Permethrin: An Effective Wood Preservative Insecticide

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ABSTRACT

Permethrin is a synthetic pyrethroid used in the wood preservation industry. The generally favorable environmental profile of pyrethroids coupled with their high efficacy led to their wide substitution of the chemically resistant organochlorines dieldrin, lindane, and chlordane formerly used for protection of buildings against wood destroying organisms. Much of the research on performance of permethrin and other pyrethroids as insecticides commenced in the 1980s was done in comparison with the performance of organochlorines. This paper reviews research that has been carried out to (1) ascertain the efficacy of permethrin as a wood preservative against insects and marine borers, (2) determine its permanence in wood (3) compare its performance to that of other pyrethroids. The drawbacks of permethrin as compared with other preservatives and pyrethroids are also discussed.

INTRODUCTION

Pyrethrins and Pyrethroids

Pyrethrins are natural insecticides extracted from the flowers of *Chrysanthemum cinerariaefolium* plant. Pyrethroids discovered in the last 50 years are a class of synthetic insecticides based upon the chemistry of pyrethrins. The effectiveness of both pyrethrins and pyrethroids as insecticides is well established (Creffield and Howick 1984; Orsler and Stone 1984). Pyrethroids which constitute 25% of the world's insecticide market are classified into two groups. Type I lack an α-cyano group in their structure (e.g., allethrin and permethrin), and Type II have the α-cyano group (e.g., deltamethrin and fenvalerate) (Horia et al. 2000). The structures of common pesticide pyrethroids are shown in table 1. Pyrethroids which were designed to improve photostability of degradation properties in pyrethrins are more effective than pyrethrins (Lloyd et al. 1998). The use of pyrethroids in wood preservation arose in the 1980s due to (1) restrictions of ecological nature to which most of pesticides especially organochlorines were submitted (2) they reveal good efficacy against a large variety of arthropod pests by contact (3) their high stability in timber; some of the more recent pyrethroids are photostable and display residual activity, (4) mammalian toxicity is reasonably low (5) they have a generally environmental favorable profile and are almost odorless (Rutherford et al. 1981; Gruening et al. 1986; Lloyd et al. 1998). The low toxicity in mammals is due to their rapid biotransformation by ester hydrolysis and/or hydroxylation. Pyrethroids used or studied in wood preservation are permethrin (Orsler and Stone 1984; Hunt et al. 2005), deltamethrin (Preston et al. 1986; Zanotto 1989; Adam and Lindlars 1996), bifenthrin (Rustenburg 1995; Creffield and Watson 2002; Hunt et al. 2005) cypermethrin (Read and Berry 1984), and decamethrin (Cross 1980; Oliveira 1983).

Permethrin

Like most members of this family of insecticides, permethrin has four isomers. Its scientific name is 3-phenoxybenzyl (1RS)-cis,trans-3-(2,2-dichlorovinyl)- 2,2-dimethylcyclopropanecarboxylate.

Different methods of permethrin synthesis result in different ratios of isomers. There is proof of a reciprocal relationship between cis-percentage of an isomeric mixture and its toxic value against wood boring insects. Permethrin an ester of the chlorine derivative of phenoxybenzylalcohol and vinyldimethylcyclopropancarboxylic acid is on the market as a (±) cis/trans-isomeric mixture between 60:40 and 25:75. The ratio 25:75 compromises between efficacy and toxicity against wood destroying (Gruening et al. 1986).

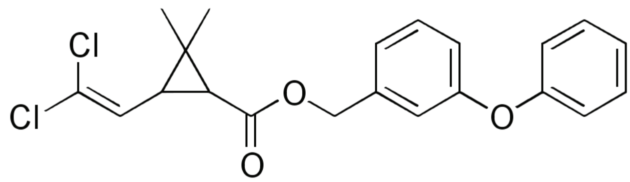


Figure 1: Chemical Structure of Permethrin

Permethrin in Wood Preservation

There are numerous reports and scientific investigations of the use of permethrin for the protection of wood products against termites and borers going back over 28 years. Permethrin is commonly used in Australia and New Zealand. It has been shown to provide effective protection against insect attack and has a satisfactory residual life when impregnated into wood products. It is commonly used as a light organic solvent preservative (LOSP) formulation, to treat timber for hazard class 2 (H2, inside above ground) or hazard class 3 (H3, outside above ground) applications. For the latter, permethrin is combined with a fungicide such as tributyltin naphthenate (TBTN) (Hunt et al. 2005). Most current modern formulations use permethrin as an insecticide and propaconazole or tebuconazole as fungicides. Some pressure-treating facilities in the United States use a mixture of fungicide 3-iodo-2-propynyl butyl carbamate (IPBC) and permethrin or chloropyrifos, to treat structural members used aboveground that will be largely protected from the weather, although this practice is not a standardized treatment (Groenier and Lebow 2006).

Bioassays on Permethrin

Screening of pyrethroids as wood preservatives was prompted by the environmental concerns of organochlorines (Read and Berry 1984). Initial studies compared their performance to that of formulations containing organochlorine compounds which gave satisfactory effectiveness in commercial use for several decades (Berry 1992). Permethrin has been studied as a wood preservative against fungi, insects, and marine borers.

Permethrin in Wood Decay Studies

The decay of framing timber treated to hazard class H1 with permethrin has been studied. In a study using model house frames, Hedley et al. (2002) evaluated fungal decay in untreated, LOSP permethrin treated wood, a combination of LOSP permethrin and IPBC (3-Iodo-2-propynyl butylcarbamate) formulation, and a boron based formulation. *Coniophora puteana* and an unidentified brown rot, which had been isolated from decaying framing in an Auckland residence were used. After 12 weeks, both fungi were well-established in untreated units and those treated with LOSP permethrin only. Negligible spread of decay was observed in units treated with LOSP permethrin plus IPBC and in those units treated with boron. Augmenting permethrin with the fungicide IPBC considerably improved the effectiveness of this treatment in controlling decay in framing (Hedley et al. 2002). Permethrin on its own does not give protection against decay fungi

Permethrin in Insecticide Studies

Permethrin has been studied and is used in protection against insects in freshly harvested wood, wood boring beetles, and termites in wood in service. In a study of Perigen, a preservative containing permethrin as the active ingredient, a 0.2% w/v solution protected against bark boring beetles for 18 weeks in recently felled unbarked pine logs. The protection was equivalent to that obtained with a 5% w/v aqueous DDT emulsion (Dominik and Skidmore 1981). Perigen is an emulsifiable concentrate containing 500 g/L

permethrin in liquid hydrocarbon. The major pest in building timbers in the UK is the common furniture beetle *Anobium punctatum*
(Berry and Read 1992). *A. punctatum, Hylotrupes bajulu,* and *Lyctus brunneus* have been widely used in studies (Berry 1977; Berry 1992; Berry and Read 1992; Read et al. 1984).

Permethrin possesses toxicity of the same order as γ-BHC (lindane) against *Hylotrupes bajulus* and *Lyctus brunneus.* Lindane an organochlorine has since been banned. However permethrin showed a lower larval toxicity than lindane against *A. punctatum.* The effect of permethrin and lindane on emergence of *A. punctatum* after 60 weeks artificial aging are broadly similar. A remedial treatment against *H. bajulus* relies on the ability of the insecticide to kill larvae in the wood, and to kill any egg-larvae resulting from survivors or fresh introductions (Berry 1977). In contrast success of a treatment against *A. punctatum* relies on the toxic effect on larvae in the wood and on the ability of the insecticide to prevent emergence of surviving insects. *A. punctatum* relies on its own pupation egg as an egg lying site and since the pupation cell may be situated in the untreated interior of the timber this could lead to reinfestation beneath the treated zone.

Cypermethrin appears to be about twice as effective as permethrin (Read and Berry 1984). In fully impregnated wood a level of 12g/m^3 of permethrin and 6g/m^3 of cypermethrin are required to prevent establishment of *H. bajulus*, while 7g/m^3 and 3.5g/m^3 of each are respectively required to prevent *A. punctatum* (Berry and Read 1992). The effectiveness of cypermethrin and permethrin vary depending on the insect species, the phase of the life cycle, and size of larva. Against mature *A. punctatum,* larvae cypermethrin is approximately equal to permethrin in effectiveness, but against egg larvae it is four times more effective (Read et al. 1984). Against emergence of adults a solvent formulation containing 0.1% cypermethrin was more effective than the permethrin solution which was ten times stronger. Against mature Hylotrupes larvae it is approximately four times more active than permethrin but as a surface spray against Lyctus a concentration of cypermethrin fifty times less than that used commercially for permethrin spray treatments prevented infestation.

Several studies demonstrate the effectiveness of permethrin in termite control (Berry 1977; Oliveira 1983; Creffield and Howick 1984; Sornnuwat et al. 1994; Peters and Creffiels 2003; Ahmed et al. 2004). As well as being incorporated into various particleboards as a termite treatment permethrins are important components of remedial treatments (Lloyd et al. 1998).

Five-mm-depth envelope treatments of permethrin and deltamethrin for the protection of softwood framing timbers *Pinus radiata* and *Pinus elliottii* against termite damage using deltamethrin 0.002% m/m and permethrin 0.02% m/m were completely successful in protecting all specimens (heartwood and sapwood) from significant damage by either *C. acinaciformis* or *S. seclusus* (Peters and Creffiels 2003). For permethrin the upper protection limit (after weathering) for Australian termites was retention of 0.08kg/m^3 for three species of termites *N. exitiosus, M. darwiniensis, and C. acicaciformis* (Creffield and Howick, 1984). *C. formosanus* reputed to have high tolerance to insecticides may require a higher retention.

Permethrin has been shown to give less efficacious results than cypermethrin, deltamethrin, decamethrin, and bifenthrin in termite toxic threshold studies (Oliveira 1993; Oliveira 1994; Sornnuwat et al. 1994). It is however more efficacious than allethrin (Tsunoda et al. 1995). Comparison with fenvalerate gave conflicting results in different studies. To evaluate the efficiency of five synthetic pyrethroids in comparison to organohlorine chlordane, deltamethrin, cypermethrin, fenvalerate, permethrin, and decamethrin were impregnated in *Pinus elliottii* (slash Pine) wood blocks and exposed to dry-wood termites (*Cryptotermes sp.* one year after the treatment. Decamethrin deltamethrin, cypermethrin and fenvalerate protected the wood at much lower concentrations than permethrin. Permethrin and all others were more efficacious than chlordane (Oliveira 1993). Similarly, Sornnuwat et al.(1994) showed that cypermethrin gave a better performance than permethrin at the same concentration (0.5%) and both performed better than Chlordane (1.0%). Olivera (1994) further showed that cypermethrin and deltamethrin provided 100% protection against *Cryptotermes sp*. in *Pinus elliotti* for 13 years. Permethrin at the same concentration provided 100% protection for only the first 3 years of the test. All the pyrethroids performed better than chlordane and natural pyrethrins. Tsunoda et al. (1985) compared the performance of allethrin, permethrin, fenvalerate, carbaryl, and chlordane against *Coptotermes formosanus* in a wood-block test. Among the three pyrethroids tested, permethrin was the most effective. All the pyrethroids were less effective than organophosphates, chlorpyrifos, fenitrothion, phoxim, and tetrachlorvinphos (Tsunoda 1985). At 0.4% for all the pyrethroids, fenvelarate gave the lowest weight loss while, allethrin was least effective with the highest weight loss in both leached and unleached samples. Termite mortality results showed that permethrin performed better than both fenvelarate and allethrin even after leaching suggesting that it was more resistant to leaching (Tsunoda 1985).

Rustenburg (1995) performed a series of tests to evaluate bifenthrin as a termiticide and showed that it protected against subterranean termites (*Coptotermes curvignatus)* by soil treatment at a lower concentration (0.03-0.06%) than permethrin which gave a similar protection at 0.25-0.5%. Laboratory bioassay using rubber wood (*Hevea brasillliensis*) treated by brushing showed bifenthrin was efficient at 0.015% versus permethrin at 0.125%. These result corroborated that of Sornnuwat et al. (1994) who also showed that bifenthrin was efficacious at a lower concentration than permethrin against subterranean termites (*Coptotermes gestroi).*

Decamethrin has been found most effective of all pyrethroids tested. Sawn timber may be dipped in a 0.0125% solution for short to medium term protection. Trials data and European Norm (EN) test results have demonstrated that dipping or vacuum pressure impregnation of deltamethrin to retention levels of as little as 10 g /m^3 protects timber for use in Hazard Classes I-III (above ground). When deltamethrin is included in glueline applications, then protection of plywood from attack by the subterranean termite (*Coptotermes havilandii)* is provided by levels of <40 g /m^3 (Adams et al. 1996). In a field test to evaluate efficacy, didecyldimethylammonium chloride required 3.5 kg/m^3 retention for complete protection. The addition of deltamethrin to didecyldimethylammonium chloride improved the termite resistance of the samples but showed some attack at 0.001kg/m^3 and complete control at 0.004kg/m^3 deltamethrin. Deltamethrin alone gave complete protection at 0.004kg/m^3 retention. Deltamethrin was far superior to permethrin in protecting southern yellow pine (*Pinus sp*.) against *Coptotermes formosanus* termites (Preston et al. 1986). These results are comparable to those of the laboratory test by Oliveira (1983).

Tests of Permethrin Against Marine Borers

Synthetic pyrethroids have been tested against marine borers in Australia and Panama. In one study, Scotts pine (*Pinus sylvestris*) sapwood blocks were impregnated with spirit solutions of N-tritylmorpholine, either alone or in combination with permethrin, deltamethrin, or cypermethrin. The preservative was applied by pressure impregnation. Samples were exposed in the intertidal zone at Mourilyan Habour, North Queensland Australia and subtidally at either end of the Panama canal. After 5 months exposure all blocks in Panama were found attacked by the pholad bivalve *Martesia striata.* In Australia all blocks had teredinid borers attack after one year exposure. However, attack by limnoriid borers was restricted to the blocks which contained no pyrethroids. The results showed that pyrethroids provide sufficient degree of protection against crustacean borers (Cragg et al. 1991).

Creosote /pyrethroids mixtures have been tried using treatment schedules designed to limit loadings of creosote and thus avoid the potential for environmental problems posed by high creosote loadings (Cragg et al. 1989). For example *Pinus sylvestris* sapwood blocks were pressure treated with solutions of permethrin, cypermethrin, or deltamethrin in BS144 creosote and exposed at marine sites in Australia, Papua New Guinea, the U.K., and Singapore. The effectiveness of these solutions in preventing marine borer attack was compared with the efficacy of creosote alone, creosote/CCA double treatment, pyrethroids alone and no treatment. Blocks at the tropical sites were installed in the intertidal zone in areas where the crustacean borer, sphaeroma is active. Teredinids (shipworms) of several species are very numerous at these sites and the bivalve borer, Martesia, is present. Limnoria colonies were found in untreated blocks at the sites in Papua New Guinea and Australia. Untreated sample blocks failed rapidly to borers, particularly teredinids. Pyrethroids alone reduced the level of crustacean borer attack and to a lesser extent, than teredinid attack. All blocks treated with creosote-containing solutions were not attacked by borers or degraded significantly by micro-organisms. Soft-rot and bacterial degradation occurred in untreated blocks and blocks treated with pyrethroids alone. Settlement by serpulid worms appears to be inhibited by the creosote/CCA double treatment, but there is no evidence of long-term inhibition of serpulid settlement by pyrethroid-containing solutions, whether with creosote or without (Cragg et al. 1989).

Comparison of Performance to Other Preservatives

To compare the effectiveness of permethrin with organo chlorines against insect attack in unbarked pine logs, Perigen, containing 0.3% w/v permethrin as the active ingredient, was found to give equivalent protection to that obtained using a 5% w/v aqueous dichloro-diphenyl-trichloroethane (DDT) emulsion (Dominik and Skidmore 1981). Although now banned DDT is one of the most highly efficient insecticides known. Light oil solvent formulations of 0.1% permethrin completely prevent emergence of beetles from normal *Anobium* populations. Similarly formulated, the chlorinated hydrocarbons dieldrin, and lindane will prevent emergence at 1% and 0.75% respectively (Berry 1992). Tests with *Anobium punctatum* larvae indicate that whereas dieldrin begins to fail at 50 ppm, the same dosage of permethrin conferred almost complete protection. In the tunneling of formosan termites (*Coptotemes formosanus)* and the Eastern subterranean termite *(Reticulitermes flavipes*) in soil, Jones (1988) showed that permethrin gave superior performance to Chlordane at the same concentration of 500 ppm. Both species tunneled significantly into chlordane treated soil and chlorpyrifos treated soil. Neither species penetrated soil treated with permethrin and after 7 days, termite survival was highest in permethrin tests indicating that termites avoided contact with the treated soil. In an above ground field test using *Coptotermes formosanus* CCA alone gave complete protection at 0.43kg/m^3 while permethrin gave a similar performance at 0.115kg/m^3 after two years in the field (Preston et al. 1986). A 0.4% permethrin formulation performed similarly as chlordane at 2.0% in ethanol in a bioassay against *Coptotermes formosanus* (Tsunoda 1985).

Mechanism of Action of Permethrin

Permethrin like other pyrethroids has a dual mode of action. It has repellent activity and insects are irritated by it and avoid material treated with the compound. In choice tests, the repellant action of permethrin has been clearly demonstrated as termites were able to utilize the alternative food source in jars containing a highly nutritious matrix in preference to feeding on the treated wood (Creffield and Howick 1984). Permethrin is also a contact poison which kills insects by strongly exciting their nervous systems. The primary mode of action is through interference with ion channels in the nerve axon, resulting in hyperactivity of the nervous system with subsequent lack of control of normal function. The nervous system becomes hypersensitive to stimuli from sense organs. Rather than sending a single impulse in response to a stimulus, permethrin-exposed nerves send a train of impulses. This excitation occurs because permethrin blocks the movement of sodium and potassium ions from outside to inside of the nerve cells (Solomon 2000). However paralyzed insects can recover.

Carrier Systems for Permethrin

Certain timbers are difficult to treat due to their anatomy. Wood composites can also be difficult to treat, due to the barriers presented by gluelines, heartwood and grain orientation (Qader 2003; Qader et al. 2005). Supercritical carbon dioxide (SC CO_2) has the potential to overcome each of these problems. The solvent system used for the delivery of wood preservatives can have a major effect on efficacy, as it can influence penetration, microdistribution, chemical reactions, and degree of fixation occurring in wood. Qader et al. (2005) treated *Eucalyptus obliqua* heartwood which is difficult-to-treat by conventional methods, *Pinus radiata* LVL and *P. radiata* sapwood with permethrin using SC CO_2 and also as a LOSP. In *P. radiata* sapwood the efficacy and retention of permethrin against termites was similar whether impregnated using SC CO_2 or LOSP. The other finding was the superior uniformity of penetration of permethrin laden SC CO_2 into the difficult to treat heartwood of *E. obliqua*, so that this timber can now be made termite resistant. This method of pyrethroid application has been patented (Qader et al. 2005). In *P. radiata* LVL, impregnation using SC CO_2 appeared to give slightly improved results against the giant northern termite *(Mastotermes darwiniensis)* most likely due to the slightly higher permethrin retentions in treated specimens after SC CO_2 impregnation. The most striking difference in performance was obtained with treated *E. obliqua* heartwood. All LOSP-treated specimens were destroyed by *M. darwiniensis*, while the 0.01% and 0.02% m/m permethrin retentions impregnated using SC CO_2 were sound. This result is likely to be due to the known problem of inadequate uniformity of LOSP penetration, and thin envelope penetration, in *E. obliqua* heartwood (Cookson and Trajstman 1996). Similarly, Subterranean Termite (*C. acinaciformis)* was controlled by treating E. obliqua heartwood with permethrin using SC CO_2, while treatment with LOSP solutions targeting 0.005% and 0.01% m/m permethrin (but falling short) failed to protect specimens adequately.

There is a difference in performance between formulations of permethrin depending on if it is in an organic solvent or is emulsion based (Berry 1992). Wood specimens treated and aged in a roof void for 5 years and then tested for emergence of adult *A. punctatum* after introduction of larvae revealed that light oil solvent formulations of 0.1% permethrin completely prevented emergence of beetles. Similarly formulated dieldrin and lindane prevented emergence at 1%. For emulsion formulations 0.1% permethrin and lindane at 0.75% allowed low levels of emergence. It would therefore appear that both lindane and permethrin are more susceptible to loss of efficiency when deposited in the more shallow distribution profile associated with emulsion formulations (Berry 1992). Permethrin in a petroleum solvent system is used to vacumm/pressure treat high grade but difficult to penetrate timber products for high quality and aesthetically pleasing applications.

Mode of Treatment

Permethrins are available in dusts, granulated, emulsifiable or liquid concentrates, and wettable powder formulations. Preservation methods used are brushing in remedial treatments against beetles (Berry 1977), as a component of wood varnishes applied by brushing and used for surface treatment (Petinarakis et al. 2000), vacuum impregnation (Berry 1977), pressure and vacuum impregnation, dipping, and spraying. No marked difference in effectiveness exists between dip- and brush-treatments. Small specimens of rubber wood (*Heavea brasiliensis*) exposed to a laboratory colony of the Asian subterranean termite (*Coptotermes gestroi* Wasmann) for 4 months after dip- or brush-treatment with six commercially available emulsifiable termiticides (cypermethrin, permethrin, bifenthrin, chlorpyrifos, and chlordane) showed no marked difference in effectiveness between dip- and brush-treatments (Sornnuwat et al. 1994). Smoke treatments are based on depositing a thin film of insecticide on wood surface each year prior to emergence of the adult beetles. Smokes containing permethrin have been shown to successfully control breeding activity of the death watch beetle (*Xestobium rufovillosum*) and have shown superior performance to smokes containing lindane and chlordane (Read 1983). The greater insecticidal activity of permethrin enables substantially smaller quantities to be applied (50-70mg/m^3 instead of 100-140mg/m^3 of lindane. Pyrethroids in paste formulations have been effective in preservation of large dimension and restricted access timbers or where treatment by conventional fluid methods may not be adequate e.g., in large cross section beams affected by the death watch beetle where treatment in depth is essential.

Permanence of Permethrin in Wood

Studies on the longevity of pyrethroids in wood are limited and work to date has concentrated almost exclusively on the effects of temperature and humidity, either in soil contact or remedial treatment situations. Such findings are also considered in the context of preliminary exposure trials which suggest significant losses of synthetic pyrethroids from timber during a construction period.
Reduction of permethrin may occur due to leaching, photodegradation, or biotransformation.

Leaching

In a weathering study involving cycles of vacuum drying, impregnation with water, soaking, and oven drying of permethrin treated wood, clear differences were observed between weathered and weathered samples in bioassay against the Subterranean termite *Nasutitermes exitiosus* (Creffield and Howick 1984).

Biodegradability and Photodegradation

The fact that significant photodegradation of pyrethroids can occur in use has been established for over 20 years. It is known, that such degradation leads to marked reductions in efficacy (Lloyd et al. 1998). In some end use areas like construction, permethrin degradation may occur by photodegradation. The low photostability of pyrethroids compared to other insecticides has restricted their use largely to indoor applications (Lloyd et al.1998). Exposure of superficially treated construction timber to natural sunlight can cause dramatic losses of pyrethroids from 200g/m^3 down to 50g/m^3 in as little as four weeks. Thus, a penetration requirement of 3mm lateral penetration was recommended (Lloyd et al.1998). Oliveira (1994) showed that permethrin is effective only for three years after impregnation in wood while deltamethrin, cypermethrin and fenvalerate were still effective 13 years after impregnation into wood against termites; indicating that they are more stable than permethrin. Lloyd et al.(1998) exposed dip treated Norway spruce (*Picea abies)* to natural sunlight, yet protected from rain, and found drastic losses of pyrethroids of up to 75 %. Rutherford et al. (1983) examined stakes below and above ground that had been in soil contact and stored in the dark in sealed glass jars in the laboratory. They found permethrin losses were far greater below ground (~90 % after 24 weeks) than above ground (~40 % after 24 weeks).

Exposure of permethrin and cypermethrin treated wood to a combination four storage environments consisting of combinations of two temperatures 20°C and 40°C and two relative humidities 60% and 90%, revealed that both insecticides showed enhanced losses at the elevated temperature of 40^oC compared to the 20^oC. Humidity had no effect on the rate of preservative loss. Emulsion formulations of both insecticides appeared more resistant to loss compared to LOSP –white spirit solution (Berry and Read 1992) After 3 years, it was concluded from chemical analyses that, although losses at room temperature were small, at the higher temperature chemical loss was accelerated. Bioassay study results using the house longhorn beetle *Hylotrupes bajulus* confirmed these (Berry and Read 1992).

Orsler and Stone (1984) demonstrated that over a period of 3 years permethrin in the outer 0.5mm of treated wood was subject to significant loss but that losses below this level in the wood were negligible. Virtually no change occurred at depths beyond 2mm from the treated woods surface in four years. Even within the outermost 2mm, where evaporation has been demonstrated for other wood preservatives, the profile was little changed. They concluded that for all but the outermost 0.5 mm of the treated battens the distribution of the permethrin is relatively permanent. Any changes noted were confined to the outermost 0.5mm of the wood sample. The results corroborated those of Cross (1980) who found that even in the outermost millimeter, there was no major reduction in loadings of permethrin after 4 weeks exposure to UV lamps at 40^oC and concluded that permethrin should have a good residual life.

To study the rate at which at which permethrin and bifenthrin are depleted from timber exposed in outdoor, above-ground applications, Hunt et al (2005) exposed *P. radiata* treated with the two chemicals to weathering and ultra violet (UV) radiation. The permethrin treated inner zones maintained relatively constant retentions over the six month period. Little if any loss of permethrin occurred below the 2 mm exposed face. Degradation or loss of permethrin from the timber in the outer 2 mm of the exposed face occurred over the six month period. The largest decrease was within the first 3 months. The loss of permethrin in the first 3 months of exposure ranged between 14 - 34 % of the initial amount measured at the start of the trial. The permethrin retention at 6 months was found to have decreased but to a much lesser extent; between <1 and 17 % of the amount at 3 months. The outermost 0.5 mm appears vulnerable to degradation rather than volatile loss, and this varies with timber species and the loading in that zone. Linking this information with published bioassay work allows speculation as to the strength of treating solutions needed for adequate long-term protection (Orsler and Stone 1984). Water-borne emulsions of insecticide and fungicide mixtures are being increasingly used in preference to light organic solvent preservatives, prompted by stringent volatile organic carbons (VOC) emission limits. This change in carrier-system is likely to exacerbate any photodegradation problems with pyrethroids since emulsions tend not to penetrate as deeply into the timber as solvent-borne preservatives (Lloyd et al. 1998). Considering all these studies, it appears that UV-radiation, hydrolysis and perhaps some other factors i.e., volatilization, could all play a part in the degradation/loss of permethrin from wood. The outdoor exposure of H2 treated framing timbers for periods of three months may lead to the loss of some permethrin from exposed surfaces. However, the efficacy of the preservative should not be compromised. Similarly, the effectiveness of envelope-treated timber (H2F) should not be compromised if left exposed outdoors for six months, providing envelope treatments of 5 mm are achieved with permethrin (Hunt et al. 2005).

Resistance

The intensive use of pyrethroids over the last 20 years has led to the development of resistance in many insect species and now represents the single most serous threat in their continued, effective use in many pest control programs (Horia et al. 2000). An important mechanism of resistance termed knockdown resistance confers cross resistance to the entire class of pyrethroids and is characterized by a reduced sensitivity of the insect nervous system to these compounds. This type of resistance has been reported in many important pest species but is best characterized in the housefly (Horia et al. 2000).

Applications of Permethrin (User classes)

Permethrin has an excellent track record as an insecticidal component of wood preservatives (Lloyd 1998). It may be applied by spray or dip on freshly harvested timber. It also is used for shipping containers (Creffield and Howick 1984), framing timbers (Peters and Creffiels 2003), and as a remedial treatment against beetles (Berry 1977). Use in remedial purposes is well established (Berry and Read 1992; Orsler et al. 1995). The most commonly used pyrethroids in remedial treatments are permethrin and cypermethrin. Orsler et al (1995) showed that aerial concentrations of permethrin following remedial treatment are always below 20µg/m^3 immediately after application and are never likely to exceed that regarded as a safe level (i.e., 125µg/m^3) and thus resulted in reduction in re-entry times of occupants after treatment when permethrin replaced Lindane for remedial purposes. The relatively low vapor pressure of permethrin leads to undetectable aerial levels found after all types of treatments (Jones 1988; Orsler et al. 1995). They concluded that permethrin is unlikely to cause health problems through aerial contamination following remedial treatment.

Commercial Permethrin Containing Formulations

The following is a description of some commercial wood preservative formulations based on permethrin:

1. **Tanalith® T**, which uses either permethrin or deltamethrin as the active termidicide. It has been developed as an envelope treatment. It contains less than 0.40% w/w permethrin in a proprietary oil solvent system. It is used to protect structural timber and certain engineered wood products against termite attack. Tanalith® T and its carrier system have no deleterious effect on the performance of adhesives, does not have a significant effect appearance of paints, stains or oils used on the timber, and improves the delay to ignition of the timber due to the dilution of wood pyrolysis gases by the preservative (Cobham and Smow 2003). The end use conditions for wood products treated with Tanalith® T are defined as "interior and protected from weather or wetting" or H2 as defined in Australian standard S1604 (Standards Australia, 2005). The required retention of permethrin in the outer 5 mm envelope zone is a minimum of 0.02% m/m. Tanalith® T protects typical framing size timber against economically important termite species such as *Coptotermes* and *Schedorhinotermes*. Tanalith® T does not however provide protection against *M. darwiniensis* and hence is not suitable for use (as a termite resistant timber) north of the Topic of Capricorn. *M. darwiniensis* does not present a significant hazard south of the Tropic of Capricorn.

2. **Tribor Plus**- This is a formulation in which permethrin is used in combination with boron compounds. It has a 20% w/w solution of disodium octaborate and 0.4% permethrin dissolved or emulsified in mono ethyleneglycol, monopropylene glycol, and water. This formulation boosts the performance of the treatment when control of emergence from heavily insect infested timber is required. It is for use as a surface applied or injected treatment for building timbers (*in situ* or new) to eradicate or prevent fungal and insect attack. Its deep penetration properties mean that damp timbers, where death watch beetle is often present can be successfully treated.
   Tribor 10 and Tribor Gel are designed to be surface applied or injected into *in situ* building timbers to eradicate and prevent fungal decay and attack by wood boring insects

3. **Tritec 120, Tritec 121, Tritec 120 Plus, and Tritec 121 Plus** -These are commercial names of preservatives containing differect amounts of permethrin for the control of the common furniture beetle (*Anobium Punctatum*) and other wood boring insects in building timbers.

4. **Perigen-** is an emulsifiable concentrate containing 500 g/L permethrin in liquid hydrocarbon for protection against wood boring beetles.

5. **Preventol® HS 75- S 50** - is a liquid formulation of a 50 % permethrin active substance.

6. **Protim H1 and Protim H2** - The levels of permethrin in **Protim H2** are higher than in **Protim H1** making it effective against subterranean termites as well as the common wood-borer. **Protim H2** also contains an effective combination of wax and resin that is designed to reduce the uptake of water by the timber during construction and is adequate for hazard level 2 (H2). Protim H1 is for hazard level 1 (H1).

Environmental Aspects and Health hazard information

Pyrethroids have limited solubility in water. A study using deltamethrin showed that under normal conditions of use the quantity of deltamethrin leached into runoff water represents a very small proportion. It was found that 0.045 to 0.125 ppm or 0.3 to 0.9% of the deltamethrin initially fixed by the wood was released in leaching wood for a period of 14 days according to European standard EN 84 (Duguet et al. 1988). For practical purposes, pyrethroids are of low toxicity due to rapid detoxification by biodegradation in mammals. Technical grade permethrin 25:75 in water suspension has an animal LD_{50} figure ranging from 1.5 to 20 g/kg body weight but when emulsified the figure is 0.3 g/kg. The skin and especially the lungs are regarded as being the most likely routes of absorption (Extoxnet 1996).

Table 1. Chemical structures and formulae of common pyrethroids

TYPE I

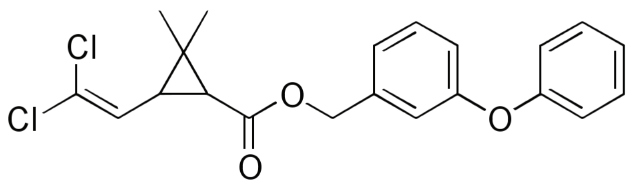
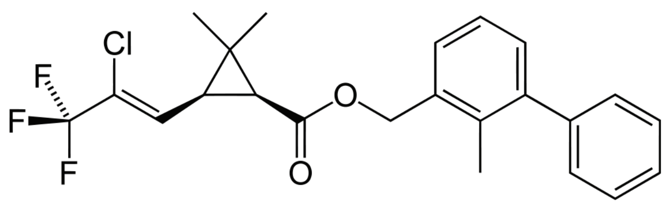
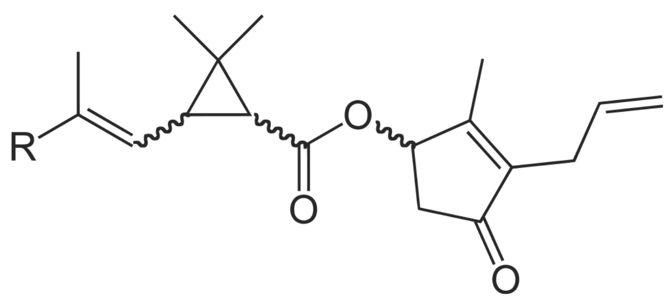
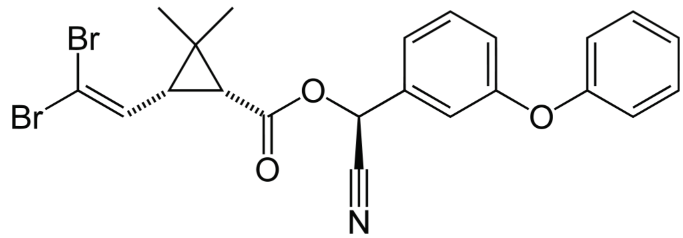
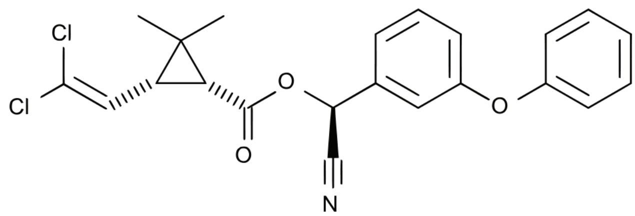
COMMON NAME	STRUCTURE
Permethrin $C_{21}H_{20}Cl_2O_3$	
Bifenthrin $C_{23}H_{22}ClF_3O_2$	
Allethrin $C_{19}H_{26}O_3$	

Table 1 (continued). Chemical structures and formulae of common pyrethroids

TYPE II

COMMON NAME	STRUCTURE
Deltamethrin Formula; $C_{22}H_{19}Br_2NO_3$	
Cypermethrin $C_{22}H_{19}Cl_2NO_3$	

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