

Application of Near Infrared Spectroscopy to Preservative-Treated Wood

**Chi-Leung So¹, Stan T. Lebow², Thomas L. Eberhardt³, Leslie H. Groom⁴
and Todd F. Shupe⁵**

¹Postdoctoral Researcher, School of Renewable Natural Resources, Louisiana State University AgCenter, Baton Rouge, Louisiana, USA

²Research Scientist, USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA

³Research Scientist, USDA Forest Service, Southern Research Station, Pineville, Louisiana, USA

⁴Project Leader, USDA Forest Service, Southern Research Station, Pineville, Louisiana, USA

⁵Professor, School of Renewable Natural Resources, Louisiana State University AgCenter, Baton Rouge, Louisiana, USA

Abstract

Near infrared (NIR) spectroscopy is now a widely-used technique in the field of forest products, especially for physical and mechanical property determinations. This technique is also ideal for the chemical analysis of wood. There has been a growing need to find a rapid, inexpensive and reliable method to distinguish between preservative-treated and untreated waste wood. It has been demonstrated that NIR spectroscopy, with multivariate analysis (MVA), can be used to distinguish between different preservative treatments. This technique is rapid, non-destructive, portable and relatively low cost. The results clearly demonstrate that this technique has potential for use in a variety of recycling and sorting applications. It has also been successfully used to predict preservative concentrations present in treated wood. A custom-made NIR scanning system, NIRVANA (Near Infrared Visual and Automated Numerical Analysis), was used for the automated scanning and prediction of preservative concentration along cross sections of ACQ-treated timbers. This may have potential for use as a quality control tool for wood treaters, especially for use with organic co-biocides, for which the preservative penetration and concentration cannot be readily assessed.

Introduction

Preservative-treated wood is widely used for the construction of decks, fences and other residential applications. The primary preservative used for residential applications in the United States had been chromated copper arsenate (CCA) until its phase out for virtually all residential applications was implemented (US Environmental Protection Agency, 2002). This has led to the introduction of replacements such as alkaline copper quat (ACQ) and

copper boron azole (CBA). Increasing amounts of CCA-treated wood reaching the end of its service life need to be sorted and processed, following strict guidelines, for its disposal.

Research efforts into sorting technologies for distinguishing between CCA- and non-CCA treated waste wood have been led by Solo-Gabriele and colleagues (Blassino et al., 2002; Solo-Gabriele et al., 2004). They have used laser induced breakdown spectroscopy (LIBS) and x-ray fluorescence (XRF) spectroscopy to quickly and accurately differentiate CCA-treated wood from untreated wood, online at a waste sorting facility for construction and demolition debris. Another possibility is the use of near infrared (NIR) spectroscopy together with multivariate analysis (MVA). This has the potential for detecting and distinguishing between a variety of preservative-treated wood with or without organic or inorganic preservatives, and can be installed online at a waste wood sorting facility or used in the field with a hand-held spectrometer (So et al., 2004).

Early work by Feldhoff and coworkers (Feldhoff et al., 1998) investigated the presence of inorganic wood preservatives on timber, this involved spectral evaluation by visual means only. However, the application of MVA techniques to the NIR spectra was first reported in So *et al.* (2004). This included studying a variety of preservative treatments, both organic and inorganic, in which the treatments were identified and distinguished, as well as the amount present. Other recent studies have determined the levels of borate (Taylor and Lloyd, 2007) and creosote (Hedrick et al., 2007) in wood.

When wood is treated with preservatives, there are minimum standards that the wood treater must adhere to for quality control, and in the United States, these are provided by the American Wood Preservers' Association (AWPA). Determining the preservative retention and the depth of penetration into the timber is of great importance. The relevant AWPA standards can be very labor-intensive and time consuming. NIR spectroscopy has also been used for these determinations, in which an automated spectra collection system, NIRVANA (Near Infrared Visual and Automated Numerical Analysis) (So et al, 2007; So et al, 2006), provided rapid and detailed analysis of preservative penetration depth (So et al, 2007).

Materials and Methods

Materials

Several commercially-treated deck boards were obtained for this study, with the following preservative/wood species combinations (described in So *et al.* 2004): CCA/Hem-Fir; CCA/Eastern Hemlock; ACZA/Douglas-fir and ACQ/Hem-Fir. Details of the sample preparation and testing are also available in So *et al.* 2004. Commercial ACQ-treated southern yellow pine (SYP) timbers were selected for spectral mapping and sample preparation is detailed in So *et al.* 2007.

Near infrared spectroscopy

NIR measurements were made using a Nexus model 670 FTIR spectrometer (ThermoNicolet, Madison, WI, USA) as described in So *et al.* 2004. Spectral mapping of the treated timber was performed using the NIRVANA system. Briefly, timber specimens were positioned on a Newport motorized stage, while the NIR spectra were collected using

an ASD FieldSpec Pro FR spectrometer (ASDI, Boulder, CO, USA). Further details are provided in So *et al.* 2007.

Multivariate analysis

Multivariate analysis of the data was performed using the Unscrambler (version 8) software (Camo, Woodbridge, NJ, USA). Multiplicative scatter correction (MSC) was applied to the NIR spectra, followed by wavelength reduction to 10 nm spacing. The NIR spectra for the calibration specimens were also averaged to one spectrum per sample. Principal component analysis (PCA) was used to observe any clustering and/or separation in the sample sets. Partial least squares (PLS) analysis was performed on the calibration spectra and calibration models were generated using full cross validation. Three wavelength ranges (full: 400-2500 nm, visible: 400-700 nm, NIR: 1000-2500 nm) were used for the analysis.

Results and Discussion

PCA was used to differentiate between the various preservative treatments applied to the wood specimens. This was performed on the complete set of samples. Fig. 1 shows the resultant scores plot. Although there is some overlap, clusters are clearly evident, differentiating the three preservative treatments of CCA, ACQ and ACZA. It can be seen that the separation between the Hem-Fir samples with different preservative treatments (CCA Hem-Fir and ACQ Hem-Fir) was much greater than the separation between the CCA samples with differing wood species (CCA East Hem and CCA Hem-Fir). This would indicate that preservative type may dominate over any differences in wood species, a requisite for sorting preservative-treated wood. Also, analysis of only the CCA samples showed clear separation between the East Hemlock and Hem-Fir species as compared with Fig. 1. These results have been discussed in more detail elsewhere (So *et al.*, 2004).

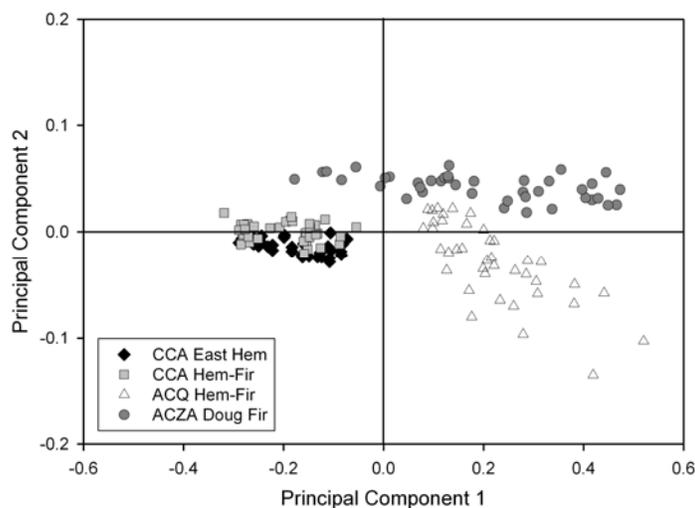


Fig. 1. PCA scores plot from all the NIR spectra collected.

PLS regression was undertaken to predict the values of preservative retention for the samples, this included the levels of CuO, CrO₃ and As₂O₅, where applicable. Only the result for the complete set of samples is shown here in Fig. 2. A strong relationship exists between the experimentally-determined CuO retention and that predicted by NIR, with a correlation coefficient (R^2) of 0.98 using five factors. Strong correlations were also obtained for CuO, CrO₃ and As₂O₅ with the CCA samples, as well as the individual sample sets (So et al., 2004).

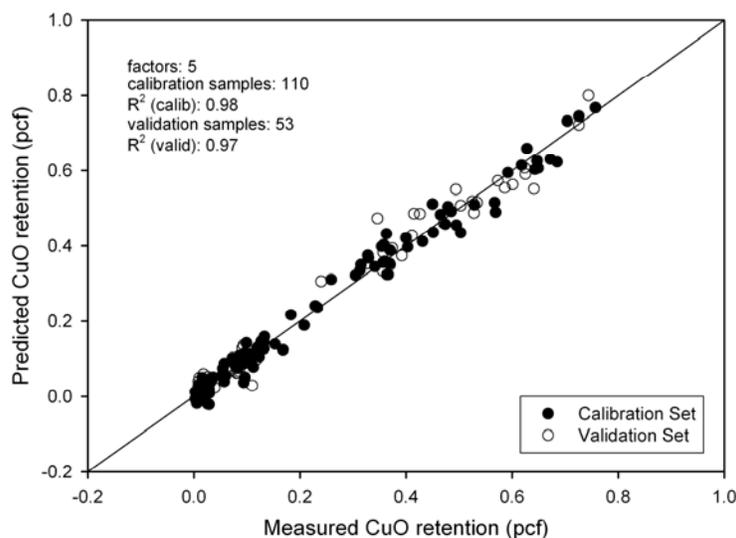


Fig. 2. Relationship between measured and NIR-predicted values of CuO retention.

NIRVANA was used for the automated spectral mapping of an ACQ-treated SYP timber specimen. This specimen was taken from a fast-growth tree with widely-spaced growth rings, exhibiting no obvious heartwood formation. CuO retention values were predicted along the specimen using previously-built models based on small ACQ-treated SYP blocks detailed in So *et al.* 2007. The resultant plots for three wavelength ranges in Fig. 3 show the variation of CuO retention and preservative penetration depth along the timber specimen between the specimen end (0 mm) and the pith, with the scan line displayed as a dashed line on the image. The scattered nature of the plot is mainly due to the earlywood and latewood bands, with the full wavelength range exhibiting the least scatter. It may be preferable to apply an ‘average’ line to the plot for analyzing the trends. Fig. 3 shows that the CuO retention steadily decreases from a maximum value at the specimen end (0 mm) to no preservative penetration (i.e., 0 pcf) beyond 80 mm. A spike in the data clearly shows the position of the pith and can be used as a reference point to verify sample alignment. An important point to note is that this technique cannot be considered a measure of color since the CuO is detected outside the visible region in the 1000-2500 nm plots. Similar mapping studies were performed on other treated timbers, including a specimen from a slow-growth tree with both heartwood and sapwood present. The result from that specimen showed no preservative penetrated the heartwood (So et al, 2007).

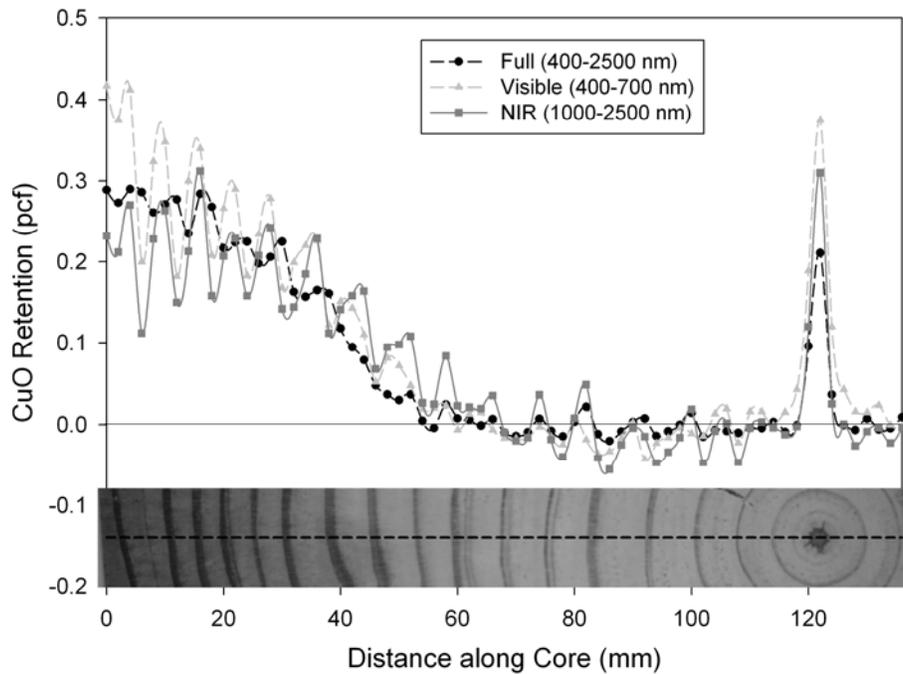


Fig. 3. Variation of CuO retention and preservative penetration depth in a section of timber from a fast-growth SYP tree

Conclusions

This brief summary clearly shows that NIR spectroscopy, in conjunction with MVA, has great potential for use in the study of preservative-treated wood. It has been demonstrated that it is possible to use PCA to separate and identify various preservative treatments applied to wood. PLS regression can be used to produce strong correlations between the measured and NIR-predicted preservative levels. Based on such models, NIRVANA may be potentially suitable for quality control assessments of treated timber by providing both rapid and detailed analysis of both the preservative retention and depth of penetration.

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