of two respective groups of 4- by 6-inch Appalachian oak after having been dipped in buffered urea-aldehyde pastes and then kiln dried. Initially, the drying conditions of the two kiln runs were almost identical. In drying the oak shown in figures 13 and 14, however, the relative humidity was reduced when the moisture content of the stock was about 53 percent. All of the checking

was initiated in about 10 hours. In drying the oak illustrated by figures 11 and 12 the initial relative humidity was not reduced, and then only slightly, until the stock had dried to an average moisture content of 40 percent. Both kiln runs were chemically seasoned but with considerably different results.

In a sense, figures 11, 12, 13, and 14 are not a true basis for comparison of the results of the Marietta pilot test with those of the Madison experiment, for, when the oak was dried to 12 percent moisture content at Madison, checks that were open at 35 percent moisture content closed completely. They are not visible in figures 11 and 12. Most of the checks shown in figures 13 and 14 likewise would have closed if the Marietta oak had been dried to 12 percent. Data obtained from measurement of the surface checks in both tests, however, indicated that the urea-treated oak at Marietta surface checked somewhat more than twice as much as urea-treated oak in the Madison experiment. Similar data indicated that the buffered-urea-aldehyde-treated oak at Marietta checked about the same amount as the urea-treated oak at Madison, or about twice as much as the buffered-urea-aldehyde-treated oak at Madison.

If chemical seasoning were to be judged solely by the Marietta pilot test, it might be considered a failure. However, the poor results were not due to the chemical treatment so much as to the drying schedule employed. Possibly, even the degrade shown by figures 11 and 12 could be materially decreased by improved schedules. The honeycombing, also, possibly could have been reduced slightly by treating this class of material with a urea-diethylene glycol solution.

Drying Time

In the study of the influence of drying schedules on the effectiveness of chemical seasoning agents, comparisons were made on the basis of quality without regard to drying time. In this case, the difference in drying time could hardly affect one's decision as to which drying schedule is the better, since both schedules produced about the same rate of drying. However, it may have been cheaper to air dry than to kiln dry the material with or without chemical treatment. When drying time and degrade are compared on the basis of economics, first one and then the other factor will assume importance depending on the value of the product and the cost of drying. It becomes a matter of either taking more time if the value of the product is too high to permit degrade, or taking more degrade if the cost of drying is relatively high. For example, clear Douglas-fir timbers can bear any reasonable cost of drying; but since dry No. 2 common timbers are worth no more than green timbers of the same size it is not feasible to spend money to dry them. Again, when southern pine timbers are dried to get the benefit of lower shipping weights, no process of drying is justified that costs more than the money saved in freight rates. End grain flooring blocks must be cut from practically check-free timbers, hence the cost of a drying process that will dry timbers without checking is a secondary consideration. A kiln charge of 3- and 4-inch pine 8 to 12 inches wide was given a treatment with buffered sodium chloride consisting of 75 pounds of salt per thousand board feet and subsequently kiln dried by an accelerated kiln schedule (without the use of steam sprays at any time)

in about 8 days. Though the stock dried faster and with much less checking than similar untreated stock could be dried, the treatment was uneconomical because the standard of drying was higher than that required for such timbers but not high enough to qualify the stock for end grain flooring.

In general, it may be said that, everything else being the same, both treated and untreated stock dry at the same rate. Hence, one could expect variously treated, matched material to dry at the same rate as untreated material, provided all groups were dried together in the same kiln run. Chemically treated stock dries faster than untreated material only when, because of its improved seasoning characteristics, the treated material is dried by a more severe drying schedule. Many experiments have been made to determine how fast chemically treated wood could be dried. The results of only a few significant experiments will be cited.

Mention has already been made of the rates at which items of salt-treated Douglas-fir dry. Due to the lower temperatures required in kiln drying urea-treated Douglas-fir in order to preserve its natural color, the drying rate of urea treated items, size for size, is not quite so rapid as for salt-treated material. In all sizes over three inches in thickness, however, both the salt and urea treatment reduce the drying period over untreated items by one-half.

There is some evidence that, under identical kiln conditions, some urea-treated items tend to dry faster than similar items treated with other chemical seasoning agents. It is known that during the drying process some of the urea undergoes chemical reaction and produces ammonia gas and possibly carbon dioxide. It is thought that, when trapped, the gases create a pressure which tends to force the water toward the surface. After 3-inch redwood had been treated with urea and sodium bicarbonate, it subsequently dried faster in identical conditions of temperature and relative humidity than matched material treated with other chemicals and in about one-half the time of untreated controls.

By best commercial practice from 45 to 50 days are required to dry untreated 10/4 walnut gunstock blanks. By an accelerated schedule, urea-treated 10/4 gunstock blanks were, through successive runs, dried in from 26 to 29 days exclusive of a 5-day treating period. In the same study matched material was treated with buffered urea aldehyde and then dried in 37 days. This apparent advantage of urea over the buffered urea aldehyde treatment was not confirmed by any other experiment. Without further research, it is impossible to say that the results of the gunstock study were due to accidental or inherent properties of walnut. Ordinarily, buffered urea-aldehyde-treated stock can be dried by more severe conditions than would be safe to use in drying urea-treated material. This is illustrated by the fact that No. 11 maple shoe lasts when treated with the buffered urea aldehyde solution were dried from a green condition to a moisture content of 8 percent or less in 36 days as compared to 41 days for urea-treated blocks of the same size. When shoe lasts of this size are commercially dried from a green condition, the drying period is usually 60 days or more.

Oak grown in various localities differs so much in its drying characteristics that miscellaneous data regarding its rates of drying and its tendency to check are apt to be misleading. In making a comparison between the drying rates of salt-treated and untreated oak, it is, therefore, necessary to base the comparison on the same species of oak cut from the same area. Some overcup oak cut from about a section of land in Catahoula Parish of Louisiana provided such data. The primary purpose of this study was the reduction or elimination of surface checking and honeycombing. On the whole, very conservative kiln schedules were therefore employed in seasoning all the material used in the studies. Table 5 shows the time taken in drying the various items of treated and untreated material from a moisture content of 100 percent or more to a moisture content of 10 percent or less. Since the controls degraded badly, it was evident that the practical limit of drying time had already been exceeded. As the salt seasoned groups dried it was evident that they could be dried with a much more severe schedule. Accordingly, two additional runs were made, one composed of salt-treated 1 by 10's, the other of salt-treated 2 by 8 planks. The schedules employed in these runs were based on all the available information concerning the drying characteristics of salt-treated overcup oak and were designed to give the fastest drying rate consistent with degrade.

By these accelerated schedules the salt-treated 4/4-inch boards were dried in 17 days including 4 days of soaking in the salt solution and the 2 by 8 planks were dried in 38 days including 8 days of soaking in the salt solution. Not only did the salt treatment make it possible to dry these two items in about 1/5 of time required to dry the untreated material but the salt-treated material was of much higher quality.

Chemical Seasoning Agents and Seasoning Degrade

Figure 15 shows the honeycombing of salt-treated material versus untreated controls in the overcup oak study just described. Matched planks in each seasoning group are placed directly above and below each other. Each set of vertically piled squares represents the width of the dry plank before they were ripped. The figure thus shows the difference between the shrinkage of the two groups.

Matched salt-treated groups that were subsequently air dried were much less honeycombed than their respective untreated control group. The honeycombing data resulting from this study are given in table 6. The first set of percentage values was based on the number of squares cut from the planks and the second set of values on the planks before they were ripped into squares. Thus, 29 percent of the salt-treated, air-seasoned, 3-inch planks were free of honeycombing but 75 percent of all the 3-inch squares produced by the planks were free of honeycomb.

The promising results of the overcup study make it evident that sodium chloride is a very effective chemical seasoning agent. When combined with invert sugar, molasses, cane or corn syrup, it was found to be particularly effective. Because of its corrosive properties, the use of common salt must

be restricted to a few items of wood and, ordinarily, salt-treated, green lumber should not be kiln dried.

To overcome corrosion, efforts were made to develop organic chemical seasoning agents. The result of these efforts culminated in the use of urea alone and urea in combination with chemicals that were noncorrosive. Urea did not prove effective in controlling the checking in thick oak or maple, although it was very beneficial with respect to the honeycombing of the latter. Table 7 indicates the ability of the more promising noncorrosive chemical seasoning agents to control seasoning degrade in 4- by 6-inch white oak.

Despite the fact that higher percentages of honeycomb-free pieces were found in all the treated than in the untreated groups, the results of the salt-treated oak make even the best of the organic treatments seem poor by comparison. The poor showing of the organic chemicals in comparison with salt may be partially explained by the difference in thickness of test material and perhaps in part by difference in species. However, 3-inch Appalachian white oak, treated with the same organic chemical and subsequently air dried, surface checked much worse than 3-inch overcup oak that was air dried after being treated with sodium chloride. In passing it may be well to observe that for purposes of air drying, oak should be piled under a cover that is weather tight. It is more important to take this precaution when air drying chemically treated than untreated oak.

Being satisfied that buffered sodium chloride would not corrode the iron works in a kiln, it was decided to test this modified sodium chloride in making a thorough study of the chemical seasoning methods of drying southern hardwood lumber.

In all preceding studies, the major objective was to dry poles, timber, thick refractory hardwood, etc. In the study made at Chapman, Ala., interest centered in the chemical seasoning of common hardwood species of lumber with various chemical seasoning agents. The end objective was to secure reliable data that would indicate which, if any, of the treatments could be profitably employed in drying such items as 4/4 and 5/4 red and white oak, 4/4 beech, 4/4 and 6/4 blackgum and sweetgum, and 3- and 4-inch pine timbers. The working plan agreed upon by the cooperators² before the work started included four kiln runs, seven items of lumber, four chemical seasoning agents and two treating methods, namely dry spread and dip. Each variable studied involved at least 120 boards or timbers of commercial length.

In order to interpret the results properly, it is necessary to understand that the purpose of the investigation was to test chemical seasoning by commercial standards. To meet these standards, an effort was made to dry 4/4 oak green from the saw to a moisture content of 7 percent in 16 days. A longer drying period was considered impractical. The drying schedules employed were therefore based on drying time first. If the drying time requirements were met, a lumber quality test could then be applied in appraising the various chemicals and the methods of their application to the lumber. This

²Bay Chemical Company, New Orleans, La., and the W. T. Smith Lumber Co., Chapman, Ala.

method of procedure is straight-forward and met the immediate objectives of the study. Since untreated and treated lots of lumber were dried together, the approach provided a means for comparing the effectiveness of the different chemical seasoning agents under different drying schedules. The method failed, however, to show the difference between the minimum time required to dry the treated and untreated stock without defects.

Run No. 1 was composed entirely of 4/4 and 5/4 oak. The test material in run No. 2 included 4/4 oak, 6/4 sweetgum, and 4/4 beech. The drying schedule used in run No. 1 was a low-temperature, low-humidity schedule. This schedule produced too much surface checking, particularly in the 5/4 stock, and yet failed to dry the 4/4 oak in 16 days.

In an effort to decrease surface checking in run No. 2, the initial relative humidities were higher than those used in run No. 1. In order to speed the drying rate, a comparatively high temperature schedule was used. The high relative humidities reduced the surface checking somewhat, but the higher temperatures increased the honeycombing. Despite some increase in drying rate, the schedule of run No. 2 resulted in a 20-day drying period for the 4/4 oak, 4 days longer than the maximum allowable drying period.

At the end of the drying process about 60 boards from each group were cross cut and a 1-inch section obtained from each board for moisture determination and for a study of honeycomb and surface checks. It was not difficult to locate and count the honeycomb checks in the sections but in general the surface checks were closed so tightly they could not be readily seen. In order to facilitate their detection and measurement, each section was dampened with carbon tetrachloride, which readily penetrated the closed checks. The carbon tetrachloride evaporated from the end-grain surface but, for a time, the chemical in the checks appeared dark, thus making it possible to detect checks that otherwise would escape notice. The total number of surface and honeycomb checks in each group of boards was obtained in this manner for both runs No. 1 and No. 2, and the results are given in table 8. Since the material in run No. 1 indicated little or no commercial seasoning degrade, it was shipped shortly after being removed from the kiln. The green and dry commercial grade of each board in each group of run No. 2 was determined. The resultant data given in table 9 served to check the results of the more laborious method of determining seasoning degrade. The total footage in each group averaged a little more than 1,000 board feet. Three groups of 4/4 and two groups of 5/4 oak lumber included in run No. 2 were unavoidably deluged by a torrential rain storm during the diffusion period. An undetermined amount of the chemical from each of the treated packages was carried away by the rain. Not being strictly comparable with the other groups in the study, the degrade data for these 5 groups are not included in tables 8 and 9.

The data in these two tables do not agree in all respects. They supplement each other, however, and permit the general conclusion that the detailed counting of surface and honeycomb checks, however minute, was a more severe test of the drying methods than a measurement of loss in footage resulting from drying. By comparing the average number of surface and honeycomb checks in control and buffered sodium chloride dry spread groups

in both runs, it appears that the comparatively low-temperature schedule of run No. 1 was the better. It further appears that, except when used with resin-forming chemicals, urea tends to promote surface checking and to reduce honeycombing. In the first run, buffered sodium chloride, whether applied by the dipping or dry spread method, reduced surface checking more than the other chemicals and in the end produced a greater percentage of boards that were free of all defects.

The information regarding the effectiveness of buffered urea-aldehyde is too meager to warrant conclusions but, on the basis of the lumber tally, it seems promising. Integrating all of the experience of the Forest Products Laboratory with sodium chloride as a chemical seasoning agent, it seems that buffered sodium chloride should be quite useful to the lumber industry. It should be quite helpful in kiln drying 4/4 and 5/4 overcup oak and in air seasoning thicker items. It might even be useful in kiln drying Alabama 4/4 and 5/4 oak. These items, however, cannot be commercially treated and dried in less than 20 days -- a fact which may interfere with adoption of the process regardless of the preseasoning treatment given the lumber.

Some items of lumber can be normally kiln dried so successfully that a preseasoning treatment seems unwarranted. In run No. 2, for instance, all treated and untreated lots of 4/4 beech and 6/4 sap sweetgum dried rapidly and without visible seasoning defects. Subsequently, a run was made on a kiln charge of 4/4 and 6/4 sap sweetgum. Half of the charge was treated with buffered sodium chloride and the other half was untreated. The charge was dried so rapidly and the untreated half was so free of seasoning losses that the expense of treating the other half was unjustified.

The Present and Future of Chemical Seasoning

Years of research have failed to weaken the fundamental hypotheses upon which the practice of chemical seasoning rests. With suitable drying equipment, chemical treatment improves the seasoning of many items of wood. Commercial acceptance of chemical seasoning requires favorable economic conditions.

Chemical seasoning first of all strives for a quality product. At present, the market conditions are such that it is unprofitable to sacrifice speed for quality. Chemical seasoning, at its best, decreases surface checking and drying time. In the framework of present economic conditions, however, the saving in drying time alone can hardly be expected to bear the entire cost of the chemical treatment. Moreover, as measured by present commercial standards, a board that was never surface checked is no better than a board containing checks that have been completely closed by drying. If and when the quality of drying is more completely reflected in the price of lumber, there will be a greater inducement to season refractory items by chemical seasoning methods. Chemical seasoning offers little promise, however, when ordinary methods are capable of profitably producing a high quality of drying or when the rules do not penalize a lumber grade because of surface checks that are not readily apparent. The cost of treating such items can hardly be recovered by the saving in drying time. The field of

chemical seasoning lies in an area where the cost of the treatment can be borne by both improved quality and drying rate. The field of chemical seasoning can be further extended to include special items of wood whose properties are improved by the chemical seasoning agent employed. For example, considerable green lumber is now being treated with buffered urea aldehyde for use in machinery employed in the manufacture of cloth. This chemical seasoning agent imparts a quality to the wood parts of machinery that minimizes friction as the cloth moves over them. For this use the cost of the chemical treatment is a minor matter as compared to the improved properties of the wood. Again, buffered sodium chloride imparts certain properties to the wood that enable it to maintain its natural bright color while air drying.

Failures and successes with various chemical seasoning agents and drying schedules, as related to different items of lumber, have developed an understanding of the principles of chemical seasoning, and a knowledge of the properties a chemical seasoning agent must have in order to produce certain results. At present, chemical seasoning is not a process that can be generally substituted for ordinary kiln drying or air drying. It supplements ordinary methods and, in the proper economic environment, will be found useful when standards and rates of drying are required that cannot be obtained by the common drying techniques.

Table 1.---Relative humidity of air in equilibrium with the vapor pressure of saturated solutions of various chemicals at 68° F.

Chemical	: Relative humidity of air in : equilibrium with saturated : solution at 68° F.
	<u>Percent</u>
Calcium chloride	32
Magnesium chloride	32
Calcium nitrate	59
Ammonium nitrate	68
Sodium nitrate (Salt peter)	76
Sodium chloride (House salt)	78
Urea	80
Ammonium sulfate	81

Table 2.--Classification of chemicals as to corrosive properties as indicated by strength of nails after exposure in chemically seasoned lumber to accelerated corrosion conditions

Rank ;	Chemical treatment	:Group ¹ : No.
1 :	Monoammonium phosphate + 2 percent potassium dichromate	: 1
2 :	Sodium dichromate	: 1
3 :	Calcium nitrate	: 1
4 :	Potassium sulphate + 2 percent potassium dichromate	: 1
5 :	Borax	: 1
6 :	Untreated	: 1
7 :	Sodium phosphate	: 1
8 :	Zinc acetate	: 2
9 :	Sodium nitrate + 2 percent potassium dichromate	: 2
10 :	Magnesium chloride	: 2
11 :	Magnesium sulphate + 2 percent potassium dichromate	: 2
12 :	Calcium nitrate + 2 percent potassium dichromate	: 2
13 :	Sodium nitrate	: 2
14 :	Manganese sulphate	: 2
15 :	Potassium sulphate	: 2
16 :	Calcium chloride	: 2
17 :	Monoammonium phosphate	: 2
18 :	Magnesium sulphate + 2 percent potassium dichromate	: 2
19 :	Magnesium sulphate + 2 percent sodium dichromate	: 2
20 :	Sodium carbonate	: 2
21 :	Magnesium sulphate (chemically pure)	: 2
22 :	Magnesium sulphate (Epsom salts)	: 2
23 :	Magnesium chloride + 2 percent potassium dichromate	: 3
24 :	Sodium chloride (chemically pure)	: 3
25 :	Sodium sulphate + 2 percent potassium dichromate	: 3
26 :	Sodium sulphate	: 3
27 :	Sodium chloride (cp) + 2 percent potassium dichromate	: 3
28 :	Sodium chloride (cp) + sodium chromglucosate : 7.25 grams per liter water	: 3
29 :	Sodium chloride (commercial) + 2 percent potassium dichromate	: 4
30 :	Sodium chloride (commercial grade) + 2 percent sodium dichromate	: 4
31 :	Sodium chloride (cp) + sodium chromglucosate	: 4
32 :	Sodium chloride (commercial grade)	: 4
33 :	Ammonium sulphate	: 5

¹Group 1 is least corrosive. Size of group equivalent to the significant difference in tensile strength, 66.9 pounds.

Table 3.--Corrosive effect of three chemicals on steel wool and galvanized iron screen

Chemical	Loss in weight due to corrosion	
	Steel wool	Galvanized iron screen
	Percent	Percent
Buffered sodium chloride	7.77	10.04
Sodium chloride	41.55	10.66
Distilled water	32.68	0.0

Table 4.--Average hardness of yellow birch and persimmon shuttle block squares chemically seasoned and resinified with buffered urea-aldehyde solution

Species	Soaked in buffered urea-aldehyde solution for:		Untreated ¹
	7 days	14 days	
	Pounds	Pounds	Pounds
Persimmon			2,300
Square	2,380	3,363	
Routed	2,575	3,284	
Yellow birch			1,260
Square	1,662	1,898	
Routed	1,943	1,979	

¹Values reported in "Strength and Related Properties of Woods Grown in the United States." U.S.D.A. Technical Bulletin No. 479 (1935).

Table 5.--Time taken in initial experiment to kiln dry salt-treated and untreated overcup oak to 10 percent moisture content¹

Items	Drying time	
	Salt-treated	Untreated
<u>Inches</u>	<u>Days</u>	<u>Days</u>
1 x 10	48	120
2 x 2	62	124
2 x 4	90	164
2 x 8	90	176
3 x 3	138	196
3 x 6	221 (15% mc)	262
3 x 12	221 (15% mc)	262

¹Treated material dried without serious degrade; untreated material degraded badly.

Table 6.--Extent of honeycombing in kiln dried and air seasoned salt-treated and untreated overcup oak

Size :	Group :	Honeycombing															
		Individual squares				Original pieces											
		None	Slight	Medium	Bad	None	Slight	Medium	Bad								
Inches:		P e r c e n t															
1 x 10:	Kiln dried, untreated	:	:	:	:	35	:	25	:	40	:	0					
	: controls	:	(Not cut into				:	:	:	:	:	:					
	: Kiln dried, salt treated	:	squares)				:	100	:	0	:	0	:	0			
	: Air seasoned, untreated	:					:	45	:	40	:	15	:	0			
	: controls	:					:	:	:	:	:	:	:				
	: Air seasoned, salt treated:	:					:	95	:	0	:	5	:	0			
2 x 2 :	Kiln dried, untreated	:	76	:	21	:	3	:	0	:	76	:	21	:	3	:	0
	: controls	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	: Kiln dried, salt treated	:	98	:	1	:	1	:	0	:	98	:	1	:	1	:	0
	: Air seasoned, untreated	:	59	:	15	:	17	:	9	:	59	:	15	:	17	:	9
	: controls	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	: Air seasoned, salt treated:	:	100	:	0	:	0	:	0	:	100	:	0	:	0	:	0
2 x 4 :	Kiln dried, untreated	:	64	:	30	:	5	:	1	:	45	:	43	:	10	:	2
	: controls	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	: Kiln dried, salt treated	:	95	:	4	:	1	:	0	:	90	:	8	:	2	:	0
	: Air seasoned, untreated	:	48	:	48	:	2	:	2	:	35	:	55	:	5	:	5
	: controls	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	: Air seasoned, salt treated:	:	98	:	2	:	0	:	0	:	95	:	5	:	0	:	0
2 x 8 :	Kiln dried, untreated	:	57	:	38	:	5	:	0	:	20	:	60	:	20	:	0
	: controls	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	: Kiln dried, salt treated	:	92	:	4	:	3	:	1	:	75	:	10	:	15	:	0
	: Air seasoned, untreated	:	32	:	53	:	15	:	0	:	0	:	40	:	60	:	0
	: controls	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	: Air seasoned, salt treated:	:	100	:	0	:	0	:	0	:	100	:	0	:	0	:	0
3 x 3 :	Kiln dried, untreated	:	47	:	28	:	5	:	20	:	47	:	28	:	5	:	20
	: controls	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	: Kiln dried, salt treated	:	84	:	11	:	5	:	0	:	84	:	11	:	5	:	0
	: Air seasoned, untreated	:	35	:	20	:	19	:	26	:	35	:	20	:	19	:	26
	: controls	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	: Air seasoned, salt treated:	:	89	:	9	:	0	:	2	:	89	:	9	:	0	:	2
3 x 6 :	Kiln dried, untreated	:	54	:	27	:	13	:	6	:	30	:	37	:	18	:	15
	: controls	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	: Kiln dried, salt treated	:	94	:	4	:	1	:	1	:	85	:	10	:	3	:	2
	: Air seasoned, untreated	:	22	:	35	:	10	:	33	:	0	:	35	:	10	:	55
	: controls	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	: Air seasoned, salt treated:	:	92	:	8	:	0	:	0	:	85	:	15	:	0	:	0
3 x 12:	Kiln dried, untreated	:	32	:	21	:	23	:	24	:	0	:	15	:	40	:	45
	: controls	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	: Kiln dried, salt treated	:	90	:	8	:	2	:	0	:	85	:	10	:	5	:	0
	: Air seasoned, untreated	:	7	:	29	:	25	:	39	:	0	:	0	:	29	:	71
	: controls	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
	: Air seasoned, salt treated:	:	75	:	14	:	11	:	0	:	29	:	29	:	42	:	0

Table 7.--Extent of honeycombing and surface checking in chemically treated 4- by 6-inch Appalachian white oak kiln dried to a moisture content of approximately 12 percent

Chemical treatment	Honeycombing				Average maximum checking per piece
	None	Slight	Moderate	Severe	
	Percent	Percent	Percent	Percent	Inches
Buffered urea aldehyde bath	48.7	36.0	12.8	2.5	49.6
Buffered urea aldehyde dip	36.0	41.0	17.9	5.1	54.3
Urea diethylene glycol dip	43.6	30.8	23.1	2.5	60.5
Diethylene glycol bath	43.6	48.8	5.1	2.5	61.0
Urea diethylene glycol bath	43.6	41.0	15.4	0	67.0
Urea bath	41.0	46.2	7.7	5.1	80.0
Urea dip	15.4	59.0	15.3	10.3	138.3
None	12.8	53.8	10.3	23.1	153.4

Table 8.--Surface and honeycomb checks in variously treated Southern hardwoods after kiln drying.

Run 1					
Chemical treatment	Average number per board section		Boards free of all seasoning defects	Boards free of honeycomb checks	
	Surface checks	Honeycomb	Percent	Percent	
<u>4/4 Oak</u>					
No treatment (controls)	2.09	1.86	28.6	62.9	
Urea dip	1.64	.39	35.7	83.9	
Buffered urea-aldehyde(dip)					
Urea-diethylene glycol(dip)	1.35	.04	60.0	96.3	
Buffered sodium chloride (dry spread)	.30	.44	72.1	85.2	
Buffered sodium chloride (dip)	.58	.61	66.1	82.3	
Averages	1.19	.67	52.5	82.1	
<u>5/4 Oak</u>					
No treatment (controls)	1.95	.63	37.2	81.4	
Urea dip	2.28	.90	40.0	78.3	
Urea-diethylene glycol(dip)	2.02	.11	42.2	93.8	
Buffered sodium chloride (dry spread)	1.21	.61	50.0	72.6	
Buffered sodium chloride (dip)	.79	.37	64.5	85.4	
Averages	1.65	.52	46.8	82.3	
Run 2					
<u>4/4 Beech</u>					
No treatment (controls)	.17	.03	83.3	95.0	
Urea dip	.44	.54	68.9	85.2	
Buffered urea-aldehyde(dip)	.22	.08	90.0	98.3	
Urea-diethylene glycol(dip)	.21	.15	78.7	88.5	
Buffered sodium chloride (dry spread)	.13		90.2	100.0	
Buffered sodium chloride (dip)	.12	.20	77.9	86.4	
Averages	.22	.17	81.5	92.2	
<u>6/4 Sweetgum</u>					
No treatment (controls)	.083	.12	90.0	93.3	
Urea dip	.06	.17	88.3	91.7	
Buffered urea-aldehyde(dip)		.02	98.3	98.3	
Urea-diethylene glycol(dip)	.133	.07	85.0	93.3	
Buffered sodium chloride (dip)	.102	.05	89.8	94.9	
Averages	.095	.08	90.3	94.3	

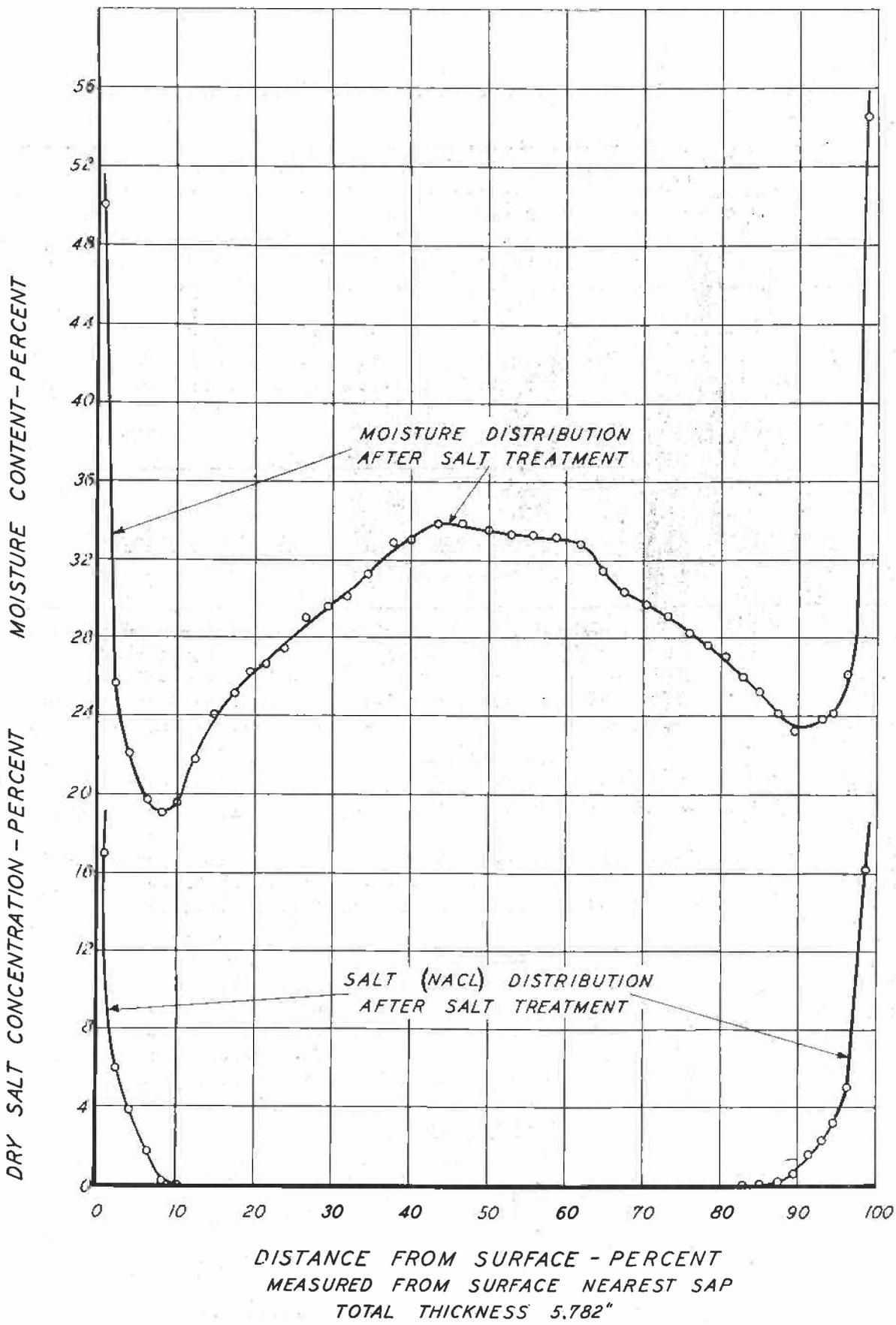
Table 9.--Results of lumber inspection of 4/4 oak in run 2 -- showing cause of degrade

Treatment	:Original: :footage ¹ :	Degrade by lumber inspection				Total	
		: Honeycomb	:Surface checks :	:Footage:	:Percent:	:Footage:	:Percent:
Buffered urea-aldehyde (dip)	: 472 :	: 22 :	: 4.66 :	:	: 22 :	: 4.66 :	
No treatment (controls)	: 623 :	: 88 :	: 14.13 :	:	: 88 :	: 14.13 :	
Buffered sodium chloride (dry spread)	: 552 :	: 16 :	: 2.90 :	:	: 16 :	: 2.90 :	

¹Does not include footage of FAS in group.

Recapitulation of seasoning degrade in 4/4 oak in run 2 after various chemical treatments

	: Urea-aldehyde dip	: No treatment (controls)	: Buffered sodium chloride (Dry spread)	:Footage:	:Percent:	:Footage:	:Percent:	:Footage:	: Percent
<u>No. 1 Common</u>									
Original	: 93 :	: 100 :	: 100 :	: 100 :	:	: 124 :	: 100 :		
On grade	: 78 :	: 83.9 :	: 83 :	: 83 :	:	: 113 :	: 91.1 :		
Dropped to:	:	:	:	:	:	:	:		
No. 2	:	:	: 5 :	: 5 :	:	: 11 :	: 8.9 :		
No. 3A	: 7 :	: 7.5 :	:	:	:	:	:		
No. 3B	: 8 :	: 8.6 :	: 12 :	: 12 :	:	:	:		
<u>No. 2 Common</u>									
Original	: 216 :	: 100 :	: 243 :	: 100 :	:	: 190 :	: 100 :		
On grade	: 216 :	: 100 :	: 185 :	: 76.1 :	:	: 190 :	: 100 :		
Dropped to:	:	:	:	:	:	:	:		
No. 3A	:	:	: 7 :	: 2.9 :	:	:	:		
No. 3B	:	:	: 51 :	: 21.0 :	:	:	:		
<u>No. 3A Common</u>									
Original	: 315 :	: 100 :	: 64 :	: 100 :	:	: 280 :	: 100 :		
On grade	: 308 :	: 97.8 :	: 51 :	: 79.7 :	:	: 272 :	: 97.1 :		
Dropped to:	:	:	:	:	:	:	:		
No. 3B	: 7 :	: 2.2 :	: 13 :	: 20.3 :	:	: 8 :	: 2.9 :		
<u>FAS</u>									
Original	: 13 :	: 100 :	:	:	:	:	:		
On grade	: 13 :	: 100 :	:	:	:	:	:		



DISTANCE FROM SURFACE - PERCENT
 MEASURED FROM SURFACE NEAREST SAP
 TOTAL THICKNESS 5.782"

Figure 1.--Moisture and chemical distribution in a 6- by 12-inch Douglas-fir heartwood timber after soaking 7 days in a saturated sodium chloride solution.

ZM23339F

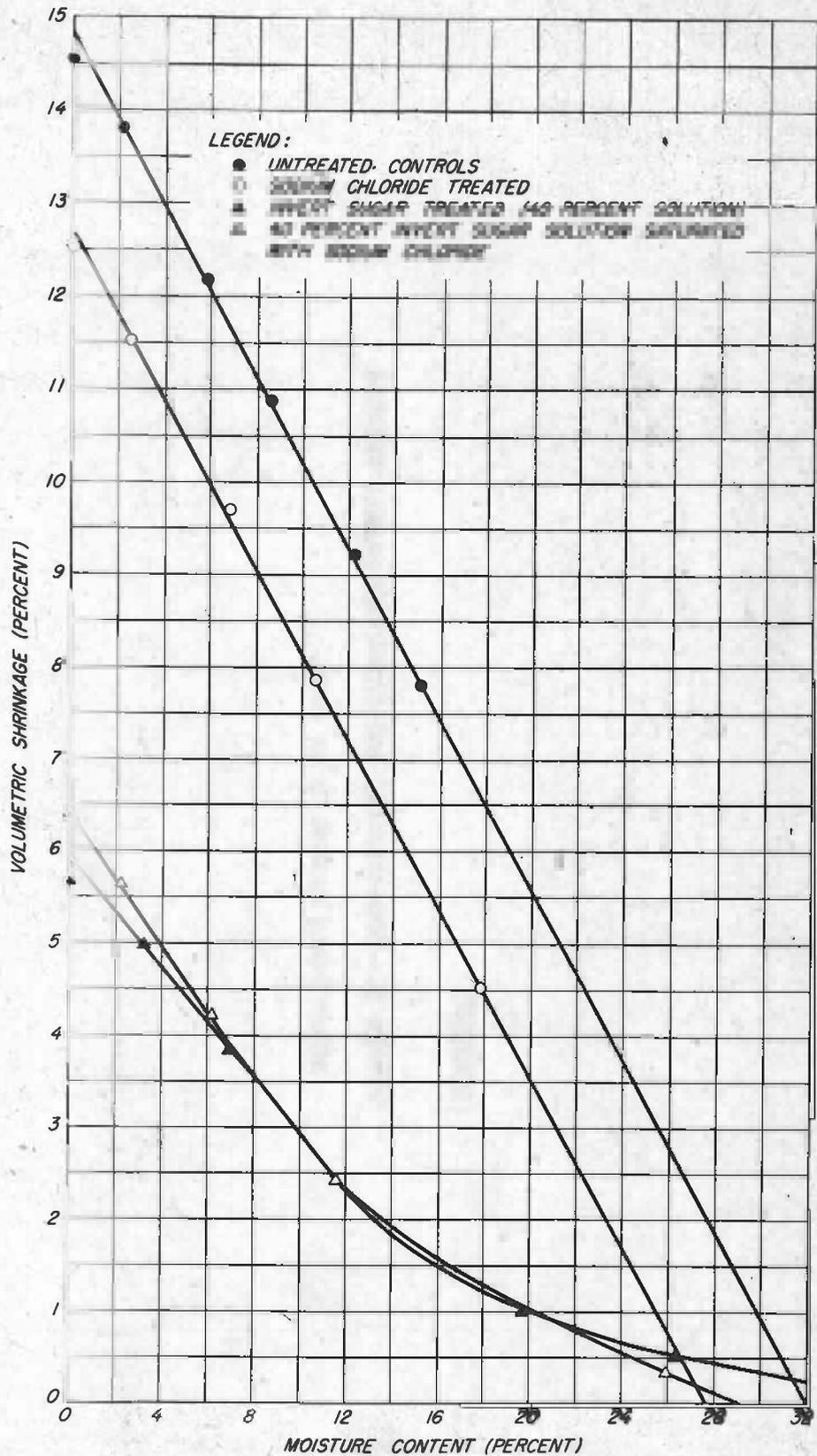


Figure 2.--Moisture-shrinkage relation of black gum strips chemically treated as indicated.

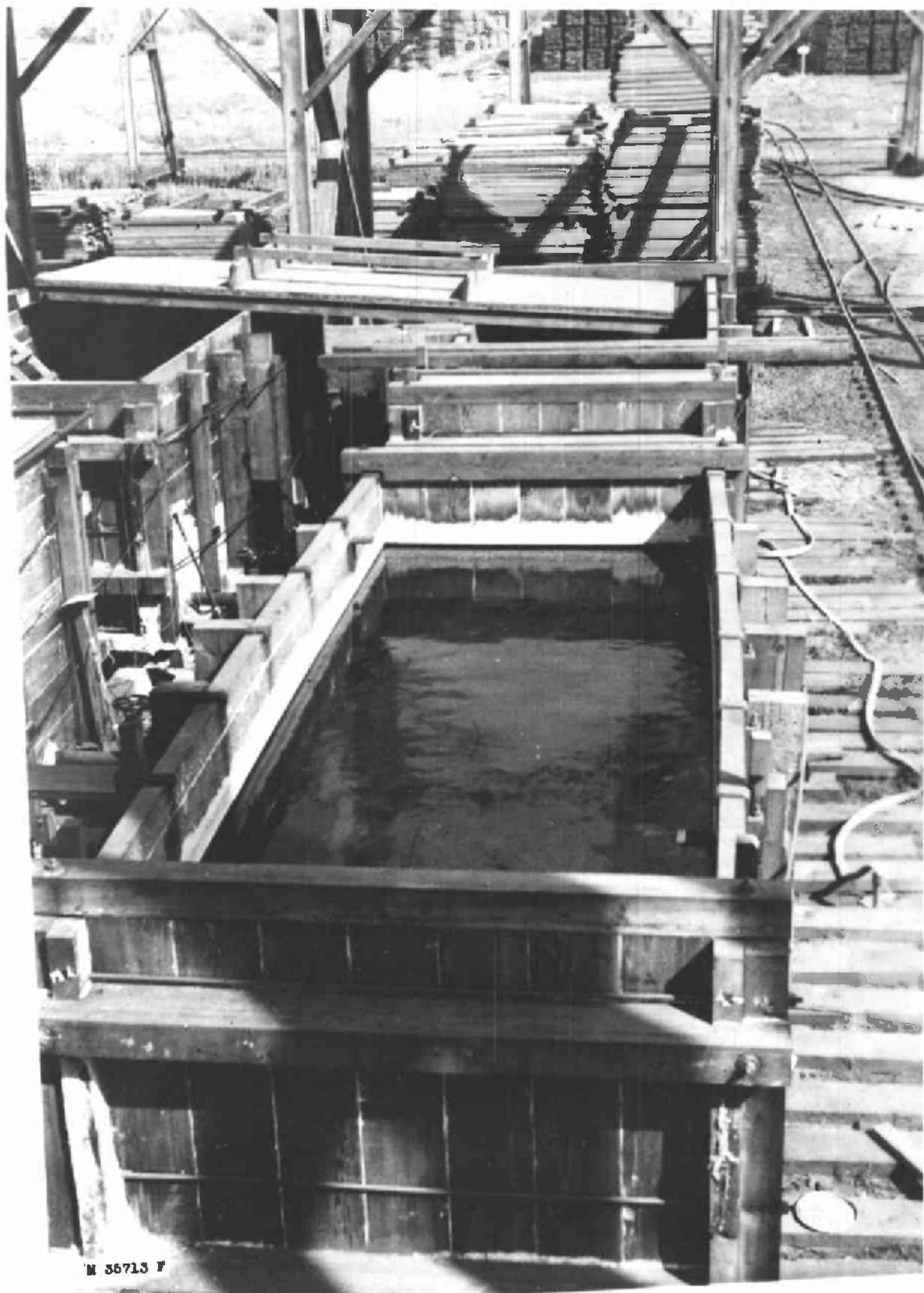
(M38499F)

Figure 3.--Urea-treated and dried oak square twisted
after being heated in an oven.



(M35713F)

Figure 4.--Tanks used in treating Douglas-fir timbers by the soaking process. Those on the right are storage tanks; those on the left are equipped with heating coils and were used for treating purposes.



M 56713 F

(M74124F)

Figure 5.—Application of a chemical seasoning
agent to lumber by the dry spreading method.

Rept. No. R1701



M 74124 P

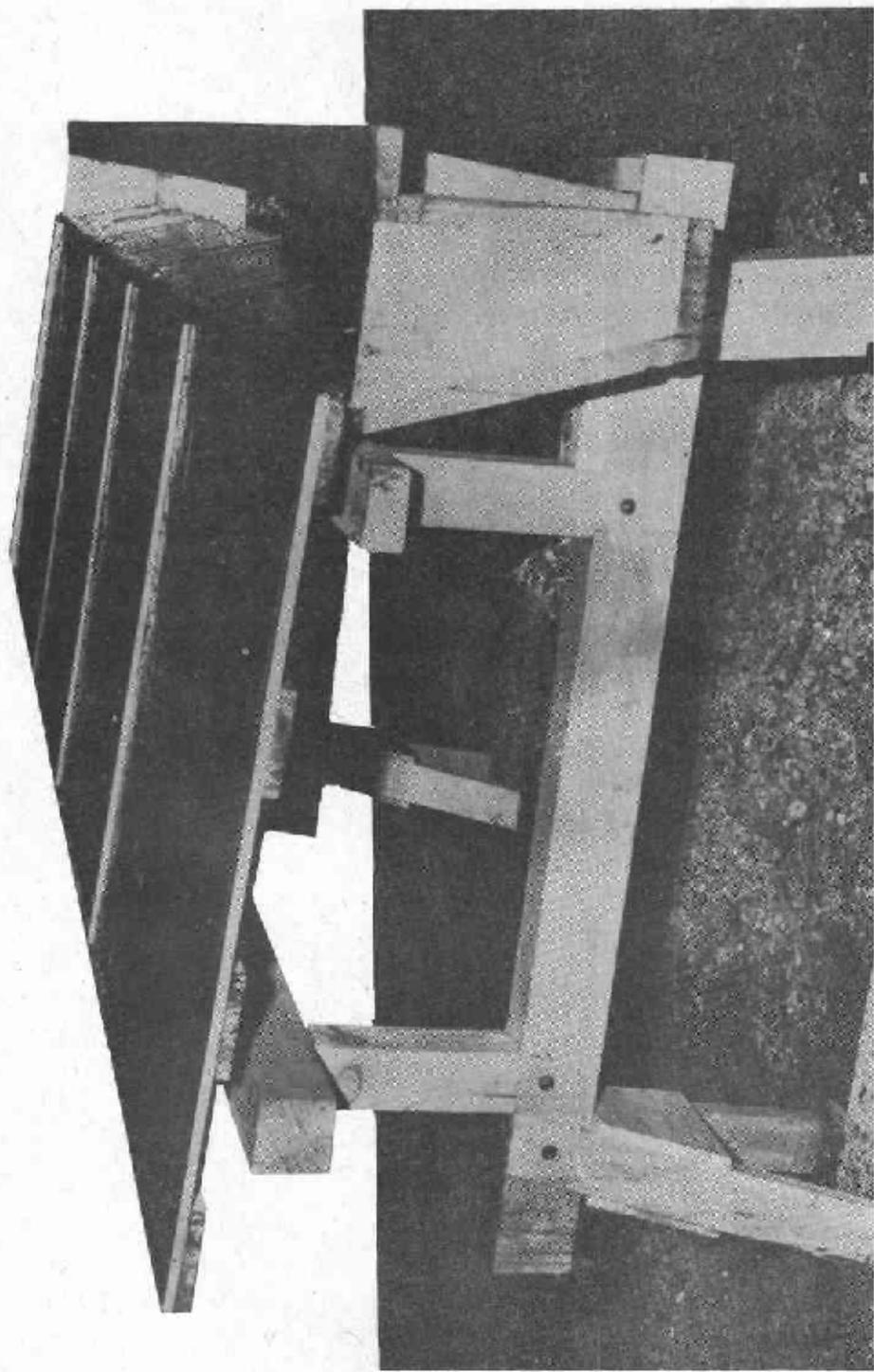


Figure 6.--Dipping vat and drain board used in the chemical seasoning at Chapman, Ala.

Z M 75903 F

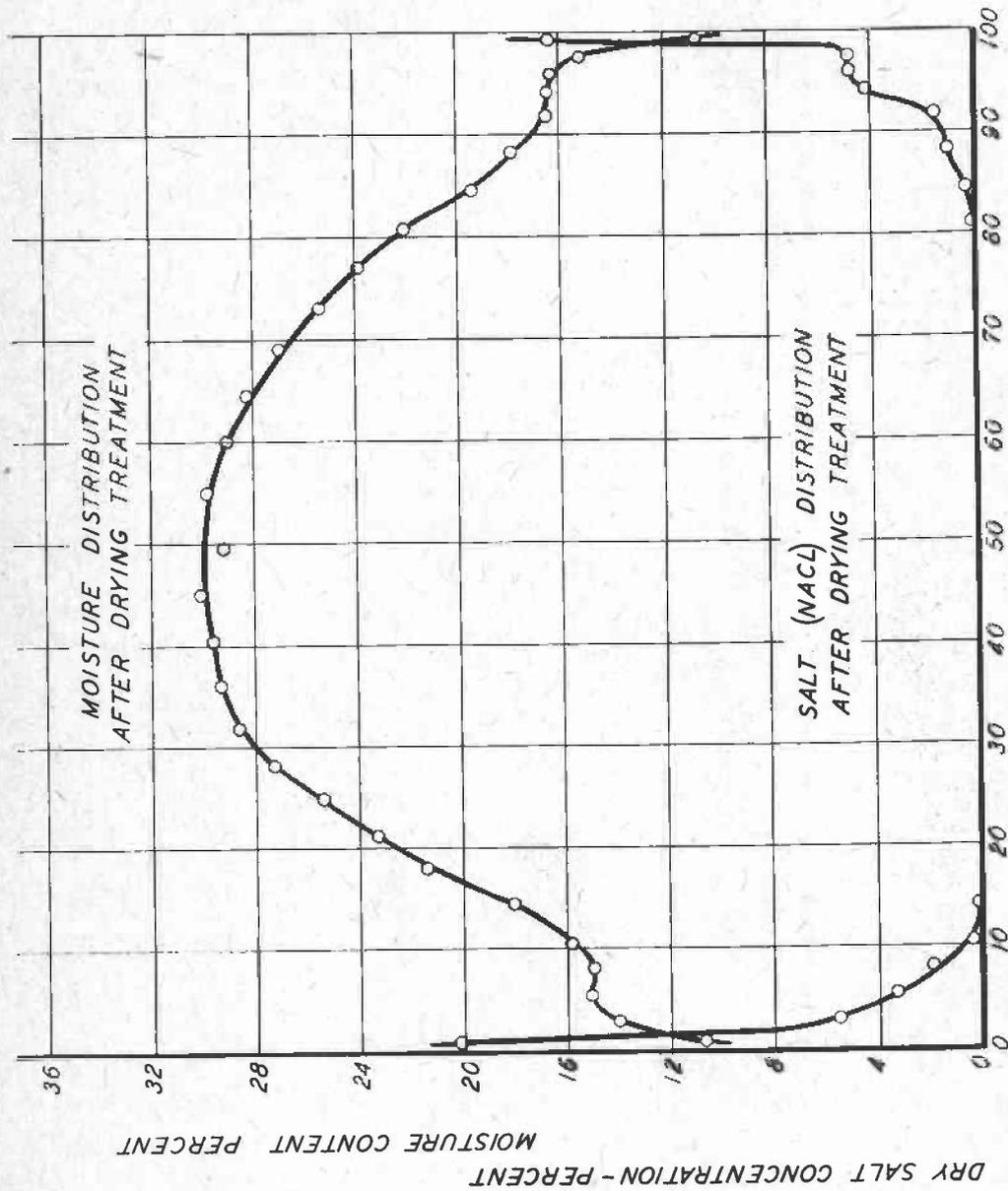


Figure 7.--Moisture and chemical distribution in a salt-treated 6-inch Douglas-fir heartwood timber after kiln drying 4 days and air drying 25 days.

ZM23394F

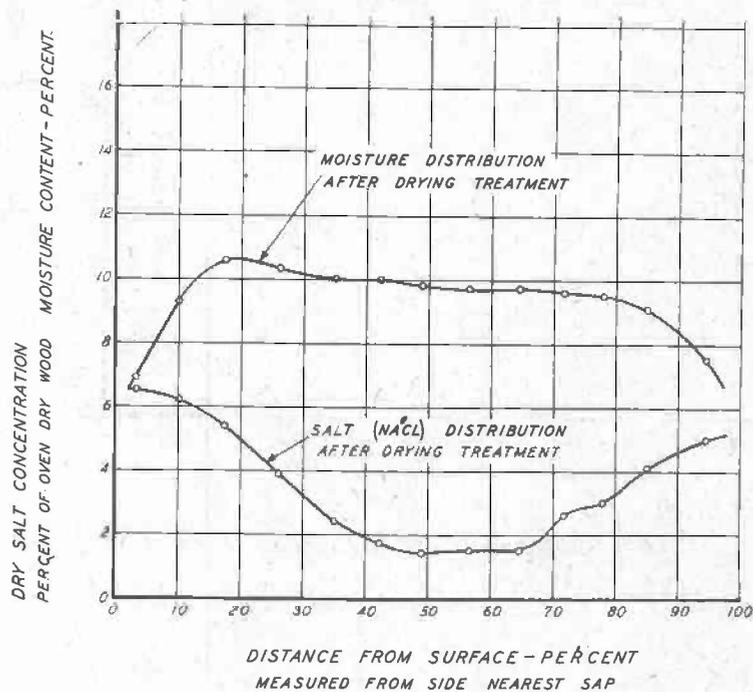
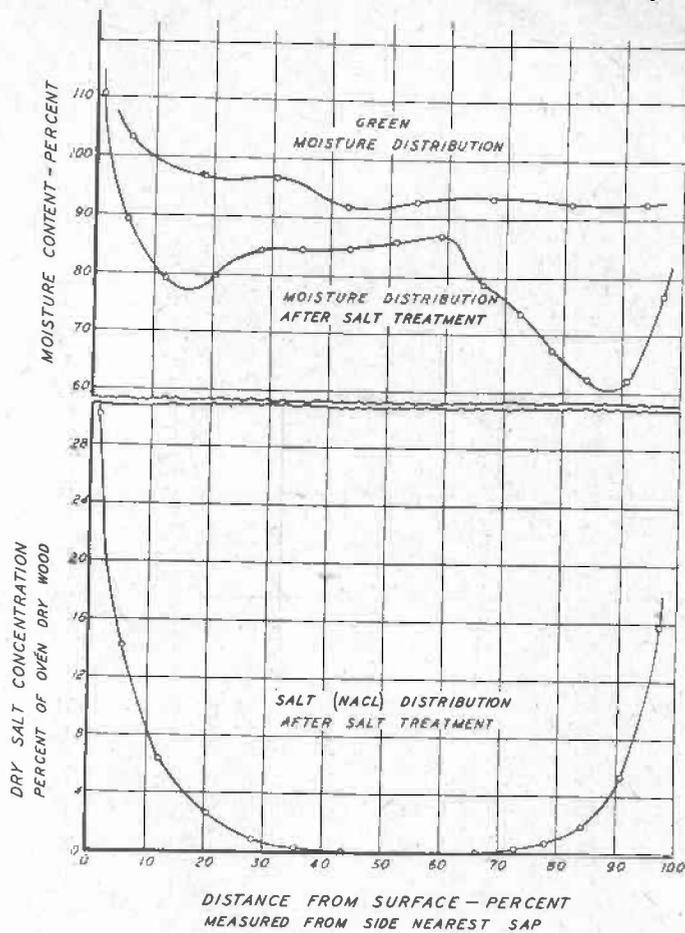


Figure 8.--Moisture and chemical distribution in a sodium-chloride-treated 2-inch red oak plank before and after air drying.

**BUFFERED
SODIUM CHLORIDE**

UNTREATED

SODIUM CHLORIDE

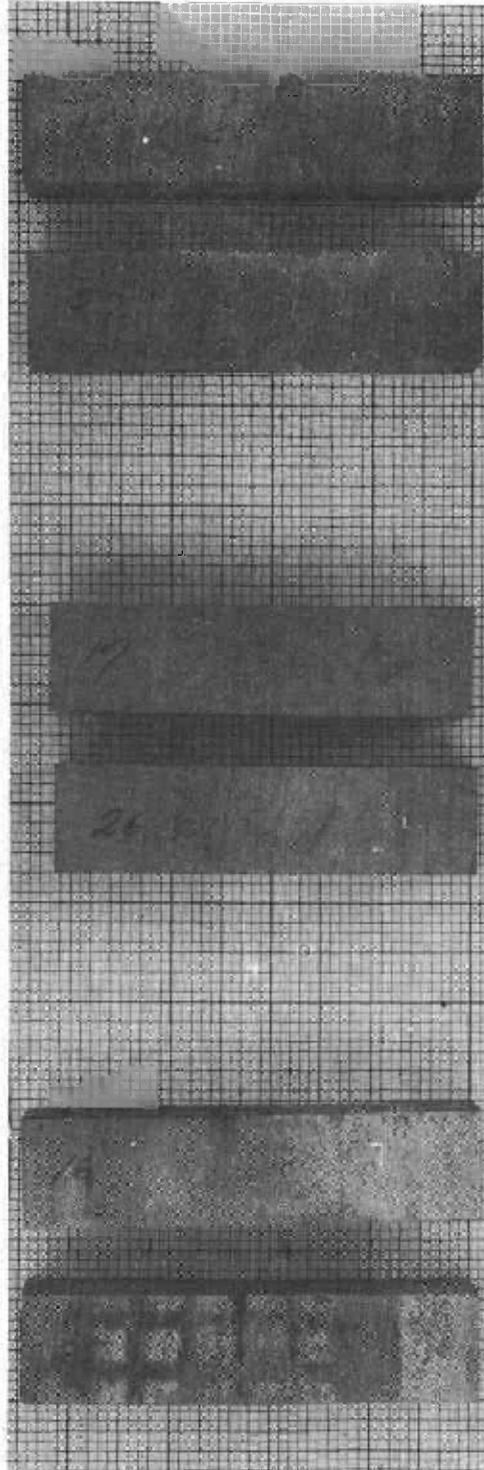


Figure 9.--Swelling of chemical-saturated basswood blocks when exposed to an atmosphere at 78 percent relative humidity.

Z X 75895 F

(M46866F)

Figure 10.--Untreated 4- by 6-inch white oak after being kiln
dried at Madison to a moisture content of approximately
12 percent.

CONTROLS

4-INCH APPALACHIAN WHITE OAK
KILN DRIED

X 46866 Z

(M46864F)

Figure 11.--Urea-treated 4- by 6-inch white oak after being kiln dried at Madison to a moisture content of approximately 12 percent.

LUREA BATH

4-INCH APPALACHIAN WHITE OAK
KILN DRIED

M 4664 P

(M46861F)

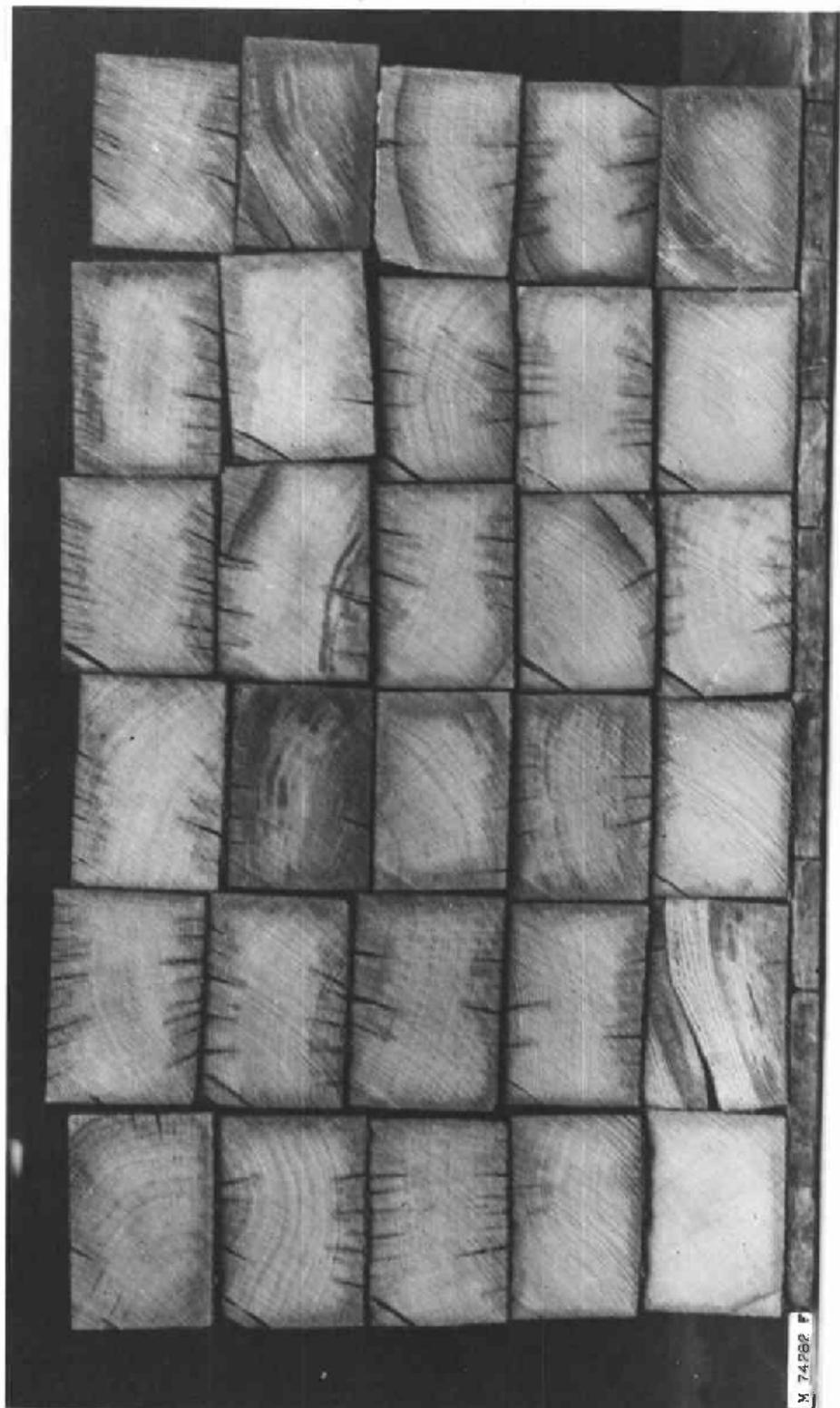
Figure 12.--Buffered urea-aldehyde-treated 4- by 6-inch white oak
after being kiln dried at Madison to a moisture content of
approximately 12 percent.

BUFFERED UREA-ALDEHYDE
DIP
4-INCH APPALACHIAN WHITE OAK
KILN DRIED

N 46861 P

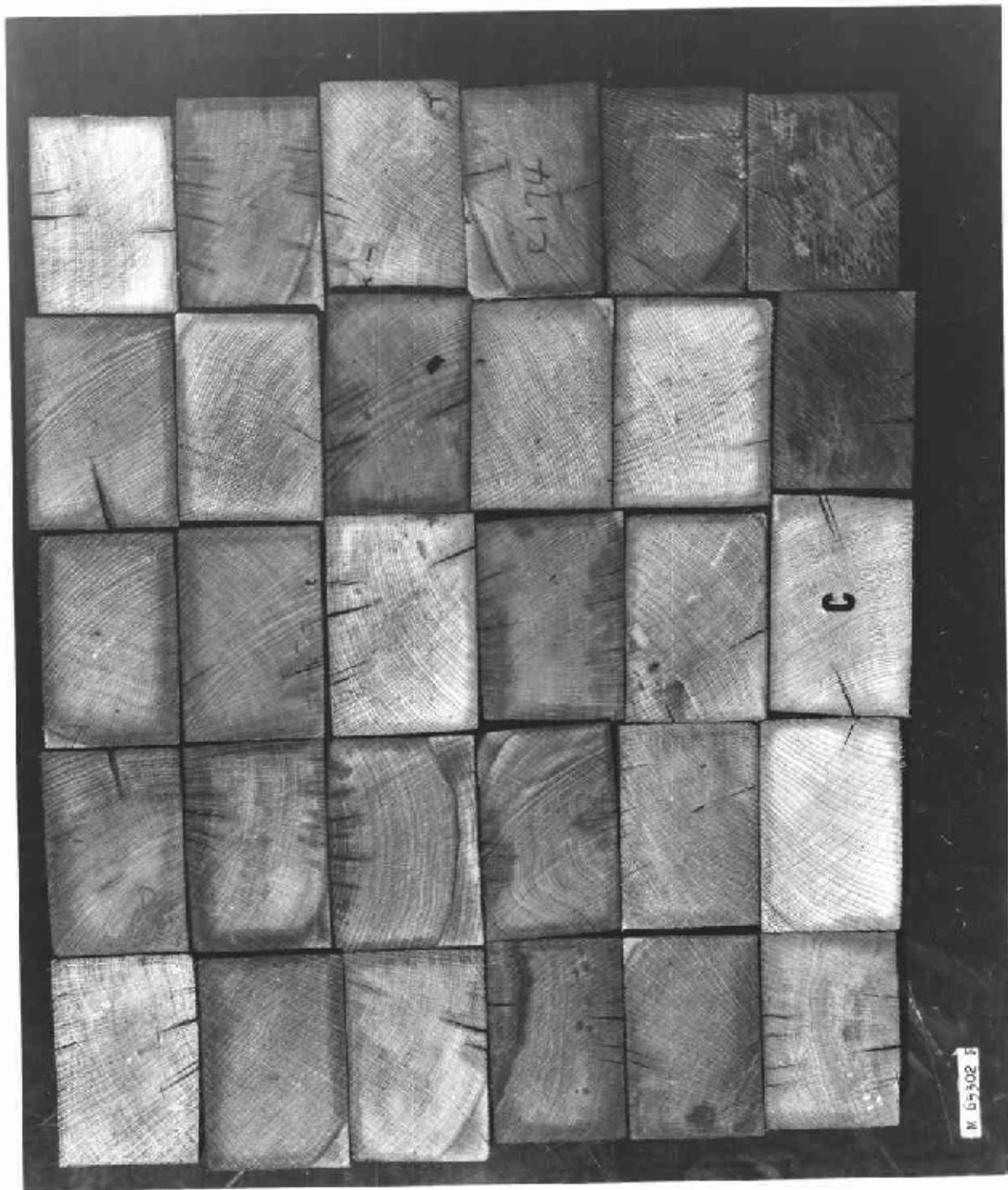
(M74282F)

Figure 13.--Urea-treated 4- by 6-inch white oak after being kiln dried at Marietta, Ohio, to a moisture content of approximately 35 percent.



(M65302F)

Figure 14. -- Buffered urea-aldehyde-treated 4- by 6-inch white oak after being kiln dried at Marietta, Ohio, to a moisture content of approximately 35 percent.



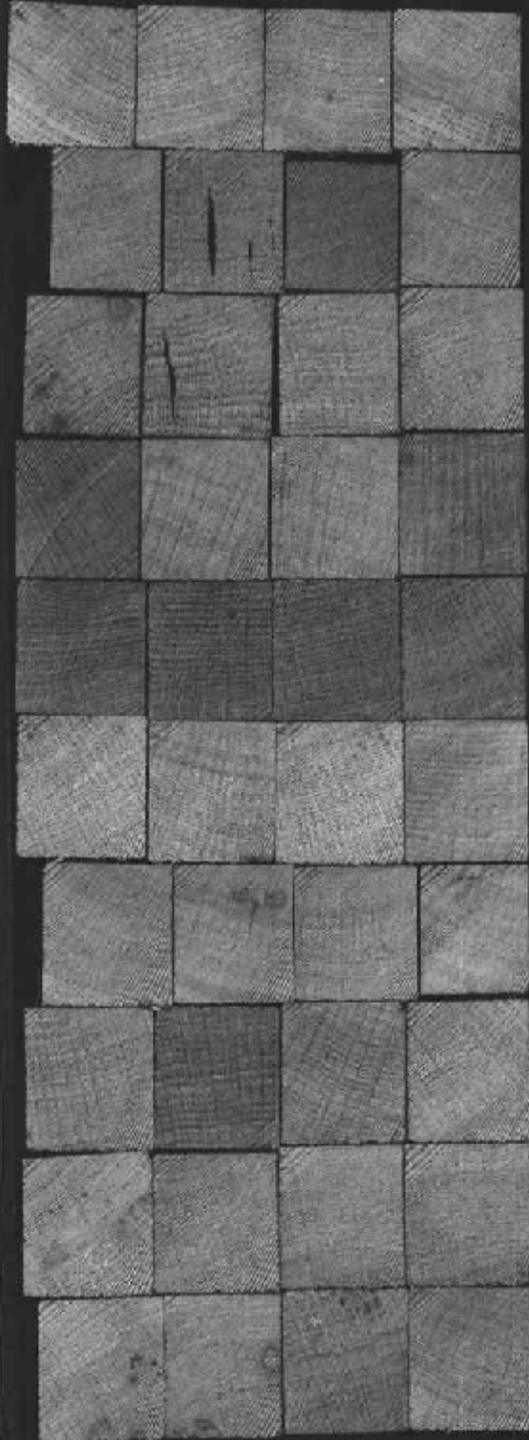
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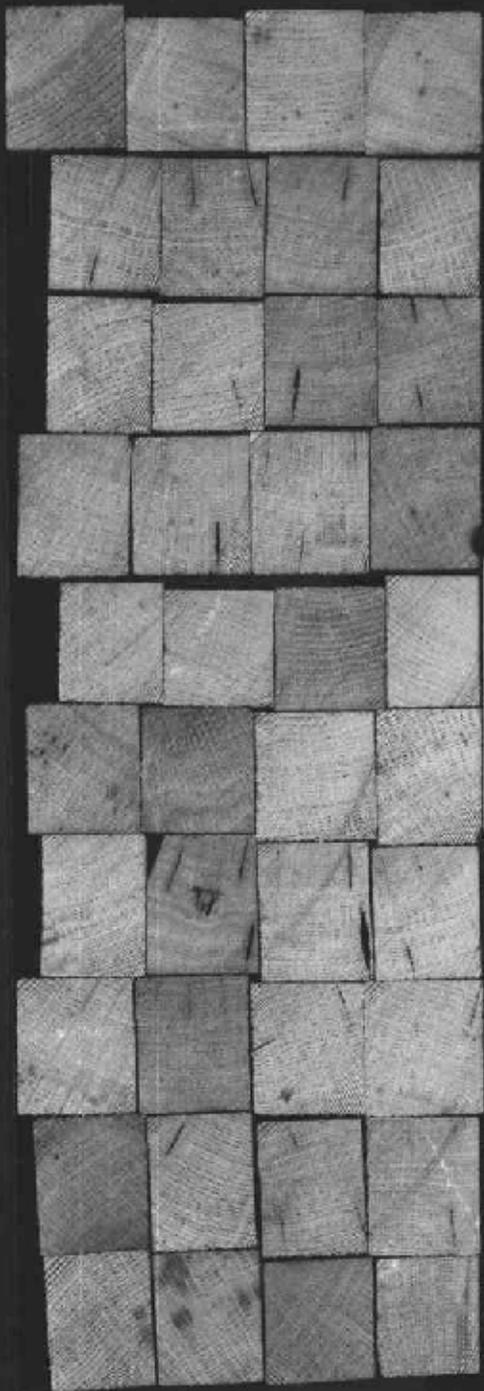
M 55302 F

(M28468F)

Figure 15.--Squares cut from salt-treated and untreated 2- by 8-
inch overcup oak planks after kiln drying for 38 days.



SALT TREATED



UNTREATED CONTROLS

OVERSEED CASE #142 2/10/00
AS 2 2 8 1508

M 26489 F