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Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch014

Chapter 14

Evaluating the Leaching of Biocides from Preservative-Treated Wood Products

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Leaching of biocides is an important consideration in the long term durability and any potential for environmental impact of treated wood products. This chapter discusses factors affecting biocide leaching, as well as methods of evaluating rate and quantity of biocide released. The extent of leaching is a function of preservative formulation, treatment methods, wood properties, type of application and exposure conditions. Wood properties such as permeability, chemistry and heartwood content affect both the amount of biocide contained in the wood as well as its resistance to leaching. A range of exposure factors and site conditions can affect leaching, but the most important of these appears to be the extent of exposure to water. For wood that is immersed in water or placed in contact with the ground the characteristics of that water (pH and inorganic and organic constituents) also play a role. For wood that is used above-ground or above water, the frequency of precipitation and patterns of wetting and drying are key considerations. Current standardized methods are intended to greatly accelerate leaching but are not well-suited to estimating leaching in service. Continued research is needed to refine methods that utilize larger specimens and more closely simulate in-service moisture conditions.

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Introduction

The depletion of biocides from preservative-treated wood products exposed to precipitation, placed in contact with soil, or immersed in water is generally referred to as leaching. Resistance to leaching is imparted in a variety of ways and may differ between formulations of the same biocide. Leaching of biocide from treated wood is of importance in both the long-term durability of the treated product and its potential for impacting the environment. The role of resistance to leaching in durability is clear, as wood treated with a readily leachable biocide may be only slightly more durable than untreated wood if placed in contact with soil or standing water. Even wood treated with a leach-resistant biocide may eventually fail if the concentration of biocide remaining in the wood falls below that needed to prevent biodeterioration. The significance of potential environmental impacts associated with leaching of biocides is less clear, but concerns have been expressed by governmental regulatory and advisory bodies, and use of biocide-treated wood has been limited in some situations. In essence, durability concerns are focused on the quantity of biocide remaining in the wood during long-term service, while environmental concerns are focused on the quantity of biocide lost from the wood. Although this distinction may appear trivial, there are practical consequences for the manner in which leaching is evaluated and the results are interpreted.

Obtaining useful and representative estimates of biocide leaching from treated wood can be challenging. Wood is an inherently variable material and this factor alone can make assessments of environmental impact more challenging. However, there other factors such as the treatment process, type of end-use application, and exposure environment that can also effect leaching. This chapter discusses some approaches used to evaluate biocide leaching and/or environmental accumulation and the influence of various aspects of these methods on research results. Focus is placed on evaluation of biocide release (leaching) rather than environmental impacts. For a detailed discussion of the potential environmental impacts of leached wood preservatives the reader is referred to "*Managing Treated Wood in Aquatic Environments*" (*1*) or *Environmental Impacts of Treated Wood* (*2*). In addition, leaching is distinguished from other forms of biocide depletion such as evaporative aging, UV degradation, or microbial decomposition, which have been previously reviewed by others (*3*, *4*).

Wood and Treatment Factors Affecting Leaching

One of the greatest contributors to variability in biocide leaching is the complexity of wood as a material. The structure, anatomy, and chemistry of wood affect the way that preservative components and leaching medium move through and react with the wood substrate.

Wood Dimensions and Proportion of End-Grain

The volume, surface area and proportion of end-grain of wood products effect the percentage and flux of biocide leached from the wood. Thinner pieces have a larger portion of their surface area exposed for leaching and allow more rapid

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water penetration. Conversely, members with larger dimensions, such as timbers, not only have a lower relative surface area but also contain a larger reservoir of preservative and might be expected to release biocide over a longer period. Larger members, especially round members, have a greater tendency to develop drying checks that can increase overall surface area and facilitate water penetration. Because the rate of movement of liquids along the grain of wood is several orders of magnitude greater than that across the grain, greater leaching is likely to occur from shorter dimensions with a higher proportion of end-grain. Because of these size and grain orientation effects, care must be taken in extrapolating the results of leaching tests with small specimens to losses from the larger members used in preservative-treated structures.

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Wood Anatomy and Chemistry

Species differences in the anatomy and chemistry of wood also affect the interactions of the preservative with the wood substrate and the permeability of the wood to liquid water (*5–8*). Permeability varies greatly among wood species, and those species that are more permeable tend to leach at a higher rate because of more rapid movement of water through the wood (*9*, *10*). Studies also indicate that preservative components may be more leachable from hardwoods than from softwoods (*11*, *12*). Wood species may also affect the distribution of preservative within the wood and the chemical reactions that occur to fix water-based preservatives within the wood (*11*, *12*).

Leaching of preservatives may also be affected by the presence and amount of heartwood. In most wood species the heartwood portion of a tree is much less permeable and sometimes more hydrophobic than sapwood portion. Heartwood portions of test specimens may contain much less preservative than sapwood and may also be more resistant to penetration of the leaching medium. These effects might be expected to result in lower leaching rates from heartwood, but this generalization may be confounded by differences in preservative fixation in heartwood or by the presence of a higher concentration of preservative at the heartwood surface (*13*).

Effect of Treatment Parameters on Leaching

Retention of Biocide

The retention of preservative in biocide-treated wood is varied intentionally according to the intended end-use, as well as unintentionally as a result of variability of the wood substrate. Typically wood is treated to low retentions when intended for use above ground (such as decking) and to higher retentions for use in ground-contact or seawater (*14*). In general leaching does increase at higher retentions, but this trend does not always hold true, nor is leaching always directly proportional to retention. Several researchers have noted that the percentage of

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leachable arsenic from CCA- treated wood decreases with increased retention (*13*, *15–19*). Increased retention does appear to result in greater leaching for the amine copper preservatives, but it is not clear whether the leaching increase is proportional to retention. At least two studies have indicated that leaching of copper from amine-copper treated wood increases more than proportionally as retention increases (*20*, *21*). Dubai et al. (*20*) theorized that greater Cu leaching at higher retentions could result from the presence of at least two types of reactive sites in the wood. Once the limited number of strong binding sites is consumed, the remaining copper reacts with a larger number of weaker binding sites and is thus more leachable. Similarly, Humar et al. (*21*) propose that a portion of the copper is initially strongly bound to the wood, and that once those reactive sites are filled the remaining copper is simply precipitated within cell walls and lumens.

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Post-Treatment Conditioning

The biocides (metals and/or organics) of waterborne wood preservatives are initially carried in water but become resistant to leaching when placed into the wood. This leaching resistance results from a range of "fixation" mechanisms that differ with preservative formulation and individual biocide. Some fixation occurs very rapidly during pressure treatment while others may take days or even weeks to reach completion, depending on post treatment storage and processing conditions. If the treated wood is placed in service before these reactions are completed, the initial release of preservative into the environment may be greater than for wood that has been adequately conditioned. Best Management Practices (BMPs) have been developed through a cooperative effort of several trade associations to ensure that commercially treated wood is produced in a manner that will minimize subsequent leaching (*22*). Research indicates that these BMPs do have practical benefit in minimizing the potential for environmental releases (*23*).

Exposure Factors Affecting Leaching

The extent of water exposure is the key to biocide depletion from preservative treated wood. Although this concept is simple, interpretation of the extent of moisture exposure for treated wood in-service is complex. Only a small fraction of the volume of treated wood in service is continually immersed in water or kept continually moist through soil contact. The greatest proportion of treated wood is used above the ground or above water where wetting is intermittent. Structures that are only intermittently exposed to precipitation will have much lower leaching rates than those continually immersed in water, especially in water or soil that contains solubilizing organic or inorganic components. In this section the role of exposure to water, and the effect of water characteristics on leaching, is discussed in more detail.

Wood Used Above-Ground or Above Water

The extent of wetting in wood used above ground or above water is not easily quantified and is dependent on construction details, precipitation characteristics, and possibly on other climatic factors such as temperature, and humidity.

Effect of Rainfall Pattern

Previous studies of treated wood exposed to simulated or natural weathering have indicated that both the pattern and rate of rainfall influence the quantity of preservative released. When expressed on the basis of mass of preservative leached per unit rainfall, greater amounts of biocide appear to be released at slower rainfall rates (*9*, *13*, *24*, *25*), presumably because the wood is wetted for a longer period and a greater proportion of the rainfall is absorbed by the wood (Figure 1). In addition, the interval between rainfall events appears to influence leaching, with greater amounts leached after longer resting periods. This type of effect has been attributed to the allowance for a longer period for soluble preservative components to diffuse to the surface from the interior of the wood products (*3*, *18*, *26–30*).

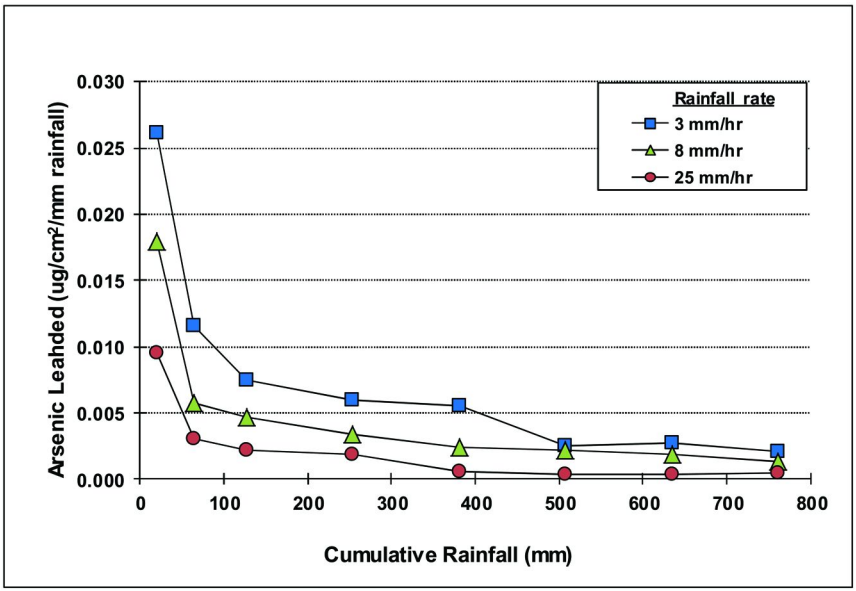

Figure 1. Effect of rainfall rate and cumulative volume on leaching of arsenic from CCA-treated wood (25).

Researchers have reported that the moisture content of pine sapwood exposed to natural weathering may range from maximums of 80% to minimums of approximately 10% (*31–38*). Average moisture contents reported for horizontal exposures ranged from 21 to 26%, whereas the averages reported for vertical

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exposure were 18.6 and 25.4%. Moisture contents reported for less permeable species such as spruce or Douglas-fir tended to be lower than those of pine species when exposed under similar conditions (*33*, *34*, *39*).

Other Climatic Factors

Climatic factors other than precipitation appear to play some role in leaching. For example, exposure to ultraviolet radiation in a weathering chamber strongly increased leaching from CCA-treated decking specimens exposed to artificial rainfall. Other factors, such as temperature and humidity, can affect the rate of drying after precipitation as well as the extent of cracking that may occur on the wood surface. One study did note that leaching, per unit rainfall, appeared to be greater during rain events with higher ambient temperature (*18*). While no leaching should occur from frozen wood, it is likely that the stresses developed during freeze-thaw cycles contribute to subsequent crack formation.

Construction and Site Parameters

In actual structures, wood moisture content can be a function of wood dimension and construction detailing. Larger dimension material may be slower to wet initially but is also slower to dry. Connections are likely to trap and hold more moisture because precipitation is absorbed through the end-grain but drying is slowed because of limited air movement. This effect was recently demonstrated by a study that compared the moisture contents of specimens exposed with and with-out end-grain connections (*40*).

The presence of shade has been shown to substantially increase the moisture content of specimens exposed above-ground (*39*), presumably by slowing drying. Vegetation associated with shading can also result in the deposition of leaf litter and other organic debris in connections and in spaces between deck boards. This organic debris traps moisture and can potentially contribute to higher wood moisture contents.

Application of Finishes and Wraps

In many applications some type of finish or coating is applied to preservative-treated wood, and there is evidence that these finishes can lessen biocide release. (*41–46*). A caveat with the use of finishes is the risks associated with surface preparation and application. Aggressive surface preparation techniques such as sanding or power washing might be expected to cause release of additional biocide into the environment. Although less common than finishes, wraps are sometimes applied to piles or poles to provide protection and enhance durability. Studies with marine piles indicate that these wraps can also be very effective in minimizing preservative release (*23*).

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Water Characteristics

The characteristics of the leaching water can also influence leaching of preservatives. The presence of some types of inorganic ions in water has been reported to increase leaching from CCA-treated wood (*16*, *47*, *48*) whereas they have been reported to decrease leaching with at least one type of preservative (*49*, *50*). Seawater has been reported to both increase and decrease leaching relative to purified or naturally occurring freshwater depending on the study conditions, preservative, and biocide component (*5*, *20*, *51*, *52*). Water pH can also affect leaching of preservatives. Leaching of CCA is greatly increased when the pH of the leaching water is lowered to below 3, and the wood itself also begins to degrade (*53*, *54*). Water pH ranges more typical of those found in the natural world are less likely to have a great effect on leaching (*55*), although leaching of copper from copper-azole treated wood was found to be greater at pH 5.5 than at pH 8.5 (*56*).

The presence of organic acids in surface waters may also affect leaching. Surface waters containing high levels of humic or fulvic acid can have the potential for increasing CCA leaching (*5*, *11*, *20*, *51*, *53*), while one study (*57*) reported that addition of humic acid to leaching water lowered concentrations of leached creosote components relative to deionized water.

Water temperature may also affect leaching, as some of the fixation products that immobilize biocide components in treated wood might be expected to be more soluble at higher temperatures (*51*, *56*). Brooks (*58*) concluded that leaching of copper from CCA-treated wood could be substantially increased as water temperatures increased from 8 to 20° C. Subsequent research indicated that leaching of both copper and tebuconazole increased at higher temperatures, although this effect was diminished with longer leaching periods (*56*). A similar temperature effect was noted in a study of release of creosote components from treated wood (*59*).

The rate of water movement around the wood can also influence leaching, although this effect has not been well quantified. Xiao and others (*59*) reported that release of creosote was greatest at the highest flow rate tested and that turbulent flow may have greatly increased leaching and Brooks (*56*) suggests that more rapid water movement may increase leaching by promoting water exchange in checks and cracks.

Effect of Soil Properties

Studies have illustrated that soil composition may affect both leaching and subsequent mobility of preservative components (*48*, *60–65*) and indicate that leaching from wood placed in soil can be greater than that of wood immersed in water (*61*, *62*, *64*). Increased leaching of biocides from wood in contact with the ground has been attributed to lower pH, and higher concentrations of inorganic soil constituents and organic acids. Soil pH often cannot be separated from the effect of other factors, such as the presence of organic acids that have been shown to increase leaching from wood treated with some types of biocides (*62*, *66*). Cooper and Ung (*66*) compared CCA losses from jack pine blocks exposed in

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garden soil and organic-rich compost and found that leaching was more than doubled by compost exposure. Inorganic components in soil have also been implicated in increasing or reducing leaching. Depletion of pentachlorophenol has been reported to be greater in soils high in copper and iron (*64*), and iron has also been implicated in increased leaching from CCA treated wood (*48*). Conversely, one report suggests that iron and aluminum in soil surrounding CCA-treated wood can retard arsenic leaching because these metals may migrate into the wood and irreversibly precipitate the arsenic (*67*).

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Test Methods for Assessing Leaching

Standardized Laboratory Test Methods

Conventional laboratory methods of evaluating preservative leaching were primarily developed to allow comparison between experimental formulations and provide information on leach resistance as it relates to long term durability. These methods utilize continuous immersion of small specimens with the goal of accelerating and amplifying leaching. As mentioned earlier, the rate of movement of liquids along the grain of the wood is several orders of magnitude greater than that across the grain, and so specimens with a high proportion of exposed end-grain will exhibit exaggerated rates of preservative leaching (*68*, *69*).

In the United States the most commonly used standardized leaching method for biocide-treated wood is AWPA Method E11-12, *Standard Method for Accelerated Evaluation of Preservative Leaching* (*14*). This method specifies biocide treatment of small (19 mm) cubes. The Japanese (JIS K 1571) and Chinese (CNS 6717) leaching methods are weathering steps in preparing specimens for exposure to biological attack (*70*, *71*). Again, the small size and grain orientation (10 by 20 by 20 mm with the 10 mm parallel to the grain) of the specimens is expected to greatly accelerate leaching. Both methods also incorporate drying events between leaching exposures. A European method (EN 84) is also intended as a conditioning step prior to biological exposure (*72*). It uses somewhat larger specimens (15 by 25 by 50 mm) with a lower proportion of end-grain than that US, Japanese or Chinese methods. Unlike the US, Japanese and Chinese methods, EN 84 does not specify agitation during leaching.

The Organization for Economic Cooperation and Development (OECD) has also developed guidelines for evaluating biocide release from preservative-treated wood, and these methods are intended for use in estimating release from in-service products. Separate methods are recommended for wood that is intended for use immersed in water versus wood that is to be used above-ground or above water. For wood to be immersed in water, the method is similar to EN -84 (*73*). For wood used above-ground, OECD guidelines describe an approach involving a brief dip immersions also utilizing small (15 by 25 by 50 mm) specimens (*74*). Although intended to simulate in-service leaching, there is some concern that this approach may not represent commercially produced lumber (*75*) or produce the moisture conditions reported for wood products exposed to natural weathering (*69*). One study which compared outdoor leaching to the OECD method concluded that the laboratory method risked underestimating in-service leaching (*76*). Use

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of simulated rainfall is also mentioned in the guideline, but only general guidance is provided for this approach.

In the US, the AWPA has also standardized a laboratory method (E20) to evaluate preservative depletion from wood placed in ground contact (*14*). This method was developed in recognition of research indicating that soil properties can affect biocide leaching (*62*, *63*). It involves burying small (14 by 14 by 250 mm) stakes in moist soil for 12 weeks. The smaller stake dimensions and the maintenance of saturated soil conditions are intended to accelerate loss of preservative. Unlike other laboratory methods, where leaching is quantified by analyzing leaching water, extent of leaching with the AWPA E20 method is determined by assaying end-matched portions of the stakes before and after exposure.

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Non-Standard Test Methods

Numerous non-standard methods have been used to evaluate preservative leaching, in part because it is recognized that standardized methods are not well suited to for providing estimates of leaching from treated wood in service. Because it is often not practical to conduct leaching studies using full-length lumber, poles, or piles, shorter specimens are typically cut from commodity-sized material. To avoid the problem of increased leaching from end-grain, specimens may be end-sealed with a waterproof sealer prior to leaching.

Many of these approaches involve immersion of specimens of varying dimensions in water for varying periods. Movement of the leaching water may be achieved by agitation (*52*) or pump circulation (*56*, *77*, *78*). Leaching water is either periodically replaced (*52*, *76*) or continually replaced using flow-through systems (*56*, *78*). Brooks (*56*) has conducted several studies of leaching from pile and lumber sections using large (40 L) tanks with a pump providing constant circulation of the leaching water. Fresh leaching water is steadily added to the tanks and samples for analysis are collected from the overflow. Brooks notes that methods without continuous water replacement risk underestimating leaching (*56*).

A variety of non-standard methods have also been used in an attempt to evaluate leaching of biocides from treated wood exposed to precipitation. The most common approach has been to expose specimens cut from product-size material to natural weathering and collect the leachate for analysis. Numerous studies have measured biocide concentrations in rainwater run-off from treated products including deck boards (*18*, *46*, *79–82*) fence boards (*83*), deck sections (*26*, *84–88*) and shingles (*24*). An advantage of this approach is that it incorporates all of the weathering and exposure factors that may affect leaching, and provides "real world" leaching data under the test conditions. These tests are also relatively simple and inexpensive to setup. A disadvantage of this approach is that the exposure conditions are uncontrolled and unpredictable, thus making it difficult to replicate an evaluation or apply the findings to other conditions. It is also difficult to accelerate testing with this approach, and depending on the weather pattern, it may take substantial time to obtain results.

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Another approach to evaluating leaching from wood exposed to precipitation is through some form of simulated rainfall (*25*, *43*, *83*, *89*). This approach allows control over rainfall rates and schedules, but the methodology and equipment are more complex than that needed for natural exposures. It is also difficult to simulate the lower rainfall intensities while maintaining realistic droplet sizes and uniform coverage of replicate specimens. Simulated rainfall also may not realistically incorporate other exposure factors, such as check formation, that potentially contribute to leaching (*3*, *18*, *43*, *84*).

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Models of Biocide Leaching

The leaching methods discussed above provide information on quantities of biocide leached under certain experimental conditions, but do not necessarily allow ready estimation of leaching from treated products in service. One proposed approach allows leaching estimation based on laboratory determination of the amount of biocide component available for leaching, the equilibrium dissociation of the biocide component into free water in the wood, and diffusion coefficients for movement in the radial, tangential, and longitudinal directions (*30*, *90*, *91*). Once these parameters are determined for a particular preservative, leaching can be estimated as a function of product dimensions and the length of time that the wood is sufficiently wet to allow diffusion. More recently a series of studies has been conducted to model leaching of copper azole biocide based on the chemical interactions of the biocide with reactive sites in the wood as well as with constituents of the leaching water (*92–94*). It uses commercially available chemistry modeling software to allow prediction of solubility, complexation and transport of biocide components under a range of conditions. A major limitation for all these modeling efforts is lack of information on the extent of time that wood products in service have sufficient moisture to allow diffusion to occur.

Evaluations of Leaching in Service

Evaluation of leaching from in-service structures offers the promise of long-term leaching data under real world conditions. A disadvantage of these types of studies is that they are specific to the conditions at that site and are difficult to relate to other exposures. It is also difficult to quantify preservative leaching from in-place structures. For in-service evaluations, leaching is generally evaluated by either assaying the treated wood to determine the quantity of preservative remaining, by collecting and analyzing environmental samples adjacent to the treated wood, or by collecting precipitation run-off from the structure.

Determining preservative loss by assaying wood after exposure requires knowledge of original preservative retention in the wood. Often original retention is assumed based on the specified target or standard retention for treated wood used in that application. This assumption can be problematic, as the initial preservative retention in a treated product can be substantially higher or lower than the target retention. Retention can vary within a single piece, more greatly

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between material in a single charge and even more greatly between charges and treating plants (*95*). Variability in retention also makes it difficult to accurately assess the quantity of preservative remaining in a structure after exposure. This type of sampling is destructive, and efforts to evaluate changes in retention over time require analysis of different samples. Because of the variability in retention within wood products, it is often difficult to draw strong conclusions about leaching based on analysis of the amount of preservative remaining in a structure.

Researchers may also attempt to evaluate leaching by collecting environmental samples adjacent to a treated structure. Because metallic preservative components such as copper, chromium, and arsenic are reactive with soil constituents and accumulate near the structure (*55*, *60*, *96*), soil concentrations can potentially provide an indication of the quantity of these components leached. However, most metallic preservative components have some mobility in soil, and thus levels of accumulation are a function of both the leaching rate of preservative components and their subsequent mobility in the soil. For organic biocides, decomposition also plays a role in soil concentrations. Environmental sampling also introduces a range of sources of variability into a leaching study. In addition to leaching rate, environmental concentrations of preservative components will be a function of background concentrations, sampling location, and soil or water characteristics.

A third, and less common, approach to evaluating in service leaching is the collection of precipitation run-off from sections of a structure. This approach was used to quantify leaching from utility poles (*97*) and roofing materials (*24*, *98*). Key factors in this approach are determining and limiting the surface area of treated wood, and quantifying the volume of run-off contacting the wood surface area.

Summary

Resistance to leaching is a key attribute for treated wood products intended for use outdoors. The rate and quantity of leaching is dependent on a range of factors including preservative characteristics, wood properties, treatment methods, type of structure, and exposure conditions. The volume, surface area and proportion of end-grain of wood products effect the percentage and flux of biocide leached from the wood. Differences in the anatomy and chemistry of wood also affect the interactions of the preservative with the wood substrate and the permeability of the wood to liquid water. Treatment methods and post-treatment conditioning steps can also affect leaching, especially for oil-type preservatives or those water-based formulations that rely on drying or lengthy chemical reactions to minimize solubility.

A range of exposure factors and site conditions can affect leaching, but the most important of these appear to be the extent of exposure to water. For wood that is immersed in water or placed in contact with the ground the characteristics of that water (pH and types of inorganic and organic constituents) may also play a role. For wood that is used above-ground or above water the frequency of precipitation and pattern of wetting and drying is a key consideration.

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The number of factors that can affect biocide leaching has made it challenging to develop accelerated test methods that provide realistic estimates of leaching that may occur in service. Current standardized test methods use small specimens that have an unrealistic surface area to volume ratio and tend to exaggerate short-term leaching. Although small specimens produce the greatest percentage loss of biocide, for more leachable biocides the small reservoir of available preservative may result in lower releases when expressed on the basis of mass-per-unit surface area. Because the extent and pattern of preservative release is dependent on both test method and type of preservative, it is difficult to anticipate how well these test methods will estimate long-term release from a new type of preservative. For wood that is intended for use in water, there is potential for utilizing immersion tests using larger specimens that are end-sealed to prevent loss of preservative through the end-grain. Water circulation and frequent water changes are needed to simulate exposure conditions and ensure that biocide accumulation in the water does not inhibit further leaching.

Developing test methods for wood exposed to leaching due to rainfall is more complex. Artificial rainfall exposures have the potential for relatively close simulation of natural rainfall events and have the additional advantage of allowing extrapolation based on volume of rainfall. However, they do not necessarily incorporate the wetting/drying cycles experienced by treated wood in service. The dip-immersion methods are simple to conduct and have the potential for simulating natural wetting and drying conditions with adjustment of immersion scenarios. However, the current use of small specimens and limited water uptake makes extrapolation to in-service leaching rates difficult. Methods that more closely simulate natural wetting and drying conditions will help to minimize the under or over-estimation that is likely to occur when extrapolating results to long-term natural exposures. Ideally, test methods would use large enough specimens and sufficient moisture changes to induce a degree of checking similar to that exhibited by treated products exposed in service. However, these conditions may be difficult to achieve in accelerated testing because large specimens are slow to gain and lose moisture. In contrast, field exposures provide realistic leaching results but are time-consuming and dependent on the weather conditions during the test. However, field exposures remain an important tool for evaluating new test methods.

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