PRESSURE AND NON PRESSURE PRESERVATION METHODS FOR RUBBER (*Hevea brasiliensis*) WOOD TREATMENT BY BORON PRESERVATIVES

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Thesis submitted in partial fulfillment for the degree of Bachelor of Science in Forestry and Environment Science

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DECLARATION

“The work described in this thesis was carried out by me at University of Sri Jayewardenepura, under the supervision of Prof. H. S.Amarasekera, and a report on this has not been submitted to any University for another degree.”

………………………………… ……………………………………..

Date Udya Madhavi Abeysinghe

SUPERVISORS' NOTE

This is to certify the work here submitted was carried out by the candidate herself. It is now approved for submission.

………………………………   ……………………………………..

Date

Supervisor,
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Head of the Department,
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Nugegoda,
Sri Lanka.

To my parents,

Who guided me to discern the truthful from the untruthful: The essence from the non-essence

I gratefully dedicate this book

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ABRIVATION

Adj. Ms	Adjusted mean square
ANOVA	Analysis of variance
AAS	Atomic Absorption Spectrophotometry
°C	Celsius
cm	Centimeter
Conc.	Concentrated
CCA	Copper chrome arsenate
CCB	Copper chrome borate
m^3	Cubic meter
DF	Degree of freedom
EMC	Equilibrium moisture content
FSP	Fibre saturation point
Fig.	Figure
FAO	Food and Agricultural Organization
g	gram
ha	Hectare
hr	Hour
ICP	Inductively coupled plasma
Kg	Kilogram
L	Littre
MS	Mean square
ml	Milliliter
mm	Millimeter
HNO_3	Nitric Acid
ppm	Parts per million
%	Percentage
H_2SO_4	Sulfuric Acid
SS	Sum of square
TRADA	Timber Research and Development Association

Pressure and non pressure preservation methods for rubber (*Hevea brasiliensis*) wood treatment by boron preservatives

Abstract

Wood is susceptible for insect and microorganism attack, though heartwood of some species is naturally durable. Rubber is cultivating as a plantation species in Sri Lanka, and it is the second largest plantation crop in the country (covers 124,000 ha). Rubber wood is less durable. Preservative application can make rubber wood more durable. Several timber preservation methods are used in Sri Lanka, but rubber wood treatment is mainly done using traditional boron diffusion treatment, which was invented in Sri Lanka in 1964. Vacuum pressure impregnation method for timber treatment is not very common for rubber wood treatment in Sri Lanka. Boron is a better preservative compared to other preservative chemicals as it does not cause discoloration of treated wood. Aim of this study is to investigate effectiveness of rubber wood treatment by boron preservatives by different treatment methods.

40.63 cm * 10.16 cm * 1.60 cm (16 inches * 4 inches * 0.63 inches) size rubber wood samples were treated by boron preservative by four different timber treatment methods. For each method, two moisture contents of wood were tested (dry and green) and two boron solution strengths were used (8% and 12%). Timber treatment methods used were dip diffusion, hot and cold open tank method, steam cold quench method and vacuum pressure impregnation method.

In dip diffusion method, timber samples were dipped in boron solution for 24 hours and thereafter these were block stacked for 1 hour. In hot and cold open tank method, timber samples were submerged in 80 ºC hot boron solution and temperature was maintained for 4 hours and allows them to cool within the same solution for 12 hours. In steam cold quench method, timber samples were steamed for 4 hours and immediately transferred them in to cold boron solution and allow them to cool for 12 hours. Timber samples were treated by vacuum pressure impregnation method as the 4th treatment method.

Effectiveness of each method was measured by chemical retention, chemical penetration and termite test. Chemical retention was measured by the weight difference before and after the treatment, chemical penetration was measured using Atomic Absorption Spectrometer and effectiveness against termite test was measured by the sandwich method. Cost of treatment of one cubic meter of rubber wood was also calculated for diffusion, hot and cold open tank method and vacuum pressure impregnation method.

Vacuum pressure impregnation method was found to be the best method for preservation of dry (12% Moisture content) rubber wood, but it is less effective in green condition. Hot and cold open tank method was the best method for preservation of green rubber wood. All treatment methods are more effective in dry condition than green condition except dip diffusion method. Effectiveness increased with the solution strength. Termite resistance was highest in Vacuum pressure impregnated dry timber. Cost of treatment of one cubic meter of rubber wood by vacuum pressure impregnation was the highest then hot and cold open tank method and diffusion method gave the lowest treatment cost. If high retention and penetration are needed vacuum pressure impregnation method should be use for the dry rubber wood treatment. Although retention and penetration is lower in Hot and cold open tank method and steam cold quench method compared with vacuum pressure impregnation method, those methods can be recommended for low hazardous situation of timber use such as indoor applications.

Key words: preservation, boron, solution strength, moisture contents, chemical retention, chemical penetration, termite test

CHAPTER ONE: INTRODUCTION

1.1 General introduction

Wood is made up of biodegradable materials such as cellulose, lignin, carbohydrate; it is susceptible for insect and other microorganism attack. Wood species contain very high amount of water, making wood is more favorable for the foreign organisms attack. This makes a main drawback for the usage of wood. Therefore wood preservation methods are used. Wood preservation is practicing from hundreds of years, that increases the life time of the wood products and decrease the amount of wood replacement. Some species have high durability than others such as teak. Many of them are moderately durable and some timber species are more susceptible for insect and microorganism attack.

Rubber (*Hevea brasiliensis*) is an introduced species to Sri Lanka more than 100 years ago, now widely spread over the wet zone and certain regions in intermediate zone. Rubber is cultivating as a plantation species mainly for latex and as a byproduct rubber wood is generated. There are 124,000 ha of rubber plantations and around 10% of those plantations are uprooting yearly. In early days there was no demand for rubber wood for construction and furniture manufacturing and people use rubber wood only as fuel wood. The demand for wood is increasing and availability of natural durable species is becoming lower. In this situation low strength less durable timber comes on to stage such as rubber. Rubber is less durable timber and it is more susceptible for insect and micro organism attack. The use of rubber wood with preservative application can be more economical. The durability of rubber wood is increased by using preservatives then preferability to this timber will be increased.

Rubber plantations produce an average of about 0.24 m^3 of peeler logs and 65 m^3 of sawn logs for every hectare felled at the end of a 25 year economic lifespan. It can be projected that rubber plantations have supplied approximately 266000 m^3 of sawn logs in 2007(Ruwanpathirana, 2011).

The major problem in rubber wood utilization is its low durability in natural state; rubber wood is highly susceptible to insect and fungal infestations due to its high starch content.

Additionally, the moisture content of timber provides conductive conditions for the entry and establishment of the fungus (Khurshid, 2005).

There are number of preservatives and preservation methods practicing in various countries. Earlier people used several natural preservatives such as mud, animal blood, animal glue and various plant extractions. However now people tend to use more synthetic preservative chemicals over those natural preservatives because of their superior qualities like easy to use, easy to produce and, high protection against deterioration. At present CCB and boron are popular preservatives that using for the rubber wood treatment in Sri Lanka. Treatment of rubber wood using boron preservatives was first invented in Sri Lanka in 1964 (Perera, 1995).

Numbers of preservation methods are using by people for the preservative application like dip diffusion, diffusion in cold solution, diffusion in hot solution, hot and cold open tank method. Novel innovations are arising day to day in this field in order to have maximum protection for the wood by preservative applications. Vacuum pressure impregnation method is not common preservation method in Sri Lanka but it is popular in all over the world.

1.2 Background to the study

Rubber wood treatment by boron preservative is practicing since many decays in Sri Lanka using traditional timber preservation methods like dip diffusion. Vacuum pressure impregnation method for the rubber wood treatment is currently practicing in few commercial timber treating companies but the preservative that they are using is CCB. Finlay Rentokil Ceylon (Pvt) Ltd one of the pioneer company in the wood treatment in Sri Lanka and it has conducted CCB treatment of timber using Vacuum pressure impregnation method. They have recently started treatment of rubber wood using boron preservatives by Vacuum pressure impregnation method and this is the first invented in Sri Lanka. In this study the effectiveness of rubber wood treatment by boron preservatives by vacuum pressure impregnation method is compared with other preservation methods diffusion, hot and cold and steam cold quench method.

1.3 Aims and objectives

Main aim of this study is investigate the most effective rubber wood treatment method and the cost effectiveness of those treatment methods.

Main objectives are

1. Compare effectiveness of four different timber treatment methods and find out the most suitable method for rubber wood treatment at green condition & dry condition by boron preservatives.

2. Find out the effectiveness of different boron concentrations for different rubber wood treatment methods.

3. Estimation of costs associated with the treatment of one cubic meter of rubber wood by Vacuum Pressure Impregnation, Hot and Cold Open tank method and Dip Diffusion treatment methods.

4. Study the air seasoning behavior of treated and untreated timber.

CHAPTER TWO: LITERATURE REVIEW

2.1 Structure of wood

Wood or xylem is found inside a covering of bark, which is composed of an inner layer, phloem and outer protective layer (outer bark). When tree grows, it adds new wood, increasing the diameter of its main stem and branches (Bowyer et al, 2007). In the living tree the outermost layer, bark which serves to protect the tree from injury, entry of destructive agencies, drying and so on. The inner layers of the bark translocate the food manufactured in the leaves to other places where it is used or stored. Between the bark and the wood is the cambiam which is a very thin layer of meristematic tissue. Which are the cells in it actively grow and divide. Cell division in the cambiam produces wood on the inside and phloem or bast tissue on the outside. The outer cylinder of the wood is the sapwood which takes part in food storage and conduction of sap. Depending on various factors such as the species and rate of growth of the tree the sapwood may be from half an inch to several inches wide. The central core of the trunk is the heart wood which does not take part in any of the physiological process of the tree but merely confers mechanical rigidity. In the center of the heart wood cylinder is the pith. In the green condition sapwood is more likely to contain much more moisture than heartwood. Wood consists essentially of four elements, vessels (pores), fibers, parenchyma and medullary rays. The function of the vessels is to conduct the sap while the fibers confer strength and rigidity. The parenchyma and medullary rays store and perhaps translocate food (Tissaverasinghe, 1971).

Stems of wood plants support the crown, conduct water and minerals upward from the roots and conduct foods and hormones from points where they are manufactured to those where they are used in growth or stored for future use (Krumer and Kozlowski,1979)

2.2 Properties of wood

Wood properties are different from species to species and these properties are change even in different trees of same species and in same tree from pith to bark and crown to root. Study of wood properties is important in preservation, processing and also using of wooden structures. The properties of wood and cellulose are profoundly affected by water (Browning, 1963).

2.2.1 Moisture content

One of the major requirements for the growth and development of living tree is water and water is major constitutes of green wood. Moisture content of living tree depends on the species and the type of wood, and may range from approximately 25% to more than 250%. In most species, the moisture content of sapwood is higher than that of heartwood. Moisture of wood is found in two forms, as free water contained in the space within the cell and as water held in the cell walls. When wood dries the free water evaporates first and this process is relatively quick. When all the free water has evaporated, leaving behind only the water found in the cell walls the wood is said to be at "fibre saturation point". In drying down to fibre saturation point no dimensional or strength changes takes place in the timber. A very slight change can takes place because it is only in theory that all the free water leaves the wood before any of the bound water. When timber is dried below fibre saturation point however shrinkage begins to takes place, mechanical properties increase in value and electrical conductivity decrease (Tissaverasinghe, 1971).

Wood is hydroscopic, therefore it responds to the changes in atmospheric humidity and loses bound water as the relative humidity drops, and regaining bound water as relative humidity increases. For a given relative humidity level, a balance is eventually reached at which the wood is no longer gaining or losing moisture. When this balance of moisture exchange is established, the amount of bound water eventually contained in a piece of wood is called equilibrium moisture content (EMC) of wood (Hoadley, 1980).

There are three methods for the determination of moisture content,

1. By determining the weight of the section of the wood and its oven dry weight and substituting these values to following formula

$$MC = \frac{Intial\ weight\ of\ the\ wood - oven\ dry\ weight\ of\ the\ wood * 100}{Oven\ dry\ weight\ of\ the\ wood}$$

2. By measuring electrical resistance of the wood between two electrodes, A moisture meter uses variations in electrical resistance to measure moisture content (FAO, 1986)
3. By measuring the electrical capacitance of 2 plates of a moisture meter with the wood as a dielectric. The dielectric constant of wood varies with moisture content.

This method is not very commonly used as resistance method, but a greater range of moisture contents can be measured (Tissaverasinghe, 1971)

2.2.2 Movement in wood

The expansion and contraction of timber is taken place due to the changes of atmospheric conditions. Wood cells are expand when they absorb water, is accompanied by simultaneous swelling. The moist materials exposed to a dry atmosphere, water is loss and shrinkage takes place (Browning, 1963). These all movements take place below the FSP. Above the FSP, wood will not shrink or swell from changes in moisture content because free water is found only in the cell cavity and is not associated within the cell walls. Wood changes in dimension as moisture content varies below the FSP and swell as it gains moisture up to FSP. Wood changing with moisture content because the cell wall polymers contain hydroxyl and other oxygen containing groups that attract moisture through hydrogen bonding. The hemicelluloses are mainly responsible for this moisture sorption but the accessible cellulose non crystalline cellulose, lignin and surface of the crystalline cellulose also play a major role in this sorption (Rowell, 1991).

2.2.3 Density

The density of the timber is varying with the species and there is a considerable variation in density between different samples of the same species. Density is defined as the mass of unit volume. Hardwood are normally dense than softwood but there are some softwood timber that are more dense than hardwood. This variation is influenced by growth rate of the tree, site conditions and genetic composition (Desch, 1981).

2.2.4 Strength of wood

The strength of the wood means the ability to resist applied or external forces or loads. External forces are resisted by virtue of internal forces which are set up in the material. The force on unit area of the cross section is called the stress (Tissaverasinghe, 1971). Wood is anisotropic, therefore mechanical properties also vary in the three principal axes.

2.2.5 Chemical composition of wood

Wood is consists of four major constituents. These are, in odor of abundance cellulose, lignin, extractives and mineral matter. Cellulose is present in wood to the extent of about 70%. Lignin is a compound of carbon, hydrogen and oxygen but it is not a carbohydrate. The extractives are not a part of the wood structure but they contribute important properties to the wood such as color, odor and resistance to decay (Tissaverasinghe, 1971).

2.3 Natural durability of wood

Some species of wood are more durable than others but none are completely resistance to decay, and a species that is said to be naturally durable will simply decay at a far slower rate than one that is said to be non durable (Richardson, 1978).

The natural durability of sapwood is lower than the heartwood, the main reason for his statement is presence of toxic substance in the heartwood that are resist the attack from foreign organisms. The presence of reserve foods in the parenchyma cells and high moisture content in sap wood may increase its susceptibility to decay and bacteria and fungi staining (Panshin and Zeeuw, 1952). The ability heartwood of any one wood species to resist decay is said to be its 'natural durability' or its decay resistance. Natural durability was initially determined by experience.

2.4 Causes of deterioration of wood

Deterioration of wood can be brought about

1. by decomposition caused by physical agencies, such as prolonged heating or exposure to weather
2. by action of foreign biological agencies such as fungi, bacteria, insects and marine borers
3. by chemical decomposition
4. through mechanical wear (Panshin and Zeeuw, 1952)

2.4.1 Decomposition caused by physical agencies

Fire has always been the enemies of wood construction due to presence of combustible materials in the wood (Panshin and Zeeuw, 1952). The quantum of deterioration caused by fire is depends on several factors, species, kind and intensity of fire and its temperature, structure, density, moisture content and chemical substances in wood (Negi,1997). In general, dense, heavy hardwoods are more resistant to burning than light, resinous softwoods. Any unprotected wood exposed to alternate wetting and rapid drying will soon suffer deterioration at the affected surfaces, which swell and shrink in response to moisture changes and develop case hardening, checking, and liftening of the grain (FAO,1986).

2.4.2 Deterioration caused by fungi

Unlike green plants containing chlorophyll, wood inhabiting fungi do not manufacture their own food but derive it from the digestion of organic matter. According to Panshin and Zeeuw, 1952 fungi which deteriorate wood divide in to two groups, wood destroying fungi and wood staining fungi. Wood destroying fungi obtain the nourishment necessary for their growth and fruiting by disintegrating cell walls, thus causing breakdown (decay) in wood. Wood staining fungi and molds in contrast derive most of their food from materials stored in cell cavities; consequently they have relatively little disintegrating effect on wood substance itself. The growth of wood inhibiting fungi depends on favorable temperature a supply of oxygen an adequate amount of moisture and the presence of suitable food supply.

Brown rot fungi decompose primarily the carbohydrate components of the wood. Their preferential decomposition of carbohydrate, cellulose and hemicelluloses leads to fractures across the grain that break the wood in to down in to brown colored cubes. White rot fungi degrade both cellulose and lignin by secretion of cellulolytic and lignolytic enzymes. They decompose lignin of middle lamella sufficiently to cause separation of cells in to fibers. The lignin is mineralized via extracellular fragmentation of the lignin polymer in to lower molecular weight moieties that are then metabolized intracellulerly. Over 600 species of white rot fungi have been found to be lignolytic converting lignin in to carbon dioxide.

2.4.3 Deterioration caused by bacteria

Bacteria cause for the breakdown of cell wall materials including lignin and easily decompose. Bacteria causes' number of diseases including plants specially in the wet wood (Panshin et al, 1952).

2.4.4 Deterioration caused by insects

Several different groups of insects attack timber and without knowledge of the biology of these groups of insects' effective measures for protection cannot be undertaken. One could classify the insects in a number of different ways such as:

- By the natural orders (scientific) to which they belong, beetles, termites, moths, etc.
- According to the stage at which they attack the wood- as trees, logs, timber and service, etc
- According to their mode of nutrition such as starch feeders, fungus feeders, etc.

Nearly all the insects that cause serious damage to timber belong to one or the other of the two orders or classes:

Coleopteran – the beetles

Isopteran – the termites (FAO, 1986)

From the standpoint of wood utilization the insects that damage wood can be segregated roughly in to those whose attacks are confined to wood before it is utilized and those whose damage is mainly restricted to wood in service pin holes and grub holes examples for the insects that damages to the wood before it utilize. Powder post beetles and termites are the most important examples of insects that attack converted wood (Panshin et al, 1952). Although insects that deteriorate wood after the conversion is concerned in this study.

Powder post beetle

The term powder post beetle is applied to the beetle of two related families, the Bostrychidae and Lyctidae (Panshin et al, 1952). Powder post beetles (*Lyctidae*) are mainly attacking on the sap wood of home grown hardwoods making 1.6 mm diameter circular tunnels while producing floury powder .Powder post beetles (*Bostrychidae*) destroy sapwood of tropical hard wood by making 5 mm diameter circular tunnels (White, 1968).

Ambrosia beetle (pinhole borer)

Ambrosia beetles are mainly attacking on the sap wood and heart wood of soft wood and hard wood. They make 0.5 mm$^{- 3}$ mm diameter circular tunnels but they do not produce dust (White, 1968).

Shipworm

Shipworms are occurring in the floating logs of sap wood and heart wood of both soft wood and hard wood. They make circular tunnels in the logs but diameter can change (White, 1968).

2.5 Termites

Termites are social insects belonging to the order *Isoptera*. A typical termite colony contains one or more fully developed females or ‘queens’; a similar number of males; and a very large number of sterile individuals of two types, or castes, known as ‘workers’ and ‘soldiers’. The soldiers’ task, as the name implies, is to identify the colony against invaders, such as the true ants which are their most deadly enemies.

Termites can be divided in to two main groups depending on whether they maintain direct contact with ground or living completely isolated from it. The former may be called subterranean (Earth dwelling) termites because they live, either wholly or partly, in the ground, and always maintain a connection with the soil even when their nests are above ground. The second group is the ‘wood dwelling termites’, which spend their lives in wood and the colonies are started by a mating pair entering wood above ground level. Dry wood termites are not so common as the subterranean types occurring mainly in coastal or very humid areas but when they do occur they may present a serious problem. Their entry into buildings cannot be checked by shields on the foundations as the adults can fly and make colonies in the dry wood (Findlay.1985).

Preservative reaction on dry wood termites

Boron in wood are toxic to the gut protozoa of dry wood termites even if they are not directly toxic to the termites them self (Tissaverasinghe and Jayathilake, 1975).

2.6 Air seasoning of wood

The process of drying wood under more or less controlled conditions is called seasoning. Controlled conditions are necessary to avoid rapid drying which is responsible for developing defects in wood. There are several seasoning methods such as air seasoning, kiln seasoning, vapour drying, chemical seasoning... etc. Vapour drying and chemical seasonings are not very common because they are costly. Sufficient air movement has to maintain through the individual stacks to ensure uniform drying (FAO, 1986). In this experiment air seasoning was carried out. Drying occur because of the differences in vapour pressure from the centre of a piece of wood outwards. As the surface layers dry, the vapour pressure in these layers falls below the vapour pressure in the wetter wood further in, and a vapour pressure gradient is build up that is conductive to the movement of moisture from centre to surface (Desch, 1981). According to Negi, 1997the general principles of seasoning of wood are:

1. The rate of drying, moisture gradient and drying stresses in the section are affected by
    a. The rate of movement of moisture through the wood
    b. Externally applied temperature
    c. Interaction of the external drying conditions such as temperature, relative humidity, rate of air circulation and the rate of moisture diffusion within the wood.
    d. Species
    e. Initial moisture content
    f. Thickness of the timber
2. At the same relative humidity, the higher the temperature, drying rate is high
3. At constant temperatures, lower relative humidities results in higher drying rates.
4. At constant temperature and relative humidity, the higher possible drying rate is obtained by rapid circulation of air across the surface of the wood.
5. Drying is faster along the longitudinal direction than in the transverse direction.

Moisture can exist in wood as free water in cell cavities and as bound water in cell walls. The moisture content at which cell walls are completely saturated, but no free water exist in cell cavities, is called the “fibre saturation point” (FSP) (US Department of Agriculture, 1974).

The E.M.C. (Equilibrium Moisture Content) of timber is depends on the ambient temperature and relative humidity of the atmosphere. Under Sri Lankan conditions variations are possible between E.M.C. values of say 12% and 18% in any one place (Tissaverasinghe, 1971).

2.7 Wood preservation

The biological origin of the wood makes more susceptible for the foreign organism attack and deterioration due to them. Wood can be protected from the attack of decay fungi, harmful insects or marine borers by applying selected chemicals as wood preservatives. The degree of protection obtained depends on the kind of preservative used an on achieving proper penetration and retention of chemicals (US Department of Agriculture, 1974). The objective of wood preservation is to introduce the preservative in to the wood so that a deep continuous layer of treated wood contains sufficient preservative to prevent decay and insect attack (FAO,1986).

2.8 Wood preservation methods

2.8.1 Non pressure treatment

Non pressure processes are carried out without the use of artificial pressure under the atmospheric pressure (FAO, 1986)

a. Brush treatment

The simplest method of applying a preservative is brushing and is normally used for preserving small individual items (FAO, 1986). Brushing is convenient way of applying a wood preservative to small individual items and it is desirable to apply preservative to timber already in situ in a building (Findlay,1985).

b. Spraying

Spraying is convenient method of applying preservatives to any large areas. (Findlay, 1985). Spraying offers more liberal and effective covering of the timber than brushing. The possibility of the preservative penetrating in to holes, cracks, splits is more in spraying (FAO, 1986). Brush application is perfectly satisfactory when it is necessary to apply a superficial coating of a high viscosity fluid, such as a paint or varnish but even then the loading on the wood surface is only about 25% of that which can be achieved by a simple spray application (Richardson, 1978).

c. Hot and cold open tank method

In this process timber is immersed in a bath or preservative which is heated for few hours and allowed to cool while the timber is still submerged in the liquid. During the heating period the air in the cells expands and much of it is expelled as bubbles. During the heating period the air in the cells contracts creating a vacuum and the preservative is drawn in to wood. Therefore practically whole of the absorption takes place during the cooling period (FAO, 1986)

d. Sap displacement method

Sap displacement method can only be applied to round timbers in green condition and uses the hydrostatic pressure due to gravity to force the preservative from the butt end of the round timber. In this method a cap is fitted to the butt end of a freshly sawn pole or round timber and then one end of a flexible tube is connected to the cap and the other end to a tank containing the preservative at a place as high as possible. There are modifications to this process such as the application of a vacuum from the top end (FAO, 1986).

e. Diffusion treatment for wood

Diffusion treatment with boron compounds is the one of the simplest, cheapest and an effective way of protecting wood from biodegradation (Dhamodaran and Gnanaharan, 1996).

Preservative treatment of wood by diffusion involves the movement of molecules by random motion from regions of high concentration to regions of lower concentration. This is typically slower method of treatment. This involve some uptake of preservative by bulk flow and thereafter preservative is further distributed by diffusion. The rate of diffusion is directly proportional to the concentration gradient as expressed for steady state diffusion in Fick's law of diffusion. Under ideal condition this can be mathematically expressed as:

$$\frac{dm}{dt} = -KA\frac{dc}{dx}$$

Where, $\frac{dm}{dt}$ = rate of transfer of solution (change in mass over time or moles hr^{-1})

$\frac{dc}{dx}$ = concentration gradient (moles per cm^{-2})

A = area (cm^2)

dc = concentration (moles in unit volume)

dx = thickness of wood piece (cm)

K = diffusion coefficient

The rate of diffusion rises with increases in temperature because there is greater available energy to overcome the kinetic force holding a molecule stationary. In addition ion velocity will increase.

Application of Fick's law indicates that after a period of diffusion the preservative concentration at a given depth is proportional to the concentration of the original applied solution. In practical applications doubling the concentration of preservative component dose not doubles the depth of penetration in a given time. Studies indicate that rates of solute diffusion in wood adopt the following ranking: longitudinal >> radial > tangential, which is also noted for bulk flow (Eaton and Hale, 1993).

The longitudinal diffusion coefficients were 10 to 20 times larger than the radial diffusion coefficients, and the radial diffusion coefficients were 2 to 4 times larger than the tangential diffusion coefficients. The longitudinal diffusion rate increased rapidly with moisture content (MC), while a slow increase in the radial diffusion rate was observed at MCs above 90%. MC did not affect the rate of tangential diffusion within the range of MCs experimented (70-110%). The effect of temperature on boron diffusion rates was more pronounced than the effect of MC. The diffusion rate increased with temperature, although slight direction dependent differences were observed (Caldaria, 2010). The timber just after the immersion is closed block stacked and completely covered with a polythene sheet so that drying is prevented as much as possible (FAO, 1986).

f. **Steam cold quench method**

Steam cold quench method is currently not practicing in Sri Lanka which is practicing in Australia for treatment of rail way sleepers. The methodology of this treatment method is 4 hour steam of wood and then flooded with preservative solution and kept fully immersed over night or for about 5-15 hours depending on the thickness of timber (Findlay 1985 and Negi,1997).

2.8.2 Pressure treatments

Applying a positive external pressure to force the liquid in to the pores of wood (Findlay, 1985). There are several types of high pressure processes some using only pressure and others using vacuum and pressure (FAO, 1986).

a. **Bethell or Full cell process**

This is the normal processes used when treating with water born solutions (FAO, 1986). The main steps in the full cell process are

1. The charge of wood sealed in the treating cylinder, and a preliminary vacuum is applied for ½ hour or more to remove the air from the cylinder and as much as possible from the wood.
2. The preservative, previously heated to somewhat above the desired treating temperature, is admitted to the cylinder without admission of air.
3. After the cylinder is filled pressure is applied until the required preservative is obtained.
4. When the pressure period is completed the preservative is withdrawn from the cylinder (US Department of Agriculture,1974).

b. **Empty cell process**

There are two main types of empty cell processes which are called rueping and lowery processes. In both processes there is no initial vacuum applied, the preservative is forced in to the wood under pressure and subsequently a vacuum is applied to remove the excess of the preservative. This process is normally used with tar oil preservatives. The main steps in the ruepning process are;

- Preliminary air pressure applied

- Fill cylinder/ hold air pressure
- Build up pressure
- Maximum pressure held
- Release pressure
- Empty cylinder of preservative
- Final vacuum period
- Release vacuum

And the main steps in the lowery process are

- Fill cylinder with preservative at atmospheric pressure
- Build up pressure
- Maximum pressure held
- Release pressure
- Empty cylinder of preservative
- Final vacuum preservative
- Release vacuum (FAO, 1986)

c. Low pressure process

The main steps of this process are,

- Application of an initial vacuum
- Flooding with preservative
- Application of pressure
- Release of pressure
- Application of final vacuum

The above steps are very similar to the steps employed in the full cell process except the pressure applied is much less (FAO, 1986).

d. Double vacuum process

A method has been called the double vacuum process, involves exposing the fully machined pieces at a moisture content not exceeding 25% to an initial vacuum, followed by a short period at atmospheric or slightly raised pressure completed by a final vacuum which is a sort of cleaning operation to remove surplus fluid from the cell cavities (Findlay, 1985).

2.9 Wood preservatives

Wood preservatives are chemical substances which, when initially applied to wood, make it resistant to attack by decaying agents. The protective effect is achieved by making the wood preservative or repellent in to the organisms that would attack it (FAO,1986).

An ideal wood preservative should have following characteristics

1. Lethal toxicity of the preservative should be high even in the low concentration against fungi, insects and marine organisms and low level of lethal effects for mammals
2. The permanence of the wood preservative in the treated wood during various uses, such as resistance to
    a. Leaching by water
    b. Quick evaporation due to the heat
    c. Chemical transformation caused by oxidation, reduction and polymerization
    d. Chemical or enzymatic action causing a lowering of toxicity level
3. High level of amenability to impregnate in the entire cross section of the wood that is being treated in order to give a more lasting effect
4. Preservative should be stable during the treatment
5. The inflammability of treated wood should not increase by the preservative
6. Do not cause adverse effects on human
7. The cost of the preservative should be low and readily available
8. Ease of transportation over long distances in wood
9. The preservative must not cause corrosion in the metals that are used in the equipment used for wood preservation
10. The painting and varnishing of the treated wood should not prevent by the preservative
11. The strength and the other properties of the wood should not be adversely affected by the preservatives (Negi,1997)

None of the current used preservatives meet all these needs. Preservative effectiveness is influenced by the protective value of the preservative chemical itself, the method of application and extent of penetration and retention of the preservative in the treated wood (US Department of Agriculture, 1974).

Wood preservatives are commonly classified in to four main groups;

a. Oil type such as creosote
b. Organic solvent type
c. Non-fixed water soluble type
d. Fixed water soluble type

Oil type preservatives

There are number of oil type preservatives such as creosote, coal tar creosote. Creosote is a brownish-black oily liquid that comes from the tar produced during the distillation or the carbonization of bituminous coal (FAO, 1986). Creosote is broadly defined as those fractions of distillates from coal tar that boil between 200-400 °C. It is complicated mixture of a large number of organic compounds. The relative proportions of these depend on the composition of the original coal tar and the method by which it was carbonized

Its advantages are;

1. High toxicity to wood destroying organisms
2. Relative insolubility in water and low volatility, which impart to it a great degree of permanence under the most varied use conditions
3. Ease of application
4. Ease with which its depth of penetration can be determined
5. General availability and relative low cost
6. Long record of satisfactory use (US Department of Agriculture, 1974)
7. Impregnation with creosote provides extra protection against moisture content changes, so that treated wood is stable and very resistant to splitting.
8. It is not normally corrosive to metals and has a high electrical resistance.

They have properties that are disadvantages for some purposes.

1. The color of the creosote and the fact that creosote-treated wood usually cannot be painted satisfactorily make this preservative unsuitable for finish lumber or other lumber used where appearance and paintability are important.
2. The odor of the creosoted wood is unpleasant to some persons. Also creosote vapors are harmful to growing plants, and foodstuffs that are sensitive to odors should not be stored where creosote odors are present.
3. Freshly creosoted timber can be ignited easily and will burn readily, producing a dense smoke.

Organic solvents

Organic solvent preservatives are very active chemicals that are highly effective as fungicides and insecticides. The chemicals are dissolved in organic solvents before application. The important and commonly used organic solvent type preservatives have been described below.

a. Benzene hexachloride (BHC)
b. Dichloro-diphenyl-Trichloroethane (DDT)
c. Synthetic pyrethroides
d. Metallic soaps
e. Precipitated soaps
f. Fused soaps

Water soluble type

Waterborne preservatives leave the wood surface comparatively clean, paintable and free from objectionable odor (US Department of Agriculture, 1974). These preservatives may further be of two types:

Leaching type

These are inorganic or organic salts that are soluble in water. They are suited only for timber which has to be used indoors as the preservatives may readily leach out when it contact with rain water. Important preservatives in this category are:

1. Zinc chloride
2. Boric acid and borax
3. Sodium pentachlorophenate
4. Benzene hexachloride

Fixed type

1. Copper-Chrome- Arsenic (CCA)
2. Acid-Cupric-Chrome composition (ACC)
3. Chromated Zinc Chloride (CZC)
4. Copper Chrome boric composition (CCB) (Negi, 1997)

Boron

The water diffusive properties of boron and its stability at relative high temperatures, it can be applied using a wide variety of treatment processes than most other wood preservatives such as CCA or creosote (Negi, 1997). In spite of many advantages of borates boron treatment did not become established as a preferred method of protecting timber because of the leachability of boron (Dhamodaran and Gnanaharan, 1996) but boron have favorable environmental characteristics lower health impacts (Calderia, 2010).

Boron-based systems are candidates for the future range of preservative formulations with lower environmental and health impacts. Boron compounds have been used for over 40 years in Australia and Europe. The principal compound being used in the United States is disodium octaborate tetrahydrate [$Na_2B_8O_{13}.4H_2O$] (boron), which is soluble in water, is colorless and diffuses readily into green wood or can be pressure impregnated into dry wood. Borates have favorable environmental characteristics, but their high susceptibility to leaching is the main obstacle to the widespread use of boron as a major component of broad spectrum wood preservatives (Calderia, 2010).

2.10 Rubber wood

The rubber tree *Hevea brasiliensis* is well known for its latex production, and now, for its timber. Rubber wood is an evenly light colored hardwood and is mainly used for furniture making (Lokmal et al, 2008). The genus *Hevea* is a member of family Euphobiaceae and comprises 10 species, *H.brasiliensis* is the only one planted commercially. *Hevea brsiliensis* is a quick growing, erect tree with a straight trunk and bark which is usually gray and fairly smooth, but varies somewhat in both color and surface. The tallest species of the genus Hevea is this *Hevea brasiliensis* which may grow over 40 m in wild and live for over 100 years. Latex tapping make reduction of growth of rubber tree and rarely exceed 25 m in plantations. (Webster and Paardekooper, 1989). Rubber wood is moderately hard and heavy with a density of 640 to 720 kg/ m^3 at 20% moisture content. Rubber timber has higher shear value (Ruwanpathirana, 2011). In Sri Lanka there are 124 000 ha of rubber plantations. (Sri Lanka socio economic data 2010, 2010).

Rubber (*Hevea brasiliensis*) is non native tree species to the Sri Lanka but one of major economical valuable tree. Latex and its products are main export items that gain high foreign income to the country. That makes peoples high contribution to the rubber tree planting; as a result rubber is the second largest plantation crop in the Sri Lanka. Latex tapping is carrying out for 20-25 years and after that period it is uneconomical for the tapping. Therefore trees are felling at that age and that produce continues wood supply to the market. General public's preferability for the rubber wood is less because it is less durable (Class III) timber. Earlier people use rubber wood mainly as fuel wood for energy generation. The scarcity of durable timber in market make rubber wood more demand and through the preservative application it makes more resistance to decay.

2.11 Atomic absorption spectrophotometry

There are several methods for the determination of chemical penetration of the treated rubber wood. Salamah et al (1989) done a study on 'Boron analysis of treated wood and solution' and studied on three different boron determination methods, colorimetry, atomic absorption spectrometry and inductitively coupled plasma methods against titration method. The final conclusion of their study is AAS, ICP and colorimetry methods are more suitable for boron determination especially for detection of very concentration of boron. Further they mentioned that use of colorimetry method is limited the color reaction which tends to change after 24 h thus affecting the absorption reading.

2.12 Economics of wood preservation

Preservation make wood more durable, therefore the replacement of wood should not carry out more frequently. According to the FAO,1986 the failure of a piece of wood in a building through decay may involve expense enormously greater than the cost of the actual piece of wood itself.

CHAPTER THREE: MATERIALS AND METHODOLOGY

3.1 Preparation of timber sample

Freshly felled rubber logs were sawn in to 40.63 cm * 10.16 cm * 1.60 cm (16 inches * 4 inches * 0.63 inches) size. Treatment for green wood was carried out immediately after the sawing and dry timber was obtained from the air seasoning of sawn wood pieces. Two ends of each piece were coated with water repellant paint.

3.2 Timber seasoning

Timber samples were air seasoned under a shed to prevent them from heavy sun light and it was protected from rain. In this experiment horizontal stacking was done. The timber samples were stacked on a platform which is made up of timber frame and a metal mesh. Rubber stickers in the size of 60 cm * 2 cm * 1.60 cm were placed in between each layer of stack. Each stack had one thickness of timber. Seasoning was done until timber sample reached to a constant weight. Weight losses and moisture contents were recorded daily.

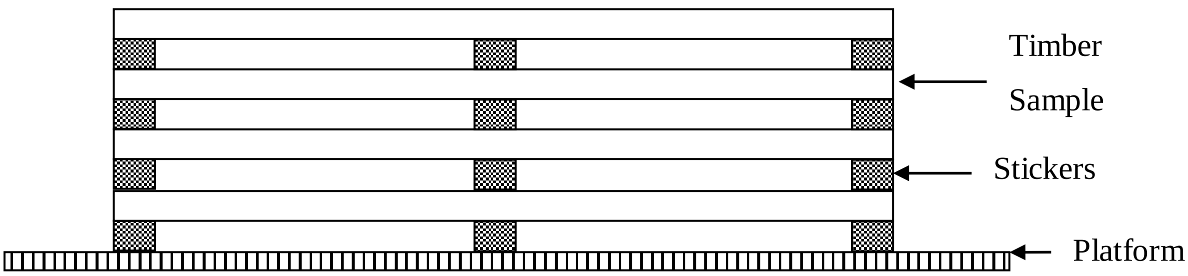


Figure 3.1: Air seasoning of rubber wood, horizontal stacking

Plate 3.1: Air seasoning of rubber wood

3.3 Preparation of boron solution

Boron preservative is a mixture of boric acid and borax in 1: 1.54 proportions. (Mason, 1966). According to this 1: 1.54 proportion of boric acid to borax and 12 % solution strength, 992.0 g boric acid to 1528.0 g borax were added to 15 L water and mixed well. Solution was top upped to 21 L (adequate amount for the submerge timber sample). The mixture was prepared in a pan. In the preparation of 8% solution strength boron solution, 660.0 g of boric acid and 1018.0 g of borax were accurately measure and dissolve them in 21 L water in the same pan. The temperature of the solution was measured by a thermometer (Annex 3.1). In the solution preparation for vacuum pressure impregnation for the 12 % solution strength, 945.0 Kg boric acid and 1455.0 Kg of borax was mixed with adequate water in mixing tank. The mixture was send to the storage tank and top up to 20 000 L. Boric acid 630.0 Kg and borax 970.0 Kg were measured accurately and mixed thoroughly in adequate amount of water and top upped it in to 20 000 L in the preparation of 8 % solution strength boron preservative solution for vacuum pressure impregnation treatment (Annex 3.2).

3.3.1 Solution strength

Solution strength is expressed as the weight of solid per unit volume of solution in percentage form.

$$Solution\ strength = \frac{Weight\ of\ the\ salt\ *100}{Volume\ of\ the\ solution}$$

(FAO, 1986)

In this study solution strength was measured in W/W % as mentioned in a study on vacuum pressure treatment for rubber wood using boron based preservatives by Salmah and Mohad Dahlan in 2007.

Theory:

Density of water at 30 °C is 995.7 Kgm^{-3}, was rounded to 1000 Kgm^{-3}. Therefore 1 L (1 m^{-3}) of water has 1000 Kg weight. (General chemistry, 2001)

According to the theory,

$$Solution\ strength \frac{W}{W}\% = \frac{Weight\ of\ the\ salt*100}{Weight\ of\ the\ solution}$$

3.4 Diffusion treatment

The 12 % solution strength, boron solution for diffusion treatment was prepared as mentioned above. Eight wood pieces were submerged in the boron solution for 24 hours at the room temperature. Rubber wood has less density than solution therefore wood pieces can float on the solution. This was prevented by placing a weight on the wood sample. Wood pieces were submerged in boron solution for 24 hours and after 24 hours it was taken out from the preservative solution. When samples were taken out from the solution they were held over the solution until excess run off of solution had stopped. Then the timber pieces were block stacked and completely covered by a black polythene sheet for 1 hour allowing diffusion in timber pieces. After 1 hour timber pieces were restacked for air seasoning. Weight of the timber pieces were recorded before immersing in the boron solution and after the 1 hour block stacking in order to calculate chemical retention. Same procedure was followed for 8% solution strength also.

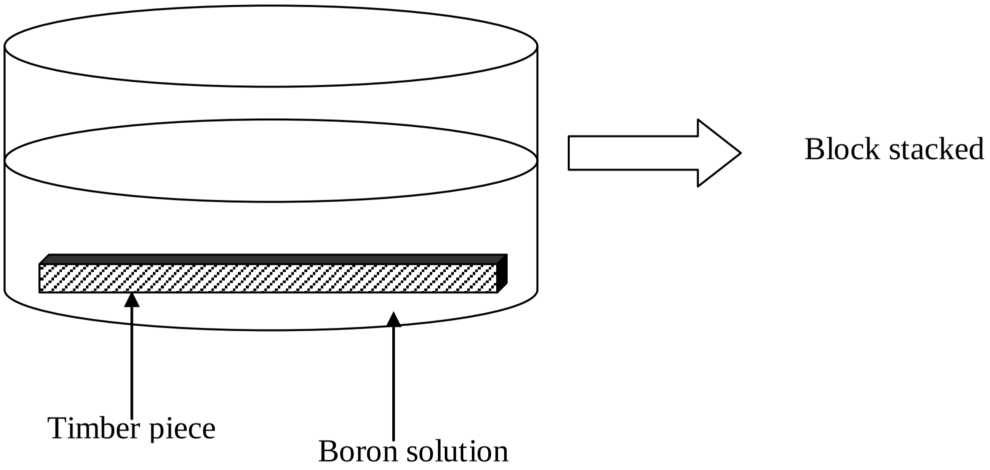


Figure: 3.2 diffusion treatment

3.5 Hot and cold open tank method

Prepared boron solution was heated for 80 °C by three heaters; 8 timber pieces were introduced to the solution after it reaches 80 °C temperature and this temperature was maintained for, four hours while timber pieces were submerged in the solution. Wood samples were then allowed to cool over one night in the same solution. Same pan used for diffusion treatment was used in this method also. Weight of the each timber piece was measured before the immersion in the hot boron solution and the after it was taken out from the cold boron solution.

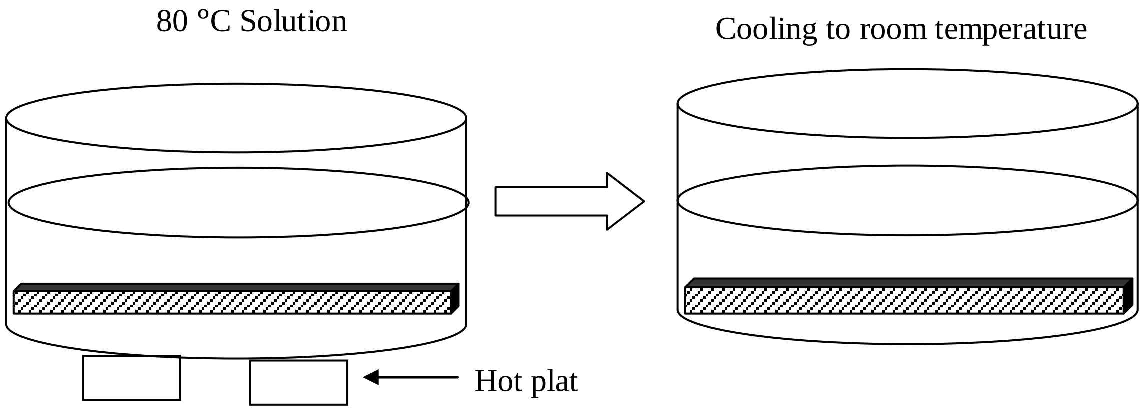


Figure 3.3: Hot and cold open tank method

3.6 Steam cold quench method

Eight wood pieces were steamed for four hours by boron steam and transfer them into another cold boron solution which has same solution strength and allowed them to cool over night. In this method two boron solutions were prepared in two pans; pans with same dimensions were used. Boron solution was heated by three heaters until steam was generated (nearly 100 °C) and then eight timber pieces were stacked on a rack (Fig: 3.4) and placed timber rack on the tripod and whole structure was kept in the pan (Fig.3.5). Pan was tightly closed by the lid and allowed to develop pressure inside it. This was maintained for four hours. After four hour steamed timber samples were immediately transferred to the boron solution in room temperature and allowed to cool over night.

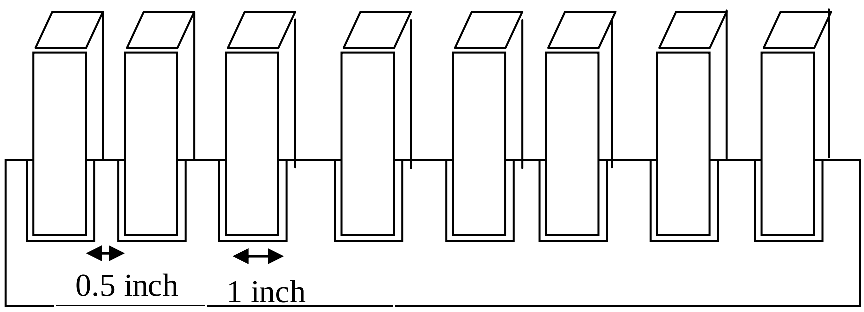


Figure: 3.4 Timber stack for steam cold quench method

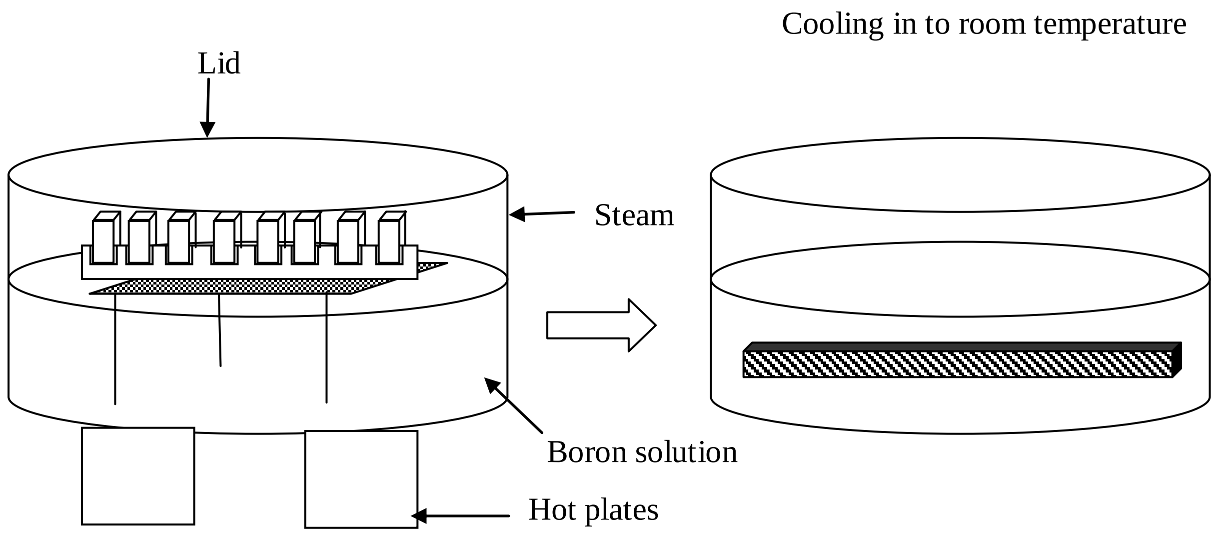
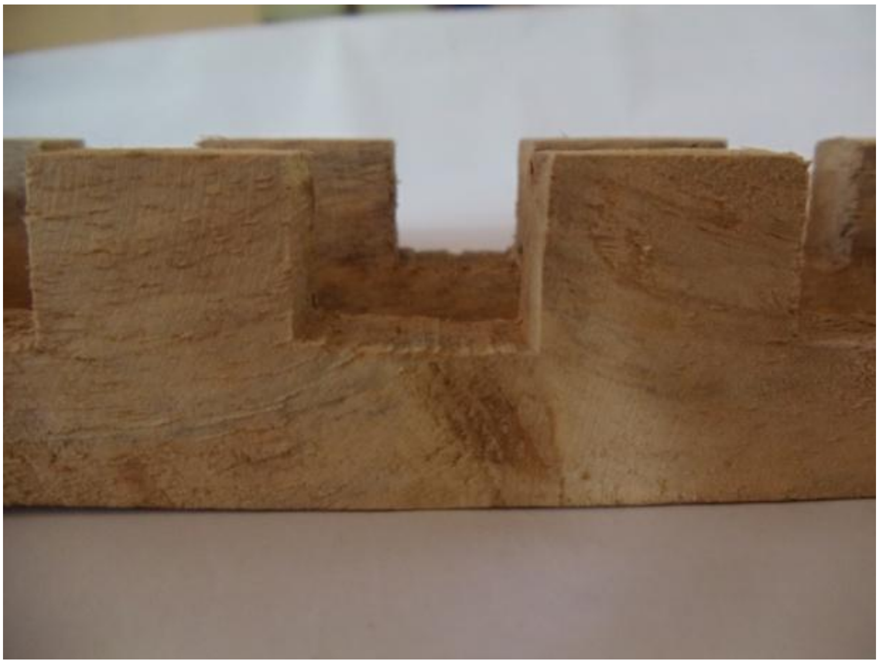


Figure: 3.5: Steam cold quench method



(a)

(b)

Plate 3.2: Structure that prepared for stack timber (a); timber stacked for treatment (b)

3.7 Vacuum pressure impregnation method

Timber pieces were stacked in the treatment chamber and closed the chamber door. A vacuum was developed in the chamber, send chemicals from storage tank while keeping the vacuum in the chamber. Valves were closed after chemicals were fully filled in the chamber and then release the vacuum, increase the pressure in the chamber. This maximum pressure was kept for 15 minutes and excess chemicals were taken back to the storage tank. The air inside the chamber was released and then make vacuum again. Door was opened after releasing the vacuum and after 20 minutes samples were taken out and make the measurements.

Table 3.1 Treatment schedule for vacuum pressure impregnation

Treatment phase	Time (minutes)
Initial vacuum (1 bar)	15
Flooding of preservative in to treatment	15

cylinder	
Pressure period (100 Psi)	15
Draining out of preservative from the cylinder	15
Final vacuum (1 bar)	20

Plate 3.3: Vacuum pressure impregnation plant of Finlay Rentokil Ceylon (Pvt) Ltd

3.8 Chemical retention

Retention is the amount of preservative chemicals retained in a unit volume of timber expressed in Kg per cubic meter (FAO, 1986). Following equation was used for the chemical retention calculation.

$$CL = \frac{W2 - W1}{V}$$

$$CR = \frac{\%S * CL}{100}$$

(Salamah and Mohd Dahlan, 2007)

CL = Chemical Load (Kgm^{-3}) W1 = Weight before the treatment (Kg)

CR = Chemical Retention (Kgm^{-3}) W2 = Weight after the treatment (Kg)

V = Volume of wood piece (m^3) SS = Solution strength (W/W %)

Weight of the timber pieces before and after the every four chemical treatments was taken. Chemical retention was calculated by the substitution of those values in to above equation. General linear model in ANOVA was done for the chemical retention of different treatment methods, different moisture conditions of the rubber wood and different boron solution strengths.

3.9 Chemical penetration

The amount of preservative penetrated in to the core of the treated wood samples was investigated using atomic absorption method. Thin slice from the exact middle of timber pieces were taken and grinded them. Accurately measured 0.25g of saw dust was measured by electric balance and 5 ml of conc. HNO_3 and conc. H_2SO_4 was added to it. Digesting was carried out by digester and final solution was top upped to 100 ml (Salamah and MohdDhlan, 2007). The amount of boron at the core of the wood piece was measured by atomic absorption spectrometer. General linear model in ANOVA was done for the chemical penetration of different treatment methods, different moisture conditions of the rubber wood and different boron solution strengths. This was conducted at chemistry laboratory University of Kelaniya.

Plate 3.4: Atomic absorption spectrophotometer

3.10 Termite test

Three slices, 10cm * 10cm * 0.5cm size was cut from the middle of the treated timber pieces like shown in the below diagram (Figure: 3.6) (Saroja, 1985 and Tissaweerasinghe, 1975). Three sandwiches were prepared for each treatment method. Three sandwiches made by untreated timber samples.

These three slices were arranged in the form of sandwich (Figure: 3.7) with 1cm hole drilled in the top two slices and the bottom slice being left intact. 4 nymphs and 6 workers of *Cryptotermes domesticus* were introduced to that chamber. The chamber was covered with a cover slip and edges were sealed with sellotape to make the chamber air-tight. Regular observations were done for take the number of days that taken to die all the introduced dry wood termites. Same number of nymphs and workers of dry wood termites were introduced to the sandwiches made from untreated wood and it was served as the controller

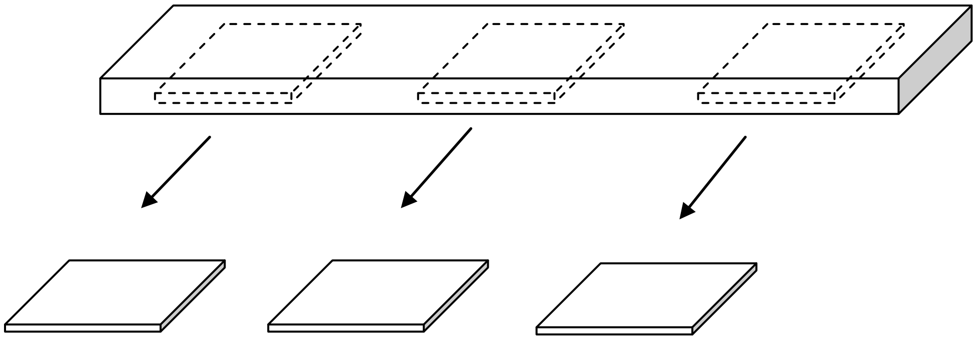


Figure 3.6: Cutting pattern of treated timber for sandwich preparation

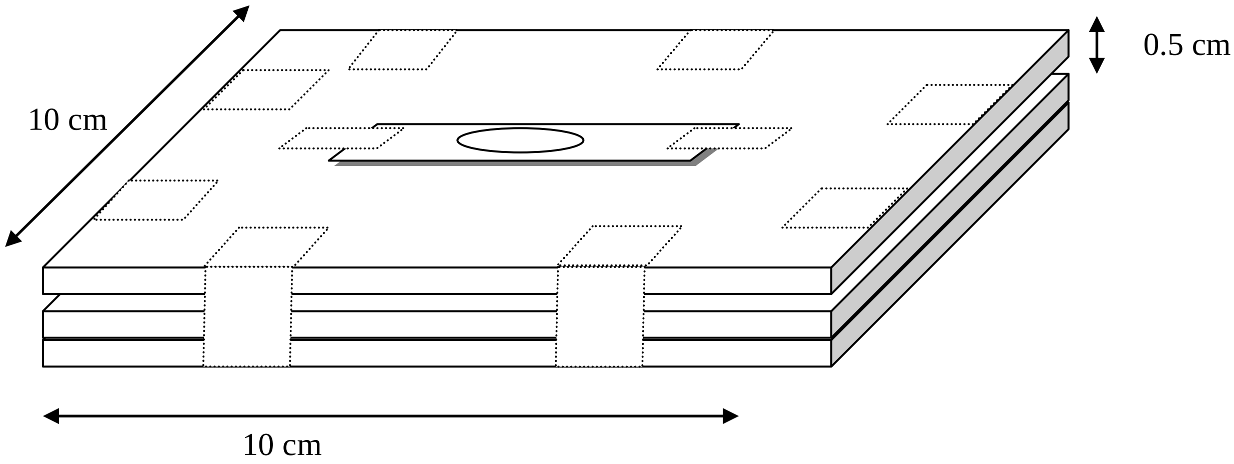


Figure 3.7: Wood sandwich

3.11 Cost of treatment

Cost of treatment of one cubic meter of rubber wood was carried out for three treatment methods, dip diffusion, hot and cold open tank method and vacuum pressure impregnation method. These calculations are based on data obtained from three industries for three different treatment methods.

Considered costs

- Energy cost
- Timber cost
- Labor cost
- Chemical cost

Equation used for the calculation,

$$Cost\ of\ treatment\ of\ one\ cubic\ meter\ of\ rubber\ wood = \frac{EC + TC + LC + CC}{V}$$

EC = Energy Cost

TC = Timber Cost

CC = Chemical Cost

LC = Labor Cost

V = Volume of timber treat for one operation (m^3)

3.11.1 Cost of treatment of one cubic meter of rubber wood by diffusion method

Data were collected for plant A, which is doing dip diffusion method for rubber wood treatment (Annex 6.1) and the calculated values were substitute to the above equation.

3.11.2 Cost of treatment of one cubic meter of rubber wood by hot and cold open tank method

Data were collected from plant B, which is practicing hot and cold open tank method for rubber wood treatment. Calculated values from the obtained data were substitute to the above equation and figure out the cost of treatment of one cubic meter of rubber wood by hot and cold open tank method (Annex 6.2).

3.11.3 Cost of treatment of one cubic meter of rubber wood by vacuum pressure impregnation method

Data collected from plant C, which is practicing vacuum pressure impregnation for rubber wood and calculated values were substitute to the above equation in order to find out the cost of treatment of one cubic meter of rubber wood by vacuum pressure impregnation method (Annex 6.3).

CHAPTER FOUR: RESULTS

4.1 Air seasoning of untreated timber

The behavior of air seasoning of 10 untreated rubber wood pieces were observed and presented in figure 4.1 (time Vs weight) and figure 4.2 (time Vs moisture %). Initial air drying rate is high during first, two weeks of air seasoning, timber samples reaches its half of initial weight within 14 days. The rate of drying is gradually decreased with time. Moisture content of the timber samples show rapid decrease in first week and the decreasing rate is reduced with time.

Fibre saturation point which is no free water is present in wood and only bound water is present (Forest product laboratory, 1974). This was taken as 25% moisture content (TRADA 1983). Timber samples reached FSP within the first week of air seasoning. E.M.C. of timber samples were in the range of 12%-15%. All the timber samples achieved their E.M.C. within 24-27 days (Annex 01).

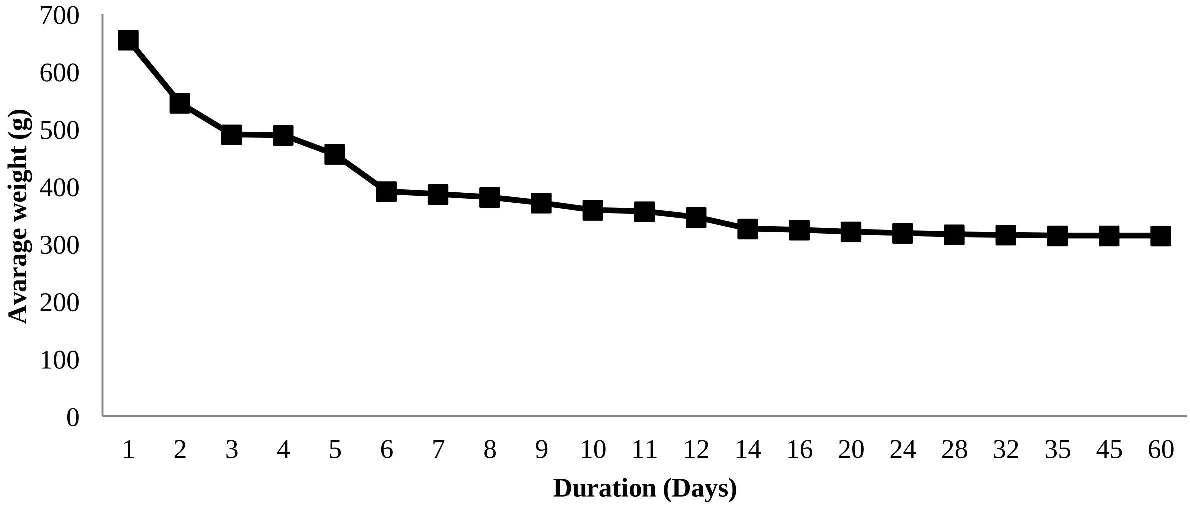


Figure4.1: Air seasoning of untreated timber (Time Vs Weight)

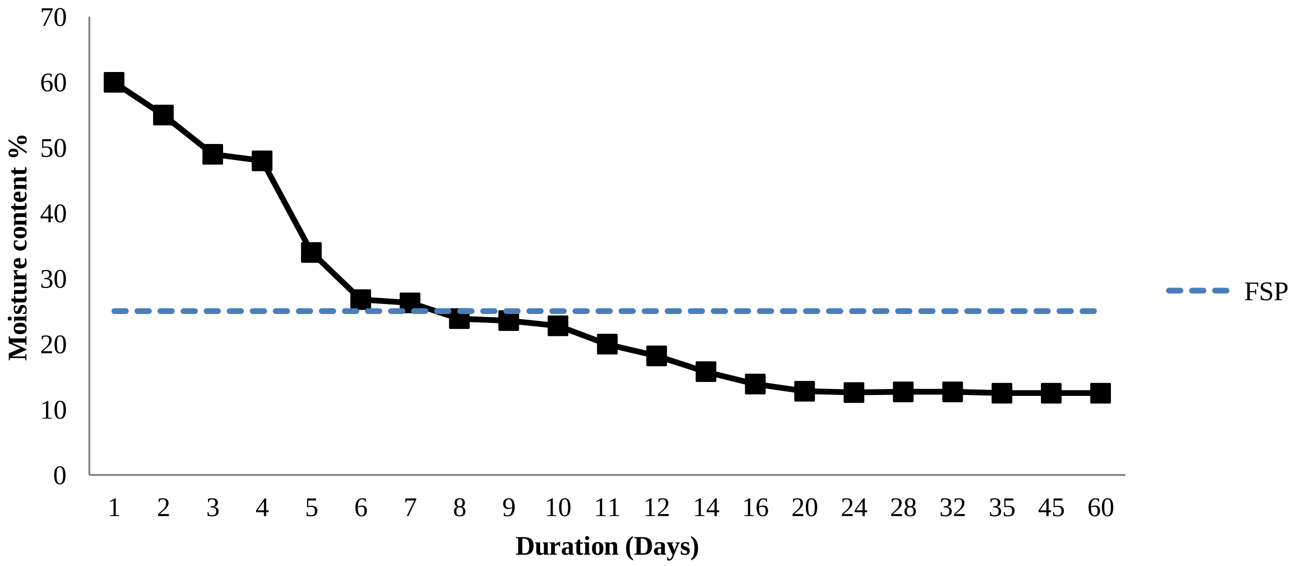


Figure 4.2: Air seasoning of untreated timber (Time Vs Moisture %)

4.2 Air seasoning behavior after the treatments

Timber samples were stacked on the same platform after the treatment by different treatment methods. The weight loss of the timber samples were measured in irregular intervals until it became constant.

Sawing and other processing of timber is easy with low moisture in the wood. Therefore it is important to observe the number of days taken to reach to a constant weight or seasoned after the treatment for each treatment method.

According to the results (Table 4.1) in every treatment method dry timber showed the fast seasoning behavior than green timber except hot and cold open tank method. Both dry wood pieces and green wood pieces treated with hot and cold open method reached to constant weight after 14 days. Vacuum pressure impregnated dry timber shows fasted drying behavior after the treatment. It took only 6 days for the complete seasoning. Steam cold quench treated green timber took the slowest drying rate (Fig 4.5), 20 days for complete seasoning. However in steam cold quench method user have to wait more time for sale the treated timber or for further processing of timber than other methods.

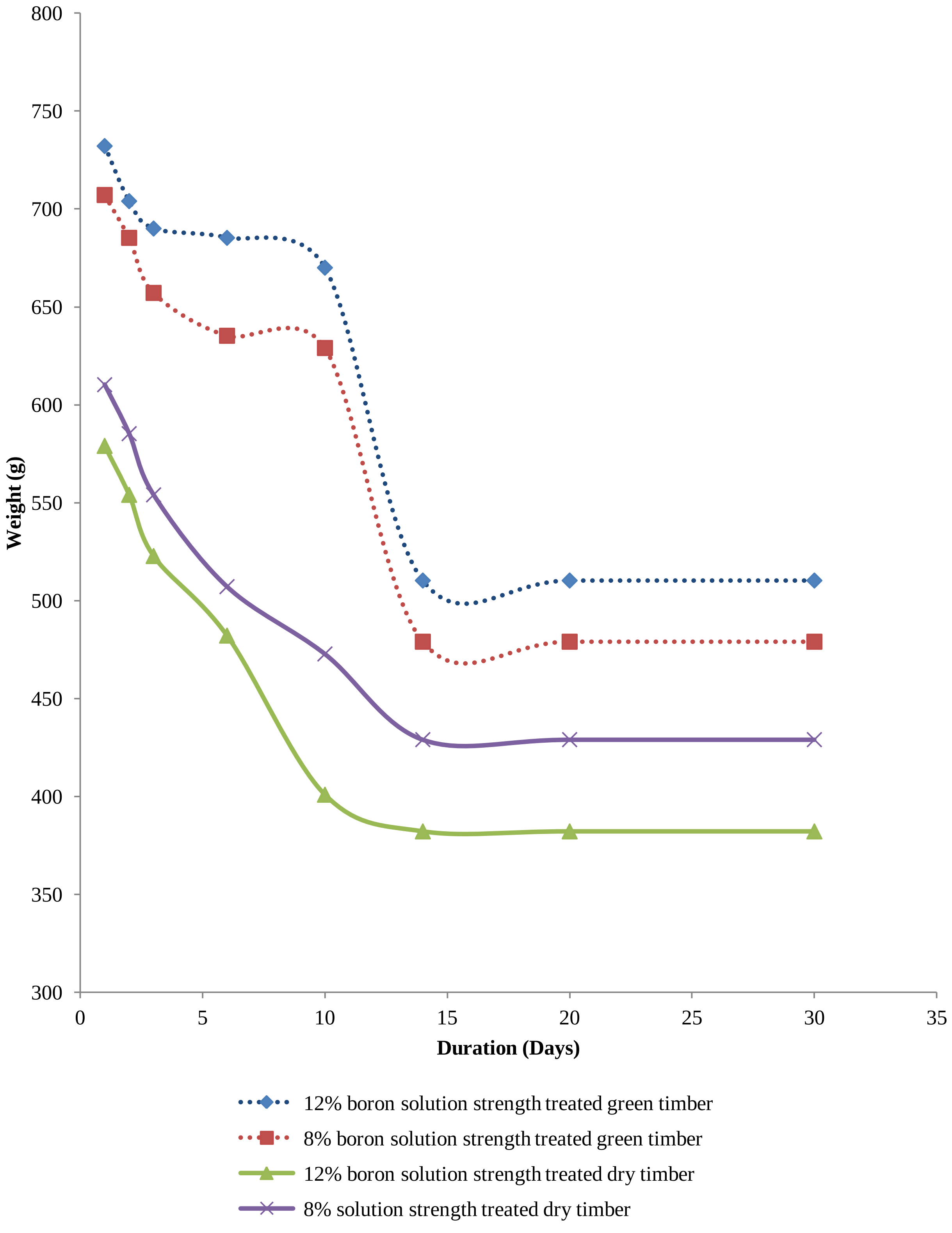


Figure 4.3: Air seasoning behavior after diffusion treatment (Annex 02, A2.1)

They achieved four different constant weights at the air seasoning. Final weight of both 12% and 8% boron solution strength treated dry timber achieved low constant weight than green timber.

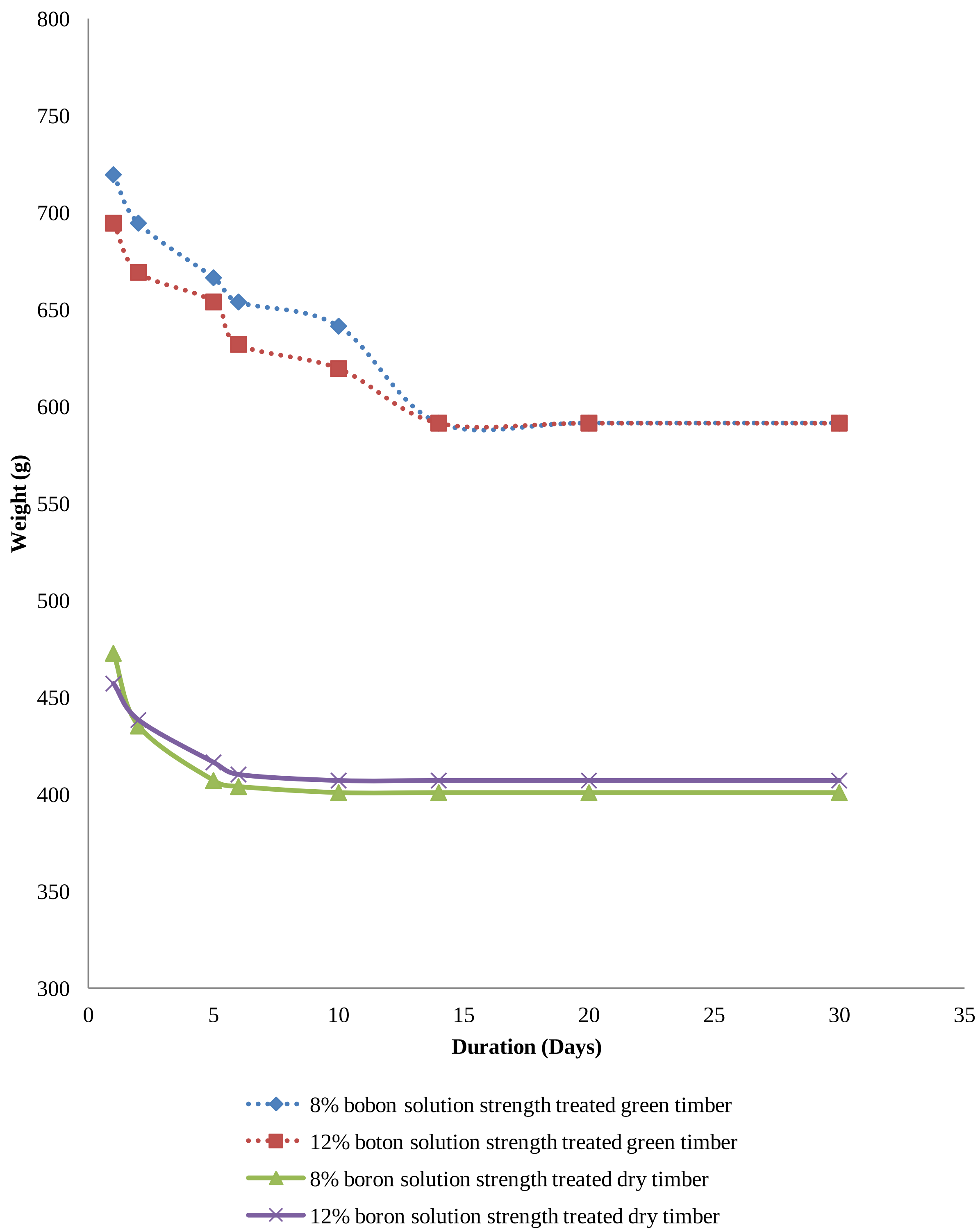


Figure 4.4: Air seasoning behavior after Hot and cold open tank method (Annex 02, A2.2)

In here both 8% and 12% boron solution strength treated green timber were achieved same final weight and both 8% and 12% solution strength treated dry timbers, final weight is lower than the green timbers.

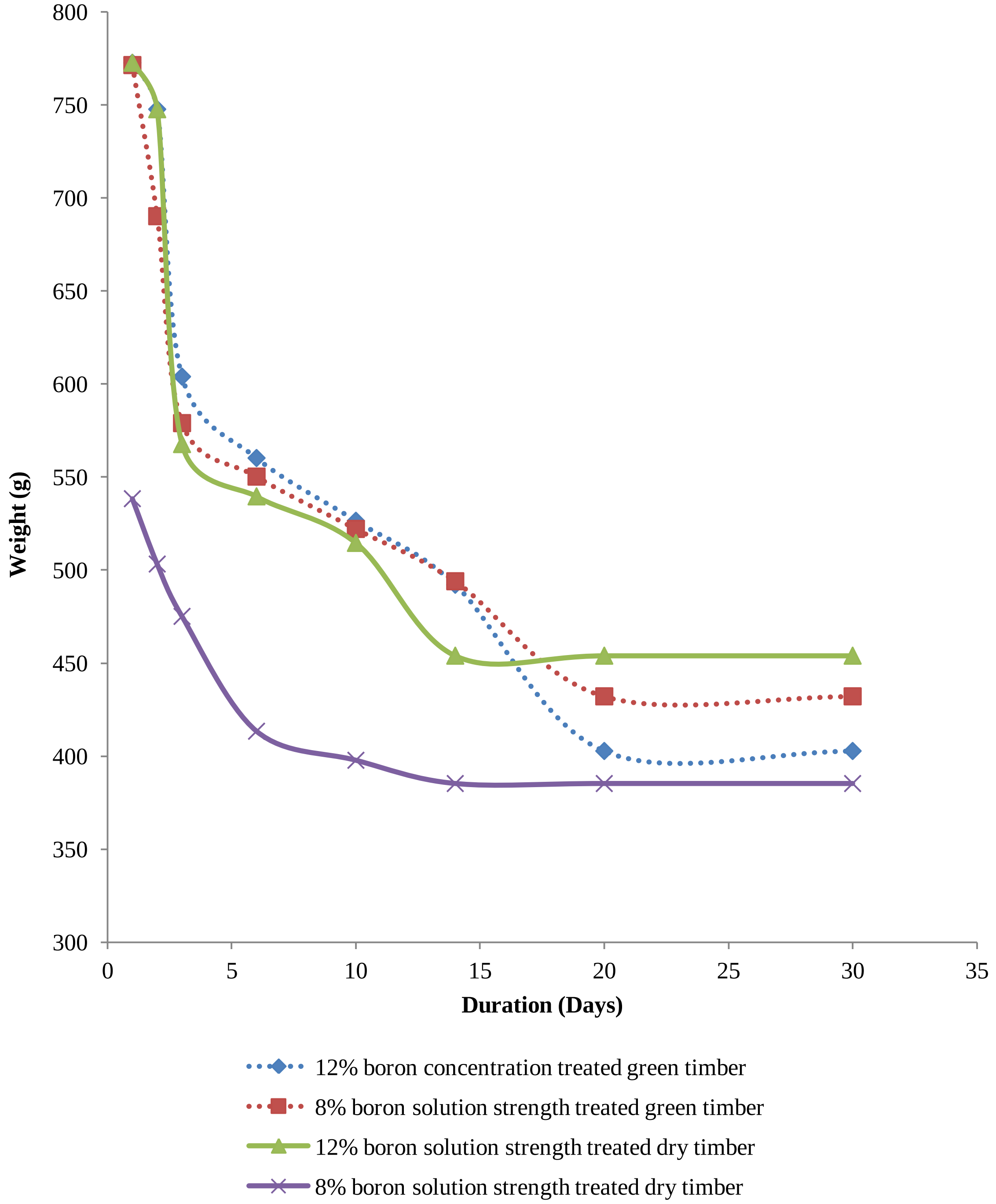


Figure 4.5: Air seasoning behavior after Steam cold quench method (Annex 02, A2.3)

Timbers that undergo four different conditions of the steam cold quench method were achieved four different final weights in the air seasoning. The final weight of the 8% boron solution strength treated dry timber < 12% boron solution strength treated green timber < 8% boron solution treated green timber < 12% boron solution strength treated dry timber.

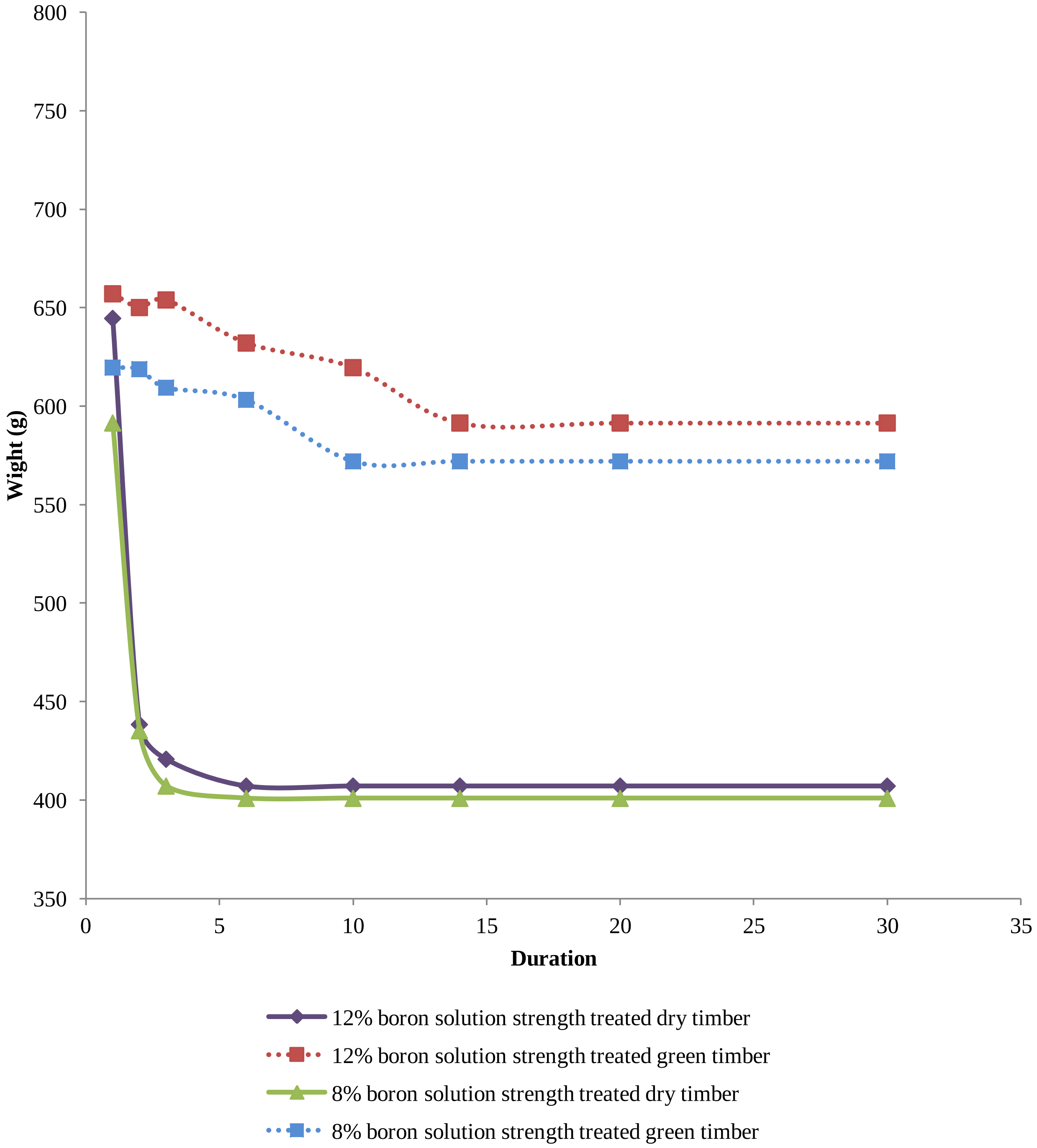


Figure 4.6: Air seasoning behavior after Vacuum pressure impregnation treatment (Annex 02, A2.4)

It is interesting to see that vacuum pressure impregnation treated dry timber shows fast drying rate than the green timbers and they achieved four different final weights in the air seasoning.

Table 4.1 Comparison of the number of days that taken to complete seasoning after treatment for different treatment methods

Treatment method	**Solution strength**	**Moisture condition**	
		Dry	Green
Vacuum pressure impregnation	8%	6	10
	12%	6	14
Steam cold quench	8%	14	20
	12%	14	20
Hot and cold open tank	8%	14	14
	12%	14	14
Diffusion	8%	10	14
	12%	10	14

Results are based eight treated wood pieces

4.3 Chemical retention

Chemical retention was calculated according to following equation in the unit of Kgm^{-3}.

$$CL = \frac{W2 - W1}{V}$$

$$CR = \frac{SS}{100} * CL$$

(Salamah and Mohd Dahlan, 2007)

CL = Chemical Load (Kgm^{-3})
CR = Chemical Retention (Kgm^{-3})
V = Volume of wood piece (m^3)

W1 = Weight before the treatment (Kg)
W2 = Weight after the treatment (Kg)
SS = Solution strength (W/W %)

Table 4.2 Mean values of chemical load (Kgm^{-3}) of treated dry and green timber for different treatment methods for two boron solution strengths

Treatment method	Solution strength	Moisture condition	
		dry	green
Vacuum pressure impregnation	8%	304.70	107.88
	12%	501.53	127.75
Steam cold quench	8%	264.96	196.83
	12%	340.66	203.47
Hot and cold open tank	8%	312.27	208.18
	12%	326.47	208.18
Diffusion	8%	36.91	61.51
	12%	54.88	63.40

Results are based in eight treated wood pieces

Table 4.3 Mean values of chemical penetration (Kgm^{-3}) of treated dry and green timber for different treatment methods for two boron solution strengths

Treatment method	Solution strength	Moisture condition	
		Dry	Green
Vacuum pressure impregnation	8%	24.38	8.63
	12%	60.18	15.33
Steam cold quench	8%	21.20	15.75
	12%	40.88	24.42
Hot and cold open tank	8%	24.98	16.66
	12%	39.18	24.98
Diffusion	8%	2.95	4.92
	12%	6.59	7.61

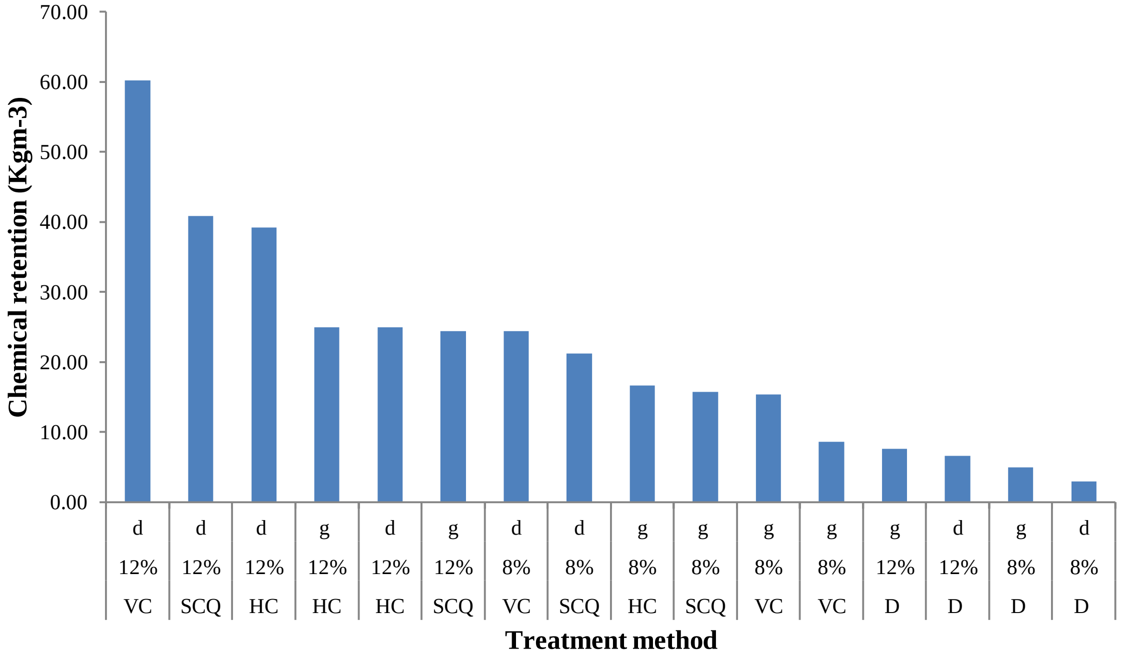
Results are based on eight treated wood pieces

Vacuum pressure impregnation for dry timber at 12% boron solution strength gave the highest chemical retention among all compared four treatment methods (Table 4.3 and Figure: 4.7). Steam cold quench method for dry timber at 12% boron solution strength gave the second highest chemical retention and Hot and cold open tank method for dry wood in 12%boron solution strength gave third best chemical retention. Diffusion treated dry and green rubber wood gave lowest chemical retention compared with other treatment methods. The graphical comparison of the treatment methods were presented in above pages where the difference of chemical retention of different treatment methods can clearly observed.

Table 4.4 Analysis of variance for chemical retention of different treatment methods

source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Treatment method	3	1310.70	1310.70	436.90	11.57	0.037
Moisture condition	1	650.80	650.80	650.80	17.23	0.025
Solution strength	1	621.27	621.27	621.27	16.45	0.027
Treatment method * moisture condition	3	516.35	516.35	172.12	4.56	0.122
Treatment method * solution strength	3	168.19	168.19	56.06	1,48	0.377
Moisture condition * solution strength	1	137.67	137.67	137.67	3.65	0.152
Error	3	113.28	113.28	37.79		
Total	15	3518.26				

According to the ANOVA results, treatment methods, solution strengths and moisture conditions are significant at $p \leq 0.05$.



VC = Vacuum pressure impregnation

SCQ = Steam cold quench

HC = Hot and cold open tank

D = Diffusion

d = dry condition

g = green condition

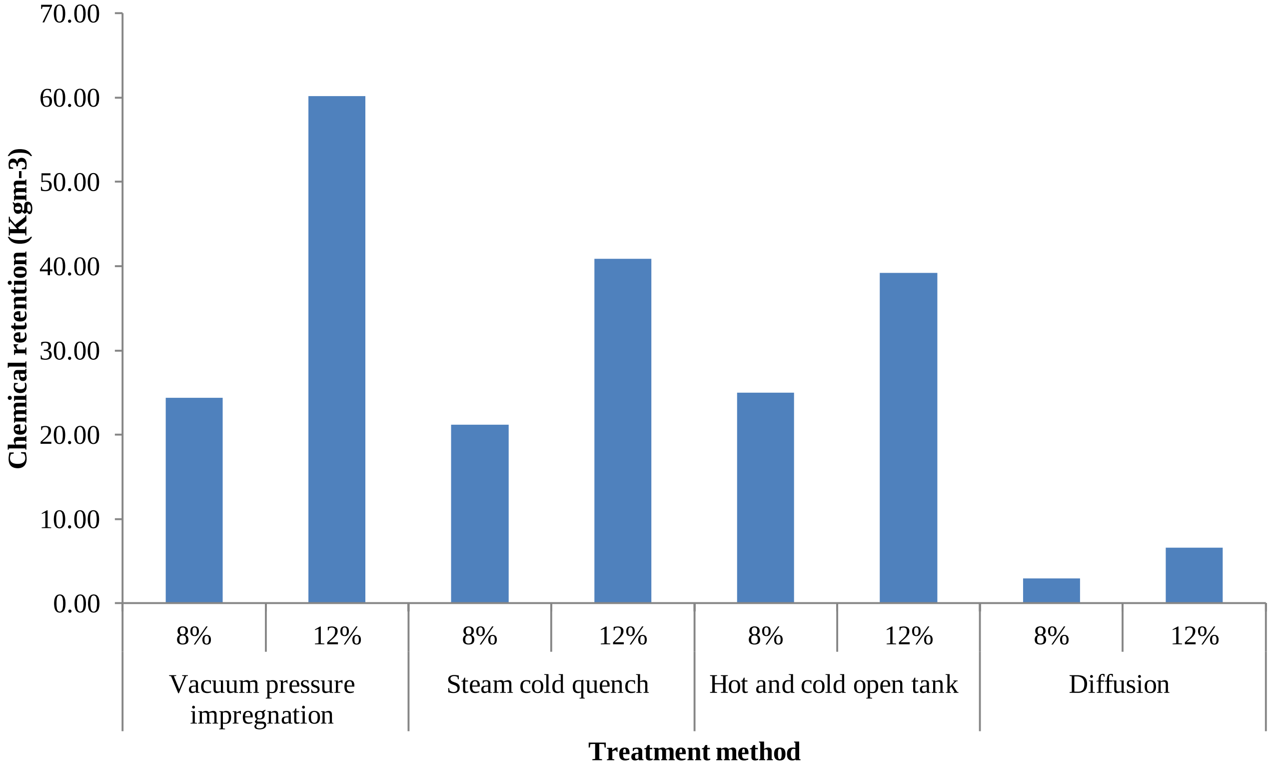
12% = 12% boron solution strength

8% = 8% boron solution strength

Figure 4.7: Chemical Retention for different treatment methods

4.3.1 Chemical retention for dry timber

Chemical retention for dry wood (moisture content 12% - 15%) for all four methods are given in fig 4.8. According to that vacuum pressure impregnation method gave the highest chemical retention than the other treatment methods for dry rubber wood. Secondly steam cold quench method and thirdly hot and cold open tank method. Diffusion had the least chemical retention for the dry timber. 8% boron solution strength treated dry timber gave relatively lower retention value than 12% solution strength treated dry timber.

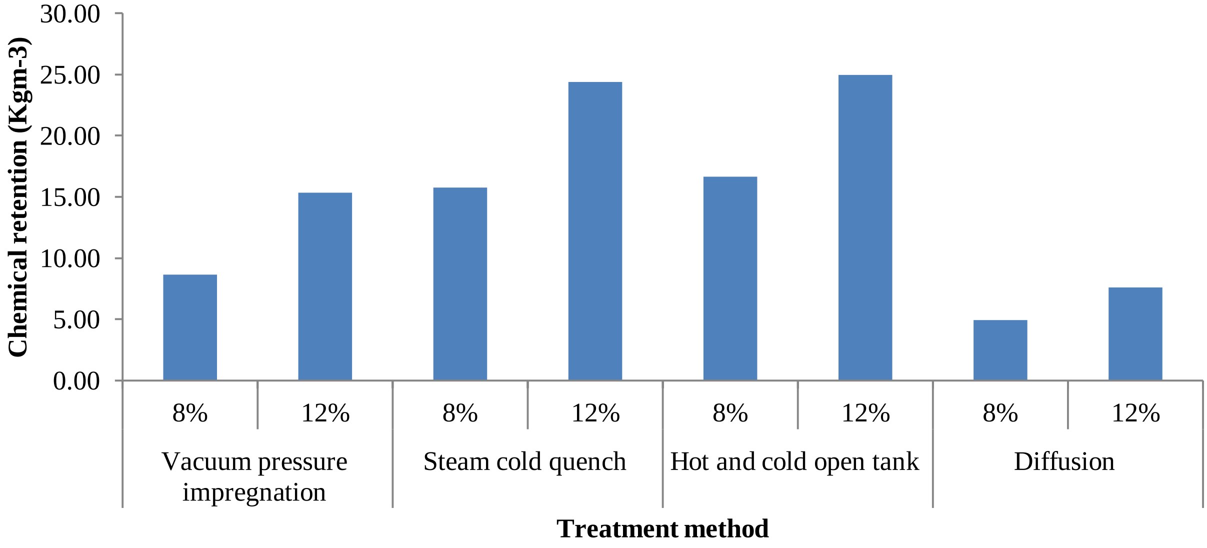


8% = 8% boron solution strength 12% = 12% boron solution strength

Figure4.8: Comparison of chemical Retention for dry timber for four treatment methods

4.3.2 Chemical retention for green timber

Hot and cold open tank method treated green rubber wood (M.C. 70%-60%) gave highest chemical retention for 12% solution strength and for the 8% solution strength also (Figure 4.9). Steam cold quench method is the second best method for treatment for green rubber wood treatment. Diffusion gave lowest chemical retention. Although vacuum pressure impregnation method gave high chemical retention for treated dry wood, it gave low chemical retention for the green rubber wood but it is high than the diffusion method.

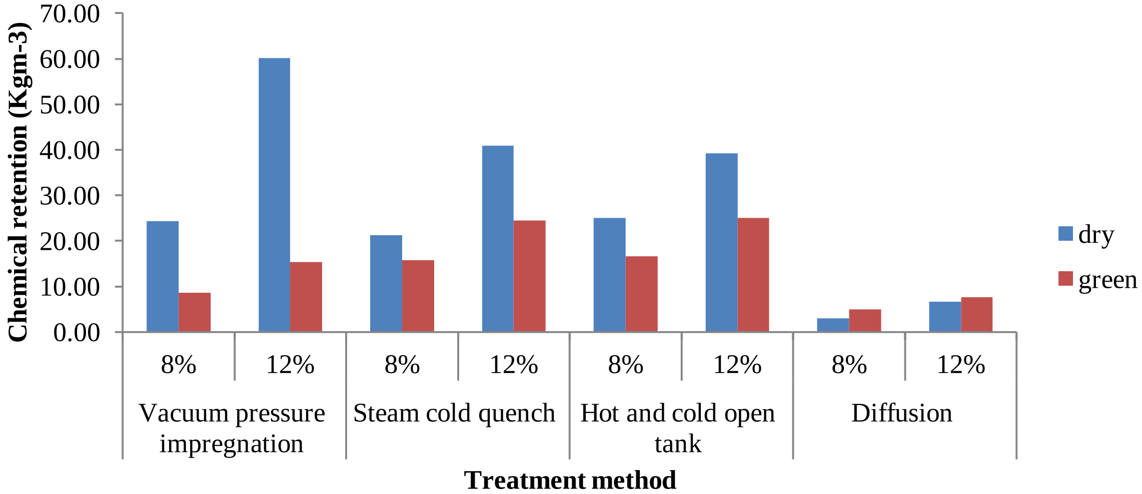


8% = 8% boron solution strength 12% = 12% boron solution strength

Figure4.9: Comparison of chemical retention for green timber for four treatment methods

4.3.3 Impact of moisture condition for chemical retention

When considering two moisture contents dry and green, for all the treatment methods dry timber gave high chemical retention for both boron solution strengths than green timber except for diffusion treatment (Figure:4.10). In diffusion treatment, green timber gave higher chemical retention than dry timber.

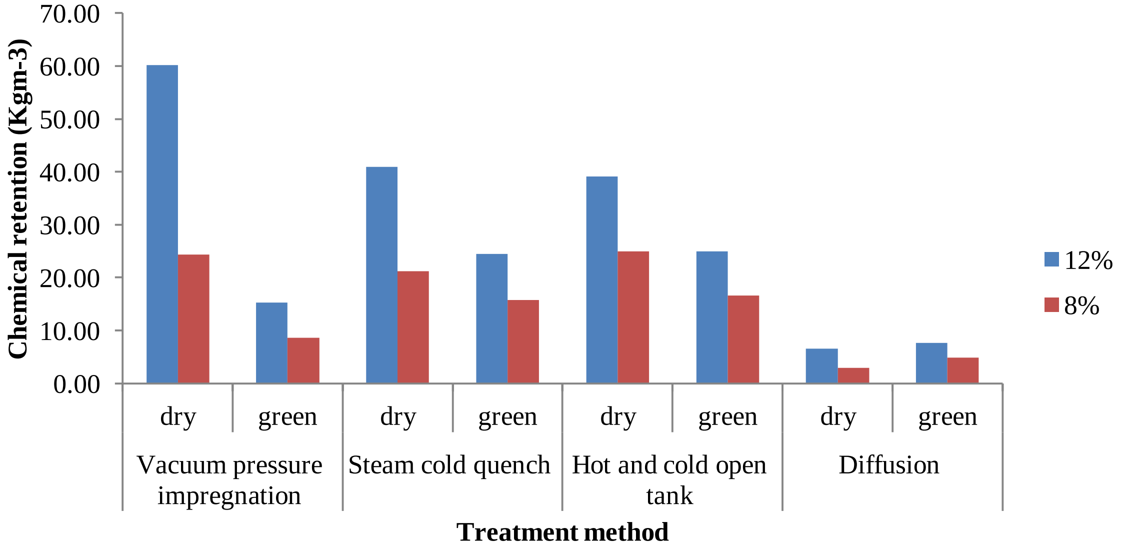


8% = 8% boron solution strength 12% = 12%boron solution strength

Figure4.10: Comparison of Chemical Retention for two different moisture contents of rubber wood

4.3.4 Impact of boron solution strength for chemical retention

12% boron solution strength gave higher chemical retention for both dry and green rubber wood than 8% boron solution strength for each treatment method (Fig 4.11). Therefore chemical retention is increases with the solution strength. There can be an optimum amount of solution strength for the preservative solution for this thickness of rubber wood. Further studies with more concentrations will be needed to find out the optimum amount of preservatives for this sample size where chemical retention is no longer increase with the solution strength.



dry = dry condition green = green condition

8% = 8% boron solution strength 12% = 12% boron solution strength

Figure4.11: Comparison of Chemical Retention for two Boron solution strengths

4.4 Chemical penetration

The amount of preservatives at the core of the treated wood samples were measured by atomic absorption spectrophotometer.

Table 4.5 The amount of preservative at the core of treated wood (ppm) for different treatment methods for different moisture conditions and different boron concentrations

Treatment method	**Solution strength**	**Moisture condition**	
		dry	green
Vacuum pressure impregnation	8%	1.573	0.421
	12%	10.305	0.644
Steam cold quench	8%	-	-
	12%	2.51	-
Hot and cold open tank	8%	0.651	-
	12%	0.703	0.691
Diffusion	8%	-	-
	12%	-	-

R^2 = 1.000 Maximum error = 11.637 ppm

- = amount of chemicals were lower than the detectable range of the instrument used

Results are based on one treated wood piece (4^{th} one from every treatment method) and three data from each one.

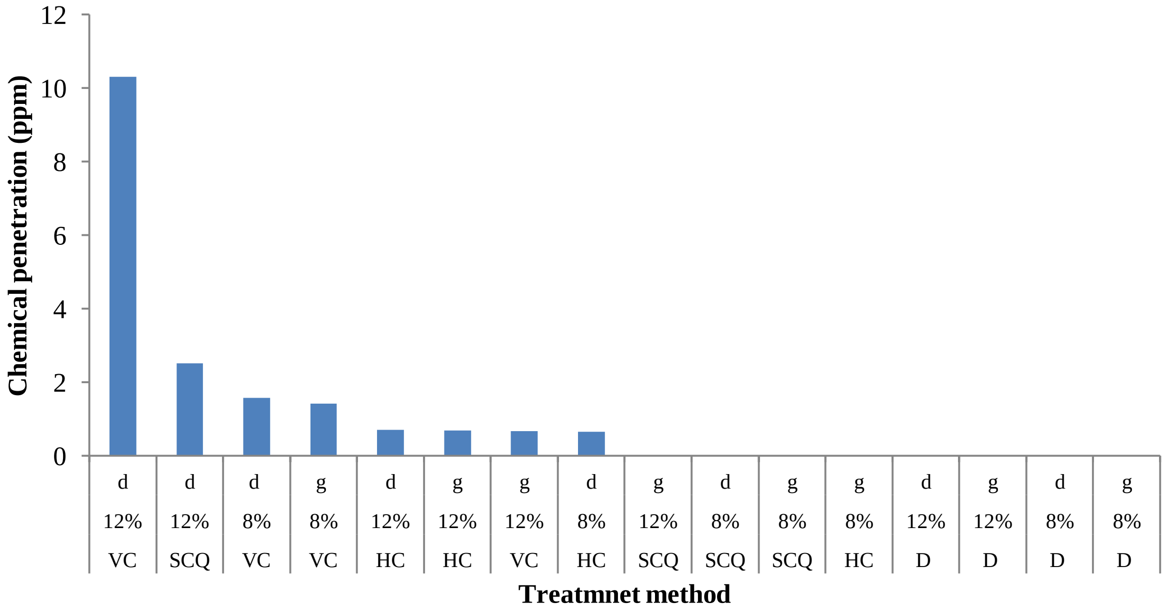
Dry timber treatment with 12% moisture condition in vacuum pressure impregnation method gave the highest penetration. According to the results steam cold quench, 8% solution strength treated dry rubber wood, steam cold quench both 12% and 8% solution strength treated green timber has very low amount of preservative in the core. Hot and cold open tank method 8% solution strength treated green timber also have very low amount of chemicals at the core. It is interesting to see that none of diffusion treated timber contained detectable amount of boron at the core.

Table 4.6 Analysis of variance for the amount of chemical penetration

source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Treatment method	3	25.365	25.365	8.455	1.94	0.299
Moisture condition	1	12.226	12.226	12.226	2.81	0.192
Solution strength	1	9.315	9.315	9.315	2.14	0.239

Treatment method * moisture condition	3	18.690	18.690	6.230	1.43	0.387
Treatment method * solution strength	3	12.446	12.446	4.149	0.95	0.515
Moisture condition * solution strength	1	6.734	6.734	6.734	1.55	0.302
Error	3	13.044	13.044	4.348		
Total	15	87.819				

ANOVA indicate that treatment methods, moisture condition and solution strength are not significant at $P \leq 0.05$.



VC = Vacuum pressure impregnation SCQ = Steam cold quench

HC = Hot and cold open tank D = Diffusion

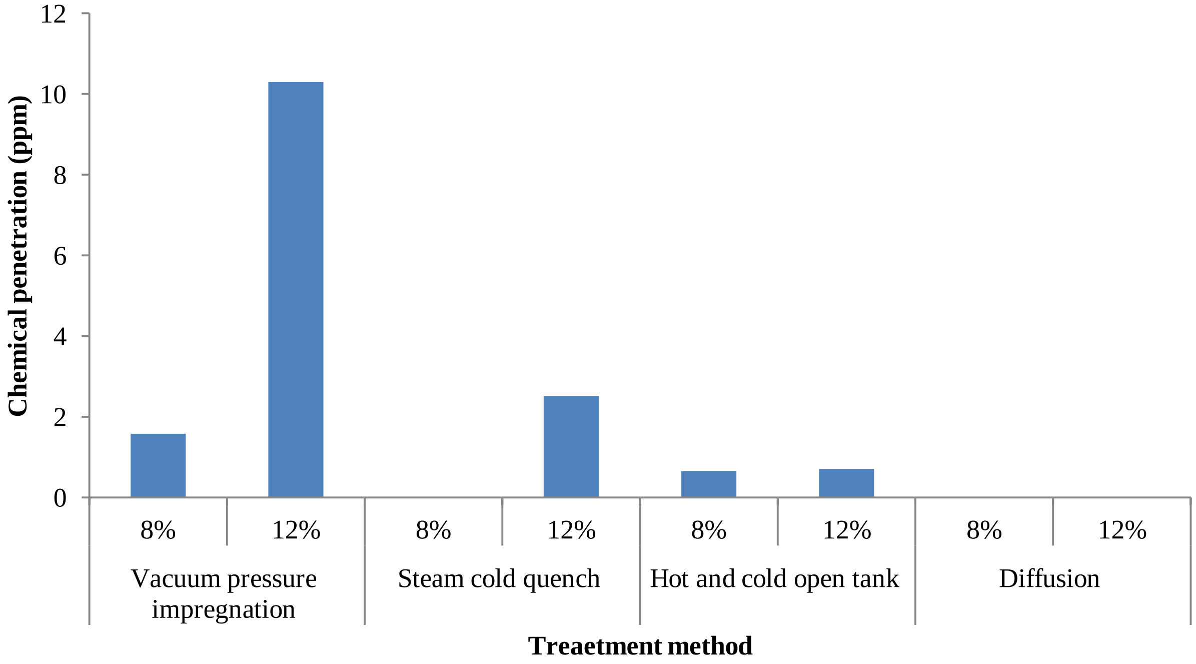
d = dry condition g = green condition

12% = 12% boron solution strength 8% = 8% boron solution strength

Figure 4.12: Chemical penetrations of different treatment methods

4.4.1 Chemical penetration for dry timber

When considering chemical penetration of treated dry rubber wood only for, four treatment methods vacuum pressure impregnated, 12% boron solution strength treated sample gave the highest chemical penetration. Vacuum pressure impregnation 8 % solution strength treated dry rubber wood contained 1.573 ppm amount of boron at the core containing highest amount of preservatives at the core. Hot and cold open tank method treated rubber wood for both 12% and 8% solution strengths gave 0.703 ppm and 0.651 ppm boron at the core (Fig 4.13).

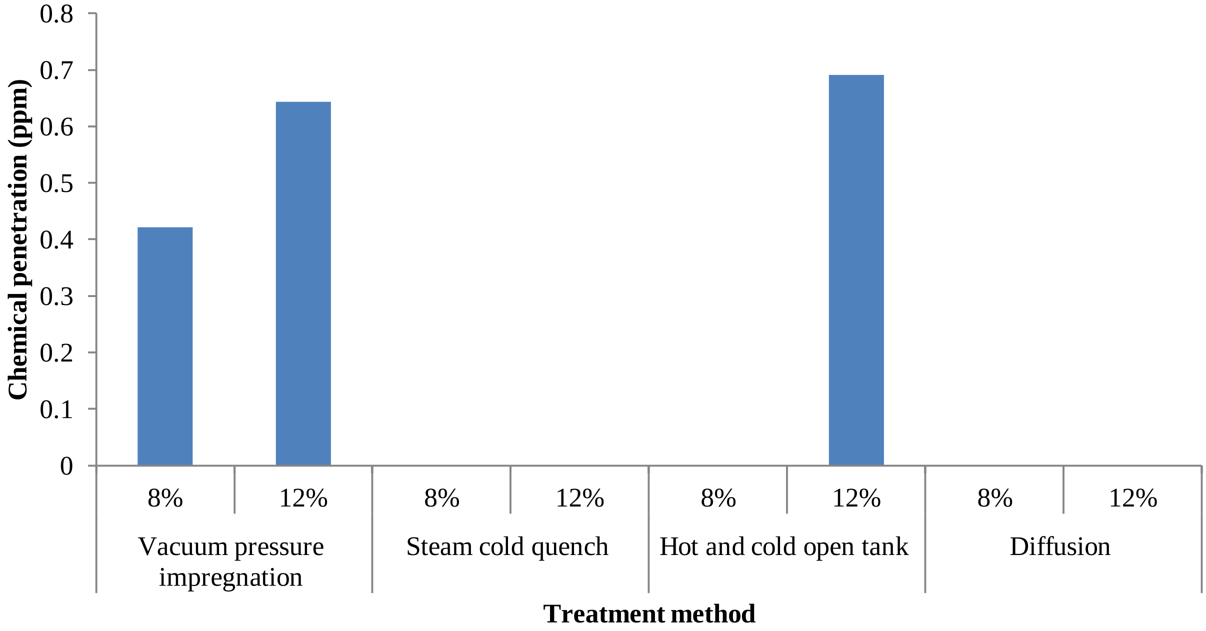


8% = 8% boron solution strength 12% = 12% boron solution strength

Figure 4.13: Comparison of chemical penetration to the core of treated timber

4.4.2 Chemical penetration for green timber

Only two treatment methods had penetration in to the core with boron preservatives; vacuum pressure impregnation and hot and cold open tank method for the green timber (figure 4.14). In vacuum pressure impregnation method boron preservatives were penetrated in to the core of the green rubber wood in both 12% and 8% solution strengths but 12% solution strength treated wood gave high amount of chemicals. Other than vacuum pressure impregnation hot and cold open tank method 12% boron solution strength treated green rubber wood gave 2.51 ppm chemicals at the core. Hot and cold open tank method 12% solution strength treated green rubber wood gave the highest chemical penetration.

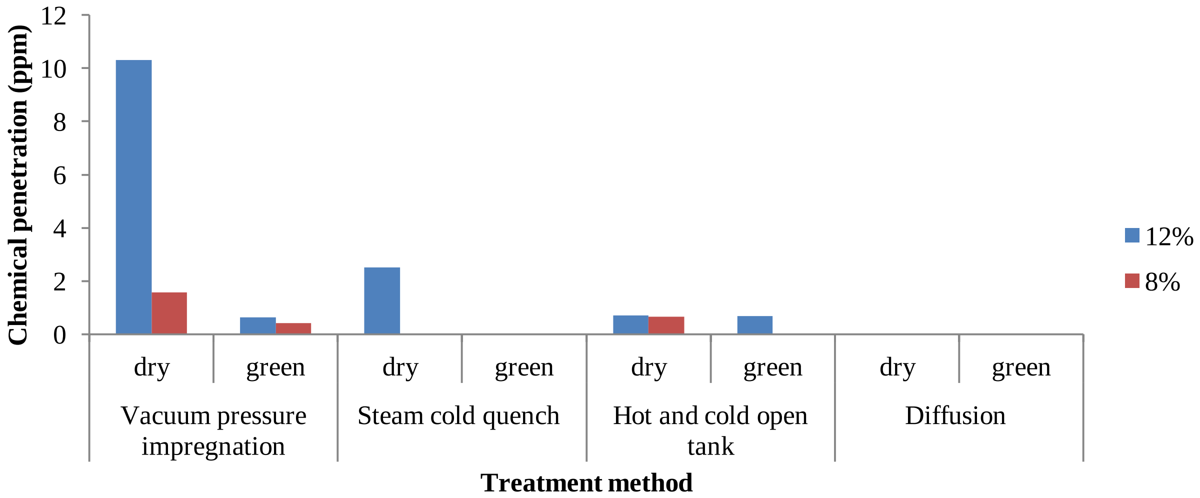


8% = 8% boron solution strength 12% = 12% boron solution strength

Figure 4.14: Chemical penetrations to the core of treated wood in green timber

4.4.3 Impact of boron solution strength for chemical penetration

When comparing chemical penetration at the 12% and 8% solution strengths (Fig 4.15) it shows that chemical penetration increased with the solution strength.

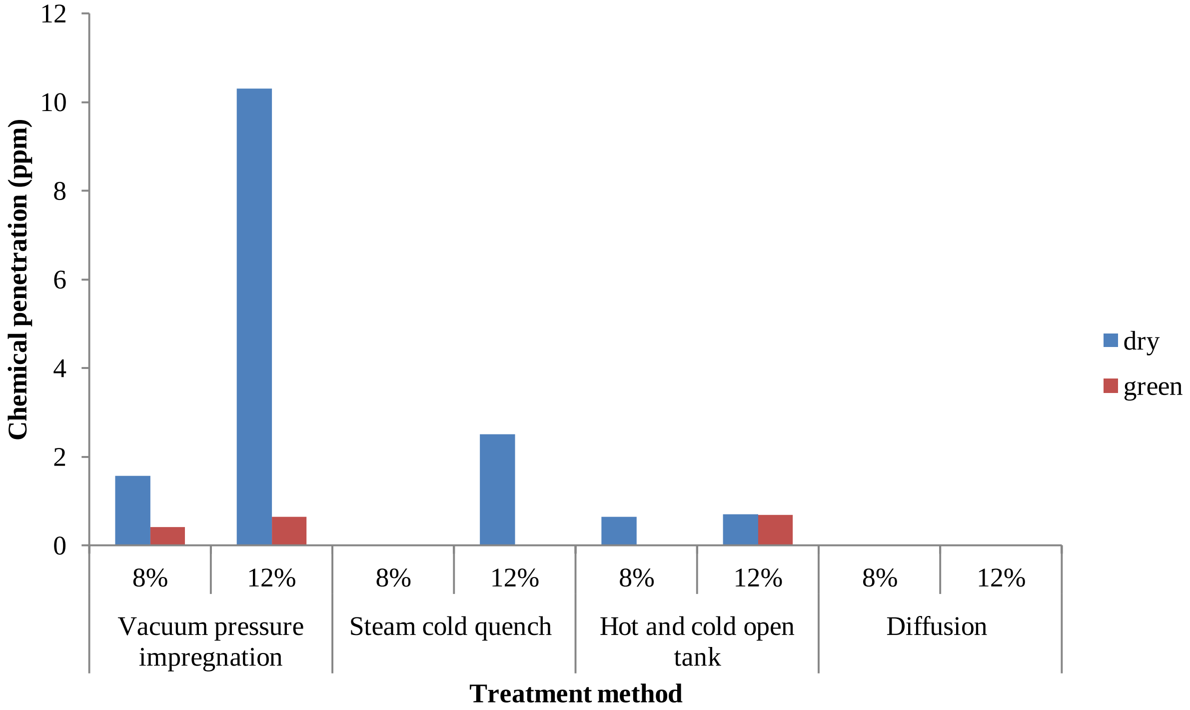


8% =8% boron solution strength 12% = 12% boron solution strength

Figure 4.15: Comparison of chemical penetration to the core of treated wood for two boron concentrations and four treatment methods

4.4.4 Impact of moisture condition for chemical penetration

When comparing chemical penetration for dry and green timber dry timber gave higher chemical penetration for, all treatment methods than green timber except for diffusion method (Fig 4.16).



8% = 8% boron solution strength

12% = 12% boron solution strength

dry = dry timber

green = green timber

Figure 4.16: Comparison of chemical penetration to the core of treated wood for dry and green conditions for, four treatment methods

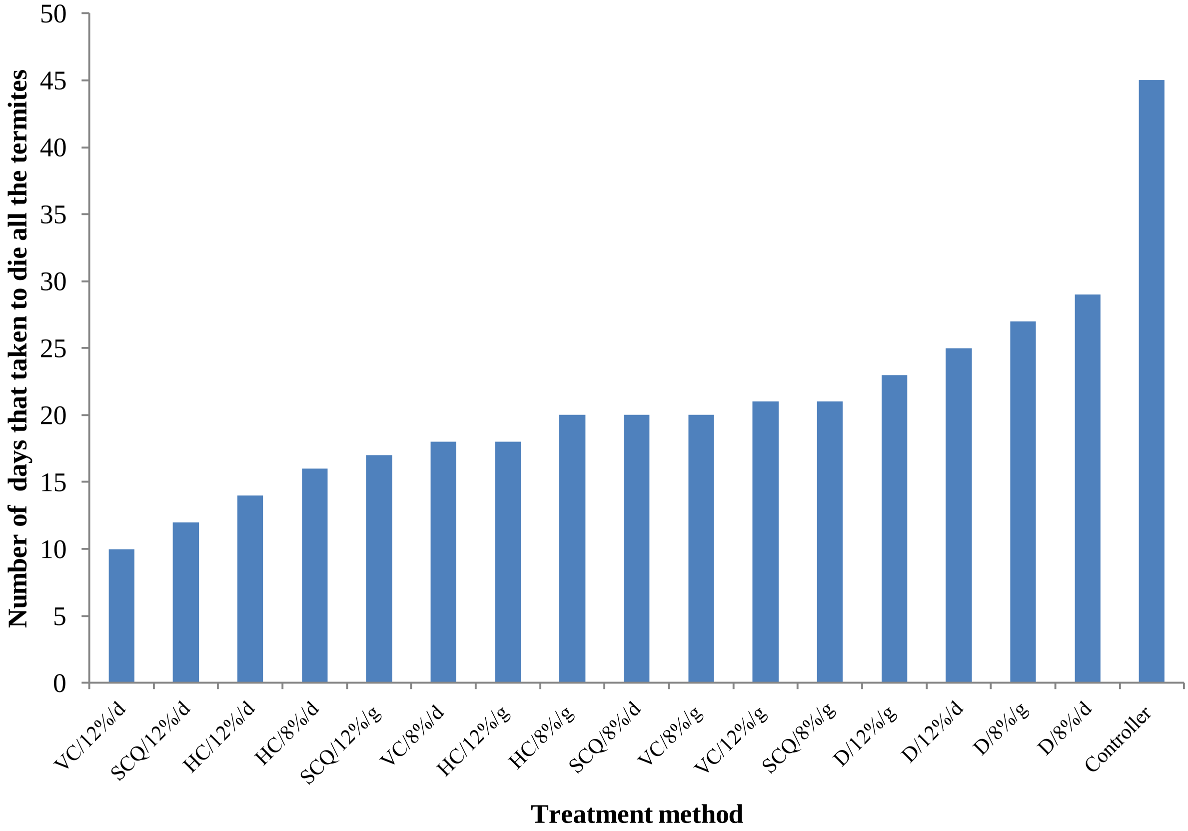
4.5 Termite test

Sandwich method was carried out for this experiment. Results are based on three sandwiches from each treatment method. Number of days that taken to die all the introduced *Cryptotermes domesticus* (Dry wood termites), 4 nymphs and 6 workers were measured. Dry wood termites that were introduced to the Vacuum pressure impregnated dry timber treated by 12% boron concentration died within 10 days after the day of introduction. Dry timbers that undergo steam cold quench method 12% boron solution strength gave second best results for termite test. Dry wood termites that introduced to that sandwiches die within 12 days after the introduction. Termites that introduced to diffusion treated dry wood timber were survived for 29 days. In the control all the introduced termites were survived 45 days.

Table 4.7 Number of days that taken to die all the introduced termites for each treatment method

Treatment method	Solution strength	Moisture condition	
		dry	green
Vacuum pressure impregnation	8%	18	20
	12%	10	21
Steam cold quench	8%	20	21
	12%	12	18
Hot and cold open tank	8%	16	20
	12%	14	17
Diffusion	8%	29	27
	12%	25	23

Results are based on three sandwiches from each treatment method



VC = Vacuum pressure impregnation SCQ = Steam cold quench

HC = Hot and cold open tank D = Diffusion

d = dry condition g = green condition

8% = 8% boron solution strength 8% = 8% boron solution strength

Figure 4.17: Number of days that taken to die all the introduced termites for different treatment methods

4.5.1 Rate of dying of dry wood termites of treated timber by different treatment methods

The rate of dying of termites for the different treatment methods is different. In some treatment methods introduced dry wood termites showed slow dying rate and in some treatment methods they showed fast dying rate. The rate of dying was slow for the all the diffusion treatment methods at the beginning and it took fast with time.

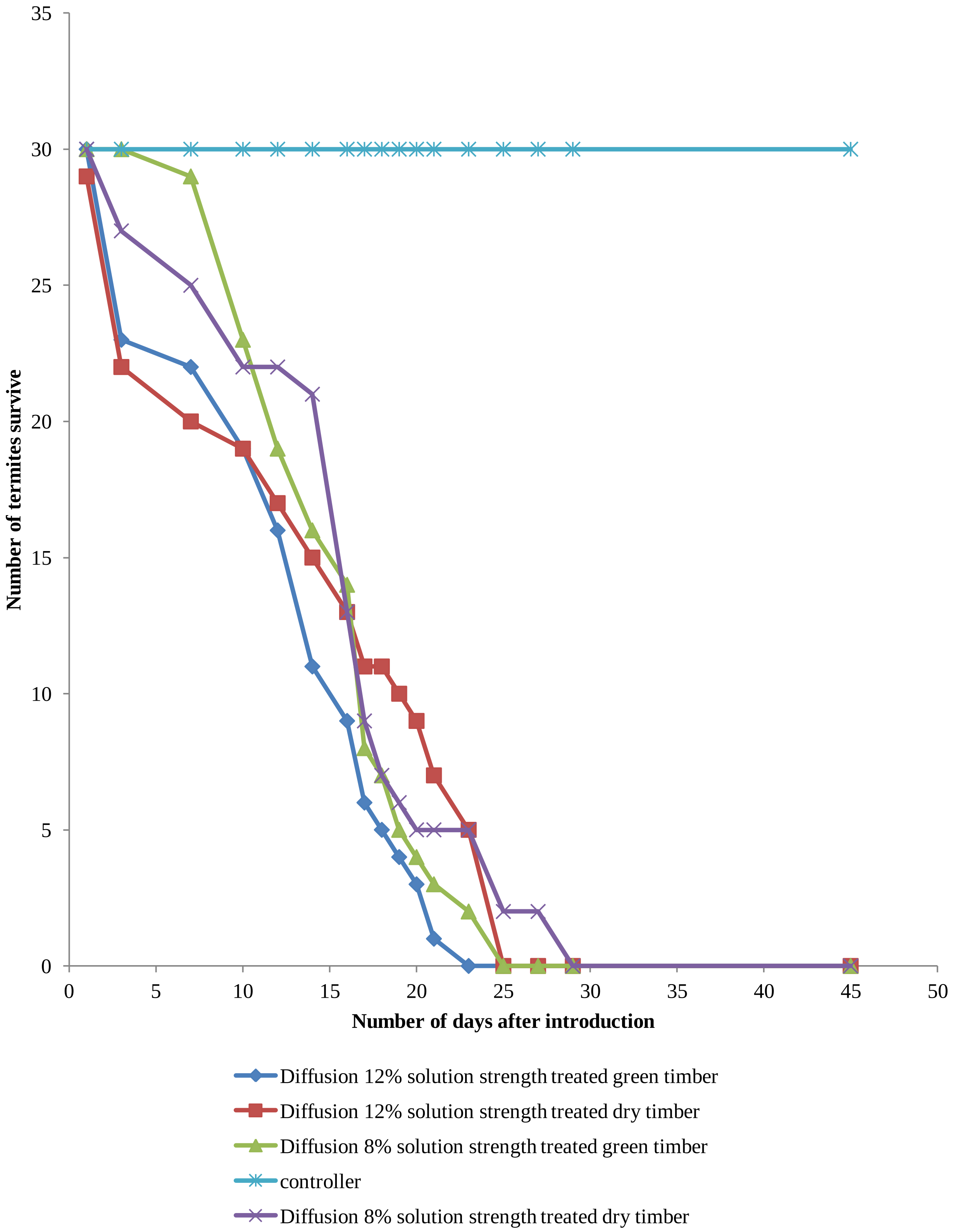


Figure 4.18: Rate of dying of introduced dry wood termites to diffusion method treated wood

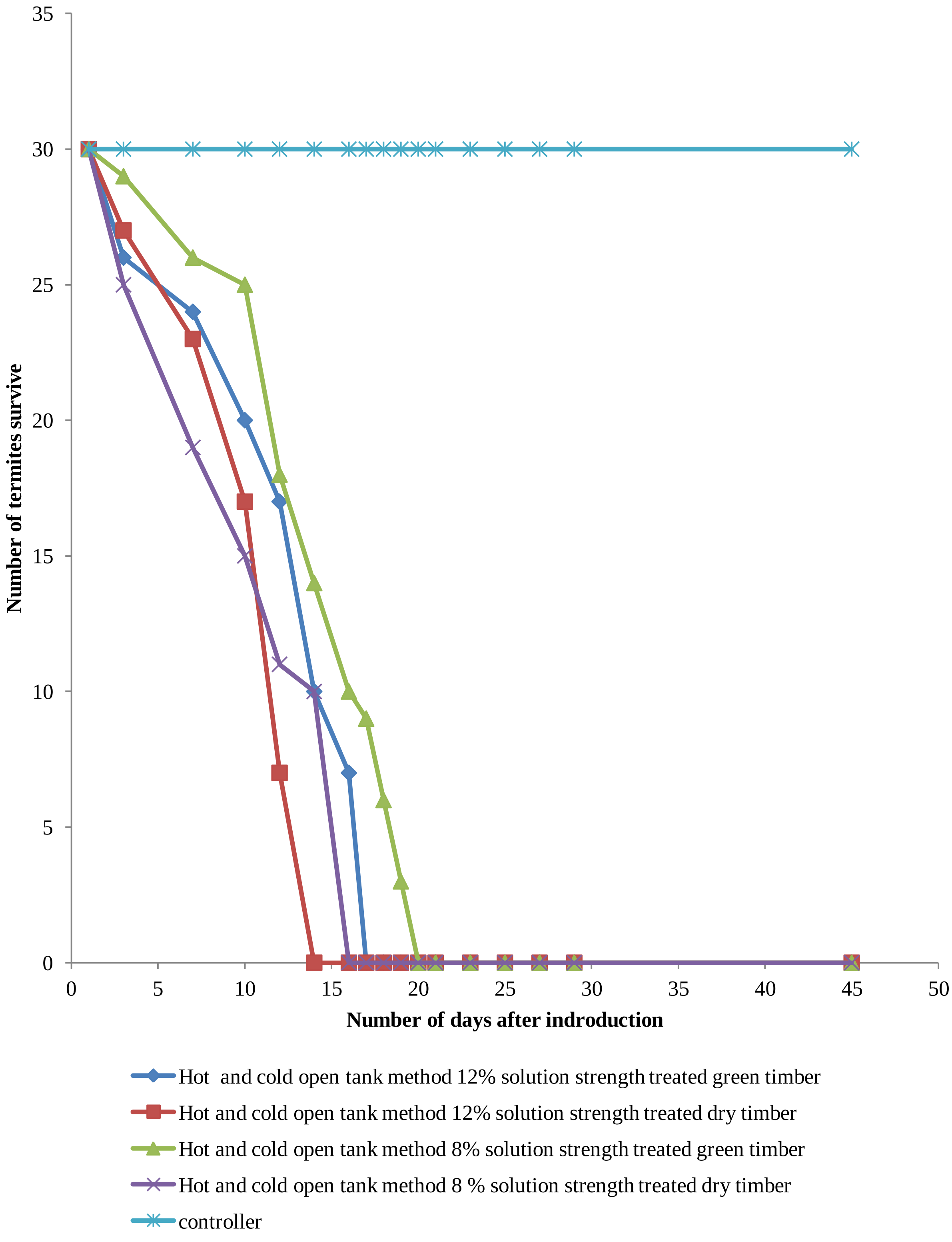


Figure 4.19: Rate of dying of introduced dry wood termites to hot and cold open tank method treated wood

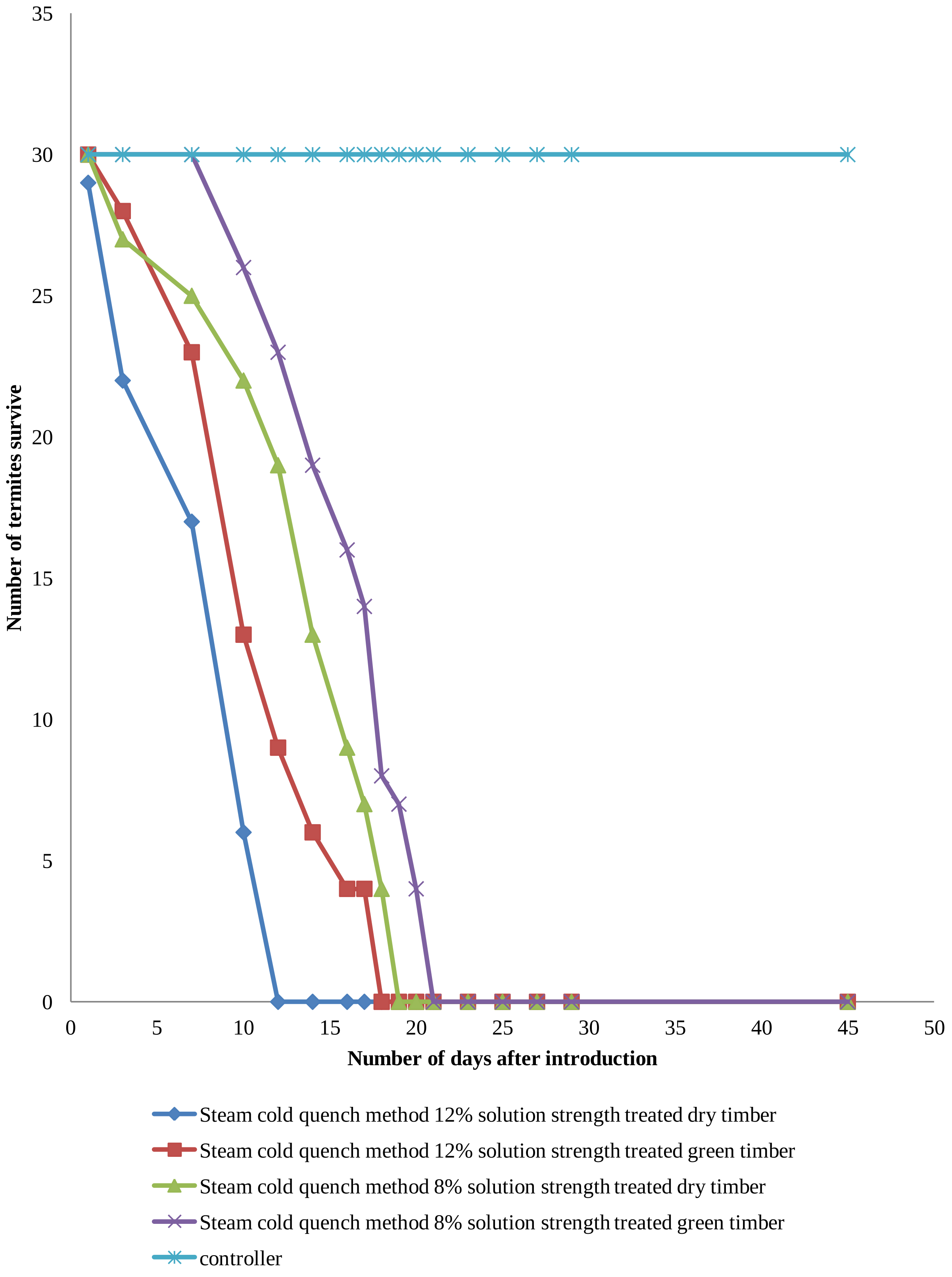


Figure 4.20: Rate of dying of introduced dry wood termites to steam cold quench method treated wood

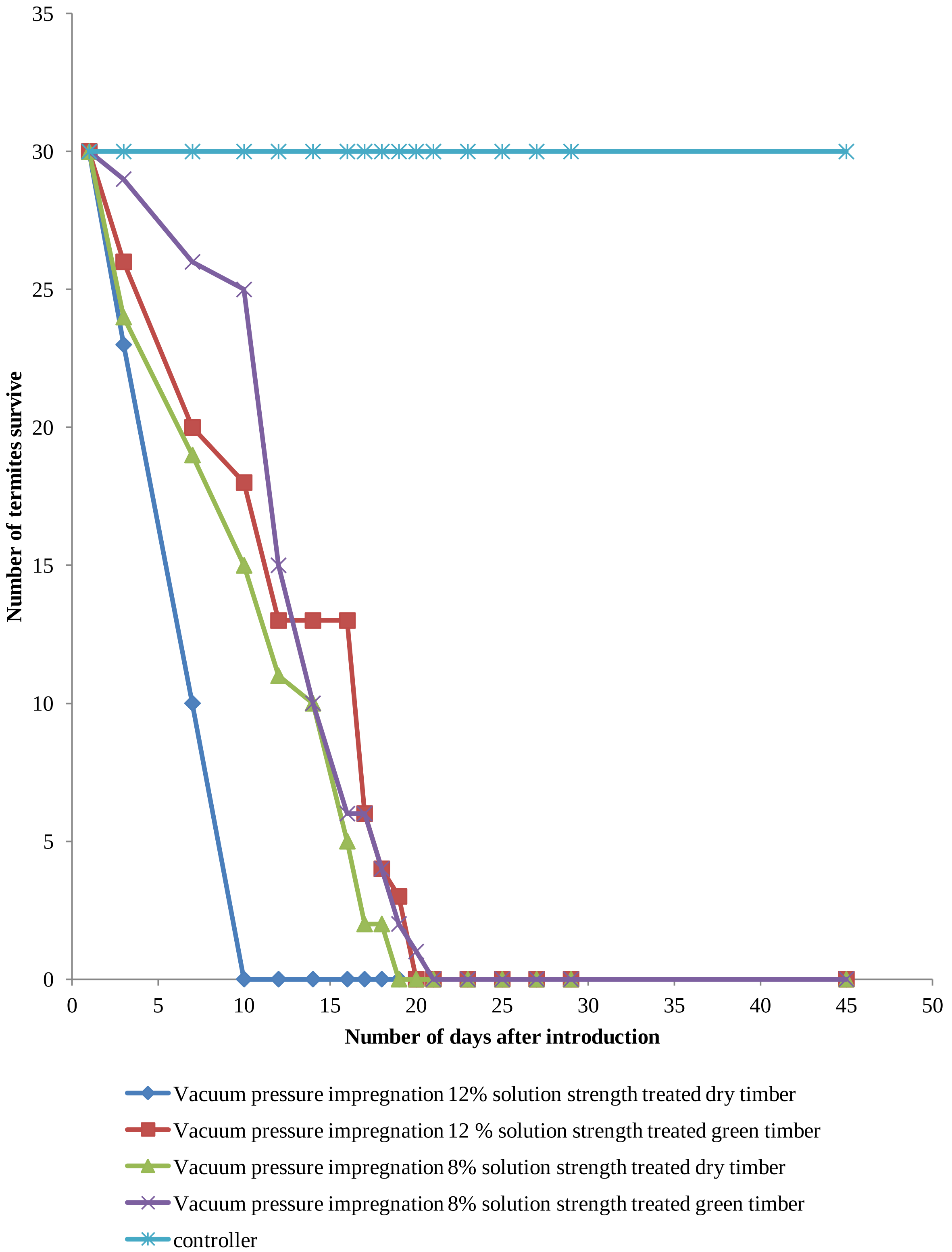


Figure 4.21: Rate of dying of introduced dry wood termites to vacuum pressure impregnation treated timber.

4.6 Cost of treatment of one cubic meter of rubber wood

Cost of treatment of one cubic meter of rubber wood for three treatment methods were carried out for three industries which are practicing those treatment methods for rubber wood for commercial purposes. Three methods are dip diffusion, hot and cold open tank method and vacuum pressure impregnation method. Cost of treatment was calculated using following equation by collected data from three industries

$$\textit{Cost of treatment of one cubic meter of rubber wood} = \frac{EC + LC + TC + CC}{V}$$

EC = Energy cost per one operation

LC = Labor cost per one operation

TC = Timber cost per one operation

CC = Chemical cost per one operation

V = Volume of timber treating per one operation

Table 4.8 Cost values and volume of timber amount for one operation for Plant A, B and C

Treatment method	**Cost values per one operation**				**Volume of timber treating per one operation (m^3)**
	EC	LC	TC	CC	
Dip Diffusion method (Plant A)	Rs.15.00	Rs.1000.00	Rs.15000.00	Rs.7695.00	2.7 m^3
Hot and Cold Open tank method (Plant B)	Rs.80.00	Rs.3000.00	Rs.15000.00	Rs.7000.00	2.7 m^3
Vacuum Pressure Impregnation method (Plant C)	Rs. 5550.00	Rs.5000.00	Rs.29970.00	Rs.29900.00	5.4 m^3

(Annex 06)

Calculation

Cost of treatment of 1m^{-3} rubber wood for dip diffusion method

$$= \frac{\text{Rs.15.00 + Rs.1000.00 + Rs.15000.00 + Rs.7695.00}}{2.7\ m^3}$$

$$= \text{Rs.8781.48}\ m^{-3}$$

Cost of treatment 1 m^{-3}of rubber wood by hot and cold open tank method

$$= \frac{\text{Rs.80.00 + Rs.3000.00 + Rs.15000 + Rs.7000.00}}{2.7\ m^3}$$

$$= \text{Rs.9288.00}\ m^{-3}$$

Cost of treatment 1 m^{-3} of rubber wood by vacuum pressure impregnation method

$$= \frac{\text{Rs.150.00 + Rs.5000.00 + Rs.29970.00+ Rs.29900}}{5.4\ m^3}$$

$$= \text{Rs.12040.00}\ m^{-3}$$

Dip diffusion method was the cheapest method of treatment of one cubic meter of rubber wood among three treatment methods. One cubic meter rubber wood treatment by hot and cold open tank method had higher cost than dip diffusion method but it is lower than vacuum pressure impregnation method. Vacuum pressure impregnation method had the highest cost of treatment for one cubic meter of rubber wood.

CHAPTER FIVE: DISCUSSION

Numbers of preservatives are used for the preservation of wood which makes non durable timber such as rubber wood. CCA, Pentachlorophenate, CCB, Creosote, Boron are some of common preservatives. Boron, is an effective preservative which do not discolor the treated wood, easy applicable and less expensive. However it can be leached out with water because it is water borne preservative. Therefore it is recommended to use boron treated wood for indoor applications (Negi, 1997).

5.1 Boron solution strength

Boron preservative is a mixture of boric acid and borax in 1:1.54 proportions, different timber treatment establishments are use different boron solution strengths for treatment. For one can dissolve 2 Kg of boric acid and 3.08 Kg of borax in 12 L of water and another can dissolve the same amount of preservative in 24 L of water. The solution strength is different in the two cases. The boron solution strengths that are used in this study were 12% and 8%. 12% is the solution strength is currently used by Finlay Rentokil and 8% solution strength is used by two other dip diffusion practicing private companies.

5.2 Chemical retention

Chemical retention of preservative treated timber is the amount of preservatives that will retain in a unit volume (FAO,1986) of treated timber. In the present study vacuum pressure impregnated 12% boron solution strength treated dry timber gave the highest chemical retention however, chemical retention in the green condition was low. Steam cold quench method treated timber gave high retention with the 12 % solution strength for both dry and green conditions.

In hot and cold open tank method treated green rubber wood shows same chemical retention for both 12% and 8% boron solution strengths. Hot and cold open tank method 12% solution strength and 8% solution strength dry timber gave 326.47 Kgm^{-3} and 312.27 Kgm^{-3} chemical loads which has only 14.19 Kgm^{-3} differences. Therefore it is clear that high chemical retention for this thickness of both green and dry rubber wood can be achieved using hot and cold open tank method (Fig: 4.11).

5.3 Chemical penetration

There are two terms with the chemical penetration; the depth of penetration and the amount of chemicals penetrated to the core of wood. Treated timbers are used in number of purposes. High chemical penetration is needed for timber used for furniture manufacturing because further processes after the treatment is done and surface layers can be removed in machining. Exposing of untreated wood can be infect by insects and other deterioration causes. Therefore it is important to use methods like vacuum pressure impregnation to obtain high chemical penetration if the treated wood will undergo further processing

Vacuum pressure impregnated 12% solution strength dry rubber wood gave the highest chemical penetration. Steam cold quench 12% solution strength treated dry rubber wood gave the second highest chemical penetration and hot and cold open tank method treated dry timber gave the third highest chemical penetration. In the vacuum pressure impregnation method external pressure is applied to the preservatives, therefore preservative is forced to penetrate in to the wood cell walls. In steam cold quench method, pan was closed with a lid therefore steam is collected in the system and that built a pressure to penetrate preservative to the wood cell walls with green timber. Hot and cold open tank method gave the highest chemical penetration with the green timber and steam cold quench method gave the second highest chemical penetration. Because of cooling after the heating vacuum is generated in hot and cold open tank method which will facilitate movement of chemicals in to the wood cell walls. However none of the diffusion treated rubber wood did not give detectable amount of chemical penetration which indicates that method provide only surface penetration.

5.4 Termite test

Termites were died quickly in timbers with high chemical retention and penetration for example vacuum pressure impregnated 12% solution strength dry timber, had the highest chemical retention and penetration and the termites that were introduced to the sandwiches made from that timber died within 10 days. Therefore it is clear that this treatment is effective in controlling the attack by dry wood termites to the timber. 8% solution strength diffusion treated dry timber gave lowest chemical retention and penetration and it took nearly one month period to die all the introduced dry wood termites. Therefore the effectiveness of the diffusion method treated wood is low. Termites that introduced to untreated control samples were survived for 45 days.

5.5 Cost calculation for treatment of one cubic meter of rubber wood for three different treatment methods

Cost of treatment of one cubic meter of rubber wood was carried out for three treatment methods based on three industries. Steam cold quench method is not currently practiced in Sri Lanka therefore cost calculation of that method was not carried out. Vacuum pressure impregnation method is the most costly method then hot and cold opens tank method. Cost of treatment of one cubic meter of rubber wood by diffusion method was lower than the other two methods.

5.6 Air seasoning of treated and untreated timber

In the air seasoning of untreated rubber wood took 8 days to achieve FSP, 25 % and took nearly one month period for achieve equilibrium moisture content (Fig: 4.2)

Diffusion treated green timber shows the same drying pattern (Fig: 4.3) and dry timber shows equal pattern for both boron solution strengths. Green timbers achieved high constant weight and dry timbers achieved lowest constant weight.

Timber should be in dry condition in order to carry out further processing after the preservative treatment. Vacuum pressure impregnated dry timber showed the fastest drying behavior by achieving constant weight within 6 days and diffusion treated dry timber took 10 days for the complete seasoning. But steam cold quench treated timber took more time to achieve a constant weight. However this seasoning pattern can vary with the thickness of the wood piece and with the weather conditions. The rapid drying behavior of vacuum pressure impregnated timber can be explained, as some amount of the excess chemicals and water on the wood piece was reabsorbed in the process of vacuum pressure impregnation.

5.7 Treatment method

Four different treatment methods were used in this study and each method has advantages and disadvantages. In considering vacuum pressure impregnation over other three treatment methods there are several advantages such as a large volume of timber can be treated in one operation, and the time that taken to complete treatment is very low. Therefore several charges can be treated within one day. The treatment chamber can be used to impregnate other wood preservatives also but plant operators would need to ensure that residual preservative in the lid did not because sludging. Cookson (1998) has mentioned in his study that the risk of growth of mould on vacuum pressure impregnated timber is low compared with timber treated with diffusion method. The major disadvantage with the vacuum pressure impregnation method, other than the cost of treatment, its high investment cost and plant operator's need special training for operate pressure plant safely.

The investment cost for the hot and cold open tank method treatment plant is lower than the vacuum pressure impregnation plant and want specially trained workers are not required for the operation.

Plate 5.1: Fungal attack to steam cold quench treated timber

Steam cold quench method treatment is used in Australia for wood preservation since long period of time but it is new to Sri Lanka. Although vacuum pressure impregnation method is the best method for dry rubber wood treatment and hot and cold open tank method is the best method for green rubber wood treatment (Chapter 6) steam cold quench method treated timber also gave good results. Steam cold quench 12% boron solution strength treated dry timber gave the second highest chemical retention, 40.88 Kgm^{-3} among all the treatment methods and steam cold quench method 12% boron solution strength treated green timber gave the third highest chemical retention in comparing chemical retention only for green timber (Fig 4.9). Steam cold quench method treated dry timber gave the second best result with the termite test among all the treatment methods and when comparing termite test for green timber steam cold quench method 12% boron solution strength treated green timber gave the second best result. In the situations where high chemical retention is needed and chemical penetration is not much important steam cold quench method can be recommended as a good treatment method to use for rubber wood preservation. It gave good chemical retention for both dry and green timber which indicates that this treatment can be used for both seasoned and unseasoned timber. However timber treated with this method took considerable time to complete air seasoning among all the treatment methods and there were fungi attack on treated wood. Therefore fast air drying (under heavy sun light) or kiln seasoning should be carried out after treatment.

CHAPTER SIX: CONCLUSION

6.1 Chemical retention

Vacuum pressure impregnation method found to be the best method for treatment of dry rubber wood (MC 12%-15%) but it is less effective for the green rubber wood. Hot and cold open tank method 12% boron solution strength treatment gave the highest chemical retention for the green rubber wood. Therefore the best method of treatment of green rubber wood in the situations where high chemical retention is needed hot and cold open tank method.

6.2 Chemical penetration

Three treatment methods gave measurable amount of preservatives at the core of treated wood and diffusion method has low chemical penetration. Among them vacuum pressure impregnation method shows the highest chemical penetration for dry wood in 12% solution strength. Although in the cause of green timber hot and cold open tank method 12% solution strength treated timber gave highest chemical penetration.

6.3 Termite test

Vacuum pressure impregnation treated 12% solution strength dry timber is most effective treatment in terms of termite resistance. Diffusion treated timber is the least effective method for termite test. In the cause of green timber hot and cold open tank method 12% boron solution strength treated timber gave the best results.

6.4 Cost of treatment of one cubic meter of rubber wood

The cheapest method of rubber wood treatment is diffusion and the vacuum pressure impregnation method is the most expensive.

6.5 Air seasoning behavior of treated and untreated rubber wood

It took 8 days for the green rubber wood to achieve FSP and 28 days to achieve EMC. Vacuum pressure impregnation treated dry timber shows the fastest drying pattern and steam cold quench treated timber shows the slowest drying pattern. Hot and cold open tank method treated wood and diffusion treated wood show moderate seasoning behaviors.

6.6 Best treatment method

As the final conclusion for the study vacuum pressure impregnation method is the best method for the treatment of dry rubber wood which gives highest chemical retention, highest chemical penetration, and best results with the termite test and show fastest air seasoning behavior. However the cost of treatment of one cubic meter of rubber wood is highest for the vacuum pressure impregnation method. Hot and cold open tank method is the best method for treatment of green rubber wood, which makes highest chemical retention, penetration and best result with the termite test for green rubber wood but it shows slow air seasoning behavior and cost of treatment is lower than vacuum pressure impregnation method.

CHAPTER SEVEN: RECOMMONDATIONS

7.1 Recommendations for the industry

1. If high retention and penetration are needed vacuum pressure impregnation method should be used for the dry rubber wood treatment.
2. Although retention and penetration is lower in hot and cold open tank method and steam cold quench method compared with vacuum pressure impregnation method these methods can be recommended for lower hazardous situation of timber use such as indoor application.
3. Seasoned rubber wood should be used in vacuum pressure impregnation and the steam cold quench method achieve high chemical retention
4. Green timber should be used in the preservative application by hot and cold open tank method and diffusion method
5. Vacuum pressure impregnated dry timber can be used in areas where dry wood termite attack is more pronounced.

7.2 Recommendations for further studies

1. Boron is water soluble preservative therefore the effectiveness of the preservative in treated rubber wood with time can be studied using the termite test.
2. The optimum solution strength for treatment can be studied by treating timber with more concentrations.

References

Bowyer J.L. Shmulsky R. Haygreen J.G. *Forest products and wood science*, fifth edition, Blackwell publishing, 2007, Pp 3-8

Browning B.L. 1963, *The chemistry of wood*, Interscience publishers, New York, London.

Caldaria F., (2010). Boron in wood preservation A review in its physico-chemical aspects. Silva lusitana 18(2). Portugal

Central bank of Sri Lanka, 2010, *Sri Lanka socio-economic data 2010* vol XXXIII. Central bank of Sri Lanka

Cookson L.J. Scown D.K. 1998. McCarthy K.M. Boron treatment methods for lyctid susceptible hardwoods growing in Tasmania. Interational research group on wood preservation.

Desch H.E. 1981, *Timber its structure, properties and utilization,* 6th edition, Timber press, Forest Grove, Oregon

Eaton R.A. and Hale M.D.C. 1993. *Wood decay pests and protection*, 1st edition, Chapmon and Hall, London

Ebbing D. 2001, *General chemistry*, 5th edition, A.I.TBS Publishers and distributors, Pp 528

FAO Forestry paper 1986. *Wood preservation manual*. FAO, United Nations, Rome. Pp 1-63, 75-115

Findlay W.P.K. 1985, *Preservation of timber in tropics*. Kluwer academic publishers group. Pp 205- 264

Gnanaharan T.K. and Dhamodaran T.K. 1996, Optimum storage period for the boron diffusion treatment of rubber wood, International research group on wood preservation, Kerala forest research institute.

Hoalday R.B. 1980, *Undestanding wood, A Craftment's guide to wood technology*, The taunton press

Khurshid A. 2005. Preservative treatment of rubber wood (*Hevea brasiliensis*) to increase its service life. Poster paper prepared for the 36th Annual Meeting. Bangalore, India International Research group.

Kramer P.J. and Kozlowski T. (1979). Physilogy of woody plants.

Lokmal N., Mohd Zaki A., Farah Fazwa M.A., Suhaimi W.C., Azmy Y., Zakaria I., Tan H., Khoo S.K. and Wan Akil T.A. (2008). Growth of several Rubber clones for timber production. *Journal of Tropical Forest Science* 20 (3).

Mason C.G.W. 1966.*Timber Preservation Laboratory Handbook*. Ceylon forest Department. Pp 1-34

Negi S.S. 1997, *Wood science and technology*, International book distributors book sellers and publishers. India

Nilanthi shilpa de silva.1996.*wood destroying insects and their attack on eight commercial timber species in Sri Lanka*. University of Peradeniya

Panshin A.J. Zeeuw C. 1952. *The text book of wood technology*, 3rd edition, McGraw Hill book company

Perera. H.C.1995.*boron treatment of rubber wood using different method.* Department of Forestry and Environment Science, University of Sri Jayewardenepura.

Richardson B.A. 1978, *Wood preservation*, The construction press London, New York

Rowell R.M. 1991, Changes in physical properties of wood and wood fiber resulting from chemical modification, International symposium on chemical modification of wood.

Ruwanpathirana N. (2011). Timber utilization in Sri Lanka. Conference on Developments in forestry and environment in Sri Lanka.

Salamah S. Mohd Dhlan. J, Habibah M. and Zarrun S. 1987. Rubber wood preservation; Dip diffusion treatment at various moisture contents. Pp 257-260 in proceeding of the Malaysian Science and Technology Congress. October 1987, Kuala Lampur, Malaysia

Salamah S. Zaitun S. and Habibah M. 1989. Boron analysis in treated wood and solution, *Journal of tropical forest science*, Forest research institute, Kuala Lampur, Malaysia

Saroja D.D.,(1985), A Study of the feeding preference of the dry wood termites: *Cryptotermes domesticus* for 16 species of timber. M Sc. dissertation, Department of forestry and environmental science, University of Sri Jayewardenepura, Sri Lanka.

Smitt D.N.R. and Williams A.I.. 1969. Wood preservation by the boron diffusion process. The effect of moisture content on diffusion time.J.Inst Wood Sci. Pp 3-10

Srivaro S., Wangport T., Matan N. and Kyokong B. (2008). Accelerated conventional temperature drying of 30mm thick rubber wood lumber. *Songklanakarin Journal of Science and Technology.*

Tissaverasinghe A.E.K. Jayathilake M.P.A. 1979, The threshold level of boron preservatives against attack by the dry wood termite- Cryptotermes domesticus- Kalotermitidae. *The Sri Lankan forester* Vol.12 No.2

Tissaverasinghe A.K.E. 1966. Preservative treatment of rubber (Hevea brasiliensis) wood by boron diffusion process. *Ceylon forester*. Vol IX

Tissaverasinghe A.K.E. 1971. *A Manual of timber utilization for Ceylon*. The Ceylon forest department. Pp 36-38, 57-63

TRADA. 1986.*Timber preservation*. Timber Research and Development Association. Pp 11-22

US Department of Agriculture, 1974, *Wood hand book, wood as an engineering material*, Forest product laboratory.

Webster C.C. and E.C.Paardekooper. 1989. *Rubber*. 1st edition. Longman Scientific and Technical co published in US with John Wiely and Sons. New York

White M.G., (1968). The inspection and treatment of houses of damage by wood boring insects. Forest products research laboratory.

ANNEXES

ANNEX 01

AIR SEASONING OF UNTREATED RUBBER WOOD

Duration (Days)	Average weight (g)	Moisture content %
1	655.5	60
2	545.5	55
3	490.5	49
4	489.6	48
5	456.6	34
6	391.6	26.8
7	386.6	26.3
8	381.6	23.9
9	371.6	23.6
10	359.1	22.8
11	356.6	20.0
12	346.6	18.2
14	326.6	15.8
16	324.6	13.9
20	321.5	12.8
24	319.0	12.6
28	316.5	12.7
32	316.0	12.7
35	314.5	12.5
45	314.5	12.5
60	314.5	12.5

ANNEX 02

AIR SEASONING OF TREATED RUBBER WOOD

A2.1 Air seasoning of diffusion treated timber

Number	day 1	day 2	day 3	day 6	day 10	day 14	day 20	day 30
D/C1/24/d/1	441.5	416.5	391.5	391.5	391.5	391.5	391.5	391.5
D/C1/24/d/2	491.5	491.5	466.5	466.5	466.5	466.5	466.5	466.5
D/C1/24/d/3	466.5	466.5	466.5	416.5	416.5	416.5	416.5	416.5
D/C1/24/d/4	441.5	416.5	391.5	391.5	366.5	391.5	391.5	391.5
D/C1/24/d/5	441.5	466.5	441.5	441.5	441.5	441.5	441.5	441.5
D/C1/24/d/6	466.5	416.5	416.5	416.5	416.5	391.5	391.5	391.5
D/C1/24/d/7	466.5	466.5	416.5	416.5	416.5	416.5	416.5	416.5
D/C1/24/d/8	441.5	366.5	341.5	341.5	341.5	341.5	341.5	341.5
Average	457.125	438.375	416.5	410.25	407.125	407.125	407.125	407.125
D/C2/26/d/1	416.5	366.5	366.5	366.5	316.5	316.5	316.5	316.5
D/C2/26/d/2	516.5	466.5	466.5	466.5	466.5	466.5	466.5	466.5
D/C2/26/d/3	391.5	366.5	341.5	341.5	316.5	316.5	316.5	316.5
D/C2/26/d/4	516.5	491.5	466.5	466.5	466.5	466.5	466.5	466.5
D/C2/26/d/5	516.5	491.5	491.5	466.5	466.5	466.5	466.5	466.5
D/C2/26/d/6	466.5	466.5	341.5	341.5	416.5	416.5	416.5	416.5
D/C2/26/d/7	441.5	316.5	291.5	291.5	266.5	266.5	266.5	266.5
D/C2/26/d/8	516.5	516.5	491.5	491.5	491.5	491.5	491.5	491.5
Average	472.75	435.25	407.125	404	400.875	400.875	400.875	400.875
D/C1/30/g/1	716.5	691.5	666.5	641.5	616.5	616.5	616.5	616.5
D/C1/30/g/2	691.5	691.5	691.5	666.5	666.5	616.5	616.5	616.5
D/C1/30/g/3	691.5	666.5	641.5	616.5	591.5	566.5	566.5	566.5
D/C1/30/g/4	716.5	691.5	666.5	641.5	616.5	616.5	616.5	616.5
D/C1/30/g/5	766.5	716.5	691.5	666.5	666.5	666.5	666.5	666.5
D/C1/30/g/6	691.5	666.5	666.5	666.5	666.5	566.5	566.5	566.5
D/C1/30/g/7	616.5	591.5	591.5	566.5	566.5	516.5	516.5	516.5
D/C1/30/g/8	666.5	638.5	616.5	591.5	566.5	566.5	566.5	566.5
Average	694.625	669.25	654	632.125	619.625	591.5	591.5	591.5
D/C2/30/g/1	766.5	716.5	691.5	666.5	666.5	616.5	616.5	616.5
D/C2/30/g/2	666.5	641.5	616.5	591.5	566.5	566.5	566.5	566.5
D/C2/30/g/3	666.5	666.5	641.5	641.5	616.5	566.5	566.5	566.5
D/C2/30/g/4	691.5	691.5	666.5	641.5	616.5	566.5	566.5	566.5
D/C2/30/g/5	666.5	666.5	666.5	666.5	666.5	516.5	516.5	516.5
D/C2/30/g/6	666.5	641.5	616.5	591.5	566.5	566.5	566.5	566.5
D/C2/30/g/7	816.5	766.5	716.5	716.5	716.5	666.5	666.5	666.5
D/C2/31/g/8	816.5	766.5	716.5	716.5	716.5	666.5	666.5	666.5
Average	719.625	694.625	666.5	654	641.5	591.5	591.5	591.5

A2.2 Air seasoning of Hot and Cold Open tank method treated rubber wood

Number	day 1	day 2	day 3	day 6	day 10	day 14	day 20	day 30
HC/C1/25/d/1	591.5	566.5	541.5	491.5	391.5	391.5	391.5	391.5
HC/C1/25/d/2	566.5	541.5	516.5	466.5	391.5	391.5	391.5	391.5
HC/C1/25/d/3	591.5	566.5	541.5	466.5	416.5	391.5	391.5	391.5
HC/C1/25/d/4	591.5	566.5	516.5	491.5	416.5	416.5	416.5	416.5
HC/C1/25/d/5	516.5	491.5	466.5	441.5	316.5	316.5	316.5	316.5
HC/C1/25/d/6	566.5	541.5	491.5	466.5	366.5	366.5	366.5	366.5
HC/C1/25/d/7	616.5	591.5	566.5	516.5	391.5	391.5	391.5	391.5
HC/C1/25/d/8	591.5	566.5	541.5	516.5	516.5	391.5	391.5	391.5
Average	579	554	522.75	482.13	400.88	382.13	382.13	382.125
HC/C1/21/g/1	716.5	691.5	666.5	666.5	666.5	516.5	516.5	516.5
HC/C1/21/g/2	741.5	716.5	691.5	666.5	666.5	516.5	516.5	516.5
HC/C1/21/g/3	691.5	666.5	666.5	666.5	666.5	491.5	491.5	491.5
HC/C1/21/g/4	766.5	741.5	741.5	741.5	741.5	566.5	566.5	566.5
HC/C1/21/g/5	716.5	691.5	666.5	666.5	641.5	466.5	466.5	466.5
HC/C1/21/g/6	816.5	766.5	766.5	766.5	766.5	566.5	566.5	566.5
HC/C1/21/g/7	716.5	691.5	666.5	666.5	666.5	491.5	491.5	491.5
HC/C1/21/g/8	691.5	666.5	641.5	641.5	616.5	466.5	466.5	466.5
Average	732.13	704	688.38	685.25	679	510.25	510.25	510.25
HC/C2/22/g/1	691.5	691.5	666.5	666.5	666.5	516.5	516.5	516.5
HC/C2/22/g/2	716.5	691.5	666.5	641.5	641.5	466.5	466.5	466.5
HC/C2/22/g/3	716.5	691.5	666.5	616.5	591.5	466.5	466.5	466.5
HC/C2/22/g/4	691.5	666.5	641.5	616.5	616.5	516.5	516.5	516.5
HC/C2/22/g/5	691.5	666.5	616.5	616.5	616.5	466.5	466.5	466.5
HC/C2/22/g/6	716.5	691.5	666.5	641.5	641.5	466.5	466.5	466.5
HC/C2/22/g/7	716.5	691.5	666.5	641.5	616.5	466.5	466.5	466.5
HC/C2/22/g/8	716.5	691.5	666.5	641.5	641.5	466.5	466.5	466.5
Average	707.13	685.25	657.13	635.25	629	479	479	479
HC/C2/30/d/1	591.5	566.5	516.5	441.5	441.5	416.5	416.5	416.5
HC/C2/30/d/2	666.5	641.5	616.5	566.5	491.5	466.5	466.5	466.5

HC/C2/30/d/3	616.5	591.5	566.5	491.5	466.5	416.5	416.5	416.5
HC/C2/30/d/4	516.5	491.5	466.5	441.5	416.5	366.5	366.5	366.5
HC/C2/30/d/5	666.5	641.5	616.5	566.5	516.5	466.5	466.5	466.5
HC/C2/30/d/6	591.5	566.5	516.5	466.5	416.5	366.5	366.5	366.5
HC/C2/30/d/7	616.5	591.5	566.5	541.5	516.5	416.5	416.5	416.5
HC/C2/30/d/8	616.5	591.5	566.5	541.5	516.5	516.5	516.5	516.5
Average	610.25	585.25	554	507.13	472.75	429	429	429

A2.3 Air seasoning of Steam Cold Quench method treated rubber wood

number	day 1	day 2	day 3	day 6	day 10	day 14	day 20	day 30
SCQ/C1/5/g/1	716.5	691.5	641.5	616.5	591.5	541.5	346.5	346.5
SCQ/C1/5/g/2	816.5	791.5	641.5	591.5	541.5	516.5	446.5	446.5
SCQ/C1/5/g/3	786.5	761.5	566.5	516.5	491.5	466.5	416.5	416.5
SCQ/C1/5/g/4	766.5	741.5	566.5	541.5	516.5	491.5	396.5	396.5
SCQ/C1/5/g/5	736.5	711.5	566.5	516.5	471.5	446.5	366.5	366.5
SCQ/C1/5/g/6	771.5	746.5	566.5	516.5	491.5	441.5	401.5	401.5
SCQ/C1/5/g/7	746.5	721.5	641.5	591.5	541.5	516.5	376.5	376.5
SCQ/C1/5/g/8	841.1	816.5	641.5	591.5	566.5	516.5	471.5	471.5
Average	772.7	747.75	604	560.25	526.5	492.125	402.75	402.75
SCQ/C1/28/d/1	716.5	691.5	516.5	491.5	466.5	416.5	416.5	416.5
SCQ/C1/28/d/2	816.5	791.5	466.5	441.5	416.5	416.5	416.5	416.5
SCQ/C1/28/d/3	786.5	761.5	466.5	466.5	466.5	466.5	466.5	466.5
SCQ/C1/28/d/4	766.5	741.5	466.5	466.5	466.5	466.5	466.5	466.5
SCQ/C1/28/d/5	736.5	711.5	466.5	466.5	466.5	466.5	466.5	466.5
SCQ/C1/28/d/6	771.5	746.5	721.5	621.5	596.5	466.5	466.5	466.5
SCQ/C1/28/d/7	746.5	721.5	671.5	646.5	596.5	466.5	466.5	466.5
SCQ/C1/28/d/8	841.5	816.5	766.5	716.5	641.5	466.5	466.5	466.5
Average	772.75	747.75	567.75	539.625	514.625	454	454	454
SCQ/C2/4/g/1	796.5	696.5	566.5	541.5	516.5	491.5	466.5	466.5
SCQ/C2/4/g/2	766.5	716.5	566.5	541.5	516.5	491.5	466.5	466.5
SCQ/C2/4/g/3	706.5	656.5	516.5	491.5	466.5	441.5	416.5	416.5
SCQ/C2/4/g/4	766.5	666.5	516.5	491.5	466.5	441.5	416.5	416.5
SCQ/C2/4/g/5	816.5	716.5	666.5	616.5	591.5	566.5	416.5	416.5
SCQ/C2/4/g/6	766.5	666.5	566.5	536.5	511.5	486.5	441.5	441.5
SCQ/C2/4/g/7	766.5	666.5	616.5	591.5	541.5	516.5	416.5	416.5
SCQ/C2/4/g/8	786.5	736.5	616.5	591.5	566.5	516.5	416.5	416.5
Average	771.5	690.25	579	550.25	522.125	494	432.125	432.125
SCQ/C2/30/d/1	466.5	441.5	416.5	366.5	366.5	366.5	366.5	366.5
SCQ/C2/30/d/2	566.5	541.5	516.5	491.5	416.5	416.5	416.5	416.5
SCQ/C2/30/d/3	516.5	460.5	435.5	366.5	366.5	366.5	366.5	366.5
SCQ/C2/30/d/4	541.5	516.5	491.5	391.5	391.5	391.5	391.5	391.5
SCQ/C2/30/d/5	641.5	591.5	566.5	466.5	466.5	416.5	416.5	416.5
SCQ/C2/30/d/6	491.5	441.5	416.5	366.5	366.5	366.5	366.5	366.5
SCQ/C2/30/d/7	566.5	541.5	491.5	416.5	416.5	391.5	391.5	391.5
SCQ/C2/30/d/8	516.5	491.5	466.5	441.5	391.5	366.5	366.5	366.5
Average	538.375	503.25	475.125	413.375	397.75	385.25	385.25	385.25

A2.4 Air seasoning of Vacuum Pressure Impregnation method treated rubber wood

number	day 1	day 2	day 3	day 6	day 10	day 14	day 20	day 30
VC/C1/d/1	591.5	416.5	391.5	391.5	391.5	391.5	391.5	391.5
VC/C1/d/2	616.5	491.5	466.5	466.5	466.5	466.5	466.5	466.5
VC/C1/d/3	616.5	466.5	466.5	416.5	416.5	416.5	416.5	416.5
VC/C1/d/4	666.5	416.5	400.5	391.5	391.5	391.5	391.5	391.5
VC/C1/d/5	666.5	466.5	441.5	441.5	441.5	441.5	441.5	441.5
VC/C1/d/6	641.5	416.5	416.5	391.5	391.5	391.5	391.5	391.5
VC/C1/d/7	691.5	466.5	441.5	416.5	416.5	416.5	416.5	416.5
VC/C1/d/8	666.5	366.5	341.5	341.5	341.5	341.5	341.5	341.5
Average	644.625	438.375	420.75	407.125	407.125	407.125	407.125	407.125
VC/C1/g/1	691.5	691.5	666.5	641.5	616.5	616.5	616.5	616.5
VC/C1/g/2	691.5	691.5	691.5	666.5	666.5	616.5	616.5	616.5
VC/C1/g/3	616.5	666.5	641.5	616.5	591.5	566.5	566.5	566.5
VC/C1/g/4	566.5	691.5	666.5	641.5	616.5	616.5	616.5	616.5
VC/C1/g/5	666.5	716.5	691.5	666.5	666.5	666.5	666.5	666.5
VC/C1/g/6	666.5	666.5	666.5	666.5	666.5	566.5	566.5	566.5
VC/C1/g/7	666.5	591.5	591.5	566.5	566.5	516.5	516.5	516.5
VC/C1/g/8	691.5	638.5	616.5	591.5	566.5	566.5	566.5	566.5
Average	657.125	669.25	654	632.125	619.625	591.5	591.5	591.5
VC/C2/g/1	666.5	666.5	666.5	666.5	616.5	616.5	616.5	616.5
VC/C2/g/2	641.5	641.5	616.5	591.5	566.5	566.5	566.5	566.5
VC/C2/g/3	666.5	666.5	641.5	641.5	566.5	566.5	566.5	566.5
VC/C2/g/4	691.5	691.5	666.5	641.5	566.5	566.5	566.5	566.5
VC/C2/g/5	541.5	541.5	541.5	541.5	516.5	516.5	516.5	516.5
VC/C2/g/6	566.5	566.5	566.5	566.5	566.5	566.5	566.5	566.5
VC/C2/g/7	566.5	566.5	566.5	566.5	566.5	566.5	566.5	566.5
VC/C2/g/8	616.5	610.5	610.5	610.5	610.5	610.5	610.5	610.5
Average	619.625	618.875	609.5	603.25	572	572	572	572
VC/C2/d/1	616.5	366.5	366.5	366.5	316.5	316.5	316.5	316.5
VC/C2/d/2	566.5	466.5	466.5	466.5	466.5	466.5	466.5	466.5
VC/C2/d/3	541.5	366.5	341.5	341.5	316.5	316.5	316.5	316.5
VC/C2/d/4	541.5	491.5	466.5	466.5	466.5	466.5	466.5	466.5
VC/C2/d/5	591.5	491.5	491.5	466.5	466.5	466.5	466.5	466.5
VC/C2/d/6	641.5	466.5	341.5	341.5	416.5	416.5	416.5	416.5
VC/C2/d/7	641.5	316.5	291.5	266.5	266.5	266.5	266.5	266.5
VC/C2/d/8	591.5	516.5	491.5	491.5	491.5	491.5	491.5	491.5
Average	591.5	435.25	407.125	400.875	400.875	400.875	400.875	400.875

D = Diffusion

HC = Hot and cold open tank

SCQ = Steam cold quench

VC = Vacuum pressure impregnation

d = dry

g = green

C1 = 12% boron solution strength

C2 = 8% boron solution strength

ANNEX 03

SOLUTION STRENGTH

3.1 Calculation of amount of preservatives that needed for 12% solution strength and 8% solution strength for diffusion, hot and cold open tank and steam cold quench treatment methods

$$\text{Solution strength W/W \%} = \frac{\text{Weight of the salt}}{\text{Weight of the solution}} * 100$$

Volume of the solution = 21 L = $0.021 m^3$ (1 L=$0.001 m^3$)

Density of water at 30°C = 1000 Kgm^{-3}

Therefore weight of 21 L of water = 21 Kg

Total weight of the salt = Wa

Substitution of data to the above equation,

$$12 = \frac{Wa}{21\ Kg} * 100$$

$$Wa = \frac{21 * 12}{100}$$

$$Wa = 2.520\ Kg$$

According to boric acid to borax 1: 1.54 proportion,

$$\text{Amount of boric acid needed} = \frac{2.520\ Kg}{2.54} = 0.992\ Kg$$

$$\text{Amount of borax needed} = \frac{2.520\ Kg * 1.54}{2.54} = 1.527\ Kg$$

For 8% solution strength,

Wb = total weight of the salt

$$8 = \frac{Wb}{21\ Kg} * 100$$

$$Wb = \frac{21 * 8}{100}$$

$Wb = 1.680$ Kg

According to boric acid to borax 1: 1.54 proportion,

Amount of boric acid needed = $\frac{1.680 \text{ Kg}}{2.54}$ = 0.661 Kg

Amount of borax needed = $\frac{1.680 \text{ Kg} * 1.54}{2.54}$ = 1.018 Kg

3.2 Calculation of amount of preservatives that needed for 12% solution strength and 8% solution strength for vacuum pressure impregnation method

Solution strength W/W % = $\frac{\textit{Weight of the salt}}{\textit{Weight of the solution}}$ ** 100*

Volume of the solution = 20 000 L = $20.0m^3$ (1 L=$0.001m^3$)

Density of water at 30°C = 1000 Kgm^{-3}

Therefore weight of 20 000 L of water = 20 000 Kg

Total weight of the salt for 12% solution strength for vacuum pressure impregnation method = Wc

Substitution of data to the above equation,

$$12 = \frac{Wc}{20\,000 \text{ Kg}} * 100$$

$$Wc = \frac{20\,000 * 12}{100}$$

$Wc = 2400.00$ Kg

According to boric acid to borax 1: 1.54 proportion,

Amount of boric acid needed = $\frac{2400 \text{ Kg}}{2.54}$ = 944.880 Kg

Amount of borax needed = $\frac{2400 \text{ Kg} * 1.54}{2.54}$ = 1455.118 Kg

For 8% solution strength,

Total weight of the salt for 12% solution strength for vacuum pressure impregnation method = Wd

$$8 = \frac{Wd}{20\,000\ Kg} * 100$$

$$Wd = \frac{20\,000 * 8}{100}$$

Wd = 1600.00 Kg

According to boric acid to borax 1: 1.54 proportion,

Amount of boric acid needed = $\frac{1600\ Kg}{2.54}$ = 629.92 Kg

Amount of borax needed = $\frac{1600\ Kg * 1.54}{2.54}$ = 970.078 Kg

ANNEX 04

CHEMICAL LOADING AND CHEMICAL RETENTION FOR DIFFENT TREATMENT METHODS

date of dip	number	CL(Kgm-3)	CR (Kgm-3)
24-Mar	D/C1/24/d/1	75.70	9.08
	D/C1/24/d/2	75.70	9.08
	D/C1/24/d/3	75.70	9.08
	D/C1/24/d/4	0.00	0.00
	D/C1/24/d/5	60.56	7.27
	D/C1/24/d/6	37.85	4.54
	D/C1/24/d/7	113.55	13.63
	D/C1/24/d/8	0.00	0.00
mean		54.88	6.59
26-Mar	D/C2/26/d/1	0.00	0.00
	D/C2/26/d/2	75.70	6.06
	D/C2/26/d/3	113.55	9.08
	D/C2/26/d/4	0.00	0.00
	D/C2/26/d/5	30.28	2.42
	D/C2/26/d/6	0.00	0.00
	D/C2/26/d/7	37.85	3.03
	D/C2/27/d/8	37.85	3.03
mean		36.90	2.95
30-Mar	D/C1/30/g/1	45.42	5.45
	D/C1/30/g/2	45.42	5.45
	D/C1/30/g/3	75.70	9.08
	D/C1/30/g/4	45.42	5.45
	D/C1/30/g/5	75.70	9.08
	D/C1/30/g/6	52.99	6.36
	D/C1/30/g/7	75.70	9.08
	D/C1/30/g/8	90.84	10.90
mean		63.40	7.61
30-Mar	D/C2/30/g/1	37.85	3.03
	D/C2/30/g/2	75.70	6.06
	D/C2/30/g/3	37.85	3.03
	D/C2/30/g/4	75.70	6.06
	D/C2/30/g/5	37.85	3.03

	D/C2/30/g/6	75.70	6.06
	D/C2/30/g/7	113.55	9.08
	D/C2/30/g/8	37.85	3.03
mean		61.51	4.92

date	number	CL (Kgm-3)	CR (Kgm-3)
25-May	HC/C1/25/d/1	302.81	36.34
	HC/C1/25/d/2	302.81	36.34
	HC/C1/25/d/3	340.66	40.88
	HC/C1/25/d/4	264.96	31.79
	HC/C1/25/d/5	378.51	45.42
	HC/C1/25/d/6	340.66	40.88
	HC/C1/25/d/7	340.66	40.88
	HC/C1/25/d/8	340.66	40.88
		326.47	39.18
21-Jun	HC/C1/21/g/1	151.40	18.17
	HC/C1/21/g/2	181.69	21.80
	HC/C1/21/g/3	189.26	22.71
	HC/C1/21/g/4	227.11	27.25
	HC/C1/21/g/5	196.83	23.62
	HC/C1/21/g/6	264.96	31.79
	HC/C1/21/g/7	204.40	24.53
	HC/C1/21/g/8	249.82	29.98
		208.18	24.98
22-Jun	HC/C2/22/g/1	181.69	14.53
	HC/C2/22/g/2	227.11	18.17
	HC/C2/22/g/3	196.83	15.75
	HC/C2/22/g/4	227.11	18.17
	HC/C2/22/g/5	189.26	15.14
	HC/C2/22/g/6	249.82	19.99
	HC/C2/22/g/7	227.11	18.17
	HC/C2/22/g/8	166.55	13.32
		208.18	16.65
30-May	HC/C2/30/d/1	340.66	27.25
	HC/C2/30/d/2	302.81	24.22
	HC/C2/30/d/3	378.51	30.28
	HC/C2/30/d/4	227.11	18.17
	HC/C2/30/d/5	340.66	27.25

	HC/C2/30/d/6	378.51	30.28
	HC/C2/30/d/7	340.66	27.25
	HC/C2/30/d/8	189.26	15.14
mean		312.27	24.98

date	number	CL (Kg/m3)	CR (Kgm-3)
5-Aug	SCQ/C1/5/g/1	151.40	18.17
	SCQ/C1/5/g/2	227.26	27.27
	SCQ/C1/5/g/3	219.54	26.34
	SCQ/C1/5/g/4	227.11	27.25
	SCQ/C1/5/g/5	181.69	21.80
	SCQ/C1/5/g/6	234.68	28.16
	SCQ/C1/5/g/7	121.12	14.53
	SCQ/C1/5/g/8	264.96	31.79
mean		203.47	24.42
28-Jul	SCQ/C1/28/d/1	423.93	50.87
	SCQ/C1/28/d/2	333.09	39.97
	SCQ/C1/28/d/3	317.95	38.15
	SCQ/C1/28/d/4	272.53	32.70
	SCQ/C1/28/d/5	302.81	36.34
	SCQ/C1/28/d/6	363.37	43.60
	SCQ/C1/28/d/7	302.81	36.34
	SCQ/C1/28/d/8	408.79	49.06
mean		340.66	40.88
4-Aug	SCQ/C2/4/g/1	121.12	9.69
	SCQ/C2/4/g/2	151.40	12.11
	SCQ/C2/4/g/3	136.26	10.90
	SCQ/C2/4/g/4	302.81	24.22
	SCQ/C2/4/g/5	227.11	18.17
	SCQ/C2/4/g/6	302.81	24.22
	SCQ/C2/4/g/7	151.40	12.11
	SCQ/C2/4/g/8	181.69	14.53
mean		196.83	15.75
30-Jul	SCQ/C2/30/d/1	189.26	15.14
	SCQ/C2/30/d/2	264.96	21.20
	SCQ/C2/30/d/3	227.11	18.17
	SCQ/C2/30/d/4	264.96	21.20
	SCQ/C2/30/d/5	378.51	30.28

	SCQ/C2/30/d/6	189.26	15.14
	SCQ/C2/30/d/7	302.81	24.22
	SCQ/C2/30/d/8	302.81	24.22
mean		264.96	21.20

date	number	CL(Kgm-3)	CR (Kgm-3)
12-Aug	VC/C1/12/g/1	189.26	22.71
	VC/C1/12/g/2	189.26	22.71
	VC/C1/12/g/3	75.70	9.08
	VC/C1/12/g/4	75.70	9.08
	VC/C1/12/g/5	151.40	18.17
	VC/C1/12/g/6	75.70	9.08
	VC/C1/12/g/7	151.40	18.17
	VC/C1/12/g/8	113.55	13.63
mean		127.75	15.33
	VC/C1/12/d/1	302.81	36.34
	VC/C1/12/d/2	454.21	54.51
	VC/C1/12/d/3	529.92	63.59
	VC/C1/12/d/4	605.62	72.67
	VC/C1/12/d/5	492.07	59.05
	VC/C1/12/d/6	567.77	68.13
	VC/C1/12/d/7	605.62	72.67
	VC/C1/12/d/8	454.21	54.51
mean		501.53	60.18
	VC/C2/02/d/1	302.81	24.22
	VC/C2/02/d/2	227.11	18.17
	VC/C2/02/d/3	227.11	18.17
	VC/C2/02/d/4	242.25	19.38
	VC/C2/02/d/5	264.96	21.20
	VC/C2/02/d/6	416.36	33.31
	VC/C2/02/d/7	416.36	33.31
	VC/C2/02/d/8	340.66	27.25
		304.70	24.38
	VC/C2/02/g/1	37.85	3.03
	VC/C2/02/g/2	68.13	5.45
	VC/C2/02/g/3	189.26	15.14
	VC/C2/02/g/4	75.70	6.06

VC/C2/02/g/5	113.55	9.08
VC/C2/02/g/6	151.40	12.11
VC/C2/02/g/7	151.40	12.11
VC/C2/02/g/8	75.70	6.06
	107.88	8.63

ANNEX 05

TERMITE TEST FOR DIFFERENT TREATMENT METHODS

Termite test

Results are based on three sandwiches from each treatment method. Number of days that taken to die all the introduced termites in to the sandwich was considered. In the table:

S1 – Sandwich 1

S2 – Sandwich 2

S3 – Sandwich 3

Number of days after introduction	Method of treatment																							
	VC/C1/d			VC/C1/g			VC/C2/d			VC/C2/g			SCQ/C1/d			SCQ/C1/g			SCQ/C2/d			SCQ/C2/g		
	S 1	S 2	S 3	S 1	S 2	S 3	S 1	S 2	S 3	S 1	S 2	S 3	S 1	S 2	S 3	S 1	S 2	S 3	S 1	S 2	S 3	S 1	S 2	S 3
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9	10	10	10	10	10	10	10	10	10
3	7	7	9	9	8	9	9	8	7	10	9	10	8	7	7	7	8	8	10	9	8	10	10	10
7	3	2	5	8	8	8	9	7	3	10	8	8	7	5	5	5	6	7	9	8	8	10	10	10
10	-	-	-	8	5	7	8	5	2	10	7	8	1	2	3	3	5	5	8	8	6	8	8	10
12	-	-	-	8	3	7	7	2	2	4	5	6	-	-	-	2	4	3	8	6	6	8	6	9
14	-	-	-	8	-	5	6	2	2	2	3	5	-	-	-	1	3	2	8	6	5	8	3	8
16	-	-	-	8	-	5	3	2	-	1	2	3	-	-	-	-	2	2	7	2	4	8	3	5
17	-	-	-	8	-	5	-	2	-	1	2	3	-	-	-	-	2	2	4	2	3	6	3	5
18	-	-	-	3	-	3	-	2	-	-	2	2	-	-	-	-	-	-	3	2	2	3	2	3
19	-	-	-	2	-	2	-	-	-	-	-	2	-	-	-	-	-	-	1	1	2	2	2	3
20	-	-	-	1	-	2	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	2	1
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Number of days after introduction	Method of treatment																							
	HC/C1/d			HC/C1/g			HC/C2/d			HC/C2/g			D/C1/d			D/C1/g			D/C2/d			D/C/2/g		
	S 1	S 2	S 3	S 1	S 2	S 3	S 1	S 2	S 3	S 1	S 2	S 3	S 1	S 2	S 3	S 1	S 2	S 3	S 1	S 2	S 3	S 1	S 2	S 3
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9	10	10	10	10	10	10	10	10	10
3	10	8	9	9	8	9	9	8	7	10	9	10	8	7	7	7	8	8	10	9	8	10	10	10
7	9	7	7	8	8	8	9	7	3	10	8	8	7	7	6	7	8	7	9	8	8	10	10	10
10	8	5	4	8	5	7	8	5	2	10	7	8	7	7	5	6	8	5	8	8	6	8	8	10
12	3	2	2	7	3	7	7	2	2	7	5	6	6	6	5	6	7	3	8	6	6	8	6	9
14	-	-	-	5	-	5	6	2	2	6	3	5	5	6	4	5	4	2	8	6	5	8	3	8
16	-	-	-	2	-	5	-	-	-	5	2	3	4	5	4	5	2	2	7	2	4	8	3	5
17	-	-	-	-	-	-	-	-	-	4	2	3	3	5	3	3	1	2	4	2	3	6	3	5
18	-	-	-	-	-	-	-	-	-	2	2	2	3	5	3	3	1	1	3	2	2	3	2	3
19	-	-	-	-	-	-	-	-	-	1	-	2	3	4	3	3	-	1	2	2	2	2	2	3
20	-	-	-	-	-	-	-	-	-	-	-	-	2	4	3	2	-	1	2	2	1	2	2	1
21	-	-	-	-	-	-	-	-	-	-	-	-	2	3	2	1	-	-	2	2	1	2	2	-
23	-	-	-	-	-	-	-	-	-	-	-	-	2	1	2	-	-	-	2	2	1	2	1	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	1	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

ANNEX 06

COST OF TREATMENT OF ONE CUBIC METER OF RUBBER WOOD FOR DIP DIFFUSION METHOD, HOT AND COLD OPEN TANK METHOD AND VACUUM PRESSURE IMPREGNATION METHOD

A6.1 Cost of treatment of one cubic meter of rubber wood by dip diffusion method

Data collected from plant A which is practicing dip diffusion method for rubber wood treatment by boron preservatives

Number of electric units per day	0.81
Price of one unit of electricity	Rs. 18.50
Number of operations per day	1
Amount of timber per one operation	2.7 m^3
Price of untreated timber	Rs.5550.00m^{-3}
Number of workers per one operation diffusion treatment	4
Daily salary	Rs.250.00
Chemical cost per one operation	Rs.7695.00

Cost calculations per one operation of dip diffusion method

Energy cost (EC) = $\frac{\text{Number of electricity units per day * Unit price of electricity}}{\text{Number of operations per day}}$

= $\frac{0.81 * \text{Rs. } 18.50}{1}$

= Rs. 14.98 (Rs.15.00)

Timber cost (TC) = Amount of timber per one operation * Unit price of untreated rubber wood

= 2.7 m^3* Rs.5550.00m^3

= Rs. 15000.00

Labor cost (LC) = $\frac{\text{Number of labors per one operation * Daily salary}}{\text{Number of operations per day}}$

$$= \frac{4 * Rs.\ 250.00}{1}$$

$$= Rs.1000.00$$

Chemical cost (CC) = Rs.7695.00

Cost of treatment of one cubic feet of rubber wood for plant B which is practicing Hot and Cold Open tank method

Number of electric units per day	4.32
Price of one unit of electricity	Rs. 18.50
Number of operations per day	1
Amount of timber per one operation	2.7 m^3
Price of untreated timber	Rs.5550.00m^3
Number of workers per one operation diffusion treatment	6
Daily salary	Rs.500.00
Chemical cost per one operation	Rs.7000.00

Cost calculations per one operation of Hot and Cold Open tank method

Energy cost (EC) = $\frac{\text{Number of electricity units per day * Unit price of electricity}}{\text{Number of operations per day}}$

= $\frac{4.32 * \text{Rs. } 18.50}{1}$

= Rs. 80.00

Timber cost (TC) = Amount of timber per one operation * Unit price of untreated rubber wood

= 2.7 m^3* Rs.5550.00m^3

= Rs. 15000.00

Labor cost (LC) = $\frac{\text{Number of labors per one operation * Daily salary}}{\text{Number of operations per day}}$

= $\frac{6 * \text{Rs. } 500.00}{1}$

= Rs.3000.00

Chemical cost (CC) = Rs.7000.00

Cost of treatment of one cubic feet of rubber wood for plant C which is practicing Vacuum Pressure Impregnation method.

Energy cost per one operation	Rs. 5550.00
Labor cost per one operation	Rs. 5000.00
Amount of timber per one operation	5.4 m^3
Price of untreated timber	Rs.5550.00m^3
Chemical cost per one operation	Rs.29900.00

Energy cost (EC) = Rs. 5550.00

Timber cost (TC) = Amount of timber per one operation * Unit price of untreated timber

= 5.4 m^3* Rs.5550.00m^3

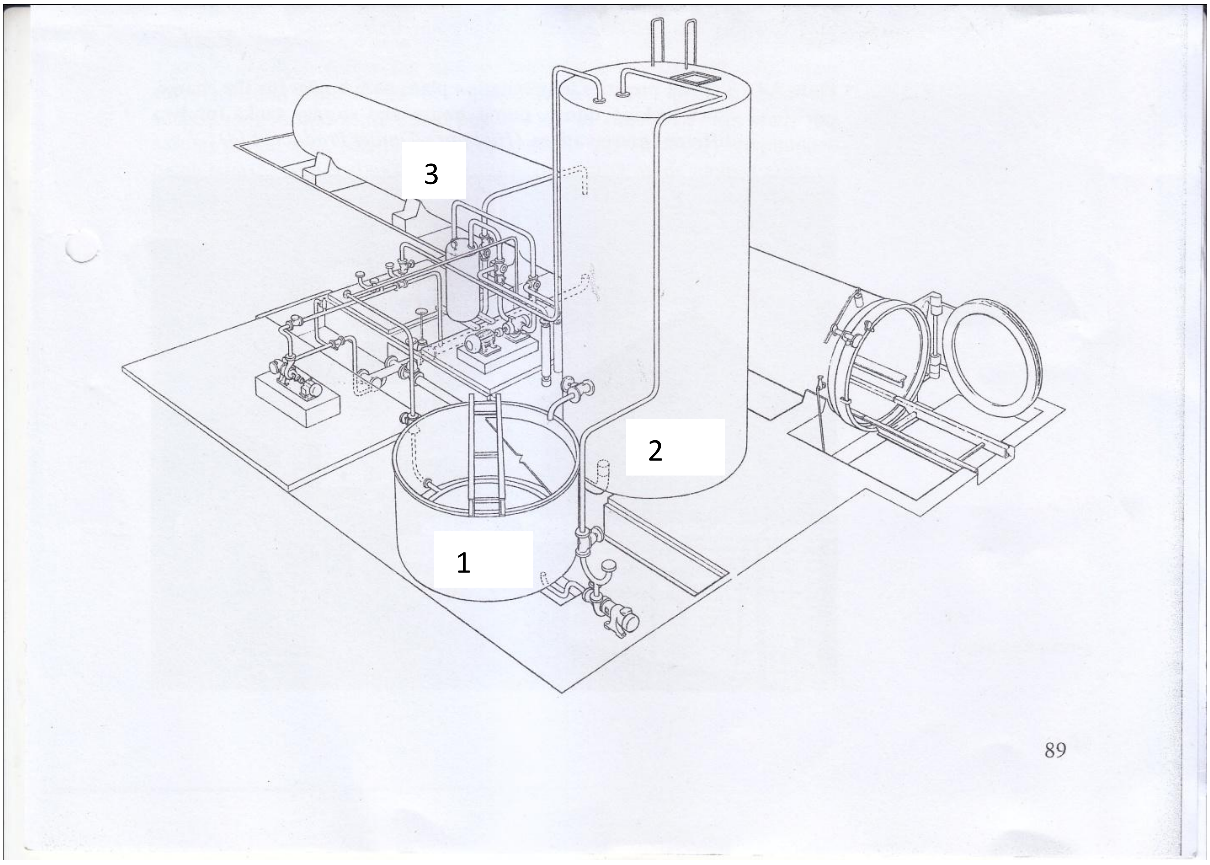
= Rs.29970.00

Labor cost (LC) = Rs. 5000.00

Chemical cost (CC) = Rs.29900.00

ANNEX 07

LAYOUT OF VACUUM PRESSURE IMPREGNATION PLANT



1. Mixing tank
2. Storage tank
3. Treatment chamber (Richardson, 1978)

Figure A7.1: Layout of vacuum pressure impregnation plant