EFFECT OF LANDFILL BURIAL ON CONDITION OF WOOD: PRELIMINARY TESTS

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Abstract. The effect of landfill exposure on residual levels of cellulose, hemicellulose, and lignin was investigated on wood materials removed from differing depths in a 5-yr-old landfill cell in western Oregon. There was little evidence of change in the levels of these components with increasing landfill cell depth in softwood lumber, softwood plywood, or hardwood lumber. The results confirm studies at other landfills showing that wood degradation rates under anaerobic conditions in landfills are much slower than predicted and that models to predict these rates need to be modified.

Keywords: Landfill, wood, deterioration, softwoods, hardwoods, carbon.

INTRODUCTION

Trees are viewed as a potential contributor to reducing atmospheric carbon dioxide levels because they sequester carbon into the wood structure (Lippke et al 2010). Trees alone are not the solution to decreasing atmospheric carbon dioxide levels, as they represent only one component of an overall reduction strategy. One aspect of using forests for carbon sequestration is that forest harvests for various building products can be used to sequester carbon within a building, while additional carbon is captured in the replanted forest. These buildings would eventually need to be replaced, creating the potential for reintroducing this carbon into the atmosphere through biological decomposition or combustion to produce energy (Puettmann et al 2010). The third disposal route would be through placement in a municipal solid waste (MSW) facility. The fate of wood materials in a landfill has important implications for estimating the length of time carbon is sequestered.

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Modern MSW facilities are characterized by lined landfilled cells with leachate collection systems designed to either capture leachate and return it to the site or process it for safe disposal. The material in the landfill is generally heavily compacted to maximize the overhead airspace and optimize capacity. The cells are largely anaerobic which should markedly slow degradation and prolong the sequestration period. Degradation becomes of interest when calculating the rates at which wood releases carbon dioxide into the atmosphere as part of a life cycle analysis (Lippke et al 2010; De la Cruz et al 2013).

Wood is inherently more resistant to degradation than other cellulosic materials, owing to the presence and arrangement of lignin (Panshin and de Zeeuw 1970). Most of the organisms that degrade wood are anaerobic because anaerobic bacteria can degrade wood (Zabel and Morrell 1992). Anaerobic processes are extremely slow as evidenced by the exceptionally long life of untreated wooden piling used to support buildings in many European cities, especially Venice. Anaerobic conditions in most MSW landfills should result in similarly slow degradation rates and the leachates in this environment could further affect the rate of degradation by creating conditions less conducive to microbial attack. Landfill leachates tend to have pH levels ranging from slightly acidic to basic and include a range of heavy metals and possibly some elevated levels of ammonia that could all affect the microbial flora present (Kjeldsen et al 2002). Understanding the rate of wood degradation in the landfill environment is important for determining the degree to which these products are sequestered over time. Degradation processes are likely to vary considerably with wood species and landfill characteristics. Developing data on degradation rates from landfills with a range of conditions, therefore, becomes important from the perspective of better understanding sequestration on a more global basis.

Although there have been a number of reviews and some controlled laboratory studies, there appear to be only limited data on the condition of wood after prolonged landfill exposure (Micales and Skog 1997; Barlaz 2004, 2006; Padgett 2009). Ximenes et al (2008) examined wood removed from landfills in Sydney, Australia, and found limited loss of hemicelluloses at one site and little evidence of loss at another. They later compared the characteristics of wood from the Sydney landfill with wood removed from a closed landfill located in the tropical part of North Queensland and found little difference between the properties of nonexposed radiata pine lumber (*Pinus radiata*) and wood of the same species exposed at the two sites, but heavier degradation of hardwoods at the tropical site (Ximenes et al 2015). They concluded that there was a need to examine the default factors used to estimate decay of wood in landfills, because current estimates tend to vastly overestimate the rate of degradation. The Sydney landfills were quite old and landfill operational practices have changed markedly since they were established. Recycling programs have diverted large portions of the waste stream from the landfill and compaction techniques designed to maximize airspace have improved. These practices may alter the rates of degradation of various waste stream components, including wood, making degradation even less likely. The lack of data on the degradation rates in more recently constructed landfill cells makes it difficult to determine the rates at which carbon from wood waste will return to the atmosphere and these rates are important in calculating the potential for using wood as part of the carbon dioxide mitigation scheme.

It can be difficult to access materials within a landfill cell and a number of studies have attempted to use constructed landfills or inserted materials into section of landfills. However, these environments cannot completely replicate an actual landfill. Retrieving wood exposed in landfills can also be problematic, but many landfills have installed collection systems to capture methane for either direct combustion or combustion for electricity cogeneration. Wells are drilled for installation of these collection systems as a landfill cell is nearing completion providing an opportunity to collect any woody debris removed during the process. The material is usually stratified by age, allowing for collection of increasingly older material with well depth. The negative side of this approach is that it is constrained by cell age, but it provides a window into the condition of materials deep within a landfill.

The goal of this research was to examine the condition of wood material removed from different layers within a 5-yr-old landfill cell in an MSW facility located in western Oregon.

MATERIALS AND METHODS

Material Collection

The facility evaluated was a regional landfill located near Corvallis, OR, that has been operated for over 60 yr. The site receives approximately 1.1 m of rainfall per year and most of this rain falls between November and April. The climate is characterized as Mediterranean with mild, wet winters and warm, dry summers. The site collects all of its leachate for processing offsite. The leachate has a pH of between 6 and 9.5 and contains traces of arsenic, chromium, nickel, zinc, and substantial amounts of ammonia (1100-1600 mg/L) (Anon, 2013; York et al 1999). The facility also installs impermeable barriers over as much of the landfill site as possible to divert rainwater to reduce leachate generation. No site-specific waste composition studies were available, but a 2009-2010 Oregon Department of Environmental Quality Waste Composition Survey indicated that the waste included 9.5% paper products, 21.4% plastics, 49.8% yard debris, 11.1% wood products, 3.4% textiles, 3.9% asphalt roofing, 7.0% metals, and 11.2% inorganics (Oregon Department of Environmental Quality [DEQ], 2010). The waste shed in the current study has regular yard debris collection and this material is composted, so the amount of organic material entering the landfill should be much lower than the statewide figure.

The cell that was examined had been established 5 yr earlier and contained material collected from both industrial and household waste sites. The surrounding community operates a comprehensive recycling program including collection of household yard debris and wood materials that should reduce the presence of these materials in the waste stream. The opportunity to collect wood from differing depths in the cell arose as part of a drilling project to establish additional methane collection wells to supply an adjacent cogeneration facility.

The wells were drilled at predetermined locations on the cell, based on optimal gas collection. A total of five wells were drilled. As each well was drilled, the operators would periodically stop to allow for collection of materials from a given horizon. Since it was not possible to collect material from a specific point in a horizon, the materials collected were classified as coming from depths corresponding to 0-6, 6-10.5, 10.5-13.5, and greater than 13.5 m. The material collected from each depth was examined and wood pieces larger than 50 mm square were retained. The wood pieces from each horizon in each of the five wells were tagged with respect to well number and depth of collection and placed into individual plastic garbage bags.

The wood pieces were returned to the laboratory and the material in the bags was placed on pallets that were irrigated from overhead with tap water for 5-7 da to remove adhering material and mitigate odor. The wood was air-dried for 2 da and then turned over to expose the underside before sprinkling for an additional 10 da. The wood was then air-dried for 14 da. Individual wood pieces were selected from each group with the goal of obtaining a mixture of nontreated softwoods, nontreated hardwoods, and preservative-treated wood. Each selected piece was assigned a number and wood species was recorded. The materials selected for testing were categorized as follows:

1. Softwood lumber (primarily Douglas fir [*Psuedotsuga menziesii*] with some Hem-Fir [a mixture of western Hemlock (*Tsuga heterphylla*) and the true firs (*Abies* spp.)])
2. Hardwood lumber (primarily from pallets including white oak [*Quercus alba*])

3. Softwood plywood (primarily composed of Douglas fir)
4. Pressure-treated wood (softwood—primarily Hem-Fir—treated with a copper-based preservative)

The most abundant material was softwood lumber that was represented in every sampling level, whereas the other materials were less abundant and were sometimes absent from a given level.

Wood Analysis

Material from a given piece of wood was ground to pass a 20-mesh screen before being analyzed. The material was analyzed for 1% alkali solubility according to ASTM Standard D-1109 wherein an oven-dried and weighed sample of the wood was boiled in 1% sodium hydroxide for 1 h, with the material then filtered on a tared filter and washed with 100 mL of hot distilled water followed by 10% acetic acid and then again with an excess of hot water (ASTM 2015). The resulting material was oven-dried at 103°C and weighed. The difference in mass between the initial and final weights represented the alkali solubility. Alkali solubility is used to assess the effects of early fungal decay on wood (Zabel and Morrell 1992). Brown rot fungi typically decompose cellulose and hemicellulose more rapidly than would be evidenced by mass loss. Alkali solubility is typically used to detect early changes in soluble sugars, but was used here to determine the potential effects of landfill exposure on the wood.

Finally, the materials were analyzed for total carbohydrates, as well as the individual levels of arabinose, galactose, xylose, and mannose according to a standard Forest Products Laboratory protocol which involves a primary hydrolysis of a dried 100 mg sample in concentrated sulfuric acid (H_2SO_4) at 30°C followed by a secondary hydrolysis of the sample diluted to 4% H_2SO_4 in an autoclave at 120°C for an hour. Klason lignin is the solid fraction retained after filtration and over-drying of the hydrolysate/digested wood mixture. The Klason lignin filtrate was dried and then mass was determined gravimetrically.

The sugar composition of the hydrolysate from the Klason lignin filtration was determined by high-performance liquid chromatography with pulsed amperometric detection (HPLC-PAD) using a Dionex ICS-3000 ion chromatograph system based on a method by Davis (1998). Total carbohydrate content was calculated by mass as the sum of the yields of the individual sugar monomers expressed in their anhydrous (polymeric) form and reported as arabinan, galactan, xylan, or mannan (Table 1).

These sugars are components of hemicellulose, which tends to be the polymer most sensitive to early degradation of wood in many applications (LeVan and Winandy 1990; Sweet and Winandy 1999; Curling et al 2002). Declines in the presence of various hemicellulose components might be a good indicator of early degradation of the wood. Total carbohydrates, while less sensitive to declines, should also show reductions in abundance, particularly in acidic environments that would tend to preferentially degrade these materials. A total of 48 landfill-exposed samples were analyzed. In addition, one Douglas fir heartwood lumber and one Hem-Fir lumber sample that had not been exposed to the landfill were evaluated for lignin, total carbohydrate, and hemicellulose sugar contents to provide comparison values. The limited replication and variability in replicates for a given category precluded statistical analysis. As a result, the goal was to determine if there were any trends with regard to changes in a given component with increasing depth in the landfill.

RESULTS AND DISCUSSION

Lignin and carbohydrate levels in the Hem-Fir and Douglas fir heartwood controls were consistent with previous reports for these materials as were the elevated levels of mannans and lower levels of xylans (Table 1) (Sjostrom 1981).

Increasing depth in a given well should correspond to increasing time in the landfill, since

Table 1. Chemical characteristics of wood-based materials removed from different depths in a municipal solid waste facility located near Corvallis, OR.

			Wood component level (%)[a]						
Material	*n*	Depth (m)	Alkali solubility	Klason lignin	Total carbohydrate	Arabinan	Galactan	Xylan	Mannan
Softwood	2	0-6	15.2 (3.5)	27.1 (1.6)	58.0 (3.4)	1.2 (0.6)	1.9 (0.5)	4.3 (1.6)	10.5 (1.1)
	9	6-10.5	14.7 (1.7)	29.3 (3.4)	57.8 (3.9)	0.7 (0.4)	1.9 (0.7)	4.6 (1.2)	10.0 (1.6)
	5	10.5-13.5	16.9 (3.6)	28.9 (1.8)	56.4 (3.6)	0.5 (0.6)	2.0 90.3)	3.4 (0.8)	11.1 (0.5)
	7	>13.5	14.9 (2.9)	31.5 (2.7)	52.0 (4.0)	0.5 (0.4)	1.8 (0.4)	3.2 (0.9)	9.8 (2.2)
Pressure-treated softwood	2	0-6	15.5 (0.2)	27.4 (3.7)	56.5 (2.9)	1.1 (0.44)	1.9 (0.5)	4.6 (0.8)	10.5 (0.6)
	1	6-10.5	19.1	30.5	50.4	1.5	2.2	3.8	10.5
	2	10.5-13.5	10.8 (0.1)	29.4 (1.6)	55.6 (4.1)	1.0 (0.1)	2.0 (0.8)	5.5 (1.5)	9.8 (1.1)
	2	>13.5	17.3 (1.5)	27.0 (1.3)	57.6 (7.5)	1.5 (1.0)	2.3 (0.8)	4.9 (2.5)	10.8 (2.4)
CDX plywood	1	0-6	16.1	28.7	53.1	1.3	2.7	3.7	10.3
	3	6-10.5	17.2 (2.2)	30.6 (1.4)	54.9 (1.8)	0.5 (0.3)	2.0 (0.5)	3.1 (1.0)	10.4 (0.5)
	3	10.5-13.5	15.0 (0.6)	24.6 (8.6)	55.1 (2.0)	0.4 (0.2)	2.3 (0.4)	3.0 90.2)	10.6 (0.3)
	4	>13.5	14.1 (2.1)	30.4 (0.6)	54.4 (3.0)	0.4 (0.5)	2.0 (0.5)	2.0 90.6)	10.9 (0.7)
Hardwood	4	0-6	18.3 (3.2)	22.5 (2.6)	55.6 (4.5)	0.6 (0.5)	1.3 (0.7)	11.2 (5.6)	4.4 (4.7)
	1	6-10.5	15.3	22.4	53.7	0.1	0.4	10.9	1.8
	1	10.5-13.5	18.1	21.7	53.9	0.3	0.5	13.7	3.3
	2	>13.5	14.9 (3.1)	21.4 (0.4)	57.2 (3.1)	0.2 (0)	0.6 (0.4)	12.8 (2.1)	2.2 (0.2)
Hardwood plywood	1	0-6 m	14.7	31.2	56.5	1.1	2.5	4.1	10.5
Nonexposed Douglas fir heartwood	1	—	—	28.3	62.1	0.4	2.3	3.0	11.9
Nonexposed Hem-Fir	1	—	—	32.9	55.0	0.1	1.2	3.6	7.9

[a] Values represent means (where there are replicates) while figures in parentheses represent one standard deviation.

mixing is unlikely once a layer is compacted. The cell that was examined was only 5 yr old, leaving relatively little time for substantial degradation; however, if degradation was beginning to occur, there would likely be shifts in the frequency of various components in the wood with increased depth. For example, xylans are abundant in hardwoods and since these hemicellulose-based sugars tend to be more sensitive to the early stages of degradation (Zabel and Morrell 1992), any deterioration might be connected with a decline in the frequency of these components. Similarly, an acidic environment might affect the carbohydrate fraction to a greater extent and this would be manifest in higher proportions of lignin in the materials. For example, Wang et al (2011) showed slight losses in both cellulose and hemicelluloses in samples buried 15 m deep for 2.5 yr in a landfill with leachate recirculation. The landfill in the current study lacked leachate recirculation that might be expected to accelerate the decomposition process (Mehta et al 2002).

Lignin content of the landfill-exposed softwood fell within the range of that found with the control softwood materials and there was no suggestion that levels changed with distance downward in the cell (Table 1). Similarly, total carbohydrate levels as well as the levels of individual sugars were similar with cell depth. Although the replication in a given well and depth was limited, the results suggest that there has been little change in wood chemistry over the up to 5-yr exposure period. The results with softwood plywood were similar to those found with the softwood lumber, with no evidence of changes in proportions of the components tested with cell depth.

There were a limited number of softwood samples that had been treated with a copper-based preservative system. These samples might be expected to degrade even more slowly than similar, nontreated wood. Lignin, carbohydrate, and sugar values in these samples appeared to be similar to those found with nontreated softwood samples removed from the same wells, suggesting that neither material was experiencing any substantive changes in composition over the exposure period.

Xylan levels in the hardwood samples tended to be higher, which is typical of hardwood species (Sjostrom 1981). As with the softwood lumber, however, there were no consistent changes in the proportions of the sugars with depth in the cell. There was also a single hardwood plywood sample from the near surface zone of the cell that was analyzed. Hardwood plywood typically consists of a softwood core surrounded by thin hardwood veneers on the outer surfaces. Thus, this material should have characteristics more similar to those for a softwood panel and the results supported that premise.

A landfill cell is clearly a hostile environment. The inherent resistance of wood to chemical and thermal degradation should help mitigate these effects and the lack of oxygen should greatly reduce the rate of biological degradation (Panshin and deZeeuw 1970; USDA 2010). The results suggest that short-term exposures under landfill conditions do not produce noticeable changes in wood chemistry. These results are similar to those found by Ximenes et al (2008, 2015) and support the need to reexamine estimates for the rate of carbon return to the atmosphere from landfilled wood (Lippke et al 2010). While every effort should be made to prolong the useful life of wood products and to avoid using limited landfill space for this material, the evidence suggests that once entombed, degradation rates of wood-based materials are likely to be far slower than predicted (De la Cruz and Barlaz 2010).

CONCLUSIONS

Exposure for up to 5 yr in compacted waste at a MSW facility did not appear to adversely affect the chemical composition of various wood products, suggesting that degradation and return of carbon in these materials to the atmosphere might be much slower than predicted.

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