Groundline Decay Prevention without Toxic Materials

Chad Roper, Fred Pfaender, and John Goodman

Amendment of the soil adjacent to a utility pole or similar buried wood with a time-released carbohydrate source slows decay dramatically, without the environmental and safety hazards associated with the introduction of toxins. Consumption of the readily degradable carbohydrate source accelerates the depletion of oxygen from the soil during saturated conditions. Because decay occurs in anaerobic conditions at 1/5th to 1/10th the rate of aerobic conditions, increases in the length of time the soil around a pole is anaerobic produce decreases in the overall rate of degradation. The addition of a simple carbohydrate source also alters the microbial community around the pole to one, which favors bacteria over wood decay fungi. Bacteria are incapable of degrading lignin and are competing with wood decay fungi for mineral and organic nutrients in the soil. Data on oxygen depletion in soil and water systems is presented to support these mechanisms. In accelerated laboratory decay studies, carbohydrate amendment allowed southern yellow pine test strips to have no loss of strength in the same time period that strips without amendment decayed completely (280 days). In the field, application of a time-released carbohydrate source slowed the rate of decay for southern yellow pine stubs (as measured by Pilodyn) to roughly 1/3 of their un-amended counterparts.

Keywords: Carbohydrate, groundline, decay, wood

INTRODUCTION

Biological degradation of wood in the environment is mediated by three major groups of organisms (Brock and Madigan, 1991). Filamentous fungi use their hyphae and extra-cellular enzymes to penetrate and degrade the wood structure. Bacteria of many genera have the ability to utilize the cellulose and hemicellulose components of wood, generally using the material to support their growth and reproduction. Finally, wood boring insects and insect larvae also participate in wood biodegradation.

Wood consists of interlocked layers of cellulose and lignin. The rigidity and structural integrity of wood depends on maintaining the lignin backbone and supporting cellulose materials. Bacteria are probably the most important in cellulose degradation, while fungi, particularly the Basidiomycetes are the most important for lignin degradation. As each layer of lignin is compromised, more cellulose becomes available (Krik and Highley, 1973). Thus, it is the action of wood decay fungi in concert with bacteria which allows for the degradation of wood in nature.

Generally, the organisms responsible for degrading the structure of wood are obligate aerobes, that is, they require oxygen for their metabolism. Ground line decay in utility poles is an example of the convergence of oxygen, fungi, and bacteria causing accelerated wood decay. A model of this process was given by the authors in an earlier publication (Pfaender et al., 1996).

For decades, humankind has looked for ways to treat wood that slow wood decay processes. Current technology has been based almost entirely on treating the wood with materials toxic to the bacteria, fungi, and insects. While this strategy has been quite effective if done properly, it has led to potential environmental problems at each pole, and major hazardous waste problems at sites where wood is treated. In addition to inhibiting microorganisms and insects, most of the chemicals also are toxins or carcinogens for

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humans and other animals. All of the major wood treating materials currently used (i.e., creosote, pentachlorophenol, and CCA) represent potential human and environmental health hazards. Currently EPA lists over 3000 present and former wood treating operations as hazardous waste sites (www.EPA.gov, 2000). The clean up of these sites represents a major liability for the wood treating industry and railroads, as well as society in general.

If we start with the premise that decay is inevitable, then our goal is to delay the onset or slow the progress of the decomposition process. One common requirement for wood decay is oxygen and another is water. In contrast to their cooperation in the degradation of wood, bacteria, and fungi are in competition for oxygen and other resources (mineral and organic nutrients, water) in the area adjacent to the surface of the wood.

Competition for available resources is a fundamental tenet of biology and is visible on all levels of life. This competition can be used to control the activity of wood decay organisms. When a readily bioavailable carbohydrate source can be added adjacent to the pole's surface, the limiting factor in the degradation of the carbohydrate source will, in fact, be another limited resource for which bacteria compete with fungi, namely oxygen. Competition for oxygen creates conditions, which are described as anaerobic (defined as extremely depleted oxygen). Anaerobic conditions cause a rapid dominance of bacteria and subsequent, slower rise of anaerobic bacteria (Swindoll et al., 1988). Bacteria are also favored over the wood decay fungi in this system because the bacteria are more readily adaptable, are able to consume the carbohydrate source and grow at a faster rate than the wood decay fungi.

Microbially mediated processes are many times slower in the absence of oxygen (Brock and Madigan, 1991). The amount of energy available to an aerobe is approximately 19 times greater than can be extracted by anaerobes from the same food materials. This will be especially true of wood decay organisms because of the unique nature of wood and its constituents. Since it is a complex polymer, cellulose, like almost all polymers, is slowly degraded anaerobically (Zeikus, 1981). Further, there are no known pathways for the anaerobic biodegradation of lignin (Colberg, 1988). A detailed review of anaerobic degradation of lignin suggests it may be biochemically possible, but is very rare in nature (Kirk and Highley, 1973).

The anaerobic community induced by the addition of carbohydrate should be either greatly slowed or completely prevented from degrading the wood. In the presence of mineral sulfates, the anaerobic community formed is likely to be one of sulfate reducers. The reduction of the sulfate should also produce hydrogen sulfide (H_2S). H_2S is known to inhibit insect activity and repel larger animals.

This report presents evidence that carbohydrate amendment accelerates the formation of anaerobic conditions in water saturated systems. It will also show that carbohydrate amendment preserves the break strength of test stakes in accelerated laboratory studies and that time-released carbohydrate amendment slows the softening of full-size, untreated, southern yellow pine stubs in field studies near Charlotte, North Carolina. The product that has resulted from this research is currently being tested independently in a laboratory at Oregon State University.

METHODS

Laboratory tests: Oxygen depletion

Rates of oxygen depletion in an aqueous solution caused by the addition of soil alone and soil with carbohydrate amendments were determined. An aqueous system was used due to the limitations of the instrument used, a membrane-based dissolved oxygen (DO) probe (YSI Biological Oxygen Monitor). Oxygen depletion caused by the addition of 1 g of soil with and without 0.1 g/carbohydrate source to 10 ml deionized water was measured over time. This apparatus was interfaced with a PC and the data logged until the dissolved oxygen reached 0 mg/l.

Laboratory tests: Test stakes

Laboratory testing was performed on model stakes (0.5 inch × 0.5 inch × 10 inch, southern yellow pine). Model stakes chosen for the study were free from visible defect (knots, cracks, etc.) as per the clear timber testing standards described by ASTM (1954). Evaluation of the wood decay process is based on visual observation of the poles after incubation (as recorded in photographs) and the ASTM procedure for testing the Static Bending Strength of wood. As per this method, all test-poles were weighed, dried in a 55°C oven for 12 h and re-weighed. When constant weight was reached, the model poles were placed on the test apparatus, which was built as a scaled down version of the apparatus described by ASTM for the 'static bending' of small, clear, timber specimens (D143-52).

The bearing block was scaled down and the distance between the bearing plates was reduced to 4 inches. Because of this width, each 10-inch test-pole could be sampled twice, once at the ground line and once well above the ground line (the clean end of the test-pole). The ASTM method, which uses 2 inch width sections of wood has been scaled down for the model pole size used. The method was further modified in that rather than comparing sections of wood of equal distance from the pith, the modified method compares sections of wood to themselves by testing two sections along the same grain. These modifications serve to apply the method to our particular case rather than alter the parameter tested. In each test, the maximum pressure exerted by the bearing block was recorded as the breaking pressure.

Field testing

During the summer of 1996, we began a field test at Lake Wiley near Charlotte, NC. This plan involved the introduction of sixteen (16) 5 foot long, full (8–12″) diameter, untreated southern yellow pine utility pole timbers into the earth. These tests used the prototype RS21 (US Patent #5,770,265) treatment material. In 1998, a second round of testing was initiated. This time 24 timbers were used, improving the statistical significance of this test and also allowing sets of timbers under each treatment protocol to be left alone until the end of the study to determine the impact of sampling on the experimental results.

To avoid the cost of breaking full size utility pole sections and to allow for repeated testing of the same pole over time, the field test at Lake Wiley has relied on a Pilodyn 6J™ penetrometer method for evaluating wood decay. The Pilodyn™ penetrometer fires a pin into the pole surface with a uniform, constant force (6 joules) and then measures the depth of penetration. At the time of planting, baseline data for the penetrability of the timbers was obtained.

Beginning in 1998, Dr. Jeff Morrell at Oregon State University initiated a field trial of the effectiveness of RS21. The study was conducted in the same manner as described above except that Pilodyn readings were taken at multiple locations above and below the ground line. Also, plugs were collected for the identification of fungi colonizing the surface of the wood.

Fungal identifications

Cultivating and identifying fungi from a wood surface is a difficult technique that combines microscopy with the enrichment of selected organisms on growth media. By examining a wood plug under the microscope, fungal hyphae are selected for enrichment and subsequent identification. Fungi are identified most conclusively by the sporophore they produce when grown on laboratory media (Brock and Madigan, 1991). After the selected hyphae are inoculated on the laboratory media, they are allowed to grow until a sporophore is formed. The shape and appearance (morphology) of this sporophore allow for the identification of the fungi. The numbers of decay and non-decay fungi are then counted and the counts reported.

RESULTS

Laboratory results: Oxygen depletion studies

The amendment of soil with a carbohydrate source should accelerate the depletion of oxygen due to increased respiration by soil microorganisms. In Fig. 1, the addition of 0.1 g of a simple carbohydrate source caused the rate of oxygen consumption to increase nearly 8 fold. Amended samples were depleted of oxygen in an average of three hours while samples that were not amended took an average of 24 h to deplete their oxygen. In nature it is difficult to deplete the oxygen in the soil around a pole continually due to its contact with the atmosphere. However in conditions where the soil is moist or saturated with water, the presence of the simple carbohydrate source causes the oxygen to be depleted much more rapidly, and therefore extends the length of time the soil around the pole will be anaerobic. As was previously mentioned, anaerobic conditions mean slower degradation, bacterial domination of resources, and possibly the elimination of lignin degradation. The impact of these changes was observed in the laboratory and field efficacy tests.

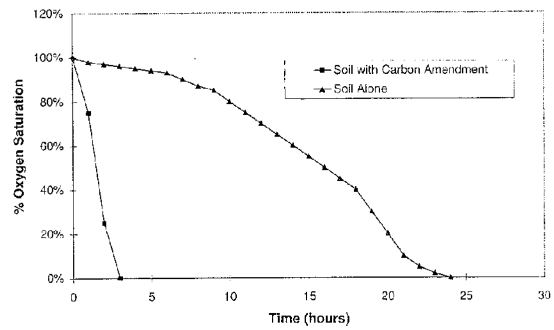

Fig. 1. Oxygen depletion in aqueous system.

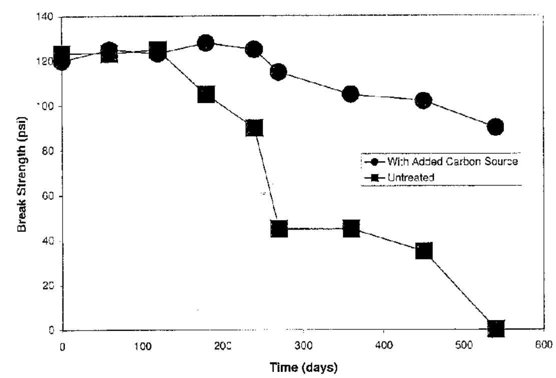

Fig. 2. Lab study of 0.5″ test strips.

Laboratory results: Test stakes

The results from the laboratory studies using model test stakes are given in Fig. 2. As can be seen, the periodic addition of a simple carbohydrate source to the stakes alters the rate at which they lose break strength. Without carbohydrate amendment, the stakes began to lose their strength very rapidly (around 180 days) and had lost all of their strength after about a year and a half. Carbohydrate amended stakes had no significant loss in strength for 270 days and retained an average of 75% of their initial break strength when the study was concluded after 18 months.

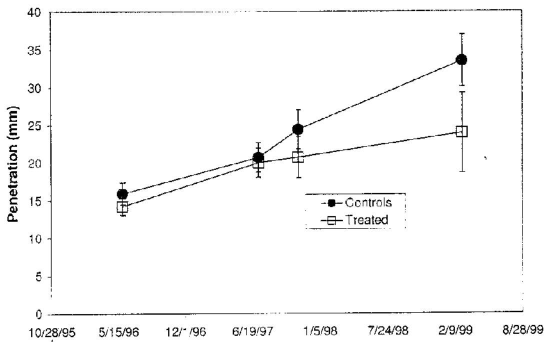

Fig. 3. Field study of time-release carbon source amendment.

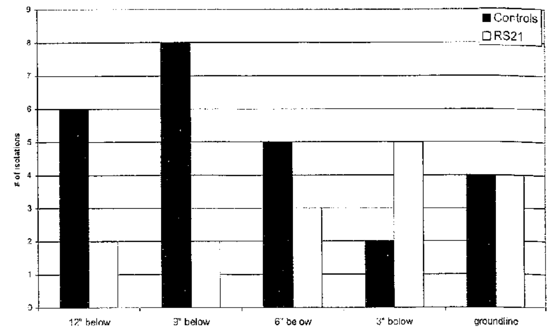

Fig. 4. Number of isolations of decay fungi from pole stubs with and without RS21.

To determine if this effect could be replicated in the field, it was necessary to modify the method of carbohydrate amendment. In the field, the direct addition of the carbohydrate source would be ineffective due to carbohydrate dilution in wet conditions. To overcome this limitation, a time-release mechanism was devised by which the carbohydrate is released whenever biological activity (and therefore the likelihood of decay) in the area is high. This technology, as well as the use of carbohydrate amendment to preserve wood in contact with soil have been patented by Triangle Laboratories (Durham, NC) and the University of North Carolina at Chapel Hill (US Patents #5,770,265 and #6,004,572).

Field results

The results of the field test of the time-release carbohydrate source amendment are given in Fig. 3. Pilodyn™ penetration increases with increasing decay and was used as a measure of wood softening for this study. Treatment material was added after decay had begun in order to simulate likely re-treatment conditions. Prior to June of 1997, the rate of decay was nearly identical in all stubs. Following the addition of the time release carbohydrate source, the rates of decay diverged significantly. Control samples (without carbohydrate source amendment) showed a 65% increase in Pilodyn™ penetration from July of 1997 to March of 1999. During the same time period, stubs with time-release carbohydrate sources added to the soil around them had an increase of penetration of only 20%. Extrapolated, this indicates a three-fold life extension caused by the addition of the time-release carbohydrate source assuming that the density of the outer wood is directly proportional to its overall strength.

External testing

RS21 is also under concurrent testing in the laboratory of Dr. Jeff Morrell at Oregon State University. In 1998, Dr. Morrell's research group established a stand of test stubs and initiated an annual sampling plan. Sampling consisted of Pilodyn measurements above and below the ground line and the collection of wood plugs for the cultivation and identification of fungi on the wood surface. Results given are from the sampling, which occurred in the summer of 1999 (Figs. 4 and 5).

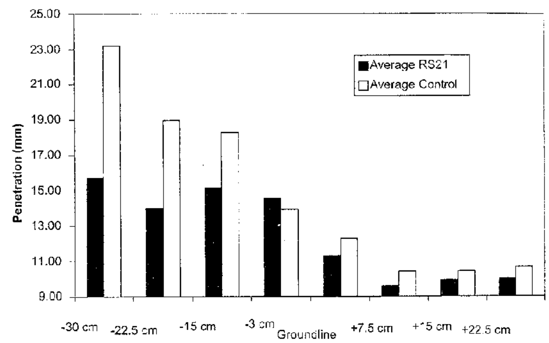

Fig. 5. Pilodyn penetration at 1 year.

Fungal cultures

Although these results come from only one year of testing, the numbers of decay fungi cultivated from the pole's surface were generally lower in the presence of RS21 (Fig. 4). At a level 3″ below the ground line, there were more decay fungi present with RS21 than with the untreated controls, but at all other depths below ground line, there were at least 20% more decay fungi culturable from the controls than were cultured from the poles which had RS21.

Pilodyn testing

The Pilodyn testing performed by Dr. Morrell's group was also conducted at multiple depths and closely mirrors the results of the fungal identifications (Fig. 5). At the ground line and just below, poles with RS21 are roughly equal in surface penetration to untreated poles. As the depth increases however, the advantage of the poles treated with RS21 begins to show. For comparison purposes, the Pilodyn measurement was taken 5–7″ (12.5–17.5 cm) below groundline in the tests conducted at Lake Wiley. At 15 cm, the surface of the poles treated with RS21 retained approximately 10% greater resistance to penetration than the control.

DISCUSSION

The results of this research indicate that carbohydrate amendment will accelerate the depletion of oxygen under water saturated soil conditions. The depletion of oxygen is believed to cause three distinct effects that lead to the preservation of wood: (1) formation of anaerobic conditions under which all biodegradative processes occur more slowly, (2) alteration of the soil microbial community to one which is predominated by bacteria (which cannot degrade lignin), and (3) reduction of added sulfate to sulfide (which is known to inhibit insects). Carbohydrate amendment is demonstrated to preserve the break strength of wood test stakes in laboratory studies, and the addition of a time-released carbohydrate source slows the softening of untreated southern yellow pine stubs in a field study. Although the external testing is still in its early stages, the preliminary results seem to be in good correlation with the results from our trials. The additional information regarding the numbers of decay fungi present supports the presumed mode of action for carbohydrate amendment. Time-released carbohydrate amendment represents an alternative to using toxic methods of groundline decay prevention.

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