Preservation of Round Timber Products

G.K. Brennan

Report No. 21

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Wood Utilisation Research Centre
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SUMMARY

Round timber used in contact with the ground can be attacked by insects and fungi, resulting in loss of strength and invariably failure. The service life inground contact depends on the timbers natural durability (which varies between species), biological hazard and whether the sapwood is treated with timber preservative. Sapwood of all species is non-durable, but most can be readily treated with timber preservatives by vacuum pressure or non-pressure treatment methods, which increase durability and service life. Heartwood generally cannot be readily penetrated with timber preservatives, but incising and boultonising can give partial treatment.

Timber natural durability, types of chemical preservatives (e.g. creosote), methods of preserving and in-service treatment methods for round timber are discussed, with particular reference to low and non-pressure methods.

INTRODUCTION

The use of round timber products such as posts and poles is widespread. The main drawback in using these products inground contact, is that untreated sapwood will be damaged or destroyed in a short time by decay and insects, which will significantly reduce strength. This problem can be overcome in most timbers by impregnating the sapwood with a wood preservative composition, thereby creating a protective envelope around the impermeable heartwood. In many cases the service life may be extended to 30 years or more. Provided the sapwood band has not split or been damaged by powder post borers (*Lyctus spp.*) before treatment and is at least 12 mm thick, most hardwood timber species are suitable for preservative treatment.

Timber does not deteriorate as a result of ageing alone; any failure is invariably the result of attack by some external agent. With adequate protection against dampness, infection, ultraviolet light and fire, it will (unless exposed to severe mechanical wear) last almost indefinitely. To some extent the reputation of timber has suffered owing to its deterioration resulting from attack by fungi or attack by insects under certain conditions and from weathering, splitting and checking causing loss of strength. Biological attack can now be delayed for prolonged periods, but the preventative measures require a clear understanding of the nature of the organisms concerned, the characteristics of the available timber species and the principles upon which timber preservation is based.

This report presents information on timbers needing protection, on wood preservatives, and on methods of treating with preservatives.

NATURAL DURABILITY

Conventionally, timbers were classified by CSIRO into four durability classes according to their relative natural resistance to biological attack of the *outer heartwood* when in ground contact (Tamblyn 1966). They are as follows;

Class 1 — timbers of the highest natural durability which may be expected to have a life of 25 years or more.

Class 2 — timbers of high natural durability which may be expected to have a life of 15 to 25 years.

Class 3 — timbers of moderate durability which last from 8 to 15 years.

Class 4	timbers of low natural durability which last up to 8 years. These timbers have about the same durability as untreated sapwood.

Thornton *et al.* (1991) presented data on the in-ground natural durability of outer heartwood for a wide range of timbers. Their classification is based on the expected life of a timber of cross-section 40 x 40 mm or greater. (a plus sign indicates more durable than most of this class; a minus sign indicates less durable than most of this class). Examples of species native to Western Australia or from the eastern States grown in Western Australia, tentatively assigned to each durability class are:

Class 1	wandoo	(*Eucalyptus wandoo* Blakely) (1+)
	yellow box	(*E. melliodora* A.Cunn. ex Schau) (1-)
Class 2	raspberry jam	(*Acacia acuminata* Benth.)
	W.A. blackbutt	(*E. patens* Benth.)
	river red gum	(*E. camaldulensis* Dehnh.) (2+)
	jarrah	(*E. marginata* Donn. ex Sm.) (2+)
	tuart	(*E. gomphocephala* DC.)
	sugar gum	(*E. cladocalyx* F. Muell) (2-)
	yellow tingle	(*E. guilfoylei* Maiden) (2-)
	red tingle	(*E. jacksonii* Maiden) (2-)
	salmon gum	(*E. salmonophloia* F. Muell) (2-3)
Class 3	marri	(*E. calophylla* R. Br. ex Lindl.) (3+)
	karri	(*E. diversicolor* F. Muell.)
	rose gum	(*E. grandis* W. Hill ex Maiden) (3-)
	bullich	(*E. megacarpa* F. Muell.) (3-)
	Tasmanian blue gum	(*E. globulus* Labill. ssp. *globulus*)
Class 4	radiata pine	(*Pinus radiata* D. Don)
	maritime pine	(*P. pinaster* Ait.)

To ensure long life under exposed conditions, it is necessary to use either the more durable species or timber of lower natural durability which has been given the recommended preservative treatment.

In timbers of Class 1 to 3, sapwood is more susceptible than heartwood to attack. Durable heartwood contains high concentrations of extractives toxic to fungi, and has vessels occluded by tyloses which may impede fungal growth (Tamblyn 1978).

Rudman (1964) concluded that decay resistance in the eucalypts is due to both the amount and toxicity of the polyphenolic heartwood extractives. After the juvenile or immature wood stage is passed, most trees produce resistant heartwood throughout their life. The resistance of this wood decreases with time (owing to changes in the nature of heartwood extractives) until it is eventually susceptible to decay, i.e. the amount of heartwood extractives is reasonably constant across the trunk, and their toxicity to fungi is not constant but decreases towards the pith. In the case of regrowth jarrah, Rudman (1964) found no relationship between average colour of jarrah wood in 45-year-old trees and its resistance to fungal attack, although extractive content varied widely. It is suggested that if posts are pressure treated with preservative a wide band of treated sapwood is an advantage and any reduction in the natural durability of the heartwood would be less of a problem.

WOOD PRESERVATIVES

Wood preservatives are biocidal formulations which are applied to wood by a variety of methods, in order to prevent damage caused by decay fungi, harmful insects or weathering.

The main characteristics of wood preserving chemicals include:

Efficacy: effective against target organisms and degrading agencies either specifically or in a mixture;

Safety: environmentally acceptable, with minimum mammalian toxicity;

Permanence: active in the wood for many years;

Economy: cost effective in maintaining treated wood as a competitive material (Greaves 1985a).

It is possible to classify the various wood preservatives into groups based on the nature of the liquid phase in which they are carried into the wood e.g. oil-borne, water-borne and organic solvent types.

OIL-BORNE PRESERVATIVES

Wood preservative oils are resistant to leaching/weathering and are suitable for application to wood which is to be used inground contact. Paintability, odour, appearance, and combustibility of the treated wood are influenced by the residual oils. Commonly used types are discussed below, including reference to environmental and health aspects.

Coal Tar Creosote

Coal tar creosote has been widely used in Australia for many years in butt treatments or open tank treatments of poles, but the total usage increased enormously after the widespread adoption of pressure treatments (Greaves 1990). A low temperature creosote manufactured from tar obtained at the relatively low temperatures of 650-850°C during generation of town gas, according to AS K55 (Standards Association of Australia 1965), was used in Australia during the early days of the timber preservation industry. In the late 1960s a high temperature creosote (HTC) manufactured according to AS 1143 (Standards Association of Australia 1973) began to replace low temperature creosote as the major form of oil-borne preservatives. Since this time the use of HTC has increased to more than 5 million litres per year (Greaves 1985a).

Creosote is the major oil-borne preservative used around the world. The trends indicate that creosote consumption has fallen by about 25 per cent during the last decade, and along with copper-chrome-arsenic is an excellent option as a long-lasting heavy duty preservative for a broad range of applications (Greaves 1990).

Beesley and Barnacle (1958) demonstrated that the prevention of decay and borer attack in the above-ground portion of eucalypt poles can be achieved with a light preservative (50 to 60 kg m^{-3}) treatment. Pressure treatment penetrates deeper than surface brushing with creosote/oil and has the additional benefit of reducing the incidence of splitting in the above-ground portion of a pole. Treatment of the butt section (375 to 450 mm below the soil surface) by brushing and soil puddling (treating the back fill with 2.3 L of creosote to form a saturated collar in the top 300 mm of soil) with creosote cannot be relied upon to protect poles in areas where decay or termite attack can occur below the treated zone. Where these conditions do not occur and sapwood has been removed, better protection is given .

The advantages of creosote include:

i) a very long and satisfactory service record world-wide (e.g. Australia, Europe, South Africa, U.S.A. and United Kingdom) under a wide variety of conditions.

ii) protection against surface weathering and reduced likelihood of splitting and checking. Bleeding of oil into freshly opened checks helps to prevent decay in the untreated heartwood.

iii) non-toxic to livestock and to humans but highly effective against wood-destroying fungi and termites. Because it is composed of a wide variety of fungitoxic components, the danger of treated poles being colonized by highly tolerant fungi is minimized (Johanson and Da Costa 1963).

Creosote Mixtures

Solutions with mineral oil in creosote are alternatives which can reduce chemical costs. In tests of pressure-treated radiata pine sleepers in South Australia, a mixture of creosote and furnace oil (60:40) showed a slight superiority over creosote alone in producing a small improvement in the mechanical life of the sleepers. This result, apparently owing to better weather protection, is common with heavy petroleum oils and any such advantage must be considered against the tendency of these oils to cause formation of troublesome sludge when mixed with creosote (Tamblyn 1967).

Objectionable features of creosote mixtures include handling problems, odour and unfavourable effects on cleanliness and paintability. The primary cause for concern with creosote mixtures seems to be associated with certain polycyclic aromatic hydrocarbons and handling difficulties created by the migratory nature of the preservative in treated timber. Recent work in Scandinavia showed that exposure to creosote did not cause an increase in deaths owing to cancer, but that incidence of skin cancer from a combination of exposure to ultra violet light and creosote might be increased (Greaves 1990).

The high ultra violet light environment of Australia, which causes skin irritation in some individuals exposed to creosote, has meant that a good deal of resistance has arisen to handling creosote-treated timber, particularly poles and sleepers. Creosote-based products have an effect on human skin called 'UV sensitization'. This is an increase in the skin's sensitivity to burning by the natural UV radiation present in sunlight. The CSIRO Division of Forest Products in collaboration with Koppers Australia Pty Ltd and Koppers-Hickson Timber Protection Pty Ltd (hereafter referred to as Koppers), consequently developed unique creosote emulsions, the use of which ensured that the creosote remained locked in the timber after treatment. PEC, a creosote emulsion referred to below, does not sensitize skin once it is impregnated in the timber.

Creosote oils and emulsions are safe to use and will perform their intended function without hazard provided the correct precautions are taken. (Koppers-Hickson 1990). Material Safety Data Sheets outline safety and handling procedures and are provided by the chemical supplier.

To avoid U.V. sensitization the following precautions are recommended:

- Avoid using the product in strong hot sunlight.
- Wear full length clothing, gloves, shoes and hat while using the product.
- Apply a UV barrier cream ('Krisopol' or 'Sea and Ski' blockout) to exposed skin such as the face, neck and wrists before use.
- Wash hands and face with soap and warm water after use (Koppers-Hickson 1990).

Pigment Emulsified Creosote (PEC)

This new preservative composition, pigment emulsified creosote (PEC), is now well established in the market place and has displaced high temperature creosote in New South Wales and Queensland.

PEC is prepared by simultaneously bringing together and emulsifying the prepared aqueous and oil phases under conditions of ultra high shear (Chin *et al.* 1986). The formulation is manufactured as an oil-in-water emulsion. This phase configuration achieves very fine initial globule size and homogeneity, and its apparent viscosity is high owing to the ratio of creosote to water (nominally 65 per cent creosote, 30 per cent water and 5 per cent non distillable components). The emulsion is inverted to water-in-oil prior to its use in the treatment plant. Unlike HTC, PEC does not crystallize and presents no problems with loss of valuable creosote components, or with the removal and disposal of crystallization products from transport, work and storage tanks, or from the treatment cylinder, pump lines and valves. The odour in and around treatment plants is reduced significantly and ground pollution obviated.

PEC-treated timber exhibits dry, oil-free surfaces and is therefore much easier to handle than timber treated with HTC. PEC does not emit irritating vapours like HTC and can be used to treat wood at temperatures of 30°C or less than those used with HTC. Industry and worker response has generally been favourable and this clean improved oil-borne preservative appears to hold much promise as a real alternative to HTC (Greaves 1986). Despite the advantages of PEC, the rail sleeper market in the eastern States has been slow to recover following union bans on creosote, and the PEC preservative is not yet used in Western Australia.

Commercial treatment plants treating round timber would require a mechanical agitator or a pump to continually circulate PEC, for best effect, as a large volume of PEC will be left standing in storage tanks for long periods. However, the emulsion is very stable if left standing for a short time (Hawkins personal communication) and can be safely warmed to 95° C in a drum or trough to adequately penetrate posts by the hot and cold bath method. It can also be applied by brushing. 'Cleansote', another emulsified creosote, has a higher pigment concentration than PEC, which causes it to be unstable when heated. Hence cold soaking the total length is recommended when treating fence posts with 'Cleansote'. Brush application of creosote oil to sapwood of the above ground portion of a post gives some short term protection from weathering and *Lyctus* or termite attack, as only the outer 2 to 3 mm is penetrated. Any checks and splits which develop while poles or posts are in-service expose untreated sapwood to insect attack and weathering. Where the sapwood has been removed e.g. by weathering, brushing creosote oil onto the heartwood can be beneficial.

Currently only PEC-treated commodities are available to the Australian public, however, if there were the demand for PEC the manufacturer (Koppers Australia) would sell 205 L or smaller drums of PEC (Hawkins personal communication). PEC has been jointly patented by CSIRO Division of Forest Products and Kopper Australia Pty Ltd in Australia (Patent No. 570984) and United States of America (Patent No. 5098472).

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Pentachlorophenol (PCP)

Pentachlorophenol is a crystalline chemical, nearly colourless, highly effective against moulds and decay fungi and soluble in a variety of petroleum solvents (Wenger 1984). Properties such as colour, odour, paintability, and fire hazard depend entirely on the solvent used. Heavy oil solvents such as diesel oil are used as carriers for the chemical for severe service conditions such as ground contact. Light volatile solvents, such as mineral spirits containing 5 per cent PCP in water-borne dip or spray type treatments, are used for controlling sapstain and mould discolouration of green timber. PCP emulsion is in wide use in the United States of America as the DURATREAT ® process.

The major concern with PCP has been expressed in relation to the presence of contaminants in commercial preparations of the chemical. In 1984 the United States Environmental Protection Authority (EPA) concluded that there was a greater risk of toxic side effects during the actual manufacture of PCP than during its use as a wood preservative (Greaves 1990). Nevertheless, the EPA required an immediate reduction of the toxic contaminant. Very little PCP is now used in Australia, but it is still an important preservative in the USA and Canada, where the major concern is now its outward movement onto the pole surface and into the soil and air.

WATER-BORNE PRESERVATIVES

Copper-chrome-arsenic (CCA) is the world's best known and most widely used water-borne preservative (Greaves 1990). CCA is the favoured preservative for the fastest growing segment of the treated timber industry i.e. sawn pine for outdoor use. A wide range of formulations fall within this grouping. There are many different CCA proprietary formulations which differ in the ratio of their active elements. Greaves (1985a) referred to the wide use of the following CCA formulations:

'Tanalith CP'
'Celcure A'
'Tanalith C'
'Tanalith O'
'Sarmix Oxcel C-680'

In addition to the above proprietary brands of CCA, a number of treaters make their own formulation from the constituent chemicals (Greaves 1985a). In Australia the major suppliers of approximately 3500 t consumed each year are Koppers Australia Pty Ltd (~70 per cent), and La Porte (~30 per cent), who supply CCA as a 60 or 85 per cent concentrate. Total use of this preservative fluctuates with demand from year to year.

CCA's are used as a permanent (fixed) treatment for both hardwoods and softwoods against all biological hazards, i.e. decay, insects (termites) and marine borers. Chromated compounds in use today have a high leach-resistance because they are converted into compounds of low solubility after treatment. Wood treated with water solutions must be dried after treatment. The dried wood is paintable and the chemicals do not create a fire hazard.

The fire resistance of untreated wooden posts depends on size, density, age, moisture content and the condition of any sapwood. Heavy timbers are harder to ignite and large timbers are more resistant than those of small cross-section. Creosote-treated round posts, both pine and hardwood, will ignite fairly easily (particularly when recently treated), but once the fire has passed the flames are self-extinguishing with the evolution of dense smoke (Dale 1966). In comparison CCA-pressure impregnated posts can ignite in grass fires. It is the 'afterglow' effect which has rightly caused much concern, because the posts that do ignite continue to burn.

A special purpose CCA preservative containing zinc and phosphorus additives was developed and patented by CSIRO (McCarthy *et al.* 1972). This preservative is referred to as anti-afterglow CCA, and after initial market acceptance about 800 t were used each year in Australia (Greaves 1985a). The formulation, was commercially available as 'Tanalith AG' and 'Sarmix 3S', and was designed to inhibit the tendency of CCA-treated posts caught in a bush fire to continue to glow and char away to ash after the main fire passed. Koppers ceased to manufacture and market 'Tanalith AG' several years ago following some incidences of early failure and concerns over the effect of the additive on long term efficacy. Anti-afterglow type additives are no longer used anywhere in Australia (Hawkins personal communication).

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CCA specifications vary around the world and are based on the different formulations and chemical compositions. The CCA formulations are expressed either as proportions of compounds or salts (e.g. $CuSO_4.5H_2O$), proportions of active oxides (e.g. CuO) or proportions of active elements (e.g. Cu).

One difference between the oxide and the salt type formulations has been the cause of consumer concern. In the latter, some sodium or potassium sulphate is produced which may crystallize on the surface of the wood as a faint white bloom during drying of the treated wood. It is not poisonous, or deleterious to the preservative and it readily wipes off with a damp cloth. In oxide formulations this by-product is not formed. In many Australian commercial treatment plants, the trend is to use oxide formulations because the white crystals formed after CCA salt treatment are not acceptable to the public.

Wood treated with an oxide formulation has a higher electrical resistance (i.e. lower conductivity). Whether this property has practical importance, even in electrical transmission poles, is controversial, as it is basically the water in the preservative that increases conductivity. Corrosion is much reduced in oxide treated commodities. Clarke and Donaldson (1969) measured the electrical conductivity on small clear specimens of spotted gum (*Eucalyptus maculata* Hook.) messmate stringybark (*E. obliqua* L'Herit) and radiata pine after they had been treated with preservative of the CCA salt or oxide formulations. They found the conductivity of the sapwood of these three species at any fixed moisture content was increased after treatment with the salt-type formulation, compared with that of water treated specimens at the same moisture content. For spotted gum and messmate stringybark, the ratio of conductivities was approximately 2:1 at 10 per cent moisture content and progressively increased to approximately 7:1 at 60 per cent moisture content. Similarly the conductivity of radiata pine sapwood specimens was increased, until at 60 per cent moisture content it was about 15 times as great as that of water treated specimens. Treatment with the oxide-type preservative had very little effect on the conductivity of the sapwood of spotted gum or messmate stringybark, but did increase the conductivity of the sapwood of radiata pine above 28 per cent moisture content.

CCA is now available only to registered commercial treatment plants. Strict environmental and health standards for the storage and use of CCA can make approval for a new commercial treatment plant expensive and time consuming. Although the chemicals in CCA are well fixed in the wood, the time taken for the fixation process depends on temperature. This delay can cause a risk of unreacted chemicals of freshly treated timber being leached from the wood by rain or during handling and storage at the treatment plant. A number of techniques based on hot air, hot water, steam and even fixation in kilns combined with drying have been used to accelerate the fixation mechanism. Such procedures will also minimize surface deposits of reaction salts on CCA-treated timbers and improve treatment plant environmental control and post treatment handling (Greaves 1990).

CCA-treated timber, particularly pine, is susceptible to weathering, checking, splitting and dimensional changes, even though it may be resistant to decay and insect attack. To enhance weather resistance, and hence service stability, CCAs containing water-repellents have been developed. Research at CSIRO Division of Forest Products, in collaboration with Koppers, led to the world's first plant-usable, stable emulsion of CCA and oil which is manufactured as an oil emulsion concentrate called PROCCA. The treated timber product is marketed as Tanalith Gold®.

PROCCA-treated timber is not only aesthetically pleasing, but exhibits extraordinary dimensional stability and better strength characteristics than CCA-treated timber (Goode *et al.* 1991). Leaching of active ingedients has been reduced more than for CCA and evidence of both fire-retardancy and reduced after-glow have been demonstrated (Butler 1989).

PROCCA is a patented product in Australia (Patent No. 604471) and a patent has been filed in Europe (No. 0227430B1) and other countries.

A high oil, high CCA content version of the emulsion, called HYCON (20 per cent oil; 12 per cent CCA) has proven successful, especially in the treatment of hardwoods. HYCON would be suitable for eucalypt poles and posts, because a higher CCA retention than for softwoods is required, and over a three-year experimental period the high oil concentration has reduced the tendency to split and crack (Greaves 1992).

There are other water-borne formulations similar to CCA that are not used in Australia e.g. acid copper chromate, ammoniacal copper arsenite, chromated zinc chloride and fluor/chrome/arsenic/phenol compositions (Wilkinson 1979).

ANTI-SAPSTAIN CHEMICALS

Pine posts and the sapwood of hardwood posts and poles in the warmer areas may be affected by sapstaining fungi, hence becoming more porous during drying, necessitating some prophylactic treatment. Sodium pentachlorophenol (NaPCP) has been the traditional treatment in the area of sapstain control (Greaves 1990). A range of chemicals are being screened both in softwoods and tropical hardwoods. Of these chemicals, the isothiazolones and triazoles have shown particular promise both in anti-sapstain control and wider wood preservation applications. Another organic chemical with potential, 2-thiocyanomethylthio benzothiazole (TCMTB), can also be formulated for solvent or aqueous use. It has been used in Australia for control of decay in poles and sapstain in sawn timber, and has been tested as a potential preservative for above-ground external joinery (Greaves 1990).

Traditional methods of applying anti-sapstain chemicals are spraying (roundwood) and dipping (sawn timber). Most anti-sapstain formulations are used either as suspensions or emulsions rather than true solutions. As such, they are prone to settling at the bottom of dip tanks or green chain dips owing to excessive sawdust or other contaminating material accumulating in tanks. It is therefore essential that tanks be regularly agitated, kept free from extraneous materials, and have excessive sawdust removed at frequent intervals (Forest Research Institute 1991). A comprehensive list of commercially available anti-sapstain chemicals used in New Zealand is given in 'What's New in Forest Research' No. 211 (Forest Research Institute 1991). Some of these chemicals are available in other countries.

Boron and Fluorine

Boron, a comparatively environmentally safe and economical element to use, possesses fungicidal and insecticidal properties (Greaves 1985a). It is usually utilized as different forms of sodium borate (different in the sense of degrees of hydration e.g. disodium octaborate tetrahydrate as 'Timbor' or 'Boracol'). Fluorine also has both fungicidal and insecticidal properties, and is mainly employed in wood preservation as sodium fluoride. Both boron and fluorine compounds are used to dip-treat green sawn building timbers to immunize any starch-rich sapwood contained within them against attack by the powder-post borers (*Lyctus spp.*). Tamblyn (1949) established that a minimum boric acid concentration of 0.14 per cent (mass/mass) retained in the timber gives complete protection of *Lyctus*-susceptible sapwood. To provide a safety margin, this minimum concentration of boric acid in the wood is set at 0.20 per cent.

To achieve a 0.20 per cent boric acid retention, a 3 per cent 'Borax' solution (30 kg 'Borax' dissolved in 1000 L of water) is required. A method of dip treating green veneer is described by Tamblyn (1949). Neither boron nor fluorine-treated timber is suitable for ground contact or exposed usage because, unlike the CCAs, neither chemical is fixed in the wood and hence can be leached.

LIGHT ORGANIC SOLVENT PRESERVATIVES (LOSPS)

Light organic solvent preservatives (LOSPs) have been used in Australia for almost 20 years. Until about 1977, they were mainly applied to timber building components by using a short (3 minute) dip. Double vacuum and low pressure vacuum treating cycles are most commonly used now, with the intention of providing long-term protection to timber for external above-ground use. LOSPs essentially consist of a solvent, a fungicide, an insecticide and water repellent waxes and resins. For example, the following chemicals have been used and many are still being used to make LOSPs:

Solvent	Fungicide	Insecticide
White spirit	PCP	Aldrin
Other petroleum fractions mineral turpentine	TBTO	Dieldrin
	PCP + TBTO	Heptachlor
	Cu naphthenate	Chlordane
	Zn naphthenate	
	Zn octoate	
	Cu 8-hydroxyquinolinate	
	MBT + TCMTB	

The Department of Agriculture of Western Australia (1991) lists those pesticides registered as acceptable in Western Australia at August 1991. Dieldrin is no longer on that register, whereas the other insecticides and fungicides are listed. Similar registers occur in other States and countries.

The current trend is to reformulate the LOSPs by using more acceptable chemicals. For example, aldrin is being replaced with synthetic pyrethroids such as permethrin, deltamethrin or cypermerthrin. Tributyltin naphthenate (TBTN) is taking the place of tributyltin oxide (TBTO) in some formulations, while some organic fungicides are being screened as replacements for PCP (Greaves 1990).

LOSPs confer a measure of stability to timber (particularly radiata pine), which waterborne treatments generally cannot achieve (Greaves 1985a). However, LOSP-treated wood does require maintenance during service and a secondary finish e.g. paint or lacquer. While LOSP-treated wood should not be used inground contact, it has some advantages not offered by either creosote or CCA. It is dry, clean and ready to use almost immediately after treatment, non-swelling, stable in service, non-corrosive and non-conducting, although it does have a strong odour and no machining should take place after treatment is completed. No really long term evidence is yet available under Australian conditions, but LOSPs should greatly enhance the life of the treated products. Petroleum-based products are used as preservative carriers, and as petrol has become expensive over the last 20 years, costs of LOSPs have increased. The cost of using a light organic solvent can be justified as timber swelling and distortion is reduced in treated timber.

While the organic solvent may not contribute directly to the preservative properties, it is certainly of considerable importance. Light petroleum distillates possess low viscosity and are able to penetrate rapidly into dry wood, so they are particularly suitable for use in preservative formulations that are designed for superficial application by brush, spray or immersion. If deep penetration of the preservative formulation is achieved, subsequent volatilization of the solvent may cause the toxicants to be carried to the surface where they will be particularly susceptible to losses by volatilization and leaching (Richardson 1978).

Double-vacuum and low-pressure processes are claimed to provide more reliable LOSP treatments of external joinery than the immersion processes which they have largely replaced. The empty-cell process of the double-vacuum low-pressure process can achieve the required penetration at reduced retentions in comparatively short treatment times, thus achieving both reliability and economy compared with dipping or immersion. An empty-cell process can also substantially reduce solvent consumption without affecting nett retentions of toxicant, however, now the emphasis is on alternative processes that use relatively volatile solvents which can be employed in liquid form for a conventional impregnation treatment and later recovered as a gas (Richardson 1978).

METHODS OF PRESERVING TIMBER

The efficacy of a treatment depends on getting the appropriate preservative retention and distribution as dictated by the end use of the treated product. All methods of timber preservation are based on permeability of timber, usually by liquid preservatives. Surface applications of preservatives are of limited value. Satisfactory treatment with wood preservatives varies with the anatomy of wood, such as the presence of resin ducts, vessels, or other openings and obstructions such as tyloses (Wenger 1984).

The vessels in hardwoods are important channels for preservative penetration (Greaves 1974). Longitudinal flow of liquids along the main penetration paths (i.e. vessels) is largely determined by the presence or absence of tyloses, which, with the pit membrane openings, govern the rate of flow of liquids. In addition, other vessel blockages, such as gums, affect the longitudinal flow of liquids along vessels. Lateral movement of a preservative from treated vessels into the surrounding cells depends on vessel pit permeability. Vertical parenchyma cells assist lateral distribution of preservative, and in some species the ray cells assist movement while in others they do not. Fibre penetration appears to be extremely variable and at best unreliable. In certain easily treated sapwoods, e.g. mountain ash (*E. regnans* F. Muell.), the fibres are usually well treated, both by water-borne and oil-borne preservatives.

Heartwood is very difficult to penetrate at pressures of 1380 kPa and in some species (e.g. karri) the heartwood has proven to be refractory even when a high pressure of 7000 kPa is used (Barnacle *et al.* 1981). Karri heartwood containing brownwood (a darker than normal heartwood caused by a wound response to fungal invasion) can be readily treated at 1380 kPa.

Some observations on the penetration pathway of creosote in radiata pine were made by Greaves and Barnacle (1971). They include:

(i) the main path of penetration is along the tracheids via the bordered pits. Penetrability is dependent on the percentage of unaspirated pits, a factor directly related to the moisture content of the wood.

(ii) radial penetration occurs in the outermost growth rings only. As the parenchyma cells become occluded by their own cell contents and the interconnecting simple pits become blocked, particularly in heartwood formation, the free passage of preservative is blocked.

(iii) the resin canals serve as a primary pathway to penetration, although this effect is not believed to be significant in the overall treatment. Oozing and subsequently oxidation of resin on the freshly cut end surfaces of logs can greatly restrict preservative penetration.

(iv) in the innermost growth rings (i.e. in the heartwood) many of the vertical canals are occluded with tylosoids (structures of similar origin to tyloses occurring in resin canals of some conifers) which also prevent uptake.

Pressure methods

When pressure is applied to the liquid in which timber is immersed, the rate and depth of penetration of treatable sapwood is increased and this is the basis of all pressure treatment. Vacuum pressure is a term used for most forms of commercial treatment because these processes employ a vacuum in the treatment schedule. Whereas the full-cell treatment (Bethell process) has an initial vacuum, the empty-cell methods (Lowry and Rueping processes) employ a final vacuum and these are well described in Greaves (1985b). Pressure impregnation requires an expensive plant with a cylinder capable of withstanding minimum operating pressures of 1380 kPa, and is normally suitable only for commercial operations.

Boultonising is a pre-conditioning treatment carried out prior to pressure treatments. Most pressure treatments involve preliminary air drying to remove some of the water present in the cell cavities, but this is bypassed in the Boultonising process which involves the immersion of the timber, under partial vacuum, in hot creosote (82 to 104°C) or other oil. The combination of heat and vacuum causes evaporation of the water which is replaced in the cell walls by the oil (Bootle 1983).

Non-pressure Methods

Several non-pressure methods can be used to treat the sapwood with preservatives. These include cold soaking, hot and cold bath, sap-replacement and sap-displacement.

Cold Soaking in Creosote

Material such as dry round fence posts can be treated to some extent by cold soaking in creosote or other oil until they will absorb no more preservative, which can take five to seven days for butt soaking, but in some cases a longer or shorter time may be necessary (CSIRO 1961). A lighter creosote treatment, taking one or two days, can be applied to the above-ground portion. The loading required depends on what hazards posts will experience in-service. This method is suitable for radiata pine and low density eucalypts (e.g. Tasmanian blue gum and mountain ash). In highly permeable timbers such as the sapwood of radiata pine, penetration can vary widely depending on:

i) the nature and viscosity of the preservative;

ii) properties of the timber such as density and moisture content;

iii) whether end or side grain is exposed;

iv) temperature;

v) other factors.

This means that time taken to achieve complete penetration can also vary widely (Dale 1967).

Trials at the Wood Utilisation Research Centre, Harvey Western Australia have confirmed that dry sapwood (less than 25 per cent moisture content) of 30-year-old regrowth marri posts with butts immersed in creosote can be effectively treated by cold soaking in 10 to 15 days.

The simplest treatment plant consists of soaking tanks made from 200 L drums, a draining trough made by cutting a drum in half lengthwise, and a leaning rail for the posts erected in the draining trough. Lifting gear will be needed for heavy pieces. A

200 L drum will hold about 10 posts and will accommodate the 760 mm depth of preservative necessary for the butt soaking. Butt soaking of dry posts will generally require 10 to 15 days, but with some species a longer or shorter time may be necessary (Anon. 1980). A cover would reduce evaporation and perhaps changes in solution strength.

Cold soaking using CCA is not an option for non-licenced operators because the preservative is only available to licenced treatment plants.

Hot and Cold Bath in Creosote (HTC)

This process involves heating the posts in steam, hot water or hot liquid preservative to drive out any air in the posts, followed by cooling in preservative, when atmospheric pressure assists capillary forces in moving the liquid to replace the air driven out (Dale 1967). Heating to just below 100°C in water, or to higher temperatures in oil or steam, is most effective.

A typical treatment schedule for a dry (i.e. sapwood less than 25 per cent moisture content) eucalypt pole of 225 mm butt diameter with 19 mm sapwood, using HTC as the heated preservative, would be:

Heat to 110°C	-	3 hours
Hold at 110°C	-	1 hour
Lower to 66°C	-	4 hours.

Hot and cold bath treatments can be done simply in a 200 L drum over an open fire but this is not recommended. For effective control and safety the preservative is usually heated by steam coils or low temperature electric elements in an insulated tank. Poles and posts can be treated full length in the horizontal position or butt treated in the vertical position to save heat and preservative, then the above-ground portion is soaked in cold creosote to give protection against weathering and *Lyctus* attack on susceptible sapwoods. Hot and cold bath treatment is not used with the fixed CCA preservatives because their solutions are not stable at high temperatures.

This treatment is most effective on dry posts, however, Barnacle (1978) discussed why large volumes of creosote can be absorbed by pine sapwood containing large volumes of free water compared with an air dried post. The sapwood of a green pine post would contain a relatively small volume of air and it is possible that this air (or much of it) would be expelled when the post is heated to about 100°C in creosote oil. In the absence of air, continuity of liquid columns in the tracheid lumens could be established and maintained by creosote/water interfaces. As moisture moves out of the post during the heating cycle, hydrostatic tension could pull creosote despite its hydrophobic properties under ordinary situations, into the sapwood where it passes readily from tracheid to tracheid because the pits (or most of them) are not yet aspirated.

In addition, when using this method Barnacle found that posts showed virtually no tendency to 'bleed' creosote after treatment, possibly owing to the continuity of liquid columns in the posts. When posts were subsequently kiln dried, the moisture loss (although very slow) affects some redistribution of creosote, presumably again by capillary forces.

Quantitative results have indicated that creosote retention in green posts was much higher than in partially air-dried posts. The retentions achieved, at least in the immersed length of the green posts, were similar to those that would be expected from a full-cell pressure treated, thoroughly dried post. The green post showed virtually no tendency to bleed creosote, even from sawn ends. In Barnacle's trial, creosote absorption was approximately uniform across the radius of the green post for the lower 1.2 m, above 1.2 m it tended to be higher in the zone 25 to 31 mm from the surface of the post than in the outer 0 to 13 mm. It was postulated that this was probably due to the outer wood drying sufficiently to allow pit aspiration before the creosote had penetrated that distance along the post.

Only two green posts of the low-density mountain ash were treated by hot and cold bath while substantially, but not completely immersed. A creosote retention of about 95 kg m^{-3} was obtained in the sapwood of these posts.

Sap-replacement and Sap-displacement

Sap-replacement can be carried out on freshly felled, debarked, natural round timber by immersing the butt end in a bath of preservative and allowing the timber to stand vertical until the level of preservative liquid ceases to drop. As the sap evaporates from the top, the preservative is drawn up through the sapwood (Timber Preservers Association of Australia 1988). Sap-replacement relies on the evaporation of sap without any pressure assistance, whereas sap-displacement involves the use of positive pressure, suction or both e.g. the Boucherie process (Stalker and MacClymont 1976).

Becker (1976) described a double diffusion treatment to treat fence posts with salts which are resistant to leaching. This involved two different treating solutions, first sodium fluoride, copper sulphate or sodium arsenate, and then sodium chromate, applied in two open tank processes with subsequent diffusion into the green sapwood. Diffusion processes have been used mainly for treating building and other sawn timber, both seasoned and unseasoned, where they afford protection against *Lyctus* and *Anobium* attack and also prevent fungal attack.

This method was recommended for use with water-borne preservatives. Generally a 3.5 per cent CCA solution was used, but now this chemical is available only to licenced preservation plants. Other water-borne preservatives, e.g. Boracol 200 RH and Busan 300 WB, will leach from the post when inground contact and are not recommended.

In good drying weather posts were treated in about one week, and although the distribution of preservative in the sapwood was not uniform the treatment proved both cheap and effective (Dale 1967). Complete immersion was undesirable in the sap-replacement method, which was therefore most convenient for treating small poles where protection around the groundline is required. Sap would be replaced readily to above groundline in poles or even further in hot dry weather.

When treating posts by the sap-replacement method, 20 cm is docked off the ends of freshly cut and debarked posts, then they are placed butt down onto a raised porous surface (e.g. a metal grid) in the base of the treatment drum. Posts should preferably be the one species and of the same size. A preservative is added and the posts are left in the preservative solution until at least three-quarters of the required amount has been absorbed. If the tops have not been treated, they should be turned over and immersed until the required amount of solution has been absorbed.

An extension of the above method is the 'Boucherie' process where freshly felled natural round timbers (usually poles) are laid at an angle, and a sealed tightly fitting cap designed to hold preservative solution is fitted to one end (Timber Preservers Association of Australia 1988). The preservative is then driven along the pole by gravity, expelling the sap at the other end. The solution displaces the free water from the sapwood of the pole and this is forced out from the other end at a rate dependent upon the applied pressure.

In the past the process was used to treat softwoods, which allow radial movement of preservative, and because they are reasonably round in cross-section permit the fitting of a pressure cap without much difficulty (Dale 1969). Treatment of hardwood poles with their narrow sapwood by sap-displacement is not so simple. Poles are often oval in section and may be split in felling, but a watertight seal must be made without blocking any of the vessels or capillaries which allow liquid movement in the sapwood. In addition, the cap must be fixed to the pole (without damaging the sapwood) to prevent the liquid pressure forcing it off (Dale 1969).

REMEDIAL TREATMENT

In-service treatments using preservatives may be useful in protecting existing structures, if they are done regularly. Before preservatives are applied to the surface of timber, much of the decayed wood is commonly scraped off.

Chemicals may be injected internally into wood, or applied externally to the surface. (Note that fumigation could also be included in this context.) Greaves (1985b) outlined some of the means of achieving internal and external application of preservatives.

Examples of remedial treatments and details of some Australian suppliers of information and materials are given below.

a) pumping thickened chemicals into pre-drilled holes for centre rot control in standing poles (e.g. 'Blue 7' gel, from Koppers; 'Blue 7' diffusable wood preservatives, Valchem (Aust.), Sydney; Busan 1022 pole preservative gel, available from Buckman Laboratories, Sydney; and Basilit BFB, Cellavit Pty Ltd, Sydney).

b) applying fused preservative rods into pre-drilled fixed diameter holes for centre rot control (e.g. Impel rods from Timber Treatment Industries Ltd, Melbourne or Polesaver rods from Preschem Pty Ltd, Melbourne).

c) using gaseous or volatile chemicals, usually administered via pre-drilled holes (e.g. methyl bromide fumigant, from Nufarm Chemicals or Top Australia).

d) brushing or spraying timber surfaces with chemicals which may protect them from leaching by the weather (e.g. CN timber oil, high temperature creosote and 'Cleansote' from Koppers or Wattyl 'Combat green' from Wattyl Aust.)

e) applying measured amounts of diffusing chemicals to wood surfaces by spray or trowel or in specialized carrying matrices (e.g. bandages) for control of soft rot in poles. (e.g. 'Blue 7' gel from Koppers ; 'Busan 1022' pole preservative gel from Buckman Laboratories, Sydney; or 'Basilit BFB' from Cellavit Pty Ltd, Sydney).

Choice of application technique and protective agent will be determined by the timber component being treated, the type of hazard, the local environment and the cost benefit.

Another in-service remedial treatment was the oxy-char process which in the past was used extensively on standing poles showing partial decay. Checks and decay pockets were scraped free of soil and scoured with a very hot flame which burned all the decayed wood and sterilized that adjacent to it. The surface of the pole was then charred and while still hot was sprayed with creosote (Dale 1967). Beesley and Barnacle (1958) found that charring the surface of a pole, without the use of a chemical has no value as a preservative treatment. The disadvantages of the treatment were its cost and the loss of cross-section that occurred each time it was done, and it was also limited in practice to 300 to 450 mm below groundline.

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