Wood Density and Decay of Pentachlorophenol-Treated Wooden Posts for Four Species in Minnesota, USA

by

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CONTENTS **Page**

LIST OF TABLES **Page**

LIST OF FIGURES

WOOD DENSITY AND DECAY OF PENTACHLOROPHENOL-TREATED WOODEN POSTS FOR FOUR SPECIES IN MINNESOTA, USA

by

Matthew B. Russell[1], Stephanie R. Patton[1], and Kyle G. Gill[2]

ABSTRACT

To understand the value of carbon stored in forest products, researchers often turn to long-term studies of wood decay and durability. This analysis examines the effects of pentachlorophenol treatments and position of wood fence posts (i.e., standing or downed) on wood characteristics after 70-plus years of exposure to decay in Cloquet, MN. Wood posts were originally treated with a pentachlorophenol solution. Compared to posts that received no wood preservative treatment, white birch (*Betula papyrifera* Marsh.) posts treated with pentachlorophenol displayed greater mass moisture and volumetric moisture content and lower wood density. No effects of pentachlorophenol were observed for aspen (*Populus* spp.) posts. Similar to comparable long-term results that used pentachlorophenol as a wood preservative, these results highlight the lasting impact of preservatives on wood durability.

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1. INTRODUCTION AND OBJECTIVES

Understanding patterns of wood decay is important to determine the long-lived values of carbon stored in wood products. Increased use of life-cycle assessments and life-cycle costs analyses can quantify the contributions of wood products in the carbon cycle. Wood is a preferred source in utility poles because it is a renewable resource, provides long-term storage of carbon, and generates fewer greenhouse gas emissions than other sources (Morrell 2016). As an example, compared to steel and concrete utility poles, wood poles treated with pentachlorophenol showed less impacts to ecological toxicity and greenhouse gas emissions (Bolin and Smith 2011).

The wood decay hazard across Minnesota is rated as "moderate" according to the American Wood Protection Association's (2014) Use Class Rating System, indicating moderate decay conditions and fungal activity. While the service life of large standing wood utility poles may reach 80 years in many parts of the United States (Morrell 2016), the half-life for carbon in downed woody debris decaying in forests may be as short as 18 and 10 years for conifers and hardwoods, respectively (Russell et al. 2014). From a forest carbon storage and sequestration perspective, understanding the role of environmental conditions is essential to better determining the characteristics of wood over extended times periods (e.g., decades).

The objective of this study is to examine the effects of pentachlorophenol treatments and position of fence posts (i.e., standing or downed) on wood characteristics after 70-plus years of exposure to decay (Fig. 1). Specific objectives are to (1) quantify how many posts of a given species and position are nondecayed in the original experiment and (2) determine the wood density and moisture content of fence posts by species and position.

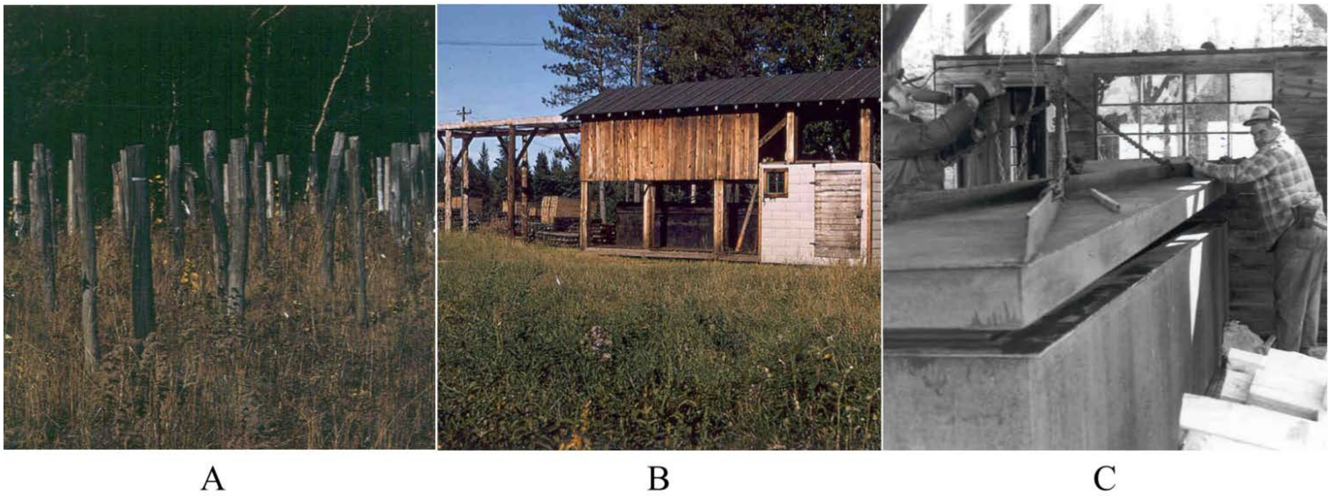

Figure 1. Historical photos of the Cloquet Forestry Center fence post experiment. (A) Fence post study in 1953. (B) Fence post treatment plant in 1956. (C) Final run of fence post treatment plant in 1985.

2. METHODS

2.1 Study area

A wooden fence post experiment was installed in an approximate 0.60-ha area at the University of Minnesota’s Cloquet Forestry Center (CFC) in 1942 (Kaufert et al. 1978; Kaufert et al. 1955). The CFC is located in the town of Cloquet, MN (46° 40’ N, 92° 30’ W). Soils at the study site are Omega loamy sand, 0-2 % slope, of sandy outwash parent material and excessively drained (USDA Natural Resources Conservation Service 2018). The climate is strongly continental, on average relatively cool and wet but with periods of extremes, and somewhat influenced by Lake Superior 32 km to the east (Reinikainen et al. 2015). From 1942 to 2017, mean annual temperature was 4.5°C while the maximum and minimum mean annual temperatures were 7.1°C in 1998 and 2.1°C in 1950, respectively. The mean annual maximum temperature was 33.9°C while the maximum and minimum highest maximum temperatures were 39.4° in 2006 and 30°C in 1985, respectively. The mean annual minimum temperature was

34.4°C while the maximum and minimum temperatures were -26.1°C in 2002 and -41.1° in 1982, respectively. The mean annual total precipitation was 79.2 cm while the maximum and minimum annual precipitation was 108.0 cm in 1991 and 50.8 cm in 1976, respectively (Eggleston 2018). Similar fence post experiments were established in St. Paul and Waseca, but were closed after the initial results were collected (Kaufert et al. 1978; Kaufert et al. 1955).

2.2 Wood preservative treatments

In 1942, posts were peeled and air-seasoned until they reached moisture content between 15 and 25%. Post were treated in a 5% oil solution of one part pentachlorophenol (Penta) dissolved in four parts of kerosene by soaking in an upright position in an open oil drum. Post were treated using one of three soaking treatments: (1) a 24-hour treatment (18 hours with bottoms down, six hours with tops down), (2) a 48-hour treatment (36 hours with bottoms down, 12 hours with tops down), or (3) non-treated controls. The two soaking treatments did not yield differences in the service lives of fence posts after 35 years (Kaufert et al. 1978), hence were considered as one treatment in this analysis.

2.3 Wooden post evaluation in 2017

In June 2017, wooden posts were inventoried for their position (standing or downed) and species. The species collected included two hardwoods (white birch [*Betula papyrifera* Marsh.] and aspen [*Populus* spp.]) and two conifers (northern white-cedar [*Thuja occidentalis* L.] and jack pine [*Pinus banksiana* Lamb.]). The hardwood species were considered “primary” species for this study because a sufficient sample size was found for both treated and untreated samples with fence posts that were both standing and downed. Two cross-sectional disks were collected from each wooden post, one disc from the top half and one from the bottom half, each a minimum of 0.20 m from the ends of the posts. Disks were approximately 2.5-cm in thickness and were cut with a chainsaw (if relatively non-decayed) or handsaw (if in advanced decay and friable). In total, 248 disks were sampled from 124 wooden posts from the four species (Table 1; Russell et al. 2018).

Table 1. The total number of wooden posts and live trees sampled[1] for the Cloquet Forestry Center fence post experiment. The number of posts with pentachlorophenol treatment in parentheses.

Species	Live trees	Standing	Downed	Total
Betula papyrifera	3 (0)	15 (7)	11 (9)	29 (16)
Populus spp.	3 (0)	9 (3)	16 (7)	28 (10)
Thuja occidentalis	3 (0)	25 (0)	0 (0)	28 (0)
Pinus banksiana	3 (0)	44 (0)	4 (0)	51 (0)
Total	12 (0)	93 (10)	31 (16)	136 (26)

[1]Two cross-sectional disks collected from each wooden post; three disks collected from each live tree.

For comparing to non-decayed samples, three live trees of each species of approximate diameter to the wooden posts were felled. Cross-sectional disks were then obtained from stump, 1.3 m, and 3.0-m heights along the main bole. Live trees were located within 500 m to the wooden post study area at the CFC.

Disks were placed in sealed plastic bags in the field and refrigerated until processed in the laboratory. The volume of each cross-sectional disk was determined using direct measurements of diameter and thickness. Samples were weighed for their fresh mass and were oven-dried at 90°C until a constant mass was achieved (approximately three days). After reweighing, we calculated density (g dry mass/cm^3 fresh volume), mass moisture content ([fresh mass - dry mass]/dry mass), and volumetric moisture content (volume of water/dry volume) for each sample (Fraver et al. 2002). These three metrics are common measures that represent wood decay through density and moisture content (Fraver et al. 2002).

2.4 Analyses

We employed linear mixed-effects models to examine the effects of pentachlorophenol treatment, post position (standing or downed), and their interaction on three attributes: density, mass moisture content, and volumetric moisture content. Response variables were log-transformed prior to analysis. The 'lme()' function from the 'nlme' package in R was used to perform this analysis (Pinheiro et al. 2017).

3. RESULTS AND DISCUSSION

Compared to posts that received no treatment, white birch posts treated with pentachlorophenol displayed greater mass moisture content (p = 0.0005), greater volumetric moisture content (p = 0.0004), and lower wood density (p = 0.0227; Table 2). Mean mass moisture content for treated white birch was 32.3 ± 0.56% (mean ± standard error) compared to 20.5 ± 0.26% for posts that were not treated. Mean volumetric moisture content for treated white birch was 25.6 ± 0.31% compared to 18.6 ± 0.19% for posts that were not treated. Mean wood density of treated white birch was 0.507 ± 0.0024 g/cm^3 compared to 0.548 ± 0.0026 g/cm^3 for posts that were not treated. For aspen, the main effect of pentachlorophenol treatment had no effect on these three wood attributes through the duration of the experiment. Although jack pine and cedar posts treated with pentachlorophenol were not sampled in this study, their mean wood density values were 0.371 ± 0.0005 g/cm^3 and 0.336 ± 0.0006 g/cm^3, respectively (Figures 2-4).

Table 2. Mixed-effects analysis of variance results for wood attributes for two primary species at the Cloquet Forestry Center fence post experiment. Data were log-transformed prior to analysis.

Attribute	Source	*F*	*p*-value
	Betula papyrifera		
Wood density	Treatment (T)	5.55	0.0227
	Position (P)	3.34	0.0741
	TxP	0.13	0.7189
Mass moisture content	Treatment (T)	13.96	0.0005
	Position (P)	17.00	0.0002
	TxP	0.036	0.8596
Volumetric moisture content	Treatment (T)	14.53	0.0004
	Position (P)	18.31	0.0001
	TxP	0.00	0.9743
	Populus spp.		
Wood density	Treatment (T)	1.49	0.2287
	Position (P)	0.21	0.6455
	TxP	3.94	0.0528
Mass moisture content	Treatment (T)	2.80	0.1008
	Position (P)	29.54	<0.0001
	TxP	9.37	0.0036
Volumetric moisture content	Treatment (T)	1.87	0.1778
	Position (P)	36.65	<0.0001
	TxP	10.93	0.0018

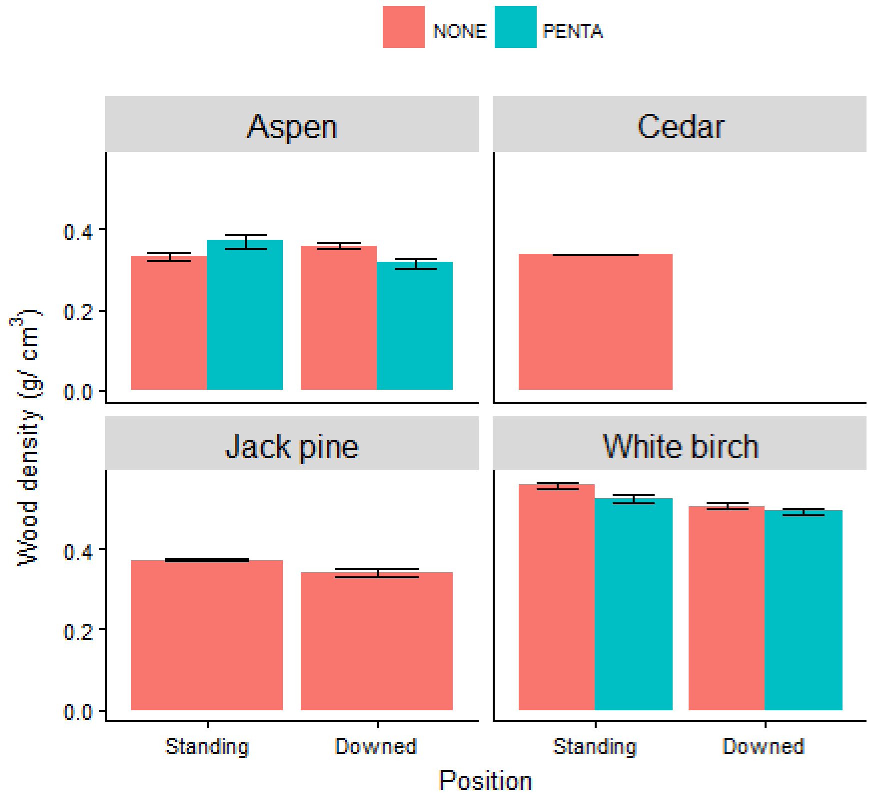

Figure 2. Wood density by fence post position for four species from the Cloquet Forestry Center fence post experiment.

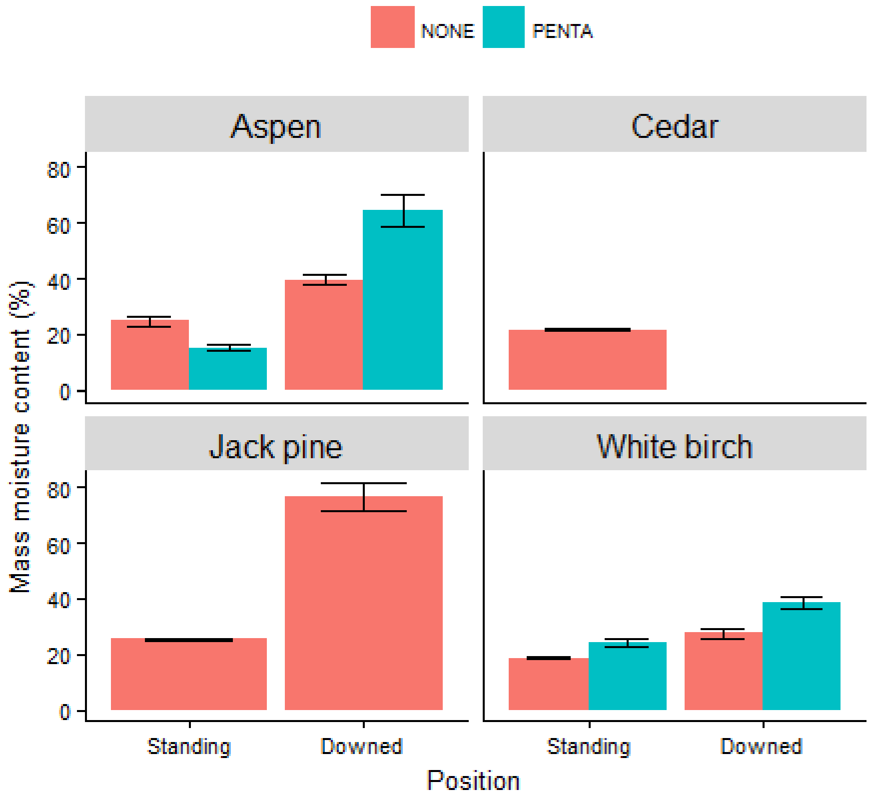

Figure 3. Mass moisture content by fence post position for four species from the Cloquet Forestry Center fence post experiment.

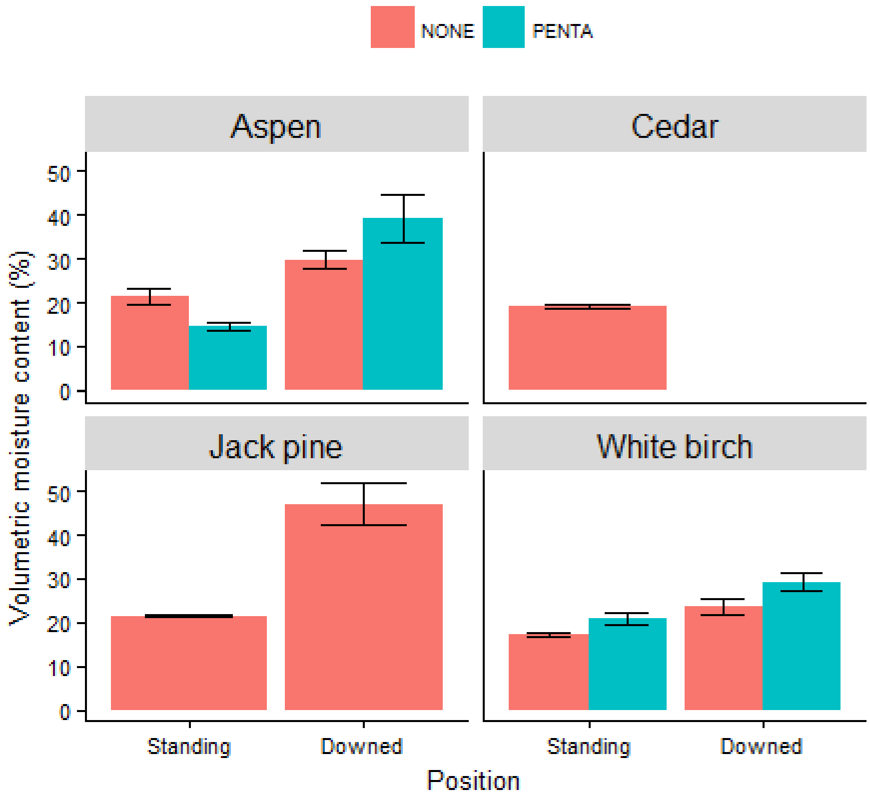

Figure 4. Volumetric moisture content by fence post position for four species from the Cloquet Forestry Center fence post experiment.

For both white birch and aspen, fence post position (standing or downed) had a significant effect on mass moisture content and volumetric moisture content, but not for wood density. Downed fence posts displayed greater mass and volumetric moisture content compared to standing posts. Mean mass moisture content ranged from 21.3 ± 0.27% for standing white birch to 50.6 ± 0.97% for downed aspen posts. Mean volumetric moisture content ranged from 18.9 ± 0.18% for standing white birch to 33.9 ± 0.38% for downed aspen posts. The interaction between fence post position and pentachlorophenol had a significant effect in mass ($p = 0.0036$) and volumetric moisture content ($p = 0.0018$) for aspen posts.

Mean wood densities obtained from the fence posts show expected trends (i.e., reduced values) with oven-dried wood reported in Miles and Smith (2009). Mean wood densities from standing fence posts were 0.35, 0.37, and 0.54 g/cm^3 for aspen, jack pine, and white birch respectively, compared to the higher values of 0.38, 0.43, and 0.55 g/cm^3 reported for those same species in Miles and Smith (2009). Only standing cedar posts displayed a mean wood density 0.34 g/cm^3 that was slightly higher than the value reported in Miles and Smith (2009; 0.31), but were within one standard deviation (0.03) of this value. For non-treated white birch posts, the ratio between standing and downed fence post wood density was 1.10, a value analogous to the ratio between standing dead trees and downed woody debris wood density of 1.04 to 1.54 in dead wood reported for hardwood species across the US in Harmon et al. (2011). Mass moisture contents for downed white birch and aspen fence posts (36.6% and 50.6%, respectively) were similar to values reported for downed woody debris in decay class 1 for these same species in Maine (55.2% and 61.2%) by Fraver et al. (2002). Volume moisture contents for downed white birch and aspen fence posts (28.2% and 33.9%, respectively) were similar to values reported for downed woody debris in decay class 1 for these same species in Maine (28.2% and 61.2%) by Fraver et al. (2002).

The finding that jack pine posts were relatively durable after 70-plus years is similar to what was observed after 13 (Kaufert et al. 1955) and 35 years (Kaufert et al. 1978). Despite the observation that pentachlorophenol treatments led to poor penetration and distribution in aspen posts and that most posts from this species failed a 100-pound pull test (Kaufert et al. 1978), wood density in pentachlorophenol-treated aspen (standing posts) was still 0.37 ± 0.01 g/cm^3 after 70-plus years. The durability of the posts at Cloquet can be compared to the pole service life of 80 years in many parts of the United States (Morrell 2016). In a pull test conducted on posts installed in Mississippi, no failures occurred in any of 75 pentachlorophenol-treated longleaf pine (*Pinus palustris* Mill.) posts after 50 years of service (Lebow et al. 2015). Comparing the "severe" wood decay hazard in Mississippi in the Lebow et al. (2015) study to the "moderate" designation in Minnesota (American Wood Preservation Association 2014), characteristics of the posts at Cloquet continue to show properties that indicate wood durability.

In conclusion, treatment of wood posts with pentachlorophenol has resulted in differences in decay and moisture loss after 70-plus years in Minnesota. Even after this duration, understanding the role of wood preservatives play in lengthening the service life of wood products, such as those found in utility poles, can have important implications in life cycle assessments and forest greenhouse gas emissions when compared to other materials such as steel and concrete. Similar to long-term results in the southern US (Lebow et al. 2015), these results highlight the lasting impact of preservatives on wood durability.

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