The Electrical Properties of Treated Wood with a Focus on Utility Pole Conductivity: Part II

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ABSTRACT

Wood is a wonderful natural resource but is prone to attack by biotic and non-biotic forces and must be preserved if used in exterior long-term exposure situations. The continued supply of power, telecommunication, and cable television is a strategic need for all residents of developed and developing countries. No published studies on the conductivity of treated utility poles have been in the public domain since Katz and Miller in 1963. This work reviews the findings to date of a longer-term, three tiered approach to the investigation of the conductivity properties of treated wooden poles using commercially available and commercially significant wood preservatives in practice today for industrial timber protection. This study is the second part of a four part series into the investigation of treated wood conductivity, with a focus on preservatives currently in use for utility poles.

Keywords: *Conductivity, creosote, chromated copper arsenate, copper naphthenate, moisture content, pentachlorophenol, resistance.*

INTRODUCTION

Historically moisture has had an effect on the physical properties of wood. Stamm (1927, 1928, 1930, 1931) recorded sets of conductivity data on many species over a broad moisture content range to which many applications were made for determining the moisture content. Pulido (1977) summarized the historical research on electrical conductivity relationships in wood. His observations on moisture and metals movement of wood treated with copper, chromium, and arsenic depicts movement of individual elements inside the wood and the fixation of the combination of these elements as a preservative in wood and established conductivity changes of each scenario when treating hard maple (*Acer saccharum* Marsh). Zelinka (2008) used Stamm's data as a basis for fit to support a theory for a percolation model that describes electrical conduction in wood below the fiber saturation point (FSP). This seems to best describe the variations among wood samples as a non homogenous material adjusting for variations of cell wall anatomy, extractives, and resin content as it relates to free and bound water.

Other important factors affecting conductivity are temperature and relative humidity described by many researchers such as Katz et al. (1963), Stamm, and Stewart (1936). Katz determined that variations in moisture can be expected for oil borne preservatives rendering them more resistive to electrical flow such as creosote and pentachlorophenol averaging 3.2 lbs per cubic foot. He also documented the retention change (1-4.4 lbs. per cubic foot) of treatment did not affect the resistance of the wood sample. An approximate change of 100% per percent moisture content was observed by Katz from fiber saturation to oven dry conditions. Similar observations by Stamm were made, "a change in moisture content from zero to about 30% of the weight of wood, the conductivity increases a million fold." The relationship is said to be linear between 0-30% moisture content in the manual for the inspection of aircraft wood and glue and beyond that point to 200% the electrical conductivity changes less than 50 fold according to Stamm (1929). Described in data below is conductivity data from southern pine (Pinus sp., SYP), used for wood utility poles, at three moisture values given by weight (oven dry, 20% (+/- 3), and above the FSP 52% (+/- 3). Data obtained from wafers were used to reduce variation associated with large wood samples and then compared to data obtained from one foot pole sections The objective of this study was to determine if chemical treatments used for utility pole treatment affected the conductivity of southern yellow pine (*Pinus sp.*) at various moisture contents. One of the target goals of this work, was to have in place, a definitive paper, proving CuNap OB treatments do not negatively impact wood pole conductivity, as some lesser informed parties tend to think that since it has "COPPER" in the name the treated wood must be conductive.

METHODS

Material Selection

Southern pine spp.(Loblolly) wooden utility poles were obtained from two commercial treating plants located in Alabama and Louisiana(Figure 1). Poles were commercially pressure treated with Creosote, Pentachlorophenol(Penta), Copper Naphthenate (CuNap), Chromated Copper Arsenate (CCA-C), and an untreated southern pine pole was used as the negative untreated control. Five poles which were geometrically similar, were sectioned after treatment to five feet in length, one foot sections were then also cut and removed from each end to remove any preservative penetration end-effect from the butt. The sections were then cut into 1 foot lengths (15 samples per treatment) and placed in a conditioned room at 75 F %, 95 RH for three months in an attempt to equilibrate to 20% MC. Five one foot sections were classified by diameter so that each treatment would have a similar diameter for ease of handling and measure. Samples that were extra were used for creating wafers, preservative analysis, and high voltage experiments.

Figure 1. Wooden utility poles were obtained from Colfax treating in Pineville, La and Cahaba Forest Products in Cahaba, Al.

Pole Conductivity Measure

ABB (a power and automation technology company) donated their facilities (Figure 2) and connected the utility pole sections to a 75 K volt coil, here electricity was gradually applied until a high voltage was reached where the current would bridge (i.e., jump across) from one energized contact across the wood and go to the ground wire on the opposite end. Using this voltage Siemens per meter could be calculated from the resistance determined by this test. This identified that wood at 20% MC would require a voltage of 10 K volts to determine the conductivity of the small wood pole sections and 150-5 K volts were needed to determine the conductivity of the smaller wafer samples.

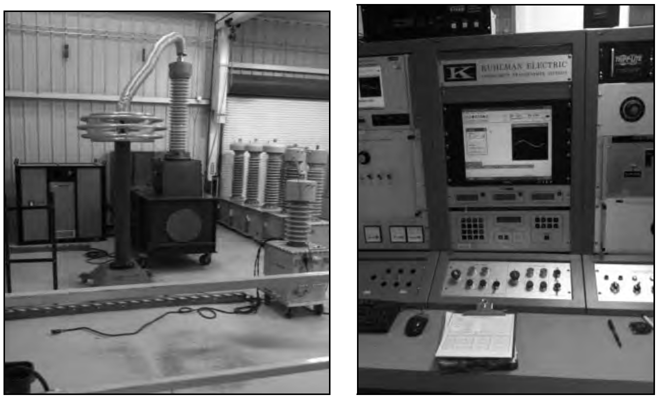


Figure 2. ABB (a power and automation technology company) facilities were used to apply high voltage to wood pole sections.

Wafer and Pole Conductivity Measure

Forty southern yellow pine (*Pinus sp*.) wafers (16 mm x 16mm x 12 mm) were used per replicate; wafers used were treated with Creosote, Pentachlorophenol, Copper Naphthenate (CuNap), Chromated Copper Arsenate (CCA), and an untreated control obtained from the outer 4” treated zone of pole stock. Resistance measurements were made using a Meger MIT 102/2 (Figure 3) recording ohms using 150-5,000 Volts over a period of one minute, the wafers were tested at 20% (+/- 3)moisture content, above the FSP 52% (+/- 3) and oven dry basis at a room temperature of 25^{o}C. The preliminary results work has been previously published at the 2010 Southeastern Utility Pole Conference and Trade Show.

Figure 3. Resistance measurements were made using a Meger MIT 102/2 recording ohms using 1-10,000 Volts over a period of one minute.

Measurements were conducted across the longitudinal face (12 mm) and in the radial direction across the grain (16 mm) as the length (ℓ), the calculation formula is found in Figure 4. Solid copper plates were adhered to a non-conductive plastic clamp to which roughly five pounds of force was applied securing each wafer in-between the copper plates so that the copper plate was larger than the wafer sample to ensure that the entire wafer was exposed to the electrical current.

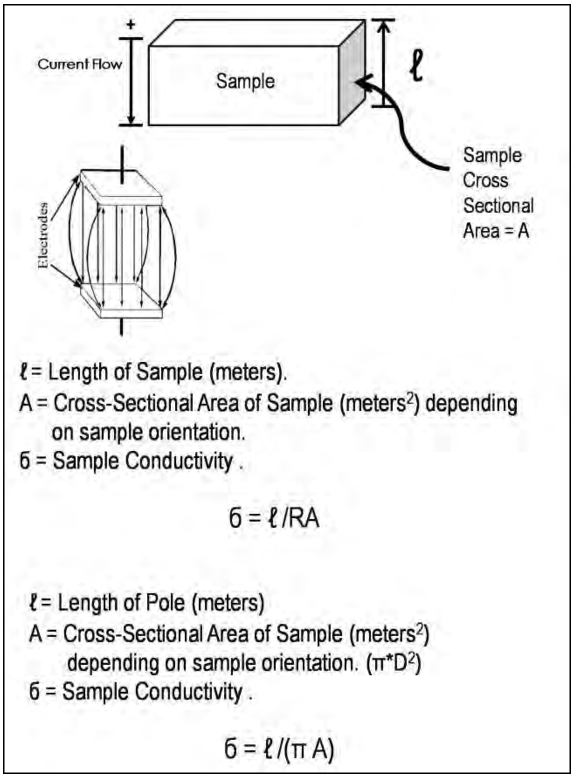


Figure 4. Measurements were made across the longitudinal face (12 mm, ℓ) and in the radial direction across the grain (16 mm, ℓ) as seen above, and Siemens per meter were calculated for wafers and poles.

The resistances of the copper plates were negligible, and the apparatus can be seen in Figure 5 attached to the Meger MIT 102/2. The clamp was secured on a 2x4 and supported on a non-conductive rubber mat to ensure that no electrical shock would occur during testing.

One foot utility pole sections were tested using a similar method as that of the wafers (Figure 6, 4), the calculation formula is found in Figure 4.

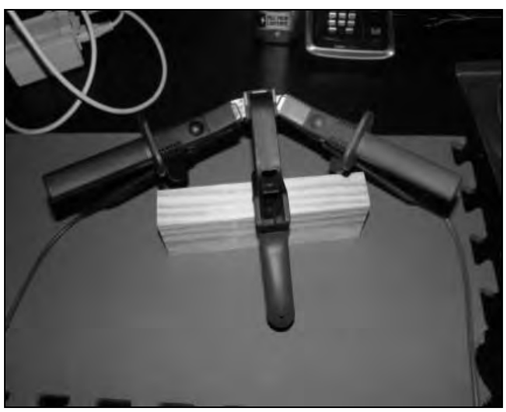


Figure 5. Solid copper plates were adhered to a non-conductive plastic clamp to which roughly five pounds of force was applied securing each wafer in-between the copper plates so that the copper plate was larger than the wafer sample to ensure that the entire wafer was exposed to the electrical current.

Initially the moisture content was to be taken with a Delmhorst dual, insulated pin type meter but data from the two butt ends and the middle sections were grossly different (an unequal moisture gradient through the pole section) therefore moisture contents were determined by oven dry weight. Work many years ago by C.W. Best indicated most treatments can alter electric moisture meter readings and correction tables should be prepared per treatment type.

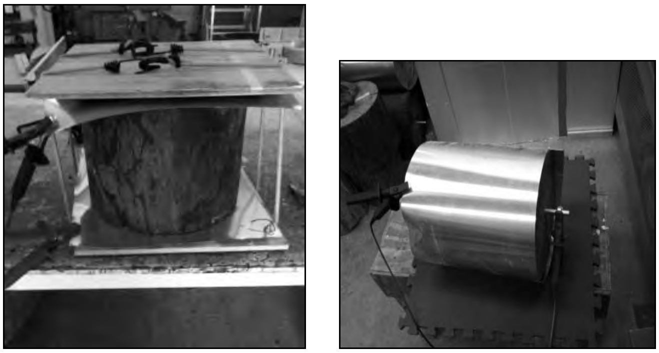


Figure 6. Testing method for one foot utility poles, similar to that used with wafers. Stainless steel was used instead of copper in both the longitudinal and cross sectional direction. Cross sectional sections were completely wrapped, and a stainless steel pole was driven through the center of the pole to record the conductivity.

Preservative Content

Wood samples were ground from the outer four inches of the treated zone, and analysis for preservative retention was completed by Timber Products Inspection for each chemical treatment using AWPA A-9. This data is found in Table 1. Penetration can be seen in Table 2. All samples meet or exceeded AWPA UC retentions and all samples had adequate penetration.

RESULTS

Pole Conductivity Measure

A 75 K volt coil was attached to a copper plate on one end of a pole section so that is was not extending past the edge of the wood where electricity was gradually applied until a high voltage was reached. This did not cause the current to bridge (i.e. jump across) from one energized contact (75 K volts) across the wood and go to the ground wire on the opposite end. Using this data it was determined that a voltage of 10 K could be used to determine Siemens per meter at 20% MC in one foot sections therefore a Meger MIT 102/2 was selected to carry out all conductivity testing.

Wafer and New Pole Conductivity Measure

Longitudinal

Conductivity of southern pine (*Pinus sp.*) wafers impregnated with selected chemical treatments used for utility poles (Creosote, Pentachlorophenol, CCA, and Copper Naphthenate) were compared in the laboratory using data measurements in the longitudinal direction (Figure 7). Using all data points the chemical treatment and moisture content significantly affected conductivity ($F= 56.76$; $d.f.= 4$; $P=< 0.0001$) and ($F=1750$; $d.f.=2$; $P=< 0.0001$) with interaction between the treatment and moisture content ($F=58.78$; $d.f.= 8$; $P=<0.0001$) . In the overall data comparison of the mean conductivity of treated wafers, conductivity was greater for untreated SYP wafers and was statistically significant ($F=299$; $d.f.= 14,584$; $P=<.0001$) (Table 4.). The overall data showed that Pentachlorophenol and Creosote were statistically the least conductive chemical treatment and Copper Naphthenate was significantly less conductive than untreated and CCA treated wafers.

Measurements for the conductivity of southern pine (*Pinus sp.*) wafers impregnated with selected chemical treatments used for utility poles (Creosote, Pentachlorophenol, CCA, and Copper Naphthenate) at oven dry conditions were compared in the longitudinal direction (Table 4, Figure 7). The chemical treatment significantly affected the conductivity of the SYP wafers at oven dry conditions (Table 4) and Creosote was significantly more conductive than other treatments (F=59.02; d.f.= 4, 195; P=<0.0001). Untreated wafers and CCA wafers conductivity were statistically less than that of Pentachlorophenol and Copper Naphthenate.

Measurements for the conductivity of southern pine (*Pinus sp*.) wafers impregnated with selected chemical treatments used for utility poles (Creosote, Pentachlorophenol, CCA, and Copper Naphthenate) at 20% (+/- 3) moisture content were compared in the longitudinal direction (Table 4, Figure 7). No significant differences were found between chemical treatments at 20% moisture content (F=0.4; d.f.= 4, 195; P= 0.8107).

Measurements for the conductivity of southern yellow pine (*Pinus sp*.) wafers impregnated with selected chemical treatments used for utility poles (Creosote, Pentachlorophenol, CCA, and Copper Naphthenate) at 52% (+/- 3) moisture content were compared in the longitudinal direction (Table 4, Figure 7). The chemical treatment significantly affected the conductivity of the wafer (F=58.39; d.f.=4, 194; P=<0.0001) and the untreated wafers were statistically more conductive. Data on pine samples using small clears showed that Pentachlorophenol and Creosote were statistically the least conductive chemical treatment and Copper Naphthenate was significantly less conductive than untreated and CCA treated wafers.

Cross sectional

Conductivity of southern pine (*Pinus sp*.) wafers impregnated with selected chemical treatments used for utility poles (Creosote, Pentachlorophenol, CCA, and Copper Naphthenate) were compared in the laboratory using all data measurements along the cross sectional direction of the wafer (Table 5, Figure 9). Using all data points the chemical treatment and moisture content significantly affected conductivity (F= 8.67; d.f.= 4; P=< 0.0001) and (F=101.33; d.f.=2; P=< 0.0001) with interaction between the treatment and moisture content (F=8.62; d.f.= 8; P=<0.0001) . In the overall data comparison of the means using conductivity was greater for untreated SYP wafers and was statistically significant (F= 21.88; d.f.= 14, 584; P=<.0001) (Table 1.). The overall data showed that the conductivity of all other chemical treatments were not significantly different.

Measurements for the conductivity of southern yellow pine (*Pinus sp*.) wafers impregnated with selected chemical treatments used for utility poles (Creosote, Pentachlorophenol, CCA, Copper Naphthenate) at oven dry conditions were compared along the cross sectional direction of the wafer (Table 5, Figure 9). The chemical treatment significantly affected the conductivity of the SYP wafers at oven dry conditions and Creosote was significantly more conductive than other treatments (F=46.11; d.f.= 4, 195; P=<0.0001). No significant differences were found between chemical treatments using the data points taken at oven dry conditions.

Measurements for the conductivity of southern yellow pine (*Pinus sp*.) wafers impregnated with selected chemical treatments used for utility poles (Creosote, Pentachlorophenol, CCA, and Copper Naphthenate) at 20% (+/- 3) moisture content were compared along the cross sectional direction of the wafer (Table 5, Figure 9). No significant differences were found between chemical treatments using the data points taken at 20% moisture content (F=1.67; d.f.= 4, 195; P= 0.1592).

Measurements for the conductivity of southern yellow pine (*Pinus sp*.) wafers impregnated with selected chemical treatments used for utility poles (Creosote, Pentachlorophenol, CCA, and Copper Naphthenate) at 52% (+/- 3) moisture content were compared along the cross sectional direction of the wafer (Table 5, Figure 9). The chemical treatment significantly affected the conductivity of the wafer (F=8.59; d.f.=4, 194; P=<0.0001) and the untreated wafer was statistically more conductive. No significant differences were found between chemical treatments using the data points taken at 52% moisture content.

Measurements for the conductivity of southern yellow pine (*Pinus sp*.) one foot utility pole sections impregnated with selected chemical treatments (Pentachlorophenol, CCA, Copper Naphthenate) at various moisture content in between (10-20% MC) were compared along the longitudinal direction of the pole sections and compared to wafer data sets from oven dry to 20% moisture content (Table 3) in longitudinal direction given that longitudinal data had the best R^2 value (R^2= 0.90). Data for conductivity of the various chemical treatments of utility poles stayed within the variability of what was observed the corresponding wafer data in the longitudinal direction (Figure 8).

DISCUSSION

Historical data, although of different species, show similar findings to that of wafer data provided and when oven dry conditions are met Stamm's conductivity data show that the average conductivity of red pine should be J x 10-^{12} S/m. This is similar to SYP wafer averages of conductivity that are J x 10-^{12} S/m. Stewart's 1936 conductivity data from Creosote utility poles and Katz et al 1963 conductivity data from Creosote and Penta treatments are comparable to wafer data discussed below. Stewart defined a safe limit for lineman that work on 5,000 volt alive lines should be 5000 volts divided by 0.01 ampere or 500,000 ohms, therefore at normal moisture percentages (8%-20%) the conductivity changes from oil borne to water borne preservative were negative and well above the set threshold. The data supports that some current leakage is plausible in utility pole if its moisture percentage is at or above 52%.

Creosote

At first glance the wafer/pole data disagrees with Katz and Miller (1963), early in their discussion they state "that moisture contents from 15% MC to fiber saturation, creosote-treated wood remained somewhat more conductive than similar untreated specimens". When comparing their data and looking at a statement later in the discussion, "poles treated with creosote offer a higher electrical resistance than do untreated poles", it is thought that the earlier statement was a type-o and that conductive should be replaced with more resistive. Creosote treated red pine data provided by Katz and Miller (1963)showed that resistance in ohms at 25% MC was J x 10^5 ohms similar to that of SYP wafer at 20% MC data J x 10^7 ohms (Table 4). Stewart (1932) documented SYP pressure treated poles over several years documenting the poles moisture content each year ranging from 19-30%, poles were air seasoned and had an average resistivity of J x 10^6 ohms similar to all other measurements from the wafer data set and Katz and Miller (1963). Differences in conductivity were seen at oven dry conditions, creosote treatments were significantly more conductive than the untreated SYP wafer and any of the other treatments. This is similar to the corrected statement from Katz and Miller showing that below 15% MC creosote displays a slightly more conductive treatment than untreated wood. Oil borne preservatives such as Creosote aid in keeping water from having the same penetration into the wood (i.e. contact with the cell wall) opposite of its water borne counterpart. This coating causes its conductivity to be slightly more at oven dry conditions because the wood cells are partially coated with oil and when moisture is introduced the opposite interaction occurs reducing its conductivity to that of oil and not water.

Pentachlorophenol

Chemical treatments were comparable to untreated wood wafers at 20% MC and the data that is published by Katz and Miller (1963)for red pine treated with Penta are similar to SYP treated with Penta. Red pine treated with Penta has a resistivity of J x 10^3 ohms at 25% MC compared to that of SYP treated with Penta having a resistance of J x 10^3 ohms at 20% MC (Table 4). Significant differences in conductivity were seen at oven dry conditions, Penta treatments were significantly more conductive than the untreated SYP and all other treatments except creosote. The two oil borne chemical treatments were similar when the moisture was above FSP having the least conductive property. Penta in P9-A oil values are similar to creosote at oven dry conditions but the solids inside creosote are slightly more conductive than penta causing a slight difference in the conductivity.

Chromated Copper Arsenate (CCA)

Pulido (1977) produced large data sets for the conductivity of CCA, these data were conductivity readings for a hard maples species and not applicable to SYP. Katz and Miller (1963) provided data on Greensalt "K" (CCA formulaion) and found that it was in general 10 times more conductive than the oil borne treatments. When wood treated with modern CCA formulations the conductivity was not the same as Greensalt "K". In oven dry conditions CCA was significantly less conductive than Creosote, Penta, and CuNap and it was significantly more conductive than the untreated control but it was only 5 times more conductive not 10. CCA was significantly more conductive than all other treatments except the untreated control at moisture content above the FSP. This is expected for the conductivity of a chemical treatment containing a metals although the CCA water borne treatment is comparable to the oil borne treatments as it relates to conductivity being within the same order of magnitude and it ranked near untreated SYP conductivity readings at every moisture content. Much work published in the past 30+ years, under the campaign " all green treated wood is not alike" hs previously published values where salt type CCA is more corrosive and more conductive than Oxide based CCA.

Copper Naphthenate (CuNap)

CuNap conductivity was similar to the untreated control and all other chemical treatments at 20% MC. Differences were observed at the oven dry condition where CuNap was more conductive than the untreated control and CCA but less conductive than both Creosote and Penta wood treatments, the other two oilborne/oil-type treatments in this study; this may be due to the properties of the carrier of CuNap having similar effect as the oil borne preservatives. When the MC was above fiber saturation CuNap conductivity readings were significantly higher than Creosote and Penta but lower than the untreated control and CCA. CuNap conductivity was comparable to the oil borne treatments that were observed in the past and the conductivity was the same as or slightly better than CCA. When moisture is held constant and both longitudinal and correctional data are compared CuNap has the lowest conductivity value of all systems evaluated in this study.

Pole Sections

Stamm's 1929 article discuses the difficulty of making conductivity readings of large wood samples because of factors such as moisture gradients, spring/summer wood composition, and other variations that affect the measurement. Moisture differences were noticed in the utility pole sections even though the environmental conditions were controlled for three months and moisture content of poles were taken using their oven dry weight. Langwing and Katz (1963) showed that from 0-20% moisture content the conductivity measurement are linear. Conductivity in the longitudinal direction were determined for each pole section (Table 3) along with its moisture content and the data points were overlaid onto a box and whisker plot showing the wafer data range from 0-20% (+/- 3) (Figure 9) . Longitudinal data is only discussed in the conclusions based on the data R^2 value was the highest for longitudinal readings (R^2= 0.9) indicating that longitudinal readings would better predict the conductivity of the pole sections. Conductivity data from the longitudinal direction taken from larger utility pole samples fit inside the data range of the wafers. Future projects should examine the conductivity of at least 500 poles KDAT of the same grade in the longitudinal direction to determine the variability of the pole cylinder of larger wood pole samples.

CONCLUSIONS

The objective of this study was to determine if chemical treatments used for utility pole treatment affected the conductivity of southern yellow pine (*Pinus sp.*) at various moisture contents. The results showed negligible changes in the electrical resistance in both the longitudinal and radial directions at all levels of moisture except for oven dry. Significant differences were noted between chemical treatments depending on moisture concentrations, but all measurements were within one order of magnitude when compared for the same moisture content. Conductivity is a material property, and thus a small clear sample of southern pine theoretically should have the same material property as that of a larger sample of southern pine. Wafers were used to reduce the many variables like the moisture gradient, chemical treatment retention and penetration seen when observing large samples to define the conductivity changes for southern pine. Moisture significantly changed the conductivity of Southern pine wood samples (500 wafers, 5 treatments) that were observed along both the cross sectional area and longitudinal area at the three noted moisture contents no matter the chemical treatment. The conductivity changed in value by 8 orders of magnitude for the longitudinal area and by 7 orders of magnitude for the cross sectional area from Oven Dry to Fiber Saturation 52% (+/- 3) (Table 2 & 3). As moisture increased the conductivity increased. Longitudinal readings were best for making predictions of Southern pine conductivity (R2= 0.878) and at normal moisture conditions (20% MC) chemical treatments did not affect the conductivity of the southern pine wood. Southern pine pole sections conductivity data were similar to and fit inside data values taken for similar treated wafers. This study, the second in a four part series, proves definatievly copper Naphthenate treated wood poles are not conductive, and in many cases less conductive that other oilborne / oil-type treatments, such as penta or creosote. This work also confirms the testing of conductivity in both pine and hardwood crossties by the TTCI, finding CuNap treated wood to be less conductive than creosote or creosote-petroleum treatments.

Table 1. Retention values of chemical treatment inside the first four inches of the wood wafers.

TREATED WOOD RETETNION	
Sample ID	**Retention**
Untreated	-0-
CCA	0.623 PCF
Copper Naphthenate	0.094 PCF
Creosote	9.07 PCF
Pentachlorophenol	0.468 PCF

Table 2. Average Chemical Treatment Pentration of the Cross Section in Inches of Poles

Average Chemical Treatment Penetration of the Cross Section in Inches of Poles			
Chemical Treatment	**Penetration**	**Heart**	**Penetration**
Untreated	0	4	0
Penta	3.5	4	4.5
CCA	3	4	5
CuNap	4	3	5
Average is based on 5 1' pole sectioncross sections pulled from five different parent poles.			

Table 3. Conductivity Measurements in the Longitudinal Direction of 1 foot Pole Sections

Conductivity Measurements in the Longitudinal Direction of 1 foot Pole Sections			
Chemical Treatment	**Siemens/meter**	**Ohm-M**	**Moisture Content**
CuNap	1.01E-08	9.94E+07	15.5
Penta	2.13E-06	4.69E+05	17.1
Untreated	1.68E-08	5.94E+07	16.2
CCA	2.96E-06	3.01E+09	16.5
*Average measurements of 5 pole samples			

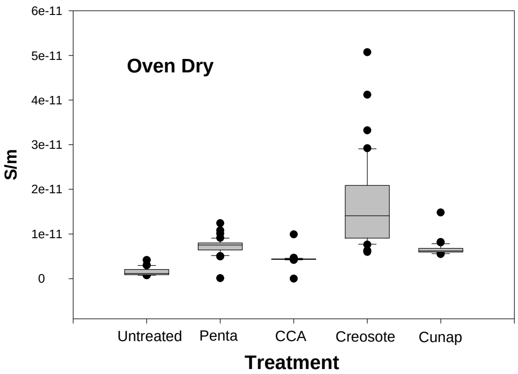
Table 4. Conductivity Measurements in the Longitudinal Direction at three moisture contents

Conductivity Measurements in the Longitudinal Direction		
Oven Dry Readings		
Siemens/meter	**Chemical Treatment**	**Conductivity Duncan Grouping**
1.6E-11	*Creosote*	*F*
7.2E-12	*Penta*	*G*
6.06E-12	*CuNap*	*G*
4.4E-12	*CCA*	*H*
1.6E-12	*Untreated*	*I*
20% Moisture Content		
8.50E-07	*Penta*	*E*
6.80E-07	*Untreated*	*E*
6.40E-07	*CCA*	*E*
6.30E-07	*CuNap*	*E*
5.00E-07	*Creosote*	*E*
Saturated		
3.10E-03	*Untreated*	*A*
2.60E-03	*CCA*	*B*
2.00E-03	*CuNap*	*C*
1.30E-03	*Creosote*	*D*
1.10E-03	*Penta*	*D*
*S·m-1 is the LS mean rounded to the nearest 10th		
40 Samples per Chemical treatment		

Table 5. Conductivity Measurements in the Cross Sectional Direction at three moisture contents.

Conductivity Measurements in the Cross Sectional Direction		
Oven Dry Readings		
Siemens/meter	**Chemical Treatment**	**Conductivity Duncan Grouping**
2.95E-11	*Creosote*	*A*
1.22E-11	*CCA*	*B*
1.15E-11	*Untreated*	*B*
1.15E-11	*Penta*	*B*
1.12E-11	*CuNap*	*B*
20% Moisture Content		
5.95E-07	*Penta*	*A*
2.85E-07	*CCA*	*AB*
9.70E-07	*Untreated*	*AB*
9.10E-08	*Creosote*	*AB*
4.64E-08	*CuNap*	*B*
Saturated		
1.18E-03	*Untreated*	*A*
4.40E-04	*Penta*	*B*
4.30E-04	*Creosote*	*B*
3.80E-04	*CCA*	*B*
3.00E-04	*CuNap*	*B*
*S·m-1 is the LS mean rounded to the nearest 10th		
40 Samples per Chemical treatment		

A)



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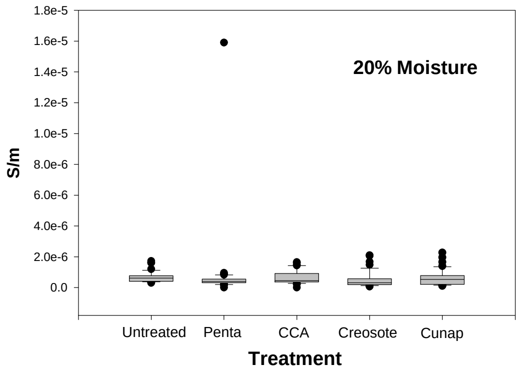

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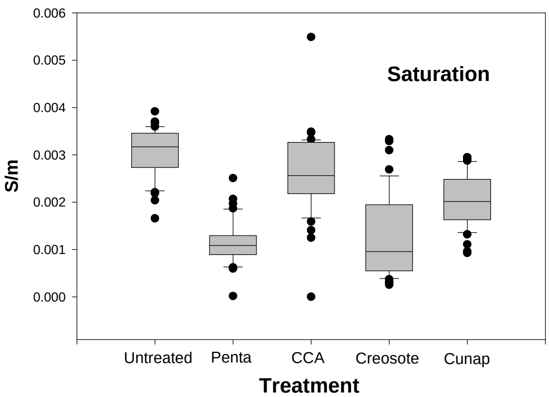

Figure 7. Box and Whisker plots of conductivity data for southern yellow pine (*Pinus sp.*) wafers impregnated with selected chemical treatments used for utility poles (Creosote, Pentachlorophenol, CCA, Copper Naphthenate), measurements made in the longitudinal direction of the wafer. (A) Longitudinal measure of conductivity at oven dry conditions consisting of 40 wafers. (B) Longitudinal measure of conductivity at 20% moisture content consisting of 40 wafers. (C) Longitudinal measure of conductivity above saturation (54%), called saturation consisting of 40 wafers.

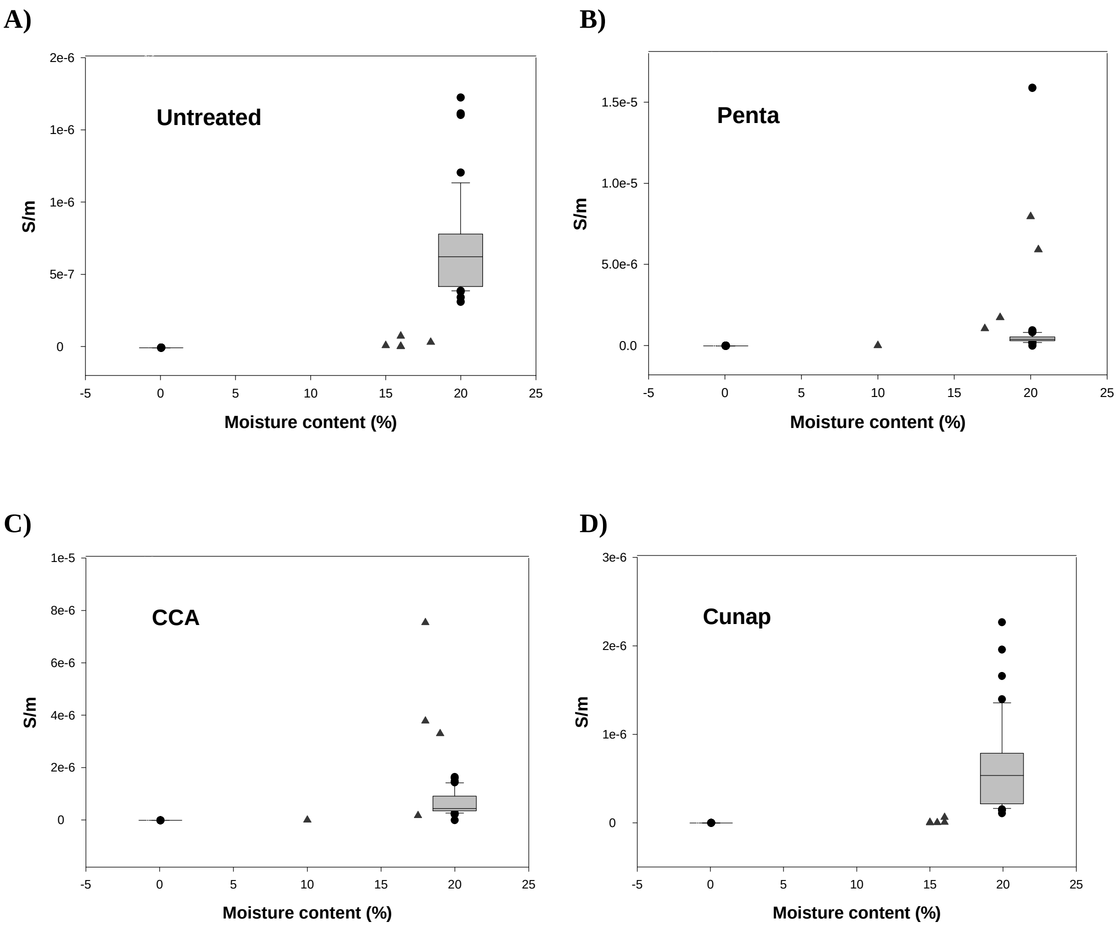

Figure 8. Box and Whisker plots of conductivity data ranging from oven dry conditions to 20% moisture content of wafer with the addition of the conductivity of five one foot utility pole sections (red triangles) plotted for untreated SYP (40) and chemically treated SYP Penta (40), CCA (40), and CuNap (40).

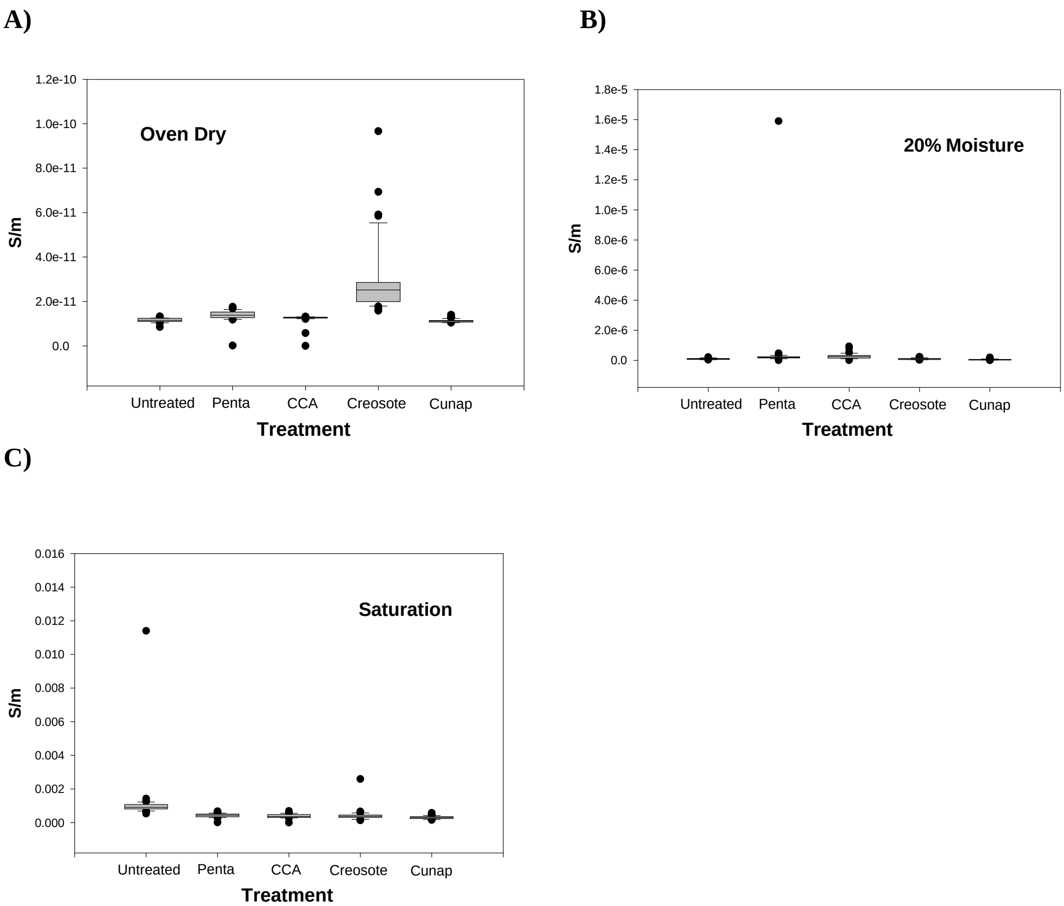

Figure 9. Box and Whisker plots of conductivity data for southern yellow pine (*Pinus sp.*) wafers impregnated with selected chemical treatments used for utility poles (Creosote, Pentachlorophenol, CCA, Copper Naphthenate), measurements made along the cross sectional direction of the wafer. (A) Cross sectional measure of conductivity at oven dry conditions consisting of 40 wafers. (B) Cross sectional measure of conductivity at 20% moisture content consisting of 40 wafers. (C) Cross sectional measure of conductivity above saturation (54%), called saturation consisting of 40 wafers.

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