WOOD AND FIBER SCIENCE

JOURNAL OF THE SOCIETY OF WOOD SCIENCE AND TECHNOLOGY

VOLUME 19 JANUARY 1987 NUMBER 1

EFFECTS OF CREOSOTE AND CCA ON MOISTURE MOVEMENT IN SOUTHERN PINE AND RED OAK[1]

Carole A. Hornicsar

Former Research Assistant

Paul R. Blankenhorn

Professor of Wood Technology
School of Forest Resources, The Pennsylvania State University
University Park, PA 16802

and

David A. Webb

Technical Director
Coal and Wood Based Products, Creosote Koppers Company, Inc.
440 College Park Drive, Monroeville, PA 15146

(Received December 1984)

ABSTRACT

A vapocup apparatus was used to determine rates of moisture movement and water-vapor permeability values for CCA- and creosote-treated red oak and southern pine. The average loading for CCA-treated specimens was 6.4 kg/m^3 (0.4 lb/ft^3) and the average loading for creosote-treated specimens was 168.2 kg/m^3 (10.5 lb/ft^3). Specimens were subjected to three different relative humidity conditions: 50%, 75%, and 90%. The rates of mass transfer increased exponentially with increasing relative humidity. The rate of moisture movement was greater for southern pine than for red oak, and greater for CCA-treated specimens than for creosote-treated specimens. The water-vapor permeability values were calculated and the values increased exponentially as relative humidity increased. For both species, CCA-treated specimens had the highest water-vapor permeability values and creosote-treated specimens the lowest.

Keywords: Southern pine, red oak, permeability, moisture movement.

INTRODUCTION

Moisture movement through wood has received considerable attention over the years. Most of the research has centered around wood drying and understanding water vapor movement under steady-state conditions below the fiber satu-

[1] This research was supported in part by funds from McIntire-Stennis Project 2606 and Koppers Company, Inc. This is Paper No. 7047 in the Journal Series of the Pennsylvania Agricultural Experiment Station and was authorized for publication on 26 October 1984.

Wood and Fiber Science, 19(1), 1987, pp. 1-8

ration point of wood and the boiling point of water. Research has been reported on water vapor and bound water moisture movement through wood (Christensen 1960; Skaar 1954, 1958; Stamm 1947, 1960b; Siau 1984), effects of wood properties on moisture movement (Stamm 1950; 1960a; Siau 1984), and effects of moisture movement on the wood properties (Bendtsen 1966; Hart 1970; Kumar and Jain 1978; Siau 1984). Various methods have been developed for determining moisture movement in wood (Skaar 1954, 1958; Stamm 1960a, b; Siau 1984).

Restricted moisture flow tends to enhance dimensional stability of wood, and low moisture contents retard the activities of wood-destroying organisms. Wood properly treated with preservatives is highly resistant to wood-destroying organisms. However, moisture flow in preservative-treated wood may promote the possibility of the preservatives leaching or migrating from the wood and provide a more hospitable environment for fungi, bacteria, or insects. Moisture movement also causes dimensional changes and influences weathering processes. For these reasons, it is important to investigate moisture movement in preservative-treated wood.

The purposes of this study were to determine the steady-state rate of moisture movement and calculate the water-vapor permeability values for chromated-copper-arsenate (CCA) and creosote-treated wood. Specimens were subjected to relative humidity and moisture content conditions similar to those found in actual use. Flow was limited to the transverse direction, and water-vapor permeability values were calculated for the transverse direction. Comparisons between preservative-treated and nontreated specimens at three relative humidity conditions were analyzed.

EXPERIMENTAL PROCEDURE

This experiment was designed to measure the rate of moisture movement in the transverse direction in two species treated with commercial wood preservatives. Red oak (*Quercus* spp.) and southern pine (*Pinus* spp.) were chosen because of their wide usage and importance to the forest products preservative industry. Similarly, creosote (AWPA, P1) and chromated-copper-arsenate (CCA) were chosen as commonly used preservatives. To assist in evaluating the results from the preservative-treated specimens, control groups of untreated red oak and southern pine from the same boards were also examined. Specimens (108 total) from each species were divided into three groups (36—control, 36—CCA, and 36—creosote) and each group was subjected to three relative humidity environments (12 at 50% RH, 12 at 75% RH, and 12 at 90% RH).

Defect-free, straight-grained red oak and southern pine logs were radially sawn, and the resulting lumber was planed to 0.33 cm in thickness. Circular specimens 6.2 cm in diameter were machined from this stock. The oven-dry weight of each specimen was determined, and the specimens were conditioned prior to treatment with CCA and creosote with a full cell process. The retention of preservative in the treated discs was determined by weighing each specimen before and immediately after preservative treatment. The average loading of CCA and creosote was 6.4 kg/m^3 (0.4 lb/ft^3) and 168.2 kg/m^3 (10.5 lb/ft^3), respectively (Hornicsar 1983).

Discs were then prepared for exposure to various relative humidity conditions. To prevent moisture movement through the end grain, the edge, containing the end grain, of each disc was coated with epoxy resin before being attached to the vapocup apparatus (Siau 1984) with a bead of silicon sealant.

The apparatus was designed to create a moisture gradient through the disc by exposing one side to a higher relative humidity than the other side. These conditions caused moisture to move through the disc, primarily in the tangential direction, from highest to lowest moisture concentration. Three sets of relative humidity conditions were chosen to simulate conditions that might be found in actual use. Saturated salt solutions were used to produce relative humidities inside the jars of 50%, 75%, and 90%. The salts selected, described in ASTM D104-51, were sodium dichromate, ammonium hydroxide, and sodium chloride. The relative humidity outside the jar was controlled by placing the apparatus in a controlled environmental chamber. The dry bulb temperature was maintained at an average of 21.7 ± 2 C and the wet bulb temperature at 11.7 ± 2 C, resulting in an average relative humidity of 15% (Hornicsar 1983).

The moisture gradient created across the specimens caused water vapor to move from the inside to the outside of the jar, resulting in a continual mass loss. The rate of moisture movement was determined by weighing each specimen apparatus at convenient intervals until the rate of mass loss remained constant over a two-week period (measured each week). The specimens were then assumed to be in the steady-state condition.

After the steady-state rate of moisture movement was determined, the discs were removed from the jars. The thickness and diameter of each specimen were measured. The end coating was cut from each disc, and they were weighed to determine the steady-state weight. The volume of each disc was determined using a water displacement method described in ASTM D2395-77. In order to determine the dry weight, the control and CCA-treated specimens were oven-dried at 105 C for 24 hours. The creosote-treated discs could not be oven-dried in the usual manner because some of the creosote will vaporize at elevated temperatures. Hence, they were placed in a vacuum oven at 58 C for 72 hours. These dry weight values were used to compute the average moisture content of each disc.

The water-vapor permeability values (Kp) for each specimen were determined by using $Kp = \frac{ml}{tA\Delta P}$ (Siau 1984).

where

m = mass transfer at steady state (g)
l = thickness (cm)
t = time (sec)
A = effective area (cm^2) and
ΔP = vapor pressure differential which equals the change in relative humidity (ΔRH) times saturated vapor pressure of water (Po) at 21.7 C divided by 100.

Equilibrium moisture content values were also determined for the relative humidity conditions. Pieces from randomly selected discs were weighed and placed in desiccators partially filled with the appropriate saturated salt solution with saturated relative humidities of 50%, 75%, and 90%. Small specimens were also

TABLE 1. *Average equilibrium moisture contents at selected relative humidity conditions for red oak and southern pine controls, CCA-treated and creosote-treated specimens.*

Species	RH (%)	Expected EMC[1] (%)	Actual EMC (%)		
			Control	CCA	Creosote
Southern pine	25	5.5	3.9	3.8	3.4
	50	9.2	9.8	9.4	6.7
	75	14.2	13.4	13.7	10.3
	90	20.6	21.7	21.7	18.3
Red oak	25	5.5	3.7	3.8	3.3
	50	9.2	9.8	9.3	6.6
	75	14.2	13.7	13.6	10.0
	90	20.6	21.5	21.5	18.0

[1] United States Forest Products Laboratory. 1974. Wood Handbook: Wood as an Engineering Material. U.S.D.A. Forest Service, Agriculture Handbook No. 72. 415 pp.

exposed to 25% relative humidity conditions by placing them in an environmentally controlled chamber. The specimens were weighed periodically until equilibrium was attained and the equilibrium moisture contents (EMC) were determined.

Statistical evaluation of steady-state rate of moisture movement and water-vapor permeability values used analysis of variance procedures outlined in the Statistical Analysis System User's Guide (11). The level of significance for all tests was 0.05. Use of the general linear models procedure compensated for the unequal sample sizes encountered in the analysis of the water-vapor permeability values.

RESULTS AND DISCUSSION

The equilibrium moisture contents (EMC) for the treated specimens (Table 1) were obtained after the specimens were used in the experiment and oven-dried. The oven-dry weights used to calculate the equilibrium moisture content values for the CCA and creosote specimens included the oven-dried weight of the wood substance and the weight of the preservative. The southern pine and red oak control specimens had EMC values (Table 1) that compared well with expected EMC values.

The CCA-treated specimens had EMC values for the southern pine and red oak specimens that were very similar to the control and expected EMC values. However, the actual amount of moisture in the CCA-treated specimens was probably higher than the control specimens because the weight of the CCA was included with the oven-dry weight of the wood substance in the calculation of the equilibrium moisture content values.

The southern pine and red oak creosote-treated specimens had lower EMC values than the control, CCA, and expected EMC values. Since the weight of the creosote was included with the oven-dry weight of the wood substance, the actual amount of moisture in the creosote-treated specimens was probably lower than the amount of moisture in the control and CCA-treated specimens.

For all treatments the rate of moisture movement increased exponentially as the relative humidity increased (Table 2). As relative humidity increased on the inside surface of the specimens, the moisture concentration gradient and water-vapor permeability values increased, resulting in an increase in the moisture movement.

For southern pine control, CCA, and creosote specimens, the rate of moisture

TABLE 2. *Summary of the average steady state rate of moisture movement data and water-vapor permeability values.*

Species	Treatment	RH (%)	Number of samples	Average MC at steady state (%)	Average steady state rate of moisture movement (10^{-6} g/sec)	Average water-vapor permeability (10^{-9} g cm/cm^{2}sec mmHg)
Southern pine	Control	50	12	7.25	0.63	1.02
		75	11	10.06	1.46	1.38
		90	10	11.72	3.21	2.44
	CCA	50	11	8.29	0.78	1.26
		75	12	10.47	1.93	1.83
		90	12	12.72	3.47	2.63
	Creosote	50	5	3.95	0.21	0.34
		75	11	5.57	0.67	0.63
		90	12	9.31	1.75	1.34
Red oak	Control	50	10	6.98	0.42	0.68
		75	12	9.33	1.15	1.09
		90	12	11.52	1.98	1.50
	CCA	50	9	8.46	0.92	1.49
		75	12	9.48	1.72	1.63
		90	12	12.08	3.25	2.47
	Creosote	50	12	5.82	0.15	0.24
		75	10	7.06	0.45	0.43
		90	10	8.02	1.32	1.00

movement increased as relative humidity increased. The difference in rate of moisture movement between 50% and 75% relative humidity was lower than the difference between 75% and 90% in all cases. However, the total amount of change in rate of moisture movement over 50% to 90% relative humidity was largest in CCA specimens, followed by controls and creosote-treated specimens.

The type of preservative treatment for the southern pine specimens also affected the rate of moisture movement. As expected, the CCA-treated specimens had the highest rate of moisture movement, controls had the next highest, and creosote-treated specimens the lowest rate of moisture movement. These differences in rate of moisture movement were due primarily to the nature of the preservative used. The hygroscopic nature of CCA tended to increase the average moisture content of the specimens, thereby increasing the ease of moisture movement (Table 2). The hydrophobic nature of creosote tended to repel water, lower the average moisture content through the sample, and decrease the rate of moisture movement.

The trends in the red oak specimens were similar to those in the southern pine specimens. Among the red oak specimens, CCA-treated specimens had the highest total rate of moisture movement, controls the next highest, and creosote-treated specimens the lowest. The difference between preservative treatments changed as relative humidity changed. The difference in rate of moisture movement between CCA and creosote and CCA and controls increased as relative humidity increased. These increases were larger than the differences in the moisture movement rates between southern pine CCA and creosote and CCA and control groups.

As expected, the rate of mass transfer increased exponentially with increasing relative humidity in all cases. This was primarily because increased relative humidity increases both moisture content and moisture gradient through the specimen. This result was similar to results reported in other studies (Stamm 1947, 1960a).

The CCA-treated specimens (Table 2) exhibited the highest rates of mass transfer. Studies have shown that water-soluble salts in wood tend to increase the equilibrium moisture content of the specimen because of the hygroscopic nature of the salt (Bendtsen 1966; Kumar and Jain 1978). This increased moisture content resulted in an increased rate of moisture movement. Similarly the hydrophobic nature of creosote tended to decrease the ability of water to move through the wood specimen. Although the rate of mass transfer through creosote-treated wood was easy to obtain, the average moisture content presented some difficulty. The fact that creosote vaporized at very low temperatures made accurate oven-dry weights very difficult to obtain.

A comparison of the data in Table 2 indicated that in most cases the southern pine specimens had greater rates of moisture movement than red oak specimens. This difference may have been associated with the increased density of red oak compared to southern pine. For control specimens, southern pine had a greater rate of moisture movement than red oak at all relative humidities. For CCA-treated specimens at 50% relative humidity, red oak had a greater rate of moisture movement than southern pine. The rate of moisture movement for all other southern pine CCA-treated specimens exceeded that of red oak. Southern pine creosote-treated specimens had a rate of moisture movement that exceeded red oak at all relative humidities. CCA treatment increased the total rate of moisture movement from 50% to 90% RH in red oak similarly to that of southern pine. This was an indication of the influence that CCA had on moisture movement in wood species of different densities.

Water-vapor permeability values (Table 2) for southern pine and red oak followed trends similar to those for the rate of moisture movement. The differences between preservative treatments were also similar, with CCA-treated specimens having the highest permeability values and creosote-treated specimens the lowest. A comparison of permeability values between species showed similar relationships as the rate of moisture movement comparisons.

The data in Table 2 indicate that as relative humidity increased, the water-vapor permeability values increased exponentially. For all species and treatments, the increase in relative humidity from 50% to 75% is lower than the increase from 75% to 90%. This is similar to the rate of moisture movement results. The preservative treatment also influences the total increase in the permeability values with the CCA-treated specimens having a higher total increase than the creosote-treated specimens.

The direction of flux was a potential source of error. In this study, mass transfer was primarily in the tangential and radial directions. Since water can move about one hundred times more readily in the longitudinal direction than the transverse direction, small grain angles may have resulted in large changes in the measured rate of moisture movement (Siau 1984). Direction of flux may have affected the distance moisture moves. Although moisture was assumed to move directly through the specimen, perpendicular to the surface, some of the moisture may actually have been moving in a diagonal pathway through the disc. Thus, even though net moisture movement was across the grain, some moisture flow may be in the longitudinal direction.

Serviceability of wood depends on many factors including environmental effects such as moisture sorption. For both species, the CCA-treated specimens had the highest rates of moisture movement and average moisture contents compared to the control and creosote-treated specimens. The average moisture content values were lower than normal because the calculations were based on oven-dry weight plus the weight of the preservative in the specimen instead of only the oven-dry wood weight. This implies that under the same environmental conditions more moisture will be sorbed by the CCA-treated wood. This additional moisture will affect the mechanical and physical properties of the CCA-treated wood compared with controls and creosote-treated wood.

SUMMARY

The vapocup method was used to determine rates of mass movement in the transverse direction and to calculate water-vapor permeability values for CCA- and creosote-treated red oak and southern pine. Groups of specimens were subjected to three different sets of relative humidity conditions—50%, 75%, and 90%. Rates of mass transfer or moisture movement were determined.

The rates of mass transfer were found to increase exponentially with increased relative humidity. This was due to an increased moisture gradient across the specimen and to an increased average moisture content of the specimen. In most instances, the rates of moisture movement were greater for southern pine than for red oak under the same conditions. This result is associated with the increased density of the red oak. CCA-treated specimens had the highest rates of mass transfer, and creosote-treated specimens the lowest.

The water-vapor permeability values were calculated, and these values increased exponentially as relative humidity increased. For each species, CCA had the highest water-vapor permeability values while creosote had the lowest. The relationships between species were similar to the moisture movement data analysis. In most relative humidity conditions, southern pine had higher permeability values than red oak. For CCA-treated specimens, red oak permeability was greater than southern pine at 50% relative humidity, while southern pine permeability values were greater than red oak at 75% and 90% relative humidities.

REFERENCES

Bendtsen, B. A. 1966. Sorption and swelling characteristics of salt-treated wood. U.S. Forest Service Forest Products Lab. Rep. 60. 45 pp.

Christensen, G. N. 1960. Kinetics of water vapor sorption by wood. I. The effect of sample thickness. Australian J. Applied Sci. 11:294–304.

Hart, C. A. 1970. Water-filled lumens in steady state flow in oak and poplar. Wood Fiber 1(4): 308–318.

Hornicsar, C. A. 1983. Effect of creosote and CCA on moisture movement in southern pine and red oak. M.S. thesis, The Pennsylvania State University.

Kumar, S., and V. K. Jain. 1978. Effects of wood preservatives on physical properties of wood. II. Effects of different salt loadings of copper-chrome-arsenic composition. Wood Fiber 9(4):262–269.

SAS User's Guide. 1979 edition. SAS Institute, Inc., Raleigh, NC. 494 pp.

Siau, J. F. 1984. Transport processes in wood. Springer-Verlag, New York. 245 pp.

SKAAR, C. 1954. Analysis of methods for determining the coefficient of moisture diffusion in wood. Forest Prod. J. 4(6):403–410.

———. 1958. Moisture movement in beechwood below fiber saturation point. Forest Prod. J. 8(12): 352–357.

STAMM, A. J. 1947. Passage of liquids, vapors, and dissolved materials through softwoods. USDA Tech. Bulletin No. 949. 80 pp.

———. 1950. Bound-water diffusion into wood in the fiber direction. Forest Prod. J. 9(1):27–32.

———. 1960a. Bound-water diffusion into wood in across the fiber direction. Forest Prod. J. 10(10): 524–528.

———. 1960b. Combined bound-water and water vapor diffusion into Sitka Spruce. Forest Prod. J. 10(12):644–648.