

CHAPTER II

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 General information on chromated copper arsenate (CCA)

When left untreated, wood in many outdoor applications becomes subject to degradation by a variety of natural causes. Wood can be protected from the attack of decay fungi, harmful insects, or marine borers by applying a chemical preservation method. Wood is treated with CCA to prolong its life. CCA is used for the 'control and prevention of damage to timber and timber structures by insects, wood rot, wood fungus and general timber decay. CCA is generally used on wood intended for outdoor uses, such as telegraph poles, decking and fencing, in landscaping, and in building structures'. It is also commonly used in playgrounds, children's cubby houses, public picnic tables, garden edgings, handrails, boat bulkheads, dock pilings and vineyard stakes. CCA-treated timber can often be identified when it is new by its green tinge but this fades with time. Wood preservatives can be divided into two general classes: (1) oil-borne preservatives and (2) waterborne preservatives such as chromated copper arsenate (CCA). Chromated copper arsenate treated wood contains copper, which serves as a fungicide; arsenic, which serves as an insecticide; and chromium, which is used to "fix" the copper and arsenic onto the wood. There are three types of CCA-treated wood: Type A, Type B, and Type C. The most common type is CCA-Type C (AWPA, 1996). A composition of CCA-Type A, B, and C are provided in Table 2.1. The amount of CCA utilized to treat the wood or "the retention level" depends upon the particular application of the wood product. Typical retention levels utilized by the industry are 0.25 pcf, 0.40 pcf, 0.60 pcf, 0.8 pcf, and 2.50 pcf. (Note: pcf = pounds of chemical per cubic foot of wood). Low retention values (0.25 pcf) are permissible for plywood, lumber, and timbers if the wood is used for above ground applications. Higher retention values are required for load bearing wood components such as pilings, structural poles, and

columns. The highest retention levels (0.8 and 2.5 pcf) are required for wood components that are used for foundations or saltwater applications (AWPA, 1996). The retention requirements for CCA-Treated Wood are shown in Table 2.2.

Table 2.1 Composition of CCA-Type A, B, and C (AWPA, 1996)

	CCA-Type A	CCA-Type B	CCA-Type C
Chromium as CrO ₃	65.5%	35.3%	47.5%
Copper as CuO	18.1%	19.6%	18.5%
Arsenic as As ₂ O ₅	16.4%	45.1%	34.0%

Table 2.2 Retention Requirements for CCA-Treated Wood (AWPA, 1996)

Application	Retention Value (lb/ft ³)
Above ground: lumber, timbers, and plywood	0.25
Ground/Freshwater contact: lumber, timbers, plywood	0.40
Salt water splash, wood foundations: lumber, timbers, and plywood structural poles	0.60
Foundation/Freshwater: pilings and columns	0.80
Salt water immersion: pilings and columns	2.50

2.1.1 General information on treating process

There are three broad classes of preservatives used for the pressure treatment of wood products:

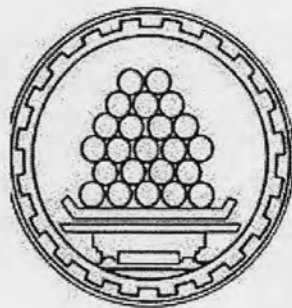
- **Waterborne** preservatives serve a wide variety of uses, including residential, commercial, marine, agricultural, recreational, and industrial applications.
- **Oil borne** preservatives are used primarily for applications such as utility poles, piling, posts, glulam beams, and timbers.
- **Creosote** preservatives, including creosote/coal tar mixtures, protect railroad ties, marine pilings, and utility poles.

For most residential, commercial, and marine building applications, waterborne preservatives are most often specified. Waterborne treatments are clean in

appearance, odorless and paintable, and are EPA-registered for both interior and exterior use without a sealer.

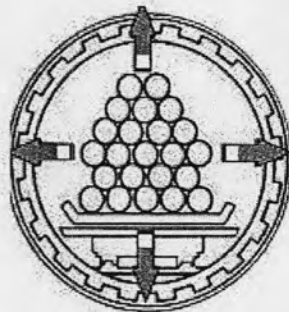
- **CCA pressure treating process**

Pressure-treated wood is the product of a carefully monitored and controlled process. Within a closed cylinder, preservatives are forced into the wood cells under pressure. The fixation process bonds the preservative within the wood fiber. This begins during the treating cycle, but continues after removal from the cylinder. The time needed to complete fixation can range from several hours to several days depending on the type of preservative, and weather conditions. CCA pressure treating processes are as follow in the Figure 2.1:



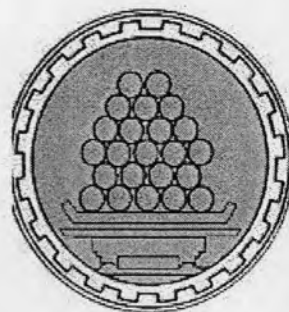
Step 1

1. Dry lumber - or timbers, plywood, or poles - is loaded into the treating cylinder.



Step 2

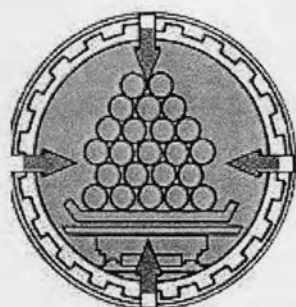
2. An initial vacuum pulls air from the cylinder and from the wood cells, making space for the preservative.



Step 3

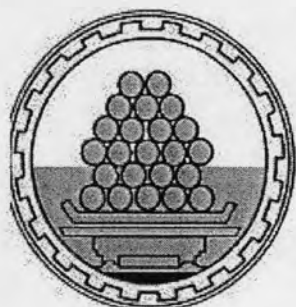
3. A diluted solution of preservative is introduced into the cylinder.

Figure 2.1 CCA pressure treating processes



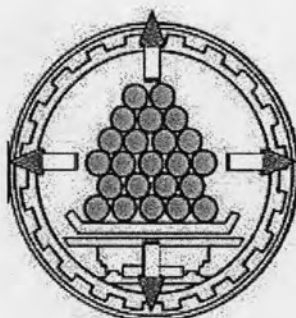
Step 4

4. Pressure pumps then force the liquid into the wood until adequate penetration is assured.



Step 5

5. At the end of the pressure period, remaining preservative solution is pumped out of the cylinder and into a storage tank for later reuse



Step 6

6. A final vacuum removes excess preservative from the cells. The wood is then taken out of the cylinder.

Figure 2.1 CCA pressure treating processes (continued)

Source:<http://www.woodtreaters.com/WoodProducts/PressureTreating/Process.asp>

2.1.2 General information on arsenic

Arsenic (As) is a naturally occurring element in the environment. The four major arsenic species of importance are the inorganic species, arsenite (As(III)) and arsenate (As(V)), and the organic species, monomethylarsonic acid (MMAA) and dimethylarsinic acid (DMAA). Toxicity among these species varies, and the inorganic species are generally more toxic. As(III) is also considered more mobile than As(V).

Arsenic has been used in several industries; it is used for the hardening of copper and lead alloys, in the pigmentation in paints and fireworks, and in the manufacturing of glass, cloth, and electrical semiconductors. Arsenic is also used extensively in the production of agricultural pesticides, which includes herbicides, insecticides, desiccants, wood preservatives, and feed additives. Arsenic in CCA and in treated wood products is predominantly in the +5 valence. Chemical and biological conditions in the environment affect the transformation between these different forms including the possible conversion to As(III), MMAA, and DMAA. Chemical conditions of importance include the pH and redox potential. Runoff from the arsenic leaching generated from industrial and agricultural wastes has resulted in increased levels of various forms of soluble arsenic in water. Inorganic arsenic is highly toxic to mammals and aquatic species. When ingested, it is readily absorbed from the gastrointestinal tract, the lungs, and to a lesser extent from the skin and is distributed throughout the body. Recently, arsenic in water supplies has been linked to arsenical dermatosis and skin cancer. Because of recent studies further revealing its toxicity, the United States Environmental Protection Agency (EPA) has classified arsenic as a human carcinogen (Group A) and has promulgated regulations lowering its maximum contaminant level in drinking water standards from its present requirement of 50 parts per billion (ppb) to 10 ppb in January 23, 2006 (EPA, 2005 and 2008).

2.1.3 General information on chromium

Chromium (Cr) is a unique metal in that its two primary species in the environment have drastically different properties. Trivalent chromium (III) compounds are not usually considered health hazards; however, hexavalent chromium (VI) compounds can be toxic if orally ingested or inhaled. There are three main points to consider in chromium chemistry. First, the dominant naturally occurring form of chromium is trivalent oxide. The second is that the other valence form of chromium tends to convert to the trivalent oxide when it comes in contact with the natural environment. Hexavalent chromium tends to be reduced to trivalent chromium by organic matter, divalent iron, and sulfides. Lastly, trivalent chromium is very slow to react. Hexavalent chromium, however, can persist in the environment for long periods of time if it does not reduce to Cr(III).

2.1.4 General information on copper

Copper compounds usually have a valence of 2+ (II, cupric) under oxidized conditions or 1+ (I, cuprous) under reducing conditions. Only substances with the divalent (2+) form are used in CCA formulations. Copper is an essential element in mammals; it is incorporated into a large number of enzymes, particularly the oxidoreductases. There is a greater risk of adverse health effects from copper deficiency than from excess copper intake. The main sources of exposure to copper are from food and drinking water. The IPCS (1998) calculated that the total intake of copper (i.e. food plus drinking water) in adults is between 1-2 mg/d, while it may occasionally reach 5 mg/d. Inhalation and dermal exposure to copper are considered to be insignificant, with inhalation exposure at 0.3-2.0 µg/d (IPCS, 1998). Due to the toxicology profile (APVMA, 2005) of copper and the high natural background exposure levels to copper in food and drinking water, the copper exposure risks to humans from the compounds present in dislodgeable residues from CCA-treated timber are considered to be negligible.

2.2 General information on hardwoods and softwoods

The distinction between hardwoods and softwoods actually has to do with plant reproduction. All trees reproduce by producing seeds, but the seed structure varies. Hardwood trees have broad leaves and are deciduous—they lose their leaves at the end of the growing season. Hardwoods are angiosperms—using flowers to pollinate for seed reproduction. Oaks, maples, birches and fruit trees are examples of hardwood trees. Hardwoods are generally not safe but far more resistant to decay than softwoods when used for exterior work. However, solid hardwood joinery is expensive compared to that of softwoods.

On the other hand, softwood trees are conifers (evergreens), which have needles or scale-like foliage and are not deciduous. Softwoods are gymnosperms, meaning they do not have flowers and use cones for seed reproduction. Examples of softwoods include pines, spruces, firs, and hemlocks. The softwood cellular structure is simple and 90-95 percent of the cells are longitudinal tracheids. Longitudinal tracheids function in water conduction and support. The limited number

of cell types makes softwoods more difficult to differentiate from one another. In general softwoods are easy to work with, which is why they make up the bulk of wood used by humans. Softwood lumber has a huge range of uses: it is a prime material for structural building components, and it is also used for furniture and other products such as millwork (e.g., mouldings, doors, and windows). Softwoods are also harvested for use in the production of paper, and for various types of boards such as medium-density fiberboards (MDF). The finer softwoods find many specialty uses.

The structure of hardwoods, in comparison, is more complex and it varies considerably between species. The majority of hardwood volume is composed of fiber cells that offer structural support to the stem. The major difference between hardwoods and softwoods is the presence of the vessel elements, or pores, that exist in hardwoods only. The main function of vessel elements is water conduction. Vessel elements can vary greatly in size, number, and spacing from one species to another, and from earlywoods to latewoods.

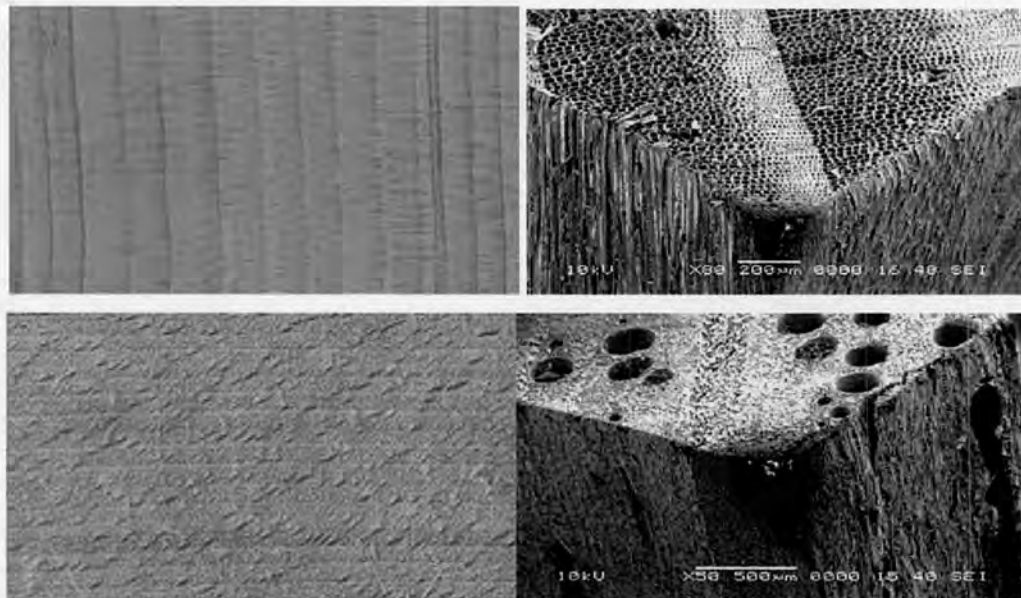


Figure 2.2 SEM images showing the presence of pores in hardwoods (Oak, top) and absence of them in softwoods (Pine, bottom)

Source:<http://www.108wood.com/index.php?lay=show&ac=article&Id=578636&Ntype=6>

2.3 Leaching tests

A leaching test is designed to estimate the leaching potential of waste when waste is disposed of in a land disposal unit. The potential for the leaching of toxic compounds or elements into underground drinking water supplies is measured because leached toxins can expose users of the water to hazardous chemicals and constituents. Two test protocols that are widely used are the TCLP and WET; they are described as follows:

2.3.1 Toxicity Characteristic Leaching Procedure (US EPA SW-846 Method 1311)

The Toxicity Characteristic Leaching Procedure (TCLP), the most commonly employed leaching test used in the United States, is a standardized test developed by the US EPA to determine if a waste is hazardous based on its toxicity characteristics (40 Code of Federal Regulations 261). The TCLP replaced the Extraction Procedure Toxicity Test (EP TOX), which was included in the first promulgation of the Resource Conservation and Recovery Act (RCRA) regulations. The TCLP was designed to simulate conditions in an anaerobic landfill and is, therefore, supposed to represent worse-case leaching conditions in a landfill where organic wastes are co-disposed. The primary extraction fluid (#1) is a buffered organic acid solution at pH 4.98. If the waste is highly alkaline, a different extraction fluid (#2) at pH 2.88 is used without a pH buffer. The determination of the appropriate leaching fluid is made by immersing 5 g of sample into 96.5 ml of deionized water and testing the pH. If the pH value of the sample is less than 5, then extraction fluid #1 is used. If the pH of the sample is greater than 5, then extraction fluid #2 is used.

2.3.2 Waste Extraction Test

The Waste Extraction Test (WET) is a leaching test developed by the Department of Toxic Substance Control (DTSC), which is one of six agencies under the umbrella of the California Environmental Protection Agency (Cal/EPA). In

Thailand, the Department of Industrial Works' Notification of 2005 (B.E. 2548) also requires the use of this method. Results of the WET are compared to the soluble threshold limit concentrations (STLCs). The WET determines the amount of a specific constituent that can be leached from the soil using a solution designed to simulate landfill leaching. It is, therefore, a useful test for situations where a soil would be exposed to landfill leachate such as the disposal of ash together with uncombusted organic wastes in a solid waste landfill. However, the WET may not be very representative of the conditions at a site where all organic materials have been completely burned. Due to the aggressive nature of the leaching in this test, samples may exceed the soluble threshold limit concentrations.

Although the WET method is similar to the TCLP, there are some important differences between the two tests as shown in the Table 2.3.

Table 2.3 Comparison of TCLP and California WET (Sivia et al, 1991)

WET	TCLP
One set extraction fluid. Citric Acid Buffer pH 5.0	Extraction fluid selection depends on sample pH: a. Acetate buffer pH 4.93 b. Acetic Acid solution pH 2.88
Sample to extraction fluid ratio is 1:10	Sample to extraction fluid ratio is 1:20
Does not specify extraction vessel design	Requires extraction bottles made of glass or polypropylene
Requires use of 0.45 µm membrane filter for extract after extraction	Requires use of 0.6 to 0.8 µm glass fiber filter
Uses mechanical shaker for extraction	Requires rotary end over end fashion at 30 rpm
Extraction period of 48 hours	18 hours
Does not require acid digestion after extraction for metals	Requires acid digestion after extraction for metals other than mercury

2.3.3 Interpretation of leachate test results

The EPA defines hazardous waste using two different mechanisms: a list specifying certain solid waste as hazardous and an identification of the waste's characteristics. The first step in this process is determining if the waste is a listed

hazardous waste. The hazardous waste listing consists of four lists: the F list, the P list, the K list, and the U list. The wood waste from arsenic or chromium treated wood is listed as F035.

Even if a waste is a listed hazardous waste, the facility must also determine if the waste exhibits hazardous characteristics by testing or applying knowledge of the waste's properties. Given these criteria, the EPA established four hazardous waste characteristics: ignitability, reactivity, corrosivity, and toxicity.

The EPA developed the toxicity characteristic (TC) to identify wastes likely to leach dangerous concentrations of toxic chemicals into ground water. Once the leachate is created via the TCLP, the waste generator must determine whether it contains any of 40 different toxic chemicals in amounts above the specified regulatory levels. The regulations describing the toxicity characteristic are codified in 40 CFR part 261.24 and the TC regulatory levels of some toxic chemicals appear in Table 2.4. These regulatory levels are based on ground water modeling studies and toxicity data that calculate the limit above which these common toxic compounds and elements threaten human health and the environment by contaminating drinking water. If the leachate sample contains a concentration above the regulatory limit for one of the specified chemicals, the waste exhibits the toxicity characteristic and carries the waste code associated with that compound or element.

Table 2.4 TCLP Toxicity Characteristic Regulatory Levels (40 CFR, part 261.24)

Waste code	Contaminants	Concentration (mg/L)
D004	Arsenic	5.0
D007	Chromium	5.0

In Thailand, the waste regulatory was developed by the Department of Industrial Work (DIW). The DIW identifies a waste as hazardous by a six-digit code along with a description to classify the waste and the waste's characteristics (i.e., ignitability, reactivity, corrosivity, and toxicity). Construction and demolition wastes (i.e. glass, plastic, and wood containing or contaminated with dangerous substances) was mentioned in 17 02 04 of the Notification of the Ministry of Industry 2005 (B.E. 2548). Code 17 02 04 is regarding hazardous waste – mirror entry (HM). Some waste

can be deemed hazardous depending on whether it contains “dangerous substances” at or above certain levels. The code states that a waste is classified as hazardous based on its level of dangerous substances. The total concentration, total threshold limit concentration (TTLC), and soluble threshold limit concentration (STLC) values are used for the identification of hazardous waste:

- Waste is considered hazardous when the total concentration of a specific hazardous substance is higher than the TTLC (Total Concentration \geq TTLC).
- If the total concentration of a specific hazardous substance is lower than the TTLC or when landfill disposal is required, the waste should be extracted by the WET. The waste is considered hazardous when the leaching solution’s contaminant(s) is either equal or higher than the STLC.

Table 2.5 Soluble threshold limit concentrations (MOI, 2005)

Contaminants	Concentration (mg/L)
Arsenic	5.0
Chromium	5.0
Copper	25.0

2.4 Landfill Leachate Quality

Pathways of concern to human health and the environment are as follows:

- The first path way is direct exposure, which includes direct human contact though the touching of wood products (e.g., dermal sorption and the ingestion of dislodged chemicals from hand-to-mouth contact) and the inhalation of wood particles during construction and maintenance activities.
- The second path way is indirect expose, which occurs when a waste contaminates the environment, through an aquifer, for example. As a drinking water source, a contaminated aquifer could then expose humans to the contaminants.

2.4.1 Construction and Demolition (C&D) Landfill

Recently, an estimated 500,000 tons of C&D waste was generated in the Bangkok Metropolitan area. At present, there is no regulation regarding the disposal of this waste. Most of the C&D waste stream is discarded on land illegally. Some C&D waste is disposed as MSW. Some C&D waste is taken by private companies for filling up land, and often times this is done without the proper sorting out of hazardous materials. These disposal methods can lead to contamination in aquifers (Tanapat, 2007).

C&D waste is known as inert and lacking of organic materials like those found in MSW. More recent studies have shown that C&D waste goes through active processes of biological activity and the leachate created is an issue worth examining. The four phases of C&D debris landfill degradation have been outlined by Jang (2000); they are provided in Table 2.6.

Table 2.6 Stages of Degradation in a C&D Landfill (Jang, 2000)

Phase	Defining Characteristics
Initial Aerobic Phase	<ul style="list-style-type: none"> • Decreased dissolved oxygen • Decreased pH (5-6) • Decreased oxidation reduction potential • Increased organic compounds • High inorganic compounds (cations and anions) concentrations • Increased metal concentrations
Transition Phase	<ul style="list-style-type: none"> • Depleted dissolved oxygen (less than 1 mg/L) • Decreased pH (5-6) • Low oxidation reduction potential (less than 250 mV) • Increased organic compounds • Increased hydrogen sulfide and alkalinity • Increased inorganic compounds (sodium, potassium, magnesium, and chloride) • Relatively high calcium and sulfate concentrations • Increased metal concentrations

Table 2.6 Stages of Degradation in a C&D Landfill (Jang, 2000) (continued)

Anaerobic and Sulfate Reducing Phase	<ul style="list-style-type: none"> • Relatively constant pH values (6-7) • Lowest oxidation reduction potential (-300 mV) • Decreased organic compound concentrations • Maximum hydrogen sulfide and alkalinity concentrations • Decreased inorganic compounds (sodium, potassium, magnesium, and chloride) • Relatively high calcium and sulfate concentrations • Low metal concentrations because of precipitation with H₂S
Final Phase	<ul style="list-style-type: none"> • Relatively constant pH values (6-7) • Slightly increased oxidation reduction potential • Low organic compound concentrations • Slowly decreasing hydrogen sulfide and alkalinity concentrations • Depleted inorganic compounds (sodium, potassium, magnesium, and chloride) • Constant calcium and sulfate concentrations • Depleted metals with continued precipitation with H₂S

Weber et al. (2002) found that the leachate collected from C&D waste test cells exceeded Florida's groundwater cleanup target levels (GWCTLs) for aluminum, arsenic, copper, manganese, iron, sulfate, and total dissolved solids (TDS). The calcium and sulfate and high TDS levels were attributed to the disposal of drywall, and the manganese likely came from wood. They also concluded that the co-disposal of CCA-treated wood likely caused the elevated levels of arsenic (the average concentration of the 42 samples was 42.8 µg/L); another environmental issue related to C&D waste disposal that they identified is gas generation.

Dissolved sulfide is capable of producing hydrogen sulfide in reduced conditions. Many landfills throughout Florida and the United States have had complaints from surrounding residents about "rotten egg" odors coming from C&D landfills (Lee, 2000).

2.4.2 Municipal Solid Waste Landfill

AIT (2004) reported that about 65% of municipal solid wastes collected in Thailand are disposed by the open dumping method. Therefore, contaminated leachate can infiltrate the ground and potentially the aquifer below it.

Heavy metal behavior in landfills has been examined relative to the MSW degradation processes. In the acid forming stage, with a lower pH, metals can be expected to leach at greater concentrations. Also the anaerobic and reducing environment of the landfill can have a great affect on metal speciation and mobility (Flyhammar et al., 1999).

Heavy metals were not found to constitute a significant pollution problem, partly because the heavy metal concentration in the leachate is often low (e.g., arsenic concentrations in MSW leachate are reported to range from 0.1 to 1.0 mg/L) and partly because of strong attenuation by sorption and precipitation (Christensen et al., 2001). The complexation of heavy metals with dissolved organic matter is significant; however, the heavy metals are still strongly attenuated in the polluted aquifers in most cases. Even though the information on attenuation processes has increased in recent years, the number of well-documented full scale leachate plumes is still low and the studies have primarily been on sandy aquifers leaving the diverse and complex attenuation processes in leachate plumes not fully understood. This review concluded that the attenuation processes in leachate plumes provides some natural remediation for most contaminants, limiting the effects of leachate on the groundwater to an area not usually exceeding 1000 meters from the landfill (Christensen et al., 2001).

2.5 Arsenic, Chromium and Copper standards from the Soil Quality, Ground Water, Groundwater Standard for Drinking Water Proposes, and Drinking Water Standards

Since there is no leachate standard in Thailand, the Groundwater Standard for Drinking Purposes from a Notification of the Ministry of Industry will be referred to, in order to compare the results of the heavy metal contents from the lysimeter test.

CCA is the chemical treatment that is widely used to treat the wood in the northern region of Thailand. Therefore, the metals might contaminate sawmills, timber treatment sites and in-service areas. It was reported that wood preserving activities had resulted in on-site soil and groundwater contamination and off-site groundwater contamination. The contaminants that caused concern at the site include hexavalent chromium and arsenic (US EPA, 2008). The standards are provided in Table 2.7 to 2.10. Table 2.7 presents arsenic, chromium and copper standards of the soil quality standards. Table 2.8 is about the groundwater standards. Groundwater standard for drinking water proposes is Table 2.9. Lastly, Table 2.10 is drinking water standards. These are the difference places that could be contaminated from wood preserving activity or in service areas.

Table 2.7 Soil quality standards for residential and agriculture propose in Thailand (MOI, 2004)

Parameters	Units	Standards (maximum allowable)
Arsenic	mg/kg	3.9
Hexavalent chromium	mg/kg	300
Copper	mg/kg	-

Table 2.8 Groundwater standards in Thailand (MOI, 2000)

Parameters	Units	Standards (maximum allowable)
Arsenic	mg/L	0.01
Hexavalent chromium	mg/L	0.05
Copper	mg/L	1.0

Table 2.9 Groundwater standards for drinking propose in Thailand (MOI, 1997)

Parameters	Units	Standards (maximum allowable)
Arsenic	mg/L	0.05
Chromium	mg/L	2
Copper	mg/L	1.5

Table 2.10 Drinking water standards in Thailand (MOI, 1999)

Parameters	Units	Standards (maximum allowable)
Arsenic	mg/L	0.05
Chromium	mg/L	0.05
Copper	mg/L	-

2.6 Related Research

Concerns about the safety and environmental impacts of preservatives used to protect wood from biodegradation have increased in recent years; there have been many studies that have quantified preservative leaching and environmental accumulation.

Cooper (1990) and Nicholson and Levi (1971) indicated that preservative components may be more leachable from hardwoods than from softwoods.

Hingston et al. (2001) conducted a review specific to CCA-treated wood leaching, including a discussion of those parameters impacting leaching. Results of leaching studies are reported in several different ways; they are reported in terms of the concentrations of preservative components in the leachate (mg/L), the fraction of the original preservative leached (%), and the leaching flux (g/cm² day). Since many different factors (e.g., wood type and preservation method, solution pH and ionic strength, leaching test liquid-to-solid ratio, specimen size, and time of contact) impact the amounts of arsenic, chromium, and copper that leach from CCA-

treated wood and because of the different reporting formats, care must be taken when comparing results from different studies.

Lebow (2004) reported that the leaching of preservatives may also be affected by the presence and amount of heartwood in a sample. In most wood species, the inner heartwood portion of a tree is much less permeable than the outer sapwood portion. Accordingly, heartwood portions of test specimens may contain much less preservatives than the sapwood portion and may also be more resistant to penetration from the leaching medium. It had been expected that these effects would result in lower leaching rates from the heartwood, but this generalization was confounded by either the differences in preservative fixation in heartwoods or by the presence of a higher concentration of preservative at the heartwood surface. Because the presence of heartwood in specimens complicates the interpretation of the leaching results, heartwood should either be avoided or quantified and reported. Standardized methods, such as American Wood Preservers Association (AWPA) Standard E11, generally specify the use of deionized or distilled water to minimize these effects. The presence of some types of inorganic ions in water had been reported to increase leaching from CCA-treated wood. Furthermore, the wood species can affect the rate of preservative loss from treated specimens. The preservative component may be more leachable from hardwoods than from softwoods.

Solo-Gabriele (1998) found that a significant amount of CCA-treated wood is entering the construction and demolition (C&D) waste stream. A significant amount of wood within this waste stream is recycled as boiler fuel. In the process, CCA is inadvertently burned for energy recovery purposes. If current practices are continued, metal concentrations in wood ash will increase due to accumulations of the CCA chemicals. The increase will likely reach levels which will characterize the ash as hazardous. A hazardous designation will increase the costs for ash disposal and will make burning wood for energy recovery purposes cost prohibitive. In order to avert this situation, efforts should focus on identifying alternative management options for CCA-treated wood waste.

The study of Solo-Gabriele (2004) involved a “pH stat” experiment, SPLP and TCLP experiments, a set of lysimeter experiments, and an analysis of groundwater in the vicinity of C&D debris disposal facilities. This study presented that arsenic from CCA-treated wood leaches primarily as either As(V) or As(III). Chromium predominantly leaches as Cr(III). If the wood is burned, the arsenic speciation of the leachates remains consistent with that of the unburned wood with As(V) and As(III) being predominant, but the chromium speciation of the leachates converts almost exclusively to Cr(VI). The degree of Cr(VI) leaching from ash is highly dependent upon the pH of the ash leachate; there were higher leachate concentrations for the samples with lower retention levels. Results of this study also showed that more As(III) leaches from weathered wood than from unweathered wood. The conversion of arsenic in the leachate towards As(III) may enhance the leaching of arsenic as wood structures increase in age. Furthermore, the results also suggest that arsenic that leaches from untreated wood is primarily in the less toxic organic form (DMAA). The arsenic that leaches from CCA-treated wood, on the other hand, tends to be in the more toxic As(V) and As(III) forms. This difference is important when evaluating the relative impacts of arsenic.

Shibata (2004) investigated the fate of the CCA chemicals, the potential for human exposure, and the leachable components from in decks. The study’s results showed that a significant portion of arsenic could be leached into the environment during the service life of the CCA-treated wood product when exposed to rainfall. During the monitoring period, the average concentration in the runoff water from the CCA-treated deck was 1,000 µg/L of arsenic and 99 µg/L of chromium. The release of these metals into the surface soil was also observed. The surface arsenic concentrations increased from 4.5 mg/kg for the 6-month soil sample to 11.5 mg/kg for the 13-month sample. The impacts of the releases were also observed in the infiltrated water samples collected from below the experimental decks. The arsenic concentrations below the CCA-treated deck increased from a background level of 2µg/L to 20µg/L during the 408-day monitoring period; the chromium concentrations were more consistent at concentrations typically between 3 to 4 µg/L. This study confirmed that CCA-chemicals are released from the wood products through both leaching and dislodging. These releases result in environmental

contamination and may serve as a source of arsenic and chromium exposure for humans.

Townsend (2004) found that eleven of the study's thirteen CCA-treated wood samples exceeded the RCRA TC limits for arsenic (5 mg/L). If CCA-treated wood were not excluded from the definition of hazardous waste, it would need to be managed as a hazardous waste in the US. Arsenic appears to present the greatest potential risk from a waste management perspective. Arsenic concentrations exceeded 5 mg/L in 9 of the 13 samples that went through a simulated rainwater test (the SPLP) and, therefore, the nine samples exceeded the drinking water standards as well. This study also found that the WET could extract more metals than the other batch leaching tests (i.e., SPLP, TCLP, and EPTOX). This is caused by its use of citric acid, which chelates heavy metals relatively more than the acids used in other tests.

Song (2005) found that in both new and weathered CCA-treated wood, Cr(VI) occurred in the range of 0.7–4% of the total Cr. Greater Cr leaching occurred at the pH extremes, with Cr(VI) only measured under alkaline pH values (pH > 9.0). Total chromium concentrations from the synthetic precipitation leaching procedure (SPLP) leachates from CCA-treated wood were consistently less than 3 mg/L with Cr(VI) below detection limits. The results suggest that the leaching of Cr(VI) from discarded CCA-treated wood should not be a concern in most landfill environments. One exception would be its disposal in landfills with alkaline leachate; Cr(VI) was observed to leach from CCA-treated wood in the presence of alkaline leachate from crushed concrete. When CCA-treated wood is combusted, chromium becomes concentrated in the ash. Cr(VI) in ash from the combustion of CCA-treated wood was found between 4 and 7% of the total chromium. In ash from the combustion of wood recovered from construction and demolition (C&D) debris (which contained some CCA-treated wood), Cr(VI) accounted for as much as 43% of the total Cr. Nearly all of the Cr in SPLP leachates produced from the ash was in the Cr(VI) form. The degree of Cr(VI) leaching from the ash was highly dependent upon the alkalinity of the ash, with higher ash leachate pH values resulting in greater concentrations of Cr(VI).

Jambeck (2006) examined the possibility of employing a monofill to keep CCA-treated wood from increasing metal concentrations in other disposal situations. Disposing of CCA-treated wood in a monofill setting means that the waste is segregated and that the leachate could be controlled separately. The concentrations of arsenic and chromium in the leachate (both above 5 mg/L) would classify it as a hazardous waste under U.S. regulations for toxicity and such generations of leachate should be minimized. CCA-treated wood with the metals extracted could also be a “safe” source of biomass energy.

Saxe et al. (2006) examined available data for evidence of arsenic migration from unlined construction and demolition (C&D) debris landfills in Florida, where CCA-treated wood is disposed. Florida was chosen because soil, groundwater, landfill design, weather, and CCA-treated wood use levels make the state a uniquely sensitive indicator for observing arsenic migration from CCA-treated wood disposal sites, should it occur. They developed and quality-checked a CCA-treated wood disposal model to estimate the amount of wood and associated arsenic disposed. By 2000, an estimated 13 million kg of arsenic in CCA-treated wood was disposed in Florida; however, groundwater monitoring data do not indicate that arsenic is migrating from unlined C&D landfills. However, their results provided evidence that highly stringent regulation of CCA-treated wood disposal, such as treatment as a hazardous waste, is unnecessary.