WATER REPELLENT ADDITIVES FOR PRESSURE TREATMENTS

Andrew R. Zahora and Charles M. Rector
Chemical Specialties Inc.
PO Box 640
Harrisburg NC 28075

ABSTRACT

This paper reports on the modification of certain characteristics of water-borne preservative treated wood through the incorporation of non-polar water repellent additives using emulsion technology. Incorporation of water repellents into CCA treatments reduced the severity of checking and other physical degradations over time, and reduced the 'hardness' of treated wood. The water repellents did not detract from the performance of CCA in Southern yellow pine. Emulsion composition influenced the stability of formulations in CCA as well as water repellent efficiency. The treatability of various wood species was greatly dependent on the particle size characteristics of emulsions. Southern yellow pine sapwood was easily penetrated by emulsions containing particles larger than 1 µm, while less permeable species required much smaller particle sizes.

INTRODUCTION

The use of water-borne preservatives, primarily chromated copper arsenate (CCA), for the treatment of wood products has increased rapidly in the last 20 years. The majority of this usage has been in the construction sector, where the cleanliness, lack of odor, and relatively low cost give water-borne treatments an advantage over oil-borne preservatives. Unfortunately, the physical performance of water-borne preservative treated wood in service has become a source of dissatisfaction among some consumers and a cause of concern for the treated wood industry. The cyclic wetting and drying of these wood products when exposed to the weather can result in rapid dimensional changes. This can lead to the formation of checks and other physical degradation, which are less pronounced in oil-borne preservative treated wood.

The options for over-coming the hygroscopicity of wood in general have been comprehensively reviewed by Rowell and Banks (1985). The best long term protection to wood from physical degradation associated with shrinkage and swelling would be through dimensional stabilization, but as yet this technology remains cost prohibitive for most commodities. A more cost effective approach for reducing the rate of physical degradation in treated wood is to decrease the rate of cyclic wood moisture changes through the use of water repellents. This can be accomplished by surface application of formulated products, but these need to be re-applied frequently to maintain performance. Conceptually the inclusion of a penetrating water repellent in

the treating solution should provide the most cost effective and maintenance free method for obtaining long term protection against physical weathering in service. The inclusion of a water repellent additive into CCA treatments to modify the physical characteristics of treated wood is not a new concept (Levi et al., 1970), but has been slow to gain wide-spread use.

Water-borne preservatives have also found extensive use in the pole treatment area, although oil-borne treatments are often preferred because of real or perceived advantages in climbability and physical integrity in service. In order to improve the climbability of CCA treated poles considerable research has been undertaken to modify CCA treatments to mitigate such effects. These efforts have included the incorporation of polyethylene glycol (PEG) at a molecular weight of about 1000 (Trumble and Messina, 1985, 1986, 1987), and the incorporation of emulsified oil (McIntyre and Fox, 1990). Inclusion of water repellent additives have also been shown to provide benefits by reducing pole hardness (Preston et al., 1989).

Our research into the incorporation of a water repellent additive into water-borne preservative treatments has been ongoing since 1987. The studies reported here describe further developments into understanding how these emulsion additives impact treatment parameters as well as influence the performance of water-borne preservative treated wood.

FORMULATION DEVELOPMENT

Three criteria were considered critical to the successful development of a water repellent additive for water-borne preservative solutions. These were: 1) the performance of the emulsified hydrophobe and its ability to impart the desired level of water repellency, 2) the ability of the formulation to remain stable in the preservative environment (specifically CCA) and also not interfere with the effectiveness of the preservative, and 3) to effectively penetrate throughout the treated zone of the wood and not interfere greatly with uptake rates and retentions.

Results form various elements of this program and how they relate to the overall effectiveness of water repellent additives are discussed below.

PERFORMANCE AS WATER REPELLENT

Many of the positive influences of water repellent additives on the checking and swelling performance of water-borne treated wood have been reported previously (Preston et al., 1989, Fowlie et al., 1990). Some of our more recent research will be updated below. All studies listed here were preformed using CCA-C as the water-borne preservative.

Immersion Studies

The major function of a water repellent treatment is to reduce the rate of water uptake and loss, and in so doing, reduce the stresses of dimensional change. This was tested in an immersion and drying study where the rates of water uptake and width swell in Southern yellow pine (SYP) samples treated with CCA or CCA with an emulsified water repellent additive (CCA-WR) were compared with that of untreated controls. Matched samples (50 x 150 x 100 mm) were end-sealed, treated, and conditioned to 12% MC. They were then submerged in water for 280 hr, with samples weighed and measured for width after specific immersion periods. After immersion, samples were placed in a conditioning chamber (21°C and 65% relative humidity) and the rate of drying and shrinkage was monitored.

The addition of a water repellent emulsion to the CCA treating solution greatly reduced both the rate of water uptake and loss, and the associated swelling in the treated samples (Figures 1 and 2). In practice, this means that the water repellent treated wood will experience less severe stresses under repeated wetting and drying regimes which would lead to extensive checking and other physical degradation.

Formulation

The formulation of water repellent additives will significantly influence their performance in wood. Of specific concern was their surfactant and hydrophobe composition, as well as their physical characteristics such as the emulsion particle size. We have investigated the performance of various commercial as well as developmental water repellent formulations using a swellometer test.

Swellometer tests were conducted with 4 sets of end-matched ponderosa pine (*Pinus ponderosa*) wafers (5 x 38 x 140 mm) cut from different boards. Wafers were full-cell treated with 1.3% CCA solutions containing 0.0, 0.25, 0.5, or 1.0% of two different commercial water repellent emulsions (as solids). All wafers were initially dried in an oven at 50°C, and then conditioned to 12% MC at 65% RH and 30°C. Matched wafers were immersed in a water bath and monitored for swell using electronic dial gauges with digital input to a computer. Results from these tests were expressed as a percent of the maximum swell after 3 hr immersion for CCA only treated wafers (unleached condition). The two different additives show a marked difference in water repellent performance (Figure 3), with formulation WR #2 even showing a inverse relationship between amount of water repellent and rate of swell. This may be due to the surfactants in WR #2 interfering with or counteracting the effectiveness of the hydrophobe used.

To further investigate how these water repellents would function in service, the same wafers were leached with water. This involved exposing the wafers to 5 cycles of 48 hr immersion in water followed by oven drying at 50°C. Wafers were then reconditioned to 12% MC and tested in the swellometer apparatus

as above. The formulation WR #1 performed identically in the leached and unleached tests, while the WR #2 formulation improved after leaching (Figure 4). The reversal of the inverse relationship of concentration of WR #2 and water repellency after leaching implies that a loss of surfactant during the leaching cycle may have occurred.

We have also investigated emulsion particle size on the anti-swelling efficiency of water repellent emulsions. These tests used research formulations which were identical in composition except for particle size. Similar matched sets of *P. ponderosa* wafers were treated with 1.2% CCA containing 1.0% solids of emulsions at one of three different particle sizes, or containing hydrophobes of different molecular weights. Differences in emulsion particle size ranging from a median of 0.13 to 0.26 µm and maximum of 0.36 to >3.8 µm did not influence the water repellency of the treated wafers (Figure 5), even though this represents a substantial difference in emulsion surface area. This suggests that the physical size of the emulsion particles may not be of great significance.

It should be noted that emulsion particle size results were obtained using a Nicomp Model 270 submicron particle sizer. These results are relative, as analysis with different technologies may result in variations in particle size distribution results.

Surface Hardness

The influence of water repellent additives on the surface hardness of SYP round-wood has been investigated using gaff penetration, pilodyn pin penetration, and pole climbing studies.

Gaff penetration studies were carried out using the technique of Williams (1986). Southern yellow pine (SYP) post quarters were full-cell treated with either CCA, or CCA with 1% or 2% water repellent additive (as solids) and equilibrated to 12% MC. They were then tested for the load required for a lineman's pole gaff to penetrate 6 and 12.5 mm into the round surface of treated (CCA or CCA-WR) post quarters relative to that required to penetrate matched untreated quarters. After this initial sampling, treated quarters were exposed on horizontal racks with the round surfaces upwards in Hilo, HI. Untreated reference quarters were not exposed. The inclusion of a water repellent additive in the CCA solution markedly reduced the force necessary for gaff penetration of these samples, both before and after a 6 month exposure in Hilo, HI (Table 1). Comparing these data with that reported by Williams (1986) suggests that the water repellent may provide a surface that is easier to penetrate than for pentachlorophenol in P-9 oil treated poles. While CCA treated quarters showed a slight increase in hardness (greater force for gaff penetration) after a weathering exposure, the CCA-WR treated samples showed a slight decrease.

Matched quarters from the gaff penetration study were also sampled for pilodyn pin penetration (6 joule, 2 mm pin) after the 6 month exposure at Hilo, HI. Whereas a slight decrease in penetration depth was observed in CCA treated quarters as compared with the untreated controls, a significant increase in pin penetration of about 2 mm was observed for the CCA-WR treated quarters (Table 1).

Further testing was carried out with end-matched post sections (150-200 mm diameter by 1.2 meter long) which were full-cell treated with either 1.7% CCA only, or 1.7% CCA with 1.0% water repellent solids additive. A second series of matched post sections were treated with CCA-WR at either 0.5% or 1.0% additive solids content. After 7 months air-drying, each post was sampled at 0.3 meter from each end at 90° intervals around the post (8 measurements per post) and compared with results from its matched section. As was observed in the post quarters tested above, pilodyn pin penetration was significantly greater (by about 2 mm) in posts treated with CCA with 1.0% water repellent added than in CCA only treated sections (Table 2). No difference was observed in penetration between posts treated with the water repellent at 0.5% and 1.0% solids content (Table 2). In comparison, Trumble and Messina (1985) did not observe any difference in pilodyn pin penetration depths between SYP poles treated with CCA or CCA/PEG, although about 2 to 3 mm pin penetration differences were observed for red and jack pine poles.

Initial charges of SYP and red pine utility poles have been successfully treated with CCA-WR. To date, only one group of poles has been subjectively assessed by linemen for climbability. Three Georgia Power linemen climbed and subjectively rated 20 CCA-WR treated poles for gaff penetration, brittleness, and climbing comfort. Comparisons were made to CCA-only treated poles. Although this was a very limited comparative study, the results suggest that the addition of this water repellent has a significant positive influence on pole climbing comfort (Figure 6).

PRESERVATIVE PERFORMANCE

It is important that any preservative additive should not negatively impact the effectiveness of the preservative itself. This includes influences both on the performance of the treated wood and also on the total treating system including interactions with the preservative solution.

Treatment Efficacy Studies

Soil block tests results using *Gloeophyllum trabeum* and *Postia placenta* showed that there was no significant difference between the performance of blocks treated with CCA or CCA with a water repellent additive. Laboratory leaching studies also found no significant differences in the leachability of CCA components from CCA and CCA/water repellent treated wood. Results from these two studies have been reported elsewhere (Preston et al., 1989).

Southern yellow pine ground contact stakes treated with two levels of CCA both with and without the incorporation of a water repellent additive have been exposed in both Hilo, HI and Harrisburg, North Carolina following the AWPA M7-83 Standard. Stake evaluations after 22 months exposure (Table 3) do not indicate any difference in performance of these stakes. Similarly, incorporation of the water repellent additive into CCA treatments of 25 x 50 x 175 mm Southern pine stakes has not significantly influenced their performance in a fungus cellar exposure after 34 months (Figure 7).

Simulated Stormwater Runoff Studies

Although the water repellent additive did not influence CCA leachability, we were also concerned with its possible influence on stormwater runoff in treating plants and storage yards. Initial studies (Fowlie et al., 1990) had tested the influence of a water repellent additive on the loss of CCA active oxides from lumber in a simulated stormwater runoff situation. This study used SYP sapwood lumber treated full-cell with 2.0% CCA oxide solutions with and without a water repellent additive. After air-drying times ranging from 1 to 48 hr, lumber was exposed to a simulated heavy rainfall (150 mm) over a relatively short period (30 minutes), and the runoff collected and analyzed. Results (Figure 8) found that the inclusion of the WR additive reduced the concentration of copper, chromium, and arsenic in the runoff by about one half after each air-drying period.

In this present study, we were interested in how a water repellent additive might affect stormwater runoff from round stock, especially when exposed to a longer simulated rainfall period. To test this, 2.4 meter long SYP posts (150 to 200 mm diameter) were cut in half and full-cell treated with either 1.7% CCA or 1.7% CCA with a water repellent added (1.0% as solids). Groups of 3 post sections from both CCA and CCA-WR treatments were then exposed to a simulated rainfall immediately (15 minutes) after treatment, or after storage for 24 hr at 20°-24°C. Post sections were placed on a support above a 0.6 x 1.2 meter collection pan and rainfall was simulated through 8 flat spray nozzles (Teejet 80015) that produced a uniform spray rate of 130 mm/hr over the surface of the posts. Posts were rotated 180° every 5 minutes and were sprayed for 2 hr under a 10 min on-10 min off regime to produce an average simulated rainfall of 65 mm/hr. This exposed all surfaces of the posts to rainfall, and the alternating on-off spraying was used to minimize the total amount of collected runoff. Runoff was collected for periods of 0-20, 20-40, 40-80, and 80-120 minutes.

Analysis of the collected runoff by ICP (Figures 9 and 10) showed that the inclusion of a water repellent additive in the CCA substantially reduced the amount of active oxides in the runoff from posts as compared with similar posts treated with only CCA. This was apparent both from posts exposed to simulated rainfall immediately after treatment, and after a 24 hr holding period. As was found in the lumber study (Figure 8), the rate of runoff was reduced to about one half that from CCA only treated posts for short-term rainfall exposure periods (less than 30 min). As the posts were exposed to longer rainfall periods, both the total concentration of metal washing off, and the relative difference between the two treatments decreased. This would be expected as the surface of the water repellent treated posts begins to wet up, allowing for any unfixed oxides to diffuse at similar rates towards the surface where they could be washed off. Metal concentrations had decreased substantially after the 24 hr holding period, but still maintained a similar relationship with decreased runoff with CCA-WR treated wood.

Formulation Stability

The stability of an additive in a preservative system may not be critical to the performance of the final product, but it does have important implications on how the preservative system can best be used. Our studies have concentrated on additive stability in the harsh oxidizing environment of CCA work solutions. We have compared various commercial water repellent additive formulations for stability in 1.3% CCA solutions. These solutions were analyzed for non-reduced chromium by titration during storage under the accelerated oxidation/reduction conditions of 50°C in closed containers. The different surfactant/hydrophobe systems used in the commercial formulations distinctly influenced the resultant stability of the formulation (Figure 11). The stability of water repellents to oxidation in CCA work solutions is important in that it will reduce the effective CCA concentration of the work solutions and therefore chemical costs, as well as produce sludging with its environmental concerns for disposal.

Within a given hydrophobe/surfactant system, emulsion particle size will determine the total surface area available for chemical interaction, and therefore may influence solution stability. Preservative solutions (1.3% a.i. CCA oxides) were made containing 1.0% water repellent additive (as solids) from emulsions of identical composition, but of two different particle sizes. These solutions were exposed for 43 days at 50°C and analyzed for non-reduced chromium by titration. The non-reduced chromium concentration decreased 6% in the solutions containing the smaller particle size emulsion (median 0.13 µm, maximum 0.36 µm particle size) whereas only a 4% decrease was observed in solutions containing the larger (median 0.26 µm, maximum >3.8 µm particle size). These solutions were also filtered through medium speed filter paper where twice as much precipitate was recovered from the smaller particle size emulsion. Both of these solutions were very stable under this harsh oxidation reduction environment, but these results do show a relative influence of particle size. The composition of the reaction precipitate contained a Cu:Cr:As metal ratio of 1:7:12, whereas the CCA initially contained a ratio of about 1:1.5:1.6.

TREATMENT PARAMETERS

The inclusion of any sort of particulate such as an emulsion into a preservative treatment could theoretically influence the rate of preservative uptake. The degree of interference can be expected to be dependent on the particle size and the size of the pit openings between cells of the wood species being treated. Previous studies suggested that a 10 µm particle size emulsion was optimum for a water repellent additive for CCA solutions (Belford and Nicholson, 1968). Our earlier developments concluded that a sub-micron particle emulsion with a median size of 0.40 µm was effective in treating SYP (Fowlie et al., 1990), although subsequent analyses of this emulsion found a median size of 0.26 µm. These emulsions rapidly penetrate SYP lumber, requiring no increase in cycle times as compared to CCA only treatments. However, in charges of posts and utility poles, where penetration of much greater distances is necessary, the inclusion of the emulsion was found to significantly increase the pressure periods necessary to treat to similar solution gauge retentions. We have been investigating modifications to the particle size distribution of emulsion systems and how this influences the rate of preservative uptake in various wood species to determine the optimum particle size necessary to treat different wood species.

The effect on wood treatability when water repellent emulsions are added to CCA solutions was investigated using small treating cylinders (100 x 310 mm). These cylinders had attached combo tanks with sight-glasses to enable visualization of gross solution uptake throughout the treatment cycle. Kiln dried round-stock sections (150-180 mm diameter by 300 mm length) of SYP were quartered and sealed to allow penetration only in the radial direction (up to 75 mm). Matched quarters were held under vacuum (>-85 kPa) for 15 min and then flooded with either CCA only or CCA with 1.0% (solids basis) of water repellent emulsions of different particle size distributions. The time between breaking vacuum and obtaining full pressure was about 15 seconds in these trials. Initial tests at 1050 kPa found that the uptake of all emulsion solutions was too fast to accurately visualize differences in uptake rates between the CCA only and emulsion solutions tested. Tests were repeated using a treatment pressure of 830 kPa, which showed distinct differences in uptake rates for the various solutions (Figure 12). While the larger particle size emulsion with some particles over 3.8 µm in diameter was distinctly slower in treating this roundstock, the smaller particle size formulations performed much better suggesting that only a minimal increase in pressure times might be expected commercially.

These tests were repeated with kiln-dried red pine roundwood (Figure 13) and also ponderosa pine and hem-fir boards (Figures 14 and 15). Penetration into the kiln-dried red pine was much slower, with even the smallest particle size tested showing restricted gauge retention. Commercial trials with air-dried red pine poles with the larger particle size emulsion were not greatly affected; penetration and retention specifications were easily met. Ponderosa pine boards were difficult to treat with the larger emulsion, but treated easily with the smaller particle sizes. Hem-fir lumber was much more difficult to treat, with even the smallest particle size emulsion tested still showing a very significant reduction in uptake rates over that observed with CCA alone. These results suggest that the emulsion particle size will directly influence the rate of preservative penetration, and that some wood species such as Hem-fir may require exceedingly small emulsion sizes to not substantially impact preservative uptake rates.

CONCLUSIONS

These studies show that the use of water repellent additives in water-borne preservatives can enhance the performance of the wood against weathering, hardness, and runoff, while having no apparent detrimental effect on protection from biodegrading organisms. The stability of water repellent formulations in CCA can vary greatly, dependent on both the surfactant and hydrophobe composition, as well as the particle size of the emulsion. Particle size of the emulsion formulation is critical to the rapid penetration of the water repellent and preservative into wood. The maximum size of emulsions necessary for rapid penetration is species dependent, with species such as SYP being easily penetrated by relatively large emulsion (some particles over 3.8 µm), while species such as hem-fir are difficult to penetrate even with emulsions with all particles under 0.36 µm.

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Table 1. Relative force of gaff and depth of Pilodyn pin penetration in matched southern yellow pine round-wood quarters.

Treatment	Relative Force or Penetration: Unweathered			Weathered 6 months		
6 mm GAFF PENETRATION						
	Kg[a]	(StD)	t[b]	Kg[a]	(StD)	t[b]
CCA	1.8	(10.9)	0.5	3.6	(10.0)	1.2
CCA-1% WR	-15.0	(5.5)	-8.2	-21.8	(8.2)	- 8.5
CCA-2% WR	-19.5	(8.2)	-7.2	-24.5	(7.3)	-10.4
Penta/P-9[c]	- 4.4	(6.0)	-2.3			
12.5 mm GAFF PENETRATION						
	Kg[a]	(StD)	t[b]	Kg[a]	(StD)	t[b]
CCA	13.2	(15.9)	2.5	16.8	(15.0)	3.6
CCA-1% WR	-28.6	(12.2)	-7.0	-37.3	(14.1)	- 8.3
CCA-2% WR	-34.1	(10.9)	-9.5	-38.6	(11.8)	-10.4
Penta/P-9[c]	- 6.3	(9.8)	-2.0			
PILODYN PIN PENETRATION (6 Joule, 2 mm pin)						
				mm[d]	(StD)	t[b]
CCA				-0.48	(0.90)	-1.7
CCA-1% WR				1.76	(0.92)	6.1
CCA-2% WR				2.52	(1.35)	5.9

a Average difference in force, (treated - untreated) where the average force for matched untreated sections was 56.6 and 113.4 kg for 6 and 12.5 mm penetration, respectively.
b $|t| > 2.3$ indicates significant difference at $\alpha=0.05$.
c Data from Williams (1986).
d Average difference in pin penetration (treated - untreated) where the average depth of penetration for matched untreated sections was 13.1 mm.

Table 2. Influence of a water repellent additive to CCA on pilodyn pin penetration (6 joule, 2 mm pin) measurements in end-matched 1.2 meter Southern yellow pine post sections.

WR Solids	Replicate Post	Moisture Content Range (@ 25 mm)		Avg Pin Penetration[a] mm	F[b]
1.0%	12	15%	(13-18%)	18.4	(5.0)
0.0%	12	14%	(12-16%)	16.2	
0.5%	13	14%	(13-21%)	16.9	(0.1)
1.0%	13	15%	(9-18%)	17.1	

a Average of 8 readings from each replicate post.
b $|F| > 4.3$ indicates a significant difference at $\alpha=0.05$ between the matched sets of post sections.

Table 3. Field exposure results from Hilo HI, or Harrisburg NC for 19 mm ground contact stakes treated with CCA or CCA with 1.0% water repellent solids added.

Treatment	CCA Retention (kg/m3)	Decay Rating: Hilo 12 mo	Hilo 22 mo	Harrisburg 12 mo	Harrisburg 22 mo
CCA	4.0	100	100	100	100
CCA	6.0	100	100	100	100
CCA-WR	4.0	100	100	100	100
CCA-WR	6.0	100	100	100	100
Untreated		54	5	76	66

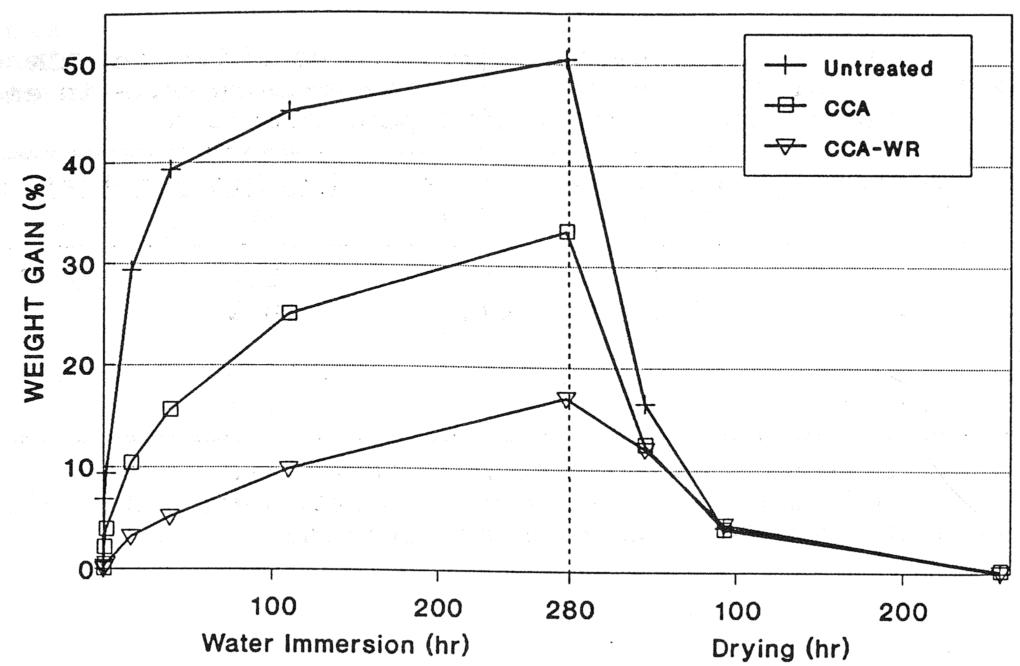

Figure 1. Effectiveness of a CCA water repellent additive on water absorption of end-sealed Southern yellow pine boards (50 x 150 x 100 mm) measured as weight gain during water immersion and subsequent drying at 21°C and 65% RH.

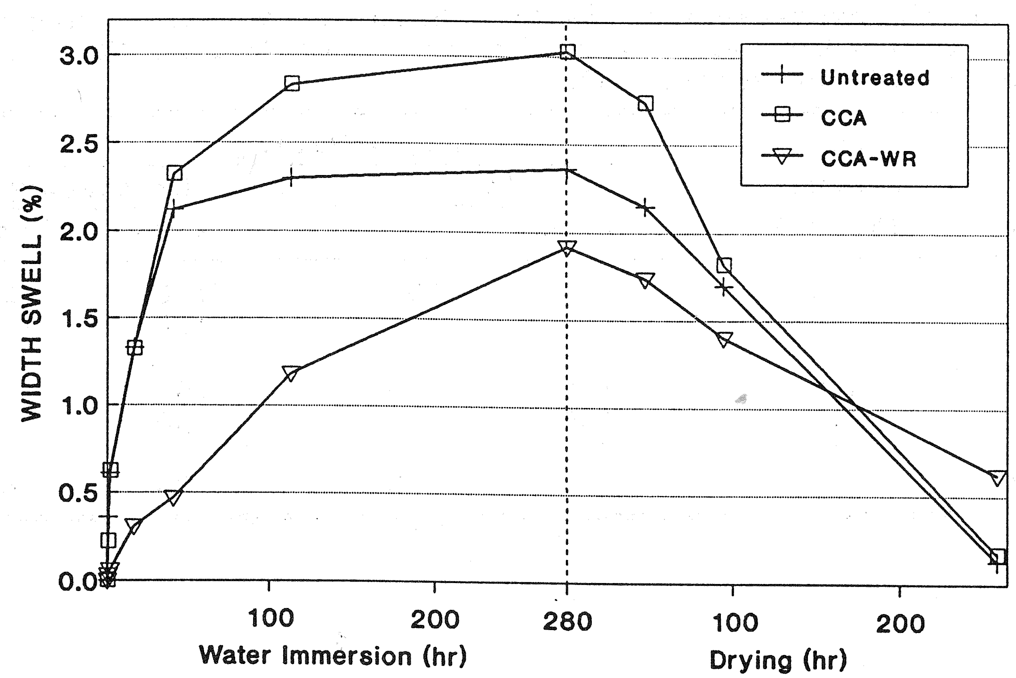

Figure 2. Effectiveness of a CCA water repellent additive on width swell of end-sealed Southern yellow pine boards (50 x 150 x 100 mm) during water immersion and subsequent drying at 21°C and 65% RH.

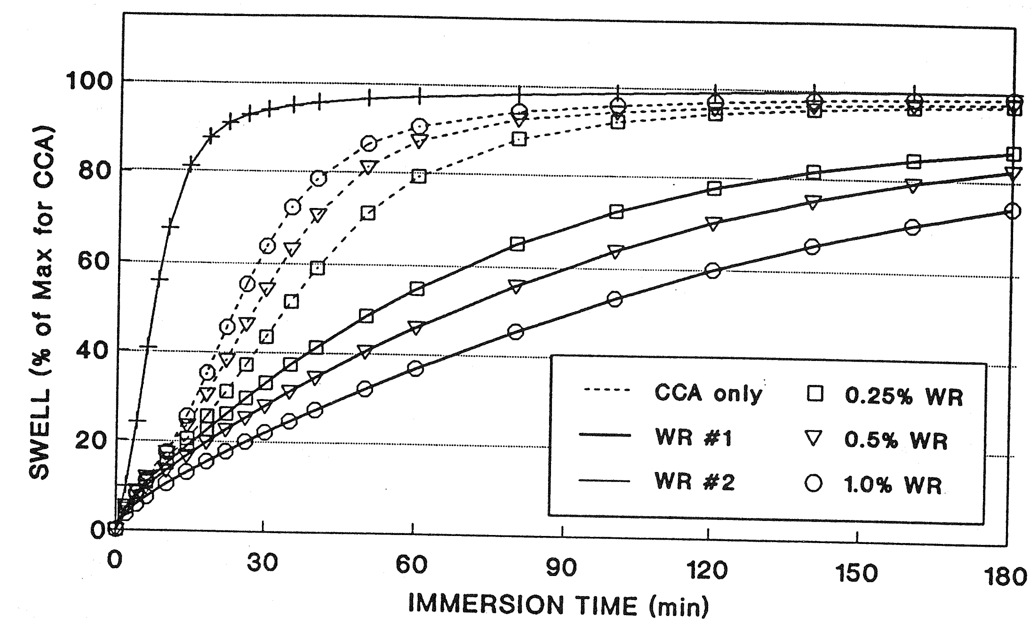

Figure 3. The average rate of swell from 4 sets of matched ponderosa pine wafers (5.0 x 38 x 140 mm) treated with 1.3% CCA with or without 3 concentrations of two commercial water repellent additives. Wafers were not leached prior to testing.

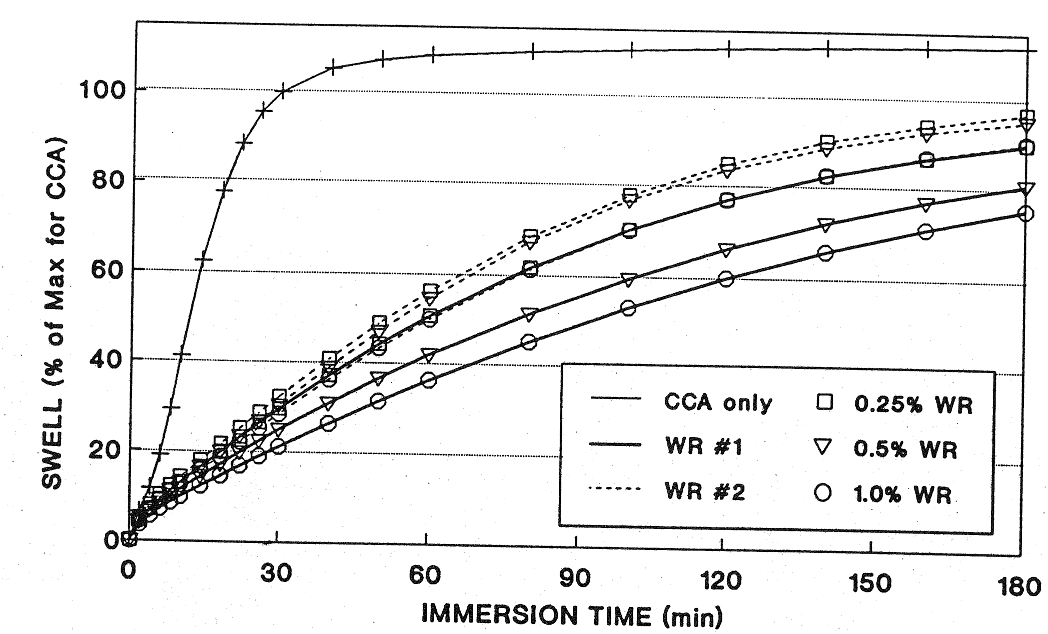

Figure 4. The average rate of swell from 4 sets of matched ponderosa pine wafers (5.0 x 38 x 140 mm) treated with 1.3% CCA with or without 3 concentrations of two commercial water repellent additives. Same wafers as in Figure 3, but after leaching.

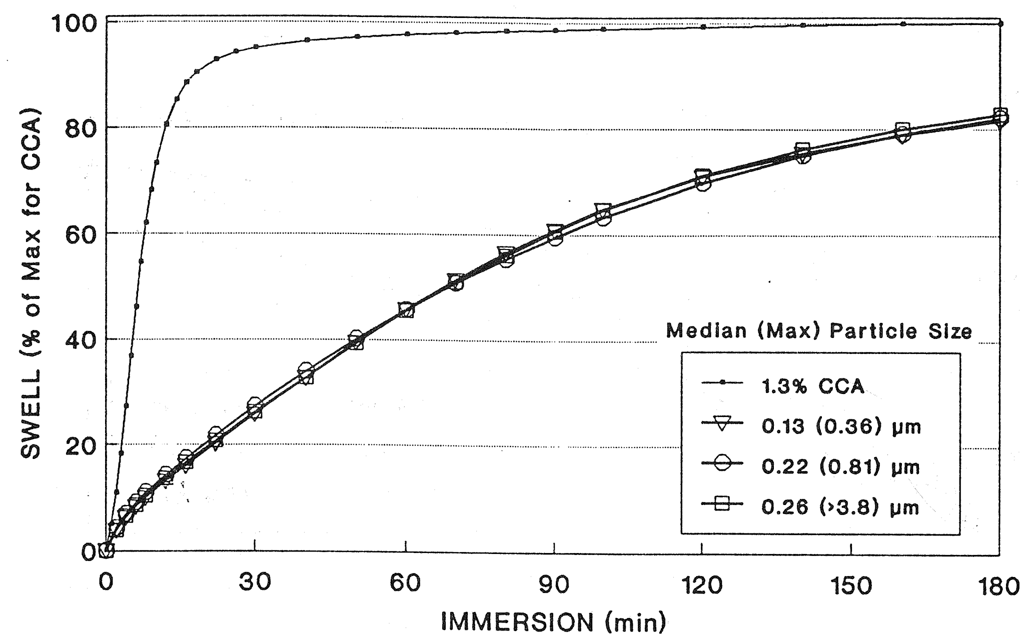

Figure 5. The average rate of swell from 4 sets of matched wafers (5.0 x 38 x 140 mm) full-cell treated with solutions of 1.3% CCA containing emulsified water repellents (1.0% solids) of different particle sizes.

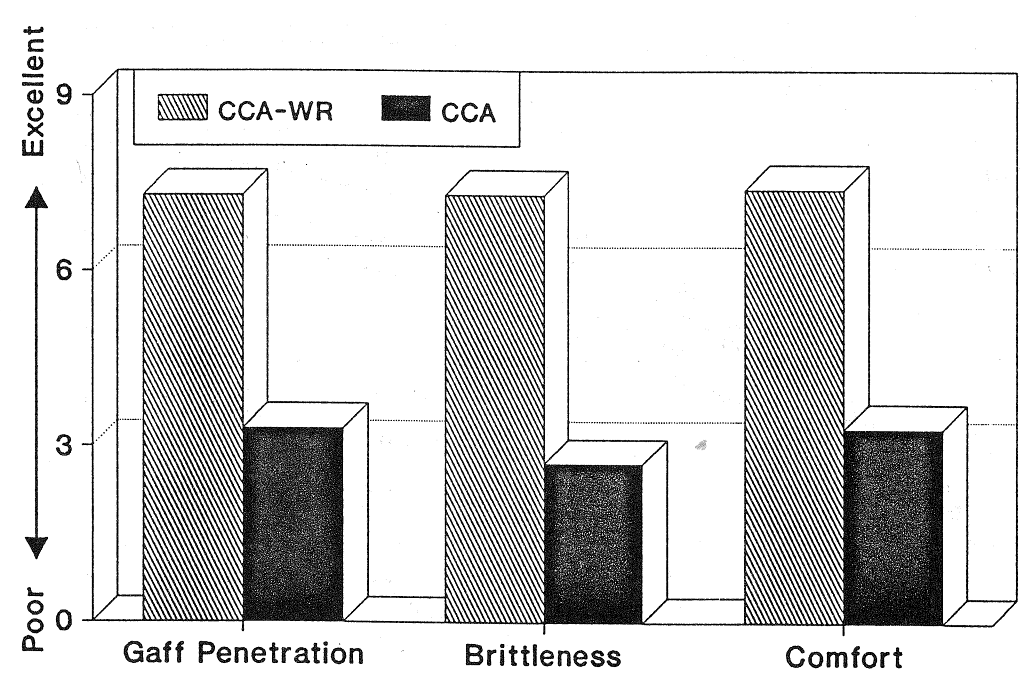

Figure 6. Average subjective ratings of 20 CCA-WR treated poles by three Georgia Power linemen 1 year after treatment and their comparison with ratings for 3 month old CCA only treated poles.

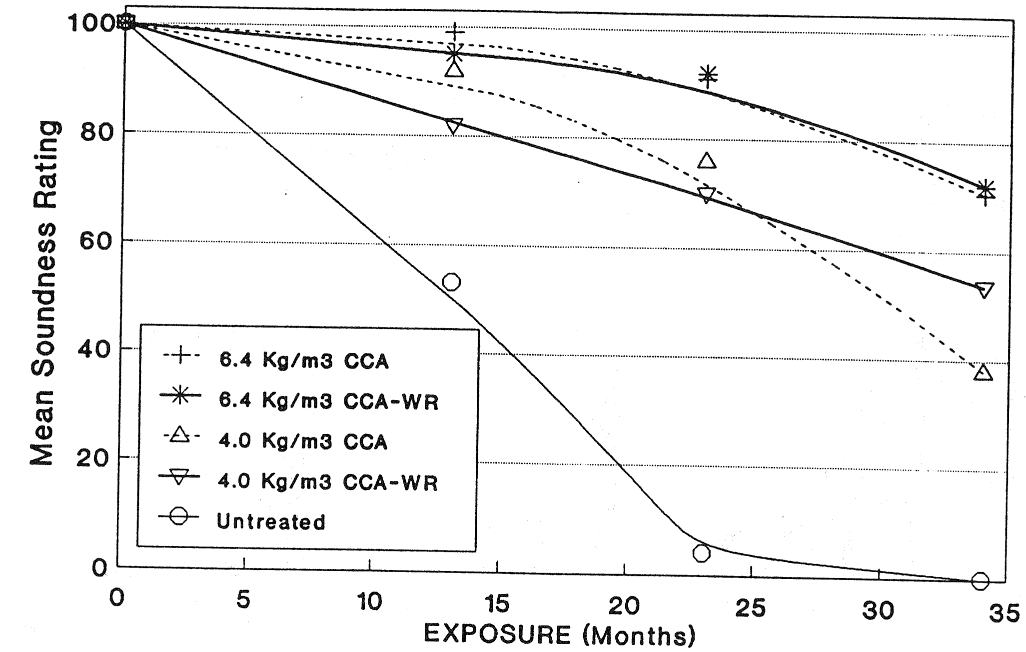

Figure 7. Performance of 12 x 25 x 200 mm stakes treated with either CCA or CCA containing 1.0% solids of a water repellent (CCA-WR) in a fungus cellar test.

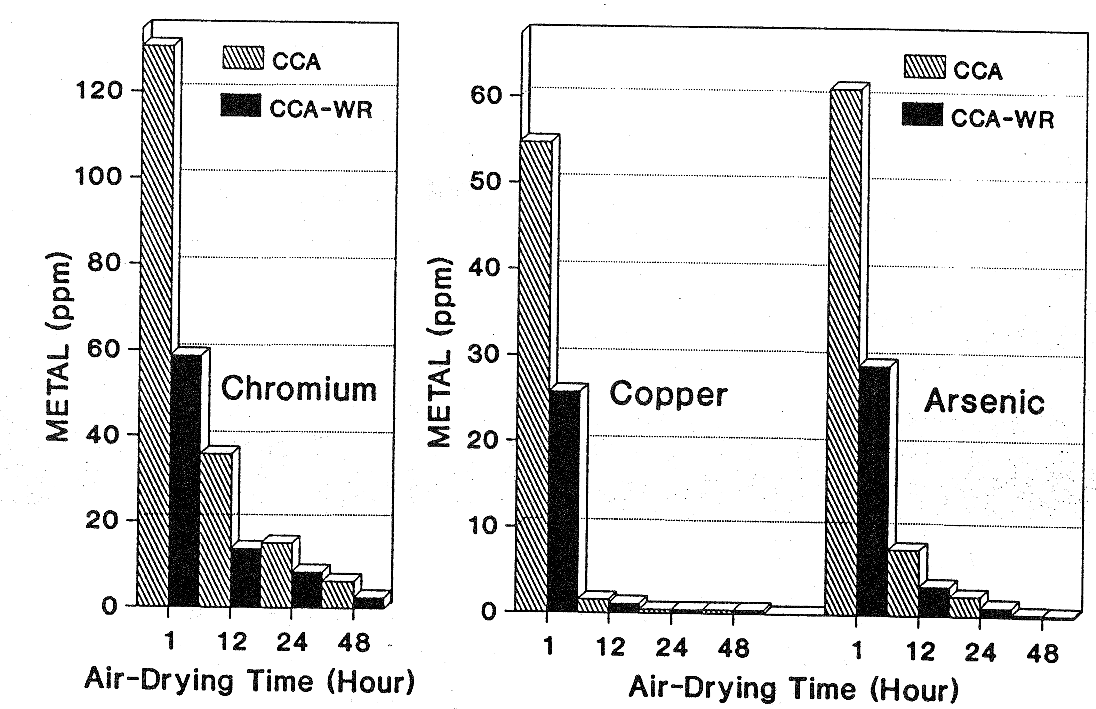

Figure 8. Elemental analysis results from a simulated stormwater runoff study (150 mm rainfall over 30 min) for CCA and CCA plus a water-repellent additive (CCA-WR) treated southern yellow pine boards (50 x 150 x 300 mm). The Y-axis is twice as large for chromium as for copper and arsenic.

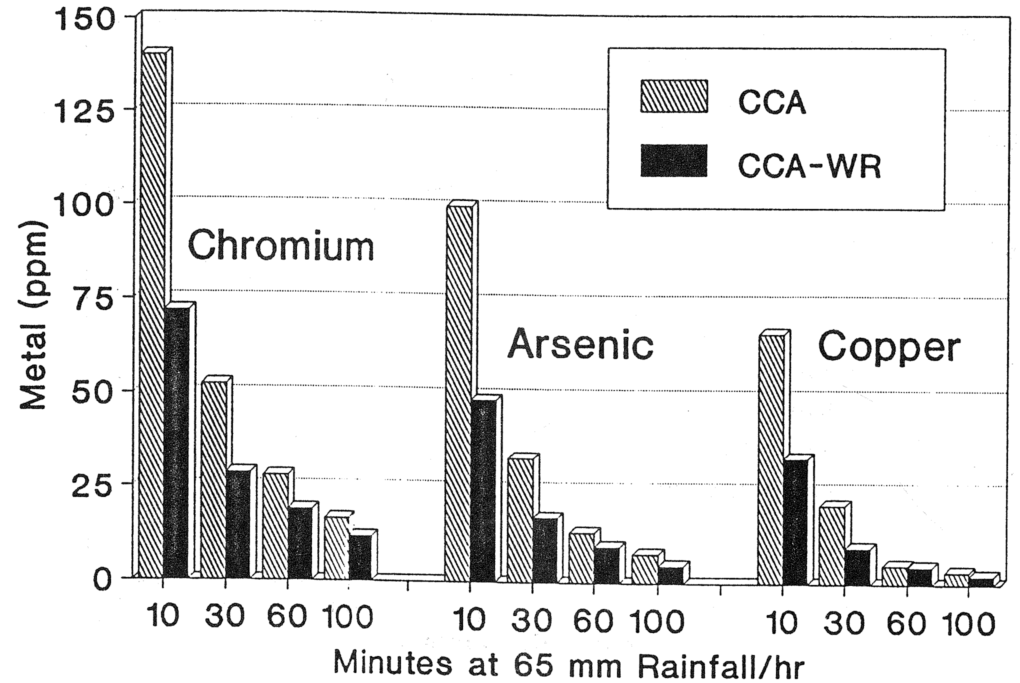

Figure 9. Stormwater runoff from Southern yellow pine posts (150 to 200 mm diameter x 1.2 m long) 15 minutes after full-cell treatment with 1.7% CCA with and without 1.0% water repellent (WR) solids added.

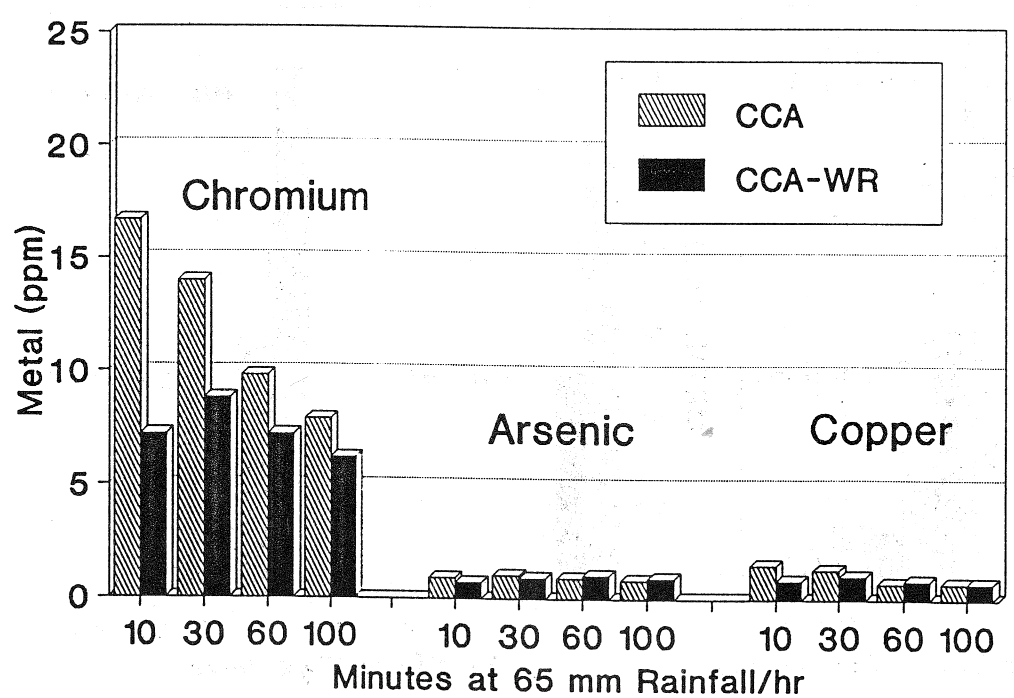

Figure 10. Stormwater runoff from Southern yellow pine posts (150 to 200 mm diameter x 1.2 m long) 24 hr after full-cell treatment with 1.7% CCA with and without 1.0% water repellent (WR) solids added.

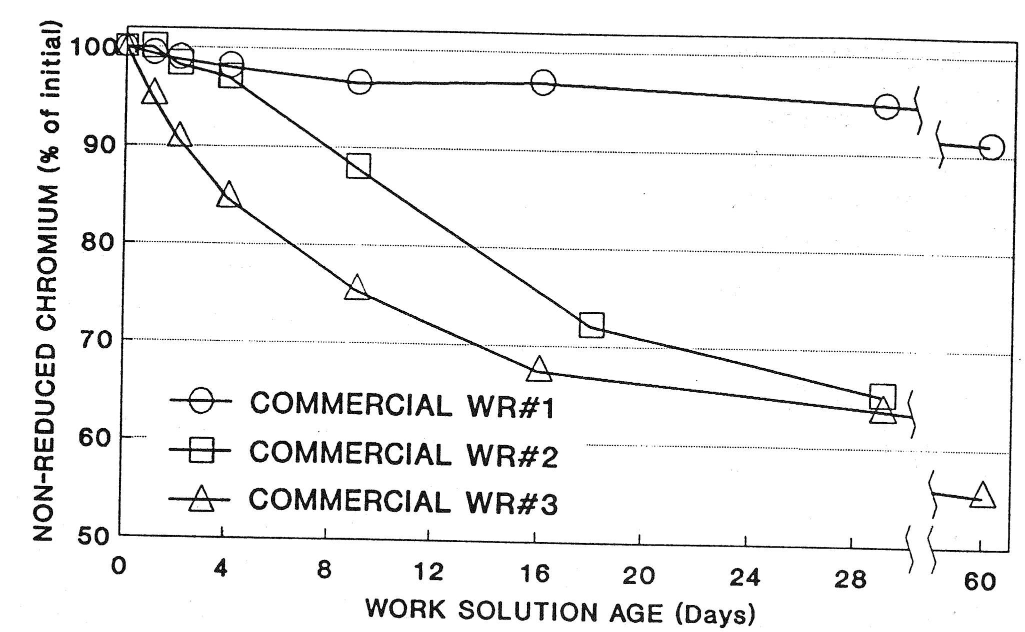

Figure 11. Stability of 1.3% CCA solutions containing 1.0% water repellent solids during storage at 50°C in closed containers.

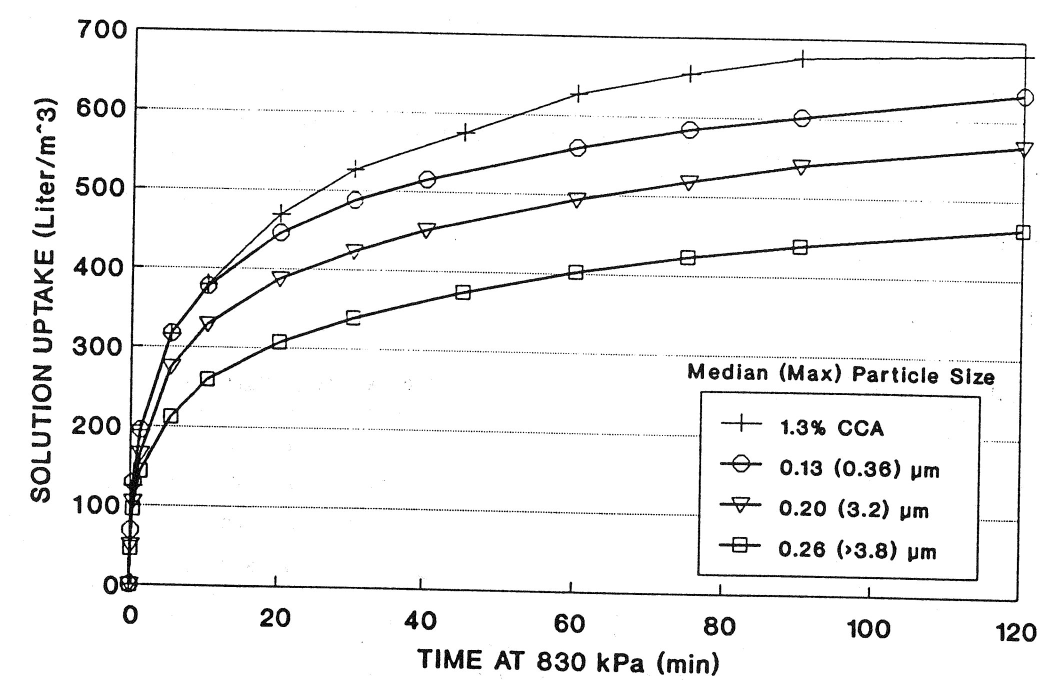

Figure 12. The influence of incorporation of emulsified water repellents (1.0% solids) of different particle size distributions into CCA solutions on the rate of solution uptake in matched quarters of kiln-dried SYP rounds. The quarters were sealed so as penetration was only in the radial direction.

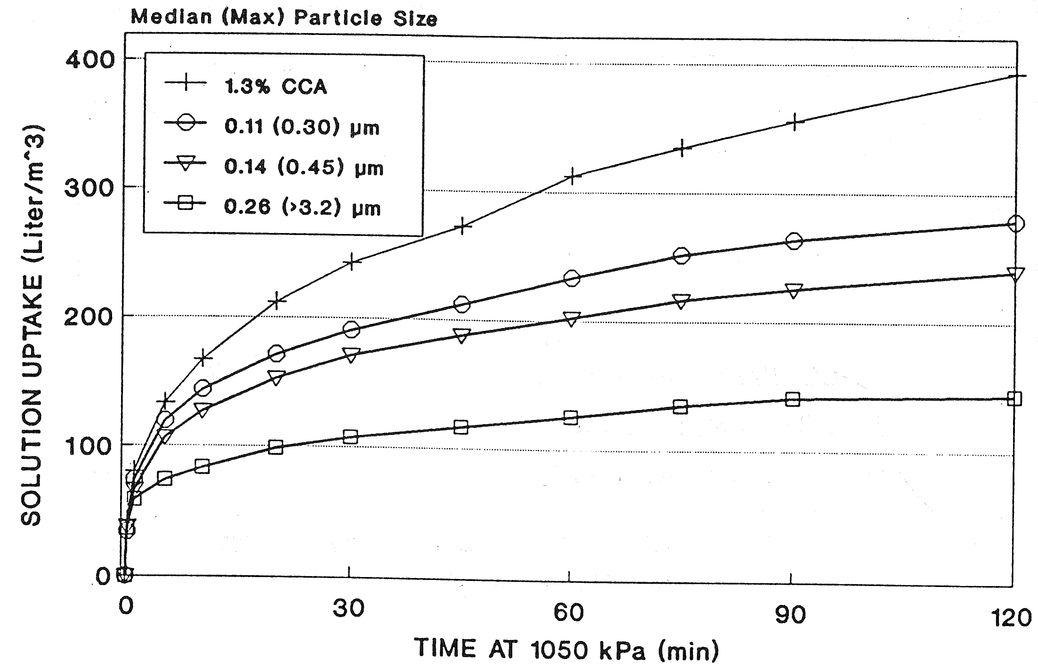

Figure 13. The influence of incorporation of emulsified water repellents (1.0% solids) of different particle size distributions into CCA solutions on the rate of solution uptake in matched quarters from kiln-dried red pine rounds. Rounds were sealed so as penetration was only in the radial direction.

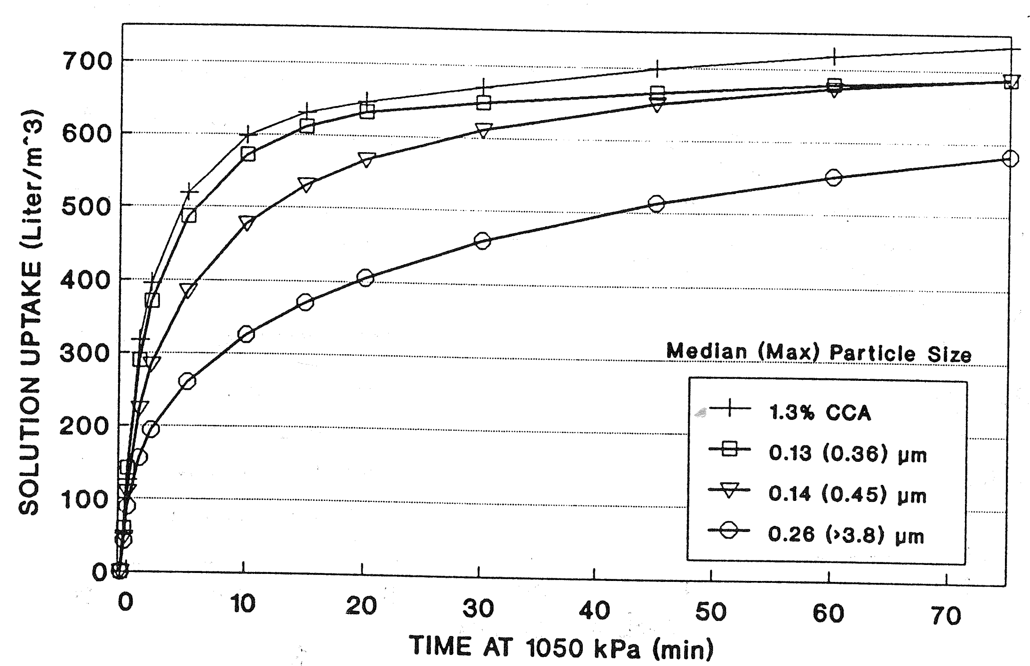

Figure 14. The influence of incorporation of emulsified water repellents (1.0% solids) of different particle size distributions into CCA solutions on the rate of solution uptake in matched end-sealed Ponderosa pine sapwood boards (20 x 90 x 300 mm).

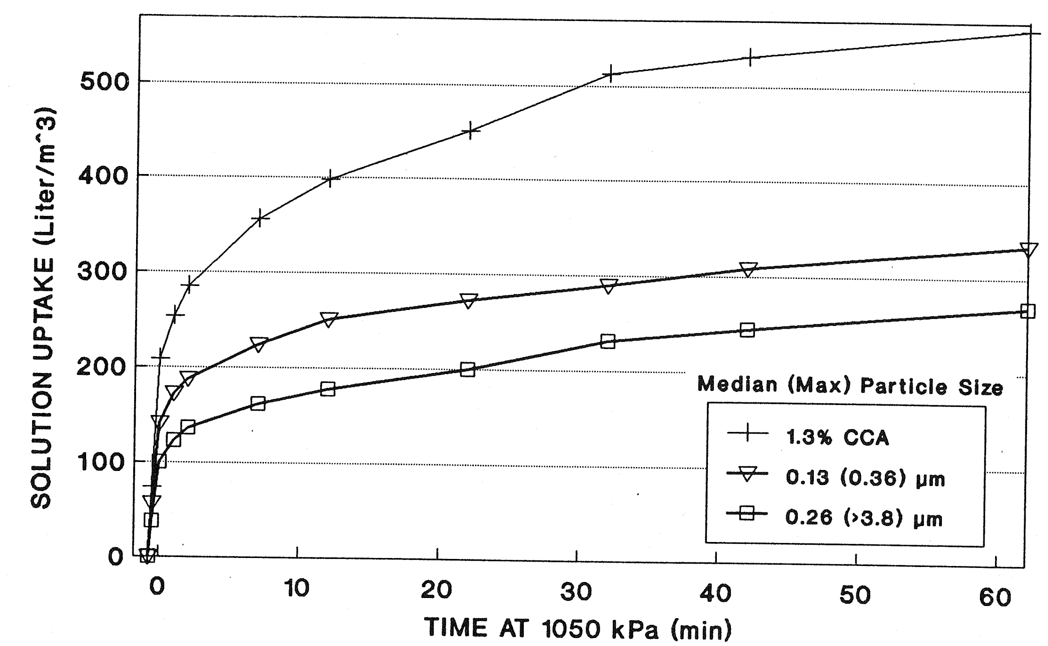

Figure 15. The influence of incorporation of emulsified water repellents (1.0% solids) of different particle size distributions into CCA solutions on the rate of solution uptake in matched end-sealed Hem-fir sapwood boards (20 x 90 x 300 mm).