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MINIMIZING SHRINKING AND SWELLING OF WOOD BY REPLACING THE WATER WITH NONVOLATILE MATERIALS

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The antishrink treatment described in this report is not a "cure-all-ills" process. It is limited in application to dimension stock; it is expensive and has not been sufficiently tested for recommendations regarding its use. It gives antishrink protection exceeding that obtained by direct impregnation over relatively short relative humidity change cycles, but whether the additional protection warrants the additional expense is also as yet unknown. Further experimentation is now being carried on with the hope of finding a cheaper, more generally applicable method. The extremely high adsorptive power of wood for water makes the solution of this problem a difficult one.

MINIMIZING SHRINKING AND SWELLING OF WOOD BY REPLACING THE WATER WITH NONVOLATILE MATERIALS[1]

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Synopsis

When either green or dry wood is impregnated with a water-insoluble oil, or molten wax or resin, the impregnating material merely enters the microscopically visible capillary structure. Water in the fine swollen structure of the cell wall can, however, be replaced by a liquid which is completely miscible with water. This liquid if also a solvent for waxes and resins can be replaced by the latter at temperatures above the melting point. This procedure has been used for getting water-insoluble waxes, oils, and resins into the intimate structure of the cell wall, using cellosolve as the intermediate solvent. Only a partial shrinkage of the wood from the green condition occurs and the subsequent dimension changes with changes in equilibrium relative humidity are materially reduced. The process can thus serve as a combined seasoning and antishrink impregnation treatment for refractory species. Data obtained by the ordinary impregnation method, and data obtained by impregnating dry wood with the waxes and resins dissolved in wood-swelling solvents are given for comparison.

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

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Introduction

Treatments for minimizing moisture content changes and accompanying shrinking and swelling of wood that have been either proposed or successfully applied fall into two classes, (1) moisture-exclusion treatments and (2) moisture-retention treatments. The former class may be further subdivided into coatings and intrafiber treatments. Coating treatments can be still further subdivided into external surface coatings and total surface coatings.

External surface coatings have received the most intensive study. Coatings that show a moisture-excluding effectiveness as high as 98 percent as compared to untreated controls when alternately exposed to relative humidities of 95 to 100 percent for two weeks, 60 percent relative humidity for two weeks, and weather exposure for six weeks for periods of over a year have been developed at the Forest Products Laboratory (1, 2, 3). These consist of coatings of aluminum leaf between coats of other materials such as paints and varnishes. Coatings of varnish, enamel, or paint containing aluminum powder give a moisture-excluding effectiveness of 90 percent and better. Bituminous paints, granular pigment paints, and spar varnish as well as synthetic resin varnishes all show a good moisture-excluding effectiveness (50 to 90 percent) when a number of coats are applied. Although this means of excluding moisture in many cases is very effective, it has the distinct disadvantage of being dependent upon the coating remaining perfectly intact. It is thus unsuitable for use where the wood is subject to considerable mechanical wear and tends to lose its effectiveness under severe weathering conditions. Subsequent cutting and nailing of the wood immediately subjects it to moisture sorption.

It would seem preferable to give the wood a treatment that would coat or fill all of the capillary structure as well as to coat the external surface. Unfortunately, aluminum powder and other granular pigments which form the basis for the best surface-protecting coatings are too coarse to penetrate the fiber cavities because the communicating openings between the fiber cavities range only from about 0.02 to 0.4 microns in diameter (4). Impregnation tests have been made using various oils, waxes, and resins (3). Impregnation of wood with linseed oil, paraffin dissolved in gasoline, molten beeswax, spar varnish and a cellulose varnish under alternate vacuum and pressure treatment gave moisture-excluding efficiencies over a period of 17 days exposure to 95 to 100 percent relative humidities of 0, 40, 47,

55, and 63 percent, respectively (3). When the wood was merely surface coated with the varnishes by applying several brush coatings, better moisture exclusion was obtained than by impregnating with the varnishes. Evidently internal surface coatings are less thoroughly formed than the surface coatings. One perfectly intact thick film seems to be superior to innumerable less complete thin films. The foregoing moisture-excluding efficiencies of impregnated wood are also liable to be considerably less over longer exposure periods. MacLean[2] immersed paraffin-impregnated blocks of wood in water

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[2]MacLean, J. D. Unpublished Forest Products Laboratory report 8-4 M22W (1928).

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and followed their dimension changes and increase in weight with time over a period of more than a year. In all cases the treated specimens swelled as much as the controls but it took 3 to 4 times as long to attain equilibrium.

Some work has also been done on minimizing dimension changes of wood by retaining rather than excluding the moisture. Treatments with sugar solutions (3) and with concentrated salt solutions are of this type. One of the authors has shown (5) that wood impregnated with strong salt solutions does not start to shrink until the prevailing relative humidity is equal to the relative vapor pressure in equilibrium with the salt solution. For example, if a block of wood is impregnated with a solution of magnesium chloride of a concentration that will attain saturation before the wood is dried to the fiber-saturation point, shrinkage will not occur until the equilibrium relative vapor pressure of the system falls below 33 percent. In many localities this may never occur so one might say that this treatment affords complete antishrink protection. This is, however, not the case as at high humidities the block will absorb so much water that it will tend to drip from the surface and carry salt with it. This may continue until virtually all of the salt has been lost. The block then loses its antishrink properties when again dried. This difficulty could be avoided by originally drying the block to a moisture content slightly below that at which shrinkage commences and applying a surface coating that would be pervious to water but not to salt and which would not loosen from the surface under the osmotic action which would result. It is questionable, however, if such a coating material exists. Treating the wood with a less hygroscopic salt, such as sodium chloride, would materially

reduce the dripping tendency at high relative humidities. A sodium chloride treated specimen would, however, start to shrink at 75 percent relative humidity, so that the anti-shrink protection would also be reduced.

When wood is treated with water-soluble materials such as salts and sugar, the solute diffuses into the water in the fine capillary structure of the wood within which swelling takes place, thus giving an intrafiber treatment. A salt solution will, in fact, attain a concentration within the adsorbed water virtually the same as in the bulk water (5). When the water is evaporated the salt will deposit in the cell wall, cutting down the total shrinkage to the oven-dry condition by an amount equal to the volume of salt deposited (5). If a water-insoluble material could be deposited within the cell walls in a similar manner, it would very likely have an appreciable effect upon the subsequent shrinking and swelling and should have none of the inherent disadvantages introduced by using water-soluble materials. Impregnation of either green or dry wood with water-insoluble materials, however, results merely in the penetration of the microscopically visible capillary structure. Water-insoluble materials which do not swell wood themselves can enter the cell walls of wood only by diffusion into a wood-swelling solvent which is adsorbed by the wood, or by the method of replacement in which water is replaced by a series of liquids in succession each of which is completely miscible with the following liquid (6).

Experimental

This paper is an introductory survey of the intrafiber treatment of wood with water-insoluble materials using the replacement and diffusion methods. The effectiveness of retarding the shrinking and swelling of wood obtained with these treating processes is compared with the effectiveness of total surface coatings obtained by direct impregnation.

The treatments were made on small wood blocks of white pine heartwood approximately 9 by 2 by 2 cm. The long dimension was in the tangential direction. A short dimension in the fiber direction was chosen in order to eliminate the factor of penetration. The results thus show maximum effects under complete impregnation conditions. These methods, at least in their present state of development, are not applicable for treating large specimens of refractory species. The effectiveness of reducing the shrinking and swelling of many

forms of dimension stock might very well be considerably less than the values given in this paper, even under the most drastic treatments. End-grain block flooring and other similar forms of small dimension stock, however, fall well within the realm of treating by these methods.

Air-dry wood with a moisture content of 7.5 percent was chosen as the starting material. The swelling of the blocks given in all the following tables are from this condition.

Replacement Process

In order to make the replacement process as simple as possible, it is desirable to use a single intermediate replacing liquid which is completely miscible with water and with the water-insoluble material that is to be deposited within the cell wall. The liquid should also boil above the boiling point of water to facilitate its replacement of water. Cellosolve (ethylene glycol monoethyl ether) was found to be an ideal solvent for this purpose (b.p. 130° to 136° C.) and was hence used for all the replacements given in this paper. It is completely miscible with water at all temperatures and with various waxes, oils, and resins at only reasonably elevated temperatures. Table 1 gives the temperature above which the various impregnating materials used form a solution with cellosolve in any proportions. The effect of adding small amounts of water to solutions of beeswax in cellosolve was determined. Complete miscibility was obtained when 3 percent of water was added to a solution of 5 percent beeswax in cellosolve. Separation into two layers resulted when 5 percent of water was added. The low water tolerance of the system thus makes it imperative that the replacement of water by cellosolve be quite complete.

The blocks were weighed to 0.01 gram and the dimensions determined with a micrometer caliper with an accuracy of from 0.002 to 0.003 cm. The blocks were then soaked in water in a vacuum desiccator, the air being removed from the blocks by alternate evacuation and releasing of the vacuum. This procedure brought the moisture content considerably above the normal green condition. This was done to make the replacement conditions uniform and as severe as would ever be encountered in practice. The blocks were then weighed, measured, and soaked in cellosolve, the volume of cellosolve used being about twice that of the water contained in the blocks. After soaking for about a week the water was distilled off under a vacuum of about 60 cm. of mercury (temperature 40° to 45° C.).

Table 1.--Temperatures above which the impregnating materials are soluble in cellosolve in all proportions

Material	Approximate melting point	Temperature of complete miscibility
	° C.	° C.
Spermaceti	43	50
Paraffin	57	87
Beeswax	68	70
Stearin	58	58
Stearic acid	58	60
Halowax	90	90
Rosin	85	95
Linseed oil	.....	120
Tung oil	.....	120

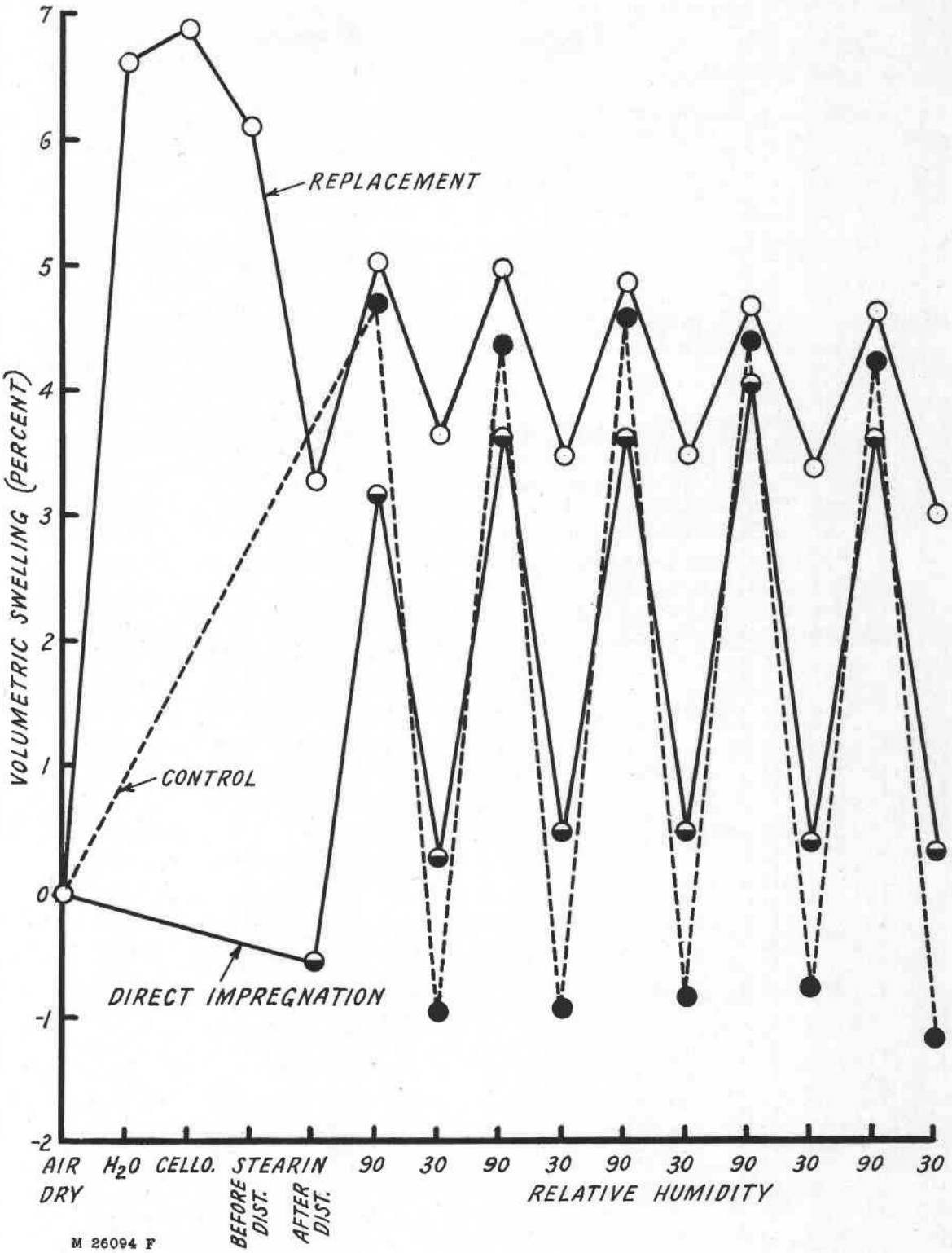
[1]Soluble at room temperature, minimum point of complete miscibility not determined.

The distillation was carried out in a number of steps, each a day apart, in order to insure complete outward diffusion of water and inward diffusion of cellosolve. About 20 to 30 percent of the total volume was distilled off each time and an equal volume of fresh cellosolve added. The water content of each of the succeeding distillates for a batch distilled eight times was 58, 41, 19, 5, 1.6, 1.3, 1.0, and 0.4 percent as determined from the refractive index. After the last distillation two of the blocks were dry distilled on a steam bath and the water content of the total distillate determined. On the basis of the dry weight of the wood it was approximately 0.2 percent. The possibility of a small amount of volatile extractive material in the wood distilling over with the cellosolve and water made this determination of the residual water by refractive index a little uncertain. For this reason a similar replacement of the water in cotton linters alpha cellulose by cellosolve was made. The residual water in this case was found to be less than 0.1 percent. Virtually all the free and adsorbed water in wood can thus be replaced by cellosolve. This replacement was made without any shrinkage occurring; in fact, there was a slight increase in dimensions resulting from soaking of the water-swollen blocks in cellosolve. Although a slight shrinkage accompanied the removal of water, the dimensions in the dry cellosolve in general remained slightly greater than the original water-soaked dimensions (fig. 1).

Subsequent replacements of the water with cellosolve in blocks at a moisture content just below the fiber-saturation point of the wood (average moisture content 25.1 percent) were carried out by heating the blocks in cellosolve to 70° C. under a vacuum which just caused continuous distillation. The total distillate obtained in 24 hours contained 20 percent water, and the blocks still retained 3 percent of water as determined from the dry distillation of the blocks. The total distillate obtained in 48 hours under the same conditions contained 6.8 percent water and the blocks but 0.25 percent water. It is thus possible to replace the water with cellosolve much faster than the replacements used in the regular measurements if the initial moisture content of the wood is at the fiber-saturation point or less. Continuous distillation and the use of higher temperatures and less vacuum are also advantageous.

Preliminary measurements made by R. C. Rounds at the Forest Products Laboratory indicated that the replacement of a water-soluble intermediate replacing agent by a

Figure 1.--Volumetric swelling of white pine blocks from the air-dry condition to different stages of the replacement and direct impregnation processes with stearin and after a series of alternate 2-week exposures to 90 and 30 percent relative humidities together with the corresponding values for the control.


7
6
5
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-1
-2
VOLUMETRIC SWELLING (PERCENT)
REPLACEMENT
CONTROL
DIRECT IMPREGNATION
AIR DRY
H2O
CELLO.
STEARIN
BEFORE DIST.
AFTER DIST.
90
30
90
30
90
30
90
30
90
30
RELATIVE HUMIDITY

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nonpolar liquid cannot be made so efficiently from the standpoint of constancy of dimensions as the original replacement (table 2). These replacements, with the exception of the acetone-toluene replacement, were made in a continuous distillation-extraction apparatus in which the blocks were kept continuously submerged in the distillate. This was necessary as the replacing liquids boil at lower temperatures than the liquids replaced. The last value given for the percentage retention of the swelling in water was determined under the most drastic replacement conditions and is perhaps a more representative value than the others. In all cases the values are practically constant for the replacement with the different nonpolar liquids, using various replacing agents. Although all the water held below the fiber-saturation point (29 percent for the white pine) can be replaced by water-soluble intermediate replacing agents without accompanying shrinkage, about 19 percent of the replacing agent corresponding to a moisture content of the wood of 5.5 percent cannot be replaced by a nonpolar liquid, although it can be removed in the presence of the nonpolar liquid with accompanying shrinkage. It is interesting that this moisture content corresponds closely with the moisture content at the inflection point in the moisture content-relative vapor pressure curve which, in turn, is believed to correspond to the initial surface-bound monomolecular layer of water (7). This surface-bound water can apparently be replaced by swelling agents which have an affinity for the wood but not by nonpolar liquids which themselves show no affinity for wood and cause no swelling.

After replacing the water with cellosolve the regular test blocks were placed in oils, molten waxes, and molten resins and held at temperatures slightly in excess of those given in table 1 for more than a week to allow the outward diffusion of cellosolve and the inward diffusion of the treating material to take place. The cellosolve was then distilled off under a reduced pressure at these temperatures in the presence of an excess of wax. A number of distillations several days apart were made to insure complete removal of the cellosolve. In all of these distillations only cellosolve distilled over so that each distillation was continued until no more visible condensate could be collected. The blocks were then weighed and measured and placed in a 90 percent relative humidity room at 80° F. All of the determinations were made in duplicate. One block was kept in the 90 percent relative humidity room for 20 weeks and the other for 2 weeks. The latter were next placed in a 30 percent relative humidity room at 80° F.

Table 2.--Retention of the external volumetric dimension-change swelling of white pine in water resulting from the replacement of the water with nonpolar liquids

Replacing material	Intermediate replacing materials	Retention of swelling in water resulting from the replacement
		Percent
Toluene	Alcohol-acetone	83.9
		84.8
		83.0
		84.8
Petroleum ether (boiling point 20°-40° C.)	Cellosolve	83.5
		84.5
		81.3
Benzene	Diacetone alcohol	85.0
		81.3
Do	Cellosolve	85.5
		86.3
		85.7
		[1]80.8

[1] All but this value were taken from the preliminary study made by R. C. Rounds at the Forest Products Laboratory. In the case of the last value, the authors carried on the extraction for three weeks. The residual cellosolve was less than 0.5 percent as determined from the refractive index and from dichromate oxidation tests.

for 2 weeks and then returned to the 90 percent relative humidity room. These blocks were put through five complete cycles after which they were placed in the 90 percent relative humidity room for 6 to 8 weeks. The blocks that were held for 20 weeks in the 90 percent room were then placed in the 30 percent relative humidity room for 6 to 8 weeks. The dimensions of each block were determined every 2 weeks for the first 20 weeks and then again at the completion of the humidity tests. The retardations of the shrinking and swelling occurring between 30 and 90 percent relative humidity referred to the control (volume change of control minus the volume change of the treated block divided by the volume change of the control) are given in table 3 for the average of four 4-week relative humidity change cycles. The first 4-week cycle gave somewhat erratic results for some of the specimens, presumably because all the cellosolve had not been previously completely removed. For this reason the averages for cycles numbers 2 through 5 are given. Similar values for the percentage retardation of the shrinking and swelling are given for a long cycle (20 weeks at 90 percent relative humidity and 6 to 8 weeks at 30 percent relative humidity).

The volumetric swelling of blocks of white pine from the air-dry condition to different stages of the process of replacing the water with stearin are shown diagrammatically in figure 1 together with the swelling occurring at each step in the subsequent 2-week exposures to 90 and 30 percent relative humidity. Corresponding data for the control and for direct impregnation with stearin are given for comparison.

Data are given in table 4 for the retardation of the shrinking and swelling of wood under various drastic replacement conditions. The values for no distillations are for cellosolve replaced blocks soaked in molten oils and waxes for a week. Subsequent values are for blocks from which cellosolve was removed by different numbers of distillations 2 days apart.

Direct Impregnation

Air-dry blocks were also impregnated directly with the oils, molten waxes, and molten resins by immersing them in the liquid at about 85° C. and alternately pulling a vacuum and releasing until air bubbles no longer appeared. These were put through the same relative humidity cycles as

Table 3.--Retardation of the shrinking and swelling of white pine due to treatment with waxes and oils for relative humidity changes between 30 and 90 percent

Treating material	Replacement method				Direct impregnation method		
	Retention of water swelling after replacement	Weight of wax or oil in wood per unit weight of wood	Retardation of shrinking and swelling		Weight of wax or oil in wood per unit weight of wood	Retardation of shrinking and swelling	
			Average of 4 short cycles	Long cycle		Average of 4 short cycles	Long cycle
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Percent		Percent	Percent		Percent	Percent
Untreated control			0.0	0.0			
Cellosolve only	102.0	2.11	- 1.3	.3			
Paraffin	28.5	1.42	+ 35.3	18.6	1.42	35.1	24.1
Spermaceti	38.8	1.58	+ 38.1	18.5			
Beeswax	47.9	1.60	+ 78.7	45.1	1.55	47.0	29.0
Stearin	64.8	1.79	+ 72.0	49.8	1.72	38.6	26.6
Stearic acid	66.1	1.69	+ 37.1	33.5	1.52		25.0
Halowax	63.9	3.14	+ 47.2		2.81	23.7	20.3
Rosin	86.1	2.31	+ 73.3				
Linseed oil	59.3	2.04	+ 45.8	33.0	1.77	27.6	23.5
Linseed oil (heated)	50.7	1.52	+ 24.6				
Tung oil	68.0	2.06	+ 32.3	21.6	1.74	25.9	20.9
Tung oil (heated)	53.5	1.42	+ 21.6				
75% Linseed oil, 25% rosin	75.4	2.12	+ 53.2	47.4	1.78	29.1	24.8
Linseed oil and beeswax	69.2	1.98	+ 65.5				
Linseed oil and stearic acid	64.6	1.93	+ 42.5				
Diglycol oleate	78.2	2.10	+ 40.9				
Glyceryl monoricinoleate	89.5	2.28	+ 78.7				

Table 4.--Effect of completeness of replacement of cellosolve by waxes and oils upon the retardation of the shrinking and swelling occurring during 4-week cycles between 30 and 90 percent relative humidity

Treating material	Number of distillations	Weight of wax or oil in wood per unit weight of wood	Retardation of shrinking and swelling
			Percent
Beeswax	0	1.25	10.8
Do	1	1.47	29.2
Do	2	1.61	42.4
Do	9	1.60	78.7
Linseed oil	0	1.41	9.7
Do	1	1.53	18.7
Do	2	1.76	25.9
Do	4	2.04	45.8
75% Linseed oil, 25% rosin	0	1.46	27.4
Do	1	1.69	41.5
Do	2	1.85	53.8
Do	4	2.12	53.2

the blocks impregnated by replacement. The retardations of shrinking and swelling resulting from these treatments are given in table 3 on the same basis as for the replacement treatments.

Diffusion Process

Oven-dry blocks were also impregnated with solutions of the oils, waxes, and resins, dissolved in wood-swelling solvents, cellosolve, methyl alcohol, and acetone. The impregnation was carried on in a similar manner to the direct impregnation with molten waxes and resins except that lower temperatures were maintained. The blocks were heated in the impregnating solutions for 4 to 5 days at temperatures slightly below the boiling point to promote diffusion of the solute into the cell walls. The volumetric swelling of wood in the dry solvents relative to its swelling in water are cellosolve 85 percent, methyl alcohol 94 percent, and acetone 63 percent. The treated blocks were dried in a vacuum oven at 45° C. after which they were subjected to similar relative humidity change cycles to those used for testing the antishrink efficiencies of the other treated blocks. The results are given in table 5 for the retardation of the shrinking and swelling obtained during one 4-week cycle.

Discussion and Conclusions

It is evident from table 2 and column 2 of table 3 that the maximum efficiencies of replacement of water with a water-insoluble material from the standpoint of retention of the water-swollen dimensions of wood is about 80 percent. The value given for rosin is higher than 80 percent but this is undoubtedly due to the fact that the residual cellosolve was not completely removed in the molten rosin. Excessive frothing of the rosin made it practically impossible to remove the last traces of cellosolve. The relatively high hygroscopicity of glyceryl monoricinoleate indicating its polar nature accounts for the more complete replacement in this case.

Replacement of water with cellosolve alone shows no change in the subsequent equilibrium swelling and shrinking (table 3). The replacement of the cellosolve with waxes, oil, or resins does, however, decrease the subsequent

dimension changes. The best results were obtained with beeswax, stearin, rosin, and linseed oil and rosin, and linseed oil and beeswax. Rosin alone is not satisfactory, however, as it caused rather severe checking of the wood.

The efficiencies of the treatments on a weight change basis, in general, paralleled those on a volume change basis. Treatments with hygroscopic materials such as the diglycol oleate and glyceryl monoricinoleate, however, gave negative efficiencies on a weight change basis. The antishrink effect of such materials is evidently similar in mechanism to the antishrink effect obtained with inorganic salts, the water being retained rather than being excluded.

The efficiencies obtained by direct impregnation with the molten waxes, oils, and resins are less than those obtained by the replacement method with the exception of paraffin in which case the efficiencies are practically the same. In the replacement with paraffin very little paraffin entered the cell wall of the wood as indicated by the low retention of water swelling (see column 2, table 3). This will account for the fact that the replacement method had no advantage over the direct impregnation method when treating with paraffin.

In all cases the efficiencies for retarding the shrinking and swelling of the treated wood decrease with an increase in the time of exposure to each of the relative humidities. (Column 4 versus 5 and column 7 versus 8, table 3.) This indicates that the retardation of shrinking and swelling is largely a matter of decreasing the rate of sorption of water rather than a shift in the true equilibrium.

Increasing the efficiency of the cellosolve replacement with waxes, oils, and resins materially increases the retardation of the dimension changes as is shown in table 4. These data, together with the diffusion data given in table 5, indicate that it is not enough to get some of the treating material into the cell wall, but that the whole structure should be filled to obtain high efficiencies. Fairly good efficiencies are obtained, however, by the simple diffusion process with beeswax and combinations of beeswax with other materials when 50 percent solutions are used. The use of a more volatile solvent than cellosolve is desirable in this process but, unfortunately, most of the highly volatile swelling solvents are poor solvents for the natural waxes, oils, and resins.

Table 5.--Effect of impregnating blocks with solutions of waxes and oils dissolved in wood-swelling solvents upon the subsequent shrinking and swelling occurring during a 4-week cycle between 30 and 90 percent relative humidity

Solvent	Treating material	Concentration by weight	Weight of wax or oil in wood per unit weight of wood	Retardation of shrinking and swelling
		Percent		Percent
Cellosolve	Paraffin	25	0.43	2.7
Do	do	50	.88	9.5
Do	Beeswax	25	.51	11.8
Do	do	50	.97	26.5
Do	Stearin	25	.51	15.1
Do	do	50	1.00	13.5
Do	Rosin	25	.52	[1]12.0
Do	do	50	1.09	[1] 8.6
Do	Paraffin 60%, stearin 40%	25	.44	10.8
Do	do	50	.94	15.6
Do	Paraffin 60%, beeswax 40%	25	.43	9.3
Do	do	50	.87	28.2
Do	Rosin 75%, beeswax 25%	25	.48	18.1
Do	do	50	1.08	34.4
Do	Linseed oil 50%, rosin 25%, beeswax 25%	25	.44	15.2
Do	do	50	.96	38.0
Acetone	Linseed oil 75%, rosin 25%	25	.59	12.2
Do	do	50	1.36	15.1
Methyl alcohol	Rosin 85%, pine oil 15%	25	.60	9.7
Do	do	50	1.28	13.5
Do	Rosin 80%, triethanolamine 20%	25	.63	3.7
Do	do	50	1.18	28.6

[1] Blocks appreciably checked.

If more highly moisture-resisting materials could be found that would dissolve in wood-swelling solvents, the amount that would have to be put into the wood to give good efficiencies might be materially reduced. Such a material is now being sought.

The replacement process not only materially decreases the dimension changes but it also causes a retention of more nearly the green dimensions of wood than any other treatment (fig. 1). The replacement process is thus of as great if not greater value in cutting down the degrade of wood due to the shrinkage occurring on initial seasoning as it is in maintaining uniform dimensions.

The replacement process as here described is unquestionably too expensive for general use. It should, however, be of value in seasoning and retaining the dimensions of small expensive articles made from refractory woods. In the case of woods, the seasoning degrade of which is small, the dry wood can be impregnated with a nonaqueous wood-swelling solvent and the replacement carried on from this stage, thus avoiding the expense of replacing the water with cellosolve. The simple process depending merely upon the diffusion of the solute from a wood-swelling solvent into the cell wall is not as yet in a state for recommendation. Because of its simplicity, further studies along this line are being made. Impregnations with synthetic resins under various conditions are also being studied and will form the material for another paper.

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