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Service Life Estimation of ACQ-treated Wood Based on Biodeterioration Resistance[1]

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ABSTRACT

The aim of this study was to estimate the service life of alkaline copper quaternary (ACQ)-treated wood. The service life of preservative-treated wood was estimated by comparing a residual quantity of ACQ in wood with toxic threshold to fungi. Indoor and outdoor leaching tests were carried out in order to predict residual ACQ quantity within wood. As a result, the leaching ratio of ACQ from treated wood above ground via precipitation was 18.1% for 50 years. When the H4 treated wood, which is traditionally used in contact with the ground and fresh water, is used above-ground, the leaching ratio of ACQ for 50 years is 18.1% and the residual quantity of ACQ is 4.2 kg/m^3, which is higher than the toxic threshold of ACQ. Thus, the H4 treated wood used above-ground will be resistant to biodeterioration for at least 50 years.

Keywords : service life, preservative treated wood, long-term emission, alkaline copper quaternary, leaching

1. INTRODUCTION

The question of wood service life in outdoor structures is vital in construction applications. A service life of 50 years is required for materials used in outdoor structures in South Korea. The United States Department of Agriculture (USDA) reported that the long-term efficacy of over 50 wood preservatives, at roughly half of specified AWPA retention for fence posts, have a calculated service life of 65 years in ground contact (Freeman *et al*., 2005). This study was initiated to investigate whether or not the domestic wood in outdoor structures can serve more than 50 years. Preservatives are predominantly used for extending the service life of structural wood. Currently, the most widely used wood preservative for exposure to the above-ground and ground environment is alkaline copper quaternary (ACQ) which replaces chromated copper arsenate (CCA) due to requirements of environmentally-friendly

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preservatives. ACQ is a water-borne preservatives whose principal weakness is emission via water such as fresh water and rainfall. If the preservative in wood is leached, the wood will lose resistance to biodeterioration.

Biological deterioration is the most important cause in service life because it can severely degrade the structural quality in just a few years. As long as a sufficient amount of preservative remains within wood, the wood has resistance to decay and insects. As mentioned above, water-borne preservatives are vulnerable to water. If the quantity of leached preservatives by water could be calculated, the service life of preservative-treated wooden components could be estimated. For instance, the service life of wood in the British Standard 8417 (2011) is estimated solely based upon the resistance of the wood to biodeterioration.

Lebow (1996) demonstrates the necessity of research to determine the in-service leaching rate of preservative from treated wood due to the difference leaching rates which depend on end-use conditions. Leaching due to weathering has been studied in outdoor exposure by several researchers (McQuire, 1976; Archer and Preston, 1994; Choi *et al*., 2004; Chung and Ruddick, 2004; Taylor and Cooper, 2005; Khan *et al*., 2006; Garcia-Valcarcel and Tadeo, 2006). However, since all of these studies have provided useful information on leaching rates under specific exposure conditions, it is difficult to reproduce these tests or use the data to predict leaching rates under other weather conditions.

Several models for fitting the emissions curve of preservatives from treated wood have been developed (Brooks, 1995; Homan and van Oosten, 1999; Paneli, 2001; Waldron *et al*., 2005; Lebow *et al*., 2008). Many leaching models were developed via indoor laboratory tests where the specimens were fully immersed in water; however, the greatest proportion of treated wood in service is not continuously in contact with water and soil. The preservative-treated wood exposed to above-ground weather such as decking and fencing has contact with occasional precipitation. When the preservative-treated wood used above-ground is exposed to weather, preservative leaching is reduced and the service life of the treated wood is extended. Thus, emission model via indoor laboratory tests should be modified based on a real exposure condition.

In this study, the service life of preservative-treated wood was estimated by comparing a residual quantity of ACQ in wood with toxic threshold to fungi. The residual quantity of ACQ in wood was predicted using a long-term emission model via laboratory indoor testing. Moreover, the preservative emission from ACQ-treated wood exposed to natural weather was monitored in order to compare them with the indoor test results.

2. MATERIALS and METHODS

2.1. Specimens

For specimen preparation, four lengths of

Table 1. Retention of wood preservatives

	Average retention (kg/m^3)		
Penetration (mm)	Copper	DDAC	Total
0-15	5.2	5.5	10.7
15-50	5.2	6.5	11.7

rounded wood, 600, 900, 1200, and 1800 mm, with the same diameter (100 mm), were treated with alkaline copper quaternary (ACQ)-type D (amine-based with Cu and didecyldimethylammonium chloride [DDAC] as a quaternary compound). The species of the specimens was of Korean pine (*Pinus densiflora*) from north-eastern South Korea. The moisture content of the specimens was approximately 30% before pressure treatment. The pressure processes included: pre-vacuum of 700 mmHg for 50 min., pressure of 18 kg/m^3 for 300 min., and post-vacuum of 600 mmHg for 30 min. in sequence. The treated specimens were cured at 60℃ for 24 hours. The wood preservatives permeated deeply into the specimens (Table 1). The both end grain faces of specimens were sealed using silicone after the curing.

2.2. Measurement of the leached copper quantities from the experiment

2.2.1. Indoor laboratory leaching test

Four lengths of treated specimens were fully immersed in distilled water (Fig. 1) adjusted to a pH of 4.5 with hydrochloric acid, to match the average rainfall pH found in the major cities of South Korea. Each specimen was put into an individual leaching container and the same volume of water was poured into each container to match that of each specimen. The specimens were fully submerged under the water with fixtures. To measure the amount of leached copper, a 50 mℓ leachate solution was sampled at 1, 2, 4, 6, 8, 10, 20, 30, 40, 50, and 64 days from the beginning of the leaching experiment. After sampling the leachate solution, the remaining water was replaced with new distilled water.

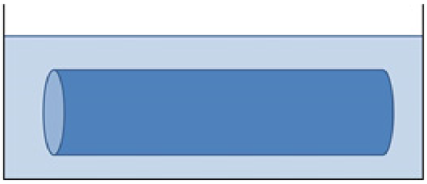

Fig. 1. Laboratory indoor leaching test; continuously contacted with water.

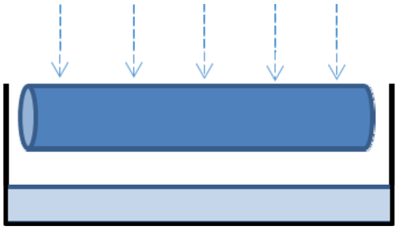

Fig. 2. Outdoor exposure leaching test; occasionally contacted with water.

2.2.2. Outdoor exposure leaching test

A treated specimen was mounted onto a container (Fig. 2) placed on the rooftop of a laboratory building in Seoul, South Korea. To measure the amount of leached copper following rainfall, a 50 mℓ leachate solution was sampled and the extant remaining water in the container was removed.

2.2.3 Measurement of leached copper

The volume of leachate solution, distilled water, in each container at the beginning of the experiment was measured using a measuring cylinder/beaker. The amount of copper in the 50-mℓ leachate samples was measured via inductively coupled plasma (ICP). The total quantity leached within a time interval (t_{n+1} - t_n) per 1 m^2 of wood surface area ($Q_d(\Delta t)$, mg/m^2) is calculated using Eq. (1)

$$Q_d(\Delta t) = C \cdot V_{leachate} / A_{wood} \qquad \text{Eq. (1)}$$

where,

C : concentration of the wood preservative component in the sampled leachate solution (50 mℓ) at a time point (mg/ℓ)

$V_{leachate}$: the volume of leachate solution (ℓ)

A_{wood}: the surface area of the wood specimen (m^2)

2.3. Long-term emission model based on flux

2.3.1. *Flux*

Flux is described as the quantity of preservative leached per 1 m^2 of wood surface area per day (mg/m^2/day). The *flux(Δt)* represents the average daily flux for each time interval (Δt) and is calculated using Eq. (2):

$$Flux(\Delta t) = Q_d(\Delta t) / \Delta t \qquad \text{Eq. (2)}$$

2.3.2. Long-term emission model

The expert group for OECD Emission Scenario Document for performing a risk assessment of wood preservatives investigated the existing emission models and adopted Paneli's model (Eq. 3) which correlates well with calculated and measured emitted preservative values (Fleuren, 2006; OECD, 2013).

In this study, Paneli's model which is based on fluxes (leaching rates) was used to estimate the amount of leached copper as follows:

$$log_{10}FLUX(\Delta t) = a + b\ log_{10}(t) + c\ log_{10}(t)^2 \qquad \text{Eq. (3)}$$

where,

a, b *and* c: parameters determined by the leaching experimental $FLUX(\Delta t) = f(t)$ curve

t : time (day)

3. RESULTS AND DISCUSSIONS

3.1. Determination of parameters for the long-term emission model

The leaching test results for full-sized specimens of various lengths obviously showed that the cumulative quantities of copper leached from longer specimens was greater than that of shorter specimens (Fig. 3). The *flux(Δt)* showed a similar trend regardless of the length of specimens although the initial fluxes of each specimen were different (Fig. 4). The *flux(Δt)* was obtained by dividing the quantity of leached copper (mg) in an unit time by the wood surface area (m^2). Thus, the *flux(Δt)* was expected to be unaffected by the length of specimens.

It was reported that the leaching performance (or the flux rates) is influenced by the wood

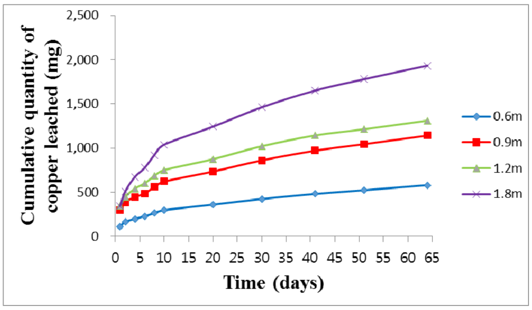

Fig. 3. Cumulative quantity of copper leached versus time (days).

surface area-to-wood volume ratio (Cooper, 1994; Hayes *et al.*, 1994) and the wood surface area-to-water volume ratio (Schoknecht *et al.*, 2003). Therefore, to minimize the influence of these ratios on the test results, the ratios were set to be consistent by pouring same volume of water in units of liter into each container as that of a wood specimen in units of cubic meter. The ratios for an end-sealed round wood was constant regardless of length if the radius of the wood is equal to that shown in Eq. (4). The wood surface area-to-wood (or water) volume was 40 m^2/m^3 (or 0.04 m^2/l) in this study.

$$\frac{Surface\ area\ of\ specimen}{Volume\ of\ specimen\ (or\ water)} = \frac{2\pi rl}{\pi r^2 l}$$

$$= \frac{2}{r}\left(or\ \frac{2}{r}\cdot\frac{1}{1000}\ in\ water\ volume\right) \qquad \text{Eq. (4)}$$

where,
r: radius of specimen
l: length of specimen

Since the effect of the specimen length was found negligible on the flux (Fig. 4), the average value of tested data was used to derive a long-term emission model of Eq. (3). A simple second order polynomial regression was selected and the parameters a, b, and c for Eq. (3) were determined as 2.608, -0.937, and 0.108, respectively. The Eq. (3) can be rewritten as follows;

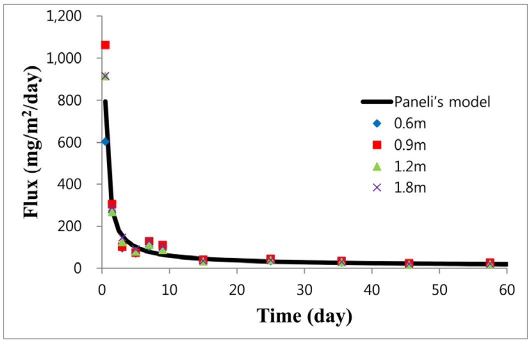

Fig. 4. Plot of daily Flux(Δt) versus time.

$$log_{10}FLUX(\Delta t) = 2.608 - 0.937\ log_{10}(t) + 0.108\ log_{10}(t)^2 \qquad \text{Eq. (5)}$$

where,
t: time (day)

3.2. Comparing the indoor and outdoor test results

The indoor test results were compared with outdoor test results. The biggest difference between the indoor and outdoor tests was how they are exposed to the water, which was assumed to be the primary cause of preservative component emission from ACQ-treated wood. In the indoor test, the specimens were fully immersed in the water containers, while the out-

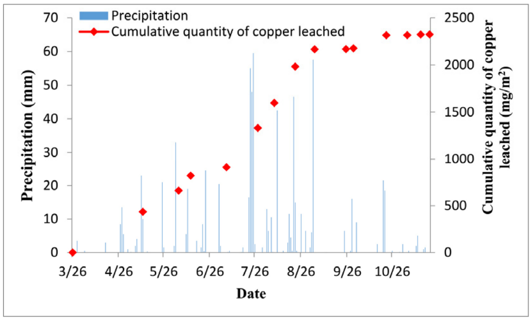

Fig. 5. Precipitation and cumulative quantity of copper leached versus time.

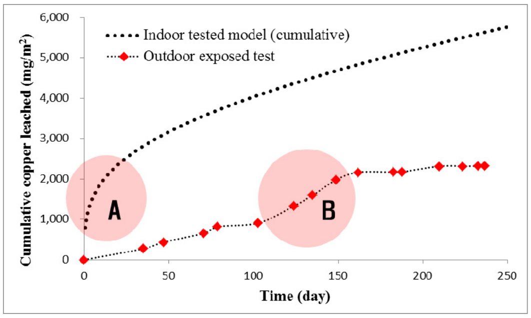

Fig. 6. Cumulative quantity of copper leached from indoor and outdoor tests (A and B: steep slope region).

door test specimens were exposed to natural weather and occasionally came into contact with water via rainfall. The outdoor test was assumed to reflect the natural environment, and the emission measurements of the preservative component was based on a cumulative precipitation of the test site. During summer, from July to August, the quantity of leached copper was rapidly increased as shown in Fig. 5. The precipitation was also concentrated from July to August. Thus, the trend of the outdoor test showed that the amount of emission was increased positively with the precipitation.

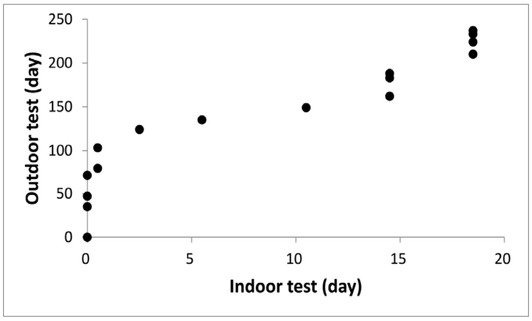

Fig. 7. Plot of outdoor test day versus indoor test day.

When comparing the indoor and outdoor tests in terms of the cumulative amount of leached copper as shown in Fig. 6, the large amount of copper leaching in the indoor test occurred in the initial days of the experiment (region A in Fig. 6). During the outdoor test, the peaks of leaching were found in summer (region B in Fig. 6). In order to match the data between the indoor and outdoor test results, the cumulative amount of leached copper was used as a common variable. As shown in Fig. 7, corresponding days of the indoor and outdoor tests respectively were plotted in reference to the same quantity of cumulative leached copper quantity in both curves of Fig. 6. It should be noted that the curve generated from the indoor test data-based model (Eq. 6) was used for comparison. This plot illustrates nonlinearity of the leaching trend in time (day) between the indoor and outdoor tests. This explains a major difficulty when attempting to predict a service life of treated wood using the data of laboratory indoor tests.

For removing the effect of nonlinear trends, the cumulative quantities of leached copper

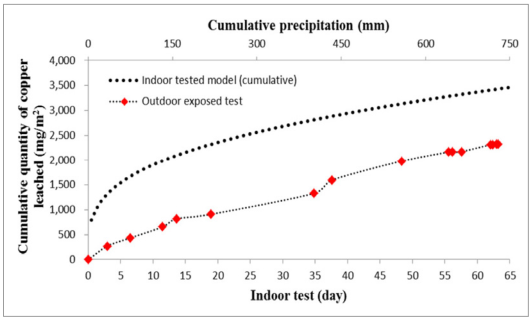

Fig. 8. Cumulative quantity of copper leached from the indoor test and cumulative precipitation.

from the outdoor test was re-plotted versus the cumulative precipitation (refer to monthly precipitation in Fig. 5), and this re-plot was able to be incorporated with the curve of the indoor tested model again as shown in Fig. 8. From this incorporation, a relationship between the day of the indoor test versus the cumulative precipitation was derived by using the same process as used for plotting Fig. 7 (i.e. the day of the indoor test vs. the day of the outdoor test). This relationship was given in Fig. 9.

3.3. A model for predicting cumulative precipitation via indoor test

Disregarding the data points in initial part of Fig. 9 (i.e. shaded region A, or approximately in 3 days of the indoor test) a linear relationship could be found between the cumulative precipitation and the indoor test day. The linear regression was calculated as Eq. 6.

$$\text{Cumulative precipitation} = 20.945 \times \text{indoor test day} + 338.92 \qquad \text{Eq. (6)}$$

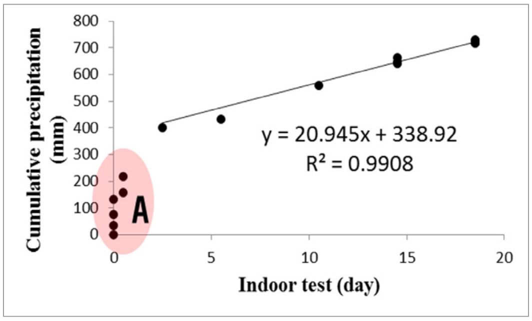

Fig. 9. Plot of cumulative precipitation versus indoor test day.

This equation implies that the required cumulative precipitation for leaching copper from ACQ-treated wood exposed to above-ground conditions can be predicted by indoor tests. For example, the precipitation in Seoul is in the range of 1,200-1,500 mm per year and, simply calculated, the cumulative precipitation of 75,000 mm is expected in 50 years. The 75,000 mm precipitation corresponds to approximately 10 years of indoor test days using Eq. (6). It means that the cumulative quantity of leached copper in 50 years by precipitation can be calculated by the indoor tested model (Eq. (5)) with 10 year-input.

3.4. Emission quantity of ACQ

As mentioned above, the cumulative quantity of copper leached by precipitation in Seoul for 50 years was 75,000 mm, which corresponds to that found for approximately 10 years of indoor test days using Eq. (6). The cumulative quantity of copper leached for 10 years using Eq. (5) was 23,533 mg/m^3 as shown in Fig. 10. The

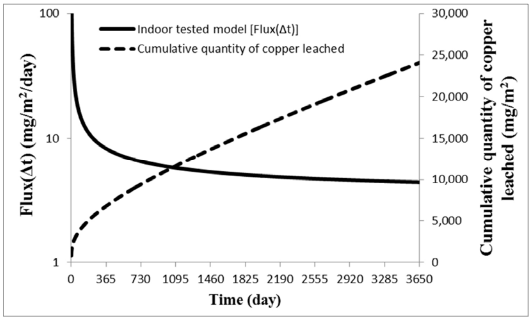

Fig. 10. Cumulative quantity of copper leached for 10 years.

long-term emission model based on flux and the unit of emission quantity is mg/m^2. However, the unit of retention of preservatives is mg/m^3. Thus, the leaching ratio ($R_{leaching}$) of copper was considered in the same units of mass, and calculated using Eq. (7). The predicted leaching ratio of copper over 10 years was 18.1% via Eq. (7):

$$R_{leaching}\,(\%) = (Q_c(t) \times A_{wood}) \,/\, (R_{sample} \times V_{wood}) \qquad \text{Eq. (7)}$$

where,

$Q_c(t)$: the cumulative quantity of copper leached through a wood area of 1 m^2 at time point t after the beginning of the experiment (mg/m^2)

R_{sample}: the retention of copper in the three sample specimens (5,200,000 mg/m^3)

V_{wood}: the volume of specimen (m^3)

When the performance of ACQ is assumed to be dependent on the leaching ratio of copper, it can be estimated that the leaching ratio of preservative is 18.1% and the residual quantity of ACQ in specimens is approximately 8.7 kg/m^3, as shown in Table 2. The tested specimens had retentions more than required for H4 which is the service grade for uses in contact with the ground and fresh water as a standard, Korea Forest Research Institute (KFRI) notification No. 2015-2 (2015). The required retention for H4 is 5.2 kg/m^3. The 18.1%-reduced retention would be approximately 4.2 kg/m^3. It means that when the H4 treated wood is used above-ground, the leaching ratio of ACQ for 50 years is 18.1% and the residual quantity of ACQ in wood would be approximately 4.2 kg/m^3. This value is higher than the toxic threshold of ACQ (Table 3), as determined by Archer *et al.* (1995). Thus, the H4 treated wood used above-ground will be resistant to biodeterioration for at least 50 years. Meanwhile, the required retention for H3 is 2.6 kg/m^3. The 18.1%-reduced retention would be approximately 2.1 kg/m^3. This value is lower than the

Table 2. Original and 18.1%-reduced retention of ACQ

Retention (kg/m^3)		
Use category	Required in standard	18.1% reduced
H3	2.6	2.1
H4	5.2	4.2
Tested Specimen	Injected in this study 10.7	18.1% reduced 8.7

Table 3. Toxic threshold of ACQ (Archer *et al.*, 1995)

Threshold (kg/m^3)	Fungi
2.4	*I. lacteus* (white rot)
1.4	*T. versicolor* (white rot)
0.7	*P. placenta* (brown rot)
0.2	*G. trabeum* (brown rot)

toxic threshold of ACQ in Table 3. Thus, the H3 treated wood used above-ground will not be resistant to biodeterioration for 50 years.

This study focused on the biodeterioration resistance of preservative-treated wood in above-ground condition. Therefore, the outdoor test was carried out above-ground exposure in this study. However, the treated wood are frequently used in ground-contact condition as well. Further studies on ground-contact condition are required.

4. CONCLUSION

In this study, the service life of ACQ-treated wood was estimated by comparing a residual quantity of ACQ in wood with toxic threshold to fungi. The residual quantity of ACQ in wood was calculated by excluding a long-term cumulative emission from the initial retention of the specimens. The long-term cumulative emission of ACQ was predicted using the flux-based model via laboratory indoor test. The preservative emission from ACQ-treated wood exposed to natural weather was monitored to compare the indoor test results.

In the outdoor test, the cumulative copper quantity was proportional to the precipitation which shows a linear relationship with indoor test days. Thus, a model for predicting cumulative precipitation was developed via the indoor test method. The model shows that the cumulative quantity of copper leached for 50 years via precipitation is equal to the copper quantity leached over 10 years predicted using the indoor test method.

As a result, the leaching ratio of preservative from treated wood was 18.1% for 50 years via precipitation. When the H4 treated wood was used above-ground, the leaching ratio of ACQ for 50 years would be 18.1% and the residual quantity of ACQ in wood will be 4.2 kg/m^3, which is higher than the toxic threshold of ACQ. Thus, the H4 treated wood used above-ground will be resistant to biodeterioration for at least 50 years.

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REFERENCES

Archer, K., Nicholas, D.D., Schultz, T.P. 1995. Screening of wood preservatives: comparison of the soil-block, agar-block, and agar-plate tests. Forest Products Journal 45(1): 86～89.

Archer, K., Preston, A. 1994. Depletion of wood preservatives after four years marine exposure in Mt. Maunganui harbour, NZ (IRG/WP94-50036). The International Research Group on Wood Preservation, Stockholm, Sweden.

Brooks, K.M. 1995. Literature review, computer model and assessment of the potential environmental risks associated with creosote treated wood products used in aquatic environments. Western Wood Preservers Institute, Vancouver, WA, USA.

British Standard (BS) 8417. 2011. Preservation of wood. Code of Practice.

Choi, S., Ruddick, J.R., Morris, P. 2004. Chemical redistribution in CCA-treated decking. Forest Products Journal 54(3): 33～37.

Chung, P.A., Ruddick, J.N.R. 2004. Leaching of copper from ACQ treated wood exposed above ground. Doc. IRG/WP 04-50219. International Research Group on Wood Preservation, Stockholm, Sweden.

Cooper, P.A. 1994. Leaching of CCA: Is it a problem? Environmental Considerations in the Manufacture, Use and Disposal of Pressure Treated Wood. Forest Products Society, Madison, WI, USA.

Fleuren, R.H.L.J. 2006. Proposal for the interpretation of leaching study data for wood preservatives (biocides), RIVM report 601516014: 69～89.

Freeman, M.H., Crawford, D.M., Lebow, P.K., Brient, J.A. 2005. A comparison of wood preservatives in posts in southern mississippi: results from a half-decade of testing. Proceedings, American Wood-Preservers' Association: 136～143.

Garcia-Valcarcel, A.l., Tadeo, J.L. 2006. Leaching of copper, chromium, and boron from treated timber during above-ground exposure. Environmental Toxicology and Chemistry 25(9): 2342～2348.

Hayes, C., Curran, P.M.T., Hynes, M.J. 1994. Preservative leaching from softwoods submerged in Irish coastal waters as measured by atomic absorption spectrophotometry. Holzforschung-International Journal of the Biology, Chemistry, Physics and Technology of Wood 48(6): 463～473.

Homan, W.J., van Oosten, A.L. 1999. Statistically stable models for determination of PEC. Int. Res. Group on Wood Preservation, Doc. IRG/WP, 99-50135.

Khan, B.I., Solo-Gabriele, H.M., Townsend, T.G., Cai, Y. 2006. Release of arsenic to the environment from CCA-treated wood. 1. Leaching and speciation during service. Environmental Science and Technology 40(3): 988～993.

Korea Forest Research Institute (KFRI) notification No. 2015-2. 2015. Standard and specification of wood products.

Lebow, S. 1996. Leaching of wood preservative components and their mobility in the environment. Summary of pertinent literature. United States Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, USA.

Lebow, S., Lebow, P., Foster, D. 2008. Estimating preservative release from treated wood exposed to precipitation. Wood and Fiber Science 40(4): 562～571.

McQuire, A.J. 1976. The performance of preservative treated marine piles in New Zealand. Sixth Conference of Harbour Engineers, Auckland, New Zealand.

Organization for Economic Co-operation and Development (OECD). 2013. Emission scenario document for wood preservatives.

Paneli, M. 2001. Suggestions for calculation of the long term emissions of preservative component(s) from treated wood, based on experimental leaching data. Working document EXGP(2001)11 of the Expert Group for the development of the OECD ESD for Wood Preservatives, August 2001.

Schoknecht, U., Wegner, R., Horn, W., Jann, O. 2003. Emission of biocides from treated materials test procedures for water and air. Environmental Science and Pollution Research 10(3): 154～161.

Taylor, J.L., Cooper, P.A. 2005. Effect of climatic variables on chromated copper arsenate (CCA) leaching during above-ground exposure. Holzforschung 59(4): 467～472.

Waldron, L., Cooper, P.A., Ung, T.Y. 2005. Prediction of long-term leaching potential of preservative-treated wood by diffusion modeling. Holzforschung 59(5): 581～588.