**Government of the Union of Myanmar**
**Ministry of Forestry**
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# Treatability of In, Yon and Taung-Thayet with Copper, Chromium and Arsenic Water-Borne Preservatives

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# အင်၊ ရိုး နှင့် တောင်သရက်သစ်တို့အား၊ ကြေးနီ-ခရိုမီယမ်နှင့် အာဆင်းနစ် ပါဝင်သော
# သစ်ကြားရှည်ခံ ဆေးရည်များဖြင့် ဆေးသွင်းနိုင်သည့် ပမာဏကို လေ့လာခြင်း

ဦးဝင်းကြည် ( ၂ )၊ B. Sc. ( For. ) Rgn., M.S ( SUNY )  အကြီးတန်းသုတေသနမှူး
သစ်တောသုတေသနဌာန

## စာတမ်းအကျဉ်းချုပ်

အင်၊ ရိုး နှင့် တောင်သရက်သစ် နမူနာတုံးများအား ၅% စီစီအေ ( စီ ) နှင့် ကြေးနီ၊ ခရိုမီယမ်နှင့် အာဆင်းနစ်ဓါတ်များ ပါဝင်သော - ရေပျော်ဝင် ဆေးရည်များဖြင့် သွတ်သွင်းပါသည်။ အသုံးပြုသော နည်းများမှာ Vacuum pressure, pressure diffusion and double diffusion  နည်းများဖြစ်ကြသည်။ AAS ဖြင့်အသုံးပြု၍ တွေ့ရှိချက်အရ၊ သစ်မျိုး ခြားနား မှုကြောင့်ဖြစ်စေ၊ ဆေးသွင်းနည်း ကွာခြားမှုကြောင့် ဖြစ်စေ၊ သစ်သားတွင် ကြေးနီပမာဏ တူညီမှုမရှိကြောင်း တွေ့ရပါသည်။ အလေးချိန်ပေါ့သော တောင်သရက်၊ ၄င်းနောက် ရိုးသစ်နမူနာများတွင်၊ အင်သစ်ထက် ကြေးနီပါဝင်မှု များပြားခဲ့ပါသည်။ ထိုနည်းတူ  diffusion processes များသည် vaccum pressure process ထက် ကြေးနီ ဆေးရည် သွင်းနိုင်မှု ပိုမိုသည်ကို တွေ့ ရှိခဲ့ရပါသည်။ ရေပါဝင်မှု ၃၀-၄၅ ရာခိုင်နှုန်းရှိသော သစ်နမူနာများတွင် ခရိုမီယမ် ဆေးရည်သွင်းနိုင်မှုမှာ ရေပါဝင်မှု ၁၃-၁၆ ရာခိုင်နှုန်းရှိသော သစ်နမူနာများထက် ပိုမိုကြောင်း တွေ့ရှိခဲ့ရပါသည်။

# Treatability of In, Yon and Taung -Thayet with Copper, Chromium and Arsenic Water-Borne Preservatives

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## Abstract

Specimens of In ( *Dipterocarpus tuberculatus* Roxb. ), Yon ( Anogeissus acuminata Wall. ) and Taungthayet ( Swintonia floribunda Griff. ) were treated with 5 percent aqueous solution of chromated copper arsenate type C and salt solutions of copper, chromium and arsenic. Methods of treatments were vacuum-pressure, pressure-diffusion and double-diffusion processes. Atomic Absorption Spectrophotometry analysis showed significant differences in copper deposition between wood of different species, and between the methods of treatment. Copper concentration was higher in the low density woods ( Taungthayet followed by Yon ) than in the other. The diffusion processes were superior to the vacuum-pressure process in this respect. A significantly higher retention of chromium was obtained in the specimens having 30 - 45 % moisture content than those having 13 - 16 %.

# Contents

# 1. Introduction

The objective of this research project was to study the effect of several variables on the treatability of some common Burmens hardwoods with chromated copper arsenate type C ( CCA-C ). Traditionally durable woods such as teak ( *Tectona grandis* Linn.f. ), pyinkado ( iron wood ) ( *Xylia dolabriformis* Benth. ), or other suitable woods are used as required to resist decay or termite attack. Widespread utilization of wood and ever increasing export markets will eventually call for proper utilization of secondary wood species or lesser-known species. Since many of these species are susceptible to the attack by fungi and insects, proteection of wood with preservatives becomes inevitable.

Industrial preservation of wood in Burma was limited to the hot and cold bath dip treating wood woth creosote for railway sleepers until the installation of a pressure impregnation plant in 1983. This plant was designed to use Tanalith CT 106, an equivalent CCA type water-borne preservative. A trial run with In ( *Dipterocarpus tuberculatus* Roxb. ) resulted in a poor penetration of preservative into the wood ( Nyunt, unpublished 1984 ). Although CCA or equivalent Cu, Cr, and As containing preservatives have evolved for half a century, rapid development in the utilization of CCA was not achieved until 1970 in the United States ( AWPA 1982 ). Within 12 years the proportion of CCA - treated wood in wood - preserving industries in the United States had increased from 5.8 percent to 37.5 percent. In fact, cleanness of treated wood, safety in handling because of the permanently fixed chemicals in treated wood, and the most important quality, resistance of CCA - treated wood to deterioration by decay fungi and insects, dictate an increase in acceptance of treated lumber.

Requirements for selection of species for this experiment were that they should represent a wide range of permeability ( treatability ), a low durability, and , finally, species that would be available in large quantities. The three species chosen generally agree to these qualities and are regared in Burma as medium grade timbers.

# 2. Literature Review

## 2.1 Structure of wood relating to preservative treatments

Since wood is extremely nonhomogeneous, there are marked difference in treatability between species. A   greater vatiation exists in treatability between hardwood species than between softwood species due to the structural complexity of the former. Sapwood is generally more permeable than hartwood both in softwoods and hardwoods. In hardwoods, vessel are generally the most permeable longitudinal flow path. An alternative path for penetration of polarliquids is through the cell wall when it is not encrusted. In woods of high permeability, the pit paths predominate, while in woods of very low permeability the cell wall path may be the most significant ( Siau 1984 ). The pit consists of a membrane across the flow path. While the membrane of the Pinaceae of the softwoods has a porous structure called margo, the pit membrane of hardwoods has no visible opening resolvable by the electron microscope ( Schmid 1965 ). Although the pit membranes of hardwoods generally are less permeable to fluids than are those of softwoods, evidence shows flow through them is possible ( Murmanis and Chudnoff 1979; Rudman 1965 ).

Preservation of wood involves both physical and chemical processes. Wood contains chemically active functional groups. When the preservative has been distributed through the wood fixation will occur either through ( 1 ) chemical interaction between the preservative and the wood structure, ( 2 ) chemical interaction between the components of the preservative themselves, or ( 3 ) physical deposition as a result of solvent loss ( Nicholas and Preston 1984 ). Effective protection of wood against wood-deteriorating microorganiams requires the accessibility of treating chemicals to the reactive sites in the wood. Cellulose, hemicelluloses and lignin are distributed throughout the wood cell wall. An aggregation of chains of crystalline cellulose is called a crystallite, which is formed by lateral bonding of long chain cellulose by hydrogen bonds. These crystallites are initially inaccessible to warter, solutes, or enzymes. Interspersed with these crystallites are the amorphous regions which are cheimically reactive and the amorphous regions which are chemically reactive and therefore significant both for the development of decay and for preservative treatment. The macrovoids, cell lumens, and microvoids within the cell wall provide reactive sites and storage space for preservative fluids. As the molecules of polar fluids enter the cell wall, the micro fibrillar framework expands laterally. For southern pine, the change in cell wall storage volume from oven-dry to water-swollen is $0.077 \ cm^3 / cm^3$ ( Rowell 1984 ). Kellogg and Wangaard ( 1969 ) calculated the microvoid volume of 18 species to be from 1.6 to 4.8 percent. Siau ( 1984 ) derived formulae to calculate the porosity or the void volume fraction to cell wall material. Early investigations of the presence of microvoids in the cell wall were made by Stem ( 1934 ), Stemm and Hansen ( 1935 ), Bailey and Vestal ( 1937 ), and Bailey ( 1938, 1939, 1957 ). Robinson ( 1972 ) calculated the largest cell wall microvoid in basswood to be 3.2 nm allowing the flow of molecules with radius up to 1.6 nm.

## 2.2    Performance of Cu, Cr, As Preservative Treated Wood

Performance of CCA-treated wood to soft-rot attack is an area currently receiving a large amount of attention by researchers. Some related type and distribution of lignin and fixation mechanism of metallic salt on to it to the soft-rot susceptibility or resistance of CCA treated wood ( Parameswaran and Peters 1980; Butcher and Nilsson 1982; Pizzi 1982 ). Other discussed the importance of amount and distribution of copper in wood cell wall ( Drysdale at al. 1980; Butcher and Nilsson 1982; Witheridge 1983; Leightly and Norton 1983 ). Better performance of oil-borne preservative treated wood to soft-rot attack was issued by Barnacle at al. ( 1983 ). Poor performance of CCA against soft-rot was confirmed by Gray and Dickinson ( 1982 ) and they developed a new formulation of CCA by adding boron into it.

## 2.3    Copper, Chromium, and Arsenic Preservatives-Development and Fixation Theories

Water-soluable compounds of copper or arsenic have been recognized as wood preservatives for about two centuries ( Weiss 1916; Henry and Jeroski 1967 ). Improvements were made by Falk and Kamesam in 1931-33 through the addition of chromium compound into the water leachable copper and arsenic formulations. ( Indian Forest Records 1937 ). Mc Mahon et al. ( 1942 ) showed potassium

dichromate, copper sulfate, and arsenic acid by themselves did not react to form insoluble substance but these can be precipitated by adding a reducing agent such as wood. Oxide type preservatives were developed later because some water - leachable materials still remain in the wood after it had been treated with salts. The oxide type preservations are now recognized as chormated copper arsenate or CCA type preservatives.

Hager ( 1969 ) reported that there were many factors which influenced the fixation of chemicals to the wood. These included ( 1 ) concentration of the treating solution, ( 2 ) chromium content, ( 3 ) solution acidity, and ( 4 ) drying time of the treated material. He indicated that copper from a copper sulfate solution alone was possible to be fixed in pine sawdust even without the fixing agent, chromium.

After a preliminary study of a wide range of copper - chrome - arsenic formulations, Smith and Williams ( 1973 ) concluded that the most effective fungicidal action was in the region containing $CuSo_4 . 5 H_2O$ ( 35 - 40 % ), $K_2 Cr_2 O_7$ ( 40 % and above ), and $As_2 O_5 . 2 H_2 O$ ( 25-15 % or less ). They said the maximum fixation of arsenic was obtained when the Cr / As ratio ( as salts ) was 1.9 or greater. Maximum fixation of copper was not so simply defined but was approximately a Cr / Cu ( as salts ) ratio of 1.7. Fahlstrom et al. ( 1967 ) explained that when the ratio of $As_2 O_5$ to $Cr O_3$ was greater than 0.66 to 1 or if the ratio of arsenic and copper to chromium is greater than 1.5 to 1 the excess arsenic was leached out, being insufficiently fixed by the chromium. Eddie and Wallace ( 1962 ) suggested that copper not fixed by the wood reacts with the hexavalent chromium prior to its reduction by wood sugars to form fixed copper chromate. Little or no copper is fixed by the arsenic. Very little fixation of arsenic was obtained by the wood substance. When chromium is reduced from hexavalent to trivalent state it reacts readily with arsenic to form chromium arsenate, which in turn has the ability to complex with lignin and cellulose.

The products formed when CCA is reacted with wood are composed mainly of copper chromate - lignin complexes, chromium arsenate - lignin complexes, and chromium arsenate precipitates on cellulose ( Pizzi 1982 ). Pizzi ( 1982 ) stated that the majority of the copper ( 83 - 90 % ) is associated with lignin in wood and only about 10 percent of the copper in the system is bound to the chromium. Pizzi ( 1983 ) suggested, for soft-rot susceptible hardwoods, to use salt-type preservatives, rather than oxide type preservatives, at low concentration. He anticipated that by lowering the proportion of arsenic in CCA formulations higher amounts of copper will be fixed through chrome to lignin as copper chromate complexes. This will improve the resistance to soft-rot of wood species of lower lignin content, that is hardwoods as opposed to softwoods.

## 2.4 Wood Preservation Processes with Cu,Cr, As Preservatives

### 2.4.1 Pressure Processes

In the United States, pressure treated wood comprises about 98.5 percent of total wood treated ( AWPA 1982 ). Pressure treatment is also widely accepted in other industrial countries ( Wilkinson 1979 ). Creosote and pentachlorophenol in heavy oil are commonly used in the empty-cell process whereas water-borne preservatives are

rarely used. Water - borne preservative is usually applied by a full-cell process and the method is usually termed as a vacuum-pressure process.

A typical vaccum - pressure process involves a preliminary vaccum of 22 inches mercury for 15 minutes  to 1 hour, filling the cylinder with preservative followed by a pressure period for 1 to 6 hours and 125 to 200 psi ( Hunt and Garratt 1967 ). Treatment of Burmese In and Kanyin wood with CCA by vaccum-pressure process resulted in superficial penetration ( Rudduck 1982 ). A vaccum 0f 20 - 25 inches for one hour and a pressure 125-140 psi for four hours were used in this experiment. There are various modifications of pressure processes depending on individual requirements ( Wilkinson 1979 ). All of these methods require special equiment and are less common than the conventional pressure methods.

## 2.4.2  Diffusion Processes

Although pressure processes are efficient methods of wood preservation, some woods are refractory and the pressure methods are not applicable. Many hardwoods in the tropics are resistant to pressure impretgnation. Baines and Saur ( 1985 ), in their summary of the literature, suggested the use of a diffusion processes for such refractory woods. Diffusion is referred to as movement of isolated molecules of a solute through a solvent. However, the word " diffusion " is usually referred in a broader sense as spontaneous spreading of either solute on the whole solution.

One disadvantage of diffusion process is leaching of treating chemical out of the wood after it has been treated. If the chemical is fixed by another chemical in the wood by applying it subsequently, the deposit so formed becomes non-leachable. This process is known as the double-diffusion process. A series of exhaustive studies has been made by Beachler and coworkers ( Beachler 1986 ). They found deeper penetration of treating chemical into the wood by the double-diffusion treatment than a single-diffusion process. Reactions, taking place between the treating chemicals and the wood, resulted in poor penetration in the  single-diffusion processes.

Diffusion of prservative into the wood is affected by factors such as temperature, diffusion period, solution concentration, types of preservative, wood moisture content, grain direction, sapwood and heartwood, and wood density ( Tamblyn 1985 ).

Diffusion is also important for pressure treatment of wood with water-brone preservative. Tamblyn ( 1985 ) explained that in many hardwoods, in the dry sapwood the initial liqued flow under pressure is largely restricted to the vessels. Better distribution of preservative, and particularly penetration into the cell wall, is atleast partly dependent on diffusion.

## 3.    Materials and Methods

## 3.1    Wood Specimens

The wood specimens used in this experiment were of Burmese origin. three hardwood species which grow naturally in the country were used:

Dipterocarpus tuberculatus Roxb.,
*Anogeissus acuminata* Wall., and
*Swintonia floribunda* Griff.

Lumber from each species was partially air-dried, cut into thirty approximately 1 x 1 x 20 inch pieces, superfficially treated with 5% calcium hypochloride and 1% mercuric chloride to prevent decay, and packed in polyethylene bags before being sent to the United States. Upon arrival, the samples were kept in a deep freezer at -18°C until used in the experiment.

## 3.1.1. Brief Descriptions of the Woods used

### Dipterocarpus tuberculatus

This species belongs to the family Dipterocarpaceae. It grows gregariously in many parts of Burma. It is obtained in large size and is available in large quantities. The timber is relatively strong in all mechanical aspects compared with teak. It is reddish-brown in color, resinous, and hard. The density is approximately 53 pcf at 12% moisture content. It is commonly used as a medium grade structural timber. The chief disadvantage is its susceptibility to termite attack. It is classed as a moderately treatable wood. The heartwood, which is the major portion of the timber, is more resistant to treatment than the sapwood.

### Anogeissus acuminata

This species belongs to the family Combretaceae. It grows well in moist mixed deciduoud forests of Burma. It is known for its toughness which is comparable to that of hickory ( Carya spp. ) of the temperate regions. It is difficult to dry. The timber is yellowish in color with straight grain. It is used for tool handles. The density is about 55 pcf at 13.4% moisture content.

### Swintonia floribunda

It belongs to the family Anacardiaceae, and grows abundantly in evergreen forests of the lower Burma. the timber is available in large sizes and good quantity. It can be employed in cheap housing and general construction. The density is 41 pcf at 13.7% moisture content. It is greyishwhite, coarse, and soft, and is subsceptible to decay in ground contact. It is said to perform well when it has been treated with crude oil.

## 3.1.2 Preparation of specimens

In order to examine the influence of the moisture xontent on preservative treatment, one half of the specimens from each species were placed in a conditioning cabinet where the relative humidity was maintained at 80 percent. The other pieces were retained in a deep freezer. An equi;ibrium moisture content was attained after 2-3 months exposure to the condioning atmosphere. the original wood samples which were kept in the deep freezer weredesignated "0" ( original ) and those in the conditioning cabinet were designated "C" ( conditioned ), so the notation "DC" referred to a conditioned Dipterocarpus spp., "SO" referred to an original Swintonia

spp., and so on. Moisture contents of the samples were determined in accordance with ASTM D 2395-69. The average moisture contents ranged from 30 to 45 percent. for sample O's and from 13 to 16 percent for sample C's depending on the species.

Each sample stick was planed and jointed to about 2.5 x 2.5 cm square and then crosscut to yield three 3 cm, two 8 cm, and one 16 cm long pieces for preservative treatments using the following precedure: After discarding two to three centimeter long trimmings from each end, a 2 cm long piece was cut from one end to measure initial moisture content. A control specimen for atomic absorption measurement, also 2 cm long, was cut from the same end. A pair of specimen, 3 cm and 8 cm long, were cut to measure vaccum pressure impregnation. Another pair was prepared for double-diffusion treatment, and a similar set of specimens was also chosen for pressure-diffusion treatment. A list of specimens alloted to the different treatments is given in Table 3.1.

The 3 cm pieces and the 8 cm pieces were used for the determination of longitudinal and transverse penetrations respectively. To do this, all four sides of the 3 cm specimens and both ends of the longer pieces were coated with epoxy throughly to restrict the directional flow of fluid as required.

## 3.2    Preservatives

## 3.2.1 Chromated Copper Arsenate, Type C, for Vaccum-pressure Treatment.

For vaccum-pressure treatments, a 50 percent concentrated solution of Chromated Copper Arsenate Type C, trade name K-33-C, was acquired from the Osmose Wood Preserving Co. of America, Inc. Formulation of the preservative was the same as prescribed in AWPA standard P5-78. A 5 percent aqueous solution was prepared and used in the treatment. Elemental components of the preservative were analysed in accordance with AWPA Standard A 11-74.

## 3.2.2. Copper, Chromium, and Arsenic Salts for Diffusion Experiments.

Double - diffusion

A mixture of an aqueous solution of copper sulfate and arsenic acid was used as the first solution in the double-diffusion processes, which was followed by an aqueous solution of sodium chromate. The following formulation was used as suggested by Baechlor and Roth ( 1964 ) with the exception that copper sulfate was used instead of zinc sulfate because the former was claimed to be more effective against soft-rot decay. Components of the treating solution were as follows:

Copper sulfate            17.45 percent,
Arsenic acid               2.93  percent,
Sodium chromate              20.92 percent,
Water            58.70 percent.

Pressure-diffusion

Only one half the concentration of copper sulfate and arsenic acid were used in the pressure-diffusion process compared with the double-diffusion process in which

wood was pressure-impregnated with the first stage solution, copper sulfate and arsenic acid, because the pressure impregnation loads the wood with suficient chemical and a diffusion gardient is not necessary to ensure that the wood receives a suitable amount of chemical. However, the same concentration of sodium chromate was used in both processes since the rate of diffusion depends on the concentration of chemical.

## 3.3.    Methods of Treatments

Methods of treatment were essentially based on two principles, pressure impregnation and diffusion. The experiment also included a combined treatment in which both pressure and diffusion treatment were employed together. This methods is referred to as the pressure-diffusion process in contrast to the double-diffusion method. The objective of the combined process was to obtain a deeper penetration of preservative into the wood and better distribution of chemicals among the various cellular components of the wood. Weights of the specimens were taken before and after each treatment. Brief ststements of each individual treatment are described as follows.

A preliminary vaccum-pressure experiments using approximately 22 inches of Hg vaccum and 100 psi pressure indicated that specimens could not be completely impregnated with a saffranin-stained water solution. Therefore, a vaccum-pressure treating schedule based on Ruddick's research ( 1985 ) was followed here.

### 3.3.1. Vaccum-pressure Process

( a )    The retort was loaded with the specimens and was sealed tightly.
( b )    Vaccum was drawn slowly until 27.5 inches Hg in 15 min.
( c )    Vaccum at 27.5 inches Hg was maintained for 1 hour.
( d )    While under vaccum, 5 percent CCA-C was introduced into the retort.
( e )    When the retort was filled with preservative solution, it was vented to atmospheric pressure in 10 minutes.
( f )    Pressure was gradually applied into the retort until 200 psi was reached in 25 minutes.
( g )    The maximum pressure of 200 psi was maintained for 3 hr.
( h )    The pressure was gradually released to atmospheric pressure in 25 minutes.
( i )    Treated specimens were allowed to sit for 30 minutes, than taken out for weighing.

After the above treatments, the 16 cm ( 6.3 in ) long specimens were cut in the middle into two halves. One set of halves was wrapped with polyethylene sheet and was kept in a conditioned room at 20 C ( 68 F ) for further diffusion of preservative into the wood. All of the remaining treated specimens were wrapped similarly and kept in a cabinet at 40 C ( 104 F ). This period of diffusion was maintained for 10 days before the specimens were oven dried for further analyses.

### 3.3.2. Double-diffusion Process

( a )    An aqueous solution of 17.45 percent copper sulfate and 2.93 percent arsenic acid was prepared in a pyrex glass container.

( b )  Wood specimens were totally immersed in the solution with a weight placed on top of them.

( c )  The container was heated on a hot plate for 2 hours when the solution started to boil.

( d )  Boiling was allowed to continue for 1 more hour.

( e )  Heating was stopped and the solution with specimens in it was allowed to cool to room temperature, 70 F.

( f )  The specimens were taken out of the container 24 hours after the heating had stopped.

( g )  Weights of the specimens were taken.

( h )  Wood Specimens were totally immersed in 20.92 percent equeous solution of sodium chromate for 24 hours.

( i )  Wood specimens were taken out of the solution and wrapped in polyethylene sheet and were kept in a cabinet at 40 C ( 104 F ) for 10 days.

( j )  Specimens were oven-dried at 103 C for 24 hours for further analysis.

### 3.3.3.  Pressure-diffusion Process

( a )   An equeous solution of 8.75 percent copper sulfate and 1.47 percent arsenic acid was prepared in a plastic container which could be fitted into the retort.

( b )  Wood specimen were immersed in the solution and a weight was placed on top of them.

( c )  The container with the  specimens in it was put into the pressure retort which was then sealed tightly.

( d )  Vaccum was drawn through the retort and maximum vaccum of 27.5 inches Hg was reached in 25 minutes.

( e )  Maximum vaccum was maintained for 1 hour.

( f )  Vaccum was released to atmospheric pressure.

( g )  Pressure was applied gradually into the retort until maximum 200 psi was reached in 25 minutes.

( h )  Maximum pressure was maintained for 3 hours.

( i )  Pressure was released in 30 minutes.

( j )   The specimens were kept submerged in the solution for another 12 hours.

( k )  The specimens were taken out and weighted.

( l )  The specimens were immersed in the second solution, 20.92 percent aqueous sodium chromate for 24 hours.

( m )  The specimens were taken out and weighed.

( n )  The specimens were wrapped in polyethylene sheet and stored in a cabinet at 40 C ( 104 F ) for 10 days.

( o )  The specimens were then oven-dried at 103 C for 1 day for further analysis.

### 3.4.   Methods of Analysis

### 3.4.1. Retention

Retention of chemicals in the treated wood could be measured for those specimens which were pressure impregnated, but for diffusion treatments it is difficult to determine the quantity of chemical that diffuse into the wood. Retention of treating

chemicals for the vaccum-pressure method were calculated by using the following equation:

$$R = \frac{0.01\ C\ (W2 - W1)}{V}$$

Where
$R$ = retention in g/cm$^3$
$C$ = concentration of chemical in percent
$W2$ = weight of specimen after treatment in g
$W1$ = weight of specimen before treatment in g
$V$ = volume of specimen after treatment in cm$^3$.

Retention in pounds per cubic foot can be obtained by multiplying the above result by 62.4 .

## 3.4.2 Penetration

Transverse sections of treated specimens were cut in the middle for analysis of penetration of copper contained in the preservative. This qualitative analysis was made by spraying a chrome azurol S solution on the sections of wood. the solution was prepared in accordance with AWPA Standard A 3-80. Assessment was made by comparing the average depths of penetration of chemical into the specimens. Uniformity of penetration and distribution of chemicals in the wood were checked visually.

## 3.4.3 Quantitative Analysis by

Atomic Absorption Spectroscopy

Analysis of elemental components of treating chemicals in the wood was carried out by using atomic absorption spectroscopy in accordance with AWPA Standard A 11-74. As this method is most applicable to the analysis of copper and chromium and is less statisfactory for arsenic, analyses were made only for the former ones. A Perkin-Elmer 403 Atomic Absorption Spectrometer was used in the experiment.

It is desirable to analyse the amount of chemical deposited at different depths of penetration. In this experiment, however, analyses were made mainly for chemicals fixed in the core sample. Core samples were made by cutting off the outer 5 mm thickness of the specimens chosen for the analysis. The inner 13 x 13 mm square ( approximately ) was taken for the analysis. Analysis of gross samples was made only for the original *Anogeissus acuminata*.

Digestions of treated wood specimens were made by using a 2:1 mixture of concentrated hydrochloric acid and nitric acid according to the methods prescribed in Section 7.1.5.4 of AWPA Standard A 11-74.

## 3.4.4. Statistical Analysis

Data was analysed using a lotus spreadsheet to calculate means and standard deviation of the results. Analysis of variance equations were obtained from Mendenhall ( 1968 ).

## 4.        Results and Discussion

Results of the experiment were evaluated as calculated retention of the treating chemicals and as deposition and fixation of copper and chromium, analysed using atomic absorption spectroscopy. Visual assessment of the penetration of copper was made be spraying the sections of treated wood with chrome azurol S as described in AWPA A3 - 80. Statistical analyses of the effects of treatment variables were made by using an F test. the variables in the experiment were :
( a )    species of wood,
( b )    mehtods of treatments,
( c )    moisture contents,
( d )    direction of penetration of the preservative fluid
( e )    diffusion stroage tenperatures, and
( f )    gross and core depositions of preservatives metals.

## 4.1.   The Calculated  Retention

Retention of preservative in wood expressed as weight per unit volume is a common unit of measure in commercial treating plants as well as for research. For vaccum-pressure treatments, it is quite reasonable to calculate the amount of chemical deposited in the treated wood. However, there might be differences in concentration of chemicals deposited depending on the depth of penetration. Since diffusion processes rely on the mobility of molecules due to concentration gradients rather than absorption of fluid, there might be no relation between calculated retention and actual deposition of the chemicals.

Average retentions of the preservative chemicals for different variables are shown in Table 4.2. the F test indicates significant differences between species, methods of treatments, and the directions of penetration at 95 percent confidence interval. Among the variables the difference in the calculated retentions due to species variation was the most important contributor, followed by differences due to direction of penetration and methods of treatments. The variation in moisture content gave no such difference in retention. Naturally, longitudinal penetration is much greater than transverse penetration because of the structural characteristics of wood. The average retention of perservative solution for the longitudinal penetration measurement was about double that of the transverse penetration measurement. The effect of methods of treatment and that of different species will be discussed later in this chapter.

## 4.2    Penetration And Distribution of Preservative

Sections of treated specimens sprayed with prepared chemical (WPA A3-80 ) showed a visible indication of the penetration and distribution of the copper componet of the treating solution. Specimens from both diffusion treatments revealed a definitely better penetration and distribution of copper than those from the vacuum-pressure treatment. The outer 4 to 8 mm of either *Swintonia* spp. or *Anogeissue* spp. from the diffusion processes were found to be well  penetrated and the chemical uniformly distributed. The specimens of *Dipterocarpus* spp. from the vaccum-pressure process showed the poorest penetration. It appeared that distribution of chemical was more uniform in the specimens of *Anogeissus* spp. than in the others. Since this method detected only the copper component of the Cu, Cr, and As -

containing preservatives, it is not possible to predict the penetration and distribution of chromium and arsenic components because the latter were not determined in this experiment. However, copper and chromium contents were analysed using the atomic absorption spectroscopy.

## 4.3    Deposition and Fixation of Copper and Chromium

Quantitative measurements of various metals in the treated wood can be accomplished by atomic absorption spectroscopy ( AAS ). Due to time limitation, it was not possible to use AAS to analyze all combinations of species, moisture contents, flow directions, and gross versus core retentions. Representative analyses to demonstrate trends were selected as shown in Table 4.3. The results of determinations of copper and chromium contents are discussed here with respect to the following variables used in the experiment.

## 4.3.1  Species of wood.

### Copper

Samples from each species with moisture contents from 30 to 45 percent were given all three treatments and the amount of copper and chromium deposited on core sections were detected by AAS. Results were analysed statistically. The average copper content by species and related analysis of variance are shown in Table 4.4.

The species factor was analysed for both groups having initial moisture contents of 13 to 16 percent and 30 to 45 percent, treated by the vaccum-pressure and pressure-diffusion processes. The average values of copper content and the ANOVA table are shown in Table 4.5. Both analyses inidicated a difference between species at the 95 percent confidence interval. These results followed the same order of treatability as shown by the cvalculated retentions in the previous section. the greatest amount of copper was fixed in *Swintonis* spp., followed by *Anogeissus* spp. and *Dipterocarpus* spp., which agreed with the visual assessment of penetration as described previously. Since the *Dipterocarpus* spp. used in the experiment was heartwood and the other species were sapwood, it is quite natural that the former absorbed less treating solution than the others.

Although no investigation was done on the influence of wood extracives, it is suspected there might be some reaction between the chromium component of the preservatives and extractives in the *Dipterocarpus* spp. The porosity ( Siau 1984 ) as well as specific gravity are rellted to the treatability of the *Anogeissus* spp. and the *Swintonia* spp. since both of the specimens used were sapwood.

### Chromium

As with the analyses of copper concentration, the average core retentions of chromium are givenin Table 4.6. and in Table 4.7. Both F tests indicated no difference in chromium content among the species at the 95 percent confidence interval.

### 4.3.2. Methods of treatment.

## Copper

Three analyses were made to distinguish betwee the methods of treatment with respect to metal concentration. All of them indicated a significant difference between the treatments in favor of the double-diffusion process. The vaccum-pressure treatment gave the lowest result for copper retention. The average retentions and ANOVA tables are shown for the analyses of data as shown below:

1. The original specimens ( moisture contents 30-45% ) representing all species and all methods  treatment:   Table 4.4.
2. Both core and gross concentrations of metal deposited on the original ( moisture contents 30-45% ) using *Anogeissus* spp. for all methods of treatment: Table 4.8.
3. All species and both groups of moisture content ( 13-16% ) for vaccum-pressure and pressure-diffusion process: Table 4.5.

## Chromium

The same analyses were made as above for the variation of chromium content as affected by different methods of treatment. No significant difference was observed when the data were analysed at the 95 percent confidence interval. These results are presented in Tables 4.6, 4.7 and 4.9.

### 4.3.3. Moisture contents.

## Copper

Table 4.8 shows the average retention of copperr deposited on core samples for each species treated by the vaccum-pressure and pressure-diffusion processes. The analysis of variance is shown in the same table. At the 95 percent confidence interval there is no significant difference in copper retention due to original moisture content. Since analysis was made for the pressure-treated specimens, it seems unlikely that there is any difference in initial penetration of copper due to moisture variation. However, further diffusion of copper into the cells wall might be helped if there is sufficient moisture in it.

## Chromium

A significant difference in chormium content due to moisture veriations was found in each species treated by the vacuum-pressure and pressure-diffusion processes. The average chormium content and F teat are shown in Table 4.7. Those speciemens having initial moisture contents from 30 to 45 percent retained about 1.5 times more chromium than thise at 13 to 16 percent moisture content. There are two possible explantations for this difference in chromium content. First, chromium was in the second of the pressure-diffusion solutions. Second, there is greater diffusivity into water-saturated cell wall material. However, no such difference was observed for the Dipterocarpus spp. treated by the vacuum-pressure method. The average

chromium retention and test are given in Table 4.10. It is probable that there might be a species - treatment interaction which was not included in the analyasis.

### 4.3.4. Diffusion-storage temperature

### Copper and Chromium

No appreciable difference was detected in either copper or chromium content due to the variation in diffusion storage for 10 days at 20 C or 40 C. The everages and analytical data are given in Table 4.10 for copper and in Table 4.11 for chromium. Due to time limitation, analysis was made only for the Dipterocarpus spp. treated by the vacuum-pressure process.

### 4.3.5. Gross and core deposition of the chemicals.

### Copper and chromium

The statistical analysis shown in Table 4.8 indicated no significant difference in copper retention between core and gross samples of *Anogeissus acuminata.*

For core samples at the 95 percent confidence interval, chromium content howed no significant difference between the sample. However, gross sampkes retained about 1.5 times more chromium than that retained by core samples at the 90 percent confidence interval. Earlier fixation of chromium near the wood surface might be the reason for this concentration gradient. The data and analyses are shown in Table 4.9.

## 5. Conclusion

This research project represents a small but basic portion of wood preservation. Valuable information learned from the project incldes:

( 1 )  variation between species of wood, direction of flow of preservative, and methods of treatment exerted greater influence on treatability of wood than the other vatiables,

( 2 )  Generally, wood of low specific gravity ( therefore more void space ) should accommodate more preservative in it. However, one should realize that not all porous sturctures are permeable unless such voids are interconnected. Therefore, recommendations on any species regrding its treatability should not be given without prior experimention on permeability of that particular wood species.

( 3 )  the diffusion treatments provide greater retention of copper, probably at the expense of higher concentration of treating solution, than the vacuum-pressure treatment. However, the proportion of chromium deposition was higher in the vacuum-pressure treatment than in the other.

( 4 )  Although longitudinal penetration is far greater than transverse penetrstion, this information may not be useful for length to thickness of most of the wood being treated is too large. However, treatments such as incising could take advantage of the greater logitudinal penetration.

( 5 )   Moisture content at the fiber saturation point or a little higher is essential for diffusion of chemicals in the wood.

## 6.   Recommendations

The this research project, attention has been given to the retention of treating chemicals in the wood. In fact, this should be the basic requirement for wood preservation. Further investigation is still lacking on the permanence of fungitoxicants in wood.

Numerous references have related the effect of water-borne preservatives on chemical properties of wood. Generally, a greater loss in mechanical properties of wood treated with water-borne preservative could be expected than that treated with oil-borne preservatives. Toughness is the one most severely affected by preservative treatment. Effects of preservatives treatments on physical and mechanical properties of Burmese woods should be studied.

A complete study in wood preservation required testing treated wood witth various agents of wood deterioration, especially decay fungi, termites, and marine organisms. A combination  of the warm humid climate of the tropics and lignin-deficient hardwoods provides a favorable situation for the development of soft-rot fungi. Many researchers are still paying attention to slove this problem.

Conventional CCA formulations have been claimed to be not as effective for hardwoods as for softwoods. Addition of boron in CCA formulations gives encouraging results in this respect. Some workers have tried CCA in combination with ammoniacal compounds, in which swelling of the cell wall provides more room for penetration of CCA preservative.

For centuries, Burma has depended on its forest resources for international trade. Domestic use of wood ranges from firewood to plywood and construction lumber. Both domestic consumption as well as exporting is increasing at an alarming rate, yet proper utilization of wood is left far behind the development of the other sectors of the nation. The rate of replenishing the cut-over forest area with fast growing tree species is encouraging. However, it seems unwise to use wood without giving it any protection. A simple diffusion treatment will greatly extend the service life of wood. This simple treatment will save harvesting of extensive forest areas, provide more wood for domestic consumption, and expand the foreign trade.

Table 3.1.  A List of specimens allotted to three treatments.

| Treatment | Specimen ID | Numbers | length cm |
|---|---|---|---|
| Vacuum-pressure | DC7 | 10 | 3 |
| | AC7 | 9 | 3 |
| | SC7 | 11 | 3 |
| | DC3 | 10 | 16 |
| | AC3 | 9 | 16 |
| | SC3 | 11 | 16 |
| | DO5 | 10 | 3 |
| | AO5 | 9 | 3 |
| | SO5 | 9 | 3 |
| | DO8 | 10 | 16 |
| | AO8 | 9 | 16 |
| | SO8 | 9 | 16 |
| Double - diffusion | DC6 | 5 | 3 |
| ( boiling in 1st.solution ) | AC6 | 5 | 3 |
| | SC6 | 5 | 3 |
| | DC1 | 5 | 8 |
| | AC1 | 5 | 8 |
| | SC1 | 5 | 8 |
| | DO3 | 10 | 3 |
| | AO3 | 9 | 3 |
| | SO3 | 9 | 3 |
| | DO7 | 10 | 8 |
| | AO7 | 9 | 8 |
| | SO7 | 9 | 8 |
| Pressure - diffusion | DC1 | 5 | 8 |
| | AC1 | 4 | 8 |
| | SC1 | 6 | 8 |
| | DC6 | 5 | 3 |
| | AC6 | 4 | 3 |
| | SC6 | 6 | 3 |
| | D04 | 10 | 3 |
| | A04 | 9 | 3 |
| | S04 | 9 | 3 |
| | DO6 | 10 | 8 |
| | A06 | 9 | 8 |
| | S06 | 9 | 8 |
| Total | | 288 | |

Table 4.2a    Average retention of preservative for different variables.

| Variable | Retention mg/cm$^3$ |
|---|---|
| Average for vacuum-pressure process | 0.304 |
| Average for double-diffusion process | 0.250 |
| Average for pressure-diffusion process | 0.329 |
| | |
| Average for *Dipterocarpus tuberculatus* | 0.147 |
| Average for *Anogeissus acuminata* | 0.325 |
| Average for *Swintonia floribunda* | 0.411 |
| | |
| Average for longitudinal penetration | 0.367 |
| Average for transverse penetration | 0.222 |
| | |
| Average for conditioned specimens | 0.305 |
| Average for original MC specimens | 0.284 |

Table 4.2b.   Statistical analysis of mean retentions.

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Treatment | 2 | 0.039 | 0.020 | 6.98 |
| Species | 2 | 0.436 | 0.218 | 77.57 |
| Direction | 1 | 0.188 | 0.188 | 67.02 |
| Moisture | 1 | 0.004 | 0.004 | 1.38 |
| Error | 29 | 0.081 | 0.003 | |
| | | | | |
| Total | 35 | | | |

Table 4.3a    Atomic absorption analysis of copper in treated speciems.

| Sample No. | Degree of dilution | Absorbance | Back ground Abs. | Net Abs | Cu in Wood mg / g | Mean Cu mg / g | Std Dev Cu |
|---|---|---|---|---|---|---|---|
| | | | CORE RETENTION ANALYSIS | | | | |
| Vacuum - pressure treatment with CCA-C and storage at 40 C | | | | | | | |
| DC3-2 | 400 | 0.106 | 0.006 | 0.100 | 0.2310 | | |
| DC3-3 | 400 | 0.280 | 0.006 | 0.274 | 0.6337 | 0.385 | 0.178 |
| DC3-9 | 400 | 0.131 | 0.006 | 0.125 | 0.2889 | | |
| DO8-2 | 400 | 0.197 | 0.006 | 0.191 | 0.4416 | | |
| DO8-7 | 400 | 0.117 | 0.006 | 0.111 | 0.2565 | 0.584 | 0.341 |
| DO8-9 | 400 | 0.462 | 0.006 | 0.456 | 1.0549 | | |
| AC3-2 | 400 | 0.340 | 0.005 | 0.335 | 0.7748 | | |
| AC3-3 | 400 | 0.020 | 0.005 | 0.015 | 0.0343 | 0.341 | 0.315 |
| AC3-6 | 400 | 0.098 | 0.005 | 0.093 | 0.2148 | | |
| AO8-3 | 400 | 0.154 | 0.005 | 0.149 | 0.3444 | | |
| AO8-5 | 400 | 0.159 | 0.005 | 0.154 | 0.3560 | 0.661 | 0.440 |
| AO8-8 | 400 | 0.560 | 0.005 | 0.555 | 1.2840 | | |
| SC3-1 | 400 | 0.161 | 0.006 | 0.155 | 0.3583 | | |
| SC3-2 | 400 | 0.083 | 0.006 | 0.077 | 0.1778 | 0.220 | 0.100 |
| SC3-5 | 400 | 0.060 | 0.006 | 0.054 | 0.1254 | | |
| SO8-4 | 400 | 0.081 | 0.006 | 0.075 | 0.1731 | | |
| SO8-7 | 400 | 0.171 | 0.006 | 0.165 | 0.3814 | 0.534 | 0.373 |
| SO8-8 | 400 | 0.459 | 0.006 | 0.453 | 1.0479 | | |
| Vacuum - pressure treatment with CCA-C and storage at 20 C | | | | | | | |
| DC3-2 | 400 | 0.174 | 0.006 | 0.168 | 0.3884 | | |
| DC3-3 | 400 | 0.275 | 0.006 | 0.269 | 0.6221 | 0.432 | 0.140 |
| DC3-9 | 400 | 0.130 | 0.006 | 0.124 | 0.2865 | | |
| DO8-2 | 400 | 0.065 | 0.006 | 0.059 | 0.1361 | | |
| DO8-7 | 400 | 0.189 | 0.006 | 0.183 | 0.4231 | 0.665 | 0.557 |
| DO8-9 | 400 | 0.626 | 0.006 | 0.620 | 1.4344 | | |
| Double-diffusion treatment with salts Cu. Cr, As | | | | | | | |
| DO7-2 | 1200 | 0.362 | 0.006 | 0.356 | 2.2166 | | |
| DO7-7 | 1200 | 0.518 | 0.006 | 0.512 | 3.1659 | 4.042 | 1.949 |
| DO7-9 | 4800 | 0.269 | 0.006 | 0.263 | 6.7435 | | |
| AO7-3 | 4800 | 0.304 | 0.005 | 0.299 | 7.6380 | | |
| AO7-5 | 4800 | 0.456 | 0.005 | 0.451 | 11.4150 | 11.258 | 2.893 |
| AO7-8 | 4800 | 0.589 | 0.005 | 0.584 | 14.7199 | | |
| SO7-4 | ? | 0.368 | 0.006 | 0.362 | 9.2035 | | |
| SO7-7 | 4800 | 0.316 | 0.006 | 0.310 | 7.9113 | 12.318 | 5.344 |
| SO7-8 | 4800 | 0.796 | 0.006 | 0.790 | 19.8387 | | |

Table 4.3a.     Atomic absorption analysis of copper in treated specimens.

| Sample No. | Degree of Dilution | Absorb-ance | Background Abs. | Net Abs. | Cu in Wood mg/g | Mean Cu mg/g | Std Dev Cu |
|---|---|---|---|---|---|---|---|
| **Pressure-diffusion treatment with salts of Cu, Cr, As.** | | | | | | | |
| DC1-6 | 400 | 0.044 | 0.006 | 0.038 | 0.0875 | | |
| DC1-8 | 400 | 0.093 | 0.006 | 0.087 | 0.2009 | 0.318 | 0.250 |
| DC1-9 | 400 | 0.294 | 0.006 | 0.288 | 0.6661 | | |
| | | | | | | | |
| DO6-2 | 400 | 0.430 | 0.006 | 0.424 | 0.9808 | | |
| DO6-7 | 400 | 0.528 | 0.006 | 0.522 | 1.2076 | | |
| DO6-8 | 400 | 0.620 | 0.006 | 0.614 | 1.4205 | 1.239 | 0.168 |
| DO6-9 | 400 | 0.589 | 0.006 | 0.583 | 1.3488 | | |
| | | | | | | | |
| AC1-6 | 1200 | 0.339 | 0.005 | 0.334 | 2.0827 | | |
| AC1-7 | 1200 | 0.450 | 0.005 | 0.445 | 2.7582 | 3.489 | 1.536 |
| AC1-9 | 4800 | 0.223 | 0.005 | 0.218 | 5.6253 | | |
| | | | | | | | |
| AO6-3 | 1200 | 0.411 | 0.005 | 0.406 | 2.5209 | | |
| AO6-5 | 1200 | 0.739 | 0.005 | 0.734 | 4.5168 | | |
| AO6-7 | 4800 | 0.302 | 0.005 | 0.297 | 7.5883 | 5.212 | 1.897 |
| AO6-8 | 4800 | 0.247 | 0.005 | 0.242 | 6.2216 | | |
| | | | | | | | |
| SC1-7 | 4800 | 0.474 | 0.006 | 0.468 | 11.8374 | | |
| SC1-9 | 1200 | 0.675 | 0.006 | 0.669 | 4.1212 | 6.379 | 3.879 |
| SC1-10 | 1200 | 0.520 | 0.006 | 0.514 | 3.1780 | | |
| | | | | | | | |
| SO6-4 | 4800 | 0.393 | 0.006 | 0.387 | 9.8247 | | |
| SO6-7 | 4800 | 0.359 | 0.006 | 0.353 | 8.9798 | | |
| SO6-8 | 4800 | 0.378 | 0.006 | 0.372 | 9.4520 | 9.129 | 0.585 |
| SO6-9 | 4800 | 0.330 | 0.006 | 0.324 | 8.2592 | | |
| **GROSS RETENTION ANALYSIS** | | | | | | | |
| **Vacuum - pressure treatment with CCA-C and storage at 40C** | | | | | | | |
| AO8-2 | 400 | 0.489 | 0.005 | 0.484 | 1.1196 | | |
| A08-6 | 400 | 0.162 | 0.005 | 0.157 | 0.3629 | 0.741 | 0.378 |
| | | | | | | | |
| **Double-diffusion treatment with salts of Cu, Cr, As** | | | | | | | |
| AO7-2 | 4800 | 0.573 | 0.005 | 0.568 | 14.3223 | | |
| AO7-6 | 1200 | 0.520 | 0.005 | 0.515 | 3.1841 | 8.753 | 5.569 |
| | | | | | | | |
| **Pressure-diffusion treatment with salts of Cu, Cr, As** | | | | | | | |
| AO6-2 | 4800 | 0.303 | 0.005 | 0.298 | 7.6132 | | |
| AO6-6 | 1200 | 0.557 | 0.005 | 0.552 | 3.4093 | 5.511 | 2.102 |

Table  4.3b    Atomic absorption analysis of copper in treated speciems.

| Sample No. | Degree of dilution | Absorbance | Back ground Abs. | Net Abs | Cu in Wood mg / g | Mean Cu mg / g | Std Dev Cu |
|---|---|---|---|---|---|---|---|
| CORE RETENTION ANALYSIS | | | | | | | |
| Vacuum - pressure treatment with CCA-C and storage at 40 C | | | | | | | |
| DC3-2 | 400 | 0.181 | 0.006 | 0.175 | 0.7388 | | |
| DC3-3 | 400 | 0.383 | 0.006 | 0.377 | 0.7383 | 1.135 | 0.434 |
| DC3-9 | 400 | 0.219 | 0.006 | 0.213 | 0.9269 | | |
| DO8-2 | 400 | 0.290 | 0.006 | 0.284 | 1.2782 | | |
| DO8-7 | 400 | 0.189 | 0.006 | 0.183 | 0.7784 | 1.387 | 0.547 |
| DO8-9 | 400 | 0.457 | 0.006 | 0.451 | 2.1044 | | |
| AC3-2 | 400 | 0.395 | 0.003 | 0.392 | 1.8125 | | |
| AC3-3 | 400 | 0.032 | 0.003 | 0.029 | 0.0165 | 1.667 | 0.973 |
| AC3-6 | 400 | 0.170 | 0.003 | 0.167 | 0.6993 | | |
| AO8-3 | 400 | 0.246 | 0.003 | 0.243 | 1.0753 | | |
| AO8-5 | 400 | 0.208 | 0.003 | 0.205 | 0.8873 | 1.667 | 0.973 |
| AO8-8 | 400 | 0.643 | 0.003 | 0.640 | 3.0396 | | |
| SC3-1 | 400 | 0.276 | 0.011 | 0.265 | 1.1842 | | |
| SC3-2 | 400 | 0.162 | 0.011 | 0.151 | 0.6201 | 0.843 | 0.245 |
| SC3-5 | 400 | 0.183 | 0.011 | 0.172 | 0.7240 | | |
| SO8-4 | 400 | 0.174 | 0.011 | 0.163 | 0.6795 | | |
| SO8-7 | 400 | 0.357 | 0.011 | 0.346 | 1.5849 | 1.496 | 0.633 |
| SO8-8 | 400 | 0.486 | 0.011 | 0.475 | 2.2232 | | |
| Vacuum - pressure treatment with CCA-C and storage at 20 C | | | | | | | |
| DC3-2 | 400 | 0.289 | 0.006 | 0.283 | 1.2732 | | |
| DC3-3 | 400 | 0.392 | 0.006 | 0.386 | 1.7828 | 1.357 | 0.319 |
| DC3-9 | 400 | 0.237 | 0.006 | 0.231 | 1.0159 | | |
| DO8-2 | 400 | 0.128 | 0.006 | 0.122 | 0.4766 | | |
| DO8-7 | 400 | 0.319 | 0.006 | 0.313 | 1.4216 | 1.407 | 0.754 |
| DO8-9 | 400 | 0.501 | 0.006 | 0.495 | 2.3222 | | |
| Double-diffusion treatment with salts Cu. Cr, As | | | | | | | |
| DO7-2 | 400 | 0.262 | 0.006 | 0.256 | 1.1396 | | |
| DO7-7 | 400 | 0.258 | 0.006 | 0.252 | 1.1198 | 1.527 | 0.562 |
| DO7-9 | 400 | 0.501 | 0.006 | 0.495 | 2.3222 | | |
| AO7-3 | 400 | 0.424 | 0.003 | 0.421 | 1.9650 | | |
| AO7-5 | 400 | 0.080 | 0.003 | 0.077 | 0.2540 | 1.060 | 0.698 |
| AO7-8 | 400 | 0.225 | 0.003 | 0.222 | 0.9714 | | |
| SO7-4 | 400 | 0.140 | 0.011 | 0.129 | 0.5112 | | |
| SO7-7 | 400 | 0.071 | 0.011 | 0.060 | 0.1698 | 0.849 | 0.733 |
| SO7-8 | 400 | 0.414 | 0.011 | 0.403 | 1.8670 | | |

Table 4.3b.    Atomic  absorption analysis of chromium in treated specimens.

| Sample | Degree of Cr Dilution | Absorbance | Background Abs. | Net Abs. | Cr in Wood mg/g | Mean in wood mg/g | Std. Dev Cu |
|---|---|---|---|---|---|---|---|
| Pressure-diffusion treatment with salts of Cu, Cr, As. | | | | | | | |
| DC1-6 | 400 | 0.053 | 0.006 | 0.047 | 0.1055 | | |
| DC1-8 | 400 | 0.074 | 0.006 | 0.068 | 0.2094 | 0.181 | 0.054 |
| DC1-9 | 400 | 0.078 | 0.006 | 0.072 | 0.2292 | | |
| | | | | | | | |
| DO6-2 | 400 | 0.273 | 0.006 | 0.267 | 1.1940 | | |
| DO6-7 | 400 | 0.236 | 0.006 | 0.230 | 1.0110 | | |
| DO6-8 | 400 | 0.299 | 0.006 | 0.293 | 1.3227 | 1.167 | 0.112 |
| DO6-9 | 400 | 0.262 | 0.006 | 0.256 | 1.1396 | | |
| | | | | | | | |
| AC1-6 | 400 | 0.238 | 0.003 | 0.235 | 1.0357 | | |
| AC1-7 | 400 | 0.166 | 0.003 | 0.163 | 0.6795 | 1.225 | 0.540 |
| AC1-9 | 400 | 0.425 | 0.003 | 0.422 | 1.6910 | | |
| | | | | | | | |
| AO6-3 | 400 | 0.100 | 0.003 | 0.097 | 0.3529 | | |
| AO6-5 | 400 | 0.487 | 0.003 | 0.484 | 2.2677 | | |
| AO6-7 | 400 | 0.415 | 0.003 | 0.412 | 1.9115 | 1.674 | 0.774 |
| AO6-8 | 400 | 0.466 | 0.003 | 0.463 | 2.1638 | | |
| | | | | | | | |
| SC1-7 | 400 | 0.495 | 0.011 | 0.484 | 2.2677 | | |
| SC1-9 | 400 | 0.139 | 0.011 | 0.128 | 0.5063 | 1.044 | 0.867 |
| SC1-10 | 400 | 0.109 | 0.011 | 0.098 | 0.3579 | | |
| | | | | | | | |
| SO6-4 | 400 | 0.204 | 0.011 | 0.193 | 0.8279 | | |
| SO6-7 | 400 | 0.249 | 0.011 | 0.238 | 1.0506 | | |
| SO6-8 | 400 | 0.479 | 0.011 | 0.468 | 2.1886 | 1.305 | 0.523 |
| SO6-9 | 400 | 0.270 | 0.011 | 0.259 | 1.1545 | | |
| | | | GROSS RETENTION ANALYSIS | | | | |
| Vacuum - pressure treatment with CCA-C and storage at 40C | | | | | | | |
| AO8-2 | 400 | 0.489 | 0.003 | 0.486 | 2.2776 | | |
| A08-6 | 400 | 0.374 | 0.003 | 0.371 | 1.7086 | 1.993 | 0.285 |
| | | | | | | | |
| Double-diffusion treatment with salts of Cu, Cr, As | | | | | | | |
| AO7-2 | 400 | 0.509 | 0.003 | 0.506 | 2.3766 | | |
| AO7-6 | 400 | 0.466 | 0.003 | 0.463 | 2.1638 | 2.270 | 0.106 |
| Pressure-diffusion treatment with salts of Cu, Cr, As | | | | | | | |
| AO6-2 | 400 | 0.523 | 0.003 | 0.520 | 2.4458 | | |
| AO6-6 | 400 | 0.513 | 0.003 | 0.510 | 2.3964 | 2.421 | 0.025 |

Table 4.4a     Average retention of copper for all species at original moisture contents.

| Variable | Retention mg / g |
|---|---|
| Average for vacuum-pressure process | 0.593 |
| Average for double-diffusion process | 9.210 |
| Average for pressure-diffusion process | 5.006 |
| Average for *Dipterocarpus tuberculatus* | 1.935 |
| Average for *Anogeissus acuminata* | 5.451 |
| Average for *Swintonia floribunda* | 7.424 |

Table 4.4b.    Statistical analysis for copper retentions.

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Species | 2 | 139.12 | 69.56 | 168.0 |
| Treatment | 2 | 334.19 | 167.1 | 403.6 |
| Replications | 2 | 51.07 | 25.53 | 61.7 |
| Error | 20 | 8.28 | 0.414 | |
| Total | 26 | | | |

Table 4.5a    Copper retention for vacuum-pressure and pressure-diffusion treatments at two moisture contents.

| Variable | Retention mg / g |
|---|---|
| Average for vacuum-pressure | 0.454 |
| Average for diffusion-pressure | 4.145 |
| Average for *Dipterocarpus tuberclatus* | 0.617 |
| Average for *Anogeissus acuminata* | 2.617 |
| Average for *Swintonia floribunda* | 2.138 |
| Average for conditioned specimens | 1.855 |
| Average for original moisture content | 2.744 |
| Average for replicate 1 | 2.471 |
| Average for replicate 2 | 1.969 |
| Average for replicate 3 | 2.459 |

Table 4.5b.      Statistical analysis of copper retentions.

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Treatment | 1 | 122.59 | 122.59 | 24.5 |
| Species | 2 | 74.84 | 37.52 | 7.5 |
| Moisture content | 1 | 7.12 | 7.12 | 1.424 |
| Replications | 2 | 1.97 | 0.99 | 0.198 |
| Error | 29 | 145.06 | 5.0 | |
| Total | 35 | | | |

Table 4.6a.      Chromium analysis for three species and three treatments

| Variable | Retention mg/g |
|---|---|
| Average for vacuum-pressure | 1.517 |
| Average for double diffusion | 1.146 |
| Average for pressure-diffusion | 1.355 |
| Average for *Dipterocarpus tuberculatus* | 1.343 |
| Average for *Anogeissus acuminata* | 1.441 |
| Average for *Swintonia floribunda* | 1.234 |

Table 4.6b.      Statistical analysis for chromium analysis.

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Species | 2 | 0.194 | 0.097 | 0.26 |
| Treatment | 2 | 0.623 | 0.312 | 0.84 |
| Replications | 2 | 5.94 | 2.968 | 8.0 |
| Error | 20 | 7.42 | 0.371 | |
| Total | 26 | | | |

Table 4.7a.      Average retention of chromium with respect to species, moisture content and methods of treatment.

| Variable | Retention mg/g |
|---|---|
| Average for vacuum-pressure treatments | 1.228 |
| Average for Pressure-diffusion treatments | 1.086 |
| Average for *Dipterocarpus tuberculatus* | 0.954 |
| Average for *Anogeissus acuminata* | 1.333 |
| Average for *Swintonia floribunda* | 1.185 |
| Average for conditioned specimens | 0.878 |
| Average for original moisture contents | 1.436 |
| Average for replication 1 | 1.046 |
| Average for replication 2 | 0.946 |
| Average for replication 3 | 1.480 |

Table 4.7b.    Statistical analysis for chromium retentions.

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Treatment | 1 | 0.183 | 0.183 | 0.39 |
| Species | 2 | 0.871 | 0.436 | 0.93 |
| Moisture content | 1 | 2.797 | 2.797 | 5.97 |
| Replications | 2 | 1.933 | 0.967 | 2.06 |
| Error | 29 | 13.576 | 0.468 | |
| | | | | |
| Total | 35 | | | |

Table 4.8a.    Copper contents between treatments and positions.

| Variable | Retention mg/g |
|---|---|
| Average for vacuum-pressure treatment | 0.701 |
| Average for double-diffusion treatment | 10.006 |
| Average for pressure-diffusion treatment | 5.362 |
| | |
| Average for core samples | 8.565 |
| Average for gross samples | 7.503 |

Table 4. 8b.  Statistical analysis of copper content in the treated wood.

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Treatments | 2 | 86.57 | 43.29 | 35.6 |
| Blocks | 1 | 0.75 | 0.75 | 0.62 |
| Error | 2 | 2.43 | 1.22 | |
| | | | | |
| Total | 5 | | | |

Table 4.9a    Chromium contents between treatments and between positions.

| Variable | Retention mg / g |
|---|---|
| Average for vacuum-pressure treatments | 1.830 |
| Average for double-diffusion treatments | 1.665 |
| Average for pressure-diffusion treatments | 2.048 |
| | |
| Average for core specimens | 2.200 |
| Average for gross specimens | 3.342 |

Table 4.9b      Statistical analysis of chromium content in the treated wood.

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Treatments | 2 | 0.147 | 0.074 | 0.75 |
| Blocks | 1 | 0.869 | 0.869 | 0.89 |
| Error | 2 | 0.195 | 0.098 | |
| Total | 5 | | | |

Table 4.10a.   Chromium contents in CCA vacuum-pressure treated wood stored for 10 days at 20 C and 40C.

| Variable | Retention mg / g |
|---|---|
| Average for 20C storage | 1.382 |
| Average for 40C storage | 1.261 |
| Average for original moisture contents | 1.397 |
| Average for conditioned specimens | 1.246 |
| Average for Replication  1 | 0.942 |
| Average for Replication  2 | 0.430 |
| Average for Replication  3 | 1.592 |

Table 4.10b.   Statistical analysis of chromium content.

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Temperature | 1 | 0.044 | 0.044 | 0.2 |
| Moisture content | 1 | 0.068 | 0.068 | 0.3 |
| Replications | 2 | 0.918 | 0.459 | 1.24 |
| Error | 7 | 2.582 | 0.369 | |
| Total | 11 | | | |

Table 4.11a.   Copper contents in CCA diffusion-treated wood stored for 10 days at 20C and 40C.

| Variable | Retention mg / g |
|---|---|
| Average for 20C storage | 0.548 |
| Average for 40C storage | 0.484 |
| Average for original moisture contents | 0.624 |
| Average for conditioned specimens | 0.408 |
| Average for Replication  1 | 0.299 |
| Average for Replication  2 | 0.484 |
| Average for Replication  3 | 0.766 |

Table 4.11b.   Statistical analysis of copper contents.

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Temperature | 1 | 0.012 | 0.012 | 0.09 |
| Moisture content | 1 | 0.140 | 0.140 | 0.99 |
| Replications | 2 | 0.442 | 0.221 | 1.56 |
| Error | 7 | 0.992 | 0.142 | |
| | | | | |
| Total | 11 | | | |

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