MEASUREMENTS OF WOOD PRESERVATIVE RETENTION

BY ELECTRICAL RESISTIVITY

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16. Abstract

Resistance measurements were made on prepared samples of loblolly pine treated with various solutions of chromated copper arsenate (CCA) with a modified Shigometer, Model OZ-67 (Osmose Wood Preserving Co. of America) using a twisted wire probe and a needle probe. Results show that over a limited range of CCA retentions and moisture contents, the equipment with the needle probe is capable of estimating the CCA retention in loblolly pine.

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Study Objectives

The purpose of this study was to generate the necessary background data, and establish the feasibility of measuring the retention levels of water-borne wood preservatives by changes in the electrical resistivity of treated wood. Specific objectives were:

a) To determine the changes in the electrical resistivity of southern pine that results from treatment with chromated copper arsenate (CCA) to retentions of 0.1 to 0.6 lb./cu. ft.

b) To determine the effects of wood moisture content, temperature, and preservative fixation on the electrical resistance of CCA-treated pine.

c) To determine whether resistance measurements will distinguish various CCA retention levels under conditions approximating those expected in the field.

Background

The impetus for this study was the need for a rather simple and sufficiently accurate technique to estimate the retention levels of water-borne preservatives in treated wood. Especially desirable is a procedure applicable in the field or in the treatment facility. Current methods and procedures are based on various spectrophotometric (colorimetric, atomic absorption) determinations of one or more preservative components in extracts, wet digests, or ashed wood samples; or by x-ray emission spectra from irradiated wood samples. Accepted procedures and industrial standards for retention measurements are published as various standards of the American Wood-Preserver's Association and American Society for Testing and Materials. These analytical procedures generally take considerable time and are expensive in instrumentation and technically trained labor.

The possibility of utilizing changes in electrical resistance to estimate retention levels seemed feasible for three reasons. First, electrical conductivity in wood is ionic, i.e., it is governed by the concentration, mobility and degree of dissociation of ionic species in the wood (Lin 1967, Brown et al. 1963, Skaar 1964). Second, research has shown that accurate measurements of moisture content with resistance-type moisture meters are affected by the presence of water-borne preservatives in the wood (James 1966). In general the presence of added electrolytes in treated wood decreased the resistance of the wood causing over-estimation of the moisture content. Third, recent research has utilized electrical resistance measurements to detect internal decay in trees and in utility poles in service (Shigo and Shigo 1974, Shortle et al. 1978). Their research used a commercially available resistance meter and wood probes that appeared suitable for measuring electrical resistance changes in preservative treated wood.

The most important environmental variables that affect the electrical resistance in wood are its moisture content and temperature (Lin 1967). Thus, these were given priority in the present studies. Also, the possible effects of preservative fixation (Pizzi 1983) were considered important. Chromated copper arsenate was chosen as the preservative because of its wide use and increasing importance in the wood industry (Gjovik and Micklewright 1982), and its specification for treatment of pine posts.

Materials and Methods

Instrumentation-

Resistance measurements were made with a Shigometer, Model OZ-67

(Osmose Wood Preserving Co. of America Inc., Buffalo, N.Y.) custom modified by the manufacturer to measure resistances from 0 to 7 x 10^6 ohms. This instrument is compact, light weight and operates on two 9-volt batteries. Two probes were used with this instrument; a needle probe similar to those used on wood moisture meters, and a twisted-wire probe for measurements inside a hole drilled into the wood. The latter probe should allow measurements deep within a piece of treated wood. Both probes are commercially available with the Shigometer.

Wood temperatures were measured with an Atkins 492 Series Thermocouple Digital Thermometer equipped with a Model 49126-K All-Purpose Probe (Atkins Technical, Inc. Gainsville, Florida).

During experiments, air temperatures were maintained by making all measurements inside a Conviron Model E-7 environmental chamber (Controlled Environments Limited, Winnipeg, Canada). To help maintain the wood at ± 1°C of the desired temperature, the experimental blocks were held in a temperature-controlled water jacket mounted inside the environmental chamber.

Procedures-

Loblolly pine blocks (3.4 x 1.5 x 1.5 inches) were cut from untreated lumber (commercial 2 x 4 inch stock). All blocks contained sapwood only and were free of knots.

Blocks were treated with freshly prepared chomated copper arsenate solutions by a full-cell process with a treatment apparatus and by procedures given in ASTM Standard D1413-76 (ASTM 1982). Preliminary experiments using concentrated dichromate solutions showed that the liquid completely and uniformly penetrated the blocks. After treatment, blocks were dried and stored at room temperature for at least 4 weeks before use. Simulated kiln drying was not used.

CCA solutions were prepared with reagent grade potassium dichromate ($K_2Cr_2O_7$), cupric sulfate ($CuSO_4 \cdot 5H_2O$) and sodium arsenate ($Na_2HAs_5O_4 \cdot 7H_2O$) to give a Type C formulation according to ASTM Standard Designation D1625-71 (ATSM 1982). Hydrochloric acid was used to adjust the final CCA solutions to pH 2.4 to 2.9 as determined by glass electrode.

From preliminary data on the amount of water taken up by the blocks during treatment, the concentrated CCA solutions were diluted so that the blocks received targeted retentions of 0.1, 0.2, 0.3, 0.4, or 0.6 lb./cu. ft. of active chemical (in CrO_3, CuO and As_2O_5 equivalents). To compare targeted to actual retentions, dry weights of random blocks were obtained before and after treatment. Table 1 shows that good agreement was found between targeted and actual retentions of active chemical.

Table 1. Targeted retentions and actual retentions of CCA in loblolly pine blocks

Targeted retention (lb./ft.^{3})	Actual retention (lb./ft.^{3})	
	Mean[a]	SD
0.6	0.56	0.04
0.4	0.39	0.06
0.3	0.31	0.06
0.2	0.17	0.01
0.1	0.11	0.11

[a]N = 4 to 6 blocks, SD = Standard Deviation

Treated blocks were brought to the appropriate moisture content by placing them over water beneath an air-tight bell jar. From a moisture absorption curve (Figure 1) experimental blocks were adjusted to the desired moisture content.

To maintain the moisture content, the blocks were removed from the bell jar and immediately wrapped in a water-impermeable plastic film (Saran Wrap, Dow-Chemical Co.). Wrapped blocks were stored in plastic

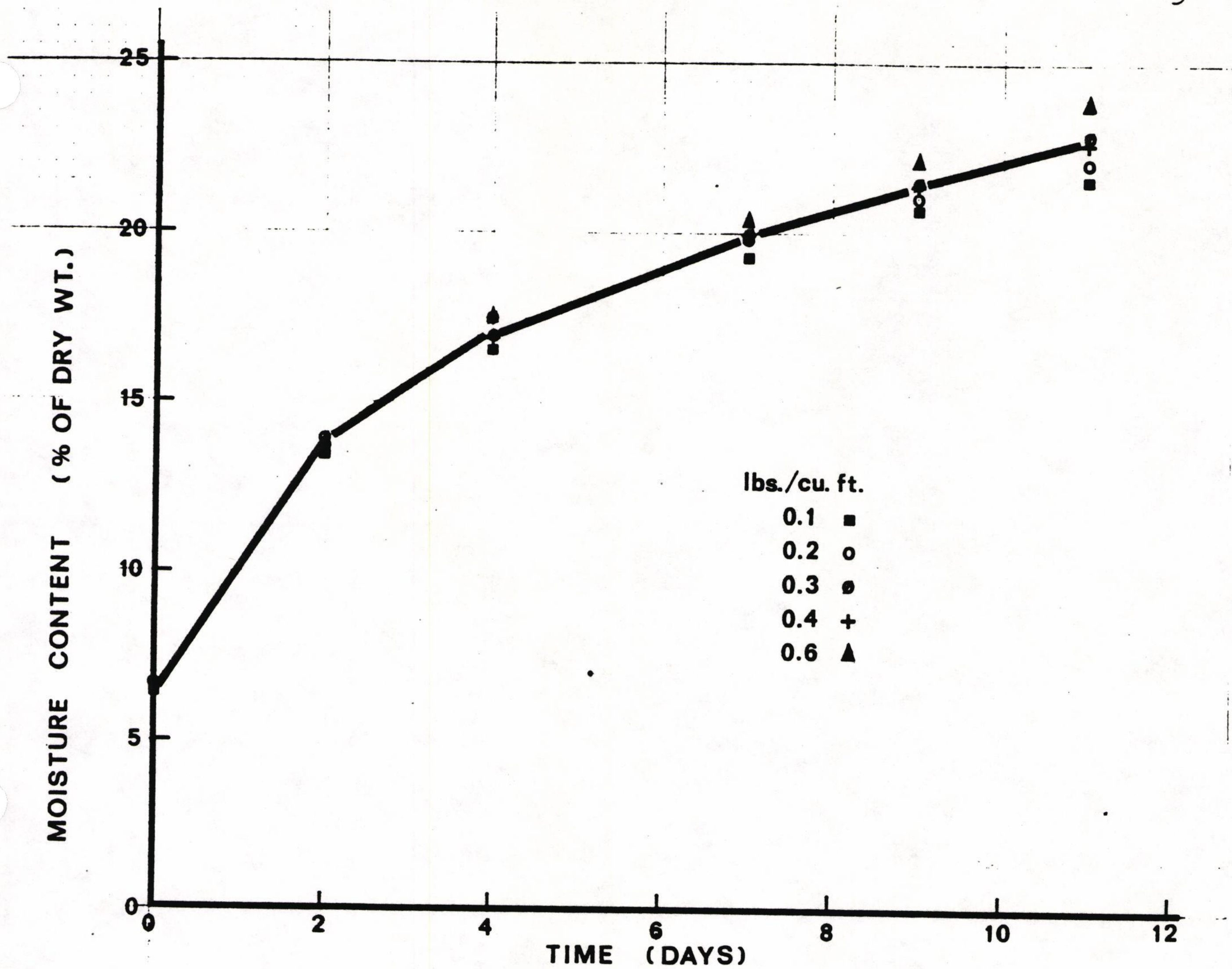

Figure 1. Moisture absorption curve for loblolly pine blocks treated to the indicated retentions of chromated copper arsenate. Each point is the average of five replicate blocks.

bags at room temperature until used for resistance measurements. A preliminary experiment showed that blocks wrapped and stored this way maintained their desired mositure content for at least 5 weeks.

Another preliminary experiment examined the equilibrium moisture distribution in wrapped blocks and whether it was maintained over time. Blocks at two retention levels (0.1 and 0.6 lb./cu.ft.) and two moisture levels (18 and 23%) were wrapped and stored. At various times a chisel was used to remove pieces of wood from the center (interior) and from the outer 0.8 to 0.16 in. (exterior) of each block. the moisture content was determined for each piece and the interior/exterior ratio calculated. Results (Fig. 2) showed that although the exteriors of the blocks had a slightly higher moisture content (0-1.5%) than did the interiors, this ratio remained nearly constant over time.

For resistance measurements with the twisted-wire probe, 7/64 in. diameter holes were drilled to a depth of 1.2-1.6 in. into the end face of each wrapped block. Holes were covered with adhesive tape, and the blocks were allowed to equilibrate in the environmental chamber for 18-20 hours before measurements were made. This equilibration period was necessary because only off-scale (high) resistance readings were obtained when measurements were taken immediately after drilling. This is believed to have been caused by the heating and consequent drying of the wood on the interior of the hole. After equilibration, four to six resistance readings were made in each hole at depths of 0.4 to 1.2 in. with the "bells" of the probe oriented perpendicular to the grain as recommended by the manufacturer. An average resistance was calculated for each block.

Blocks for needle probe measurements were equilibrated in the

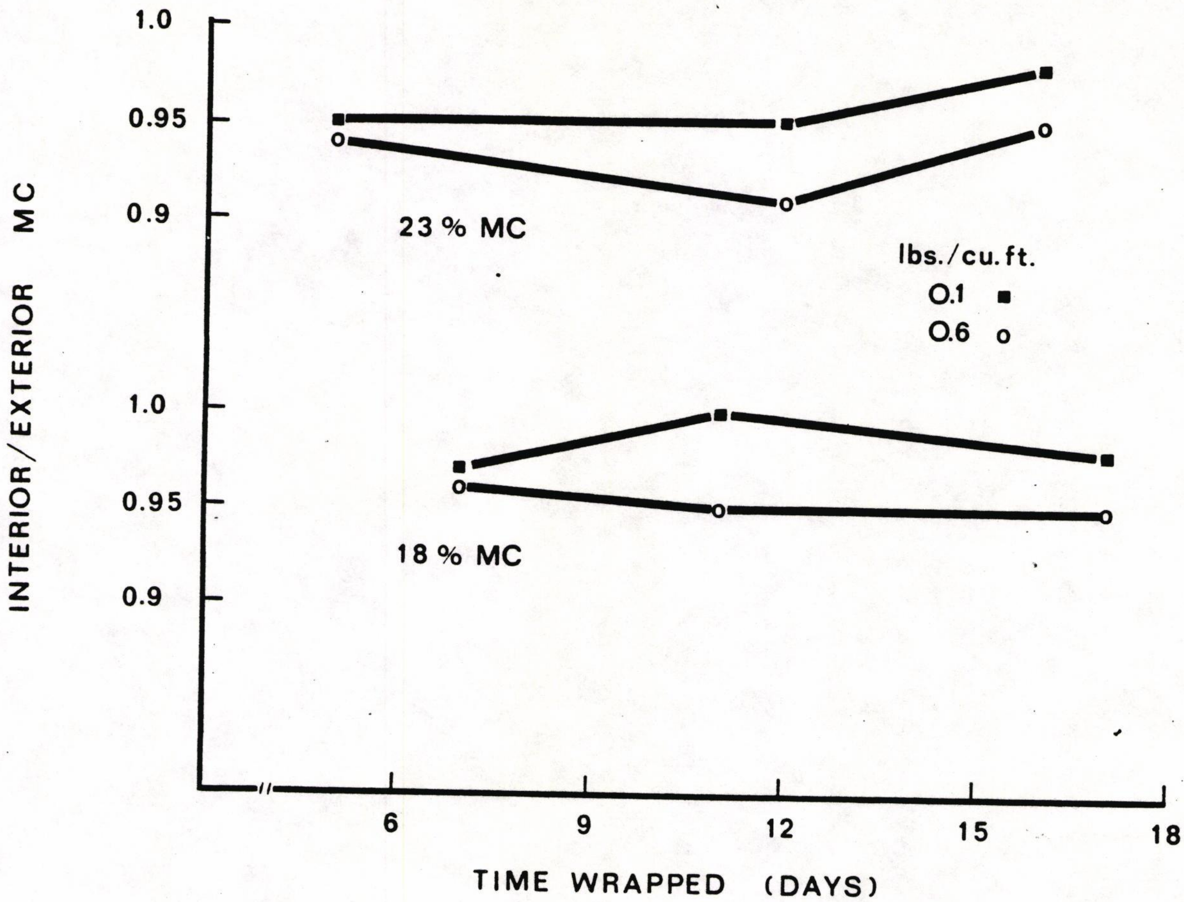

Figure 2. Equilibrium moisture distribution in CCA-treated pine blocks wrapped and stored in water-impermeable plastic film. Each point is the average of six determinations of the interior (center) to exterior (outer 0.08 - 0.16 inches) ratio. The experiment was done at moisture contents of 18 and 23% with blocks treated to 0.1 and 0.6 lb./cu.ft. MC = moisture content.

chamber for 10 or more hours. Four to six resistance readings were made with the probes oriented parallel to the grain, and an average resistance was calculated for each block.

After resistance readings were taken the blocks were unwrapped, immediately weighed and oven dried at 100-103°C. Moisture content (on a dry weight basis) was calculated for each block.

Results

Absence of fixation effects -

Two experiments were done to determine if changes in electrical resistance occurred in treated blocks during the post-treatment fixation period. Three different groups of blocks (5 per group) were held for either 42, 60 or 77 days after treatment to a 0.2 lb./cu. ft. retention. After moisture equilibration to 16%, the blocks had average resistances of 5.0×10^6, 4.7×10^6 and 4.2×10^6 ohms respectively, when measured with the needle probe at 20°C. Similar groups of blocks treated to 0.4 lb./cu. ft. and held for the same time periods had resistances of 2.6×10^6, and 2.5×10^6 and 3.5×10^6 ohms respectively. From these results there was no indication that changes in resistance arose from major changes in ion concentration or ion mobility during preservative fixation.

Also, during the course of the studies reported below, blocks were used anytime from 4 to 30 weeks after treatment. Although the blocks were randomized among the treatments and experiments, no effects on electrical resistance attributable to the time since treatment were apparent.

Needle probe measurements -

The effects of increasing CCA retentions on the electrical resistance at four moisture levels and five temperatures are given in detail in Tables 2 - 6.

Blocks equilibrated at 12% moisture content gave off-scale (high) resistance readings regardless of the CCA retention or temperature, therefore, the data are not given. At the other moisture contents examined the electrical resistance decreased with increased moisture and with increased temperature. The effect of increased CCA retention was clearly evident; as the retention increased the resistance decreased.

The data from Tables 2-6 were plotted as $\log_{10}$ resistance versus moisture content. The data for blocks measured at 19-21°C are shown in Figure 3. Although there was considerable variability among the individual blocks (see discussion), the figure shows that CCA retentions could be estimated from the plot if the moisture content and resistance were known.

Needle probe measurements of unknowns -

To test whether the CCA retention of unknowns could be correctly estimated, a total of 50 blocks were treated and measured in a blind experiment. Neither the person who treated the blocks nor the person who made the resistance measurements knew the CCA levels until all data were collected. Five retentions of CCA were used and measurements were made at two moisture contents at 20°C. The curves in Fig. 3 were used to estimate the CCA retention of each block.

The results revealed that on the average, for the unknown blocks treated at the lowest retentions (0.165 and 0.2 lb./ cu. ft), the resistance technique overestimated the actual retentions, more so at the higher moisture content (Table 7). Blocks treated at the two highest levels (0.4 and 0.5 lb./cu. ft.) were estimated correctly on the average. When the same data were collated with respect to the 0.4 lb./cu. ft. specification for treatment of posts, it was found that at 17 - 18% moisture content three out of 15 substandard blocks (all three were 0.33 lb./cu. ft.) were estimated to meet the speci-

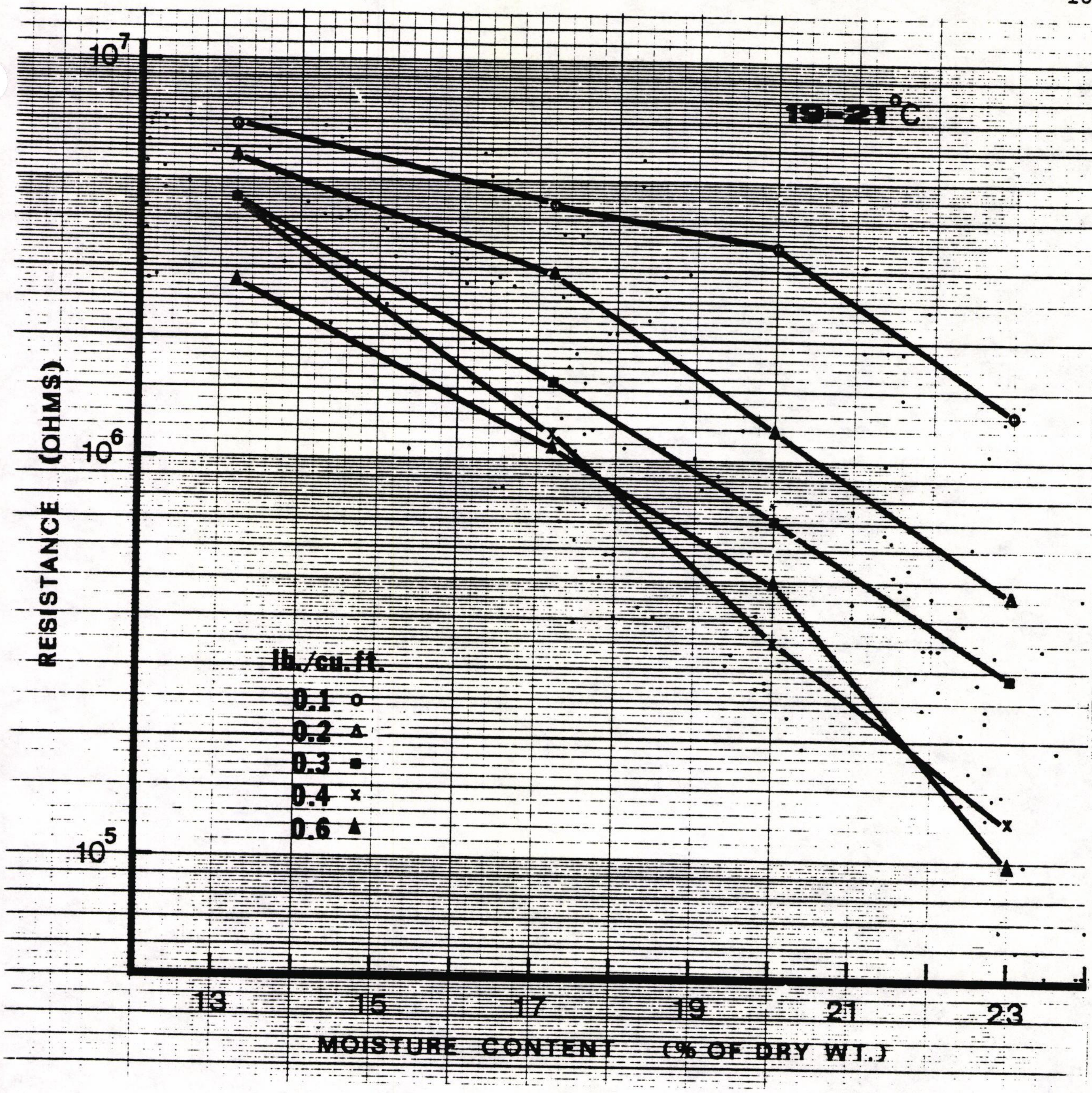

Figure 3. Semi-logarithmic plot of resistance versus moisture content at five retentions of CCA. Resistances were measured at 19-21°C. The large symbols are the means from Table 3. Also shown are the data points for about 80% of the individual blocks measured. Others are obscured by the lines or are off-scale to the left or right.

fication. Only one of 10 blocks treated at or above 0.4 lb./cu. ft. (one at 0.4 lb. / cu. ft.) was estimated to be substandard. At 21 - 22% moisture content, five substandard blocks (four at 0.33 and one at 0.165 lb./ cu. ft.) were estimated to meet the specification, while all blocks treated at 0.4 and 0.5 lb./cu. ft. were correctly estimated.

Eight unknown CCA-treated posts were obtained from the Arkansas State Highway and Transportation Department. Six blocks similar in size and grain orientation to those used in the experiments above were cut from each post. Three blocks were equilibrated to each of two moisture contents and each block was measured at two temperatures. CCA retentions were estimated from the curves in Fig. 3 for 20°C and from a similar plot of the data from Table 5. The results in Table 9 show that by resistance measurements, all blocks were estimated to have retentions at or less than 0.1 lb./cu. ft.

Twisted-wire probe measurements -

Resistance measurements with the twisted-wire probe are given in Tables 10-14. In general the resistance decreased with increases in moisture content, temperature and CCA retention. However, the range of useful resistance readings was poor (1 - 7×10^6 ohms). Readings less than 1×10^6 ohms rarely occurred and frequently resistances occurred that exceeded the upper limit of the instrument's range. Resistance readings within and between blocks were highly variable. It was found late in this research that one source of this variability arose from the handling of the twisted-wire probe. The resistance readings were influenced by the way in which the probe was held in the experimenter's hands. Because of this effect, work with this probe was discontinued and measurements of the unknowns were not made.

Discussion

The results of this study show that over a limited range of CCA retentions and moisture contents, the modified Shigometer equipped with a needle probe is capable of estimating the CCA retentions in loblolly pine. Eighty percent of the unknowns that received substandard treatments were correctly detected, while 90 to 100% of the unknowns that received retentions of 0.4 lb./cu. ft. or more were correctly estimated. The instrument used (maximum resistance of 7×10^6 ohms) appeared useful above 14% moisture content. Below this level a resistance bridge with greater sensitivity would be required. However, because the relative changes in resistance attributed to changes in CCA retention decreased as the moisture content decreased (Tables 2 - 6 and Fig. 3), it is questionable whether useful measurements to estimate CCA content could be made below 12 - 13% moisture content. Also, at moisture contents of 14 - 20% and at all temperatures, the resistance readings for blocks treated at 0.3, 0.4 and 0.6 lb./cu. ft. tended to converge and in some cases the readings overlapped (Tables 2 - 6 and Fig. 3). This suggests that a plateau may have been reached at which moisture content became the overriding limiting factor in ion mobility.

Because this study was designed to examine the practicality of using resistance measurements, no attempt was made to compare the data for its fit to theoretical considerations of ion mobility and electrical resistance of wood (Lin 1967). Moreover, although the CCA solutions, wood moisture content and temperature were controlled as well as possible, we did not control variables arising from wood specific gravity, annual ring widths, and resin and ash content. All these could affect the resistance measurements and the uniformity of the CCA treatments. These and other wood-derived variables are the most likely sources of the variability in the data collected.

All the unknown samples supplied by the Arkansas State Highway and Transportation Department were estimated to contain 0.1 lb./cu. ft. or less of

CCA. Whether this is due to; a) the fact that all the samples actually contained substandard retentions near 0.1 lb./cu. ft., b) the composition of the CCA used to treat the posts, c) the effects of post treatment processing, e.g. kiln drying, d) possible leaching of ions from the wood, or a combination of these factors is not known. Because resistance measurements depend on the concentration and mobility of ions; predominantly K^+, Na^+, Cl^-, SO_4^{-2} (i.e. the counter ions that accompany the active species that become fixed in the wood), the salts and acid used to formulate the CCA solution will greatly affect the results. Standard tables and curves would have to be prepared for CCA solutions made with different salts or oxides of the active ingredients.

The twisted-wire probe was less sensitive to CCA changes than was the needle probe. The instability and effects of handling on the performance of this probe may occur because the probe is designed to measure maximum resistances of 5×10^5 ohms, and therefore, may not be sufficiently insulated to stably measure resistances in the megaohm range. Better insulation may improve its capability. Also, communication with Osmose Inc. (personal communication) suggests that erratic readings with this probe arise from a build-up of charge on the probe contacts at high resistances.

Implementation Statement

The results of this project show that electrical resistance measurements are a potentially useful and reasonably rapid method of estimating CCA retentions in the 0.1 to 0.6 lb./cu. ft. range. Implementation of this technique would require the operator to have available standard curves or tables of resistances for various formulations of the preservative, and corrections for temperature and moisture effects. He would need to measure the wood temperature and moisture content in addition to electrical resistance.

The moisture content would be the most time consuming variable to determine. In the present work we found (although did not thoroughly study) that small pieces of treated wood could be brought to a suitable moisture content for resistance measurements (16 to 20%) in 18 - 20 hours. With the availablity of common laboratory equipment (moist chamber, drying oven and balance) resistance readings and estimated CCA retentions could be available within 36 to 48 hours after sampling of the wood.

Two procedures can be envisioned depending upon the suspected moisture content of the wood. For wood with moisture contents of greater than 14%, temperature and resistance readings could be made in the field, and samples of the wood taken for an overnight determination of its moisture content. For wood with low moisture content, samples would be taken to the laboratory where they would be brought to a suitable moisture content overnight before resistance measurements would be made.

Future work on this problem would include: a) Development of tables and/or standard curves, and temperature and moisture content correction factors for different preservative formulations and solutions made with different salts or oxides of the active ingredients. b) Determination of the feasibility and speed with which the needle probe could be used to estimate CCA retentions in increment cores or other small wood samples cut from treated wood. This could allow the use of resistance measurements to be an important supplementary step in the current procedure that employs increment core sampling for the chemical analysis of CCA retentions.

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Table 2. Relationship of moisture content and CCA retention to the electrical resistance (needle probe) at 14-15°C

% Moisture content	CCA retention ($lb./ft.^3$)				
(dry wt. basis)	0.1	0.2	0.3	0.4	0.6
	------------ Resistance in megaohms (SEM) ------------				
14.4	6.80 (0.04)[a]	6.00 (0.44)	4.89 (0.40)	4.82 (0.46)	3.03 (0.49)
17.4	4.86 (0.56)	4.65 (0.36)	1.40 (0.26)	1.79 (0.24)	1.84 (0.82)
19.4	5.36 (0.55)	2.52 (0.35)	1.43 (0.17)	0.47 (0.05)	1.17 (0.24)
23.1	2.41 (0.19)	0.82 (0.08)	0.61 (0.04)	0.25 (0.09)	0.18 (0.04)

[a] N = 4 to 8 blocks, SEM = Standard Error of the Mean

Table 3. Relationship of moisture content and CCA retention to the electrical resistance (needle probe) at 19-21°C

% Moisture content (dry wt. basis)	CCA retention ($lb./ft.^3$) 0.1	0.2	0.3	0.4	0.6
	Resistance in megaohms (SEM)				
13.2	6.83 (0.13)[a]	5.66 (0.43)	4.50 (0.57)	4.61 (0.32)	2.79 (0.32)
17.2	4.36 (0.38)	2.92 (0.32)	1.56 (0.29)	1.15 (0.11)	1.08 (0.25)
20.0	3.45 (0.54)	1.22 (0.18)	0.72 (0.09)	0.35 (0.04)	0.50 (0.13)
23.0	1.31 (0.21)	0.46 (0.06)	0.29 (0.04)	0.12 (0.02)	0.10 (0.02)

[a] N = 8 to 15 blocks, SEM = Standard Error of the Mean

Table 4. Relationship of moisture content and CCA retention to the electrical resistance (needle probe) at 24-26°C

% Moisture content (dry wt. basis)	CCA retention ($lb./ft.^3$) 0.1	0.2	0.3	0.4	0.6
	Resistance in megaohms (SEM)				
14.4	5.90 (0.45)[a]	4.73 (0.54)	2.85 (0.55)	3.23 (0.14)	1.74 (0.24)
17.4	2.97 (0.71)	2.90 (0.32)	0.73 (0.17)	0.74 (0.08)	0.93 (0.29)
19.4	3.32 (0.51)	1.26 (0.22)	0.60 (0.10)	0.25 (0.03)	0.50 (0.11)
23.1	1.42 (0.13)	0.42 (0.08)	0.30 (0.03)	0.12 (0.04)	0.11 (0.03)

[a] N = 4 to 8 blocks, SEM = Standard Error of the Mean

Table 5. Relationship of moisture content and CCA retention to the electrical resistance (needle probe) at 28-30°C

% Moisture cotent	CCA retention (lb./ft.^{3})				
(dry wt. basis)	0.1	0.2	0.3	0.4	0.6
	---------- Resistance in megaohms (SEM) ----------				
14.4	5.67 (0.43)[a]	4.52 (0.66)	2.30 (0.60)	2.51 (0.13)	1.39 (0.26)
17.4	2.13 (0.37)	2.25 (0.32)	0.57 (0.12)	0.70 (0.09)	0.70 (0.28)
19.4	2.76 (0.43)	0.90 (0.19)	0.51 (0.09)	0.19 (0.02)	0.39 (0.08)
23.1	0.93 (0.10)	0.28 (0.05)	0.19 (0.01)	0.09 (0.02)	0.07 (0.01)

[a] N = 3 to 8 blocks, SEM = Standard Error of the Mean

Table 6. Relationship of moisture content and CCA retention to the electrical resistance (needle probe) at 34-36°C

% Moisture content	CCA retention (lb./ft.^{3})				
(dry wt. basis)	0.1	0.2	0.3	0.4	0.6
	---------- Resistance in megaohms (SEM) ----------				
14.4	4.80 (0.62)[a]	3.30 (0.72)	1.76 (0.10)	2.12 (0.39)	1.11 (0.23)
17.4	1.78 (0.41)	1.79 (0.20)	0.50 (0.07)	0.55 (0.07)	0.67 (0.37)
19.4	2.16 (0.42)	0.58 (0.09)	0.30 (0.06)	0.15 (0.01)	0.23 (0.05)
23.1	0.68 (0.09)	0.23 (0.04)	0.15 (0.01)	0.06 (0.01)	0.06 (0.01)

[a] N = 3 to 8 blocks, SEM = Standaed Error of the Mean

Table 7. Determination of CCA retentions of unknowns by electrical resistance measurements (needle probe) at two moisture contents at 20°C

Moisture content (%)	Treated retention (lb./ft.^{3})	Average resistance (SEM) N = 5	Experimental[a] retention (lb./ft.^{3})
17-18	0.165	2.09 (0.23)	0.2-0.3
	0.25	1.45 (0.11)	0.3
	0.33	1.08 (0.20)	0.3-0.4
	0.40	0.93 (0.08)	0.4-0.6
	0.50	0.76 (0.05)	0.4-0.6
21-22	0.165	0.39 (0.02)	0.3
	0.25	0.25 (0.01)	0.3-0.4
	0.33	0.20 (0.03)	0.4-0.6
	0.40	0.17 (0.03)	0.4-0.6
	0.5	0.16 (0.02)	0.4-0.6

[a] Determined using the moisture content, average resistance and the curves in Fig.3.

Table 8. Ability of electrical resistance measurements (needle probe) to detect pine blocks treated to specification (0.4 lb./ft.^{3}) or to substandard retentions of CCA

	Number of blocks rated as:		
17-18 % MC	Substandard[a]	At or above 0.4 lb./ft.^{3} [b]	Totals
Actually treated	15	10	25
Correctly estimated	12	9	25
Incorrectly estimated	3	1	
21-22 % MC			
Actually treated	15	10	25
Correctly estimated	10	10	25
Incorrectly estimated	5	0	

[a] 0.165, 0.25 and 0.33 lb./ft.^{3}

[b] 0.4 and 0.5 lb./ft.^{3}

Table 9. Resistance readings and estimated CCA retentions of pine posts (unknowns) supplied by the Arkansas State Highway and Transportation Department

Temperature	Post No.	Moisture content (%)	Resistance[a] (megaohms)	CCA retention[b] (lb./ft.^{3})
20°C	1	22.2	3.83 (0.29)	<0.1
		19.4	6.34 (0.39)	<0.1
	2	21.5	5.23 (0.05)	<0.1
		18.8	6.98 (0.04)	<0.1
	3	21.8	3.37 (0.20)	0.1
		18.5	6.53 (0.20)	<0.1
	4	24.1	2.89 (1.06)	<0.1
		18.9	6.48 (0.12)	<0.1
	5	21.9	4.12 (0.67)	0.1
		18.3	6.60 (0.16)	<0.1
	6	21.8	4.40 (0.41)	<0.1
		18.8	6.69 (0.09)	<0.1
	7	24.7	3.01 (0.57)	---[c]
		19.7	6.26 (0.13)	<0.1
	8	23.0	4.24 (0.25)	<0.1
		19.6	6.79 (0.17)	<0.1
29.5°C	1	22.2	2.48 (0.14)	<0.1
		19.4	5.42 (0.32)	<0.1
	2	21.5	3.47 (0.15)	<0.1
		18.8	5.91 (0.43)	<0.1
	3	21.8	1.90 (0.16)	0.1
		18.5	4.83 (0.50)	<0.1
	4	24.1	1.75 (0.75)	---[c]
		18.9	4.94 (0.22)	<0.1
	5	21.9	2.69 (0.54)	0.1
		18.3	5.73 (0.11)	<0.1
	6	21.8	2.97 (0.26)	<0.1
		18.8	5.94 (0.41)	<0.1
	7	24.7	1.80 (0.51)	---[c]
		19.7	5.33 (0.40)	<0.1
	8	23.0	2.87 (0.26)	<0.1
		19.6	6.06 (0.36)	<0.1

[a] Average (SEM) of 3 blocks from each post at each moisture content.

[b] Estimated from the curves in Figure 3 for measurements made at 20°C and from a similar plot of the data from Table 5 for measurements made at 29.5°C. This plot is not shown.

[c] Moisture content exceeds the standard curves, therefore, CCA retentions could not be estimated.

Table 10. Relationship of moisture content and CCA retention to the electrical resistance (twisted-wire probe) at 13-15°C

% Moisture content (dry wt. basis)	CCA retention ($lb./ft.^3$) 0.1	0.2	0.3	0.4	0.6
	Resistance in megaohms (SEM)				
14.4	6.77 (0.08)[a]	6.88 (0.02)	6.88 (0.06)	6.89 (0.07)	6.76 (0.02)
19.5	6.70 (0.04)	6.48 (0.07)	6.38 (0.09)	3.45 (0.14)	6.41 (0.03)
23.3	6.42 (0.06)	5.60 (1.52)	6.45 (0.08)	3.42 (0.69)	5.13 (0.68)

[a] N = 4 to 8 blocks, SEM = Standard Erreo of the Mean

Table 11. Relationship of moisture content and CCA retention to the electrical resistance (twisted-wire probe) at 19-21°C

% Moisture content	CCA retention ($lb./ft.^3$)				
(dry wt. basis)	0.1	0.2	0.3	0.4	0.6
	---------- Resistance in megaohms (SEM) ----------				
13.6	OS[a]	OS	OS	OS	OS
16.7	6.71 (0.19)	OS	6.72 (0.18)	7.10 (0.00)	6.64 (0.16)
21.4	---[b]	5.20 (0.33)	---	5.10 (0.26)	---
22.8	6.13 (0.07)	5.28 (0.25)	4.97 (0.34)	1.96 (0.32)	2.68 (0.42)

[a] N = 4 to 9 blocks, SEM = Standard Error of the Mean, OS = off-scale, i.e. greater than 7.11 megaohms for all blocks.

[b] Not determined

Table 12. Relationship of moisture content and CCA retention to the electrical resistance (twisted-wire probe) at 24-26°C

% Moisture content	CCA retention (lb./ft.^{3})				
(dry wt. basis)	0.1	0.2	0.3	0.4	0.6
	---- Resistance in megaohms (SEM) ----				
14.4	6.41 (0.04)[a]	6.34 (0.04)	6.45 (0.03)	6.34 (0.12)	6.32 (0.05)
19.5	6.24 (0.05)	5.00 (0.71)	5.74 (0.19)	4.07 (0.37)	4.82 (0.30)
23.3	5.85 (0.15)	4.80 (0.50)	3.57 (0.71)	1.79 (0.34)	3.50 (1.18)

[a] N = 4 to 8 blocks, SEM = Standard Error of the Mean

Table 13. Relationship of moisture content and CCA retention to the electrical resistance (twisted-wire probe) at 28-30°C

% Moisture content	CCA retention (lb./ft.^{3})				
(dry wt. basis)	0.1	0.2	0.3	0.4	0.6
	---------- Resistance in megaohms (SEM) ----------				
19.2	6.18 (0.13)[a]	5.70 (0.35)	5.44 (0.37)	---[b]	4.69 (0.33)
22.4	5.73 (0.10)	3.89 (0.64)	3.18 (0.66)	1.04 (0.38)	1.45 (0.36)

[a] N = 4 blocks, SEM = Standard Error of the Mean

[b] Not determined

Table 14. Relationship of moisture content and CCA retention to the electrical resistance (twisted-wire probe) at 35-36°C

% Moisture content	CCA retention (lb./ft.^{3})				
(dry wt. basis)	0.1	0.2	0.3	0.4	0.6
	Resistance in megaohms (SEM)				
14.4	6.34 (0.04)[a]	6.12 (0.18)	6.23 (0.11)	6.16 (0.06)	6.24 (0.03)
19.5	6.09 (0.02)	4.90 (0.63)	5.05 (0.46)	3.36 (0.46)	4.66 (0.54)
23.3	5.37 (0.23)	3.82 (0.22)	3.15 (0.33)	1.24 (0.22)	1.93 (0.22)

[a] N = 4 to 8 blocks, SEM = Standard Error of the Mean