Electrical Impedance Study of Borate/Creosote Dual Treated Wood Crossties

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Executive Summary

From 2005 to 2007, 151 white oak ties that had been positively identified for species and matched for similar characteristics, boxed heart and void of defects and treated with wood preservatives were tested for electrical impedance. 51 ties had been treated with creosote to Norfolk Southern railroad's standards and approximately 100 ties had been pre-treated with disodium octaborate tetrahydrate (DOT) and subsequently treated with creosote to NS standards. The data collected were examined by a statistician independent of the data collection team and without commercial interest in wood preserving, and two primary conclusions were reached through this analysis:

1) Moisture content (MC) is the primary driver for the electrical impedance properties of wood ties
2) Borate pre-treatments in the amounts tested have no discernable impact on the impedance of wood ties at MC levels in the primary data set analyzed ranging between 25 and 39 percent.

Additionally, several other observations were made:

A) The relationship between MC and electrical impedance is non-linear and thus requires measurements for each individual tie when testing for impedance.
B) Wood samples treated either with creosote only or pre-treated with borates and then treated with creosote exhibit similar impedance characteristics when MC exceeds certain MC thresholds. As an example, in the samples of treated crossties tested, impedance never falls below 10 kOhms when the MC is lower than 39%. Since MC threshold in commercial treating plants at which point materials are normally processed is 40% for mixed hardwoods and 50% for oaks (based on standard three inch borings), measuring impedance immediately after processing will be unproductive and will not produce a true picture of the electrical properties of any treated wood tie product. *Compounding this issue, and in this regard it is important to note, The Wood Handbook (reference manual for wood properties) states that once moisture in a wood sample exceeds the fiber saturation point (generally between 28-30%) increases in conductivity are "erratic". Also based on this knowledge it can be assumed that in track applications where ties might achieve 40% MC or above for a period of time, some creosote and some borate/creosote ties will very likely exhibit impedance values less than 10 kOhms.*
C) In a comparative test like the one here it was determined that the data set must include a minimum of 25 control ties (creosote-only) to compare to a minimum of 25 other treated

wood ties to produce desired confidence levels. If additional variables are included such as varying species, the number of ties in the sample will need to be increased. Also, given the relative difficulties experienced during data collection it is suggested that a few extra ties in each set of ties be included for safety's sake. Finally, it must be noted that without the use of multiple regression analysis, even in the case of the specific data analyzed herein, the number of ties would necessarily need to be larger than stated in this recommendation to provide the desired level of confidence.

Introduction

For decades it has been hypothesized that borate-based compounds could be utilized as an effective enhancement for timber crossties in a multi-step wood preservation process. This process would employ a primary oil-borne wood preservative such as creosote as a dual treatment following a borate pre-treatment.

The reasoning behind this is that borate compounds such as disodium octaborate tetrahydrate (DOT) remain mobile in wet wood, diffusing throughout difficult to treat species, thus providing protection for areas of timber ties normally not reached by a primary preservative. [1] Considering that several timber tie species are refractory (i.e., hard to treat), this enhancement promises significant extension of tie life in extreme decay and termite hazard conditions.

In 1987, AAR/RTA/MSU began an in-revenue-service research project that would put this hypothesis to the test. The results of that study indeed showed that DOT could be used as a pre-treatment followed by creosote treatment to effectively preserve the entire cross-section of both refractory and non-refractory species of timber ties and remain efficacious against decay and termite attack for at least 20 years.[2]

Following the publication of these results two Class 1 railroads, Norfolk-Southern Corporation and Canadian National Railway, embarked on ambitious programs to procure and install borate pre-treated ties for track applications in high decay/high termite hazard areas.

To date over 1 million pre-treated ties have been produced and installed in maintenance-of-way programs for these and other railroads. These installations have occurred in many different types of track applications, including mainline signaled track, and all ties are reported as performing well.

Even so, questions have been raised by a potential user about the electrical impedance properties of timber ties that contain borate compounds. Since no wood-specific test methodology has ever been developed to measure electrical impedance, nor is there any substantive quantitative evidence about the subject, these questions raised corollary questions about the electrical impedance properties of non-borate creosote only treated ties. And finally, questions have also been raised about whether or not borate compounds increase wood timber's affinity for moisture (hygroscopicity).

[1] References 1,2,3
[2] References 4,5,6,7

A search of industry archives and other resources found little data that could be referenced as to any tests conducted on timber ties for electrical impedance. Although there may be some data where such research may have been conducted, it was generally done so on small samples as part of other evaluations. In some cases the tests were conducted when the wood was in one state of MC and then in a subsequent laboratory-induced "wetter" state of MC.[3]

AAR's recommendation[4] for timber ties is that the ties must have a minimum of 7,000 Ohms resistivity. At least one Class 1 railroad raised that minimum to 10,000 Ohms.

With no large-scale research available to reference and no wood specific test methodology in existence, TASKpro in conjunction with Seaman Timber Company, and Osmose, and within the guidelines of Norfolk-Southern Corporation's current commercial specifications, undertook a project to measure the electrical impedance properties of 151 borate pre-treated and creosote-only white oak ties over a period of the last three years. The following is a discussion of the results of that study.

Methodology

Beginning in 2005 a mill-run selection of ties including white oak, red oak, and hickory was set aside out of normal commercial wood preserving plant production runs to be measured for electrical impedance properties. These ties were borate pre-treated/creosote dual treated and creosote-only treated to Norfolk-Southern standards for pre-treated and creosote-only ties. The ties were pre-plated to NS standards with 8" x 15" tie plates and two cut spikes per plate[5]. After some initial readings it became apparent that mill-run intermixed species provided a level of inconsistency in measurements that would require larger samples to be evaluated to develop meaningful and valid data, so much so, as to potentially render the research impractical. Some of the reasons for this, in addition to the intermingling of species, were that anomalies including varying amounts of sapwood in some species and defects such as worm holes, checks, splits, shake and knot-holes were present in the mill-run ties.

Thus, 150 boxed-heart white oak ties (2 sets of 50 each borate pre-treated[6] and 1 set of 50 creosote only ties) visually matched for a lack of sapwood and defects were used for data collection, analysis, and reporting. The majority of results discussed are from the measurements made on these ties hand selected for similar physical properties.[7]

A 6V battery was used to apply a charge across the leads and a digital multimeter was used to measure mA. Then a calculation was made to convert these readings to kOhms.

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[3] AREMA 30 concrete tie impedance test (AREMA Standards Chapter 30)

[4] Internal UPRR document (attached)

[5] A test was run in which additional spikes were added to the un-spiked holes in order to see if the additional spikes changed impedance values. The test indicated that the same reading was achieved using two or five leads on each plate and it was decided to measure using two leads per plate. Additionally, since this test was performed as much to see the relative differences between creosote only and borate/creosote ties in addition to developing a range of impedance values, simply being consistent with the methodology was considered the most important factor. This reasoning applied to the decision not to install rail as well, especially considering that there was not an attempt being made to create a track circuit and that rail weights vary between various railroad track applications.

[6] See borate pre-treating standard attached

[7] Ties were selected by Jim Watt of The Crosstie Connection

Pre-Plated Test Ties

In 2006 and 2007 the same ties were re-measured using essentially the same technique.[8]

In 2005 and 2006, MC measurements were made of the tie sets using general treating plant practice (average MC was determined using approximately 10-15 core borings per 50 ties randomly selected and oven dried). In 2007, due to the analysis of the 2005 and 2006 data which confirmed that MC was driving the change in impedance values rather than treatment type, more detailed methods of measuring MC were initiated.

First, in the March 2007 evaluation core borings from select two or three tie sets were measured for MC and matched to the impedance of those ties. Then following the statistical analysis of the January and March 2007 data a July 2007 data set was taken and individual tie MC was measured and matched to that specific tie's impedance measurement. The reasons for taking this final set of MC/impedance measurements and the results that it provided will be discussed in the sections below.

Finally, after all the data was collected an independent statistician performed multiple regression analysis to assist in developing, refining, and verifying conclusions.

During the three and a half year study many things were learned. These will be segregated into two separate sections, Findings and Conclusions from Direct Measurement and Findings, where the complete discussion of methodology as it relates to statistical analysis is discussed, and Conclusions from Pertinent Reference Reports, where key information not heretofore documented in the railroad industry is revealed.

Findings and Conclusions from Direct Measurement

The findings and conclusions from the direct measurement process are written in two sections. Part 1 describes the 2005, 2006, January 2007 and March 2007 data gathering methods in greater detail and then the analysis of that data. Part 2 describes the reasons for developing a more

[8] In 2006, failure of the multimeter half way through the measurement process necessitated calculation of kOhms using a slightly modified measurement technique approved by an independent electrical engineer. Direct readings of Ohms were made across all of the ties with the leads in the same position on the tie plates and a conversion to kOhms was made by calculation

pristine data set as it relates to MC measurements; this data was collected from the same ties on July 17, 2007. Part 2 also includes the analysis of the data and resulting conclusions.

Part 1

The conclusions of this analysis are:

1. MC is the primary driver in terms of tie impedance.
2. Borate pre-treatment has no discernable impact on impedance in the primary test data analyzed where MC is in the range of 25 to 39 percent.
3. Given the impedance "explained" by MC, the remaining differences in impedance remain unknown. That is, even though borates are not a causal factor in impedance differences between individual ties in this test, the reasons for the differences measured largely remain a mystery. Some candidate factors to investigate are suggested in the text details below.

Two data sets are examined in Part 1 of this paper. The primary data is that collected in March 2007. The secondary data was previously collected in 2005, 2006, and January 2007. The advantage of the March 2007 data set is that MC was measured with a greater degree of accuracy, which allowed the use of more advanced statistical techniques. Both sets of data were collected at Seaman Timber Company, and consist of electrical impedance (in kOhms), MC (in percent by weight), wood type (white oak or red oak), and pre-treatment (borate or not).

The March 2007 data set

The merging of data is shown in Appendix 1. The process involved matching MC measurements with impedance readings. Impedance was recorded for individual crossties, but even though improvements were made in MC collection, which increased the accuracy of the measured data over the multi-year data set, MC was not recorded for each tie (see Part 2 for further discussion). Moisture was measured in a process whereby cores extracted from two or three ties were placed in a bottle, weighed, dried, weighed again, and MC calculated. This yielded “average” MC for the two or three ties. As shown in Appendix 1 this “average” was assumed to be an accurate MC measure for each of the two or three ties in a given bottle.

The next step involved screening the data (Appendix 2) for values that lie outside three standard deviations from the sample mean. One such value was found and discarded leaving 56 sample ties with a mean value of 95 kOhms. MC was in the range 25 percent to 39 percent with a mean of 32 percent. The screened data was arranged for analytical purposes in Appendix 3 where graphs of impedance and MC can be seen.

The first statistical test is shown in Appendix 4, regression 1, where the hypothesis is: **"Borate pre-treatment has an effect on impedance".** The diagnostic statistics used here are the regression coefficient (-15) and the standard error of the regression coefficient (13). The regression coefficient postulates that borate pre-treatment reduces impedance by 15 kOhms. The standard deviation measures uncertainty about this statement (or the size of the regression coefficient.) To be 95 percent confident about the statement, two standard errors are added to each side of the coefficient. That is, borate reduces impedance by as little as -15 + (2 times 13) = -15 + 26 = 11 KOhms. On the other side, impedance could be affected by as much as -15 - 26 = -41 kOhms. This range (11 to -41) includes the value zero, indicating no effect of borate on impedance. **At the 95 percent confidence level borate fails to demonstrate an effect on impedance.**

The second test is shown on the Appendix 4, regression 2, where the hypothesis is: **“MC has an effect on impedance".** The diagnostic statistics used here are the regression coefficient (-5.1) and the standard error of the regression coefficient (1.5). The regression coefficient indicates that a one percentage point increase in MC reduces impedance by 5.1 kOhms. At a 95 percent confidence level, the effect could be as little as 2 kOhms reduction, or as great as 8.1 kOhms reduction. **Since this interval does not include the value zero one can be confident that higher MC reduces impedance.**

The third test is shown in Appendix 5, regression 3, where the hypothesis is: **"MC and borate pre-treatment have an effect on impedance".** The purpose here is to evaluate the data for the effects of moisture and search for any effect borate might possess. The diagnostic statistic for this purpose is the t-statistic, which measures the regression coefficient divided by the uncertainty surrounding the coefficient; for this sample size a t-statistic of 2.0 or greater (absolute value) indicates the variable is significantly related to impedance. This is essentially the same test as explained above, only the results are easier to digest. **MC passes this test, but borate pre-treatment has no effect on impedance.**

The fourth test is shown in Appendix 5, regression 4, where the hypothesis is: **"MC, borate, and wood type have an effect on impedance”.** The t-statistics indicate MC has an effect on impedance but borate and wood type (red vs. white oak) do not. **Since an insufficient number of ties were measured (only five red oak ties are included in this sample) this is an inadequate test for different wood types.**

The fifth test is shown on the Appendix 6, regression 5, where the hypothesis is: **“MC and wood type have an effect on impedance".** Again, **since only five red oak ties were included in the sample** and no other species (other than white oak) are included this test does not include enough data to be conclusive. **More observations of this or other species are needed to reach any valid conclusion.**

The sixth and seventh tests repeat hypotheses from tests 2 and 3 above, but utilize a logarithmic equation form.

The sixth test (regression 6) results in the best equation form and results. The logarithm of impedance is shown to depend on MC. In this regression, the F statistic (explained variance in impedance divided by unexplained variance) is higher than any of the other equations tested. Also the t-statistic (4) indicates a relatively small degree of uncertainty surrounding the regression coefficient. **Again MC is shown to be the driver that affects impedance.**

The seventh test is an attempt to give a complete test for borate pre-treatment. The t-statistic indicates a large amount of uncertainty surrounding borate’s regression coefficient, and the conclusion is that when controlling for the effects of MC, **borate has no significant effect on impedance** (see Appendix 7.)

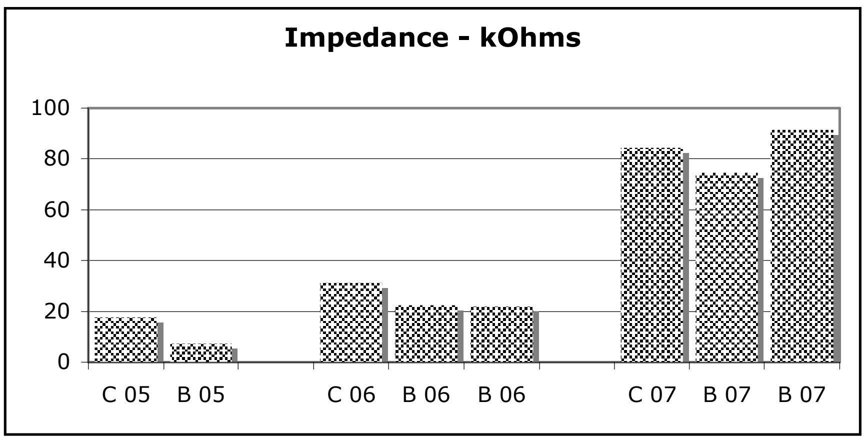
Finally, the eighth test represents the best results in Part 1, seen in Appendix 9. This is a repeat hypothesis: **"MC has an effect on the logarithm of impedance"**. But, here an adjustment has been made to MC of the ties measured on March 19, 2007; it was assumed that the ties tested lost some moisture since the impedance measure was made, on January 31, 2007. Thus, an estimate was made of lost moisture (see appendix 8: "MC adjustment"), and this lost moisture was mathematically added back to the March moisture levels. This should have restored moisture to January 2007 levels when the first 2007 impedance values were collected. The regression was performed with this adjusted MC data, and the F statistic and t-statistic improve. **This slightly improves the MC cause-and-effect relationship.**

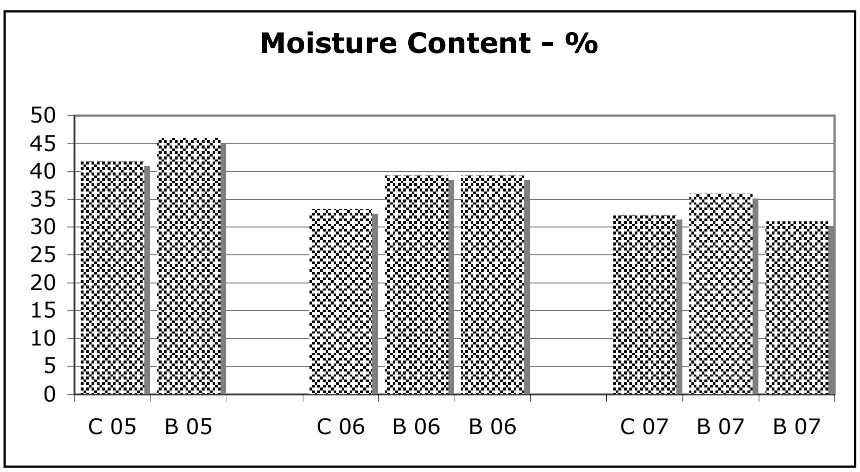
However, one finding must be emphasized. The amount of “unexplained” variance in impedance is very large. In Appendix 9, it can be seen that unexplained variance is 77 percent of total variance. This means impedance is quite different from one tie to the next and most of this difference is not explained by factors/variables in the equation. Since the residuals (equation errors) are not small, but rather large, it indicates “other factors/variables” could be in play. In addition to this there is other evidence that "something is missing" from the equation. This is illustrated by the pattern of the residuals (see graph in Appendix 9). The residuals are closely correlated with the impedance values whereas a random pattern of residuals is desired. If a regression equation explains most of the impedance differences among ties the residuals will be small. Additionally the residuals will not be correlated with anything, they will be random. This means that in future experiments on tie impedance an effort should be made to include other variables that might help explain why impedance varies from one tie to the next.

The Multi-Year Data Set

A larger data set has been assembled which includes grouped data from 2005, 2006, and 2007. This data set contains only white oak ties. They are tracked through time with impedance measured on three dates, and group MC estimated by sub-sample on the same three dates. The summary data are presented below, where “B 05” signifies the 2005 borate sample, and “C 05” represents the 2005 creosote-only (non-borate) sample. The same identification method is used for the other years.

Sample	date	Mean MC %	Mean kOhms	sample size
Borate	5/15/05	45.95	7.30	59
Non-B	5/15/05	41.88	17.66	51
Borate	4/6/06	39.30	22.45	32
Borate	4/6/06	39.30	21.94	35
Non-B	4/6/06	33.30	31.18	30
Borate	1/31/07	35.97	74.47	55
Borate	1/31/07	31.11	91.40	37
Non-B	1/31/07	32.28	84.41	35





Some data were discarded due to suspected measurement error and previously discussed deviation issues. The data collection team wanted to measure ties that were as closely matched as possible for species, age, and MC. Thus, in eliminating as many variables as possible, any impedance differences seen would necessarily be the result of only the borate pre-treatment. However, if this experimental logic is followed it assumes that there are no other significant causes for impedance to differ from one sample of ties from the other.

Instead, the tests conducted on the 2007 data suggest that a very large amount of variance in impedance is in fact unexplained by the variables measured in this experiment. This suggests that matching tie samples (borate vs. non-borate) by trying to use comparable species, age, and MC is not enough to assure that a measured impedance difference between the two samples (one borate and one non-borate) is due to only borate pre-treatment.

Examination of the sample data above leads to two conclusions:

1. As crossties age they lose MC and gain impedance.
2. Comparison of these sample data fails to provide evidence that links borate treatment to loss of impedance.

Another lesson can be learned from this experiment. An attempt to match MC between two tie samples is very difficult to accomplish and is an impractical approach. This can be seen in the non-borate sample which in 2005 and 2006 has significantly lower moisture than the borate samples. Yet, by 2007 the non-borate sample has slightly higher moisture than one of the borate samples. Since physically controlling MC is impractical this should be handled analytically as is done with multiple regression.

Interestingly, one might be tempted to conclude from the 2005 data that borate (with an average 7.3 kOhms) causes lower impedance (lower than the non-borate 17.66 kOhms). However, this ignores the fact that MC of both samples is extremely high, especially the borate sample (46 percent as compared to 42 percent MC for non-borate.) Thus, one should expect the more moist borate sample to have lower impedance. The borate sample has impedance that is 10.35 kOhms lower than the non-borate sample. The equation, regression 8, is used to predict the expected impedance difference, given the MC difference. The equation predicts the moist borate sample should have impedance 10.14 kOhms lower than the dryer non-borate sample. This comparison is complicated by problems in data collection and measurement, but the indication is that the impedance difference reflects moisture difference. The 2007 sample data exhibit a very similar result; oddly, the 2006 data do not fit this pattern, and one is lead to question the accuracy of the sample data, especially the impedance readings (see footnote 8).

Another lesson revealed by the experiment has to do with measuring MC. In the earlier data collection efforts each of the eight tie samples was sub-sampled where the MC of the eight ties was measured. The mean value of a sub-sample (eight ties) was used to represent mean MC of a sample (from 30 to 92 ties.) The experimental logic is that if average moisture of two like samples is the same the average impedance should be the same. The problem is that two like samples with the same mean MC can have different impedance values due to differing “distributions of MC” among individual ties within the samples. This would not be the case if impedance and MC were linearly related, but regression equation 6 and previous studies in "The Wood Handbook" testify that the relationship is non-linear (see mathematical demonstration of this in Appendix 10). Thus, future experiments should document MC (and any other variables that can be measured consistently) for each individual tie.

Despite this, the experiment's results should be examined for what might be learned. When sample mean values are compared, clearly they are different. For example, the 2005 borate sample has a mean of 7.3 kOhms, while the non-borate sample has a mean of 17.66, a difference of 10.35. Is this difference large enough to indicate the populations’ mean values (all white oak ties of this age) are different? Calculations suggest one can be 95 percent confident that the population means are different by as little as 7.8 kOhms or as much as 12.88 kOhms. The conclusion is the population of borate ties possesses less impedance. However, as has been demonstrated in the above discussion, differences in MC are the explanation for differences in impedance, not the presence of borates.

In 2007 the sample means fail to demonstrate any differences between borate and non-borate populations. Calculations suggest one can be 95 percent confident the population means differ by as little as -11.86, or as much as 18.12 (borate data combined). The range of values here contains zero, indicating the probability of no difference. The conclusion here is that at the 95 percent confidence level one cannot say the populations (borate vs. non-borate) differ in impedance. This reinforces the regression conclusions.

Recommendations

"The Wood Handbook" states that when MC is above the fiber saturation point (28 to 30 percent, as are most of the sample ties) changes in moisture bring about erratic changes in impedance. This erratic nature of the data should cause one to delay impedance testing until moisture levels fall at least into the mid to low 30's, where impedance has stabilized somewhat. The erratic changes in impedance could be investigated further. In terms of the other factors that might affect impedance: temperature, species, tie defects, and geological/geographical area in which the tree grew are possible variables that might be consistently measured.

Secondly, the erratic nature of wood may require test standards for wood that are much more sophisticated and costly than for homogeneous materials like concrete. For example, it is certain from the results seen so far that comparative tests which utilize control samples may be required for valid observations to be made.

From this experiment it should be apparent that attempts to match tie samples with the same MC are not practical. One would like to physically control MC and observe the impact of other factors (borate pre-treatment vs. not) on impedance. But, since this is not practical, a most effective means for analyzing data like this is multiple regression, as demonstrated in this study. Each tie should be measured for impedance, age, MC, and other prospective variables, as noted above.

Secondly, experiments conducted on ties with high levels of moisture are subject to erratic impedance results, which by themselves, would require larger sample sizes, and even so, might be misleading.

Part 2

Reviewers of the report that is now recorded as Part 1 in this paper felt comfortable with its conclusions; yet it still contained questions regarding the MC measurement methods employed. As explained above and mathematically in the appendices, MCs should not be averaged, but should be measured for each crosstie. Without this the data sets are subject to measurement bias. Also, impedance and MC should be measured at the same time. Thus, additional measurements were made July 2007 in an effort to create a pristine data set where impedance and MC were measured for each individual white oak only crosstie. This data collection effort indeed did eliminate measurement bias and standardized wood type.

These data are shown in Appendix 11. The top group shows data as reported. The second group identifies data screened for data points above or below three standard deviations from the mean. Three data points were discarded, leaving 55 observations. The third group displays data arranged for input to regression analysis.

The first test is shown in Appendix 12, regression 9, where the hypothesis is: **"MC and borate pre-treatment have an effect on impedance".** The purpose here is to adjust the data for the effects of moisture, and search for any effect borate might possess. The diagnostic statistic for this purpose is the t-statistic, which measures the regression coefficient divided by the uncertainty surrounding the coefficient; for this sample size a t-statistic of 2.0 or greater (absolute value) indicates the variable is significantly related to impedance. **MC is shown to possess statistical significance, but borate pre-treatment is shown to have no effect on impedance.**

The second test (Appendix 12, regression 10) is an attempt to give a better test for borate pre-treatment. The hypothesis is: **"MC and borate pre-treatment have an effect on impedance".** This equation form allows for the non-linear effects of MC, and this fits well, improving the statistical reliability of the equation. However, the t-statistic for borate indicates a large amount of uncertainty surrounding the regression coefficient. **Thus, the conclusion is that when controlling for the effects of MC, borate has no significant impact on impedance**.

The last equation shown (Appendix 13, regression 11) is the best equation from the pristine data set. The hypothesis is **"MC has an effect on the logarithm of impedance"** The equation illustrates the nonlinear relationship between MC and impedance. Borate pre-treatment is not included as a causal variable, and plays no role. **This further reinforces the main conclusion of this analysis that borate pre-treatment does not have an effect on impedance.**

Conclusions

These experiments were undertaken to determine what effect, if any, borate treatment has on electrical impedance of wood crossties. Data were collected and analyzed as summarized above. Experimental refinements were undertaken in order to eliminate error and uncertainties. From multiple statistical tests these results lead to the conclusion that borate pre-treatment has no discernable effect on the impedance of wood crossties.

Findings and Conclusions from Reference Reports

If one accepts the findings of the data analysis above then there is only one remaining question: Do borates, when applied at the levels now in use in commercial pre-treatment of wood crossties, cause significant and varying differences in MC in timber ties? In other words, are ties that contain DOT at the levels employed commercially more hygroscopic (likely to increase in MC) than ties not containing borates.

As has been carefully demonstrated above, trying to control and then consistently measure MC in wood ties is impractical. So, developing data along these lines, even if possible, would likely be cost prohibitive. So many samples would need to be tested and in a side-by-side comparative test as to render the entire process just as impractical as controlling MC in ties.

Fortunately, answers for this question have already been thoroughly researched.[9] In 1980 in the Journal of the Institute of Wood Science, J. Dulat reported on "The Effects of Borate Preservatives and Fire Retardants on Hygroscopicity and Moisture Content Equilibria in Timber" (see Document 2 attached).

Even using borate loadings far greater than what is used in today's commercial pre-treatment Dulat says that his research is ***"the final and conclusive proof that none of the borates tested [including DOT] enhanced in any way the normal equilibrium MC of the timber over the range of relative humidities from 30-90%".***

In fact, Dulat also suggests that DOT actually brings about a slight lowering of equilibrium MC in wood. This point is mentioned here because it has been observed and reported anecdotally, by two separate treating companies now in commercial production of borate pre-treated ties, that the air-drying of wood ties pre-treated with DOT occurs significantly faster than non-borated ties. In effect, what some now suggest is that DOT, as a pre-treatment, acts as a "lubricant" for moisture movement in the air-drying process and actually helps to liberate moisture in an accelerated manner. At the very least, based upon its efficacy against decay causing organisms[10], DOT inhibits moisture uptake due to decreased fungal growth on wood ties during the air-drying process.

To put additional emphasis on this research it should be noted that the retentions of DOT in wood samples measured in Dulat's research were 12.5 to 37.5 times greater (weight-to-weight) than today's commercial level of DOT pre-treatment used in wood ties.

Another salient point must be expressed here. In Dulat's work DOT was applied as a stand alone treatment in the wood samples measured. In the railroad applications described here, creosote is applied over the DOT pre-treatment. There is a wealth of information available that describes moisture movement in wood and how it can be retarded by waxes and other compounds that act as a vapor and wetting retardant. Creosote has also been shown through its long history of use to

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[9] J. Dulat, Jour. Inst. Wood Science, 1980, v8, pp 214-220 (attached in its entirety)
[10] References 1,8,9,10,11

be an excellent “weather-proofing” compound. Thus, by applying creosote as an additional treatment “over” the DOT, users not only gain the value of additional wood preservation properties, but also the value that creosote brings to the product as a weather-proofing moisture retardant. Evidence of this is further presented in that the long-term AAR/MSU/RTA test ties retained efficacious levels of DOT 17 years after they were put into service in “wet” climate areas even though DOT remains water soluble in pre-treated ties.

Summary and Conclusion

Even though DOT pre-treated ties have now been used for over 20 years in mainline track and, since 2004, have reached the status of commercialization with over 1,000,000 ties now in use in multiple Class 1 and other railroad track applications, some questions about the electrical properties of these ties have arisen from a potential user of this technology. This paper describes why these concerns are unwarranted.

The use of DOT in levels used today as a commercial pre-treatment for wood ties does not create any impedance issues in comparison to non-borate wood ties. The primary driver for changes in impedance in wood ties as it relates to the evaluation of DOT pre-treatments is MC of the tie. Furthermore, DOT does not enhance or increase the likelihood of moisture absorption in timber even at high relative humidities.

Thus, it can be concluded, given appropriate standards for application and quality control processes in place in commercial wood preserving plants, that DOT can be safely and effectively used as a pre-treatment for wood ties, including those destined for use in mainline signaled track applications where track impedance is a limiting factor.

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Appendix 1: Assemble data Page 1

Impedance data has been merged with moisture content data on this page.

Bottle #	Tie #	Bottle wt	Gr + Bottle	Gr Wood Wt	Dry + Bottle	Dry Wood Wt	MC %	Borate 1/31/2007 Sample	Reading (mA)	Reading (V) Battery	kOhms White Oak	MC %
White oak CREO/BORATE												
G	44A	98.158	100.753	2.595	100.11	1.952	32.94	44A	0.09	6.45	71.67	32.94
	33A							33A	0.08	6.45	80.63	32.94
H	32A	104.435	107.236	2.801	106.545	2.11	32.75	32A	0.08	6.45	80.63	32.75
	34A							34A	0.08	6.45	80.63	32.75
I	45A	97.398	100.162	2.764	99.488	2.09	32.25	45A	0.06	6.45	107.50	32.25
	41A							41A	0.08	6.45	80.63	32.25
J	31A	98.01	100.701	2.691	100.137	2.127	26.52	31A	0.09	6.45	71.67	26.52
	18A							18A	0.04	6.45	161.25	26.52
AVG						mean	31.11				mean	31.11
MEDIAN						median	32.50				median	32.50

Bottle #	Tie #	Bottle wt	Gr + Bottle	Gr Wood Wt	Dry + Bottle	Dry Wood Wt	MC %	Sample	NonBorate 1/31/2007 Reading (mA)	Reading (V) Battery	kOhms WhiteOak	MC %
White oak CREO-ONLY												
K	5	82.529	85.254	2.725	84.556	2.027	34.44	5	0.07	6.46	92.29	34.44
	14							14	0.06	6.47	107.83	34.44
L	15	95.773	98.232	2.459	97.675	1.902	29.28	15	0.05	6.47	129.40	29.28
	20							20	0.03	6.47	215.67	29.28
M	19	97.014	99.657	2.643	99.004	1.99	32.81	19	0.05	6.47	129.40	32.81
	29							29	0.13	6.47	49.77	32.81
N	32	94.503	97.054	2.551	96.427	1.924	32.59	32	0.08	6.45	80.63	32.59
	39							39	0.21	6.45	30.71	32.59
AVG						mean	32.28				mean	32.28
MEDIAN						median	32.70				median	32.70

Appendix 1: Assemble data Page 2

Bottle #	Tie #	Bottle wt	Gr + Bottle	Gr Wood Wt	Dry + Bottle	Dry Wood Wt	MC %	Borate 1/31/2007 Sample	Reading (mA)	Reading (V) Battery	kOhms	MC %
White & red oak CREO-BORATE												
G	**52**	98.177	100.765	2.588	100.06	1.883	37.44	52			31.5	37.44
	56							56	0.07	6.3	90.00	37.44
H	69	104.454	107.045	2.591	106.37	1.916	35.23	69	0.19	6.48	34.11	35.23
	63							63	0.06	6.48	108.00	35.23
I	**72**	97.399	101.339	3.94	100.387	2.988	31.86	72			162	31.86
	65							65	0.04	6.48	162.00	31.86
	82							82	0.02	6.48	324.00	31.86
J	83	97.999	100.548	2.549	99.851	1.852	37.63	83	0.08	6.48	81.00	37.63
	101							101	0.08	6.48	81.00	37.63
K	**88**	82.531	84.953	2.422	84.345	1.814	33.52	88			72	33.52
	99							99	0.12	6.48	54.00	33.52
L	105	95.771	98.317	2.546	97.599	1.828	39.28	105	0.06	6.47	107.83	39.28
	111							111			9.8	39.28
M	109	97.012	99.779	2.767	99.072	2.06	34.32	109	0.08	6.47	80.88	34.32
	113							113			64.8	34.32
N	116	94.503	96.941	2.438	96.264	1.761	38.44	116	0.15	6.48	43.20	38.44
	122							122	0.33	6.48	19.64	38.44
AVG						mean	35.97				mean	35.72
MEDIAN						median	36.33				median	35.23

A's **3/19/2011**

Bottle #	Tie #	Bottle wt	Gr + Bottle	Gr wood wt	Dry + Bottle	Dry wood wt	MC %	Borate 1/31/2007 Borate Sample	Reading (mA)	Reading (V) Battery	kOhms White Oak	MC %
A	43A	95.397	97.900	2.503	97.355	1.958	27.83	43A	0.03	6.45	215.00	27.83
	13A						27.83	13A	0.12	6.45	53.75	27.83
F	15A	96.311	99.091	2.780	98.495	2.184	27.29	15A	0.09	6.47	71.89	27.29
	12A						27.29	12A	0.07	6.47	92.43	27.29
G	9A	98.181	100.700	2.519	100.145	1.964	28.26	9A	0.09	6.47	71.89	28.26
	46A						28.26	46A	0.04	6.47	161.75	28.26
N	8A	94.505	97.284	2.779	96.625	2.12	31.08	8A	0.13	6.47	49.77	31.08
	21A						31.08	21A	0.09	6.47	71.89	31.08

NON-A's **3/19/2011**

Appendix 1: Assemble data Page 3

								Sample	**NonBorate 1/31/2007**	**Reading (V)**	**kOhms**	
Bottle #	Tie #	Bottle wt	Gr + Bottle	Gr wood wt	Dry + Bottle	Dry wood wt	MC %	**Tie #**	**Reading (mA)**	**Battery**	**WhiteOak**	**MC %**
B	43	95.104	97.658	2.554	97.094	1.99	28.34	43	0.05	6.45	129.00	28.34
	42						28.34	42	0.06	6.45	107.50	28.34
C	41	96.349	98.945	2.596	98.381	2.032	27.76	41	0.06	6.45	107.50	27.76
	36						27.76	36	0.04	6.45	161.25	27.76
H	37	104.451	107.333	2.882	106.587	2.136	34.93	37	0.17	6.45	37.94	34.93
	45						34.93	45	0.1	6.45	64.50	34.93
I	49	97.395	100.257	2.862	99.579	2.184	31.04	49	0.1	6.45	64.50	31.04
	48						31.04	48	0.09	6.45	71.67	31.04
J	46	98.002	100.582	2.58	99.936	1.934	33.40	46	0.06	6.45	107.50	33.40
	35						33.40	35	0.13	6.45	49.62	33.40
K	44	82.531	85.254	2.723	84.544	2.013	35.27	44	0.03	6.45	215.00	35.27
	27						35.27	27	0.3	6.54	21.80	35.27
L	22	99.634	102.111	2.477	101.608	1.974	25.48	22	0.08	6.45	80.63	25.48
	21						25.48	21	0.06	6.45	107.50	25.48
M	26	97.014	99.492	2.478	98.997	1.983	24.96	26	0.08	6.45	80.63	24.96
	17						24.96	17	0.04	6.47	161.75	24.96

Appendix 2: Screen data page 1

Data from "assemble data" page is arranged in columns here.
Secondly, data points beyond 3 standard deviations are discarded (one point.)

	mA	V	kOhms	MC
avg	0.0898	6.460	95.66	32
sd	0.0603	0.028	56.93093	3.871976
3 sd	0.1808	0.084	170.7928	11.61593
upper 3sd	**0.2706**	**6.543**	**266**	**44**
min	0.0200	6.300	9.80	24.96
max	0.3300	6.540	324	39

3/15/2007 Tie ID	Reading (mA)	Reading (V) Battery	kOhms	MC %	Borate=1	red oak=1	
44A	0.09	6.45	72	33	1	0	
33A	0.08	6.45	81	33	1	0	
32A	0.08	6.45	81	33	1	0	
34A	0.08	6.45	81	33	1	0	
45A	0.06	6.45	108	32	1	0	
41A	0.08	6.45	81	32	1	0	
31A	0.09	6.45	72	27	1	0	
18A	0.04	6.45	161	27	1	0	
5	0.07	6.46	92	34	0	0	
14	0.06	6.47	108	34	0	0	
15	0.05	6.47	129	29	0	0	
20	0.03	6.47	216	29	0	0	
19	0.05	6.47	129	33	0	0	
29	0.13	6.47	50	33	0	0	
32	0.08	6.45	81	33	0	0	
39	0.21	6.45	31	33	0	0	
52			32	37	1	1	
56	0.07	6.3	90	37	1	0	
69	0.19	6.48	34	35	1	0	
63	0.06	6.48	108	35	1	0	
72			162	32	1	1	
65	0.04	6.48	162	32	1	0	
82	0.02	6.48	**324**	32	1	0	screen
83	0.08	6.48	81	38	1	0	

Appendix 2: Screen data page 2

101	0.08	6.48	81	38	1	0
88			72	34	1	1
99	0.12	6.48	54	34	1	0
105	0.06	6.47	108	39	1	0
111			9.8	39	1	1
109	0.08	6.47	81	34	1	0
113			65	34	1	1
116	0.15	6.48	43	38	1	0
122	0.33	6.48	20	38	1	0
43A	0.03	6.45	215	28	1	0
13A	0.12	6.45	54	28	1	0
15A	0.09	6.47	72	27	1	0
12A	0.07	6.47	92	27	1	0
9A	0.09	6.47	72	28	1	0
46A	0.04	6.47	162	28	1	0
8A	0.13	6.47	50	31	1	0
21A	0.09	6.47	72	31	1	0
43	0.05	6.45	129	28	0	0
42	0.06	6.45	108	28	0	0
41	0.06	6.45	108	28	0	0
36	0.04	6.45	161	28	0	0
37	0.17	6.45	38	35	0	0
45	0.1	6.45	65	35	0	0
49	0.1	6.45	65	31	0	0
48	0.09	6.45	72	31	0	0
46	0.06	6.45	108	33	0	0
35	0.13	6.45	50	33	0	0
44	0.03	6.45	215	35	0	0
27	0.3	6.54	22	35	0	0
22	0.08	6.45	81	25	0	0
21	0.06	6.45	108	25	0	0
26	0.08	6.45	81	25	0	0
17	0.04	6.47	162	25	0	0

Appendix 3: Data for regression page 1

Log (kOhms)	kOhms	MC %	Borate=1	red oak =1
	10			
1.855	72	33	1	0
1.906	81	33	1	0
1.906	81	33	1	0
1.906	81	33	1	0
2.031	108	32	1	0
1.906	81	32	1	0
1.855	72	27	1	0
2.207	161	27	1	0
1.965	92	34	0	0
2.033	108	34	0	0
2.112	129	29	0	0
2.334	216	29	0	0
2.112	129	33	0	0
1.697	50	33	0	0
1.906	81	33	0	0
1.487	31	33	0	0
1.498	32	37	1	1
1.954	90	37	1	0
1.533	34	35	1	0
2.033	108	35	1	0
2.210	162	32	1	1
2.210	162	32	1	0
1.908	81	38	1	0
1.908	81	38	1	0
1.857	72	34	1	1
1.732	54	34	1	0
2.033	108	39	1	0
0.991	9.80	39	1	1
1.908	81	34	1	0
1.812	65	34	1	1
1.635	43	38	1	0
1.293	20	38	1	0
2.332	215	28	1	0
1.730	54	28	1	0
1.857	72	27	1	0
1.966	92	27	1	0
1.857	72	28	1	0
2.209	162	28	1	0
1.697	50	31	1	0
1.857	72	31	1	0
2.111	129	28	0	0
2.031	108	28	0	0
2.031	108	28	0	0
2.207	161	28	0	0
1.579	38	35	0	0
1.810	65	35	0	0
1.810	65	31	0	0
1.855	72	31	0	0

Appendix 3: Data for regression page 2

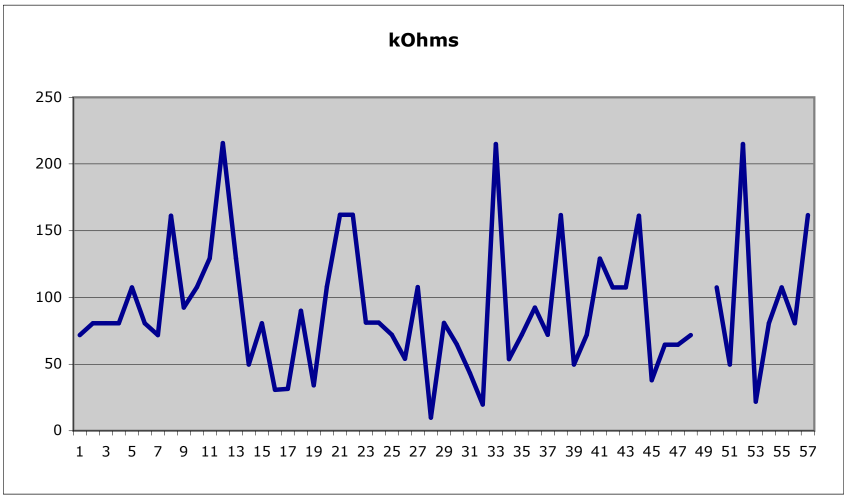
2.031	108	33	0	0
1.696	50	33	0	0
2.332	215	35	0	0
1.338	22	35	0	0
1.906	81	25	0	0
2.031	108	25	0	0
1.906	81	25	0	0
2.209	162	25	0	0

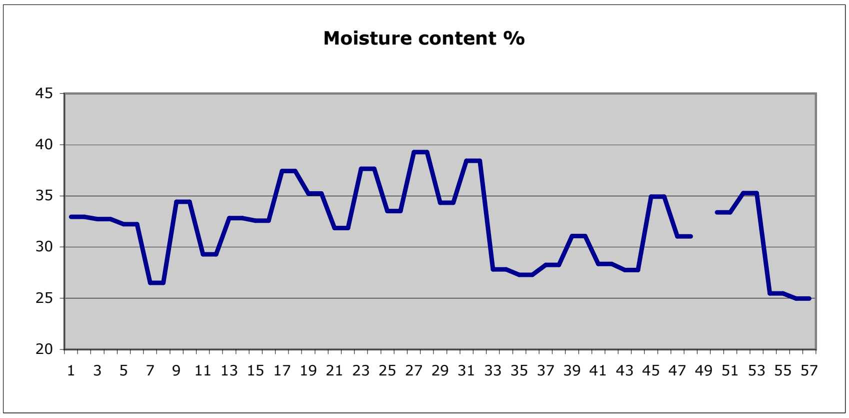
max	39
min	25

Log (kOhms)	kOhms	MC % adj for change	Borate=1
1.855		33	1
1.906		33	1
1.906		33	1
1.906		33	1
2.031		32	1
1.906		32	1
1.855		27	1
2.207		27	1
1.965		34	0
2.033		34	0
2.112		29	0
2.334		29	0
2.112		33	0
1.697		33	0
1.906		33	0
1.487		33	0
1.498		37	1
1.954		37	1
1.533		35	1
2.033		35	1
2.210		32	1
2.210		32	1
1.908		38	1
1.908		38	1
1.857		34	1
1.732		34	1
2.033		39	1
0.991		39	1
1.908		34	1
1.812		34	1
1.635		38	1
1.293		38	1
2.332		28	1
1.730		28	1
1.857		28	1

Appendix 3: Data for regression page 3

1.966	28	1
1.857	29	1
2.209	29	1
1.697	32	1
1.857	32	1
2.111	29	0
2.031	29	0
2.031	28	0
2.207	28	0
1.579	36	0
1.810	36	0
1.810	32	0
1.855	32	0
2.031	34	0
1.696	34	0
2.332	36	0
1.338	36	0
1.906	26	0
2.031	26	0
1.906	26	0
2.209	26	0





Appendix 4: Regressions 1 & 2

SUMMARY OUTPUT

Regression 1
kOhms = f (borate)

Regression Statistics	
Multiple R	0.15519373
R Square	0.02408509
Adjusted R Square	0.0060126
Standard Error	48.1779421
Observations	56

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3093.33276	3093.33276	1.3326931	0.2534
Residual	54	125340.162	2321		
Total	55	128433.494	2335		

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	100.165311	9.83428125	10.1853209	3.5557E-14	80.4487641	119.881857
borate	**-15.0185**	**13.0095313**	-1.15442328	0.25341009	-41.1010453	11.0640339

How confident can one be of the coefficient value (B) is -15.0185?
One can be 95% sure B lies between -41 and 11.
Notice this range includes zero, meaning borate has no effect on kOhms.

confidence	**95%**	90%	80%	50%
high value	**11.0**	6.7	1.8	-6.2
low value	**-41.0**	-36.8	-31.9	-23.9

Conclusion: borate does not produce a statistically significant effect on impedance.

SUMMARY OUTPUT

Regression 2
kOhms = f (MC%)

Regression Statistics	
Multiple R	0.40965602
R Square	0.16781806
Adjusted R Square	0.15240728
Standard Error	44.4888739
Observations	56

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	21553.4596	21553.4596	10.889656	**0.00172**	**0.99828**
Residual	54	106880.035	1979.2599			
Total	55	128433.494				

One can be 99.8% sure MC has some effect on kOhms.

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	253.895416	49.544248	5.12461943	4.1162E-06	154.56518	353.225652
MC %	**-5.0669**	**1.5354**	-3.29994788	0.00171688	-8.14523478	-1.98849794

How confident can one be of the coefficient value (B) is 5.0669? **-1.996**
One can be 95% sure B lies between -8.1 and -2.0. **-8.138**
This range excludes the value zero.
Conclusion: moisture content has a statistically significant effect on impedance.

Appendix 5: Regressions 3 & 4

SUMMARY OUTPUT

Regression 3
kOhms = f (MC%, borate)

Regression Statistics	
Multiple R	0.41260508
R Square	0.17024295
Adjusted R Square	0.13893137
Standard Error	44.8411446
Observations	56

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	21864.8973	10932.4486	5.43705926	0.00711541
Residual	53	106568.597	2010.72825		
Total	55	128433.494			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	251.402178	50.3367915	4.99440211	6.7729E-06	150.439362	352.364993
MC %	-4.90093116	1.60400256	-3.05543849	0.00351417	-8.11815279	-1.68370953
Borate	-4.93908404	12.5498202	**-0.39355815**	0.69548611	-30.1108351	20.232667

Conclusion: While accounting for the effect of moisture content, borate has no significant effect on impedance.

SUMMARY OUTPUT

Regression 4
kOhms = f (MC%, borate, red oak)

Regression Statistics	
Multiple R	0.41438198
R Square	0.17171243
Adjusted R Square	0.12392661
Standard Error	45.2301523
Observations	56

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	22053.6273	7351.20911	3.59337612	0.01953805
Residual	52	106379.867	2045.76667		
Total	55	128433.494			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	248.206807	51.8519317	4.78683819	1.445E-05	144.158296	352.255318
MC %	-4.79738305	1.65344565	-2.90144586	0.00543449	-8.11526441	-1.47950169
borate	-4.08401773	12.9679523	**-0.31493158**	0.7540739	-30.1061172	21.9380817
red oak	-6.835372	22.5045152	**-0.30373336**	0.76254307	-51.9939846	38.3232406

Conclusion: While accounting for the effect of moisture content, borate has no significant effect on impedance.
Also, red oak ties cannot be distinguished from white oak ties in this impedance experiment.

Appendix 6: Regressions 5 & 6

SUMMARY OUTPUT

Regression 5
kOhms = f (MC%, red oak)

Regression Statistics	
Multiple R	0.41247133
R Square	0.1701326
Adjusted R Square	0.13881685
Standard Error	44.8441263
Observations	56

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	21850.7243	10925.3622	5.43281239	0.00714053
Residual	53	106582.77	2010.99566		
Total	55	128433.494			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	249.452	51.2597133	4.86643378	1.0607E-05	146.638038	352.265963
MC %	-4.90481708	1.60406393	-3.05774414	0.00349132	-8.1221618	-1.68747235
red oak	-8.37395799	21.7803393	**-0.38447326**	0.70216611	-52.0597852	35.3118693

Conclusion: red oak ties cannot be distinguished from white oak ties in this impedance experiment.

SUMMARY OUTPUT

Regression 6
Log (kOhms) = f (MC%)

Regression Statistics	
Multiple R	0.4812612
R Square	0.23161234
Adjusted R Square	0.21738294
Standard Error	0.23209238
Observations	56

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.87679252	0.87679252	**16.2770269**	0.00017347
Residual	54	2.90881108	0.05386687		
Total	55	3.7856036	0.06882916		

Unexplained variance/total variance : 78.3%

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.93038504	0.25846557	11.3376222	6.6765E-16	2.41219276	3.44857731
MC %	-0.03231688	0.00801017	**-4.03448**	0.00017347	-0.0483763	-0.01625745

Conclusion: The logarithmic equation fits the data better than the linear equation
Conclusion: moisture content has a statistically significant effect on impedance.

Appendix 7: Regression 7

SUMMARY OUTPUT

Regression 7
Log (kOhms) = f (MC%, borate)

Regression Statistics	
Multiple R	0.48166379
R Square	0.232
Adjusted R Square	0.20301887
Standard Error	0.23421259
Observations	56

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.87826005	0.43913002	8.00520845	0.00091637
Residual	53	2.90734356	0.05485554		
Total	55	3.7856036			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.92497287	0.26291725	11.1250702	1.7742E-15	2.39762766	3.45231808
MC %	-0.03195667	0.00837797	-3.81437133	0.00035833	-0.04876075	-0.0151526
borate	-0.01072145	0.06554975	**-0.16356203**	0.87069806	-0.1421976	0.1207547

Conclusion: While accounting for the effect of moisture content, borate has no significant effect on impedance.

Appendix 8: Moisture content adjustment

To increase sample size, moisture readings were made on March 19, 2007. The impedance readings on these ties were made on January 31, 2007, a difference of 47 days, during which moisture content could have declined. To test the possible distorting effects on moisture content (MC), all moisture and time specific data was used, as shown below.

estimated date of sawing 8/13/2004

Sample	date	Age (in days)	MC%	Log (MC%)
Non-Borate 5/15/05	5/15/2005	275	41.9	1.622
Non-Borate 4/6/2006	4/6/2006	601	33.3	1.522
NonBorate 1/31/2007	1/31/2007	901	32.3	1.509
Borate 5/15/05	5/15/2005	275	46.0	1.662
Borate 4/6/2006	4/6/2006	601	39.3	1.594
Borate 1/31/2007	1/31/2007	901	36.0	1.556

Next, a simple regression is used to identify the time / moisture relationship.

SUMMARY OUTPUT Log (MC %) = f (Age)

Regression Statistics	
Multiple R	0.831654763
R Square	0.691649645
Adjusted R Square	0.614562056
Standard Error	0.036882257
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.01220497	0.01220497	8.97225683	0.04012472
Residual	4	0.0054412	0.0013603		
Total	5	0.01764617			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.682180437	0.03799917	44.2688776	1.557E-06	1.57667784	1.78768304
Age (days)	-0.00017643	5.89E-05	-2.99537257	0.04012472	-0.00033996	-1.2895E-05

simulate age equation:

date of measurement	age	Log (MC%)	MC %
1/31/2007	901	1.523	33.36
3/19/2007	948	1.515	32.73
change	47		**-0.63**

SUMMARY OUTPUT

Appendix 9: Regression 8

Best equation
Log (kOhms) = f (MC%)
… with moisture content adjustment

Regression Statistics	
Multiple R	0.49115758
R Square	0.24123576
Adjusted R Square	0.22718457
Standard Error	0.23063442
Observations	56

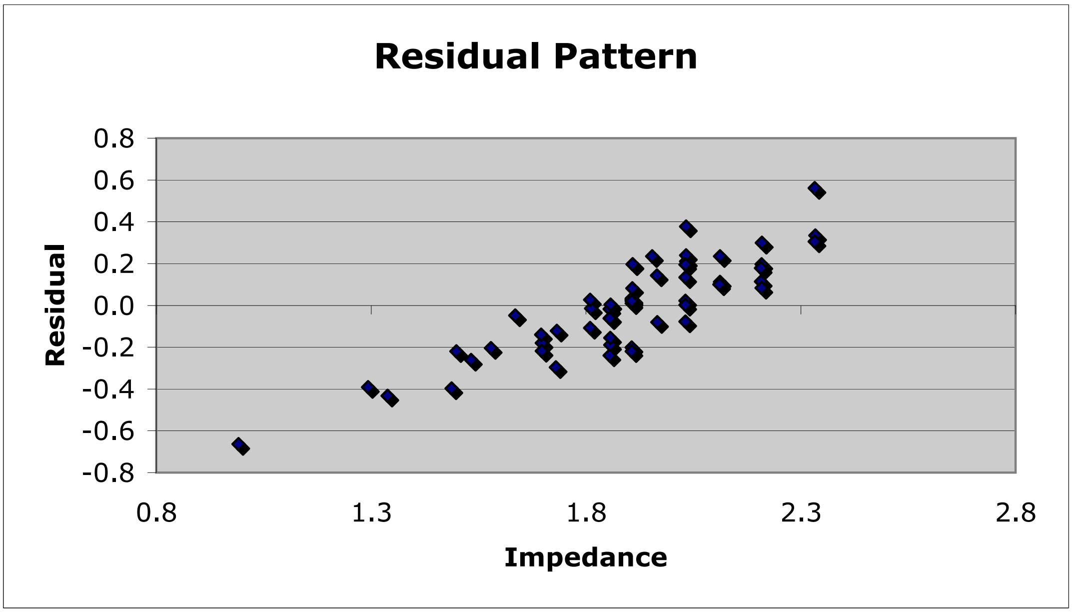
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.91322298	0.91322298	**17.1683517**	**0.00012124**
Residual	54	2.87238062	**0.05319223**	< unexplained variance	
Total	55	3.7856036	**0.06882916**	< total variance	

Unexplained/ total variance = 77.3%

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	3.00591422	0.26984267	11.1395067	1.3072E-15	2.46491224	3.54691619
MC %	-0.03438443	0.00829846	**-4.14347097**	0.00012124	-0.05102184	-0.01774702

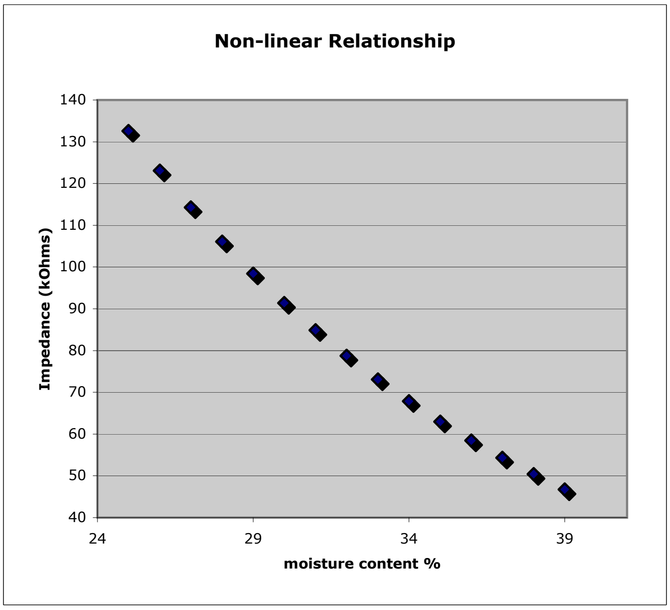
Conclusion: Impedance depends on moisture content.



Appendix 10: Non-linear relationship

Can average moisture content (MC) of a sample of ties serve as a useful indicator of expected impedance (Ohms)?
Result: a non-linear relationship exists between impedance and MC. The equation (regression 6) is simulated below, with graphic representation.

MC %	expected Log(kOhms)	expected kOhms
25	2.122	132.6
26	2.090	123.1
27	2.058	114.2
28	2.026	106.1
29	1.993	98.4
30	1.961	91.4
31	1.929	84.8
32	1.896	78.7
33	1.864	73.1
34	1.832	67.9
35	1.799	63.0
36	1.767	58.5
37	1.735	54.3
38	1.702	50.4
39	1.670	46.8



Average moisture content from a sample of ties can produce results which are biased in terms of targeting an expected value of impedance. For example, two ties with MC of 25 and 39 have an average MC of 32. The expected impedance, according to the equation, is 78.7. However, the true impedance values are 132.6 and 46.8, with an average impedance of 89.7, which is almost 14 percent higher than the "true" average value.

Sample of 2

MC %	
32.00	
kOhms	
89.7	13.9%

The significance of this possible bias is reduced by having a large sample size. A sample of 8 ties was used in more than one case, and the probability of drawing polar extreme MC values is small. A more likely draw of 8 ties would cluster around the middle of the MC range. A case is shown below where the resulting bias is only about 4 percent.

Sample of 8

MC %	expected Log(kOhms)	expected kOhms	
29	1.993	98.4	
35	1.799	63.0	
30	1.961	91.4	
34	1.832	67.9	
28	2.026	106.1	
32	1.896	78.7	
33	1.864	73.1	
32	1.896	78.7	
32	< average >	82.2	
		78.7	4.3%

Conclusion: representing a sample with an average moisture content can mislead the observer as to the expected value of impedance, and should not be proposed as an industry standard.

Appendix 11: Pristine data set   Page 1

Electrical Impedance Study
Seaman Timber Company
7/16-17/2007

Tie#	NonBorate 7/16/2007	Reading (V)	kOhms	Moisture Content
	Reading (mA)	Battery	WhiteOak	
3	0.43	6.3	14.65	44.88
8	0.27	6.3	23.33	52.53
9	0.12	6.3	52.50	36.93
12	0.11	6.3	57.27	46.57
14	0.11	6.3	57.27	36.72
15	0.12	6.3	52.50	35.22
17	0.11	6.3	57.27	30.19
21	0.12	6.3	52.50	32.53
22	0.13	6.3	48.46	37.38
26	0.18	6.3	35.00	33.2
29	0.24	6.3	26.25	48.25
31	0.25	6.3	25.20	51.98
32	0.15	6.3	42.00	32.42
33	0.11	6.3	57.27	38.46
35	0.27	6.3	23.33	44.53
37	0.34	6.3	18.53	45.73
38	0.18	6.3	35.00	42.46
41	0.18	6.3	35.00	37.40
42	0.13	6.3	48.46	36.81
44	0.09	6.3	70.00	32.17
45	0.23	6.3	27.39	36.26
47	0.25	6.3	25.20	43.39
48	0.21	6.3	30.00	32.15
49	0.17	6.3	37.06	41.42
50	0.18	6.3	35.00	34.50
25	0.18	6.3	35.00	40.19
39	0.42	6.3	15.00	31.02
30	0.12	6.3	52.50	29.07
Min	**0.09**		**14.65**	**29.07**
Max	**0.43**		**70.00**	**52.53**
Avg	**0.19**		**39.46**	**38.73**
Median	**0.18**		**35.00**	**37.38**

Tie #	Borate 7/16/2007	Reading (V)	kOhms	Moisture Content
	Reading (mA)	Battery	WhiteOak	
54	0.17	6.3	37.06	34.12
56	0.22	6.3	28.64	37.21
8A	0.22	6.3	28.64	32.55
63	0.19	6.3	33.16	41.62
10A	0.12	6.3	52.50	40.04
11A	0.24	6.3	26.25	38.54
13A	0.18	6.3	35.00	31.41
18A	0.08	6.3	78.75	33.37
81	0.23	6.3	27.39	32.62
82	0.13	6.3	48.46	30.29
22A	0.15	6.3	42.00	36.30
24A	0.15	6.3	42.00	36.68
99	0.20	6.3	31.50	35.82
105	0.17	6.3	37.06	30.27
109	0.16	6.3	39.38	35.38
29A	0.10	6.3	63.00	34.81
36A	0.17	6.3	37.06	34.93
125	0.13	6.3	48.46	33.78
126	0.07	6.3	90.00	23.41
127	0.15	6.3	42.00	39.06
128	0.17	6.3	37.06	39.31
41A	0.14	6.3	45.00	40.73
45A	0.07	6.3	90.00	33.62
136	0.18	6.3	35.00	38.93
137	0.11	6.3	57.27	31.6
141	0.22	6.3	28.64	32.29
142	0.06	6.3	105.00	24.85
144	0.14	6.3	45.00	33.91
150	0.27	6.3	23.33	41.98
151	0.11	6.3	57.27	27.9
Min	**0.07**		**23.33**	**23.41**
Max	**0.24**		**105.00**	**41.98**
Avg	**0.16**		**46.40**	**34.58**
Median	**0.16**		**42.00**	**33.85**

Appendix 11: Pristine data set   Page 2
Screening

Tie #	Borate 7/16/2007	Reading (V)	kOhms	Moisture Content		
	Reading (mA)	Battery	WhiteOak			
Tie#	NonBorate 7/16/2007	Reading (V)	kOhms	Moisture Content	borate =1	
	Reading (mA)	Battery	WhiteOak			
3	**0.43**	6.3	14.65	44.88	0	screen
8	0.27	6.3	23.33	52.53	0	
9	0.12	6.3	52.50	36.93	0	
12	0.11	6.3	57.27	46.57	0	
14	0.11	6.3	57.27	36.72	0	
15	0.12	6.3	52.50	35.22	0	
17	0.11	6.3	57.27	30.19	0	
21	0.12	6.3	52.50	32.53	0	
22	0.13	6.3	48.46	37.38	0	
26	0.18	6.3	35.00	33.2	0	
29	0.24	6.3	26.25	48.25	0	
31	0.25	6.3	25.20	51.98	0	
32	0.15	6.3	42.00	32.42	0	
33	0.11	6.3	57.27	38.46	0	
35	0.27	6.3	23.33	44.53	0	
37	0.34	6.3	18.53	45.73	0	
38	0.18	6.3	35.00	42.46	0	
41	0.18	6.3	35.00	37.40	0	
42	0.13	6.3	48.46	36.81	0	
44	0.09	6.3	70.00	32.17	0	
45	0.23	6.3	27.39	36.26	0	
47	0.25	6.3	25.20	43.39	0	
48	0.21	6.3	30.00	32.15	0	
49	0.17	6.3	37.06	41.42	0	
50	0.18	6.3	35.00	34.50	0	
25	0.18	6.3	35.00	40.19	0	
39	**0.42**	6.3	15.00	31.02	0	screen
30	0.12	6.3	52.50	29.07	0	
54	0.17	6.3	37.06	34.12	1	
56	0.22	6.3	28.64	37.21	1	
8A	0.22	6.3	28.64	32.55	1	
63	0.19	6.3	33.16	41.62	1	
10A	0.12	6.3	52.50	40.04	1	
11A	0.24	6.3	26.25	38.54	1	
13A	0.18	6.3	35.00	31.41	1	
18A	0.08	6.3	78.75	33.37	1	
81	0.23	6.3	27.39	32.62	1	
82	0.13	6.3	48.46	30.29	1	

Appendix 11: Pristine data set Page 3

22A	0.15	6.3	42.00	36.30	1	
24A	0.15	6.3	42.00	36.68	1	
99	0.20	6.3	31.50	35.82	1	
105	0.17	6.3	37.06	30.27	1	
109	0.16	6.3	39.38	35.38	1	
29A	0.10	6.3	63.00	34.81	1	
36A	0.17	6.3	37.06	34.93	1	
125	0.13	6.3	48.46	33.78	1	
126	0.07	6.3	90.00	23.41	1	
127	0.15	6.3	42.00	39.06	1	
128	0.17	6.3	37.06	39.31	1	
41A	0.14	6.3	45.00	40.73	1	
45A	0.07	6.3	90.00	33.62	1	
136	0.18	6.3	35.00	38.93	1	
137	0.11	6.3	57.27	31.6	1	
141	0.22	6.3	28.64	32.29	1	
142	0.06	6.3	**105.00**	24.85	1	screen
144	0.14	6.3	45.00	33.91	1	
150	0.27	6.3	23.33	41.98	1	
151	0.11	6.3	57.27	27.9	1	

stdev	0.0754	0.0	18.33	5.934
3 stdev	0.2263	0.0	54.99	17.803
mean	0.1741	6.3	42.77	36.581
mean+3std	0.4005	6.3	97.77	54.384
mean-3std	-0.0522	6.3	-12.22	18.778
max	0.4300	6.3	105.00	52.528
min	0.0600	6.3	14.65	23.410
	mA	V	KOhms	MC

Arranging the Pristine Data for Regression Analysis

Tie #	Borate 7/16/2007	Reading (V)	kOhms	Moisture Content			
	Reading (mA)	Battery	WhiteOak				
Tie#	NonBorate 7/16/2007	Reading (V)	kOhms	Moisture Content	borate =	Log (Kohms)	
	Reading (mA)	Battery	WhiteOak				
8	0.27	6.3	23.33	52.53	0	1.368	1
9	0.12	6.3	52.50	36.93	0	1.720	2
12	0.11	6.3	57.27	46.57	0	1.758	3
14	0.11	6.3	57.27	36.72	0	1.758	4
15	0.12	6.3	52.50	35.22	0	1.720	5
17	0.11	6.3	57.27	30.19	0	1.758	6
21	0.12	6.3	52.50	32.53	0	1.720	7
22	0.13	6.3	48.46	37.38	0	1.685	8
26	0.18	6.3	35.00	33.2	0	1.544	9
29	0.24	6.3	26.25	48.25	0	1.419	10
31	0.25	6.3	25.20	51.98	0	1.401	11
32	0.15	6.3	42.00	32.42	0	1.623	12
33	0.11	6.3	57.27	38.46	0	1.758	13
35	0.27	6.3	23.33	44.53	0	1.368	14
37	0.34	6.3	18.53	45.73	0	1.268	15
38	0.18	6.3	35.00	42.46	0	1.544	16
41	0.18	6.3	35.00	37.40	0	1.544	17
42	0.13	6.3	48.46	36.81	0	1.685	18
44	0.09	6.3	70.00	32.17	0	1.845	19
45	0.23	6.3	27.39	36.26	0	1.438	20

Appendix 11: Pristine data set Page 4

47	0.25	6.3	25.20	43.39	0	1.401	21
48	0.21	6.3	30.00	32.15	0	1.477	22
49	0.17	6.3	37.06	41.42	0	1.569	23
50	0.18	6.3	35.00	34.50	0	1.544	24
25	0.18	6.3	35.00	40.19	0	1.544	25
30	0.12	6.3	52.50	29.07	0	1.720	26
54	0.17	6.3	37.06	34.12	1	1.569	27
56	0.22	6.3	28.64	37.21	1	1.457	28
8A	0.22	6.3	28.64	32.55	1	1.457	29
63	0.19	6.3	33.16	41.62	1	1.521	30
10A	0.12	6.3	52.50	40.04	1	1.720	31
11A	0.24	6.3	26.25	38.54	1	1.419	32
13A	0.18	6.3	35.00	31.41	1	1.544	33
18A	0.08	6.3	78.75	33.37	1	1.896	34
81	0.23	6.3	27.39	32.62	1	1.438	35
82	0.13	6.3	48.46	30.29	1	1.685	36
22A	0.15	6.3	42.00	36.30	1	1.623	37
24A	0.15	6.3	42.00	36.68	1	1.623	38
99	0.20	6.3	31.50	35.82	1	1.498	39
105	0.17	6.3	37.06	30.27	1	1.569	40
109	0.16	6.3	39.38	35.38	1	1.595	41
29A	0.10	6.3	63.00	34.81	1	1.799	42
36A	0.17	6.3	37.06	34.93	1	1.569	43
125	0.13	6.3	48.46	33.78	1	1.685	44
126	0.07	6.3	90.00	23.41	1	1.954	45
127	0.15	6.3	42.00	39.06	1	1.623	46
128	0.17	6.3	37.06	39.31	1	1.569	47
41A	0.14	6.3	45.00	40.73	1	1.653	48
45A	0.07	6.3	90.00	33.62	1	1.954	49
136	0.18	6.3	35.00	38.93	1	1.544	50
137	0.11	6.3	57.27	31.6	1	1.758	51
141	0.22	6.3	28.64	32.29	1	1.457	52
144	0.14	6.3	45.00	33.91	1	1.653	53
150	0.27	6.3	23.33	41.98	1	1.368	54
151	0.11	6.3	57.27	27.9	1	1.758	55

SUMMARY OUTPUT

Appendix 12: Regression 9 & 10

Regression 9
KOhms = f (MC, Borate)
Linear equation

Regression Statistics	
Multiple R	0.50913027
R Square	0.25921363
Adjusted R Square	0.23072185
Standard Error	13.9801419
Observations	55

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	3556.24247	1778.12124	9.09783817	0.00040928
Residual	52	10163.1072	195.444368		
Total	54	13719.3496			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	97.7464679	13.9881465	6.98780701	5.1752E-09	69.6771991	125.815737
MC	-1.46966283	0.35364505	-4.15575682	0.00012126	-2.17930353	-0.76002214
Borate	-2.06113443	4.01663792	-0.51314917	0.6100203	-10.1211079	5.99883904

Conclusion: While accounting for the effect of moisture content, borate has no significant effect on impedance.

SUMMARY OUTPUT

Regression 10
Log (Kohms) = f (MC, Borate)

Regression Statistics	
Multiple R	0.54719284
R Square	0.29942
Adjusted R Square	0.27247462
Standard Error	0.13162027
Observations	55

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.38500997	0.19250498	11.1121071	9.5918E-05
Residual	52	0.90084257	0.0173239		
Total	54	1.28585253			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.17893979	0.13169563	16.5452701	2.2874E-22	1.91467317	2.4432064
MC	-0.01534135	0.0033295	-4.60770521	2.672E-05	-0.02202247	-0.00866022
Borate	-0.02400194	0.03781585	-0.63470571	0.5284032	-0.09988499	0.05188112

Conclusion: While accounting for the effect of moisture content, borate has no significant effect on impedance.

SUMMARY OUTPUT

Appendix 13: Regression 11

Best equation
Log (Kohms) = f (MC)

Regression Statistics	
Multiple R	0.54221076
R Square	0.29399251
Adjusted R Square	0.28067161
Standard Error	0.13087669
Observations	55

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.37803101	0.37803101	22.070025	1.9043E-05
Residual	53	0.90782152	0.01712871		
Total	54	1.28585253			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.13979972	0.11570834	18.493047	8.9438E-25	1.90771819	2.37188125
MC	-0.01462057	0.00311217	-4.69787452	1.9043E-05	-0.02086279	-0.00837835

Conclusion: Impedance depends on moisture content.

June 6, 1994
file: 060694.bor

TO: BRUCE WILLIAMS
BILL THOMPSON
GARY HUNTER

FROM: DAVID McCORD

RE: CONDUCTIVITY TEST ON [redacted] TREATED TIES AT LIVONIA

SUMMERY

[redacted] the minimum A.A.R. recommendation of 7000 ohms and the U.P. standard of 10,000 ohms per tie when wet. [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

THE EFFECTS OF BORATE PRESERVATIVES AND FIRE RETARDANTS ON HYGROSCOPICITY AND MOISTURE CONTENT EQUILIBRIA IN TIMBER

by

J. DULAT

J. Inst. Wood Science, 1980, 8, 214-20

THE EFFECTS OF BORATE PRESERVATIVES AND FIRE RETARDANTS ON HYGROSCOPICITY AND MOISTURE CONTENT EQUILIBRIA IN TIMBER

by J. DULAT*

Summary

Matched sets of wood blocks were impregnated with aqueous solutions of borates. Half of the number of sets were air dried to 50–70 per cent water and the other half were heated at 105°C. All the sets were stored in chambers in circulating air maintained at constant relative humidities of about 30, 60 and 90 per cent. The variation of weights of the test blocks with time was monitored and from the plots of water desorption and water absorption curves it was concluded that:

1. **Borates do not enhance the hygroscopicity of timber.**
2. **Sodium borates have no significant effect on the equilibrium moisture content of timber.**
3. **Boric acid in wood brings about a slight lowering of the equilibrium moisture content, presumably through formation of bonds, electrostatic rather than chemical in character, with the wood fibre.**
4. **The effect of borates on the rate of drying of wet timber is insignificant to slight, depending on the loading.**

Introduction

Boric acid and hydrated sodium borates are relatively stable compounds showing no marked tendency to hygroscopicity or efflorescence at ambient temperatures and over a wide range of relative humidities, and yet there appears to be a deep-rooted belief that they enhance the hygroscopicity of timber when used as preservatives or flame retardants (Brazier and Laidlaw, 1974). This belief appears to spring mainly from a few papers published in the technical literature. In one of these (McKnight, 1962) the author arrived at erroneous conclusions because he failed to take into consideration the water contents of boric acid and borax, viz:

Compound	*Water %*
Boric acid, H_3BO_3	43·7
Borax, $Na_2B_4O_7.10H_2O$	47·24

He dried the test blocks treated with the solutions of the borates in an oven at 105°C without apparently realising that a large proportion of the water would be removed from the crystalline borates by this treatment. After subsequent transfer to the humidity chamber, the timber absorbed water to the usual equilibrium level whilst boric acid and borax regained all the water lost during oven drying. The specimens were weighed and the total water absorbed was plotted as a curve. The upward displacement of the curves for boric acid and borax in relation to that of the untreated control probably accounts for the difference due to the water regained by the borates. Hence his conclusion that 'boric acid and borax confer an increased hygroscopicity on wood through the entire relative humidity range' is wrong and the fact that he obtained at 92·6 per cent RH a higher absorption figure for borax than for boric acid is at least partly due to the former containing more water when fully hydrated (see above).

Bendsen (1966) had some doubts about the effects of borates presumably because in his experiments he did not allow adequate time for equilibria to be established. However, feeling that something was wrong with the experimental conditions, he concluded that with regard to hygroscopic effects 'boric acid and borax should be grouped along with diammonium phosphate and monoammonium phosphate'.

Since it is conceivable that borates in timber may form bonds with some components of the wood and thereby affect the normal moisture content equilibria, the tests described in this report were carried out with the object of finding out whether such effects are of significance in the usual practice of preservation and flameproofing of timber with borates.

Materials

The materials used for the treatment of timber or timber products such as chipboard, insulation board and cellulose fibre are boric acid and mixtures of borax with boric acid. Borax is hardly ever used on its own but it has been included in this study for completeness. Representative of the most frequently used mixture of borax and boric acid is the commercial product 'Polybor',† a spray-dried intimate mixture of the two compounds in the form of powder having the approximate composition of disodium octaborate tetrahydrate, $Na_2B_8O_{13}.4H_2O$. An advantage specific to the DOT composition is that when it comes out of solution, it does so in the form of a thin layer of amorphous glass which does not block the passages between timber cells like growing crystals do. Even if, after humidity cycling, it may slowly turn into the crystalline species of sodium pentaborate and borax these remain so small as to be undetectable by X-rays.

A specific difficulty in tests with boric acid is that the compound is slightly volatile with steam. After a prolonged period of exposure of timber specimens containing the acid to circulating air some of the material is lost and corrections for this must be made; no significant loss occurs under such conditions from wood treated with borax or DOT.

Methods

1 Impregnation and treatment of test blocks

A batch of 500 redwood (Pinus sylvestris) sapwood

*Borax Research Ltd, Cox Lane, Chessington, Surrey KT9 1SJ, England.

†Trade mark of US Borax.

blocks, 5 × 2·5 × 1·5 cm, ex Penarth Research Centre were air conditioned and individually weighed (ADW). A group of 20 blocks were sampled from the above batch to cover the full range of weights, oven dried at 105°C for 18 hours and weighed (ODW). From the results the relationship: ODW = 0·9181 ADW was obtained. Another group of 20 blocks were vacuum impregnated with water following the method given in British Standard 838:1921, pp. 12–13, and weighed. The formula obtained from the results, viz.

$$H_2O\% \text{ (ODW)} = 361{\cdot}72–23{\cdot}923 \text{ (ODW)}$$

was used to calculate the concentrations of borates in the impregnating solutions to give the required borate retentions in the wood.

A total of 180 blocks of middle range weights (8·5–9·3 g) were selected from the remaining 460 and divided into six groups of 30 blocks each. Five of these groups were impregnated with solutions of borates and one (control) with water using the method described in BS 838:1961. The strengths of borate solutions were such as to obtain loadings of 5, 10 and 15 per cent DOT, 5 per cent borax and 5 per cent boric acid, all percentages by weight of oven dry wood (ODW). The blocks were individually reweighed after the impregnation and the exact weight of borate content calculated from the weight of solution absorbed. From the results of experiments carried out in another context it is known that the borates are not absorbed preferentially from the solution to a measurable degree if the impregnation is carried out as described in the above British Standard.

From the 30 impregnated blocks in each group, six blocks showing the widest variation from the average borate retention were rejected and the remainder, ie 24 blocks were further sub-divided into six sets of four specimens each.

The blocks were stood on watch glasses and allowed to dry slowly in the air at ambient temperature for four days. They were then heated gently for three hours at 50°C in a ventilated oven to bring their total moisture contents to 50–70 per cent (ODW) and weighed.

Half of the total number of sets were heated in a ventilated oven at 105°C for 18 hours, allowed to cool and weighed. The test blocks treated with boric acid suffered some loss of the acid. A suitable correction for this was applied on the basis of the results of a separately conducted experiment on an additional set of similar specimens.

2 Moisture absorption and desorption tests

All the sets of test blocks were transferred immediately after treatment to three constant humidity chambers of 6 ft^3 capacity each. These were well insulated cabinets maintained at a constant temperature of 25°C throughout the duration of the experiment. Relative humidities of approximately 29, 61 and 89 per cent were maintained in the chambers using slurries of calcium chloride, ammonium nitrate and sodium carbonate, respectively, placed in trays with exposed surface areas of about 1·5 ft^2. A moderate rate of air circulation was maintained all the time except after each opening of the door of the cabinet when the fan speed was increased for a few minutes to re-establish quickly the correct humidity. The latter was monitored by measuring the voltage difference between two, ie wet and dry bulb chromel-alumel thermocouple probes. The dry bulb temperature was measured independently using mercury in glass thermometers.

The test blocks were weighed at suitable time intervals individually but the data used in the plotting of the weight change curves are all averages of four determinations.

Note: For simplicity, the approximate figures of 30, 60 and 90 per cent relative humidity are used in the body of the paper.

3 Water of hydration of borates

Borates hold on to their water of hydration quite firmly at ambient temperatures but they become dehydrated to a varying degree when heated at 105°C and they may not regain all the water lost when transferred from the oven to air having a moderate or low relative humidity. For this reason 1 g samples of the borate powders (a) hydrated and (b) after heating for 18 hours at 105°C were placed on Petri dishes, kept in the humidity chambers along with the test blocks and the changes in their weights with time were monitored so that the equilibrium moisture contents associated with the timber could be calculated from the total moisture contents in the blocks as found less the water of hydration of the borates.

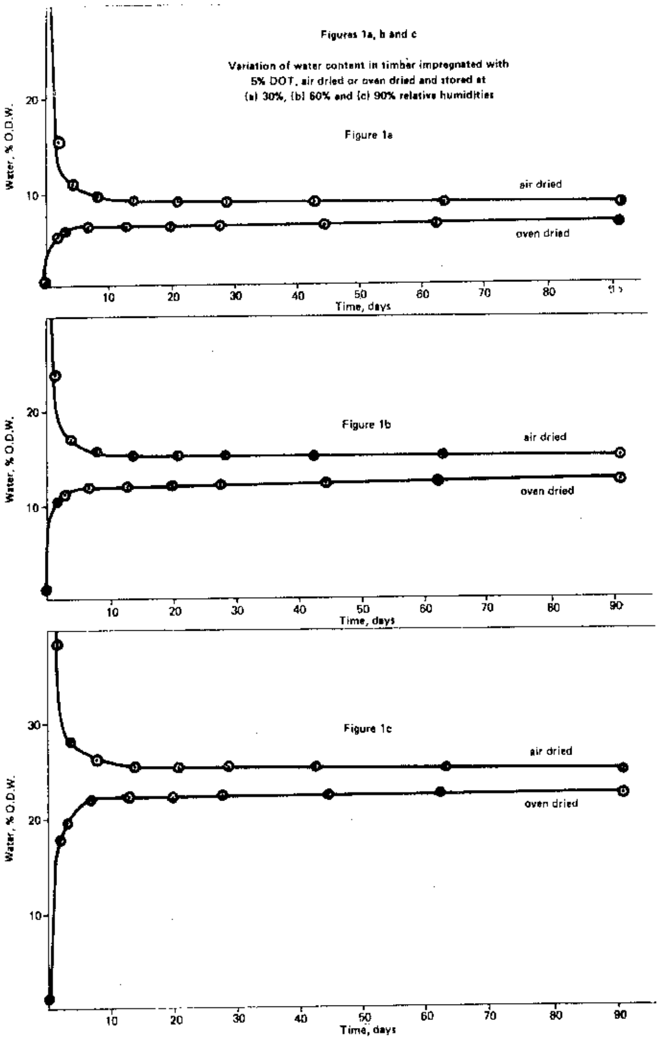
The 'sodium octaborate tetrahydrate' is an amorphous mixture of water deficient borates. For a strict comparison of the variation of the water content of this material when in timber (where it was introduced as an aqueous solution) with that of the solid powder on its own, the latter should have been dissolved in water, air dried, ground, one sample introduced into the humidity chamber and one heated at 105°C and then placed in the chamber. However, from the results of similar work carried out in another context it is known (Isted, 1975) that the final proportion of water hydration reached would have been practically independent of the path taken so that, for simplicity, 1 g samples of the original product in the powder form were in the chambers.

Results

Figures 1–5 show the variation of water content with time in timber impregnated with the borates, air dried or oven dried and stored at the relative humidities of approx (a) 30, (b) 60 and (c) 90 per cent.

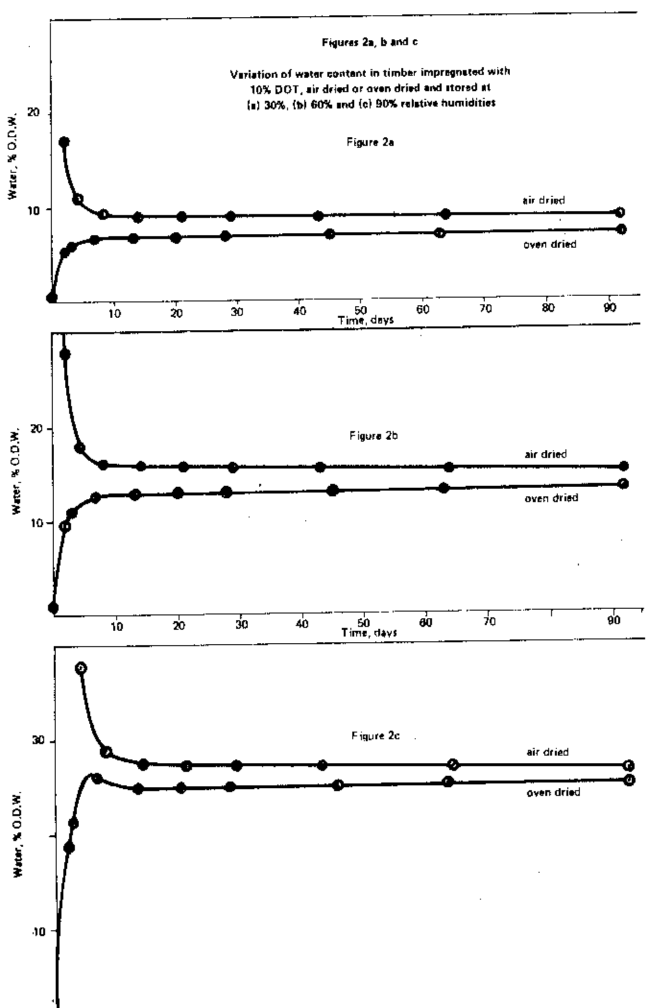
Figures 6a, b and c show the variation of water content in the controls, ie redwood blocks impregnated with water only.

Figures 7–9 show the variation in water contents in the borate powders stored, or oven dried and then stored in the same constant humidity chambers as the test blocks.



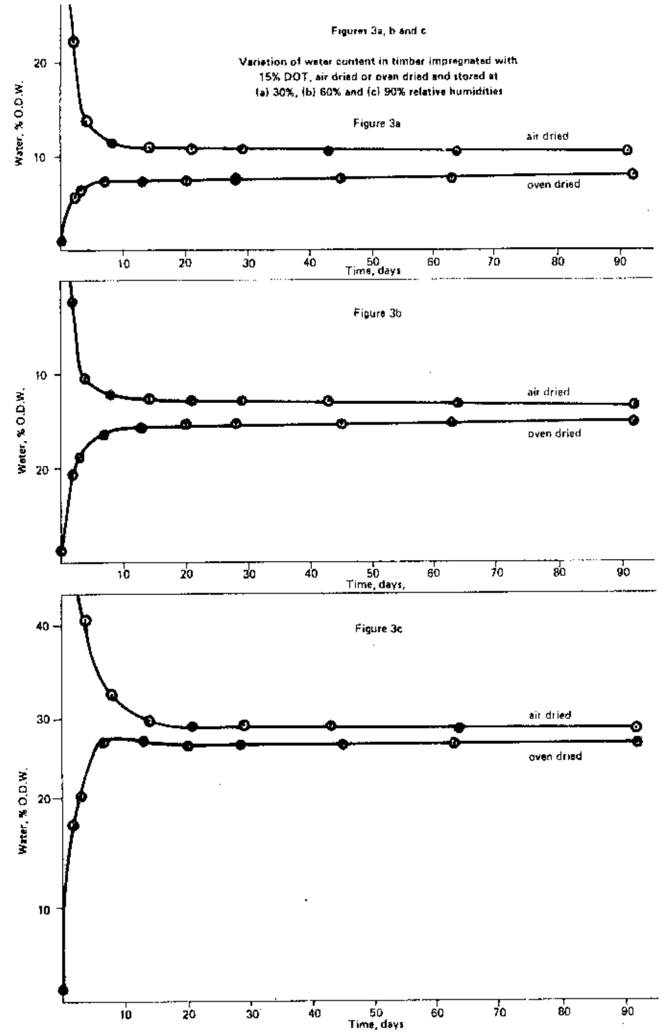
Figures 1a, b and c

Variation of water content in timber impregnated with 5% DOT, air dried or oven dried and stored at (a) 30%, (b) 60% and (c) 90% relative humidities



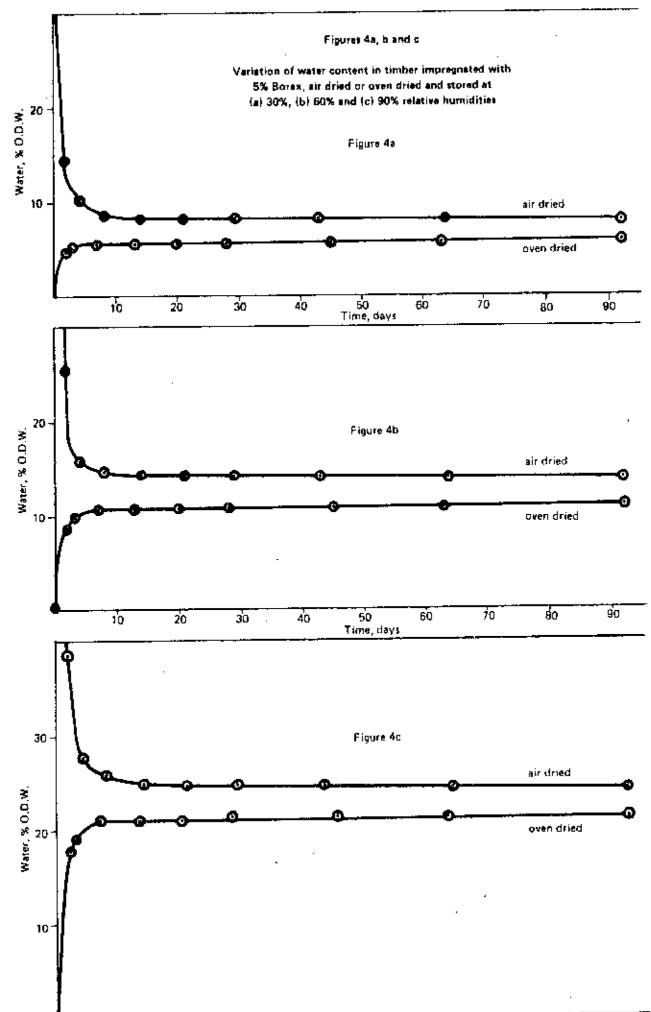
Figures 2a, b and c

Variation of water content in timber impregnated with 10% DOT, air dried or oven dried and stored at (a) 30%, (b) 60% and (c) 90% relative humidities



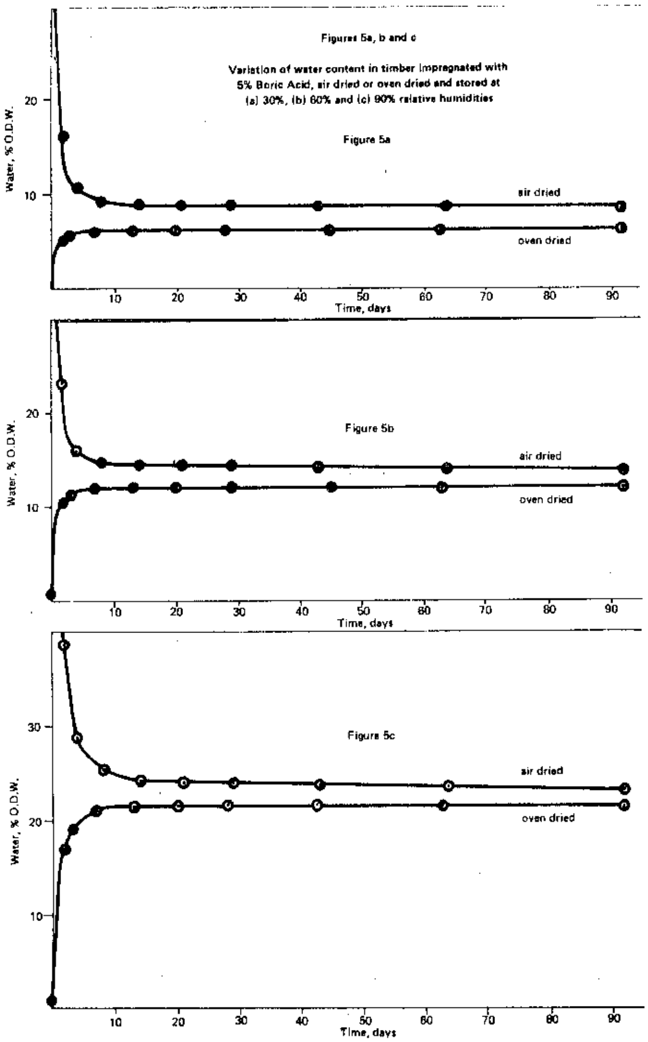
Figures 3a, b and c

Variation of water content in timber impregnated with 15% DOT, air dried or oven dried and stored at (a) 30%, (b) 60% and (c) 90% relative humidities



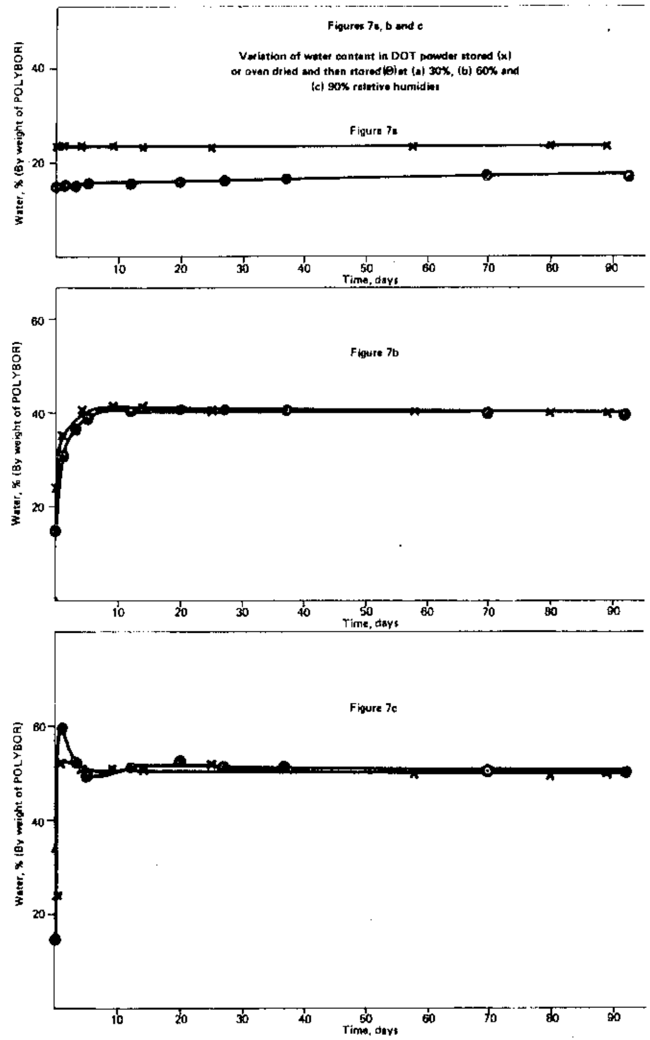
Figures 4a, b and c

Variation of water content in timber impregnated with 5% Borax, air dried or oven dried and stored at (a) 30%, (b) 60% and (c) 90% relative humidities



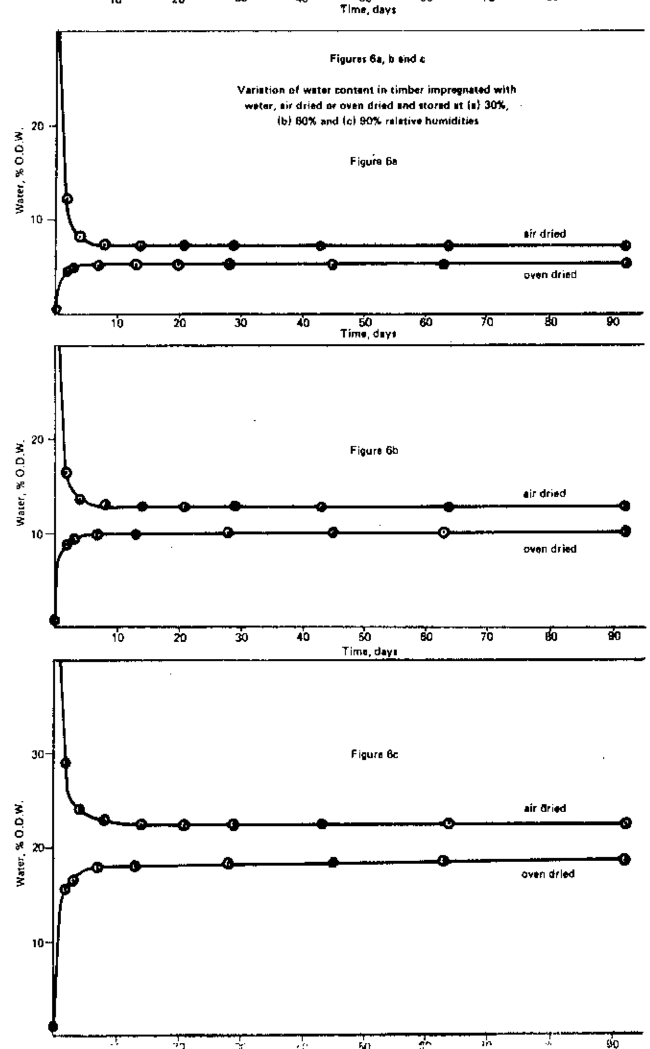
Figures 5a, b and c

Variation of water content in timber impregnated with 5% Boric Acid, air dried or oven dried and stored at (a) 30%, (b) 60% and (c) 90% relative humidities



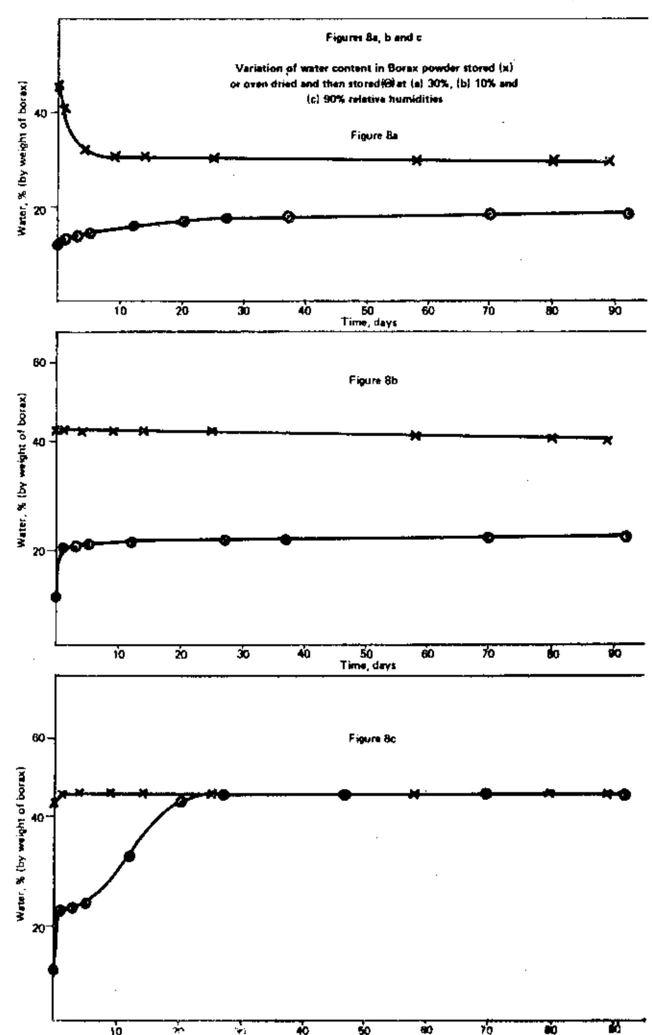
Figures 7a, b and c

Variation of water content in DOT powder stored (x) or oven dried and then stored (⊖) at (a) 30%, (b) 60% and (c) 90% relative humidies



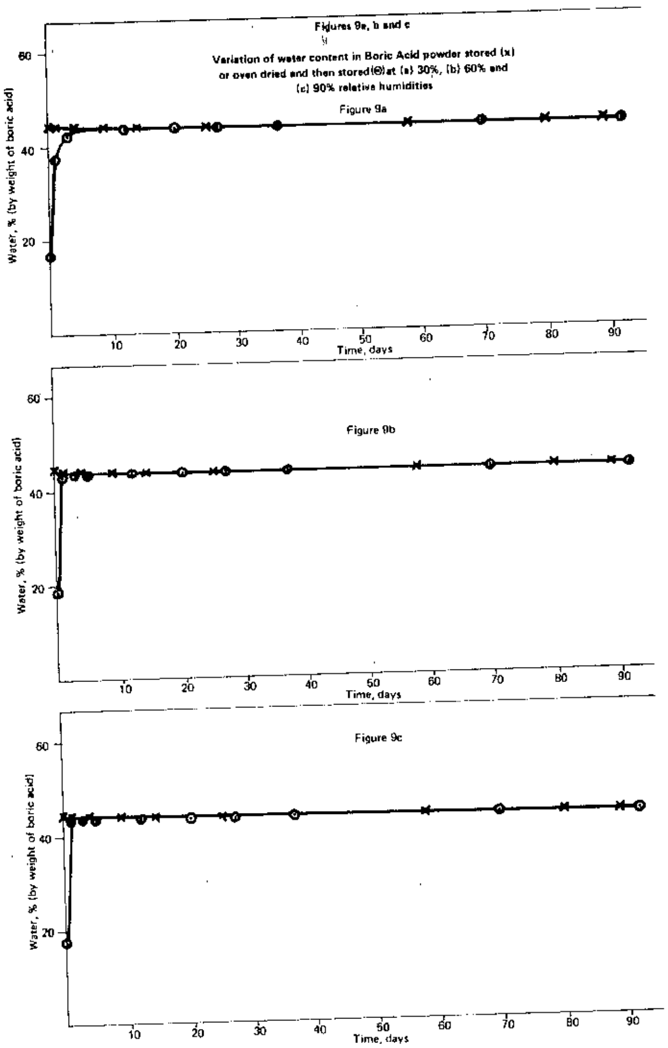
Figures 6a, b and c

Variation of water content in timber impregnated with water, air dried or oven dried and stored at (a) 30%, (b) 60% and (c) 90% relative humidities



Figures 8a, b and c

Variation of water content in Borax powder stored (x) or oven dried and then stored (⊖) at (a) 30%, (b) 10% and (c) 90% relative humidities



Figures 9a, b and c

Variation of water content in Boric Acid powder stored (x) or oven dried and then stored (⊖) at (a) 30%, (b) 60% and (c) 90% relative humidities

The curves for boric acid shown in Figs 5 and 9 are based on data corrected for the loss of the compound through volatilisation. The losses were determined separately and amounted to 6 per cent of the acid originally introduced into the test blocks when these were heated at 105°C for 18 hours. Some loss was expected from the test blocks to the circulating air in the humidity chambers, but this was found to be too small to be measured and was ignored. The losses from boric acid powder were 6·7 per cent on heating at 105°C and a further 5 per cent during the three months period of storage in the circulating air of the humidity chambers. There were no measurable losses of borate from the sodium borates, whether in timber or as powders.

The equilibrium moisture contents associated with the timber on completion of the three months storage tests of borate treated blocks were calculated by subtracting the water of hydration of the borates, as shown in Figs 7–9, from the total moisture contents in the blocks shown in Figs 1–5. The results, together with those obtained with the water-only control, are listed in Tables 1 and 2.

TABLE 1 **Water associated with wood after air drying and 92 days storage in air at 25°C and 30, 60 and 90 per cent relative humidities**

Borate in wood	Water, H_2O% (ODW)		
	30% RH	60% RH	90% RH
DOT,* 5%	7·5	12·7	22·2
DOT, 10%	6·3	11·0	21·5
DOT, 15%	6·9	10·6	21·3
Borax, 5%	6·4	11·6	21·7
Boric acid, 5%	6·2	11·6	20·9
None, control	7·1	12·7	22·3

*'Disodium octaborate tetrahydrate', approx $Na_2B_8O_{13}.4H_2O$

TABLE 2 **Water associated with wood after oven drying at 105°C and 92 days storage in air at 25°C and 30, 60 and 90 per cent relative humidities**

Borate in wood	Water, H_2O% (ODW)		
	30% RH	60% RH	90% RH
DOT*, 5%	5·6	10·1	19·7
DOT, 10%	5·4	9·0	20
DOT, 15%	5·2	8·7	19·8
Borax, 5%	4·7	9·8	18·8
Boric acid, 5%	4·0	9·8	19·3
None, control	5·3	10·2	18·6

*'Disodium octaborate tetrahydrate', approx $Na_2B_8O_{13}\cdot 4H_2O$

Discussion

1 Total moisture in borate treated wood

On comparison of the shapes of the curves in Figs 1–5 with those of the water-only control shown in Fig 6, it is seen that they are all very similar, and that the times required for the equilibria to be reached are of about the same order of magnitude, ie mostly 7–14 days. The loss of all water above the equilibrium level from the blocks containing the highest, ie 15 per cent (ODW) loading of the 'disodium octaborate tetrahydrate' and stored at the highest relative humidity, ie 90 per cent, took about 20 days, but even in this case the amount of free water that the timber contained after 14 days was only about 1 per cent more than in the timber without the borate (cf Fig 6c). Such slight delay in the drying is readily explainable in terms of a weak physical barrier to the evaporation of water. If the pits were solidly blocked the delay would have been considerably greater, and if the borate were to contribute to the hygroscopicity of the timber at 90 per cent RH the rate of drying would be expected to be many times slower than for the water-only control. A confirmation of this is in the fact that the rates of reaching equilibria in the 'desorption' condition do not differ significantly from those in the 'absorption' condition; if the borates contributed to the hygroscopicity of the timber, the rates of moisture loss would have been considerably lower than those of moisture gain.

2 Water of hydration of borate powders

(i) 'Disodium octaborate tetrahydrate'

The powder having the approximate composition of $Na_2B_8O_{13}.4H_2O$ is not a stoichiometric compound but an amorphous mixture of water deficient borates. When recovered as a solid from an aqueous solution it remains an amorphous glass giving no X-ray patterns attributable to crystalline borates and yet it contains water of hydration stoichiometrically related to mixtures of fully hydrated borates. Theoretically, these mixtures could consist of: (a) borax and boric acid which would contain 69·8 per cent water by weight of DOT, (b) sodium pentaborate, borax and boric acid (50·2 per cent H_2O by wt of DOT) or (c) sodium pentaborate and borax according to the reaction:

$$3\,Na_2B_8O_{13}.4H_2O + 18H_2O = 2Na_2B_{10}O_{16}.10H_2O + Na_2B_4O_7.10H_2O.$$

The last mixture would contain 43·7 per cent water (by weight of DOT) and appears to be the most likely end product when equilibrium is established. Before, however, an equilibrium is reached there is a transient stage, at least at sufficiently high relative humidities, during which a mixture with a higher water of hydration content is formed before transformation to the final more stable state. This can be seen illustrated on the example of the 'absorption' curve for the powder in Fig 7c, and to a lesser extent by the 'absorption' curves for the timber blocks containing 10 and 15 per cent of the borate in Figs 2c and 3c.

(ii) Borax

The theoretical water content of borax decahydrate, $Na_2B_4O_7.10H_2O$ is 47·24 per cent. When stored at 90 per cent RH, the compound retains its full complement of water of hydration (Fig 8c). At lower humidities it looses some of the water of hydration; under the conditions of these tests the moisture contents read off the curves in Figs 8a and b were taken to be about 29 and 43 per cent, respectively, the percentages being quoted by weight of borax.

When borax is partially dehydrated on heating at 105°C and then introduced into the humidity chambers, it regains its full complement of water of hydration at 90 per cent RH, but rehydrates to only 19 and 23 per cent (by weight of borax) water at 30 per cent and 60 per cent RH respectively within the 92 days period of storage.

(iii) Boric acid

The theoretical water content of boric acid is 43·7 per cent and, as seen from Figs 9a, b and c, this proportion of water is steadily held by the compound at relative humidities from 30 to 90 per cent. Water lost on heating is readily regained within a few days, even at 30 per cent RH. In the absence of air circulation the boric acid powder would take longer time to rehydrate completely at low relative humidities.

3 Moisture associated with the wood substance

For the purpose of assessment of the results of this study it is assumed that the moisture associated with the wood block is the total moisture found less that chemically bound with the borate at the respective relative humidities. Summaries of these differences on completion of the 92 days storage period are given in Tables 1 and 2. Although, as is generally known, the precision of moisture determination results in timber is not particularly high, bearing in mind that every datum given in this report is the average of four separate determinations on sets of matched redwood blocks, a precision of ± 0·5 per cent in the water content data is conservatively estimated. On this basis it is seen from the results listed in Table 1 that with the exception of the data for boric acid and three out of nine results for DOT, there is no significant difference in the percentages of water found in the test blocks whether treated with water only (bottom line) or with borates other than boric acid; the values obtained with the latter appear to be consistently lower than in the control (cf 6·2 vs 7·1; 11·6 vs 12·7 and 20·9 vs 22·3).

The data of Table 1 are taken to be *the final and conclusive proof that none of the borates tested enhanced in any way the normal equilibrium moisture content of the timber over the range of relative humidities from 30 to 90 per cent.* The only inference from the data obtained with boric acid is that its presence brings about a slight lowering of the equilibrium moisture contents. There is also an indication that DOT may have a similar, though less marked effect.

Accepting the same, ie ± 0·5 per cent, precision for the results shown in Table 2 it would appear that boric acid and DOT bring about a slight increase in the moisture content of timber dried at 105°C and then stored at 90 per cent RH, cf 19·3, 19·7, 20 and 19·8 per cent vs 18·6 per cent for the control. However, it must be noted that none of these results exceeds the 22·3 per cent found for the control in Table 1, or even the average of 22·3 and 18·6, ie 20·5 per cent which might be nearer to the true equilibrium moisture content. Furthermore, it is proposed that the only reason for the slightly higher values found for the borate treated blocks is that the borate protected the timber when this was heated for 18 hours at 105°C against the irreversible changes suffered by the control which, because of these changes, was unable to regain the equilibrium moisture content which it would have in the absence of heating. It is interesting to note that the order of moisture contents, at least in column 3 of Table 2, and hence the order of protection given to the timber against thermal degradation is DOT > boric acid > borax, ie in agreement with the known ranking of efficiency of these borates as flameproofing agents.

The observed effect of boric acid to decrease the equilibrium moisture content of timber is presumably of little practical importance because the effect is so small, but the phenomenon is of considerable theoretical interest. In the course of another study carried out by the author on flameproofing of chipboard and wood fibre with borates (Dulat, 1976) it was found that boric acid tends to adhere firmly to the outermost edges of chips or the tips of wood fibres. It was concluded that the bonding was not chemical but brought about by electrostatic forces between the negatively charged fibres and the acid. It is conceivable that the same forces operate in such a way as to decrease slightly the equilibrium moisture content of timber.

Acknowledgements

The author wishes to thank Mrs L. A. Noyes and Messrs S. G. Arber and R. C. Isted for carrying out the experimental work.

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OSMOSE
DUAL-TREATMENT SPECIFICATION FOR TIMBER CROSSTIES AND SWITCH TIES USING SODIUM BORATE FOLLOWED BY A CREOSOTE OVER-TREATMENT

May 16, 2007

I. GENERAL REQUIREMENTS

Scope:

This specification covers the processing and dual-treatment of crossties and switch ties with disodium octaborate tetrahydrate dissolved in water followed by a creosote over-treatment. The borate solution shall be made only with TIMBOR INDUSTRIAL as supplied through the OSMOSE, INC. This specification is intended to meet or exceed all applicable AWPA Standards relative to preservative treatment of crossties and switch ties.

This specification applies to all facilities providing either treating services or treated wood products utilizing TIMBOR INDUSTRIAL.

This specification will be used in conjunction with the following AWPA Standards:

- AWPA Standard U1-06 – User Specification for Treated Wood
- AWPA Standard T1-06 – Processing and Treatment Standard – except as supplemented herein.
- AWPA Standards P5-06

A. Plant Equipment:

Treating plants shall be equipped with thermometers, gauges, and instruments necessary to indicate and record accurately the conditions at all stages of treatment. All equipment shall be maintained in acceptable, proper working condition, and shall show on the front of the instrument the last calibration certification made on that instrument or gauge. The apparatus and chemicals necessary for making the analyses and tests required by OSMOSE shall be provided by plant operators and kept in condition for use at all times.

B. Specie Categories:

Category 1 – White Oak and Hickory

Category 2 – Sweet Gum, Mixed Hardwoods, and Red Oak

C. Borate Pretreatment Specifications:

1. Pretreatment conditions:

a. Ties should be unseasoned with preferred moisture contents in the 70% to 90%+ range. Moisture contents for mixed hardwoods and gums should be no lower than 40% and oaks and hickories no lower than 50%. Initial loading and subsequent diffusion is enhanced by high initial moisture content.

2. **Pretreatment stacking and tram loading:**

a. Ties are to be branded, saw-kerfed nine inches back from each end on top and bottom, 100% end-plated with embossed plates, or tagged for the borate dual-treatment procedure to assure against loss within the general tie population.
b. All ties must be incised to a minimum depth of 1/2”.
c. Ties should be bulk-stacked without spacing or stickers between ties
d. If ties are banded, the bands should not be tight, so the ties can move slightly as they are submerged in the liquid. Either metallic or synthetic bands or straps may be used.

3. **Delivery System:**
Pressure Cylinder (insulated):

1. Solution must be mixed in a separate mixing tank before introduction to the cylinder.
2. Solution strength should be at a minimum concentration of 20% Disodium octaborate (DOT) wt / wt (13.5% B_2O_3).
3. Solution temperature should be 120-150°F while treating.
4. **Solution temperature must be maintained at a minimum of 85°F, in order that dissolved borate will not fall out of solution. Insulated storage tanks are recommended.**

D. Borate Treatment:

1. Pressure Cylinder:

a. Preheat cylinder and ties with live steam for 15 minutes at maximum 245°F to prevent solution from cooling when making contact with ties. In freezing weather apply steam at a maximum of 245°F for 30 minutes.
b. Apply initial vacuum for 5-10 minutes at 15” Hg to facilitate the filling of the cylinder.
c. Pressure period for Category 1 ties (oak and hickory) shall be 30 minutes at minimum 125 psi or until desired net injection of DOT is achieved
d. Pressure period for Category 2 ties shall be 15 minutes at minimum 125 psi or until desired net injection is achieved
e. Final vacuum period shall be 5 minutes at 15” Hg.

f. Results of treatment shall be minimum net gauge retention of 0.25 PCF (DOT) ± 5% or an average of 1.0 pound of borate per crosstie (7”x 9”x 8.5’) for each charge.
g. Variations in species and within species may necessitate minor adjustments in the above treating schedule in order to achieve the target retention.

E. Diffusion Period after Initial Borate Treatment:

1. General:

The accelerated diffusion period is the most critical part of the dual borate-creosote treating process. The borates that are located in high concentrations within one inch of the tie surface must be allowed to migrate to the center of the tie. The moisture in the cells of the interior wood will allow the surface water to migrate by diffusing from an area of high concentration to an area of lower concentration in the heartwood. As this water diffuses through the wood, it carries the dissolved sodium borate along with it. This can take from two weeks in some mixed hardwoods to four weeks in the oaks. Diffusion periods will vary depending on site, climatic conditions, and the quality of the diffusion storage facility. The ties cannot be allowed to dry at all for the duration of this diffusion period.

Once the borates are sufficiently diffused away from the surface, they can be removed from the sheds or covered area and stacked for air-drying in the usual manner.

2. Diffusion Storage Specifications:

a. Ties must be taken from the treating cylinder drip pad to the diffusion storage area as soon as they are drip free. The bundles cannot be exposed to rain without a temporary covering.
b. A small tarp can be placed over each bundle as it is carried to the diffusion storage area, if they have to be moved in the rain.
c. Bulk-stacked ties are to be placed in orderly stacks and rows within the storage shed or covered area. They must be stacked closely together to minimize drying and air flow.
d. Storage sheds must have solid roofs and solid sides and ends extending all of the way to the ground. Entryways must have solid doors that can be operated quickly. Doors must be kept closed except when actually moving bundles.
e. If using bundle or pile tarps, they must be constructed so that the tarps extend completely to the ground. They must be weighted or fastened to prevent blowing and must fit snugly around the stacks to prevent moisture loss from drafts or venting. The sections of tarps must be small enough that they can be put around small increments of stacks quickly to minimize moisture losses.
f. Access aisles are necessary so that penetration samples can be taken during the diffusion period. These aisles must be oriented so that the sides of the ties are

accessible for borings. If frames and tarps are used, the tarp can be raised from the front while borings are taken from each run.

g. In order that sufficient diffusion time can be controlled, weekly production runs of ties should be clearly marked.

3. **Penetration Testing During Diffusion:**

a. 3" diffusion status (penetration) borings should be taken from the narrow side of 10 ties that are representative of the normal production charges for that week. Borings must be taken midway between the ends and midway between top and bottom of the tie. Ties should be bored from ground level to the top of the stacks.

b. Frequency of testing should be 10 borings at one week intervals during the start-up and qualification phase of the operation. Testing may be stopped when the required diffusion zone is penetrated. Reduced sampling (e.g. bore after 3 weeks) may be permitted once the diffusion rate has been established for the site and climatic conditions. There may be seasonal variations.

c. Diffusion storage should continue until the median penetration of 10 cores is a minimum of 1.5" from the surface. Penetration is determined using a color test (AWPA A3) on cores removed from the midpoint of the ties and shows a red to orange color.

II. SEASONING AND CONDITIONING OF BORATE TIES

A. Air Seasoning Borate Treated Crossties and Switch Ties:

After the diffusion period, ties are restacked into an air-drying configuration and moved to the air-drying yard. Each completed run of green borate ties will be clearly identified and dated on the front of the run, conforming to the fiscal or status month in which completed. A suitable pile cover shall be placed on the top package of each individual stack. A maximum of 30 days will be allowed for the construction, completion and dating of any given run of ties. Each completed run of ties will be scheduled for treatment when moisture contents fall to specified levels. The month stacked shall not count as a drying month; i.e., January – November equals a 10-month period.

For air-dried runs, 5 of the 20 borings required for moisture assessment shall be taken from the hacks on the ends of the runs. Sufficient runs must be sampled to yield a representative moisture content that will allow proper creosote penetration in all of the ties that have satisfied drying requirements for that month.

A solid 3" boring shall be taken midway between the ends and midway from the top to bottom of each tie sampled. Switch ties shall be sampled four feet from either end. All species within a run should be included in the moisture content determination.

The whole 3" boring shall be dried, and the finished moisture content percentage shall not exceed the following limits:

- White oak-Hickory 50% maximum moisture content
- Mixed Hardwoods 40% maximum moisture content

The stacking method that normally produces the best results for a particular locality shall be used. However, regardless of stacking method, all stacks must be supported on treated sills. The first layer of ties shall be off the ground by 12” or more. Space between the stacks or runs shall be dictated by site and climate.

Horizontal and vertical alignment of ties within a stack or run must be equal to provide for adequate air circulation within and between stacks or runs of ties. When stickers are used for air-drying, they must be treated and at least 1 1/2” thick.

All seasoning yards shall be so located and constructed to provide for free, unobstructed flow of prevailing air currents, and complete water drainage away from the stacks of seasoning ties. Seasoning yards will be kept free and clear of grass, weeds, decayed wood and other objects that inhibit good seasoning.

B. Artificial Seasoning (Boultonizing)

BORATE CROSSTIES OR SWITCH TIES SHOULD NOT BE BOULTONIZED AS A STANDARD PRODUCTION PROCEDURE. The Boulton cycle removes approximately half of the borates from the ties.
When Boultonizing is absolutely necessary, as in the case of switch ties, bridge ties, flanges, and crossings, that the borate solution strength and treating process should be adjusted to compensate for the expected 50% loss of borates in the Boultonizing process.

Plants should recognize and adjust for the risks of borates in the creosote solution and waste water downstream from the treating cylinder.

III. TREATMENT PROCEDURES FOR BORATE TIES

Ties should be creosote treated using the same procedures applied to dry non-borate treated ties.